İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

COLD PRESSURE AND RESISTANCE WELDING OF COPPER WIRES

M.Sc. Thesis by

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SUMMARY

Nowadays companies seek just in time, low-cost and high quality manufacturing. Continuity of production is the basic factor that makes it possible to comply with these criteria. Welding machines are of substantial importance in maintaining the continuity of production. In wire drawing industry, welding machines are used;

i. For welding the wires that fracture during the drawing process,
ii. For adding wire ends while advancing to a new spool,
iii. For adjusting the weight and length of the finished spool,
iv. For welding the stranded wires which fracture during the process.

Wire drawing is a simple deformation process of a metallic material in a special die called matrix, so as to increase its length and reduce its cross-section. The starting material of the drawing process is a rod. Preannealing can be made in order to impart the desired ductility to the material, in accordance with the desired amount of deformation. Once the wire has been drawn, heat treatments regarding the desired mechanical properties can be applied. Finally, the drawn wire can be stored as spools or coils.

Wire butt welding is made in Turkey and the rest of the world by various methods. The most popular two among those are, cold pressure and resistance welding. Cold welding is applied to analogous or unanalogous, especially non-ferrous metals, and is carried out at room temperature, under a critical pressure. Resistance butt welding is a method of joining metals in which the heat necessary for welding is generated by the resistance of the stock to electrical conduct. This method has proven satisfactory in joining ferrous and non-ferrous materials in almost every commercially available form.

In this study, two alternative methods, cold pressure welding and resistance welding, used commonly in the copper wire drawing industry are compared in technological and economical view points.

ÖZET

Günümüzde şirketler kısa sürede, düşük maliyette, kaliteli ürün üretme peşindedirler. Üretimin devamlılığı, bunu sağlayan en önemli unsurdur. Tel çekme endüstrisinde, üretimin sürekliliğini sağlamada kaynak makineleri önemli bir yer tutmaktadır. Kaynak makineleri tel çekme endüstrisinde;

i. Tel çekme prosesi sırasında kopan telleri kaynak etmede,
ii. Bir makara bittiğinde, diğer makaraya geçerken telleri birbirine eklemede,
iii. Biten makaranın metrajını ve ağırlığını ayarlamada,
iv. Bükümlü tellerde kopan tellerin birbirlerine kaynak edilmesinde kullanılırlar.

Metalik bir malzemenin matris adı verilen bir kalıp içinden çekilerek kesidinin küçültülüp boyunun uzatılması işlemine çekme denir. Çekme işlemi genellikle oda sıcaklığında yapılır. Tel çekme işleminde hammadde, sıcak işlem ürünü filmaşin adı verilen çubuktur. Uygulanacak deformasyon oranına göre malzemede işlem öncesi istenen sünekliği sağlamak için ön tavlama yapılabilir. Tel üretildikten sonra istenen mekanik özelliklere göre gereken ısıl işlemler uygulanabilir. Son işlem olarak teller kangal veya bobin halinde sarılırlar.

Türkiye'de ve dünyada çeşitli yöntemlerle tel kaynağı yapılmaktadır. Bunlardan en popüler iki kaynak yöntemi; soğuk basınç kaynağı ve direnç kaynağıdır. Soğuk basınç kaynağı, benzer veya benzer olmayan, özellikle demir dışı metalleri kaynak etmede kullanılan, prosesin oda sıcaklığında kritik bir basınç değeri altında gerçekleştiği bir kaynak yöntemidir. Direnç kaynağı ise; gerekli ısının, elektrik akımının bir direnç devresine doğru geçişi sonucu üretildiği bir metal kaynağı yöntemidir. Bu metod demir ve demirdışı malzemelerin kaynaklanmasında, hemen hemen her ticari uygulamada tatmin edici sonuçlar vermiştir.

Bu çalışmada bakır tel çekme endüstrisinde yaygın olarak kullanılan ve birbirine alternatif olan soğuk basınç kaynağı ve direnç kaynağı yöntemlerinin teknolojik ve ekonomik açıdan kıyaslanması amaçlanmıştır.

