**İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY**

# ANALYSIS OF MATERIALS USED IN MOSAIC MAKING

**M.Sc. Thesis by**
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**Department : Architecture**

**Programme : Environmental Control and Building Technology**

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**<u>İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ</u>**

# MOZAİK YAPIMINDA KULLANILAN MALZEMELERİN ANALİZİ

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## FOREWORD

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**December 2008** Nihal EFE

**Architect**

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## ABBREVIATIONS

| | |
|---|---|
| **AD** | : After Date |
| **ANCerS** | : American Ceramic Society |
| **ANSI** | : American National Standards Institute |
| **ASTM** | : American Society for Testing and Materials |
| **BC** | : Before Christ |
| **BS** | : British Standards |
| **COF** | : Coefficient of Friction |
| **EN** | : European Norm |
| **etc** | : And so on |
| **ISO** | : International Standardization Organization |
| **MIA** | : Marble Institute of America |
| **MMSA** | : Materials and Methods Standards Association |
| **St** | : Saint |
| **TCA** | : International Trade Corporation |
| **US** | : United States |
| **UV** | : Ultraviolet |

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## ANALYSIS OF MATERIALS USED IN MOSAIC MAKING


## SUMMARY

Mosaic consists of small pieces of colored materials such as ceramic, stone and glass, set closely together, to form a smooth and sometimes patterned surface. Mosaic art has become a field that began with the demand of aesthetics, the need for clothing and covering the floors, walls, and objects in ancient times. The oldest mosaics being used as conical simple clay pegs embedded in the mud walls by Sumerians in 4000 BC, have showed progress in color, aesthetic appearance, field of use and the application methods. Thus, it became a material of pattern used on the daily life objects, ritual objects, architectural frontages, and floor assembles and they have adorned churches and cathedrals, private dwellings and public spaces for several thousand years. Today, mosaic is being produced both in industrial field and in artistic way of expression by a wide range of materials and techniques. Mosaics are seen in architectural applications that add a new aesthetic value and identification, also covers the surfaces with the advantage of the material. Although, design styles, materials, tools, and techniques of mosaic have changed and evolved through the centuries, main mosaic materials are still same as the traditional ones, ceramic, stone and glass.

This research utilizes the development of mosaics in the material and field of use changing by time in history; while investigating the artistic and industrial productions by explaining the assortments, performance properties, fields of use and application methods. For this reason, first, definition and historical development of mosaics are given, and then, general use of mosaic in buildings and performance properties excepted from mosaics are analyzed. According to the obtained information, main materials used in mosaic making are specified as ceramic, stone and glass, and also their particularly research that includes their definition, historical development, performance properties, processing and installation methods are evaluated. Thus, in conclusion, according to the analyses, performance of materials used in mosaic making is specified in point of their expected properties.

## MOZAİK YAPIMINDA KULLANILAN MALZEMELERİN ANALİZİ


## ÖZET

Mozaik, seramik, taş, cam gibi malzemelerin küçük parçalar halinde, düz bazen desenli yüzeyler oluşturmak için bir araya getirildiği bir uygulamadır. Mozaik sanatı, tarih öncesi çağlardaki uygarlıklardan günümüze dek, ihtiyaçlar ve yaşama estetik değerler katma isteği doğrultusunda başlamış bir uygulama ve kullanım alanı olmuştur. M.Ö. 4000'de Sümerler tarafından kil ile basit şekillendirmeler sonucu kerpiç duvara gömülerek ilk kez kullanılmış olan mozaik, zaman içinde malzeme, renk, estetik kaygı, kullanım alanı ve uygulama açısından gelişme göstermiş; günlük yaşam içinde kullanım eşyası ve ritüel objeleri gibi ürünlerin yüzeyini kaplama, mimaride cephe ve zemin kaplama gibi alanlarda hizmet vermeye başlamıştır. Yüzyıllardır kilise ve katedralleri, özel evler ile kamu alanlarını süsleyen mozaik malzeme, çeşitli sanat akımlarının etkisi ile çağdaş uygulamalara dönüşmüş, böylece çağdaş sanat içinde de yerini almaya başlamıştır. Günümüzde mozaik, endüstriyel ve artistik alanda birçok teknik ve malzeme ile üretilerek, kaplama malzemesi amacıyla kullanılmaktadır. Mozaikler mimari yapılara, kullanım eşyalarına, sanatsal çalışmalara estetik açıdan değer katmakta ve aynı zamanda yüzeylerde birçok avantajı nedeniyle kaplama malzemesi olarak kullanılmaktadır. Dizayn stilleri, malzemeler, üretim ve uygulama teknikleri zamanla değişmiş olmakla birlikte, mozaik yapımında kullanılan ana malzemeler geleneksel malzemelerle aynı kalmış olup, bunlar seramik, taş ve camdır.

Bu tez çalışması, mozaiğin tarih içinde gelişimini malzeme ve kullanım alanları açısından değerlendirirken, endüstriyel ve sanatsal alanda üretilerek geniş alanda kullanılan mozaikleri çeşitleri, özellikleri, kullanım alanları ve uygulama yöntemleri ile açıklayarak anlatmaktadır. Bu amaçla, öncelikle mozaiğin tanımı yapılmış, tarihsel süreç içindeki gelişimine yer verilmiş ve sonrasında mozaiğin yapı içinde kullanımı ve malzemeden beklenen performans özellikleri ele alınmıştır. Tarihsel gelişimin incelenmesiyle elde edilen bilgiler doğrultusunda, mozaik yapımında kullanılan başlıca malzemeler seramik, taş ve cam olarak belirlenmiş ve bu malzemeler tanımları, tarihsel gelişimleri, performans özellikleri, üretim ve uygulama yöntemleri bakımından ele alınarak değerlendirilmiştir. Sonuç bölümünde ise, yapılan analizler doğrultusunda, mozaik yapımında kullanılan malzemelerin beklenilen özellikleri açısından performansları belirtilmiştir.

# 1. INTRODUCTION

Mosaic is an ancient and contemporary art form which uses individual pieces of materials placed together to create a design or images. For thousands of years, people have been using tiny colored tiles of materials such as ceramic, stone, glass to create incredible images and patterns on the floors, walls and ceilings of buildings. Today mosaic is being produced both in industrial field and in artistic way of expression by a wide range of materials and techniques.

Mosaic has a wide range of using areas in buildings. In general, it is used in buildings as a surface finishing material. Advantages like solidity, durability, resistance to frost, color-fastness and so on, make mosaic a practical form of architectural decoration. It can be as practical as tiles in a bathroom, shower room, or a kitchen, and can be used on walls, floors and surfaces with equal success. Mosaics may also be used for exterior use and other wet areas such as swimming pools.

## 1.1 Purpose of the Thesis

Mosaic art has become a field that began with the demand of aesthetics, the need for clothing and covering the floors, walls, and objects in ancient times. Today, mosaics are seen in architectural applications that add a new aesthetic value and identification and also they cover the surfaces with the advantages of the material.

The aim of this study is to make the analyses of materials used in mosaic making in different ways and specify their performance properties and then, to evaluate these materials in direction of their usage and performance, according to the obtained information. To this end, first, mosaic art's definition is given, historical development is analyzed, next; general using in buildings and performance properties of mosaic's are given, and then main mosaic materials; ceramic, stone and glass are analyzed particularly in point of their definition, historical development, performance properties, processing and installation methods.

## 1.2 Background

In this study, materials used in mosaic making are analyzed in point of their definition, historical development, performance properties, processing and installation methods.

This thesis includes five chapters. In the first chapter (this chapter), the purpose of the thesis, its background and the hypothesis are explained.

In chapter two, mosaic art is defined and its historical development is classified under seven headings including, Classical period mosaics, Hellenistic period mosaics, Roman mosaics, Byzantine mosaics, Renaissance mosaics and nineteenth and twentieth century mosaics.

In the third chapter, usage of mosaic in buildings is determined and performance properties expected from mosaics are examined under nine headings including, durability, abrasion/wear and impact resistance, resistance to frost, resistance to chemicals, movement and cracking, changes in appearance, maintenance and cleaning, slip resistance and cost.

In chapter four, main mosaic materials are classified under three title as ceramic, stone and glass and their particularly analysis that includes the definition, historical development, performance properties and processing are determined. Lastly, mosaic tile installation is explained.

In the fifth (last) chapter, ceramic, stone and glass mosaic materials performance is specified in point of their expected properties and according to this information; mosaic's general assessment is made.

## 1.3 Hypothesis

Mosaic is a material that appeared in ancient times and still goes on using. Today mosaic is used in many architectural and artistic fields with changed design styles, materials, producing and installation techniques.

Some of the examples of ancient time mosaics have been survived up to now show us that mosaic is a quite durable material. Nevertheless, if properties of mosaic are not known, there is no use for a long period. So, in the selection and application of mosaic material, performance properties of material analyzed carefully.

When deciding what material to use in your mosaic, there are a number of practical things to take into account. Principally, selected material for mosaic should be suitable for where it will be placed or used. For example, if the mosaic will go of outside, selected material should be frost resistance or if the mosaic will be used in a high trafficked place, it should be stand up to wear. In summary, it is important to select the proper material, with the analyzing of performance properties, for the application area, to get the expected performance from mosaic.

# 2. MOSAIC ART

In art, mosaic is a decoration of a surface with designs made up of closely set, usually variously colored, small pieces of material such as stone, mineral, glass, tile, or shell.

Technical insight is the key to both the creation and the appreciation of mosaic, and the technical aspects of the art require special emphasis. There are also significant stylistic, religious, and cultural aspects of mosaic, which has played an important role in Western art and has appeared in other cultures. Although mosaic is an art form that appears in widely separated places and at different times in history, in only one place—Byzantium—and at one time—fourth to fourteenth centuries—did it rise to become the leading pictorial art [1].

## 2.1 Definition

Mosaic has been defined by Hayler as the combination of different-colored small pieces of hard substances, such as marbles, stones, pastes of glass, etc., to form a design, which may be either a geometrical pattern or a picture. Professor Delamotte is more explanatory. He says — "By mosaic we understand the art of putting together pieces of various materials, either white or parti-colored, in such a way as to form definite patterns. Just as a musical note differs from a mere sound by the fact that there is a certain rhythmical arrangement of pulsation instead of vibration repeated at no certain interval, so does a mosaic pavement, for instance, differ from an ordinary pavement in having the materials arranged in a certain order according to their shape and color. We do not wish to imply that pavement is the only purpose to which mosaic can be applied, but it gives the readiest means of explaining what we mean by mosaic" [2].

## 2.2 Historical Development of Mosaic Art

Mosaic is a contemporary art form with ancient roots and a rich cultural heritage. Mosaics were first created thousands of years ago and have appeared in cultures around the world and at different times in history ever since. Although some magnificent finds indicate that peoples as widely dispersed in time and place as Aztecs in Central America and the natives of New Guinea created mosaics as sacred objects, the preponderance of lasting examples shows that contemporary methods and styles derive mainly from European and Near Eastern traditions [3].

### 2.2.1 Classical period mosaics

As an art form, mosaic had a rather simple and utilitarian beginning, seemingly invented primarily to provide inexpensive and durable flooring. Originally, small beach pebbles were set, unaltered from their natural form and color, into a thick coat of cement, artisans soon discovered, however, that the stones could be arranged in decorative patterns [4].

The art of making mosaic floors with natural pebbles was the precursor of true mosaic, in which colored stones, terracotta, and eventually glass, were broken or cut to make artificial tesserae of various shapes and sizes which could be fitted together to make more detailed and more sophisticated pictures. At first, these pebble mosaics were uncomplicated and confined to geometric shapes. Generally, the artists used only black and white stones. Examples of this type, dating back to the eight century BC, have found at Gordion in Asia Minor, (Figure 2.1 and Figure 2.2) [4, 5].

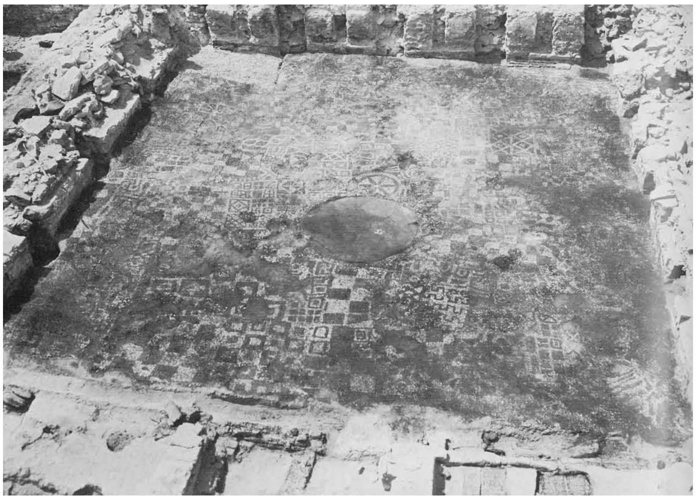

**Figure 2.1 :** Phrygian mosaic floor in Burned Building, Gordion, Ankara [5]

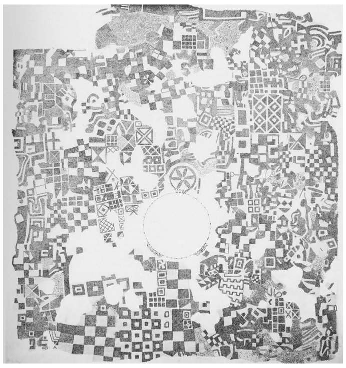

**Figure 2.2 :** Drawing of Phrygian mosaic floor by J. S. [5]

The earliest decorated mosaics to survive in Greece date from the late fifth century BC. It must remain doubtful whether they were influenced by the early examples of decorated pebble mosaics in Asia Minor and Assyria; an independent evolution is perhaps more likely. Although precise dates are often lacking, there are enough, which possess “termini" established on archaeological or historical grounds to permit a general outline of their development. The largest group consists of the pavements from the New Town at Olynthos in northern Greece [6].

The earliest stage is represented by a mosaic from the Centaur Bath in Corinth, a building constructed in the last quarter of the fifth century (Figure 2.3 and Figure 2.4) [6].

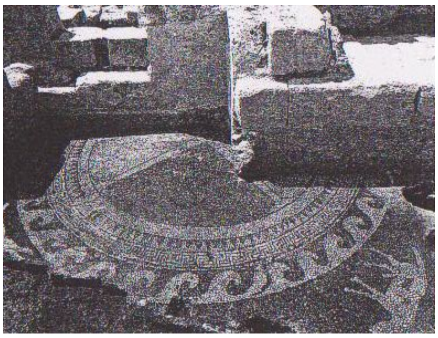

**Figure 2.3 :** General view of Centaur Bath, Corinth, Greece [6]

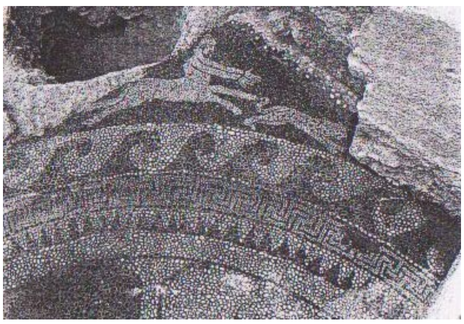

**Figure 2.4 :** Detail of north-east corner, Centaur Bath, Greece [6]

Following this initial stage, a group may be distinguished which belongs to the late Classical period, from the early fourth century. This period is best represented by most of the mosaics from Olynthos, by several pavements from Corinth and Sikyon, and by the House of the Mosaics at Eretria. The pavements of this period are composed of smooth natural pebbles; the average sizes vary from as little as one centimeter in diameter in some floors to five centimeters or more in others; most are between one and two centimeters. The designs are normally laid in white against a dark ground, though examples of dark-on light are found occasionally. Some floors are strictly bichrome, others use pebbles of additional colors, yellow, red, and green, for details, or scatter them at random among the stones of the background [6].

The mosaics of this period have found almost exclusively in private houses, in contrast to the plain pebble floors of the archaic period, which have found in temples. Their use here testifies to the increasing demand of the wealthier citizens for elegance and comfort in their domestic surroundings. In the Villa of Good Fortune, one of the grandest houses at Olynthos, two small rooms decorated with motifs give an indication of their probable significance (Figure 2.5 and Figure 2.6). One of the other finest examples of this group comes from the House of the Mosaics at Eretria (Figure 2.7) [6].

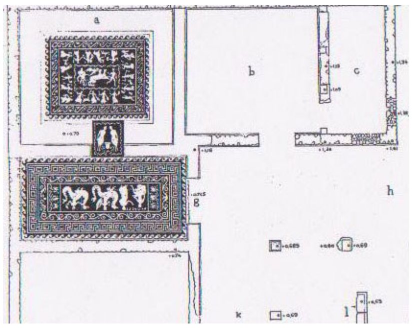

**Figure 2.5 :** Villa of Good Fortune, plan, Olynthos, Greek [6]

**Figure 2.6 :** Dionysiac mosaic, Villa of Good Fortune, Olynthos [6]

**Figure 2.7 :** House of the Mosaics, anteroom and andron, Eretria, Greek [6]

### 2.2.2 Hellenistic period mosaics

This next group belongs to the early Hellenistic Period, approximately the last third of the fourth century BC. [6]. In this period, the mosaic is carried out in the limited range of four colors – black, white, red, and yellow with their intermediate tones – to which some Greek painters of the fifth and fourth centuries are known to have restricted their palettes [7].

In the Hellenistic period, artists had invented a new kind of mosaic that permitted the best mosaicists to create designs that more closely approximated true paintings. The new technique employed "tesserae". These tiny cut stones gave the artist much greater flexibility because their size and shape could be adjusted at will, eliminating the need for lead strips to indicate contours and interior details. Much more gradual gradations of color also became possible, and mosaicists finally could aspire to rival the achievements of panel painters [4].

Hellenistic period mosaics illustrate the know-how of the first skilled workers in mosaic to appear in the history of Hellenistic art. Still using limited means, and exploiting only moderately the possibilities of color, they composed amazingly vigorous and elegant pictures, set in decorative foliated scrolls conspicuous for inventiveness and magnificence. The use of tesserae of varied colors created a multiplicity of possible applications for an art that found its way into individual dwellings, has it had already done into palaces [8].

This period starts with the spectacular pebble mosaics at Pella. These mosaics show important stylistic and technical innovations [9]. One of the finest examples of Hellenistic mosaic is in the palace of Philip II of Macedon, at Pella. The palace was decorated with superb mosaic floors, dating from the end of the fourth century BC (Figure 2.8) [10]. In addition, House I.1 contained figured mosaics of a Lion Hunt and of Dionysus (Figure 2.9, Figure 2.10, and Figure 2.11), both occupying the centre of a large andrones, while threshold panels represented a griffin with its prey and a pair of centaurs [6].

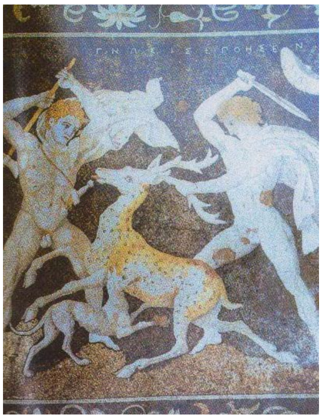

**Figure 2.8 :** Floor mosaic, stag hunt, Palace of Philip of Macedon, Pella [10]

**Figure 2.9 :** Lion hunt, House I.1, Pella, Greek [6]

**Figure 2.10 :** Dionysus on leopard, House I.1, Pella, Greek [6]

**Figure 2.11 :** Mosaic in House III N of the Theatre Quarter, Delos, Greek [12]

From about the middle of the second century, mosaics are found in wealthy houses all over the Hellenistic world [9]. Many houses have mosaics in a variety of different types of room; there is a parallel increase in the frequency and complexity of wall painting [11]. The decoration of Hellenistic houses can be understood in terms of hierarchies, which marked out the relative importance of the room and spaces in the house. In mosaics, the hierarchy is related to the materials used and the complexity of the design. Surviving houses from Delos, Morgantina, and Monte Iato are analyzed in detail to suggest how a contemporary visitor might have read their decoration (Figure 2.12 and Figure 2.13) [12].

**Figure 2.12 :** Mosaic in House III N of the Theatre Quarter, Delos, Greek [12]

**Figure 2.13 :** Mosaic in the Pappalardo house, Morgantina, Sicily [12]

### 2.2.3 Roman mosaics

The Romans exploited the functional and decorative qualities of the medium to the full, using it both for hardwearing pavimental and intricate mural decoration (Figure 2.14). Mosaics have been found across the entire area of the Roman Empire exhibiting an enormous range of genres and styles from conventionalized compositions depicting the gods to closely observed scenes of everyday life, simple monochrome 'silhouette' images, detailed studies of animals and an inexhaustible repertoire of abstract border and infill designs [13].

**Figure 2.14 :** The Moroccan pavement accords with convention for emblemata [14]

The Romans were great masters of mosaic flooring and run the gamut of possible production – from small-scale works for domestic interiors to enormous pavimental mosaics for civic spaces. They developed an extensive 'grammar' of repeat geometric patterns for borders and in-filled areas, which they used in conjunction with emblemata, intricate representational panels [13]. One of the examples of mosaic flooring is in the Roman Villa at Chedworth (Figure 2.15). The villa dates from the early second century AD and was occupied until the late fourth century. The mosaic floors were composed of red tile chippings, white limestone, purple sandstone, and blue and grey limestone [10].

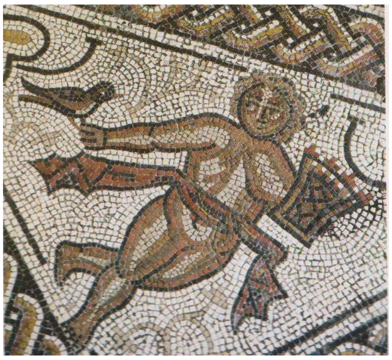

**Figure 2.15 :** Mosaic of spring, Roman Villa, Chedworth [10]

A frequent criticism of Roman floor mosaics is that their patterns contrast too strongly with their backgrounds and frequently appear to project from the floor. And sometimes, as in some mosaics from Rome's Baths of Diocletian, the geometry has become so vigorously active that the floor can appear unlevel (Figure 2.16) [14].

**Figure 2.16 :** A spirited geometric mosaic pavement pattern at a bath, Rome [14]

The newer method of creating mosaic with stone tesserae was enthusiastically embraced by the Romans, who used it with great dexterity in their homes (Figure 2.17) and temples. Many of the Roman mosaics were located in public buildings and common areas, and in cathedrals throughout Europe [3, 14]. The Romans used a much simpler monochromatic style of mosaic to decorate communal areas such as shops, baths, etc. because this style was quicker and less expensive to complete yet still durable and beautiful [15].

**Figure 2.17 :** Mosaic of a Roman Villa, Piazza Armerina, Sicily [14]

There are several conventional types of Roman mosaic. One is the so-called "opus tessellatum" composed of small cubes of stone or ceramic materials placed in regular manner of colored materials were bedded in a more irregular fashion to produce simple geometric pattern. In another type called "opus vermiculatum", the pieces of colored materials were bedded in a more irregular fashion to produce pictorial effects (Figure 2.18). This technique was very similar to the opus tesselatum, differing mostly in the way in which the pieces were cut to shape and size best suited for the design that was being created. The outlines of figures were more accurately depicted [17]. When used for the decoration of the surface of the walls and vaults the type was known as "opus musivum", and it is figured so prominently in Early Christian work. A technique closely related to mosaic is "opus sectile", marquetry, with pieces of marble and other colored materials cut carefully to shape to fit the contours of the design (Figure 2.19)[16, 14].

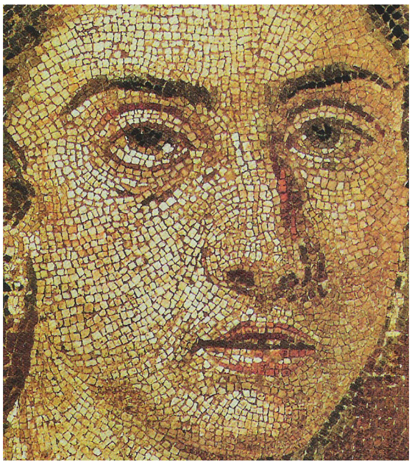

**Figure 2.18 :** An example of opus vermiculatum, made of tiny tesserae [14]

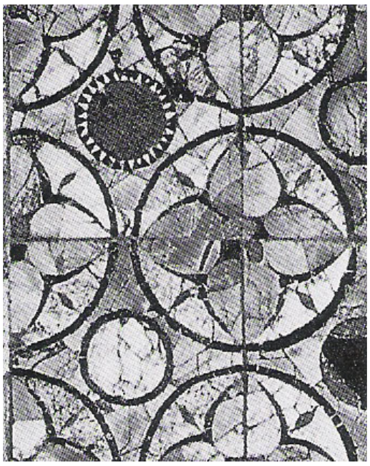

**Figure 2.19 :** A pavement of opus sectile, made of larger pieces of colored stone [14]

### 2.2.4 Byzantine mosaics

The art of mosaic reached new levels of skill and importance in the buildings of the Byzantine era. Byzantine mosaics are distinguished from their predecessors by the size of their tesserae, being generally smaller than used by the Romans. They are also distinguished by their glitter, their backgrounds often having been made of reflective glass squares bonded with gold leaf [14].

Subject matter for many Byzantine mosaics was religious, but perhaps even more famous among Byzantine examples are the highly stylized secular portraits at S. Vitale of the emperor Justinian and his empress Theodora, shown carrying offerings to the altar (Figure 2.20) [13, 14].


**Figure 2.20 :** Mosaic of an imperial procession, S. Vitale, Ravenna, Italy [13]

In the Byzantine era, from the fifth to the fifteenth centuries, mosaics were created to cover entire walls and ceilings, and in the fifteenth and sixteenth centuries, important Italian painters designed mosaics for the great cathedrals, including St. Mark's Basilica in Rome (Figure 2.21 and Figure 2.22)[14, 18]. The Basilica of San Marco contains the largest surviving areas of mosaic in the world (see Figure 23). The floors are completely covered in mosaics, dating from the ninth century to the eleventh. Murano Cathedral, also in Venice lagoon, has another wonderful Byzantine mosaic pavement (see Figure 24) [10].

The Byzantine Era saw the greatest flowering ever known of mosaic as an art form. Mosaics no longer were confined to discrete panels but know covered entire walls and ceilings with images. Immense figures became important design elements and matched the scale of the surrounding architecture [3].

**Figure 2.21 :** Interior view of St. Mark's Basilica, Venice [14]

**Figure 2.22 :** Mosaic in the vault of St. Mark's Basilica, Venice [14]

**Figure 2.23 :** Marble and mosaic pavement, Basilica of San Marco, Venice [10]

**Figure 2.24 :** Mosaic of peacocks feeding, Cathedral of S.S. Maria Donato [10]

While early Byzantine mosaics reveal significant classical influences toward realism, later works look more like icons: the figures appear practically motionless on a field of gold tesserae. Another evolution in style was the use of lines of color to model the faces and garments of the subjects [3].

In its earliest beginnings, however, mosaic leaned strongly in the direction of simplicity and quite coloration. In the first century after Christ, limestone and marble were used almost to the exclusion of other materials. Floor mosaics carried simply in black and white. But in the more opulent Byzantine era, monotones gave way to brilliant color. White and soft hued backgrounds were replaced by shimmering gold. The accelerated glass industry manufactured tesserae in literally hundreds of shades [19].

The Byzantines were responsible for “lifting” mosaics from the floor to the ceiling, and for pioneering the use of specialized glass, made specifically for mosaics called “smalti.” Christian artists would later take advantage of both of these evolutions to decorate their places of worship with immense and spectacular representations of biblical subjects and scenes [15].

### 2.2.5 Mosaics in renaissance

With the coming of the Renaissance and its resuscitation of painting and other art forms, mosaic became almost obscured [19].

As the Renaissance took hold, particularly in Italy, there was a renewed interest in pictorial realism and a rejection of the use of gold so common to mosaics. Mosaics continued to be used in church decoration, but they increasingly began to imitate contemporary painting [3].

During the fifteenth and sixteenth centuries, great Italian painters provided “cartoons” for others to construct as mosaics. Some artists, including Titian and Tintoretto, went so far as to have early Byzantine mosaics removed from St. Mark’s Basilica in Venice and replaced by their more modern works. At St. Peter’s in Rome, the dome was decorated with mosaics done from the cartoons of Cavalier d’Arpino, and exquisite mosaic reproductions of sixteenth and seventeenth century masterpieces were installed at the altar. The Venetian and Vatican workshops, established to complete and maintain the mosaics in St. Mark’s and St. Peter’s, subsequently become major European centers for mosaic production [3].

### 2.2.6 Revival of mosaics in nineteenth and twentieth centuries

By the eighteenth century interest in mosaic art was again apparent and Rome became a centre for mosaic revival as preserved in works created St. Peter's Basilica and miniature mosaics comprised of minute tesserae. The arrival of the Art Nouveau period during the 1890s and the early 1900s brought further changes to mosaic style. Art Nouveau and particularly its Catalan offshoot, modernism, resulted in many civic buildings being adorned with an exuberant agglomeration of abstract and stylized pattern (Figure 2.25). Artists began creating works reminiscent of the organic curves and shapes found in nature as well as bold geometric lines and configurations. This led to a more informal and spontaneous composition style not previously demonstrated [13, 20].

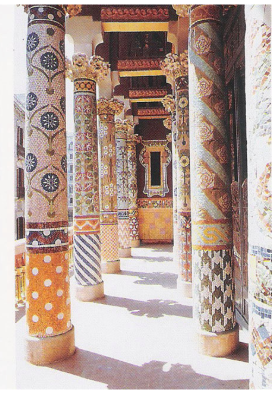

**Figure 2.25 :** Mosaic column [13]

The eclectic historicism of the nineteenth century fuelled a revival of arts and crafts of all kinds, including mosaic, which became increasingly widely practiced, with dedicated schools springing up to serve large public commissions [13]. Some of the most extensive nineteenth century mosaic pavements are those designed for Cologne Cathedral (see Figure 2.26 and Figure 2.27). Pebble mosaics, made by setting pebbles of contrasted colors in mortar, were used externally in courtyards, stables and gardens, often laid in attractive patterns (Figure 2.28) [10].

**Figure 2.26 :** Mosaic pavements of Ana Maternus Kapelle, Cologne Cathedral [10]


**Figure 2.27 :** Detail of mosaics showing God creating the River Tigris [10]

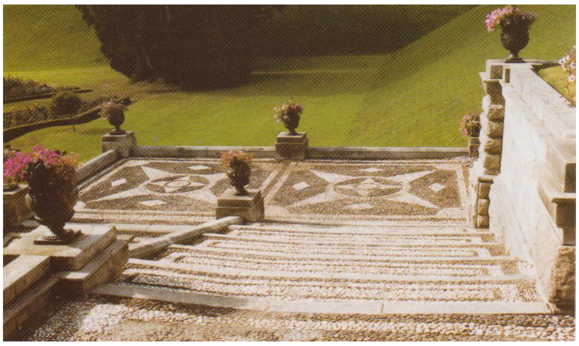

**Figure 2.28 :** Nineteenth century pebble mosaic, garden terrace steps, Ireland [10]

It was not until the middle of the nineteenth century that mosaic began to reassume a role of importance. In the field of mural decoration much of the actual work was executed by Italian artists, imported for that purpose. Typical examples of murals produced during that era are to be found in England: in the reredos (alter screen) of Westminster Abbey, for example. In the main hall of Parliament are others made from designs by Sir Alfred Poynter, an English painter who also worked in stained glass, mosaic, and ceramics. Yet even in the work of so skilled a designer, joints between the closely set tesserae were almost invisible, thereby creating a polished surface that neglected the material; the murals were more nearly illustrations than the pure design for which mosaic is best-suited [19].

In the eighteenth and nineteenth century gave way to the twentieth, Antoni Gaudi, an innovative Spanish architect, took the unusual step of placing mosaics on exterior rather than interior walls of buildings. Working primarily in Barcelona, he created startling new architectural forms, many of which he covered with outer skins of mosaic (Figure 2.29 and Figure 2.30). Gaudi was influenced by the Moorish tradition of glazed tile mosaic, but he improvised designs using fragments of tiles, bits of rubble, and other objects trouvés [3, 13].

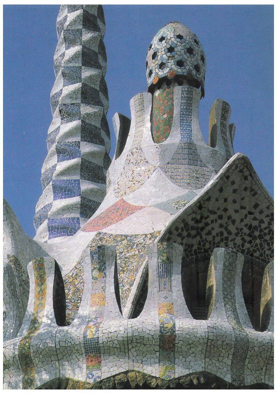

**Figure 2.29 :** Mosaics in Park Guell, Barcelona [13]

**Figure 2.30 :** Mosaics in Park Guell, Barcelona [13]

## 3. GENERAL USE OF MOSAICS IN BUILDINGS

Mosaics are seen in architectural applications and object covers that add a new aesthetic value and identification also adhere the surfaces with the advantage of the material [21]. They are used in buildings as a surface finishing material. If properly grouted, mosaic can be just as practical as tiles in a bathroom, shower room, or a kitchen, and can be used on walls, floors and surfaces with equal success [13]. Unglazed mosaics may be used for exterior use and other wet areas such as swimming pools, where good slip resistant is important [22].

### 3.1 Surface Finishing Materials

The material that makes up the structure for floors, walls, and ceilings may often be left as the final surface. But from prehistoric times, the desire to provide better protection from the elements, or to ornament the surfaces, or simply the provide an agreeable tactile environment has led to a proliferation of materials used solely as a surface finish, like mosaic. While some materials may be suitable for any floor, wall or ceiling, other materials will predominate in one location or another [23].

Finish work refers to the methods, materials, and treatments that comprise the interior and exterior finished surfaces of a building. Finishes are all visible as an integral element of the completed structure; in fact, most of what one sees in a completed building is the finish work that is superimposed over the building's structural framework. Interior finishes include floor finishes, wall finishes, and ceiling finishes. Exterior finishes consist of the entire outside surface of a building, including wall coverings, ornamentation, and protective coatings [24].

#### 3.1.1 Floor finishes

The main points to be covered in specifying finishes are:

- Quality of material
- Preparation of the base
- The thickness of the material, and the number of coats

Requirements for thickness may depend upon the degree of wear and tear expected, the thickness required for resilience, the minimum thickness required to ensure good adhesion and freedom from cracking. A fairly early decision on the thickness of various adjoining finishes is essential if awkward junctions are to be avoided [25].

Floor finishing materials must be durable enough to withstand wear and be resistant to abrasions. Quality of installation affects long-term durability and aesthetic appeal of a finish. A flooring material should be resistant to dirt, moisture, grease, and staining [26].

Many of the materials used for floor finishes are of proprietary types, and often they must be laid by specialists. In such cases, reference should be made to the specialists firms for full details of properties and methods of lying [25].

Floor finishing operations require cleanliness and freedom from traffic, so other trades are banished from the area as the flooring materials are applied [27].

#### 3.1.1.1 Floor tiles

Ceramic and stone tile flooring materials are solid and durable. Glass tile is surprisingly durable as well.

Floor tile is installed in two phases: setting and grouting. Setting attaches the tiles to the flooring substrate with mortar.

The width and color of the grout joints affect the selection of a tile floor. Because floors are likely to be exposed to more dirt than walls, it makes sense to keep the grout lines subdued and non-contrasting. Even well installed and sealed grout joints will pick up some hard to remove dirt over time; using a dirt hiding color of grout can minimize the impact. Tighter grout lines leave less exposed grout to get dirty or become loose. Most tile floors clean easily. Dark color may show residue from cleaning products, however, and highly glazed finishes may be scratched by inappropriate cleaning practices.

Grout used to fill the spaces between tiles is selected to match the qualities of the tile and the conditions of the installation. Epoxy grout is impervious to water, very strong, and much more resistant to stains and chemicals than cement grouts. Waterproof membranes can be installed under tile in areas that are frequently exposed to water [26].

#### 3.1.1.2 Mosaic floor tiles

Roman influence has pervaded the design of mosaic floors for hundreds of years. Because floors are a permanent feature of a room, providing its key note, they have tended to be more conservatively designed than other surfaces [13].

Whatever their inspiration, all floors must be hardwearing and most must be absolutely smooth [13]. Unglazed, tumbled or honed mosaics can be used for floors but a sealer is always a safe addition to protect against stains [28].

### 3.1.2 Wall and ceiling finishes

Materials for walls and ceilings come from a variety of sources, both natural and fabricated. Some materials used on walls and ceilings can also be used on floors; others are appropriate only for walls or ceilings. Wall and ceiling materials are hard or rigid, flexible or soft, and their weight varies from heavy to light [29].

Wall coverings, applied to interior or exterior structural walls as a final finish, are supplied pre-finished or unfinished in either roll or sheet form [30].

#### 3.1.2.1 Wall tiles

Wall tile, unlike floor tile, is free from the burden of bearing weight or withstanding heavy traffic, and so can be thinner, have finer finishes, and, in some cases, be less expensive [31].

The aesthetic quality of a wall tile is based on its surface alone, but it is the whole assembly that determines its performance. The basic components of a tile assembly are tile, setting bed, setting material, grout and waterproofing (if a wet application) [32].

Tiles are completely rigid and the joints are usually grouted in cement. It is essential therefore that there should be good adhesion to be backing and the backing should be completely rigid [33].

The range of colors in enamels is wide and increasing, but the combination of colors and mottled effects available gives a very wide range of choice. Because of this, and because glazing is done to individual orders, it is not easy to match up with old tiles even if the manufacturer's color number or description is known [33].

#### 3.1.2.2 Mosaic wall tiles

Walls are perfect canvases for mosaic [13]. Colorful mosaics are as beautiful on walls as they are on floors. Small colorful tiles made of ceramic, porcelain, terra-cotta, or cement can be installed on walls to form patterns and pictures – or just to add a splash of color. The small size of mosaic tiles makes them particularly suited for neatly covering curved walls [31].

Mosaic tiles are particularly practicable in kitchens and bathrooms where splashes could damage paintwork and the most pleasing effects can often be achieved with the simplest designs [13].

## 3.2 Selection Criteria of Surface Finishing Materials

Every material selection process is employed to fulfill a simple need, identifying the best material for a particular application. A material exhibits behavior as a result of combinations of mechanical, physical, thermal, electrical and magnetic properties, and characteristics such as cost and availability, processing and finishing. Extrinsic properties can, and often do, change with time [34].

The selection of a finish material is determined by its characteristics, cost, and aesthetic effect. Exterior surfaces must be weather resistant, durable, relatively free of maintenance, and architecturally appropriate in scale, texture, pattern, color, and so on. Interior surfaces must also be durable, easy to maintain, functional (considering fire, thermal, and acoustical qualities where appropriate), and aesthetically suitable. As most of what is visible in a finished building is finish work, it is obvious that architects must give serious consider to the design, detailing, and execution of a structure's finish work [24].

As designers select finishes for projects and present them to clients, they asses each alternative for its aesthetic contribution to the design concept. Designers also must consider how a material will perform under the conditions of the project. They rate materials for durability, colorfastness and fading, and stain and water resistance, and evaluate them for ease of maintenance. Materials may be tested and labeled by the manufacturer for light, moderate, or heavy use [26].

### 3.2.1 Floor finishing materials

It is wise to select flooring according to the following criteria: Beauty means good design merit and integrity. Flooring should be appealing even if there were no other furnishing in the interior. Graceful aging in the form of a patina, or mellowing of the finish through continued use. Permanent flooring is often in place for ten or twenty years, and many historic interiors that have stood the test of time feature hard materials that have lasted and continued to be beautiful, for a century or more. Subfloor preparation supports and enhances the finishing material. Heavy materials such as stone, tile or brick require a sturdy subfloor, which will raise the floor level. Life cycle costing is the total cost divided by the numbers of years of expected us. Surprisingly, more costly products often have a lower life cycle cost because they do not require replacing. Upkeep means maintenance frequency and ease of cleaning. Hard flooring materials generally require less care than resilient ones. Surfaces with grooves or indentations tend to trap dirt. Natural materials are superior at camouflaging tracked-in soil. Durability is the ability to withstand traffic. Particularly in high-traffic areas, avoid flooring materials that are vulnerable to wear. Smooth hard resilient floorings without added texture are slippery, especially when wet. To avoid accidents due to visual confusion, flooring should avoid glare, three-dimensional patterns, or abrupt pattern changes that would create a depth illusion. Summary of data that was explained above is given in Table 3.1 [29].

**Table 3.1:** General properties of floor finishing materials [29]

| | |
|---|---|
| Appearance | Beauty means good design merit and integrity. Flooring should be appealing. |
| Service life | Permanent flooring is often in place for ten or twenty years and hard materials have lasted for a century or more. |
| Subfloor preparation | Heavy materials such as stone, tile require sturdy subfloor |
| Cost | More costly products often have a lower life-cycle cost because they do not require replacing. |
| Maintenance | Hard flooring materials generally require less care than resilient ones. Natural materials are superior at camouflaging tracked-in soil. |
| Durability | Particularly in high-traffic areas, avoid flooring materials that are vulnerable to wear |
| Slipperiness | Smooth hard resilient floorings without added texture are slippery, especially when wet. To avoid accidents due to visual confusion, flooring should avoid glare, three-dimensional patterns, or abrupt pattern changes that would create a depth illusion |

### 3.2.2 Wall finishing materials

Generally, hard materials echo and reflect or amplify more sound; flexible and soft materials absorb sound. Permanently installed materials initially cost more but may be the least costly in the long run, as they require little finishing, upkeep, or replacement. These include stone, wood, tile, and brick. Interiors need to be flexible for change. Shifts in the lifestyles of occupants will benefit from flexible materials that can be replaced. Upkeep is major consideration where there is limited time or budget for cleaning or where traffic or youngsters would tend to soil, mark, or damage the wall surfaces. The size of the space can be a determining factor. Heavy textures, large patterns, and dark or intense colors close in spaces, making them appear smaller, whereas smooth or subtle textures, small patterns, and light or dull colors visually expand spaces. The function of the interior should determine wall material durability. Heavily used areas need impervious materials; little used areas can accommodate more fragile treatments. Summary of data that was explained above is given in table 3.2 [29].

**Table 3.2:** General properties of wall finishing materials [29]

| | |
|---|---|
| Noise | Hard materials echo, soft materials absorb sound |
| Cost | Permanently installed materials initially cost more but may be the least costly in the long run |
| Flexibility for change | Interiors need to be flexible for change |
| Maintenance | It is important especially when there is limited time or budget for cleaning. |
| The size of space | Heavy textures, large patterns, and dark or intense colors close in spaces, whereas smooth or subtle textures, small patterns, and light colors expand spaces |
| Durability | Heavily used areas need impervious materials; little used areas can accommodate more fragile treatments. |

## 3.3 Performance Properties Expected from Finishing Materials

All materials have essential properties that make them applicable for a given purpose. The criteria for selection, at a very basic level, are the material's ability to withstand forces without excessive deformations or actual failures [35].

### 3.3.1 Durability

The ASTM committee defines durability as the safe performance of a structure or a portion of a structure for the designed life expectancy or the capability of a building product, component, assembly or construction to perform the functions for which it is designed and constructed [36].

Durability involves evaluating a material for its ability to stand up to its intended use. Materials are rated for their resistance to abrasion, exposure to sun, and freeze/thaw cycles. Some materials will melt when they come in contact with a heat source; other will deteriorate from contact with alcohol or acetone. Water will damage or weaken some materials, while others will dry out in low humidity. The preparation of the substrate (for example, a clean, smooth surface) for installation of the material and the use of proper installation procedures affect the durability of a material, as does its finish [26].

Durability usually is connected with a relatively slow rate of deterioration or change of state is minimal. The durability of different material types, which is in practice a statistical entity due to variations in a material and its environment, depends fundamentally on their chemical and physical bonds [36].

By way of summary, materials can be said, therefore, to have an inherent tendency to change, the rate of change being dependent on the characteristics of a material and the severity of its exposure to deteriorating factors. Those factors that primarily influence durability are given in Table 3.3 [37].

### 3.3.2 Abrasion/wear and impact resistance

Abrasion is defined as the wear or removal of the surface of a solid material as a result of relative movement of other solid bodies in contact with it. It may occur whenever the surfaces of two materials are rubbed against one another. The factors that influence its extent are:

1. The period of time during which the rubbing takes place;
2. The surface characteristics of the two materials in contact;
3. The resistance to rubbing that is provided by the two surfaces.

The last is directly related to the properties of the surface of the materials and the pressure exerted during rubbing.

**Table 3.3:** Factors that primarily influence durability [37]

| Deterioration | | Substances Involved | | Material Commonly Affected |
|---|---|---|---|---|
| Cause | Effects | Type | Source | |
| Cleaning and maintenance | Physical and chemical changes | WATER + Abrasives Acids Alkali | Cleansing agents | All building materials, their surfaces in particular |
| Frost action | Physical change occurring mainly in exposed and wet conditions and normally resulting in surface disintegration and cracking | WATER | Rain mainly, sometimes ground water | Porous materials (bricks and sedimentary stones notably), especially when used externally |
| Moisture content changes | Physical effects only:<br>1.Contraction during drying out resulting in cracking, surface crazing, warping<br>2.Expansion on exposure to moisture resulting in cracking<br>3.Expansion or contraction | WATER (liquid or vapor) | 1.Inherent in the material or building process<br>2.Atmosphere, condensation, rainwater, ground | Porous materials |
| Temperature changes | Distortion<br>Cracking | Heat energy related to surface characteristics and thermal capacity of materials with location and amount of thermal insulation layer an important determinant of effects | 1.Externally-air temperature and solar radiation<br>2.Internally and externally-air temperature and local heat sources | All building materials |
| Industrial processes | Mainly decomposition; usually of a specific type depending on chemicals/materials involved | WATER + Various substances | 1.During processes<br>2. Storage<br>3.Spillage<br>4.Fumes | Most building materials |

During the construction and life of a building, abrasion is more normally associated with actual damage to the surface of materials. At best, it may only affect the appearance of the material or, at worst, cause permanent damage.

Some conditions within buildings are known to be more conducive to damage than others, while at the same time some materials are known to be more resistant to abrasion. Once the severity of conditions has been assessed, it is then possible to consider three courses of action:

1. To protect the surface of materials with some form of applied finish, usually thin and often temporary, and to ensure that frequent renewal is possible;
2. To select finishes which, although they may be liable to damage in the severest conditions anticipated, are used in such a way that affected areas may be easily renewed; or
3. To select materials which are known to resist abrasion in the severest conditions.

Surfaces subject to abrasion should have finishes chosen which are either highly resistant or are easily replaced [37].

Impact strength marks a material's capacity to absorb impact without fracturing. It is defined as the total energy from elastic deformation to fracture which a material can absorb before breaking under impact [38].

Impact is concerned with the sudden application of a load on a material. It is apparent that there are innumerable instances, both during construction and in the life of the building, when materials may be subjected to this form of loading. Whenever it occurs, impact results in stresses that are momentarily higher than those from the same static load. In simple terms, impact takes place when two objects, at least one of which is in motion, collide with one another. Depending on the relative strengths of the materials and the intensity of the forces resulting on impact, there may be damage to the object, or in some cases to both. The strength of the materials and the intensity of the force are obviously closely related, but it is convenient to consider these separately [37].

### 3.3.3 Resistance to frost

Frost action describes the cause and effects of water that freezes in porous materials. Frost action is associated with changes in temperature and the moisture content of the relevant materials [37].

Water expands when it freezes and where it is contained in pores or other interstices it may cause decay. Materials with a laminar structure are more liable to deteriorate [39].

The frost resistance of materials is dependent on the interrelationship of three factors, namely:

1. The properties of materials
2. The position in which the material is used
3. Climate conditions [37]

Table 3.4 gives general information about the performance of some common materials when they are exposed to frost action [39].

**Table 3.4:** Susceptibility of materials to deterioration as a result of frost action [39]

| Class of Material | How Affected |
|---|---|
| Natural stone | Variable. Best stones unaffected. Some stones with pronounced cleavage along bedding planes are unsuitable for copings or cornices. |
| Clay Products | Best bricks and tiles unaffected but some insufficiently fired products and those having flaws of structure originating in the machine, may deteriorate, especially bricks in coping, and tiles on flat-pitched roofs. |

### 3.3.4 Resistance to chemicals

Chemical attack is taken to mean chemical actions, which have deleterious effects on materials. Almost all materials for building may be subjected to chemical action of one kind or another during the life of a building [40].

### 3.3.5 Movement and cracking

Movement in a finishing material is harmful if its leads to cracking, swelling and buckling or to a general loosening of the bond by which the finish is held to the base material [25]. Movement can give rise to considerable stresses and if these exceed the strength of materials, cracks or buckling occur [39].