CHAPTER 1. INTRODUCTION

Resistance welding and cold pressure welding are the most popular welding methods used in wire drawing industry. These welding methods are used in various stages of drawing process to join wire ends for the following drawing stages. Resistance and cold pressure welding methods have several advantages and disadvantages with respect to each other.

Cold pressure welding is quite probably the earliest welding process known in the British Isles. Examples have been found from the Bronze Age (circa 700 B.C.) of gold boxes hammer welded at room temperature. It is only since the Second World War that attention has been paid to extending the range of cold pressure welding away from traditional uses, but already the process is widely employed in the electrical and canning industries. The outstanding features of the process one that welding is carried out at room temperature, equipment is simple and easy to operate, and the welds are free from many defects associated with fusion welding. Cold pressure welding is a process which pressure, associated with a certain minimum amount of deformation, is responsible for welding together two metal surfaces. The process is carried out at room temperature and no heat is supplied from any external source. It is a solid state welding process and does not involve the use of fillers. In cold pressure welding two metal surfaces are pressed together by dies. The metal of the interface deforms to allow virgin metal to come into contact, and after a certain amount of deformation and/or interfacial extension takes place the surfaces bond together. The process is used most widely for joining a wide range of non-ferrous metals.

Resistance welding is the full metallurgical combination or integration of two or more parts and nothing has been added or taken away except the pressure and heat. The composition of the welded area is a perfect continuation of the parts, both physically and metallurgically. Resistance welding was discovered in 1877. However, no really substantial progress took place much before 1930, and the most ambitious strides have been made since the ending of the Second World War. Resistance welding techniques, therefore, are becoming increasingly important because of their tremendous economic and manufacturing advantages. Metals that can be successfully resistance welded may be in the form of tubes, shafts, strips, forgings, castings, rings or extrusions, and structural steel shapes of varying character. Almost all type of steel and most of the nonferrous metals, such as copper and copper alloys can be successfully resistance welded.

In this study, cold pressure welding and resistance welding techniques are compared in technical and economical bases for copper wire industry.

CHAPTER 2. COLD PRESSURE WELDING

Cold pressure welding is a method of joining of similar or dissimilar ductile metals by bringing the surfaces to be joined into an intimate and expanding area of contact under pressure [1]. The most important requirement for cold butt welding is a particular amount of deformation with appropriate pressure. Cold presssure welding is a rather unique form of solid phase welding, it is unique because the welding is carried out at ambient temperatures while other forms of solid phase welding are carried out at elevated temperatures, although while these temperatures are high, the material is not molten, merely more ductile [2].

The major divisions of cold welding are lap welding, butt welding and slide welding. Other deformation welding processes such as roll welding and ultrasonic welding also are often performed at room temperature [3].

2.1. Background For Cold Pressure Welding

Cold pressure welding has long been exploited, as early as 3000 years B.C. the Egyptians prepared iron by hammering a metal sponge in order to weld the red hot particals together. Blacksmiths also, for example, have hammer welded wrought iron for centuries. But always these forms of welding were carried out at high temperatures [2].

The first known example in Britain of hammer welding at ambient temperatures and therefore it was pure cold presssure welding, dates back to the late bronze age around 700 years B.C. the material used was gold, in the fact gold boxes made by this process have been found during excavation work [2].

The first scientific observation of cold presssure welding was in 1724 by the reverend J. I. Desaguliers [4], who demonstrated this phenomena to the royal society and later published the detailes in the scientific journal of the time. He found that by taking two lead balls about 25 mm each in diameter, pressing them together and at the same time twisting them, the two pieces were joined to each other. The joint strength measured on a steelyard and although the results were eratic, good bonds were produced with some as strong as the parent metal [2].

It would then appear that after this early start to cold presssure welding, very little happened until the second world war accelerated developments, especially in Germany where light alloy cooler elements for aircraft were pressure welded, although it is understood that this welding was carried out at elevated temperatures [2].

2.2. Principle of Operation

Generally there is a reluctance among people unfamiliar with the process to accept a method of welding that does not involve heat or electricity and some form of flux to make the joins, after a demonstration the question is always, "how are the two pieces of metal joined?" [2].

There have been several explanations as to the actual mechanism by which a cold pressure weld is obtained, for example by re-crystalisation or by an energy hypotesis but most have been either experimentally disproved or refuted on theoretical grounds [2].