It is possible to avoid cracking by using a material strong enough to resist developing stress [38]. Also it would be a mistake to think that all such movements can be entirely eliminated by careful design and construction and by careful choice of materials. Even if all errors and accidents were avoided, some movement would still be caused by natural phenomena such as temperature changes and changes in moisture content [25].

The various causes of movement in buildings are; movement due to moisture variations, to temperature differences, to vibration, to chemical action and to loading [25]. Cracking is the result of the overstressing of materials due to one or more of the movements given in Table 3.5. In addition, how a material is used, where it is used and the way it is exposed to water, heat and so on, are the other factors, which influence the resistance to cracking [37].

**Table 3.5:** Principal causes and effects of movements responsible for cracking [37]

| Cause | Effect | Duration, Frequency | Examples of Materials or Components Affected | Notes |
|---|---|---|---|---|
| 1.Restraint of Internal Movements | | | | |
| (a)Temperature changes | Expansion and contraction | Intermittent, diurnal, seasonal | All | Extend of movement is influenced by thermal coefficient, exposure, color, thermal capacity |
| (b) Moisture content changes: | | | | |
| 1. Initial moisture absorption | Irreversible expansion | Relatively short term, due to absorption of moisture after manufacture | Brick and other ceramic products | Depend on age of product: most movement occurs within first 3 months of product's life |
| 2. Initial moisture release | Irreversible contraction | Relatively short term | Mortar, concrete, sand-lime bricks, ceramic products | May require measures to control or distribute cracking in masonry |
| 3. Alternate absorption release or moisture in service | Expansion and contraction | Periodic | Most porous building materials | In claddings, humidity gradient or non-homogeneity may be significant |
| 2. Chemical Changes | | | | |
| a) Moisture expansion of ceramics | Expansion, permanent | Over many years | Fired clay bricks and tiles | Tiled floors and walls |
| 3. Physical Changes | | | | |
| (a) Ice or crystalline salt formation | Expansion in building materials<br>Frost heave in soils | Intermittent, dependent on weather conditions and moisture content of materials | Porous natural stones, very exposed brickwork | In walling, damage usually confined to surface spalling or erosion<br>Cracking in exposed ground-floor slabs |

### 3.3.6 Changes in appearance

All materials change in appearance or composition to some extend when exposed to the physical and chemical conditions that arise or prevail around and within constructions.

Materials can be said, therefore, to have an inherent tendency to change, the rate of change being dependent on the characteristics of a material and the severity of its exposure to deteriorating factors [37].

Change in appearance is important, even if it does not involve deterioration. Sometimes the change which occurs over a period of time is considered an asset, as is softens the appearance of a building and adds a special character of its own. Other types of change are detrimental. The factors, which affect the changes in appearance are; solubility, frost action, sunlight, mechanical damage, cleaning, and staining [25].

### 3.3.7 Slip resistance

The danger of accidents occurring as a result of slippery floors is sufficient to make the provision of a non-slip finish very desirable in most places. Unfortunately there is often a conflict between the requirements for a non-slip finish and a surface which does not hold dirt and which is easy to keep clean. It is necessary therefore to consider which requirement is to carry most weight. In public buildings, safety is very important, and there are also special places, such as homes for old people, where the absence of a slippery finish is essential. In hospitals cleanliness and non-slipperiness are both important and the resulting problem is one which has not yet been solved entirely satisfactorily [25].

Resistance to slip can derive either from the frictional properties of the material, from the frequency of joints, or the slight indentation of the material under pressure from the foot. Slipperiness can also be cause by wear or by water, or the transfer of wax polish on the soles of shoes from one floor surface to an adjacent one [33]. All mosaic tiles are generally quite slip resistant, no matter what material, because of the large number of grout lines [31].

The ASTM procedure states that the measurement made by this apparatus is believed to be one important factor relative to slip resistance. Other factors can affect slip resistance, such as the degree of wear on the shoe and flooring material; the presence of foreign matter, such as water, oils, and dirt; the length of the human stride at the time of the slip; the type of floor finish; and the physical and mental condition of the person. Therefore, this test method should be used to develop a property of the flooring surface under laboratory conditions and should not be used to determine slip resistance under field conditions unless those conditions are fully described [41].

### 3.3.8 Cost

In the choice of materials, however, economic considerations generally favor investment in materials having low maintenance requirements [39].

Ease and expense of cleaning, length of life and ease of renewal, must be taken into consideration in assessing the true cost of floor finishes. It is important to consider the whole cost of sub-floor, preparation and surface finishing is in order to obtain a reasonable comparison of cost [25].

# 4. MATERIALS USED IN MOSAIC MAKING

Making mosaics is a process for butting bits and pieces together – for creating marvelous designs from nothing much at all. It is an art form with a long and glorious history; for thousands of years, people have been collecting fragments of stone, glass, and pottery to fill blank spaces with their designs [3]. Using tiny colored clay tiles, artists have created incredible images and patterns on the floors, walls, and ceilings of buildings from Greek temples to Byzantine cathedrals. Today, the individual tiles are ceramic, porcelain, terracotta, stone, or other tile cut into small pieces. They are often mounted on a mesh backing so that large squares of many tiles can be installed at once. These squares may be a solid color or contain a pattern or image. Individual mosaic tiles are also available for making custom accents and mosaics. The variety of patterns and designs available in prefabricated mosaic tile squares is extensive and adding just a few squares to a floor or a wall has a striking effect [31].

The ability to cut rocks into small, regular units known as tesserae liberated the medium from its strictly functional role. This was a critical turning point for mosaics. Using these uniform pieces, stone murals could be applied to walls, ceilings, or other objects. In addition, widespread production of glass allowed its regular incorporation into mosaics; its radiant, reflective qualities were accentuated against mortar, bringing new life to the art form. Following these improvements, ceramic tesserae were also included in mosaics. But it wasn't until the mid-twentieth century that the bridge between the three mosaic media would be anchored by mixed-media mosaic artists. In this final advancement, random objects are embedded into a composition, placing the emphasis on the parts rather than on the whole [42].

Mosaics are composed from a variety of product types (made from individual tesserae that could be vitrified or earthenware ceramic, glass or natural stone) and can be unglazed or glazed [43]. Their small size coupled with the multiple grout joints make mosaics excellent choices for areas frequently exposed to water, such as bathroom floors, showers, countertops, pool decks, and outdoor areas [28].

Three main materials used in mosaic making are;

- Ceramic
- Stone
- Glass

## 4.1 Ceramic

Ceramic is one of the oldest professions, dating back to the time that the earliest civilizations were forming. Traditional ceramics (earthenware, bricks, tile, refractories, glass, cement, and white-wares) have evolved over many centuries and continue to be indispensable today. Within the past century, though, there has been an enormous increase in the number and uses of ceramics [44].

Ceramics are typically produced by the application of heat upon processed clays and other natural raw materials to form a rigid product. Ceramic products that use naturally occurring rocks and minerals as a starting material must undergo special processing in order to control purity, particle size, particle size distribution, and heterogeneity. These attributes play a big role in the final properties of the finished ceramic [45].

Ceramics are made from a mixture of mineral material (generally quartz sand) and a clay binder (hydrated aluminum silicate) with impurities such as chalk, dolomite and sulphates, plasticized with water. The mixture is shaped, dried to remove making and absorbed water, and fired. During fired hydrate water, carbon dioxide and other gases are driven off, re-crystallization takes place and glass is formed producing a hard, insoluble material [39].

### 4.1.1 Introduction

Most people associate the word "ceramics" with pottery, sculpture, sanitary ware, tiles, etc. and whereas this view is not incorrect, it is incomplete because it considers only the traditional or silicate-based ceramics. Today the field of ceramic science or engineering encompasses much more than silicates and can be divided into traditional and advanced ceramics [46].

The first ceramics were the low-firing earthenware's that appeared some 10,000 years ago when humans had mastered the use of fire. Those early potters used simple pit firing, for they lacked kilns (specially designed ovens) for firing their wares. Nonetheless, the production of this early, unsophisticated earthenware's was the starting point for the subsequent development of ceramics [47].

The mass production of iron and steel, which began in the latter half of the nineteenth century, required the development of new refractory ceramics, entailing a shift from the use of conventional fireclays to refractory materials containing silica, alumina, chrome-magnesia, or magnesia [47].

#### 4.1.1.1 Ceramic tiles

Ceramic tile of various shapes, sizes, thickness, colors, and surface finishes are manufactured for use as a surfacing material for interior and exterior floors and walls where a quality surface is desired [48]. They are made from refined clay, which is ground, then pressed into moulds under great pressure before being fired at very high temperatures. The result is an exceptionally durable tile, which is very regular in dimension and coloring. Understandably, ceramic tiles are most at home in clean-lined modern interiors or in wherever such regularity is an asset [49].

Ceramic tile is made from nonmetallic minerals fired at high temperatures and manufactured in modular unit sizes (tiles), which facilitate installation. The term ceramic tile includes several products of varying dimensions, properties, and appearance [50]:

Glazed Wall Tile: 101.6 x 101.6 mm or 108 x 108 mm units used mainly on walls, but some are sufficiently abrasion resistant to be suitable for floors.

Ceramic Mosaic Tile: 25.4 x 25.4 mm, 25.4 x 50.8, or 50.8 x 50.8 mm units used mostly for floors, but used also on walls (Figure 4.1, Figure 4.2 and Figure 4.3) [50, 51].

Paver Tile: Floor units similar to mosaic tile but generally 101.6 x 101.6 mm or larger.

Quarry Tile: 177.8 x 177.8 mm or larger natural clay units for floors. Other sizes and shapes are also available [50].

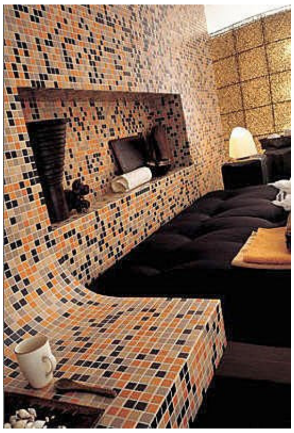

**Figure 4.1 :** Wall application of ceramic mosaic tiles [51]

**Figure 4.2 :** Floor application of non-slip ceramic mosaic tiles [51]

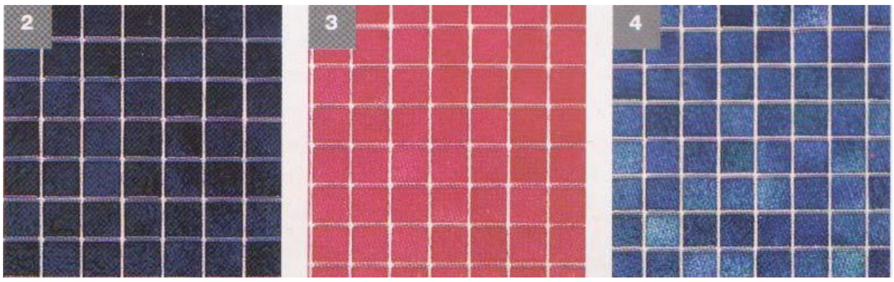


**Figure 4.3 :** Examples of ceramic mosaic tiles [51]

**4.1.1.2 Ceramic mosaic tiles**

Ceramic mosaic tile is made in two body types, porcelain and natural clay, in relatively small sizes. It is generally about 6.4 mm thick, with a surface area of less than 3871 mm². Typical sizes are 25.4 x 25.4 mm, 25.4 x 50.8 mm, and 50.8 x 50.8 mm. This tile may be either glazed or unglazed. Unglazed tiles have a wide range of natural earth colors that extend throughout the body of each tile. Additives can be mixed in with the other components for special effects: abrasives for slip-resistant tile and carbon black for conductive tile [50]. Also pigments are added to the porcelain or clay mixture, and therefore the color is dispersed throughout the tile (Figure 4.4) [41, 52].

**Figure 4.4 :** Ceramic mosaic tiles are available in rich, vibrant color pallet [52]

Available types include:

Unglazed Porcelain (Frost-proof) Tile: Made by firing refined ceramic materials; dense, impervious, smooth, and highly stain and wear resistant; clear, luminous colors or granular blends; available with abrasive surface in a few sizes and colors.

Glazed Porcelain (Frost-proof) Tile: Made with the same body as unglazed porcelain tile; glazed with clear (transparent) glaze, ceramic glaze, textured glaze, metallic glaze, or special decorator glaze.

Unglazed Natural Clay (Frost-proof or Non-frost-proof) Tile: Dense and abrasion resistant; made from unwashed clays; rugged and slightly textured surface tough enough to minimize slipping; easily cleaned; also available with a slip-resistant face in 25.4 x 25.4 mm squares only, in limited colors.

Glazed Natural Clay (Frost-proof or Non-frost-proof) Tile: Tile has a same body as unglazed natural clay tile with a clear, ceramic, metallic, or decorator glaze.

Conductive Tile: Impervious, with additives that minimize electrostatic build-up and explosion hazard in rooms where explosive gas mixtures are used, such as hospital rooms and laboratories [50].

All types of ceramic mosaics are suitable for walls, floors, and countertops, both inside and outside. Unglazed tiles are produced in either square-edged or cushion-edged types, depending on the manufacturer [30].

Table 4.1 summarizes the generally available types, sizes, and uses of ceramic mosaic tiles [50].

**Table 4.1:** Summary of ceramic mosaic tile products [50]

| Tile and Description | Suitable Uses | Limitations | Nominal Sizes, mm |
|---|---|---|---|
| Porcelain body, unglazed | All uses, interior and exterior, floors and walls; especially suitable for bathrooms, kitchens and swimming pools | None except limitations imposed by installation method and grout | 6.4 mm thick: 25.4 x 25.4 mm, 50.8 x 25.4 mm, 50.8 x 50.8 mm |
| Porcelain body, glazed | Interior and exterior walls in residential, commercial and institutional buildings; decorative inserts with above tile | Not suitable for floors Relatively short term | |
| Natural clay body, unglazed | Swimming pool runways; floors of porches, entrances and game rooms in the home; floors and walls of commercial, institutional and industrial building | Exterior use requires special frost-proof body | |
| Natural clay body, glazed | Walls in residential, commercial and institutional buildings; decorative inserts with above tile | Exterior use requires special frost-proof body | |
| Conductive | Exterior and interior; from moderate to extra heavy-duty floors in all types of construction | | |

Ceramic mosaic tiles are mounted on a backing sheet of rubber, plastic, paper or heavy thread, to facilitate application. Because of their small size, these tiles adapt well to contoured or irregular surfaces [53]. General data on ceramic mosaic tile products is given in Table 4.2 [33].

**Table 4.2:** Ceramic mosaic tile products [33]

| Ceramic Mosaic | Properties | Color and Pattern | Dimensions | Laying | Surface Treatment and Maintenance |
|---|---|---|---|---|---|
| Refined clay plus calcium flint and feldspar, fired at over 1200 ºC | Extremely good wearing qualities and impervious to oils, alkalis and most acids throughout depth | Good colors include white, green, grey, blue and deep red. Normally plain surfaces only | Thickness: 12.7 mm Squares, hexagons, etc., from 12.7 mm sides up to 50.8 mm | Tesserae are delivered to site mounted to pattern on paper and in a 9.525 mm bed of cement and sand (1:2) on a screed floor | Paper is stripped off from face and joints grouted and the floor cleaned as for plain tiles Easy to keep clean |

### 4.1.2 Definition of ceramic

The American Society for Testing and Materials (ASTM) defines a ceramic article as "an article having a glazed or unglazed body of crystalline or partly crystalline structure, or of glass, which body is produced from essentially inorganic, non-metallic substances and either is formed from a molten mass which solidifies on cooling, or is formed and simultaneously or subsequently matured by the action of the heat" [54].

The etymology of the term shows that it derives from the Greek "keramos", meaning "a potter" or "a pottery." However, the Greek word is related to an older Sanskrit root, meaning "to burn"; as used by the Greeks themselves, its primary meaning was simply "burnt stuff" or "burned earth." The fundamental concept contained in the term was that of a product obtained through the action of fire upon earthy materials [55].

In 1822, silica refractories were first made; they contained no clay, but were made by the normal ceramic process of shaping a moist batch, drying the shaped ware and firing it. The word 'ceramic', while retaining its original sense of a product made from clay, thus tacitly began to include other products made by the same general process of manufacture. There has in a consequence been no difficulty in permitting the term to embrace the many new non-clay materials now being used in electrical, nuclear and high-temperature engineering [47].

In the USA a radical extension of meaning was authorized by the American Ceramic Society (ACerS) in 1920; chemically, clay is a silicate and it was proposed that the term 'ceramic' should be applied to all the silicate industries; this brought in glass, vitreous enamel, and hydraulic cement. In Europe, this wider meaning of the word has not yet been fully accepted [47].

#### 4.1.2.1 Ceramic tiles

The ceramic floor tiles are defined by Standards of International ISO 13006:1998 like, "Ceramic tile is simply a mixture of clays which have been shaped and fired at high temperatures resulting in a hard body. This hard body may then be left untreated or it may receive a glazed wear layer [56].

EN 87 specifies, "Ceramic wall and floor tiles are building materials which are generally designed for use as floor and wall coverings, both indoors and outdoors, regardless of shape or size. Ceramic wall and floor tiles are not, therefore, combustible and are light-fast. Wall and floor tiles may be glazed, unglazed or engobed. Glazes are glass-like, impervious coatings, and engobes are matt, clay based coatings, which may also be porous. Glazed wall and floor tiles are produced either by single or by twice firing" [57].

#### 4.1.2.2 Ceramic mosaic tiles

American National Standard Specifications for ceramic tile, ANSI A 137.1 defines ceramic mosaic tile as a tile formed by either the dust-press or plastic method, usually 0.64 to 0.95 cm thick, and having a facial area of less than 39 $cm^2$. Ceramic mosaic tiles may be of either porcelain or natural clay composition and they may be either plain or with an abrasive mixture throughout [57].

Ceramic mosaics are defined by size (generally less than 25 mm) [31]. Since they are dense-bodied vitreous tiles, they resist water, stains, impact, and abrasion, making them suitable for practically any application, indoors or out. Surface textures range from a smooth, glassy surface for walls and countertops to a textured slip-resistant surface for use on floors [53].

### 4.1.3 Historical development of ceramics

Ceramic materials, manufactured from fired clay, have been used in construction since at least 4000 BC in Egypt, and represent the earliest manufactured building materials. The variety of traditional ceramic products used within the building industry arises from the wide range of natural and blended clay used for their production [22].

The art of making ceramic tile is also as old as civilization. Over 5000 years ago the Sumerians and the Babylonians produced brilliantly glazed tiles to protect the sun-dried bricks of their temples and palaces [30].

#### 4.1.3.1 Before the Christian era

Ceramic ware during this period was made largely from native clays, which produced rather soft earthenware. Hand molding and wheel throwing was usual, but some ware, was formed in fired clay molds. Terra cotta was made in rather large pieces. Glazes containing lead and tin were commonly used with a variety of colors. The finish consisted of a fine fraction of clay separated by suspension in water. When applied as a glaze it could be dried and fired to a smooth dense layer on the ware.

Ceramic shaping in the earliest times was achieved in various ways. Balls of clay were formed into the desired shape by pressing with fist and finger or by pounding with a stone. In many places, flat “bats” of clay were made by pounding, spreading, and rolling, to form the bottom of a vessel.

Potters had soon noticed that differing sources of clay behaved in differing ways when being worked, and particularly when being fired. Firing took place originally in an “open fire”. Significant technical achievements can be recorded at the period around 3500 BC: on the one hand the potter’s wheel, and on the other, the earliest glazes, and in their train, glass.

In the course of many centuries there had been developed, from the primitive method of baking in an open fire, a technique of firing in a proper installation designed for this purpose. It had been noticed that the heat must be kept in by means of walls and that it was advantageous to have a firing chamber separate from the baking compartment.

In this period, ceramics were used largely in the household, but art ware, such as painted Greek vases, was also produced. The ancient potter did not seem to have the social standing of sculptor and painters [58].

**Ceramic tiles**

The origins of ceramic tile date back 5000 years, as evidenced by burnt natural clay tiles found by archeologists in early Egyptian and Babylonian excavations [50]. Archaeologists have discovered that thin slabs of fired clay, decorated and glazed in Egypt about 4700 BC [41]. One of the most interesting of these is a small temple erected about 3200 BC in the city of Erech in ancient Sumerian. The clay walls are decorated in a zigzag pattern of colorful tile mosaics in black, red, and white. The individual tiles are actually clay cones inserted into the walls, with only their round bases protruding. At one side of the temple stands a row of massive columns decorated with the same mosaics [30].

Decorative and functional clay tiles were also an essential part of later Greek and Roman architecture [50]. The Romans used fired clay pipes to carry water and sewage and used terra cotta to construct and decorate their public and private buildings [41].

#### 4.1.3.2 During the Christian era

In this period a great variety of pottery was made nearly everywhere, but most of it was earthenware. However, one of the most stupendous ceramic developments of all time occurred in China. The earthenware produced at the beginning of the period was gradually refined to a stoneware and finally to the pure white translucent porcelain [58].

The Chinese developed numerous glaze types, ranging from simple lead glazes to feldspathic glazes. “Celadon” stoneware emerged and also a further type of stoneware which in its properties pointed to later developments – the original “proto-porcelain” [57].

**Ceramic tiles**

In Europe, decorated tiles did not come into general use outside Moorish Spain until the second half of the twelfth century. By the end of the twelfth century, use and manufacture of Ceramic tiles had spread across Italy and Spain and into the rest of Europe. Until that time, they were mainly used to decorate the floors of Cathedrals and Churches. The skill had eventually vanished from Europe in the sixteenth century following the reformation [59].

#### 4.1.3.3 Eighteenth century

In the Western World, at the start of the eighteenth century, there was continued production of generally undistinguished earthenware. On the other hand, strenuous efforts were being made on the Continent to duplicate Chinese porcelain. The early attempts produced a type of frit porcelain in which glass was added to the earthenware body.

Thus, vitreous pottery produced on the Continent continuous to be largely a hard porcelain body made of a kaolin-feldspar-quartz mixture, bisque fired at low temperature and glost fired at a high temperature. Thus, a pattern was set for both tableware and art-ware in the continental area that is still going on [58].

#### 4.1.3.4 Nineteenth century

The earthenware potteries saw few changes during this period except for greater use of coal. However, Hoffman in Germany invented the continuous-chamber kiln, quite unaware that this principle had been used in China many years earlier. Again, England was the original home of the steam engine, so this source of powder became available at the end of the century and must have been a factor in modernizing the potteries.

Toward the end of the nineteenth century, electric powder pointed to exciting new possibilities of working at very much higher temperatures than had been possible before. Thus, electrochemistry began in France and led rapidly to giant steps at the start of the next century [58].

The qualities of cleanliness and good looks can be further extended when tiles are used in conjunction with water, particularly when the water is in motion, as in a fountain. The sense of coolness is heightened and a mood of freshness and sparkle is created. Tiles provide an ideal material for the basins of fountains; their glazed surfaces offer a far greater range of colors than natural stone or even marble could achieve [60].

**Ceramic tiles**

Until the nineteenth century, tile making was essentially a craft-based business and, even though in some places tile manufacture was an important part of the local economy, it was essentially a workshop operation. The Industrial Revolution introduced new techniques for preparing and forming clay into tiles, using such improvements as steam powder and iron presses, and these techniques in turn necessitated special factory buildings, even more importantly the changes in industry created an unprecedented demand for decorative building materials. Supplying the dual needs of mass production on the one hand and elaborate decoration on the other required a radically different combination of skills and philosophies from those of previous generations. Thus in nineteenth-century decorative tile-making art and industry were brought together in a new and fascinating relationship.

A large quantity of nineteenth century wall tiles were decorated with molding or some form of relief decoration; this was cheap and particularly easy to achieve by using metal dies in the presses, which formed the clay dust into tile and relief decoration in one process.

Ingenious use of this industrial method of clay dust pressing even led to the production of a tile form of mosaic, patented by Maws in 1862 but later used by a variety of manufacturers. The face of the 'patent mosaic' tile was intended, with lines representing the joints between the tesserae.

In the nineteenth century, the traditional purpose of wall tiling as a means of keeping buildings cool was extended in other important directions – tiles as a means of keeping buildings both clean and hygienic. In some instances, tiles were also used for their light-reflecting qualities and even as a fireproof lining for ceilings and vaulting. The growth of the population had resulted in overcrowding and associated insanitary conditions, and as concern for public health and hygiene rose, the hard, smooth glazed surfaces of mass-produced tiles grew in popularity.

In the nineteenth century, using tiles in the home, especially for bathrooms and kitchens, has now become so commonplace that many people would regard them as indispensable.

Industrial mass production of tiles and their improved distribution enabled the homes of all sectors of nineteenth-century society, whether situated in a traditional tile-making area or not, to benefit from a ceramic material that could be both cheap and beautiful [60].

#### 4.1.3.5 Twentieth century

The manufacture of ceramics in this period showed very few significant changes except for the powerful electric furnaces for making silicon carbide, fused alumina, and fused magnesia. Other changes were the increased use of gas and oil for kiln fuel, the start of tunnel kilns, and the use of electric motors for more powerful forming machines.

However, there was an increasing understanding of the various ceramic materials and their forming and firing, and improvements were made in treating clays and other minerals. All these things were building a foundation for the enormous leap in the next period [58].

**Ceramic tiles**

In the United States, production of ceramic tile was spurred by the introduction of the dust-press method at the end of the nineteenth century. Samuel Keys is credited with first producing floor and wall tile in Pittsburg in 1867. By 1937 there were 52 manufacturers of ceramic tile in the United States. It is generally agreed that more improvements in tile manufacturing and installation techniques have been made by the U.S. ceramics industry during the past 70 years than in the preceding 70 centuries [50].

### 4.1.4 General behaviour of ceramics

The most important advantageous features of ceramic materials are:

- Low electrical conductivity,
- Low thermal conductivity,
- Low density,
- High strength at high temperatures,
- Wear resistance,
- Corrosion resistance,

These properties lead to applications in many technical areas.

The low electrical conductivity leads to applications in insulating techniques. Spark plugs are the best-known applications in engine manufacturing. The low thermal conductivity is used, for instance, for the protection tiles of the Space Shuttle and in the form of insulation layers in combusting chambers.

The resistance against corrosion leads to applications as heat exchangers for corrosive agents. In biomechanics, the compatibility of ceramics with human bodies is of high importance.

The excellent wear resistance is exploited for cutting tools, as roller bearings or in the textile industry.

The high temperature strength is used in nuclear fusion technology applications, in the development of gas turbines and in the field of solar energy.

The main disadvantages of ceramics are:

- Low tensile strength at room temperature for some materials,
- Brittleness,
- Large scatter of strengths,
- Sub-critical crack extension.

Brittleness means that failure occurs without prior measurable plastic deformation. This is due to the strong atomic bonding of ceramics, which lead to high stresses for the motion of dislocations. Thus, failure can start from small flaws before plastic deformation is possible. This fact can also be expressed in low resistance against crack extension, which is characterized by the fracture toughness. The absence of local plastic deformation leads to failure at locations of high local stresses, e.g. at notches, at contacts between different material or during thermal shock.

The large scatter of strength is caused by the statistical distribution of the flaw size and the flaw location. This requires a statistical description of the strength and a relation between failure probability and the stress distribution in a component.

Sub-critical crack extension can cause failure under constant or cyclic loading during the operation of component and will lead, consequently, to a limited lifetime [61].

#### 4.1.4.1 Ceramic tiles

Ceramic tiles are hardwearing, easy to clean, stain and heat resistant, waterproof and inflammable. They provide a functional, hygienic covering for walls, floors and other surfaces. Floor tiles generally comprise harder, thicker clay than wall tiles, with low porosity and water absorption, and a more durable surface. They are also stable and safe to use and live with. Tiles are reusable. They will not biodegrade, but neither are they toxic [62].

The beauty of ceramics is the astonishing choice of colors, shapes, patterns and textures. The familiar rustic palette of earthy shades is complemented by a whole range of more vivid colors in solid, shaded or variegated forms, and tones of white, black and grey. Patterns are equally varied, from the verve and individuality of hand-painted decoration to machine-made glaze, embossed or relief designs. Ceramic tiles do not acquire any discernible patina with use, but the fact that they are relatively unchanging can be welcome where a fresh, clean look is desired [49].

In general, ordinary ceramic wall tiles are not suitable for outdoor mosaics. Such tiles are porous and absorb water that can then freeze, causing cracking.

Some ceramic tile has been high-fired and is designated “frost-proof” or “frost resistant.” Floor tiles are often rated specifically for water absorption. “Vitrified” floor tiles have an absorption rating between 0.5 and 3 percent, and can withstand freeze-thaw cycles. Porcelain floor tiles have an even lower absorption rating, but come in a limited range of colors [31].

#### 4.1.4.2 Ceramic mosaic tiles

Most ceramic tile made specifically for mosaic use is frost-proof. Among them are tiles that are not glazed at all; the color is mixed right into the clay. They come in a nice range of colors and are extremely durable, making them a good choice for outdoor projects [31]. These tiles are impervious to water and have a dense body [30]. They resist water, stains, impact, and abrasion, making them suitable for practically any application, indoors or out [53].

### 4.1.5 Performance properties expected from ceramics

As floor and wall covering, ceramic tile serves a dual function: an aesthetic function as a design component and a technical function as a finishing building material. As a building material, ceramic tile must be able to withstand a range of environmental stresses [43].

**Table 4.3:** General properties of ceramic materials [62]

| Property | Ceramic |
|---|---|
| Mechanical | |
| Tensile strength | 100 max |
| Compressive strength | 600 max |
| Impact | Poor |
| Hardness | Can be 2600 |
| Creep strength | Excellent |
| Physical | |
| Density | 0.1 to 0.6 |
| Conductivity | |
| Heat | Poor to fair |
| Electricity | Nil to some |
| Coefficient of expansion (thermal) | Low |
| Water absorption | Some |
| Chemical | |
| Chemical resistance | Excellent |

During firing, increases in temperature are accompanied by more complete re-crystallization and an increase in the formatting of glassy material promoting greater density, hardness, strength, resistance to chemicals and to frost, and greater dimensional stability [39]. In Table 4.3, general properties of ceramic materials are given [63].

The product performance standards contain the technical characteristics and the required tolerance values that must be met or exceeded for the tile to conform to the standard [41].

#### 4.1.5.1 Durability

Ceramic tile provides a durable surface that maintains good looks indefinitely. They are used extensively in nonresidential settings because of its durability [29]. Service life of ceramic materials under various conditions is shown in Table 4.4 [36].

For glazed ceramic tiles use in residences, all types of glazes are sufficiently durable, but for public buildings subjected to severe traffic, a special high-fire type of glaze is available [48].

**Table 4.4:** Order of magnitude classification of the age or service life of ceramic materials [36]

| | Class of degradation factors and expected age | | | |
|---|---|---|---|---|
| | 1<br>Very severe exposure[1] | 2<br>Severe exposure[2] | 3<br>Mild exposure[3] | 4<br>Very mild exposure* |
| Materials | Age in years | | | |
| Strong ceramic materials | 100 to 1000 | 1000 to 10000 | 1 million | >10 million |
| Ceramic materials | 1 to 100 | 100 to 1000 | 10000 | >100000 |

Note: [1] Frost, snow, ice, thawing, great changes in temperature and humidity, erosion, dissolution, strong sunlight, pollution, conditions with strong corroding effects, for example, seawater, polluted water, corroding chemicals, etc.
[2] Average variable outdoor conditions, moderate changes in freezing and thawing.
[3] Moderate temperature, dry, slight changes in environment
* Dry, very slight ventilation, low temperature, no sunlight, constant conditions.

#### 4.1.5.2 Abrasion/wear and impact resistance

Many ceramics show outstanding abrasion resistance, because of their high hardness relative to the abrasive particle. One of their weaknesses, however, is an inability to withstand impact, that is, they have low fracture toughness. At high unit loads, ceramics are also subject to micro fracture, which can lead to high wear loss rates.

Alumina, zirconia, and silicon nitride, among others, are currently used for wear-resistant applications [64].

Ceramic tiles good or superior abrasion resistance makes them uniquely suited for areas exposed to severe foot traffic or in intermittent or continuous contact with water or corrosive chemicals [50]. Factors affecting wear of ceramics are given in Table 4.5 [65]. Glazed tiles are less good at resisting abrasion and matt tiles can wear down to a smoother surface [49].

**Table 4.5:** Factors affecting wear of ceramics [65]

| Wear factor | Variables affecting wear factors | |
|---|---|---|
| Nature of the abrasive | Size | Wear increases with increasing particle size |
| | Shape | Angular particles cause about twice the wear of rounded ones |
| | Density | Dense materials create greater wear since kinetic energy of the particles in higher |
| | Hardness | Wear increases rapidly when the particle hardness exceeds that of the surface being abraded |
| | Concentration | In slurry systems, wear increases with concentration |
| Nature of contact | Velocity | The rate of wear increases rapidly with increasing velocity |
| | Impact angle | Wear increases when the impingement angle is increase towards 90ºC |
| | Load | Increased throughput causes an increase in wear rate |
| | Corrosivity | Complex interaction, but greater severity corrosion, lower wear resistance |
| Wear material | Fracture toughness | Greater wear resistance is usually obtained with higher fracture toughness |
| | Corrosion resistance | Very complex, but wear best for inert materials |
| | Porosity | Wear resistance best for materials with zero porosity |
| | Coefficient of friction | Lower coefficient of friction generally gives better wear resistance |
| | Grain size | For many sintered ceramics, fine grain size usually gives better wear resistance |
| | Hardness | Higher hardness ceramics usually have better wear resistance |

#### 4.1.5.3 Resistance to frost

Ceramic products vary widely in degrees of the frost resistance, which is essential for products exposed externally [39].

Wall and floor tiles molded from dust with only 2 % to 5 % moisture content have little drying contraction and very much greater accuracy is possible. In addition, glazes, which are to be exposed externally, must be frost resistant [39].

Frost resistance goes hand in hand with water absorption. The less water the tile absorbs, the greater its frost resistance [66].

Water Absorption: Tile bodies have varying degrees of density and porosity, resulting in greater or lesser perviousness to moisture. Tile with a body that has absorption of less than 0.5% is impervious; tile with absorption of 0.5% to 3% is vitreous. The low absorption of impervious and vitreous tiles makes them suitable for exterior installations subject to freezing and to interior installations, such as swimming pools, that are subject to continuous immersion in water. Semi-vitreous tiles, with absorption of 3% to 7%, and non-vitreous tile, with absorption between 7% and 18%, are not suitable for exposure to freezing or immersion in water. Water absorption measurement of ceramic tiles defined by ANSI is given in Table 4.6 [50].

**Table 4.6:** Water absorption measurement of ceramic tiles (ANSI) [50]

| | |
|---|---|
| Non-vitreous Tile | Absorbs 7% or greater. Suited for indoor use only. |
| Semi-vitreous Tile | Absorbs between 3% and 7%. Suited for indoor use only. |
| Vitreous Tile | Absorbs between 0.5% and 3%. Suited for both interior and exterior use. They are frost resistant. |
| Impervious Tile | Absorbs less than 0.5%. Suited for both interior and exterior use. They are frost resistant. They are also considered the strongest tile. |

While the glazed surface of any tile is impervious to water, glazed tiles are not necessary more water-resistant than those that are unglazed. If the glazed surface is scratched or abraded, water will penetrate into the tile body. Water can also enter through grout joints between the tiles. The density or porosity becomes important when choosing tiles for wet conditions (such as in a bathroom or on a kitchen countertop) because water absorbed by porous tiles can harbor bacteria and will eventually penetrate through the tile to the substrate, loosening the adhesive bond [53].

Water absorption tests can also be used as a good indicator to predict the stain resistance of unglazed tile. The lower water absorption means, the greater stain resistance [41].

### 4.1.5.4 Resistance to chemicals

Practically all ceramic materials have excellent chemical resistance, being relatively inert to all chemicals except hydrofluoric acid and, to some extent, hot caustic solutions [67].

Ceramic tiles resist staining, household chemicals and swimming-pool water cleanser, as well as alkalis and acids [68]. Glazed tile and even some unglazed tiles resist practically all solutions that could cause staining in other types of products [66].

#### 4.1.5.5 Movement and cracking

To minimize any movement in tiling, backgrounds should be completely stable. This is a most difficult criterion to achieve. Backgrounds should be structurally as well as chemically stable and not subject to deflection in use [68].

A sound vitrified glaze is virtually impermeable if its composition is accurately matched to the properties of the body and thereby subsequent micro cracking will be avoided [39].

The density of clay also determines if the tile is suitable for outdoor use. Tiles that are too porous, absorbing more than 3% moisture will freeze and crack if installed outdoors in cold climates [66].

#### 4.1.5.6 Changes in appearance

While most colored materials will be altered by long exposure to light, colors in ceramic tiles are unaffected and will not change or fade from exposure [66].

#### 4.1.5.7 Maintenance and cleaning

Ceramic tiles do not retain dust or residues. Therefore, they are recommended low upkeep. Plain water or a damp cloth is generally all that is required to keep the tile clean. Grout may soil or discolor. Silicone treatments will make grout less susceptible to soil. Newer developments in grout are more resistant to stain [29, 66].

#### 4.1.5.8 Slip resistance

The slip resistance of ceramic tile in ordinary applications is comparable to that of most hard surface flooring materials and it is significantly better than some. Unglazed tiles have greater slip resistance than glazed tiles and are recommended for areas subjected to high water spillage. Many glazed and unglazed tiles also feature an abrasive grit on their surface, increasing their slip resistance substantially. These tiles are particularly suited to public areas with direct access to the outdoors [66].

Glazed tiles tend to be slippery especially when wet. If this characteristic is undesirable (for example, for floors), then unglazed tile, which has a homogenous composition, or tile incorporation a dispersed abrasion should be used [69].

Some non-slip floor tiles also have textured or matte finish glazes, and some glazes have abrasives added for better traction [33].

In general, ceramic tiles are slightly slippery, but non-slip versions containing silicon carbide are available, and ones with ribbed, ridged or studded textures give a better grip underfoot [49].

#### 4.1.5.9 Cost

Ceramic tiles cost range low to high. Costs vary considerably in ceramic tiles. Imported tiles from France and Italy can be expensive. Labor to install is also high. However, because it is permanent, the life-cycle cost is low [29].

#### 4.1.5.10 Dimensions and surface quality

Ceramic tiles may be very regular in dimension. This precision gives the tiles a crisp, contemporary look, accentuated by the fact that the tiling can be more closely spaced since sizes and shapes are so accurate [49].

The surface texture of ceramic tile relates to its reflectance qualities. For example, a perfectly smooth tile will have a much higher reflectance rate than a rough surface tile, although both tiles have identical glazes [41].

### 4.1.6 Ceramic design and process

The successful application of ceramics depends greatly on the ability of the design engineer to develop structures and components in ways that properly utilize the advantageous properties of ceramics and minimize the impact of limiting characteristics. Similarly, the material properties that are achieved for a certain ceramic composition depend almost entirely on the processing of raw materials. Thus, the design and processing of ceramic materials have been the principal research thrusts in ceramics for several decades prior to the 1990s, during which research continues [55].

#### 4.1.6.1 Design

The first step in the design process is to select a material that has the properties required for the application. Historically, performance expectations of traditional ceramics were modest, because hardness, imperviousness, and moderate or low levels of mechanical strength were the only requirements. In the modern era, compositions of ceramic materials that exhibit a wide range of electrical, mechanical, and thermal properties have been developed.

Although processing is a key determinant of the ultimate properties of most ceramics, selecting the proper chemistry is necessary, both to achieve the desired overall behavior of the ceramic and to permit fabrication of a cost-effective structure or component. As a broad generalization, oxide materials are less expensive and are easier to process, whereas the non-oxides offer superior mechanical properties and greater thermal stability. However, each application is different and material selection must be performed on a case-by-case basis.

A very simple design strategy is to consider aluminum oxide as the default material for structural applications and to move to higher or lower performance materials, as required. Aluminum oxide offers very good, but not outstanding, performance with respect to strength, toughness, wear resistance, thermal stability, thermal shock resistance, and other properties. It is excellent in terms of high thermal conductivity, and it is available at relatively low cost. If subsequent design requirements indicate a need for high strength, material selection can move in the direction of silicon carbide or hot pressed silicon nitride. If greater toughness at low temperature is required, a move to more expensive, but tougher, partially stabilized zirconia may be justified. If catastrophic failure protection is necessary at very high temperature and if high cost is not an obstacle, a broad range of selection possibilities exists among ceramic-matrix fiber-reinforced composite materials [55].

#### 4.1.6.2 Ceramic processing methods

Ceramic processing is a sequential activity that starts with raw materials, proceeds through batch preparation and forming, and concludes with firing and surface finishing, as required by the application (figure 4.5) [55, 65].

**Raw materials**

Ceramics are usually prepared from raw materials in the form of powders. However, the raw materials used for traditional ceramics are different from those used for advanced ceramics.

For traditional ceramics, the raw materials are commonly of mineral origin and are beneficiated to remove impurities and to prepare the raw materials for subsequent ceramic processing. Traditional ceramic raw materials consist of silica, clays, fluxes, and refractory materials. Silica is obtained either from massive quartz rock deposits or from pure quartz sands.

Clay minerals are enormously diverse, but the most commonly used materials are kaolin and talc. Most of clays are used in traditional ceramic compositions because of their ability to generate plasticity in the body when mixed with water.

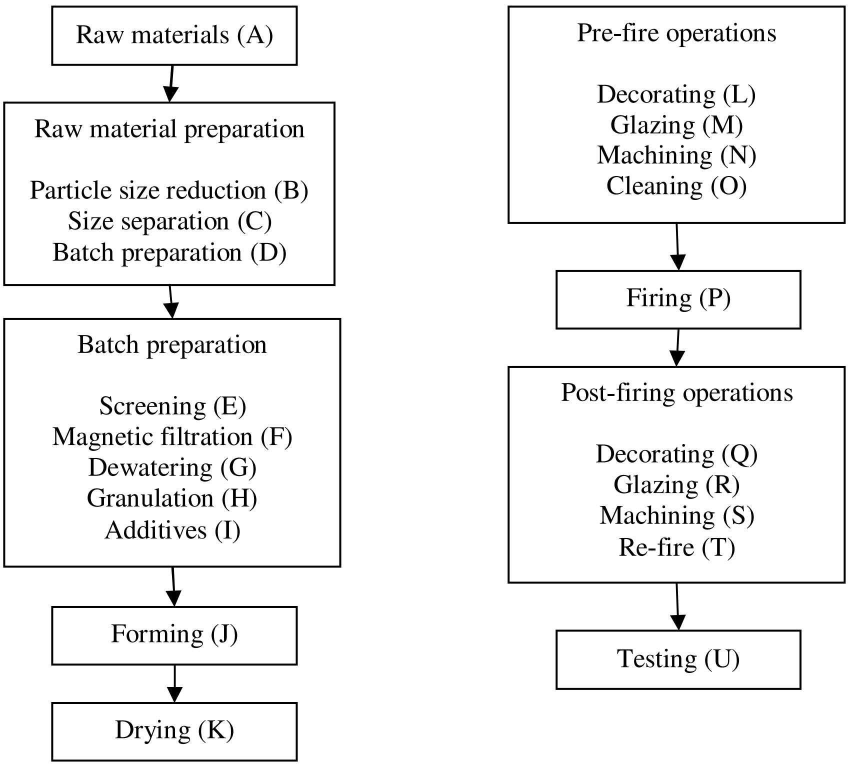


**Figure 4.5 :** Fabrication process for various ceramic types [65]

Fluxes are minerals, such as feldspars or nepheline syenite that contain alkali oxides to promote the fusion of silica and alumina to form a glassy phase during firing. The use of these fluxing minerals permits the processing of traditional ceramics at practical temperatures.

Refractory materials are a separate class of ceramics and include oxides, carbides, and other materials that withstand extremely high temperatures. Their principal use is in the preparation of high-temperature forms used as furnace linings to resist the attack of molten glasses and metals.

For advanced ceramics, the raw materials are usually chemically prepared powders of high purity. Powders of aluminum oxide, zirconium oxide, silicon carbide, silicon nitride, and aluminum nitride are examples of highly processed raw materials for advanced ceramics. The powder process routes vary greatly, but several common objectives for all processes are high chemical purity, controlled particle size and distribution, high reactivity, and freedom from hard agglomerates, or aggregates, that will not break down during mixing and subsequent processing [55].

**Preperation for forming**

Before the powder raw materials can be formed, they must be prepared into various states that are compatible with the forming process. Powders used in dry pressing processes are usually spray dried prior to pressing. The spray drying preparation permits the uniform incorporation of additives, such as binders and lubricants, into the powder mix. Because spray drying is a granulation process, it combines many sub-micrometer-sized powders particles into larger spherical particles that have excellent flow and die-filling characteristics [55].

**Forming processess**

A wide range of forming processes is used; the ceramic engineer can choose whichever process best suits a particular application. Dry pressing and injection molding are the processes that are widely used for small pieces. The proper forming process for a particular component or structure depends on many parameters, the principal ones being the size and shape of the component and the anticipated production volume [55]. With the exception of cotto and clinker, which are shaped by extrusion, all types of ceramic tiles are shaped by dry pressing, generally with hydraulic presses [43].

Dry pressing is a forming process in which nearly dry, free-flowing powders that are compacted under high pressure to the desired shape. Dry processing is most efficient and economical when large quantities of simple, small shapes are required. In particular, the aspect ratio of the component is important.

The development of improved die design that incorporates multi-segment punches, floating die cavities, two-directional pressing, and special time/pressure cycles, have reduced density gradients and increased the scope of shapes that can be commercially produced by dry pressing. The use of lubricants, both internal and external to the ceramic powder, reduce friction during the pressing process, facilitating forming, and further reducing undesirable density variations.

The main advantage of injection molding is that, in principle, large quantities of very intricate parts can be quickly formed, analogous to polymer injection molding. In practice, a large amount of polymer binder/plasticizer is required to generate the required flow behavior. The removal of this binder and the subsequent densification of the component can cause serious problems and is the limiting issue in the application of injection molding to ceramics. Binder burnout is greatly facilitated if the part of small and recent research into cellulose-based binders offers the possibility of greatly reduced binder levels [55].

**Glazes and glazing**

Glazes are mixtures of frits, sand, kaolin, coloring agents and opacifers, mostly applied wet using different systems. Decoration is often obtained by silk-screening. The double-firing technique in which glaze is applied to the previously fired body, is still used today for products in majolica and cottoforte. In the single-firing method glaze is applied to the dried raw body before firing. Many innovative techniques have been developed to improve the mechanical features of the glazed surface. Some of the most important are dry applications and press glazing (the application of the glaze in powder form when pressing the body) [43].

**Firing**

Firing is done at higher temperatures, typically above 1000˚C [24]. Single-layer fast-firing kilns are used for most products. Firing temperatures range between 1000°C to 1020°C for porous products; 1050°C to 1200°C for single-fired products; and 1200°C to 1220°C for porcelain. Exposure to high temperatures results in chemical and physical changes in ceramic powders that lead to the development of strength and other desirable properties. Two general processes are important in firing ceramics: vitrification and sintering. Vitrification occurs when constituent materials react at elevated temperatures to form a substantial amount of liquid phase, which acts to consolidate the ceramic body through the capillary forces. Ceramic bodies that do not form substantial amounts of a liquid phase at elevated temperatures densify by a solid-state diffusion process known as sintering. Surface-area reduction is the principal driving force for sintering.

A firing schedule is the product of time and temperature, where small trade-offs in these areas can be made without varying the out-come [55].

#### 4.1.6.3 Ceramic tile production

Ceramic tiles are manufactured in standard ceramic production processes. Ceramic wall and floor tiles are prepared from a mixture of ball clays, sand, fluxes, colors and other mineral raw materials, they undergo more or less intensive processing such as milling, screening, blending, wetting etc., are shaped by pressing, extrusion, casting or other processes, normally at room temperature, they are subsequently dried and finally fired at high temperature [57].

In particular, however, tile is pressed into much thinner bisques and smaller surface sizes and then baked. The baking and face glazing produce a variety of finishes that make tile suitable for decorative purposes. Tile is used to surface either walls or floors. It has a hard, glossy surface that is impervious to moisture and resists soiling. It is easy to keep clean [70].

Like all ceramic material, ceramic tiles are durable, hygienic, non-combustible, fire-resistant and easy to maintain. Tiles are also rigid and feature relatively low resistance to shock. These features are intrinsic to the nature of ceramic materials [43].

Porcelain types of ceramic tiles are made by the dust-press method from a carefully proportioned blend of ceramic materials with a vitreous (glasslike) body, which is resistant to freezing and thawing and to abrasive wear. A wide range of colors is obtained by adding mineral pigments to the mix, so that the color goes all the way through the tile. The surface may be mottled, textured, or glazed. Natural-clay types are made of natural clays or shales, which produce a strong, longwearing body with a slightly textured surface. The color range of natural-clay tile is generally limited to the natural colors of the clays, although some color variations may be obtained by the additions of mineral oxides and dyes [30].