The currently accepted hypotesis that accounts for a cold pressure weld taking place is basically as follows:

The atoms of metals are held together by the metallic bond, so called because it is peculiar to metallic substances. The bond can be described as a cloud of free negatively charged electrons, envoloping ionised positively charged atoms into a unit as a result of attractive forces, so , if two metallic surfaces are brought together with a space of only a few angstroms seperation and there are 300 million angstroms to 1 centimetre, interaction between the free electrons and ionised atoms can occur, this will eliminate the potential barrier allowing the electron cloud to be common. This now affects a bond and therefore a weld.

This is a rather awesome description, a more simplified explanation is that if two surfaces are, when considered on an atomic scale , atomatically flat and atomatically clean and they are put together a bond is affected equal to that of the parent metal.

Because this process of metal bonding can be carried out at room temperature, it has been termed cold pressure welding [5].

Cold presssure welding has been used as an industrial process for several years. Application of the process to the welding of aluminium and copper foil, sheet, wire, rod and tubes for electrical, electronic and other industries are reviewed [1].

Metal surfaces are seldom clean and may be covered with layers of oxide, hydroxide, adsorbed and chemi-sorbed liquids or vapours, all of which prevent intimate contact extending over the area to be joined. Furthermore, metal surfaces are rarely flat when considered on an atomic scale. If it were possible to bring two perfectly clean and coplanar surfaces into intimate contact, the resultant joint would be at least as strong as the metal itself [5]. So in order to obtain maximum weld efficiency any form of surface contamination must be reduced to a minimum, while the area of contact (weld area) has to be made as large as possible. It is suggested that to evaluate various methods of preparing the surfaces for high quality cold welding one should use as a criterion the strength of specimen joints made under standardised welding conditions, but with different methods of preparing the mating surfaces like mechanical cleaning, heating, washing in pure solvents etc. [6].

Butt welding is the superior of the techniques used in cold welding; it fulfils most of the requirements of a perfect weld; namely, continuity, homogeneity, and properties closely allied to those of the parent metal.

In earlier applications of cold pressure butt welding the upset and radial displacement of the interfaces was made in a single step. Single upset welding is not normally used for welding butt joints in wires smaller than 3/16-inch in diameter [7]. A cross section of a single upset butt joint in type 1100 aluminum is shown in Fig. 2.1 [7]. This technique had several disadvantages: it was necessary to first square off the ends to be joined; the surfaces had to be kept free of contamination and the amount of material which projected from the gripping die was such that bending and lack of coaxiality could occur, spoiling the correct flow of metal [5].

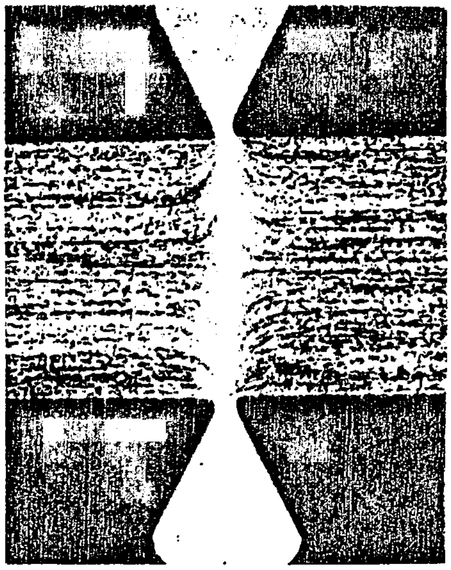


Fig. 2.1 Single upset cold welding in type 1100 aluminum wire [7]

Then came the system of butt welding developed by G.E.C. [6] which employs what is known as the 'multi upset principle', that is to say that when the material is inserted in the die, each time the machine is actuated the material is gripped by the die and fed forward. In this way, the two opposing faces as they are pushed against each other are streched and enlarged over their entire surfaces area, the oxide and other surface impurities are forced outwards from the core of the material and a bond is affected. Fig. 2.2 illustrates the various stages involved in making a multiple upset butt weld between strips [7]. A minimum of four upsets is recomended to ensure all impurities are squeezed out of the interfaces. The design and precision with which the die is manufactured and its partnership with expertly designed and crafted machines, ensure the reliability and integrity of each and every weld. The advantages of this type of welding are easily seen in practice; there is no preparation of the ends of the wire or rod prior to welding, the alignment of the two butt ends is automatic as the material is placed in the die, there is no heat setting to be arrived at, no gap setting to be made, this is built into the die and no spring pressure to be set. Any one of these things incorrectly set on a resistance butt welder would result in a weld failure [2]. A modern pressure welding machine can be seen in Fig. 2.3.

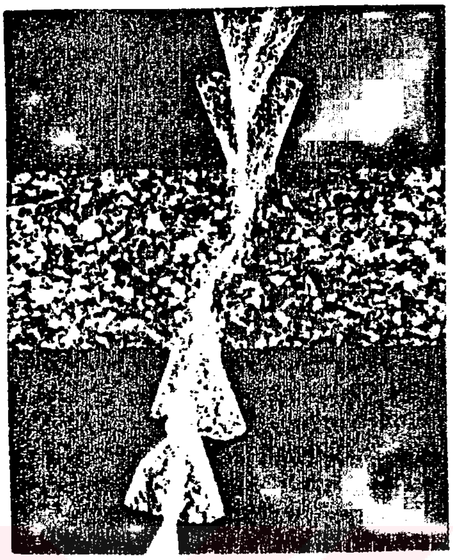
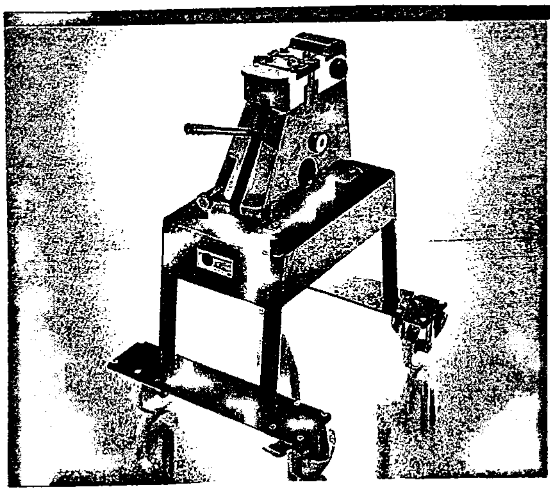


Fig. 2.2 Multiple upset cold welding in type 1100 aluminum wire using an offset flash technique [7]



Operation:	Manual	
Capacities:	**Copper:**	
	1.00mm - 3.60mm	
	E.C.Aluminium:	
	1.00mm - 5.00mm	
Dimensions	length:	440mm
	width:	220mm
	height:	370mm
Nett Weight	32kg	
Gross Weight	40kg	

Fig. 2.3 Cold pressure welding machine for wire welding [2]

During welding operation, the parts must be positioned in the clamping dies with sufficient initial extension of each part between the dies to ensure adequate upset. However, extension of the parts should not be excessive to avoid bending of the parts. The upsetting force will cause the parts to bend or assume an S-shaped curve as shown in Fig. 2.4, if the initial die opening is too large. The ends can deflect and slide past one

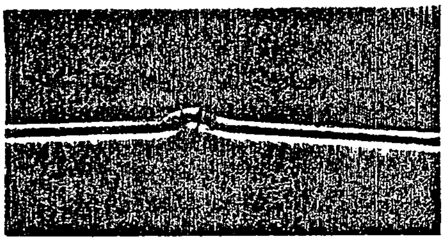


Fig. 2.4 Bending produced during upset form excessive projecting lengths [7]

another when force is applied if the projecting length of each part exceeds about twice the thickness or diameter of the parts. In other words, the initial opening between the dies should be no greater than four times the diameter or thickness of the parts. This distance is the maximum total upset that can be used to effect welding. The minimum upset distance varies with the alloy being joined.

The welding dies must firmly grip the parts to prevent slippage when upset force is applied. Any slippage will reduce the amount of upset. For a firm grip, the diemensions of the parts must be within close tolerance so that the dies can nearly close to hold each part securely. The allowable tolerance depends on;

i. The design of the die and die holder,

ii. The gripping surface finish

Deep knurling on the gripping surfaces will indent into the part. In most cases, the allowable tolerance for a round part is about 3 % of the diameter.