Because of a mosaic tile's small size, the individual tiles are mounted on a sheet to simplify setting. By definition of the TCA (International Trade Corporation), mounted tile is; tile assembled into units or sheets by suitable material to facilitate handling and installation. Tile may be face-mounted, back mounted, or edge-mounted. Face-mounted tile assemblies may have paper or other suitable material applied to the face of each tile, usually by water-soluble adhesives so that it can be easily removes after installation, but prior to grouting of the joints. Back mounted tile assemblies may have perforated paper, fiber mesh, resin, or other suitable material bonded to the back and/or edges of each tile, which becomes an integral part of the tile installation. Back mounted and edge-mounted tile assemblies shall have a sufficient exposure of tile and joints surrounding each tile to comply with bond strength requirements. Tile manufacturers must specify whether back-mounted and edge-mounted tile assemblies are suitable for installation in swimming pools, on exteriors, and/or in wet areas [41].

Not so long ago, tile was available in a relatively limited number of colors, shapes, and finishes (such as a few smooth, pastel-colored tiles). However, that is no longer the case. Today, there is a variety available. For walls and floors, you can get tile in a variety of shapes (diamond, curved, and so on) and in a great variety of colors and textures, from sand to smooth [70].

### 4.2 Stone

Natural stone is perhaps the oldest, most abundant and most durable "readymade" building material, found predominantly in hilly areas. Various types and forms of natural stone can also be processed to produce other building materials [65]. It is obtained by taking rock from the earth and reducing it to the required shapes and sizes for construction [27].

Stone has been used as a structural material, as a finish material, and as roofing throughout the centuries. With the development of new materials and new methods of construction, it is now used almost entirely for its decorative value. The range of color, texture, and finish of stone is almost inexhaustible. While some types of stone are available only in limited quantities or areas, others are found all over the world [30].

### 4.2.1 Introduction

Stone is one of the original natural materials used in construction by prehistoric people. As such, it has served literally as the foundation of all architectural efforts, from prehistory to the turn of the last century. Today, stone is used for aggregates or as a surface finish material, in the form of veneer, paving, shingles, counter tops, and various decorative items [24]. Table 4.7 summarizes the uses of stone in the building industry [71].

Stones are usually selected because of its aesthetic qualities, with casual reference, at best, to basic data on porosity, pore size, moisture absorption, and other critical physical and chemical parameters. A more effective exchange of information of stone, based on its actual performance in place, rather than the development of new laboratory information were among the committee's recommendations [38].

Traditionally, stone has been a material of low cost and local availability. Every region of the world possesses some useful stone of some variety, although only a small minority of available stone has ever been useful as a structural material. Assessing the structural viability of stone can be a tricky proposition because the material is a natural resource of great diversity in consistency, composition and quantity. While this lends certain distinctive qualities to the material, it introduces risk. As a result, today stone is primarily used for nonstructural purposes, having been soundly (and irreversibly) replaced by steel and concrete. The overwhelmingly nonstructural use of stone today has essentially transformed the material into a surface treatment. In fact, some of the latest technological developments have been focused on producing ever-thinner slices of the material, sometimes reinforced with textiles or light metals [34].

**Table 4.7:** Uses of stone in the building industry [71]

| Type of Stone | Minerals | Areas of use |
|---|---|---|
| Granite | Feldspar<br>Quartz<br>Mica | Crushed stone; structures; floor finishes; wall cladding |
| Limestone | Lime | Ground to lime-flour; smaller structures |
| Marble | Lime/dolomite | Structures above ground; floor finishes; cladding |
| Slate | Quartz<br>Feldspar<br>Mica | Roof covering; wall cladding; floor finishes |

#### 4.2.1.1 Stone tiles

Various forms of natural stone, including marble, travertine, granite, sandstone, limestone, and slate, are used for interior and exterior floor and wall surfaces in the form of tile (Figure 4.6 and Figure 4.7) [48, 51].

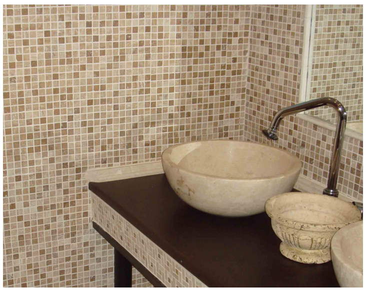

**Figure 4.6 :** Wall application of stone mosaic tiles [51]

**Figure 4.7 :** Floor application of stone mosaic tiles [51]

Floor tiles of limestone and marble, usually produced in a thickness of 2-3 cm, while sandstone is around 8-10 cm thick because of its lower strength. Granite has a much greater variety of form and size. Round stones and square cobblestones from 5-12 cm can be used. All stones can be polished, which simplifies maintenance. Slate floors are often laid as tiles, which are cut into squares or rectangles [71].

Wall tiles of slate or other stones, produced in many different sizes. As they are not exposed to heavy loading, large dimensions can be used even with weaker types of stone [71].

Stone tiles may be subject to soft spots, uneven wear, cracks, fissure, spalling and warping. As such, a stone tile installation requires considerably more care and maintenance than a ceramic tile installation, although the actual setting techniques for both materials are basically the same [31].

### 4.2.2 Classification of stone

Architectural application of stone is often discussed mainly in reference to granite, travertine, limestone, marble, sandstone and slate. These materials have been the primary stone sources for architectural applications both structural and nonstructural in pre-modern and modern architecture [34].

Stone is classified geologically as igneous, sedimentary, and metamorphic. The characteristics of each type have a definite bearing on their durability and use. Igneous rock is the product of heat and pressure, such as that caused by volcanic activity and pressure exerted by the shifting of the earth's surface. These are the hardest types of rock such as the granites. Sedimentary rock is made up of silt or the skeletal remains of marine life that have been deposited by ancient seas. In this group are sandstone and limestone. Metamorphic rock is formed by the gradual change in the character and structure of igneous and sedimentary rock. Examples of these rock types are slate and marble. Classification of stone is listed in Table 4.8[30, 71].

**Table 4.8:** Summary of classification of stone

| Type of Rock | Name of Stone |
|---|---|
| Igneous | Granite |
| Sedimentary | Limestone |
| | Sandstone |
| Metamorphic | Marble |
| | Slate |

#### 4.2.2.1 Granite

Granite is an igneous rock that has been formed and cooled beneath the earth's surface. It varies from a finely granulated form to one that is crystalline in nature [30]. It is a very hard stone with a coarse, granular but even-flecked pattern. From earliest times, it was chosen as a principal building material and its legacy is visible across the world [62].

Standard ASTM C119 defines granite as "the visibly granular, igneous rock generally ranging in color from pink to light or dark grey and consisting mostly of quartz and feldspar… accompanied by one or more dark minerals. The texture is typically homogenous but may be gneissic or porphyritic… Some dark granular igneous rock, though not properly granite, are included in the definition…" [72].

Granite is a mosaic of mineral crystals, principally feldspar and quartz, and can be obtained in a range of colors that includes gray, black, pink, red, brown, buff, and green (Figure 4.8 and 4.9) [43, 51]. Its more than 100 colors are due to varying feldspar content [62]. Granite is nonporous, hard, strong, and durable, the most nearly permanent of building stones, suitable for use in contact with the ground or exposed to severe weathering. Its surface can be finished in any of a number of textures including a mirror-like polish [27]. Its surface polishes well, but can also be shot-blasted, acid-washed, honed, riven, sanded, bush-hammered, tumbled, aged or thermally treated to fracture the crystals for a rough, skid-resistant texture. It is not sensitive to moderate to high heat [62].

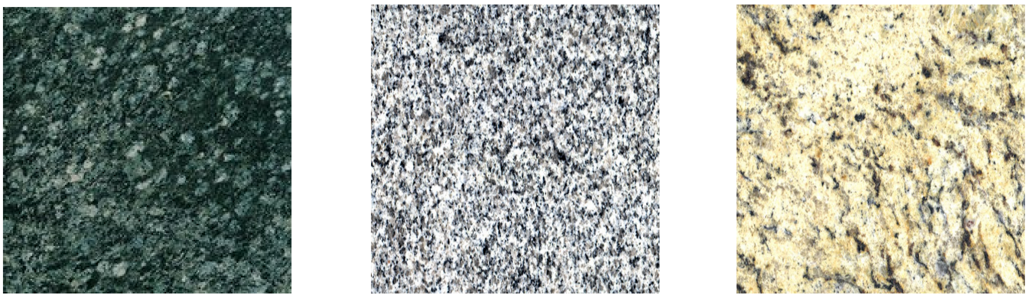

**Figure 4.8 :** Examples of granite tiles [51]

**Figure 4.9 :** Examples of granite mosaic tiles [51]

Granite has very high failing strength in compression, only a tiny fraction of which is normally employed in buildings. Because granites are extremely dense and hard, they are very costly to quarry, cut and surface, but they can be smoothed mechanically to a glass-like self-polish. Being extremely resistant to knocks and abrasion, granite is eminently suitable for roadway kerbs, bridge cutwaters, jetties, spur stones to gateways, bollards, external steps to many important buildings, and heavy-duty paving as slabs or sets. Most of granites are virtually impermeable and serve as damp-proof courses provided the vertical joints between blocks are designed to prevent water movement [39].

Use and Maintenance: As granite can be polished to a very smooth finish, it makes a hygienic surface ideal for kitchen countertops and backsplashes – matching sinks and basins are also available. It is also fashioned into bathroom vanity units, lining for shower walls and floors, doorknobs, hearths and fireplace surrounds. Outdoors, its ability to withstand environmental effect makes it a good choice for garden paving, benches, fountains and features; it is also the traditional stone for Japanese garden lanterns and bridges. Its surface is porous and will stain if unsealed [62].

Granite is available in custom slabs or tile squares in sizes ranging from 101.6 x 101.6 mm, 203.2 x 203.2 mm, 304.8 x 304.8 mm, 330.2 x 330.2 mm, 406.4 x 406.4 mm and 609.6 x 609.6 mm [28].

#### 4.2.2.2 Limestone

Limestone is one of the most abundant sedimentary rocks. It is a medium-hard stone of fine, sandy appearance with occasional prominent grains or veins. Lighter, paler colors are often used architecturally, but limestone occurs naturally in many different forms and colors (Figure 4.10 and Figure 4.11), and is used in kitchens, bathrooms and for floors [51, 62].

**Figure 4.10 :** Examples of limestone tiles [51]

**Figure 4.11 :** Examples of limestone mosaic tiles first: honed surface, sesond: split face surface, third: tumbled surface [51]

Limestone may be composed either of calcium carbonate or of a mixture of calcium and magnesium carbonates, originally furnished in either case by the skeletons or shells of marine organisms. Its color ranges from almost white through gray and buff to iron oxide red. It is a porous stone that contains considerable ground water when quarried. While still saturated, most limestones are easy to work but are susceptible to frost damage. After seasoning in the air to evaporate the quarry sap, the stone becomes harder and is resistant to frost damage [27]. Finishes can be polished to a reflective mirror gloss, honed (giving a satin smooth but non-reflective finish); riven or bush-hammered to give a rougher surface or tumbled (polished irregular shapes); it can also be sanded or aged. Limestone dissolves easily in acids, but is not sensitive to heat [62].

Limestone floor and wall tiles are available in regular or random sizes for laying straight or diagonally, indoors or out. On patios or wet areas, a riven or textured surface can reduce slipping. Limestone is also used for countertops and backsplashes, basins, sinks, bathtubs and shower ledges, but its surface must be well protected and maintained. Surfaces should be sealed against chemical damage and staining [62].

#### 4.2.2.3 Sandstone

Sandstone is amongst the most widespread of geological building materials, with a long history of use. Its layered formation has enabled it to be easily quarried, split and built with, form as far back as the Neolithic period [73].

Sandstone is a sedimentary rock composed of angular or rounded grains of sand held together by a cementitious material. Cementitious materials containing a high percentage of iron oxides give sandstone red to brown tones. This type of sandstone, sometimes called brownstone or redstone, is soft and easy to work, but it is not always durable. Certain sandstones, classed as Ohio sandstone, have been formed under extreme pressure and contain very little cementing material. These light grey or buff stones are easy to work and are also hard and durable (Figure 4.12 and Figure 4.13) [30, 51].

**Figure 4.12 :** Examples of sandstone tiles [51]

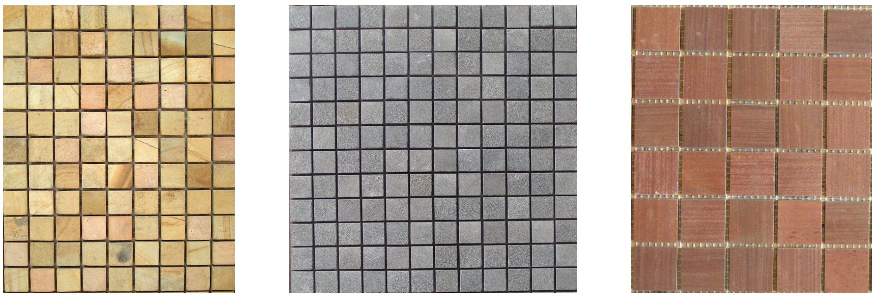

**Figure 4.13 :** Examples of sandstone mosaic tiles [51]

Like limestone, it tends to be porous and absorbent, and hence only moderately durable. Most sandstones wear rapidly under traffic- but some are relatively hard and conveniently thin-bedded for this purpose. They do not take a polish and are unsuitable for thin veneers, though they may be used for external cladding of lower storey [74].

The best sandstones are extremely durable but sandstones become dirty more readily and weather less attractively than limestones. Sandstones in industrial areas may decay rapidly if they receive washings from limestones.

The bedding planes in sandstones are very closely spaced and they are often visible. Some can be split into flagstones and a layer of mica is often seen on the riven surface [39].

#### 4.2.2.4 Marble

Marble is a re-crystallized form of limestone. It is easily carved and polished and occurs in white, black, and nearly every color, often with beautiful patterns of veining (Figure 4.14 and Figure 4.15) [27, 51]. It is a delicately beautiful stone, easily worked, that has been used since ancient times for sculpture and building and still carries connotations of luxury and affluence. These qualities have made it widely sought after and, despite its weight and bulk, it has always been transported far from its origins [55].

**Figure 4.14 :** Examples of marble tiles [51]

**Figure 4.15 :** Examples of marble mosaic tiles [51]

The term “marble” is quite a loose term and includes litho-types, which are different in composition and origin and have different commercial characteristics too. According to standard ASTM C119 the Marble Group includes stone which “comprises a variety of compositional and texture types, ranging from pure carbonate to rocks containing very little carbonate that are classed commercially as marble. Most marbles possess an interlocking texture and a range of grain size from cryptocrystalline to 5 mm. All marbles as here defined must be capable of taking a polish” [72].

Marble is generally very hard, dense and resistant to abrasion. Veins are sometimes weak but satisfactory repairs can be made with modern adhesives. Like granite, marble takes an excellent self-polish which greatly enhances its appearance [39].

The beauty of marble comes from the veins, streaks and washes of color caused by minerals that meander though the porous carbonate rock [62].

Marble crumbles readily when exposed to a moist atmosphere, and its surface will pit in rain unless properly sealed. It is heatproof, but can be stained and damaged by acids and must be sealed for high-traffic areas or kitchens [62].

Use and maintenance: Marble has many suitable uses indoors, including fireplace surrounds, backsplashes and shower surrounds. Sinks, bowls, basins and bathtubs can be carved out of a single block. It is favored by cooks, but when used for countertops, it must be sealed and use cutting boards to avoid knife marks. Marble is easy to carve and highly tactile, so is a choice stone for carving into decorative features. Polished marble is slippery when wet, so it is not suitable as outdoor paving [62].

Marble floors may be installed with slabs of any size to suit the design of the architect. Standard size of marble tile, 203.2 x 406.4 mm, 254 x 508 mm, and 304.8

mm², are always obtainable, the standard thickness being 22.225 mm, 31.75 mm, 38.1 mm, and 250.8 mm. Marbles of proved resistance to abrasion should be chosen, and the surface should have a fine sanded or honed finished not polished [75].

Small, unpolished marble tiles can be aged to give them an old-world appearance. These tiles are tumbled in a solution of water, sand, and mild acid in large barrels. Marble tiles are sold in various sizes, shapes, and styles allowing for flexibility in design and pattern. Data on marble mosaic tile products are given in Table 4.9. Once considered a luxury, marble is now being more widely used, for purposes throughout homes [28, 33].

**Table 4.9:** Marble mosaic tile products [33]

| | Properties | Color and Pattern | Dimensions | Laying | Surface Treatment and Maintenance |
|---|---|---|---|---|---|
| Cut from natural rock | Generally hard-wearing qualities depending on kind of marble. Rather cold, hard and noisy. Harmed by acids but resists oils, alkalis and water. May become slippery when worn. | Basic colors include white, cream, grey, "stone", "parchment", golden yellow, bright green, blue-grey, blue-black and black, with veins or ribbons of various colors. Surfaces may be polished, sanded or matt. | Thickness: Usually about 12.7 mm rectangles with sides from 9.525 to 25.4 mm. | Tesserae are delivered to site mounted to pattern on paper in 185856 mm² panels and set in a 9.525 mm bed of cement and sand on a screeded floor. | Surface is finished with electric polisher. Cleaning is with warm water and a non-caustic detergent. |

#### 4.2.2.5 Slate

Most slates are composed of high-silica clays laid down as silt in ancient sea bottoms. This clay has formed into rock that can be split into thin sheets with smooth regular faces along natural cleavage lines. The colors of slate are caused by small amounts of impurities such as iron, carbon, and chlorite. The colors may be nonfading or weathering (change color with exposure to the weather), depending on the nature of the coloring agent.

Slate is produced with several surface finishes. It may be natural cleft, with no surface finish except the obtained by natural cleavage, or semi-rubbed, with approximately 50% of the natural cleft face removed. It may be given a hone finish, similar to a sand-rubbed finish, but with a very smooth surface [30].

Properties: Slate has a characteristic cleavage that allows it to be split easily along one plane but not another. Slate is chiefly composed of quartz and illite, with mica, calcite, and minor quantities of other various minerals. Slate has long life and durability. It has high strength and resists chipping, cracking, and abrasion. A few types of slate are capable of withstanding rapid freeze-thaw cycles, but most are not. Slate absorbs only 1/4% to 1% when immersed in water, for 24 hours. That, together with its dense, compact structure and resistance to chemical acids, gives it a high sanitary value and makes it easy to clean [50].

Slates vary in color (Figure 4.16 and Figure 4.17), but are most commonly black, gray, red, purple, green, and multicolored variations of these. A red color is due to the presence of hematite, and green colors are due to chlorite. Gray and black are due to carbon and/or graphite. Shades of red (purple) and tan are related to varying amounts of iron oxides. Slates from a particular area may be available in only one color [50, 66].

**Figure 4.16 :** Examples of slate tiles [66]

**Figure 4.17 :** Examples of slate mosaic tiles [66]

Slate tiles, sometimes called “gauge rubbed tiles,” are available in slabs and large-format units, but most are stocked only in either 304.8 x 304.8 mm or 609.6 x 609.6 mm sizes. In some slates, irregular random shapes are available up to 1.2 m to a side. Some slates come in sizes from 152.4 x 152.4 mm up to 304.8 x 304.8 mm in 76.2 mm increments. Custom sizes are also available. Size range varies with thickness. In some slates, the pieces furnished are roughly rectangular, with about 85% of their edges sawn. Trimming is required to achieve uniform joints and a "broken ice" appearance [50].

Natural cleft face and bottom are usually specified for interior tile surfaces having random shapes arranged in an irregular pattern. This finish provides a longwearing, slip-resistant surface. The bottoms should be gauge-rubbed for thin-set application [50].

The finish for sawn slate flooring is usually a natural cleft surface, but some slates are sand rubbed and others have a machine face or are honed [50]. Data on slate tile products is given in Table 4.10 [33].

**Table 4.10:** Slate tile products [33]

| | Properties | Color and Pattern | Special remarks | Dimensions | Laying | Surface Treatment and Maintenance |
|---|---|---|---|---|---|---|
| Cut from natural material | Extremely hard-wearing. Rather cold, hard and noisy. Impervious to water but stained by oils | Colors range from green to blue to purple-black. Surface may be smooth, sawn or as split | Combines good appearance with very hard-wearing properties and minimum of upkeep | Tiles up to 381 x 381 mm Thickness: 19.05 mm to 25.4 mm | Laid in 12.7 mm bed of cement and sand on a concrete sub-floor. | Cleaning is with warm clean water. Dirt cannot penetrate the surface |

### 4.2.3 Historical development of stone

Stone has been recognized as a building material since the earliest days. Almost all famous monuments of classic times, of the medieval and Renaissance periods, and of the eighteenth and early nineteenth centuries were erected in stone, since stone alone could contribute the qualities of strength, beauty, dignity, and durability worthy of monumental architecture. Stonewalls carried the loads, and stone foundations supported the entire building [75].

Stone, whether it is granite, marble, limestone, travertine, or sandstone, has been used extensively throughout history in every country and culture. Ancient peoples carved a variety of stone and left us a record of their communities, daily lives, and religious symbols. They quarried stone locally or imported it along trade routes all over the world. They cut, carved, and decorated all types of stone for temples, churches, basilicas, and residences and adorned walls with stone murals, borders, cornices, friezes and bas-relief designs. They combined different colors of marble, granite, and limestone to create gorgeous floors, columns, tables, and chairs that are still marvels thousands of years later [28].

Since the development of steel and concrete and their employment in the foundations and structural members of buildings, the use of stone has been more confined to the facing or outer shell of walls and to the embellishment of interiors, and for these purposes it continues to be highly valued [75].

#### 4.2.3.1 Before the Christian era

The use of stone in construction was increasingly appreciated, and rulers of ancient civilizations understood the permanence of stone edifices. The great pyramids of Giza and the nearby Sphinx, constructed more than 4000 years ago, are among the grandest monuments of humankind, and a testament to the durability of stone. The pyramids of Giza were constructed of limestone, and the Great Sphinx was carved from sandstone [76].

Granite and limestone slabs covered floors, and granite columns supported the interior walls and heavy roofs of ancient Egyptian temples dating from 3000 BC. Many colorful granite pillars or columns dating back to 1500 BC have been found in Egypt [28].

Temple building continued through the rise of Greek and Roman civilizations. Many temples were built at the threshold of the classical period of Greek civilization. Temples whose primary purpose was to house images of the gods and to preserve the offerings of the faithful were built of stone using post and lintel construction techniques. Temples such as the Temple of Aphaia, built of limestone circa 500 BC, and the Temple of Hera II, also constructed of limestone, circa 460 BC, are examples of the development of Greek architecture incorporating the massive use of stone.

The Roman Empire was expanding, and great civic centers were planned throughout its reaches. Its planners solved problems of water supply for many of the new towns by diverting nearby springs and building grand aqueduct systems to transport the water. During this period, one of the more adventurous uses of stone was as facings or claddings of concrete and stone structures, such as in the Coliseum at Rome. Although today the exterior of the Coliseum has the appearance of being bullet ridden, in actuality the holes in the surface are the locations of the original anchors that attached marble veneer panels to the structure [76].

**Stone mosaic tiles**

Stone was the dominant material for making mosaics, beginning with the uncut pebbles used thousands of years ago by the Greeks [3]. The primitive mosaics found in Greece, as in the Roman world, are simple pebble-work, formed of small pebbles arranged in a geometric pattern or outlines. These were made by the Greeks up to the period of Alexander, at which point their use was at its highest, as can be seen by the surviving examples at Olynthus and Pella [77]. Although their palette was limited to a fairly narrow range of earth tones, the ancient Greeks were able to create pebble mosaics of astounding beauty and refinement [3]. They also cut natural stone into small triangles, squares, and rectangles called tesserae [18].

Stone mosaic work reached specialized levels in Greece, Rome and Pompeii, and India. Many beautiful ancient Greek temples were built using polished and painted sandstone in a colorful array of blues, yellow and green foils, out-lines in vermilion and more foils in red and blue. Alabaster was often used in Assyrian reliefs and murals, intricately decorated with stylized leaves and trees. Limestone columns in India dating from the reign of King Asako in the third century BC are completely carved and layered with rows of ornamentation believed to be copied from textile and carpet patterns [28].

The first decorative floorings were developed by the Romans. Their mosaic floors of small marble chips set in cement have lasted through the centuries. Builders of the Byzantine and the later Moslem Empires carried this form of construction to its highest point when they paved, not only floors, but also columns, walls, and the underside of domes with colorful marble and glass mosaic [30].

### 4.2.3.2 During the Christian era

Cut and polished stone tiles have had a much greater use during the twentieth century, especially in public buildings. The products are not strongly layered and therefore need a developed technology to cut them to shape and divide them into layers [71].

**Stone mosaic tiles**

In the first century after Christ, marbles and limestone were used almost exclusively in mosaic. These stones were imported primarily from Italy, and their color range was dull and limited [78].

The use of mosaic declined in Italy towards the tenth century AD, but in the twelfth century, a new phase of the art appeared in Rome, and under Byzantine influence many fine pavements were laid. They were wrought with morsels of porphyry and precious marbles, mostly obtained from ancient buildings, and arranged in patterns usually in the form of meandering bands surrounding discs, sliced from marble columns.

Another type of marble floor embodying a 'graffito' technique was developed in Italy, in the latter half of the fourteenth century and practiced during the next two hundred years. Almost the entire floor of the Cathedral there is laid with it [16].

#### 4.2.3.3 Nineteenth century

During the past two centuries, the use of stone in construction was limited to government buildings, large-scale public gathering places, and homes of the wealthy. The reason was that the same labor-intensive stone-processing techniques used for centuries previous were still practiced, making the use of stone exclusive because of its high cost.

As architects of the day explored newer materials to achieve the design generated by the international movement, multimaterial curtain wall systems were developed by using various metals, terra cotta, glass, and masonry. Many of the systems were successful, but some were not. The appetite for the beauty of natural stone was growing stronger, and the stone industry was finally caught up in the momentum. Stone producers developed new methods of block extraction, and fabricators invented more efficient equipment to process stone with precision, and most important, thinner dimensions. Stone producers realized the increased market potential of thin dimensional stone resulting from lower material and shipping costs. By the middle of the nineteenth century, the integration of stone veneers within true curtain wall systems had begun [76].

#### 4.2.3.4 Twentieth century

Technology has dramatically changed the stone industry in the past 25 years and has enabled producers to process stones into thin modules, thereby reducing waste. And because of improved delivery systems, a material that was once considered a luxury is now available to the general public. To produce a stone floor as recently as 1950 required a stone module of a minimum 19.05 mm thickness and utilizing a full mortar bed, for a total of 50.8 to 76.2 mm overall thickness. The finishing of this floor required grinding and polishing the stone in place, which was time-consuming and costly. A stone floor could be installed only in government buildings or for the very wealthy. Through technology, machinery has been developed capable of producing uniformly thin stone modules to a now standard dimension of 9.525 mm, which can be thin-set in a mortar bed of 3.175 mm, at a price that the average construction budget can accommodate [76].

**Stone mosaic tiles**

Cut and polished stone tiles have had a greater use during the twentieth century, especially in public buildings. The products are not strongly layered and therefore need a developed technology to cut them to shape and divide them into layers [71].

Because its granular, non-polished surface is often preferred to the hard brilliance of other materials, stone is also widely used in modern mosaics. At the University of Mexico in Mexico City, for example, the mosaics covering the exterior of the library by Juan O'Gorman (1951–53) and the exterior of the stadium by Diego Rivera (1957) are made with natural stone [1].

### 4.2.4 Performance properties expected from stone

The properties of types of stone depend essentially on the way they have been formed. Igneous rocks, as the name implies, are forged in great heat, deep below the Earth's surface. Sedimentary rocks, such as limestone, sandstone and travertine, are compressed sediments, laid down millennia ago by rivers and seas. These sometimes expose tiny fossils and shells. Metamorphic rocks, which include marble, quartzite and slate, vary in origin, but have all been transformed by additional pressures and stresses [62].

The properties of natural stone vary considerably, and therefore, one must choose carefully with regard to strength, porosity, absorption, and permeability. General properties of building stones are given in Table 4.11. It is also important to select a surface finish that will appropriate to the stone type and suitable for the function it must perform. Surface finishes range from very rough (quarry face, split face, or sawed finish) to quite smooth (rubbed finish, honed finish, or polished finish) [24, 39, 69].

Natural stones are strong in compression. The thermal coefficient of expansion of limestone and marble is low, about that of bricks, but allowance for thermal movement must be made with sandstone, slate and granite [39].

**Table 4.11:** General properties of building stones [21]

| | Specific gravity | | Density kg/m³ | Porosity % | Toughness. | Thermal movement mm/m per 90°C per cent approx. | Moisture movement mm/m for dry-wet change |
|---|---|---|---|---|---|---|---|
| | True | Bulk | | | | | |
| Granite | 2.599-3.080 | 2.60-3.04 | 2560-3200 | 0.4-3.8 | 8 – 27 | 0.93 | none |
| Limestone | 2.700-2.860 | 1.87-2.69 | 1950-2400 | 1.1-31.0 | 5 – 20 | 0.25 (porous limestone) | 0.8 |
| | | | | | | 0.34 (dense limestone) | negligible |
| Sandstone | | 2.2-2.7 | 2130-2750 | 1.9-27.3 | 2 – 35 | 1.0 | approx. 0.7 |
| Marble | 2.718-2.879 | 2.64-2.86 | 2880 | 0.4-2.1 | 2 – 23 | 0.34 | negligible |
| Slate | 2.771-2.898 | 2.74-2.89 | 2800-3040 | 0.1-1.7 | 10 – 56 | 0.93 | negligible |

The factors that affect the deterioration of stone include its composition, structure, and surface conditions, interaction of the surrounding microclimate and environment with the stone and the methods that temper these destructive tendencies [38].

Building stones materials and applications are listed in Table 4.12 [79].

#### 4.2.4.1 Durability

Rocks of the same general kind, such as limestone, sandstone, and marble, differ very much in durability; some are soft and porous and others dense and hard. For instance, certain limestones and marbles stand well for exterior work, and others are never used except for interior trim and decoration [75]. Service life of stone materials under various conditions is shown in Table 4.13 [36].

**Table 4.12:** Building stone materials and applications [79]

| Type | Granites | Limestone | Sandstone | Marbles | Slates |
|---|---|---|---|---|---|
| Use | Walling, cladding plinths, tiling, surrounds and steps | Walling, cladding and tiling | Walling, cladding and tiling | Window surround, floors and stairs, tiling | Cladding sills, coping steps, tiling and paving |
| Composition | Walling, cladding plinths, tiling, surrounds and steps | Largely calcium carbonate | Quartz in all mica and feldspar grains in some. Bonded largely with silica or calcium carbonate | Mainly calcium carbonate | Mainly silica, alumina and iron oxides |
| Method of production | Quarried, cut to size (masoning and sawing), finish as required, eg patterned, rock faced, fair picked, fine axed, rubbed, eggshell or polished | | | | |
| Specific weight kg/m³ | 2400-2900 | 1900-2700 | 1950-2550 | 2725-2900 | 2400-2900 |
| Compressive strength MN/m² | 90-146 | 9-59 | 21-105 | About 60 | 75-200 |
| Water absorption % | 0.1-0.5 | 2.5-11 | 2-8.5 | 0.1-0.5 | 0.1 |
| Durability | Dependent on thermal performance, resistance to chemicals and application in construction | | | | |
| Resistance to effect of soluble salts | Poor to good | Poor to very good | Poor to good | Good | Good |
| Resistance to frost | Good to excellent | Poor to very good | Poor to excellent | Good to excellent | Good to excellent |
| Effect of chemicals | Resistance to most chemicals | Attacked by acids | Resistant to most acids except calcareous types which are attacked | Attacked by acids | Mainly resistant to acids |
| Ease of cleaning | Difficult to clean | Fairly easy to clean | Difficult to clean | | Difficult to clean |
| Ease of working | Hard | Easy to hard | Hard | Fairly hard | Hard |

**Table 4.13:** Order of magnitude classification of the age or service life of stone materials [36]

| | Class of degradation factors and expected age | | | |
|---|---|---|---|---|
| | 1<br>Very severe exposure¹ | 2<br>Severe exposure² | 3<br>Mild exposure³ | 4<br>Very mild* exposure |
| Materials | Age in years | | | |
| Strong natural rock | 100 to 1000 | 1000 to 10000 | 100000 | >1 million |
| Natural rock | 10 to 100 | 100 to 1000 | 10000 | >100000 |

Note: ¹ Frost, snow, ice, thawing, great changes in temperature and humidity, erosion, dissolution, strong sunlight, pollution, conditions with strong corroding effects, for example, seawater, polluted water, corroding chemicals, etc.

² Average variable outdoor conditions, moderate changes in freezing and thawing.

³ Moderate temperature, dry, slight changes in environment

* Dry, very slight ventilation, low temperature, no sunlight, constant conditions

Natural stones are generally extremely durable but deterioration may result from wrong choice of stone and relates them to exposures. Other causes of deterioration include faulty design and workmanship, atmospheric pollution, soluble salt action, frost, solution, wetting and drying, rusting of ferrous metals and sometimes vegetation [39].

#### 4.2.4.2 Abrasion/wear and impact resistance

The abrasion resistance of a rock is its ability to withstand wear. This is fundamental in assessing a material's suitability for internal and external flooring. Wear resistant of stone materials listed in Table 4.14 [69, 72].

**Table 4.14:** Wear resistance of stone materials

| Stone | Range | Average |
|---|---|---|
| Granite | 43.9 – 87.9 | 60.8 |
| Limestone | 1.3 – 24.1 | 8.4 |
| Sandstone | 1.6 – 29.0 | 13.3 |
| Marble | 6.7 – 41.7 | 18.9 |
| Slate | 5.6 – 11.7 | 7.7 |

Like any natural material, stone is subject to wear and decay; unlike most, however, significant deterioration is measured on a very long timescale indeed [51].

A stone's hardness will determine its ability to resist wear caused by scratching produced by foot traffic. The harder the stone, the more difficult it is to achieve a polish and, consequently, the more difficult to walk the polish off. The hardness of a stone is determined in part by the mineral composition and by the density of the stone. Granites, as a group, have good hardness characteristics; however, there are many limestones and marbles that are extremely hard owing to the geologic deposition and metamorphism experienced at the time of their formation [79].

Abrasion resistance is measured by a scuffing method that removes surface particles similar to the action of foot traffic. Abrasion resistance for commercial flooring should be at least a hardness value of 10, as measured by ASTM C241. The Marble Institute of America (MIA) recommends a hardness value of 12. This value is not necessary for single-family homes [41]. Different stones in the same area should have hardness values within 5 points to each other [50].

When two or more varieties of stone are used for flooring, the abrasive resistance of each should be examined to be sure that they are approximately the same. If they are not, unequal wear will result, in time, in an uneven surface [75].

The impact strength of a rock gives indications as to the strength of a material subjected to concentrated loads. This is fairly important when a material is to be used for external and internal floorings and shelves [72].

#### 4.2.4.3 Resistance to frost

Frost is the most active agent in the destruction of stone. In those parts of the country where the temperature is never below freezing or where the atmosphere is very dry almost any stones may be used with good results. But where frost and wet weather often occur, a porous stone containing much water will be seriously affected when the water freezes, especially if the pores are crooked and the ice cannot expand [75].

Damage, often rapid, may occur in stones, which are frozen when they are very wet or where water is retained in cracks or in shells on horizontal surfaces. It is not clear to what extend frost damage results either from the expansion of water or from a mechanism analogous to frost heave in soils [39].

External exposure of samples in trays, which hold water, provides a long-term test for frost resistant. Stones, which survive for three years, are probably resistant and those, which are unaffected after seven years, are almost certainly resistant [39].

Stones used in exterior installations that are exposed to freezing temperatures must be freeze-thaw stable; that is, they must have low water absorption. A volume of water expands to 8% of its size when it freezes; therefore, stones that have a lower rate of absorption should be used in cold weather exterior conditions. A stone with a high rate of absorption installed at exterior locations will absorb moisture, and as the water freezes and expands, the surface can break from the stone, cracks may develop, areas near anchors will become vulnerable, and the entire stone module may break free from the setting bed [76].

#### 4.2.4.4 Resistance to chemicals

Granite is very resistant to ordinary chemicals. Innumerable examples of the stone have retained a very high natural polish for a century or more in highly polluted industrial atmospheres which is a sure test of durability. No other stone can retain a natural polish for many years in such conditions and granite is used for external wall cladding where 'permanent' good appearance is required. Unlike granite, however, marble is attacked by acids and a polished surface is not retained for very long externally in a polluted atmosphere [39]. Marble's porous structure also means that it will stain easily unless its surface is protected by sealant on a regular basis. It is not suitable for countertops because oil, alcohol or chemicals can permanently stain the surface, but makes durable floors and walls. Limestone requires a sealant and regular maintenance to protect it from oil, alcohol, acids in cleaning products, and the chemicals present in some water supplies that can stain its finish [28]. Limestones are attacked by acids to an extent which is related to their density. In the past, slate was used for its acid and alkali resistance as laboratory bench tops, urinal slabs and lavatory basin tops [39].

#### 4.2.4.5 Movement and cracking

Stone requires a perfectly dry, even base that is not prone to movement – any chamber or flex in the base floor will lead to cracking [51].

Cracks are also caused by physical forces. On the face of it, it is natural to believe, that many cracks occur or increase as a result of frost. But this is not so – frost more often is the cause of peeling. This might be caused by the fact that water manages to run off from cracks, before frost sets in.

Cracking can also be due to pressure an especially tension brought about by external factors, including usage and movement. Cracks caused by temperature differences between the front and rear side of a stone are not unusual, e.g. in a thin and weak stone used as facing on a façade [80].

#### 4.2.4.6 Changes in appearance

Natural stones usually retain their good appearance inside buildings. Externally if left to weather naturally, limestones improve in appearance and slate does sometimes, but granites and marbles seldom do.

The fact that no two blocks of stone are identical in appearance, even within one quarry, provides visual interest, but it means that even large samples can give only a general indication of color, veining and texture.

Sugaring sometimes occurs on exposed surfaces and highly colored marbles tend to fade. Also, although marble is virtually impervious, discoloration can result in damp conditions and the backs of slabs must be sealed with shellac to protect them from 'wet' constructions [39].

#### 4.2.4.7 Maintenance and cleaning

Maintenance refers to regularly scheduled activities intended to keep the stone clean and free from contaminants, maintaining the factory finish, and to replace the damaged stone. The success of these activities is depending on the proper stone selection and the selection of the finish [76]. The maintenance requirements of stone materials are given in Table 4.15 [29].

**Table 4.15:** Maintenance requirements of stone materials [29]

| | |
|---|---|
| Granite | Low upkeep; wipe, sweep, vacuum, or damp cloth if necessary. Use very mild detergent and remove soap residue. Polish with cloths. |
| Limestone | Dust or wipe with clear lukewarm water or mild, nonoily detergent if stone is sealed. |
| Marble | Clean with warm water and infrequently with soap and water, taking care to rinse well. |
| Slate | Low upkeep; sweep, vacuum, clean with mild soap and water. Do not wax. |

Stone is a natural material that is characterized by a wide range of mineral compositions and textures. Each type has unique physical and chemical properties that may influence the choice of cleaning method. Characteristics such as compressive and flexural strength are typically less significant in selection of cleaning systems than mineral composition, porosity and internal structure [73].

To maintain good appearance, to minimize the likelihood of decay and to prevent defects becoming concealed by soot deposits, stonework that is exposed externally should be cleaned regularly and defective joints should be raked out and re-pointed.

BS 6270 refers to cleaning using water, chemicals, sand blasting and carborundum discs. The necessary frequency of cleaning depends upon the kind of stone, the degree of atmospheric pollution, the exposure and the required finish – varying from rock-faced to extremely smooth and glass-like. Limestone which is freely washed by rain is ‘self cleansing’ but in protected positions limestones and sandstones may require cleaning at 5 to 10 year intervals, while in polluted atmospheres polished marble may have to be cleaned every month [39].

#### 4.2.4.8 Slip resistance

All stone floors are slippery when wet apart from sandstone. Water and mild detergents should be used for cleaning and polishes should be avoided as they can make walking surfaces slippery and dangerous. [68].

The number of abrasives used in the finishing process and the length of time the stone is exposed to the process that determines the level of polish, and there are infinite levels of a polished finish. Many stones with a lower level of polished finish attain a 0.5 COF and can therefore be considered to be slip-resistant walking surfaces. Stones that can be finished with a lower sheen, such as a honed finish, and can achieve a 0.6 coefficient of friction should be considered for use in areas where the public will be using the stone as a walking surface [76].

Granite and sandstone sets, widely used in outdoor paving, can also be used in the interior, particularly where robust and non-slip surfaces are desirable [51]. Natural cleaved texture slate makes it inherently slip resistant and suitable for exterior application and wet conditions [76]. Polished marble can be slippery when wet and caution should be exercised before installing it in shower or tub areas [28].

#### 4.2.4.9 Cost

The question of cost must always be among the first considerations in an architect's choice of stone; this question depends on the proximity of the quarry, abundance of the stone, and its workability. Other things being equal, a stone from a nearby quarry should be less expensive than one from a great distance, a stone produced on a large scale cheaper than one that is scarce, and a stone quarried and dressed with ease more economical than one upon which excessive time and labor must be spend [75].

The price of stone varies from fairly expensive to astronomical, according to the type, and, while reclaimed or salvaged stone can occasionally be an economical choice [51]. The more abundant sedimentary stones are the least expensive. Slate and marble are often double the prizes. Granites can be equivalent in price to the metamorphic stones and also much higher depending on color and availability [68]. Table 4.16 gives a summary of data on the cost of stone materials [29].

**Table 4.16:** Cost of stone materials [29]

| Types of Stone | Cost |
|---|---|
| Granite | High |
| Limestone | High |
| Sandstone | High |
| Marble | Very high |
| Slate | Moderate to high |

### 4.2.5 Stone design and process

Quarrying, transporting and working stone has always been a slow, costly, labor-intensive process, and one that has not appreciably improved since mechanization [51].

#### 4.2.5.1 Design

The essentials of design come under such headings as truth, beauty, grace, style, strength, vitality, balance and symmetry, breadth, scale, proportion, color, and restraint. Many of these have an important bearing upon the use of stone; it is even safe to say that some can really only be achieved successfully with stone, while others have an equal bearing whatever type of material is used.

'Trust' and 'beauty' are general terms, and while it is not easy to define beauty, trust has certain well-defined connotations. Decorum can be achieved by the use of specific stones; granite for decoration and strength, light-colored limestone for grace and style, the right combination of materials to achieved vitality, balance and symmetry, and the use of the right quantities to give scale and proportion. Obviously, the possibilities are enormous [81].

Building stone may be judged by five standards: appearance, economy, durability, strength and ease of maintenance. In selecting a stone an architect will probably first judge the appearance, that is, the suitability of the stone in color, texture, aging qualities, and general characteristics to the type and style of the building he is designing. In color and texture there is a wide range of choice, from brilliant hues to dull, from warm tones to cold, and from coarseness and roughness of texture to extreme fineness and density. As to aging qualities, certain stones, especially the granites, soften very slowly in tone and outline, retaining indefinitely a wire edge and a hard contour. Other stones, however, will mellow in tone and outline without losing their lasting qualities [75].

#### 4.2.5.2 Stone processing methods

The methodology used for the extraction and processing of stone is basically the same today as it was in ancient times. When the early builders discovered outcrops of slate and cliff faces of sandstone exposed through natural weathering, they learned that larger units of stone could be removed from these deposits than they had been able to gather from the fields by hand. Techniques were developed whereby the natural faults could be exploited to aid in the extraction of stone from their deposits. Slate faces could be split into thin sheets and used as roofing material. Sandstone boulders could be pried from their benches with levers, and smaller stone blocks could then be shaped with metal pick axes. These small blocks could be used to build load-bearing walls for homes and places of gathering. These are the same basic techniques that are used today for quarrying natural stone; the difference, however, is that we have 4000 years of experience to drive the high technology available to us today [76].

**Quarrying**

Stone quarrying has always been based on a simple and labor-intensive technology which had difficulty in competing with growing industrialization. The work was heavy and could cause physical damage to workers. Developing technology could make the work lighter and should make stone a more competitive material [71].

Present-day methods of quarrying stone are similar to those used by the ancient Egyptians. The Egyptians drove wooden wedges into natural faults of the stone and then poured water onto them. The swelling of the wood wedges split the rock into sizes suitable for the mason to work into final shape with hand tools. Quarries begun by the Romans and the Greeks are still in use today [30].

The ability to quarry a stone in the form of a block is dependent upon the characteristics of the rock deposit. Desirable deposits are generally large and compact, with fewer occurrences of natural faults and cracks. Limestone, travertine, marble, granite, and some sandstone can be quarried to produce a block that is capable, with further processing, of yielding large slabs [76].

Sandstone and limestone are stratified, which simplifies their removal from their natural beds. The size of stones will vary from quarry to quarry. In stratified rock a series of holes is drilled perpendicular to the stratification, and the material between the holes is removed. Stones are then split from the quarry along the lines of stratification. In rock that is not stratified, such as granite, holes must be drilled both horizontally and vertically into the bed.

In quarrying of softer stones, such as limestone, sandstone, and some marbles, channeling machines or wire saws may be used to remove the rough stones. The harder stones must still be removed by drilling and wedges. Light charges of powder may be used to form the channels or remove the stone. One of the newer methods of splitting stone from its natural bed is use of flame drill to heat portions of the bed to a very high temperature. Then water is applied to the heated portion to disintegrate the rock [30].

**Surface finishing**

When the stones have been removed from the quarry, they are taken to finishing mill for final dressing. Some stones may be used just as they come from the quarry, with the quarry face unchanged. Most stones are split and then cut to the size needed for final installation [30].

Stone that has been quarried requires further processing in anticipation of its final use, whether it is to be fabricated in slab form or as tile, for decorative purposes or for functional requirements. Not all stones are capable of achieving all of the finishes described: the ability of a stone to achieve a finish is determined by the texture, structure, hardness, density, and mineral composition of the specific stone. In addition, not all of the finishes are appropriate for all uses; many of the textured finishes are suitable only for use in vertical applications [76].

Stone finishes include honed, polished, sanded, riven and textured. Honed – a matt satiny texture – is smooth and non-reflective and provides friction where stone is to be used for flooring. Honing is simply grinding to produce a smooth but dull surface in granite, marble and hard sandstone. Though less eye-catching than a polished face, honed surfaces are non-slippery and do not show nicks and scuff marks so easily – hence they are more appropriate for paving stones than for interior paneling. Polishing provides a highly reflective gloss finish. Only the harder types of stone, such as granite, marble and travertine, will take a high polish. This finish is generally too slippery to be suitable for floors. Sanded finishes are more abrasive and slip-resistant than honed finishes. Riven is a finish unique to slate. Textured or distressed finishes – flaming, tumbling, sandblasting and bush hammering – bring out the colors and create an impression of weathering. Tumbling blurs and softens hard edges in a way that is suggestive of wear, flaming releases the quartz content of particular types of stone [51, 74].

#### 4.2.5.3 Stone tile production

Smaller blocks may be used for the production of tile because the overall size required is less than the size required for slabs. The utilization of smaller blocks maximizes the yields of a quarry. Blocks containing fissures or other flaws may be used for tile production by working around these areas, where slab production would not be possible. However, multi-blade disc saws are more effective when using larger and more regularly shaped blocks.

The finishing of stone tile is similar to slab finishing; the primary difference is that finished slabs require additional sawing to the desired dimensions. Tile is finished, cut to the desired size, beveled, and packaged for final installation at once location.

The width of the tile line can be adjusted to accommodate finished widths of up to 609.6 x 609.6 mm, depending on the type of equipment. The strips that are sawn from the rough blocks are typically sawn to double the desired thickness. The strips are the length of the block from which they are sawn and are loaded onto rollers that link the equipment and transport the strips through the various finishing and sawing stages. The first stage is splitting the sprit into two equal pieces with a horizontally oriented saw. The strips are separated and fed through the first series of stationary polishing wheels, which are used to grind the thickness of the stone to a calibrated dimension. The polishing stages are the same as those in the polishing of slabs, beginning with coarse abrasive discs and working up to finer abrasives. The cylinders that drive the discs are stationary, as compared with the moving discs used for finishing slabs, because the width of the tile is smaller than that of a slab. The speed of the disc rotation, combined with the abrasives of the disc, determine the level of polish of the stone. Upon completion of the finishing process, the strips are sawn with the use of multiple discs saws mounted in tandem, which cut the strips to the desired dimension. The smaller modules are rotated and cut in the opposite direction to produce a square tile module.

To produce a beveled edge on the tile, the sawn tile modules pass through a series of polishing discs that are oriented at an angle to grind off the rough edge, creating a uniform bevel along the top of the four sides [76].