Somewhat wider tolerances are permissible for rectangular shaped parts because the dies usually bear on only two sides. The gap between the closed grips must, however be small to obtain uniform upsetting of metal. It shoul be no more than about 10% of the part thickness.

The application of upset force causes the metal between the dies to upset laterally as illustrated in Fig. 2.5. This lateral flow of metal

i. Breaks up the oxide film present on the abutting surfaces and carries most of it out the joint.

ii. Enables oxide-free metal on one side of the interface to achieve intimate contact with oxide-free metal on the other side.

iii. Provides the energy that enables the contacting surfaces to achieve a submicroscopic bond registry with one another.

Thus, all requirements needed to form a metal bond are fulfilled and a metallurgical union forms [7].

2.3. Weldable Metals

Most of the non-ferrous metals are cold weldable and while copper and aluminium are the most common, various alloys like Aldrey, Tripple E, Constantan, 70/30 brass, zinc, silver and silver alloys, nickel, gold and many others have good cold weldability. Plated wires such as tinned copper, silver plated, nickel plated can all be welded to themselves or to plain copper. This brings us to a very interesting phenomena, that of welding two dissimilar metals together such as copper to aluminium [2].

Cold welding may be used to butt weld aluminium and copper wires ranging from 0,10 mm to 30 mm diameter.

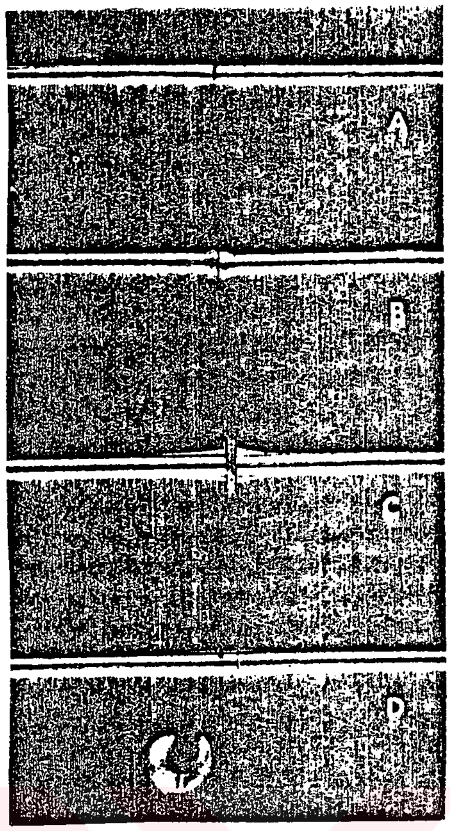


Fig. 2.5 Stages of upset during butt cold weld [2]

All the usual methods of joining these two materials together, resistance welding, friction welding or flame brazing, all result in a rapid breakdown of the joint, this breakdown or reaction in a copper/aluminium joint begins to take place as soon as the two metals are placed together. The problem is the oxides and the air space left between the interfaces during these methods of welding, not the dissimilarity between the metals themselves. However, with cold pressure welding these oxides and air spaces are squeezed out in the weld process and since no heat is applied only the metallurgical changes that operate at ambient temperatures occur.

Thus cold pressure welding provides the most satisfactory way of joining copper to aluminium without the formation of brittle inter-metallic compounds. In order words the quality is excellent it produces a worked structure as opposed to the cast structure obtained in fusion welding. For example, a layered structure forms at the interface in an aluminum – copper weldment at elevated temperatures as shown in Fig. 2.6. Furthermore, there is no heat affected zone with unsuitable properties [7].