## 4.3 Glass

Glass is an amorphous, inorganic, translucent non-crystalline substance, composed largely of silica, sodium oxide, and calcium oxide [23].

Glass is arguably the most remarkable material ever discovered by man. Made from the melting and cooling of the earth's most abundant mineral, it provides a substance that is transparent and rock hard, and so chemically inert that almost anything can be kept in a container made from it. It has given us the lens, the bottle, the fiber optic cable, fabrics and the window. In the 4000 years of its known history, it has been drawn into use across the whole world of human endeavor [82].

### 4.3.1 Introduction

Glass may be describe as a translucent or transparent non-crystalline solid, consisting essentially of a silicate or an alkali metal combined with a calcium or lead silicate, with the addition of varying proportions of other minerals. The ingredients and their proportions vary, depending upon the type of glass to be manufactured [33].

Its multi-faceted character and usefulness is spread throughout our lives and language, and the abundance and cheapness of its principal raw ingredient, silica, give glass a unique place in the history of artifacts and technology, and make it very special material for the contemporary designer, from optics and telecommunications to electrical engineering [82].

Glass is produced by melting sand, soda ash, limestone, dolomite, alumina, feldspar, potash, borax, cullet (broken glass) and/or other ingredients, at about 1500º C, shaping it, and allowing it to cool slowly to prevent cracking. Although the earliest forms of glass were produced a few thousand years ago, its large-scale production and use in buildings is less than two centuries old [79].

Glass has its own material developments, which have and will bring new aesthetic qualities to architecture. In the ebb and flow of human achievement and spirit, generating architectural styles, glass will continue to have its functional place in building, but its future expression will be enhanced by the new technologies, such as holography, electro-chromic and electro-luminescence [83].

#### 4.3.1.1 Glass tiles

Glass tiles draw on traditional techniques of glass artists, jewelry-making and ceramic-tile manufacture to form brilliantly colored tiles that can be used on walls and floors for a dramatic practical surface. As well as regular-sized glass tiles, mosaic patterns of tiny glass or tesserae are produced for a range of creative designs. Glass tiles are particularly effective where their translucence and sparkle can be appreciated.

Tiles can be pure glass or a combination of glass and ceramic, some with mixed or contrasting colors, others with metallic finishes. They can be produced by fusing – joining colored glass pieces by melting at high temperatures – and slumping. Slumped glass tiles often vary in depth and feature tiny bubbles. These diffuse the light and distort images, reducing transparency but creating interesting effects. Glass tiles are scratch-resistance, durable, hygienic, frost-proof and inflammable. They are impervious to water and staining, and resist chemical attack.

Glass tiles perform well in areas of high moisture. They work well outdoors where brilliant colors are highlighted by the sun; they can also be incorporated into stained-glass windows. Most are not suitable for floors, because they are slippery when wet. Many tiles have a raised decorative effect. Flat tiles are extremely hard, making ideal countertops. Most are translucent, so any coloring or patterning on the underlying surface needs to be considered; adhesive also needs careful application to avoid marring the finished effect [62].

In today's market, there is an incredible selection of glass tile available (Figure 4.18). There are transparent glass tiles in multiple, smoked colors, and opaque and shimmering iridescent glazes. Other glass tiles are hand painted in primary colors or soft tones, and can be used to create unique custom murals or theme tiles set as accents on a large, solid tile background. Some glass tiles have raised relief subjects or running designs useful for borders. Glass tiles are naturally waterproof, making them good choices for showers, tub surrounds, backsplashes, pools, and outside fountains [28, 84].

#### 4.3.1.2 Glass mosaic tiles

Glass is the material most commonly associated with mosaic. Indeed, glass is the staple of the mosaicist's art [78].

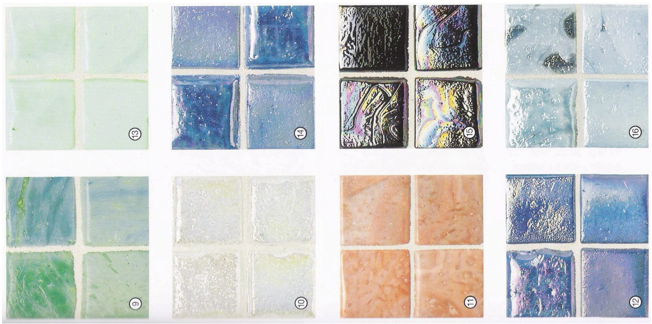

**Figure 4.18 :** Examples of glass tiles [84]

Distinctive depth effects are created in glass mosaics, which are created by cutting squares of clear float glass and coating on one surface with a colored layer of paint. These squares are then adhered to a flexible backing of PVB. Applications are for bathrooms, wail surfaces and countertops in residential and commercial interiors (Figure 4.19) [52, 85].

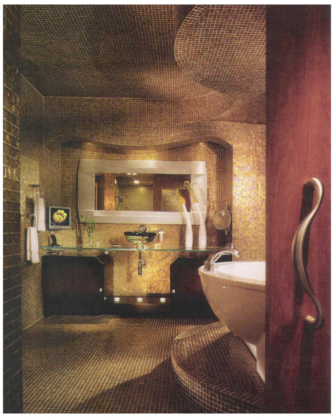

**Figure 4.19 :** Examples of glass mosaic tile application [52]

Glass mosaic tiles come in a wide range of colors (Figure 4.20). Prices of different colors vary widely. Glass tile with pure gold use as a pigment can be extremely expensive, whereas other pigments are quite inexpensive. Tile may be assembled on sheets in the pattern in which it is to be installed. Glass tesserae may be individually cut, fit, and mounted, face down, on heavy paper to form mosaic murals. The sheets are then cut in sections, to be fitted together on the wall by the tile setter. After the setting bed has hardened, the paper is removed from the tile face, revealing the design [30, 51].

Glass mosaic tiles are attached in sets to paper or mesh backing sheets for quicker laying; they can be used alone or in conjunction with ceramic tiles [62].

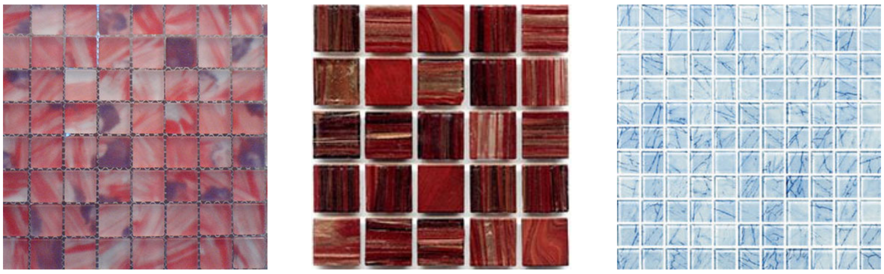

**Figure 4.20 :** Examples of glass mosaic tiles [51]

Available glass mosaic tile types include;

Stained Glass: Stained glass and other types of translucent colored glass make handsome mosaics, especially when applied to a surface that allows the light to shine through. More common, though, are opaque glass tiles that are prefabricated specifically for mosaics (Figure 4.21) [3, 51].

**Figure 4.21 :** Examples of stained glass mosaic tiles [51]

Vitreous Glass: Vitreous glass is machine-molded into thin square tiles with a smooth surface on the face and slightly beveled edges underneath. Vitreous glass tiles come pasted onto sheets of paper or plastic mesh. They are available in various sizes but are most common in 2 cm squares about 3 mm thick. Vitreous glass is also available in a wide range of colors, including some with metallic veins of gold or copper (Figure 4.22). It is frost proof, extremely durable, and stains resistant [3, 51].

Vitreous tiles can be used on floors, walls, counters, and decorative pieces. They have a flat surface and textured surface [15].

**Figure 4.22 :** Examples of vitreous glass mosaic tiles [51]

Smalti: Smalti are handmade glass tesserae produced in relatively small quantities according to classic Venetian traditions. Molten glass, colored with metallic oxides, is pressed into large slabs about 1 cm thick, then split by hand into small rectangles. The uneven, cut side becomes the face of each piece, producing a brilliant surface unparalleled by other materials. To make gold and silver smalti, a thin sheet of metal leaf is sandwiched between two layers of glass, and the whole assembly is fused together. In addition to gold and silver, smalti are available in a full range of colors (Figure 4.23) [3, 51].

**Figure 4.23 :** Examples of smalti mosaic tiles [52]

Fused Glass: In the fused manufacturing method, flat glass (usually float glass, such as glass used on car windshields) is cut into tiles shapes and then fired in a furnace. As glass is clear, it will show the tile underpay unless treated with color, so this method usually involves the addition of color – by adding it on top or under the glass. Fused glass tiles are often translucent tiles, with a layer of opaque color visible through the tile (Figure 4.24).

Fused tiles are often treated with an etching or other coating, for aethetic reasons, or to increase resistance to abrasion. Fused tiles can come in virtually any size – from mosaics to large format [86].

**Figure 4.24 :** Examples of fused glass mosaic tiles [84]

Mosaic tile is an excellent choice for smaller areas. It requires the same preparation and handling as larger tiles, with a few differences. Sheets of mosaic tile are held together by a fabric mesh underneath. This makes them more difficult to hold, place, and move. They may not be square with your guidelines when you first lay them down. And mosaic tiles will require many more temporary spacers and much more grout.

Variations in color and texture are just as likely with mosaic tile as with individual tiles, so buy all your tiles from the same lot and batch. Mortar or mastic intended for ceramic tile may not work with glass mosaic tile. Finally, if the finished project will be exposed to the elements, make sure you have adhesive and grout suitable for outdoor use [87].

### 4.3.2 Definition of glass

Many earlier writers insist on this criterion: “A glass … is a material, formed by cooling from the normal liquid state, which has shown no discontinuous change … at any temperature, but has become more or less rigid through a progressive increase in its viscosity”, according to Jones, or, more succinctly, “glass is an inorganic product of fusion which has been cooled to a rigid condition without crystallization” as taken from the ASTM Standards for glass [88].

The term glass refers to materials, usually blends of metallic oxides, predominantly silica, which does not crystallize when cooled from the liquid to the solid state. It is non-crystalline or amorphous structure of glass that gives rise to its transparency [22].

The word “glass” is derived from an Indo-European root meaning “shiny,” which has also given us the words glare, glow, and glaze. The word “vitreous” comes from the Latin word for glass [88].

### 4.3.3 Historical development of glass

Glass is one of the most magical off all materials. Three and a half thousand years ago in the Middle East it was discovered that, with the application of heat, soda, lime and sand formed a hard, transparent material. In ancient times, formed pieces of colored glass were considered as valuable as precious stones and in the past, glass was used mainly for windows, permitting light and sun to enter a home or building. Ever since, glass making has undergone a more or less constant process of technological development. Once purely decorative in application, glass is now a thoroughly architectural material [41, 51].

#### 4.3.3.1 Before the Christian era

Glass production is likely to have originated in Mesopotamia in 3000 BC, where it was produced in chunks and used as precious jewels. By the time, it reached ancient Egypt, the technique of wrapping molten glass over a form to create vessels and decorative objects had evolved [63]. The ancient Egyptians valued glass as a precious stone, setting both natural stones and glass in the gold ornaments found in the tomb of Tutankhamen [23].

At first glass was used only for decorative objects, but later it was molded or pressed into vessels. The invention of glass blowing in about the first century BC greatly increased the use of glass for practical purposes in Roman times, mainly for vessels but later for windows. In the West, glass manufacturing was dispersed to isolated sites after the fall of the Roman Empire, but was continued in Byzantium and later in the Middle East by the Arabs [82].

It seems most likely that the imaginative leap, which led to the invention of blown glass originated in the Syria/Palestine area in the first century BC, the blowing of glass was the first important step in the development of glass in architecture. It demanded techniques for raising temperatures to around 1500ºC, and a certain amount of courageous skill. The technique spread from Syria to Egypt, and was used both for vessels and for large flat dishes (the precursors of window glasses); Egyptian glass was so greatly valued by the Roman conquerors that it was used as tribute [82].

The Romans adopted this technique and the use of glass for decoration spread throughout their empire. The glass industry continued to grow in Mesopotamia and Egypt, but in Europe there was a full following the decline of the Roman Empire [62].

**Glass mosaic tiles**

The Egyptians, Greeks and Romans all concentrated chiefly on pavement mosaics in which there was naturally small opportunity for glass, which in any case demanded a different technique from stone, because of its superior responsiveness to light, and which was more suited to the subtler arrangements made possible in mural decoration by the different angle of view [89].

#### 4.3.3.2 During the Christian era

The importance of the ancient influence of Syrians on glass development cannot be underestimated. The technique of spinning discs, which was to prove an essential craft to the development of northern glazing, was in use Syria in the eighth century. It was at about this time that the Venetian glass industry was beginning. By the tenth century, the Venetian glass industry was established, and an erstwhile mainly nomadic activity had a new base.

The Venetians were originally renowned for decorative glassware and glass vessels, but they soon expanded their expertise into window glass and lenses for spectacles. Significantly, Venice was to see the perfection of the skill of making mirrors in the fourteenth century, using a reflective backing of tin and mercury, and flat glass made in Venice and in northern Europe was produced both by the cylinder method and by spinning.

At the turn of the first millennium, while the Venetians were establishing their techniques, particularly for the bullions produced by spinning, the northern European makers had consolidated and perfected the two techniques necessary to permit the glories of the Gothic Age. By AD 1000, they had established a widespread glass industry, and were using both spinning and the cylinder method to satisfy the increasing demands of the church and their own climate with its long winters and often overcast skies.

The cylinder method was described in the early twelfth century. In this early description, a technique for flat glass making is set out which was to be used for 800 years. A hollow iron tube was used to pick up a ball of molten glass. It was then blown into a bubble that became a sphere, which, as it was swung from side to side, became a cylinder with a hemispherical end. This end was cut and pinched in the centre. The centre was gripped by a ‘punty’, and the other end, still soft, opened up to create a full cylinder. The cylinder could then be reheated cut down in length, flattened out, and smoothed [82].

Neither crown glass nor cylinder glass was of sufficient optical quality for the fine mirrors desired by the seventeenth century nobility; for this reason, plate glass was first produced, in France, in the late seventeenth century. Molten glass was cast into frames, spread into sheets by rollers, cooled, then ground flat and polished with abrasives, first on one side and then the other. The result was a costly glass of near-perfect optical quality, in sheets of unprecedented large size. Before long, mechanization of the grinding and polishing operations brought down the price of plate glass to a level that allowed it to be used for storefronts in both Europe and America [27].

It was not until the seventeenth century that the development of lead glass made a major step forward in the know-how of glassmaking. This invention was to enable the glazing of large windows, a technology that brought glass into the history of architecture. Examination of ancient pieces revealed that four main manufacturing methods were standard; rod and core forming, casting with open and closed moulds, free blowing and blowing into moulds and forms. Coloring of glass, through the addition of metallic oxides, had already been perfected by ancient workers, most often using copper, manganese or cobalt [90].

**Glass mosaic tiles**

Except for glazed tiles and glass inlays, there was no attempt at an architectural application of glass, nor was there to be any until the beginning of the Christian Era, when glass was apparently first used in mosaics [89].

Colored glass was used for decoration in buildings on walls, floors and ceilings, both in private and public buildings. An early example from a Coptic Egypt setting is the upper part of a mosaic wall that has cut pieces of colored glass with Christian motifs. This technique was mastered and used to embellish architecture during the Byzantine period. Small glass pieces for mosaic continued to be made in Rome and Alexandria to decorate walls, ceilings and floors in Byzantine churches [90].

The beauty of Byzantine interior mosaic decoration is due to the use of smaller tesserae than in their Roman or early Christian counterparts and to the bonding of the reflective glass squares to gold leaf, silver, or mother-of-pearl [26].

In the fourth and fifth centuries AD early Christian wall mosaics utilized glass tesserae which provided a greater range and color intensity than in the earlier marble mosaics. Decorated fountains, altars, and grand scale wall murals were now possible with the evolution of mosaic art. The use of gold and silver smalti, made by sandwiching thin pieces of the precious metals between the glasses, added another dimension to the art form. Byzantine mosaic art contributed the use of gold and silver cubes, tilted to illuminate and reflect light in special ways to add a new perspective and dimension to mosaic artwork [20].

#### 4.3.3.3 Nineteenth century

In the nineteenth century public and commercial buildings, however, glass achieved a new architectural virtuosity. Cheap rolled plate glass was available from the mid-century onwards. Winter gardens, conservatories, and shopping arcades provided a convincing demonstration of the dramatic potential of the material [51].

In this century, the cylinder process evolved into a method of drawing cylinders of molten glass vertically from a crucible, enabling the routine, economical production of cylinders [27].

**Glass mosaic tiles**

In this period, mosaics were composed of small cubes of glass of bright colors, or covered with gold, and they were set in a plaster ground fixed to the brick vaulting or arches. All the cubes, however, were not of glass; the whites and pale colors, as, for instance, those used to represent flesh tints and light draperies, being often of marble. In the earlier mosaics, the cubes are more irregular in shape and size than in the later ones. The gold cubes were made of clear glass, on which a thin flake of gold was laid, and then glazed over and burnt in, being thus rendered practically imperishable. The colored glass cubes were of equal color right through [89].

#### 4.3.3.4 The twentieth century

Glass size, flatness, and clarity were gradually improved through a combination of hand and mechanical polishing and grinding, but it was not until the beginning of the twentieth century that technology was able to develop beyond hand-blown techniques to machine-manufactured glass. The size of the cylinder of glass used to form flat panes gradually increased, reducing textural imperfections [62].

From the initial development of high-volume glass light-bulb production in the 1920s, to the invention of float glass used to make glazing in the 1950s, to the first fiber optics produced in the 1970s, the twentieth century saw innovation in processing lead to an expansion in the range of applications for glass. Although its principal constituent is silica, over the years just about every other element has been added to alter the properties of the base material. Glass has the mechanical rigidity of a crystalline material but the random, disordered arrangement of molecules that characterizes a liquid. The molecules are locked in this random arrangement by cooling the glass from its liquid state at a high temperature [91].

New glass is being developed all the time, with increased size, structural abilities or surface strength, large or small curves, UV filters and solar reflectors, smart glass, which can change from clear to opaque at a touch, and self-cleaning glass [62].

**Glass mosaic tiles**

In the twentieth century, the Art Nouveau period embraced the use of glass in art and design. The clean, flowing patterns achieved by skilled mosaic artists lent itself perfectly to the stylized, nature-inspired characteristics of the period. Stained glass was especially valued during these years.

Throughout much of the twentieth century, glass tile fell out of favor in interior design, as artists and architects opted for more modern, synthesized materials. At the same time, however, mosaics never completely disappeared. Outside of the home, they remained a popular choice for public and religious buildings.

Turn of the twenty-first century has seen yet another rise in mosaic work. Innovations in manufacturing and technology have made glass tiles a reasonable surface option for the home, while the ever-present versatility of glass tile allows the material to be used with traditional and modern design alike [92].

### 4.3.4 Performance properties expected from glass

The eventual properties of glass are dependent upon the glass former used, the impurities in it, and the other materials added to aid manufacture and improve performance [82]. General physical properties of glass tiles are shown in Table 4.17.

**Table 4.17:** Physical properties of glass tiles [93, 94]

| Property | Glass |
|---|---|
| Specific gravity kg/m³ | 2200 |
| Density kg/m³ | 2500 |
| Hardness (Mohs scale) | Min. 5 |
| Thermal conductivity (k) W/m ºC | 0.149 to 2.09 |
| Tensile strength MPa | 27 to 69 |
| Water absorption | Average< 3, max.3,3 |
| Chemical resistance | resistant |
| Thermal shock resistance | resistant |
| Frost resistance | min.50 cycles ( -15 / +15°C ) |
| Size allowance | ±0,5% |
| Resistance to abrasion | 1 - 4 |

#### 4.3.4.1 Durability

Glass is one of the most durable building materials. The durability of modern architectural glass under ordinary conditions of exposure is excellent, and therefore the possibility of deterioration is usually ignored [83]. Nevertheless all glasses are liable in some degree to atmospheric attack and with a poor quality glass, or under conditions of exposure slightly more rigorous than the normal, serious changes can sometimes occur [89].

Glass tiles may not be suitable for heavy commercial installations where maximum durability is required [59].

#### 4.3.4.2 Abrasion /wear and impact resistance

The ability of a surface to resist abrasion damage is usually considered under the general term of 'hardness'. With abrasion damage, different mechanisms contribute to its formation depending on the loading level used. For example, light loads first produce scratches with some plastic deformation of the surface; this is different to the cracking effect resulting from scratches produced by heavy loads [83].

#### 4.3.4.3 Resistance to frost

Almost all glass tiles are also frost resistant when installed properly.

#### 4.3.4.4 Resistance to chemicals

In general, glass has excellent chemical resistance to solvents, alkalis, and acids, except hydrofluoric acid [95]. It is damaged by alkaline solutions. The runoff alkali from masonry or concrete structures can stain or etch the glass. The alkali in most soaps, if in contact with a glass surface for a period of time, will etch glass sufficiently that it cannot be restored to its original brilliance regardless of the rubbing and polishing. Glass is also slowly dissolved by water [30].

Dilute acids, with the notable exception of hydrofluoric acid, and even many concentrated acids, have in general no greater effect than pure water. Indeed, the presence of the acid may often lessen, and sometimes almost completely prevent, the attack. Alkaline solutions, on the other hand, attack glass readily. Fortunately, these are not formed on the surface of glass in the natural course of weathering, except in so far as alkaline substances are extracted from the glass itself.

Another form of attack by alkali has been observed where glass tiles are set in portland cement mortar. The tiles have been cracked and sodium silicate has exuded through the cracks. The remedy hear is to coat the backs of the tiles with bituminous emulsion before they are fixed [89].

#### 4.3.4.5 Movement and cracking

The production of glass tile involves the fusing of glass to colored glazes at temperatures above 900ºC followed by a rapid cooling of the individual pieces to room temperature. Even at these extreme firing and cooling temperatures in the stage of production, the glass tile pieces do not show any occurrences of cracking or stressing in any manner [96].

#### 4.3.4.6 Changes in appearance

Color of glass tiles will not fade over time [59].

#### 4.3.4.7 Maintenance and cleaning

Generally, tile with lower absorption rates are easier to maintain because they are more resistant to staining. They do not readily absorb grease, chemicals and other staining agents [59].

To preserve its surface, glass should be cleaned regularly. Dust can reduce the thermal and visual performance of glass, increase its thermal absorption and reduce its life. In extreme cases, the glass may become discolored. Glass should be cleaned with non-alkaline solutions [97].

During cleaning, care must be taken to ensure that the wet cloth used does not push dry particles of dust and sand ahead of it and thus causes scratches. Wetting the glass well beforehand is therefore vital [93].

#### 4.3.4.8 Slip resistance

Glass is slippery when wet, even if treated by sandblasting, and should not normally be considered for external locations [22]. Vitreous glass is not suitable for flooring applications because it is too slippery [51].

Glass tiles are usually slippery when wet, and for safety reasons, commercial floors in high traffic areas that are exposed to rain or spillage are often marked with "caution – slippery when wet" signs. If small format (25.4 × 25.4 mm or smaller) tiles are used on floors, the relatively frequent grout lines create texture that inhibit slippage [51].

#### 4.3.4.9 Cost

Prices of different colors vary widely. Glass tile with pure gold use as a pigment can be extremely expensive, whereas other pigments are quite inexpensive.

Glass tiles cost high as an imported item [29]. But their cost is lower than unglazed ceramic tiles [59].

### 4.3.5 Glass design and process

Developments in the way it is made, and in particular, the evolution of secondary manufacturing and processing techniques, have revolutionized applications in our own century, and in the process have changed the architecture.

Technology is at the root of these changes, and only by understanding the technology of glass, its physics and chemistry, and the technologies associated with its manufacture, can the designer become fluent in its use. By looking at what it is, how it is made and what its properties are, we can judge its potential and its limitations [82].

#### 4.3.5.1 Glass processing methods

Glass making is essentially very simple and involves three steps: melting, forming and carefully controlled cooling. Melting creates a molten mass in which the various constituents are completely mixed. Forming is carried out as the temperature of the hot 'melt' falls, and its viscosity gradually increases to the point where it can be shaped. The final process is commonly called 'annealing' in the glass industry, which properly means the process of controlled heating and cooling to achieved a desired physical state [82].

The basic materials used in the manufacture of glass for construction purposes are sand (silica), soda (sodium oxide), and lime (calcium oxide), with the addition or substitution of various other chemicals to modify the characteristics of the resultant glass products [30].