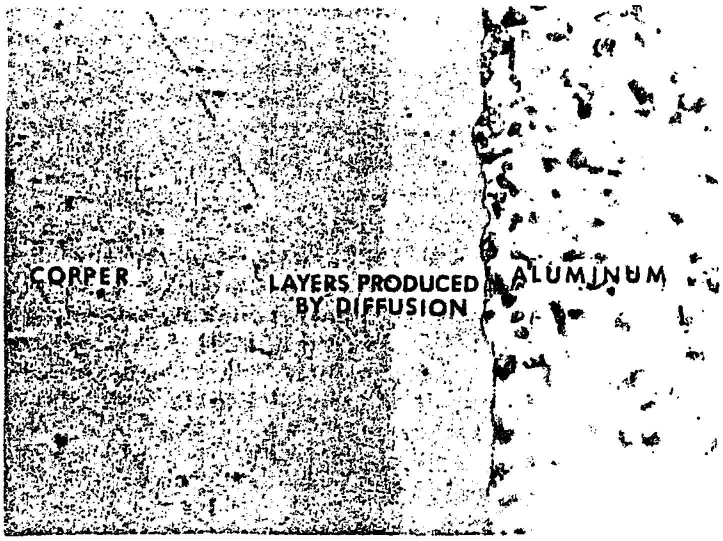


Fig. 2.6 Layered structure in an aluminum–copper weld after exposure at 500F for 60 days [7]

2.4. Equipment

A word about the important part the dies play in the cold butt weld process. Firstly they must grip the material firmly; to assist the grip of the die, the inside of the cavity is either etched with an electric pencil, or when the die is to be used for welding large sizes of aluminium, a screw thread is put in the cavity before the die is heat treated. Very important is the gap between the two faces or noses of the die. Too large and the material will just collapse or bend away. This dimension is taken care of during manufacture and cannot be changed. Lastly there is the offset of the die noses, this has the effect of making the weld look out of line around the circumference of the material. The purpose of the offset is to break the flash into two halves so that removel is easy otherwise the flash is likely to remain as a loose ring around the material and have to be cut off. The noses of the die also have to be sharp enough to virtually pinch off the flash around the weld thus ensuring that complete flash removel is a simple matter. The hardness and temper of the die is most important as well, in the early days of cold welding, die breakage was very common, long after a machine was designed to weld 8 mm copper rod there were problems in containing the necessary forces within a die of this size.

Dies can also be manufactured to suit various profiles as long as the profile allows the die to be made in two halves (necessary for the removal of the welded wire) and the cross sectional area is within the capasity of the machine.

It is also possible to weld two different diameters together. Generally the larger diameter should not be more than 30% greater than the smaller. In practise, if the copper is considerably smaller in diameter to the aluminium, the copper will merely embed itself into the aluminium and no weld is achieved.

The mechanical and electrical properties of butt welds are excellent in both similar and dissimilar metal welds.

Tests carried out to compare the mechanical properties of cold welds and resistance butt welds. In ½-hard commercially pure aluminium, showed that cold welds have weld efficiencies of 98-100%, whereas resistance butt welds have only a 50% efficiency [1].

CHAPTER 3. RESISTANCE WELDING

Resistance welding is a group of welding processes that produce coalescense of the faying surfaces with the heat obtained from resistance of the work to the flow of the welding current in a circuit of which the work is a part and by the application of pressure [8].

3.1 Background For Resistance Welding

Any discussion of resistance welding would be incomplete without mention of its inventor, Professor Elihu Thomson [9]. In the year 1877, when but twenty-four years of age, he was lecturing regularly at the Franklin Institute accident occurred which resulted in the discovery of resistance welding as it is known and practiced today.

For one of his experiments ProfessorThompson used a simple spark coil to step up battery current to a high-tension discharge for the purpose of charging condensers, or Leyden jars. It occurred to him that it would be of interest not only to his audience but also to himself to learn what would happen if the process were reserved, *i.e.*, to pass the charge from the jars through the "spark-coil" after charging them with a power-driven static machine. Current was passed through the "secondary winding," which was made of fine wire, while the "primary winding," made of heavier wire, had the terminals held together in rather light contact. The result was that this discharge of current through the fine wire of the secondary securely fused or "welded" the terminals of the primary circuit. Thus was resistance welding born and its basic principle has never been changed.

At the time Professor Thomson was almost wholly engaged in an exhaustive series of experiments in concention with apparatus for generating current for the arc lamp. This work required so much of his time that experiments in resistance welding were put aside for nearly nine years.

In the early part of 1886, continuing his experimentation, he perfected the process and applied for parents covering his invention: one a process parent and the other a welding-clamp parent. The original process parent application covered butt welding only and simply involved the joining of two pieces of metal of equal area.

Experimental work continued in butt welding, and then in the year 1898 here probably occurred the first authentic use of spot welding, after which the development of resistance welding steadily advanced and its application became more widely diversified.

The largest users of spot welding during these first years of its life were the kitchen-utensil manufacturers who used it for welding handles to pans instead of using the former method of riveting. The wagon-manufacturing industry also quickly adopted it when it was shown that production costs could be greatly reduced.

One of the things which undoubtedly retarded the development of the resistance-welding industry was that in the early days no welding apparatus was disposed of as an outright sale. Each welding unit was built for a specific operation and was installed only on a royalty basis. The user paid for the unit and there-after paid a specified amount for each weld made on the apparatus. This arrangement continued for a considerable length of time and was considered fair and equitable to both parties, because the new method of welding was far superior to any of the old methods of joining and was so much faster that it proved very profitable to all concerned.

In addition to this royalty arrangement the growth of the resistance-welding industry was also retarded by the fact that all manufacture of this type of equipment was controlled by one company. However, as he process became more extensively used, other companies entered into the manufacture of equipment, which in turn led to parent suits and countersuits, argued through the courts until 1916 when five companies were licensed to build spot-welding equipment. All these patent claims and licensing arguments eventually wore themselves out and today, with but few exceptions, resistance-welding manufacturers sell equipment on an outright basis and without royalties.

When spot welding came into general use, the natural reaction was to look for a process by which more than one spot weld could be made on a single piece of equipment. This led to the discovery that by attaching electodes to the opposite sides of the secondary of the transformer-placing them against two thicknesses of light-gauge material and backing it up with a copper conductor-two welds could be made simultaneously. This became known as series welding.

Then with the introduction of the all-steel body in the automotive industry, a multiple method of spot welding became a necessity and this led to the development of the hydromatic principle of welding. Later the ultraspeed method of welding was developed, and by 1939 experiments were being conducted to utilize a number of small welding transformers arranged in groups, making two to four welds from each transformer.

The Second World War interrupted these experiments, and little was done in the development of this type of welding until the latter part of 1945. However, by early 1946 these experiments became a reality and now the welding industry recognizes the multiple-transformer system as the most efficient known method of producing multiple spot welds. Great strides have also been taken in the development of welding aluminum and aluminum alloys as well as in the use of stored-energy types of welding equipment.

Thus it will be seen that though discovery of resistance welding occurred in 1877, no really substantial progress took place much bafore 1930, and the most ambitious strides have been made since the ending of the Second World War.

The future holds promise of great advancement for the industry and in the national economy, through increasing realization that, working as a composite team, desinging, manufacturing, tooling and welding engineers can substantially lower production costs of many, many metal-made products [9].

3.2. Principle of Operation

The resistance welding processes differ from arc welding in that pressure is used but filler metal or fluxes are not. Four factors are involved in making a resistance weld. They are;

i. The amount of current that passes through the work,
ii. The pressure that the electrodes transfer to the work,
iii. The time the current flows through the work,
iv. The area of the electrode tip in contact with the work.

Heat is generated by the passage of electrical current through a resistance circuit. The maximum amount of heat is generated at the point of maximum resistance, which is at the surface between the parts being joined. The high current, up to 100000 A at low voltage, generates sufficient heat at this resistance point so that the metal reaches a plastic state. The force applied before, during, and after the current flow forges the heated parts together so that coalescence will occur. Pressure is required throughout the entire welding cycle to assure a continuous electrical circuit. The amount of current employed and the time period are related to the heat input required to overcome heat losses and raise the temperature of the metal to the welding temperature [8].

Heat is also generated at the contact between the welding electrodes and the work. This amonut of heat generated is lower since the resistance between high-conductivity electrode material and the work is less than that between the two workpieces. In most applications the electrodes are water cooled to minimize the heat generated [8].

Resistance welds are made very quickly; however, each process has its own time cycle. Resistance welding operations are automatic. Good-quality welds depends on the prope set up and adjustment of the equipment and adherence to weld schedules. The position of making resistance welds is not a factor, particularly when welding thinner materials [8].