**Melting**

Glass has traditionally been melted in a "batch" in a pot or crucible of refractory ceramic material. Raw materials are mixed to the desired composition and either heated in the crucible or added to already molten glass. The low melting constituents (alkali oxides) melt and dissolve the higher melting constituents such as quartz and alumina [88].

The proportions of the materials vary according to the type of glass to be made. Raw materials are fused together in the furnace at about 1100ºC, and the molten glass is drawn as required. Most furnaces now are continuous, the ingredients are tipped in at one end and the furnace is designed so that the heat is applied to render the mass molten and cause it to flow slowly to the far end, where it is drawn continuously, depending upon the fabricating method used [33].

Quantity production of glass, especially soda-lime and borosilicate compositions, is continuous in a large "tank" or furnace made of special refractory brick; a characteristic tank is 15 x 25 m in size, with glass 1.5 m deep, giving a daily production of as much as 700 metric tons of glass. The tank is heated by combustion of oil or natural gas across the glass surface. Melting temperatures are about 1200-1300ºC. The furnace is separated into two positions by a refractory "wall" over which glass flows. The mixed raw materials are fed onto the top of the molten glass in the melting chamber, in which the glass becomes more homogeneous and bubbles are removed.

In the refining chamber, the glass is "fined" by the removal of bubbles. The bubbles contain trapped air (oxygen and nitrogen) and decomposition products of the raw materials, mainly carbon dioxide. Large bubbles rise to the top of the melt, but most bubbles are too small to be removed in this way; the gases in them must dissolve in the melt to collapse the bubbles. This dissolution is aided by fining agents added to the glass batch. Arsenic and antimony oxides are common fining agents. They have two oxidation states, and increase dissolution rates of gases by changing the oxidation state of the melt. Sulfates are also common fining agents; they also function by changing the oxidation state of the melt [88].

**Forming**

Forming method includes blowing, pressing, drawing, rolling and casting [95].

**Cooling**

After forming to the shape required, glass must be cooled slowly (annealed) to relieve the strains, which would otherwise result. The description-annealed glass is used to distinguish ordinary glass from the toughened product [39].

Broadly, there are three forms of modification to the basic manufacturing processes.

Tinted: Body tinted glass products are produced by small additions of metal oxides to the float or rolled glass composition. These small additions color the glass bronze, green, blue or grey but do not affect the basic properties of the glass except for changes in the solar energy transmission.

Coated: Modified properties are produced from the basic glass by means of surface coatings applied, in this case, on-line during the basic manufacture. They have advantages of hardness and durability over off-line coatings applied after the basic manufacture. Coatings may modify some or all of the solar energy transmission, color, and thermal insulation properties.

Wired: Wired glass is made by rolling processes. In one such process, a steel wire mesh is sandwiched between two separate ribbons of glass and passed through a pair of consolidating rollers, which may also impress a required pattern. The rough cast surface may be polished to obtain clear transparency [83].

The wire mesh holds the glass together when it is cracked and even when it is severely shattered. It is much used where some degree of fire resistance is needed, as it is graded as having a period of ½ hour under BS 476 standard test [33].

**Surface finishing**

Fine surface textures are applied, of varying degrees and varieties, using edge-work and beveling, brilliant cutting, engraving, sand-blasting, grinding, and aciding and acid embossing [78]. They may be factory or hand applied, and the glass may be subsequently heat-treated or bent [83].

Edge-work and beveling: Edges of the sheet can be finished in a variety of ways, the most common being beveling.

Brilliant Cutting: This is one method of decorating to glass and is obtained by the use of grinding wheels of the requisite section cutting the glass in various ways. The cuts may be finished polished or unpolished.

Engraving: In this type of decoration the surface of the glass is cut by a small revolving engraving wheel and any suitable design on both flat and curved glass may be executed in this way. Cuts may be finished polished or unpolished.

Sandblasting: This type of work may be used either for obscuring glass after manufacture or for purely decorative work. It is executed by directing a jet of sand under high pressure on to the surface of the glass. Unusually shaped holes are often cut by this method. There are four main types of finish:

Surface of matt finish: This finish leaves a flat obscured surface.

Deep or grave: This finish is similar to (a) but has a more deeply bitten surface.

Modeled sandblast: This has a deeply bitten surface of varying depth giving a mottled appearance.

Shaded sandblast: This is a method of shading the obscuring effect.

Grinding: By this method, the surface of the glass is obscured by means of grinding with an abrasive. The surface is similar but finer than sandblasting and the fineness of the surface depends upon the abrasive used.

Aciding or acid embossing: This is a method of obscuring the glass by treating the surface with hydrofluoric acid. The nature of the finish depends upon the number of applications of the acid. There are mainly six types of finish:

White acid finish: The surface resulting from one application of the acid.

Satin or velvet finish: The surface resulting from more than one treatment of acid.

Single embossing: This is a design with a second acid treatment based on the surface resulting from a single treatment of the acid.

Double embossing: A design resulting from two further acid treatments on a surface resulting from a single acid treatment.

Stippling: This surface is produced by using an acid combined with mica or similar inert material. The action of the acid varies as the mica protects the glass from its action and so produces a stippled effect.

Silvering: The old method of silvering, now in disuse, was to coat the back of the glass with an amalgam and thin. This gave a dull type of mirror and lacked permanency.

The modern method is to use silver as follows:

The glass to be silvered is placed on a table and all grease, etc., is cleaned off with a felt pad and a mixture of ammonia and whiting.

An ending of putty is placed around the edge of the glass to prevent the deposit running off, and the glass is then covered with liquid is drained off and the surface washed with distilled water, and dried with a chamois leather.

The silvering should be protected with a coat of shellac, which is then painted. If the mirror is to be used in damp atmosphere, lead should be used over the shellac, in lieu of paint.

Gold and pewter may be used in place of the silver in a similar manner [33].

#### 4.3.5.2 Glass tile production

Glass-like crystalline formed from molten glass and other coloring oxides at a temperature above 1000°C, shaped into mosaic size squares by roller or press molds [59].

Glass mosaic is mirrored or opaque glass, fabric backed, cut into squares or rectangular units. The fabric backing remains uncut and is used to paste up the material on the wall surface. Being supple and flexible, it may be fixed round corners and over curves and can be applied to almost any type of substructure. It is an appropriate decoration for places of entertainment where its gaiety and sparkle, especially in the case of mirrored glass, may be given full play [89].

## 4.4 Installing mosaic tile

In tile installation, there is a choice of methods, a technique to be used with each, and a finishing process called grouting [98]. The simplest way of laying mosaic is to use sheets of mosaic that are pre-stuck to a backing and apply them in the same way as tiles [51].

Tiles may be set into plastic mortar or adhesive or may be bonded to hardened mortar. When the bond is sufficiently strong to prevent the tile from moving, the joints between tiles should be grouted.

The tiles may be face mounted, back mounted, or edged bonded. Face-mounted tiles are stuck face down on paper or other suitable material with a water-soluble adhesive so that the sheet can be removed easily after tile setting, before the joints are grouted. For back-mounted tiles, the backside, and for edge-bonded tiles, the edges are adhered to perforated paper, fiber mesh, resin, or other suitable material, which remains in place after tile setting [69].

### 4.4.1 Plan the layout

Layout is unquestionably one of the most important aspects to a good tile installation. Quite often a good layout goes unnoticed by the untrained eye because it looks right. If a poor layout is done, however, the entire effect can be ruined and displeasing even to the untrained eye.

Proper layout is required by the tile industry, and there are four basic items considered important to proper layout.

- The size of the cuts.
- Straight and true work.
- Straight and uniform joint lines.
- Accurate floating of mortar walls to obtain flat and true surfaces as well as aid to good layout [99].

### 4.4.2 Applying adhesive/mortar

Formerly, tile was installed with portland cement (a so-called mud job), but today, the job is usually done (on floors and walls) with adhesive. A wide variety of adhesives is available, and you should check with a tile dealer to ensure that you select the proper one [70].

Four basic methods have been developed for the setting of tile. Each of these methods has features that make it particularly valuable for specific installations. New methods developed within the last twenty years have not only increased the versatility of tile as a wall and floor surfacing material, but have reduced the cost of tile installations [30].

Portland Cement Mortar is the conventional mortar, for setting tile consist of one part of portland cement to five parts of sand for floors and one part of cement, six parts of sand, and up to one part of hydrated lime for walls. If the setting bed is applied over wood studs, it is reinforced with metal lath, and the studs are protected with waterproof building paper. In wood stud construction, the setting bed is applied over a scratch coat of portland cement plaster. Only enough wall or floor area is covered with the setting bed to allow the tile to be pressed into true alignment. A bond coat of neat portland cement paste, is applied over the setting bed while it is still wet. Tiles that have been soaked in water for at least a half hour then pressed or beat into the bond coat. After curing, the tile is grouted with portland cement or other grout [30].

Dry-set Mortar is applied with a notched trowel to a suitable backing. This method eliminates the need for soaking the tile and its backing before installation. Dry-set mortar should never be applied directly to gypsum plaster, masonite, or wood [30].

Organic Adhesives are produced which are ready for use without the addition of liquids and cure by evaporation. They are applied with a notched trowel to properly prepared surfaces. As with other thin-set methods, the under-bed must be perfectly true. Any irregularities in the surface of the under-bed will be reflected in the tile surface. Priming is recommended for most surfaces. This method is generally not suitable for wet areas such as kitchens, bathrooms, and showers or in areas subject to heavy traffic. The tile must not be grouted until the solvent in the adhesive are toxic and inflammable and must be handled with care [30]. A wide variety of adhesives is available for ceramic tiles as is shown in Table 4.18 [71].

**Table 4.18:** Different types of adhesives for mosaic tiles [71]

| Type of adhesive | Main constituents | Water-proof scale | Areas of use |
|---|---|---|---|
| Mineral Adhesives | | | |
| Water-glass glue | Water-glass, lime, stone dust, water | 1 | Ceramic tiles and paper |
| Cement-based glue | Portland cement, stone dust, possibly acryl, water | 2 | Ceramic tiles, aerated concrete |
| Synthetic Resins | | | |
| Epoxide adhesive | Epichlorhydrin, phenol, alcohol | 1 | Concrete, stone, glass, metal, plastic, ceramic tiles |
| Plant-based and Cellulose Adhesives | | | |
| Natural rubber adhesive | Natural rubber or recycled rubber, organic solvents | 2 | Ceramic tiles, linoleum |

Notes:
1: Outdoor use, but sheltered from rain
2: For outdoor use

Epoxy Mortar resins, mixed on the job with a resin hardener, are used where a high bond strength or resistance to acids is important. This mortar is applied in a smooth, thin layer and will bond to either wet or dry surfaces. The mortar must be applied and the tile set within a given time after the resin and hardener have been mixed. The pot life of the material after it is mixed, its adhesive qualities and chemical resistance, and application methods vary with the manufacturer. The manufacturers' instructions must be followed carefully.

Furan Mortar consists of furan resin and hardener similar to the two-part epoxy system. The properties vary with the manufacturer [30].

### 4.4.3 Applying grout

Grout is the material that fills the joints. It once was available only in white, but today you can get grout in many different colors, and it makes a nice accent material to the tile [70]. Several types of grout are used for this purpose as is shown in Table 4.19 [41].

Because each mosaic tile is so small, the grouting has a much grater impact on both the appearance and the performance of the final surface. Visually, the color of grouting can have an impact on the design. Matching light grouting with light-colored mosaic, or dark with dark, makes the effect more seamless; contrasting, on the other hand, emphasizes the pieced nature of the effect and can be more graphic [51].

Portland cement grout is composed of grey or white portland cement mixed with water to a creamy consistency and forced between the joints from the outside. This type of grout tends to show unevenness in color owing to variations in the depth of the bed and porosity of the surface [30]. The portland cement-sand grout joints will have a definite effect on the appearance of the finished tile installation [100].

Commercial grouts are produced by a number of manufacturers. Some consist of white portland cement mixed with titanium dioxide to produce a uniformly white joint. Others are colored to match or contrast with particular tile colors. Non-staining grouts of epoxy resin have been developed for use in locations subject to excessive staining action. They are particularly valuable where an acid- or alkali-resistant floor is needed. Flexible grouts, latex rubbers specially compounded for mixing with portland cement grout, are available for use where movement in the underlying structure is anticipated. These products require strict adherence to the manufacturers' instructions [30].

**Table 4.19:** Different types of grouts for mosaic tiles [41]

| W= Wall Use<br>F= Floor Use | Standard Unsanded Cement Grout (3) | Standard Sanded Cement Grout (3) | Polymer Modified Unsanded Tile Grout (3,6) | Polymer Modified Sanded Tile Grout (3,6) | Modified Epoxy Emulsion (3) | 100% Solid Epoxy (1,2,3,4) | Mastic Grout (2,3) |
|---|---|---|---|---|---|---|---|
| Mosaic tiles | W,F | W,F | W,F | W,F | W,F | W,F | W,F |
| **USE** | | | | | | | |
| Exposure | W,F | W,F | W,F | W,F | W,F | W,F | W,F |
| Wet areas (7) | W,F | W,F | W,F | W,F | W,F | W,F | W,F |
| Exteriors (5,6,7) | W,F | W,F | W,F | W,F | W,F (3) | W,F | |
| **PERFORMANCE** | (Note: There are five performance ratings, from best [A] to minimal [D]) | | | | | | |
| Suggested joint widths | 1.588 to 3.175mm | 3.175 to 15.88mm | 1.588 to 3.175mm | 3.175 to 15.88mm | 1.588 to 15.88mm | 1.588 to15.88 | 1.588 to6.35 |
| Stain resistance | D | D | C | C | C | A | B |
| Crack resistance | D | D | C | C | C | B | C |
| Color availability | B | B | B | B | B | B | B |

Note:

(1) Mainly used for chemical resistant properties
(2) Special cleaning procedures and materials recommended
(3) Follow manufacturer's directions
(4) Epoxies are recommended for prolonged temperatures up to 60ºC
(5) Some types of glazed ceramic tiles may be permanently stained when grouted with pigmented grout of contrasting color
(6) Latex modification may be required in areas subject to freezing temperatures
(7) Colored cementitious grouts may darken when wet

Acid should not be used on colored grouts. Even the acid in vinegar will be detrimental on dark or black grout. The acid can make a whitish haze over the grout joints. It does little good to have a colored grout when the color is hidden by a whitish film. Acid will often cause irregular shades of light and dark in colored grout [100].

# 5. CONCLUSION AND RECOMMENDATIONS

Mosaic is an ancient and contemporary art form, which uses small tiles of materials such as ceramic, stone, glass, places them together to create a design or images.

Mosaic has a long and glorious history. For thousands of years, artists have created incredible images and patterns on the floors, walls and ceilings of buildings by using tiny colored tiles.

Today, mosaic has become more of a “creative” art form and not just a decorative one. It is being produced both in industrial field and in artistic way of expression by a wide range of materials and techniques. The individual tiles are ceramic, porcelain, terracotta, stone, or other tile cut into small pieces. They are often mounted on a mesh backing so that large squares of many tiles can be installed at once. These squares may be a solid color or contain a pattern or image. Individual mosaic tiles are also available for making custom accents and mosaics. The variety of patterns and designs available in prefabricated mosaic tile squares is extensive and adding just a few squares to a floor or a wall has a striking effect.

Mosaic has a wide range of using areas in buildings. Solidity, resistance to moisture, durability and color-fastness make mosaic a practical form of architectural decoration. However, when deciding what material to use in your mosaic, there are a number of practical things to take into account. Principally, selected material for mosaic should be suitable for where it will be placed or used. For example, if the mosaic will go of outside, selected material should be frost resistance or if the mosaic will be used in a high trafficked place, it should be stand up to wear. So, it is important to select the proper material for the application area, to get the expected results from mosaic. Main considerations that determine this are defined as the performance properties of materials used in mosaic making.

Mosaics are composed from a variety of product types, but the main materials used in mosaic making are ceramic, stone and glass.

Ceramic mosaic tiles are small, flat units composed of clay or clay mixtures fired in kilns at high temperatures. They are set on floor, wall, or ceiling areas to provide permanent, waterproof, durable, and easily maintained finish surfaces. Ceramic mosaic tile may be installed on the interior or exterior of a building, depending on the density of the tile, its finish, and its method of installation.

Finishes for ceramic mosaic tiles vary greatly, but essentially, they are either glazed or unglazed. Glazed tiles have a glassy, waterproof surface produced by ceramic material that is fused on their faces. The glazes may be several different textures, or degrees of matte finish, and they normally range from pure white to jet black and every hue in between. Unglazed tiles derive their color and texture from the clays used in their manufacture, or from minerals that are added prior to firing.

All types of ceramic mosaics are suitable for walls and floors both inside and outside, according to the properties, shown in Table 5.1.

**Table 5.1 :** Analysis of ceramic mosaic materials

| Ceramic mosaic tiles | Properties | Performance Ratings |
|---|---|---|
| Durability | Ceramic tile provides a durable surface that maintains good looks indefinitely. | A |
| Abrasion and impact resistance | Many ceramics show outstanding abrasion resistance, because of their high hardness relative to the abrasive particle. One of their weaknesses, however, is an inability to withstand impact, that is, they have low fracture toughness | B |
| Resistance to frost | Ceramic products vary widely in degrees of the frost resistance. In general, frost resistance tiles are available. | B |
| Resistance to chemicals | Ceramic tiles have the ability of chemical resistance. | A |
| Movement and cracking | To minimize any movement in tiling, backgrounds should be completely stable. Also, if its composition is accurately matched to the properties of the body there will be no micro cracking. | C |
| Maintenance and cleaning | Ceramic tiles are recommended low upkeep | A |
| Slip resistance | In general, ceramic tiles are slightly slippery, but non-slip versions containing silicon carbide are available, and ones with ribbed, ridged or studded textures give a better grip underfoot. | B-D |
| Cost | Ceramic tiles cost range low to high | B-D (20-60) |

Note: A: 100-80, B: 80-60, C: 60-40, D: 40-20, E: 20-0

Ceramic tile is frequently used on walls and floors when an easily cleaned, waterproof and durable surface is desired. One use of ceramic tile is as a backsplash in the kitchen. When ceramic tile is used for these purposes, the grout can be sealed by use of a commercial sealer or by using a lemon oil furniture polish. Ceramic tile is also used for the surrounds of showers and bathtubs and for bathroom walls in general. These three uses are probably the most common ones, but ceramic tile may also be used on the walls in foyers and ball-ways (plain, patterned, or displaying a logo) and as a heat-resistant material around fireplaces and stoves.

Stone is one of the original natural materials used in buildings by prehistoric people. Today, stone is generally used for aggregates and as a surface material.

There are mainly five types of stone materials; granite, limestone, sandstone, marble and slate, that are used for stone tiling. Granite is a beautiful, natural material suitable for countertops, showers, tub surrounds, walls, flooring or just about anywhere. Granite has a hard, dense surface and a granular texture and can stand up to oil, alcohol and chemical cleaners that stain other stones. Limestone is suitable for countertops, showers, fireplace facing, entryways, and floors because it is water resistant, heatproof, and very durable. Sandstone is great for flooring and should be sealed for indoor use to protect it from stains. On interior and exterior walking surfaces, the quality of marble has been proven many times over. The physical properties of marble give it extraordinary strength and impart a water and dirt-proof surface. Slates can be has with riven textures which vary from silky and smooth to very rough, or sawn, sanded or finely rubbed surfaces. Being very hard and denser than granite it also takes a good natural polish but does not retain it as well.

Stone mosaics can be used to create protective or decorative effects almost anywhere, from walls, floors and ceilings to fireplaces, according to the properties shown in Table 5.2 and Table 5.3. Tiles are practical and attractive materials that can be used indoors and out, and in a range of styles.

Glass is an amorphous, inorganic, translucent non-crystalline substance, composed largely of silica, sodium oxide, and calcium oxide.

Glass tiles are scratch-resistance, durable, hygienic, frost-proof and inflammable. They are impervious to water and staining, and resist chemical attack. Glass tiles perform well in areas of high moisture. Most are not suitable for floors, because they are slippery when wet. Many tiles have a raised decorative effect. Most are translucent, so any coloring or patterning on the underlying surface needs to be considered; adhesive also needs careful application to avoid marring the finished effect.

**Table 5.2 :** Properties of stone mosaic materials

| Stone mosaic tiles | Properties |
|---|---|
| Durability | Natural stones are generally extremely durable but deterioration may result from wrong choice of stone and relates them to exposures. Also, surface finishing of stone effects its durability. |
| Abrasion and impact resistance | Like any natural material, stone is subject to wear and decay; unlike most, however, significant deterioration is measured on a very long timescale indeed. |
| Resistance to frost | Stones used in exterior installations that are exposed to freezing temperatures must be freeze-thaw stable; that is, they must have low water absorption. |
| Resistance to chemicals | Stone's resistance to chemicals depend on their porous structure.<br>The most porous the stone, the easier it is to stain |
| Movement and cracking | Cracking can also be due to pressure an especially tension brought about by external factors, including usage and movement.<br>Wrong choice of materials are the cause of many cracks. |
| Changes in appearance | Natural stones usually retain their good appearance inside buildings. But in external usage, deterioration may occur. So surface finish of stone should be decided carefully. |
| Maintenance and cleaning | To maintain good appearance, to minimize the likelihood of decay and to prevent defects becoming concealed by soot deposits, stonework that is exposed externally should be cleaned regularly and defective joints should be raked out and re-pointed. |
| Slip resistance | All stone floors are slippery when wet apart from sandstone. But stones can be finished with a suitable finis like honed, to provide a non-slip surface. |
| Cost | The price of stone varies from fairly expensive to astronomical, according to the type |

**Table 5.3 :** Analysis of stone mosaic materials

| Stone mosaic tiles | Granite | Limestone | Sandstone | Marble | Slate |
|---|---|---|---|---|---|
| Durability | A | C | C | B | A |
| Abrasion and impact resistance | A | D | C | B | E |
| Resistance to frost | A - B | B - D | A - D | A - B | A - B |
| Resistance to chemicals | A | D | C | C | A |
| Movement and cracking | B | D | D | B | B |
| Changes in appearance | B | C | C | B | D |
| Maintenance and cleaning | C | C | D | D | C |
| Slip resistance | B | C | A | D | B |
| Cost | A | C | C | B | D |
| | (90) | (40) | (40) | (65) | (20) |

Note: A: 100-80, B: 80-60, C: 60-40, D: 40-20, E: 20-0

In today's market, there is an incredible selection of glass mosaic tiles available. There are transparent glass tiles in multiple, smoked colors, and opaque and shimmering iridescent glazes. Other glass tiles are hand painted in primary colors or soft tones, and can be used to create unique custom murals or theme tiles set as accents on a large, solid tile background. Some glass tiles have raised relief subjects or running designs useful for borders. Glass tiles are naturally waterproof, making them good choices for showers, tub surrounds, backsplashes, pools, and outside fountains.

**Table 5.4 :** Analysis of glass mosaic materials

| Glass mosaic tiles | Properties | Performance Ratings |
|---|---|---|
| Durability | Glass is one of the most durable building materials. Under conditions of exposure slightly more rigorous than the normal, serious changes can sometimes occur. | B |
| Abrasion and impact resistance | Glass tiles are resistance to abrasion but cracking effect resulting from scratches may be produced by heavy loads. | B |
| Resistance to frost | Almost all glass tiles are also frost resistant when installed properly. | A |
| Resistance to chemicals | Glass has excellent chemical resistance to solvents, alkalis, and acids, except hydrofluoric acid. | B |
| Movement and cracking | The glass tile pieces do not show any occurrences of cracking or stressing in any manner. | C |
| Changes in appearance | Color of glass tiles will not fade over time. | A |
| Maintenance and cleaning | To preserve its surface, glass should be cleaned regularly. During cleaning, care must be taken to ensure that the wet cloth used does not push dry particles of dust and sand ahead of it and thus causes scratches. | A |
| Slip resistance | Glass mosaic floors are slippery when wet. | C |
| Cost | Prices of different colors vary widely. Glass tile with pure gold use as a pigment can be extremely expensive, whereas other pigments are quite inexpensive. | C-D (20-50) |

Note: A: 100-80, B: 80-60, C: 60-40, D: 40-20, E: 20-0

Mosaic is a pretty good durable material that maintains its good appearance and stability for a long period time. One of the most important factors, which provide this, is to select the proper material. For this reason, first, requirements related to properties of the surface to be covered should be specified, then mosaic material's performance properties should be analyzed if it answers these requirements or not. After selecting suitable material, with a good installation, it is possible to get very durable and aesthetic areas.

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