It is possible to weld practically an unlimited number of metals an decombinations of metals by one or more of the resistance-welding processes. Some typical welds are illustrated in Fig. 3.1. Although certain difficulties are encountered in welding some combinations because of great differences in metallurgical resistance to jointure temperature, plastic temperature ranges, etc., the extensive field open in practical metal combinations for resistance welding is starling [9].

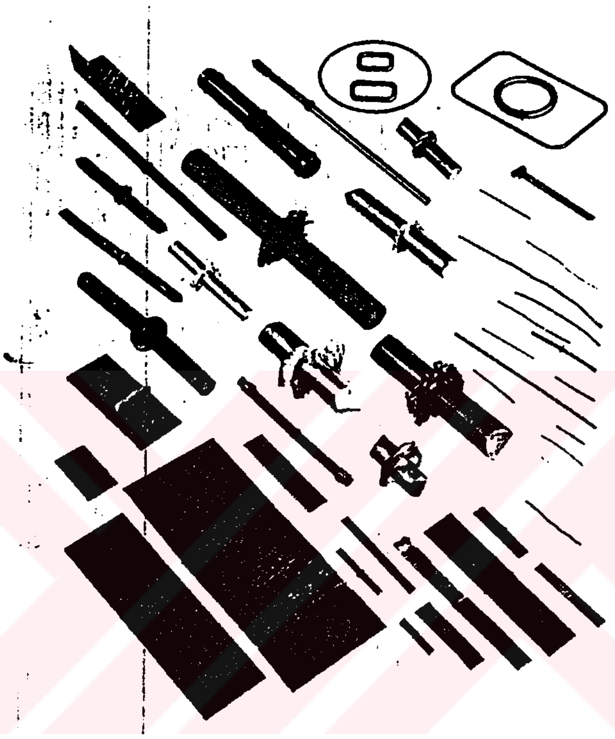


Fig. 3.1 Typical welds of various materials [9]

Resistance welding is widely used by the mass-production industries, where production runs and consistent conditions are maintained. Welding is performed with operators who normally load and unload the welding machine and push the switch to initiate the weld operation. The automotive industry is the major user followed by the appliance industry. It is used by many industries manufacturing a variety of products made of thinner-gauge metals and for manufacturing pipe, tubing, and smaller structural sections. Resistance welding has the advantage of producing a high volume of work at high speeds that are reproducible with high quality [8].

There are four major classifications, according to process, of resistence welds. They are spot, seam, projection, and butt welds of either the upset-butt or flsh-butt types. In this study we will be interested in Resistance Butt Welding.

3.3. Resistance Butt Welding

Resistance butt welding is a method of joining in which the heat necessary for fusion is generated by resistance of the stock to passage of an electrical current. Pressure is applied before heating starts and is maintained throughout the hetaing and fusion period [10].

Flash butt welds are made on a welding machine having one stationary platen and one movable platen on which are mounted the flash-welding dies or clamps which securely hold the parts to be welded, while serving to conduct the current through the parts.This method has proven satisfactory in joining nonferrous materials in almost every commercially available form [9]. A resistance butt welding machine is given in Fig. 3.2 as an example [10].

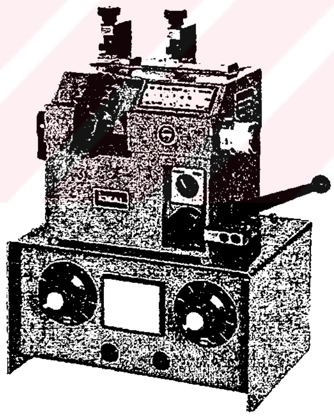


Fig. 3.2 Resistance butt welding machine for wire welding [11]

In the butt weld, while clamps apply pressure to the parts, welding current is passed from one piece into the other, thereby causing the ends of the two pieces to become heated. When the heat is sufficient to weld the two pieces together completely, current is shut off and a butt weld results. The passage of sufficient current through the two parts has resulted in a complete weld at the abutting ends.

Resistance butt welds are made from parent metals without filler materials; therefore, they can be made to have almost the same physical qualities. These welds, after passing through the drawing process, are difficult to locate and thus can be considered part of a continuous wire having full identy with the parent metal [10]. In Fig 3.3, the rod that is being resistance welded is shown.

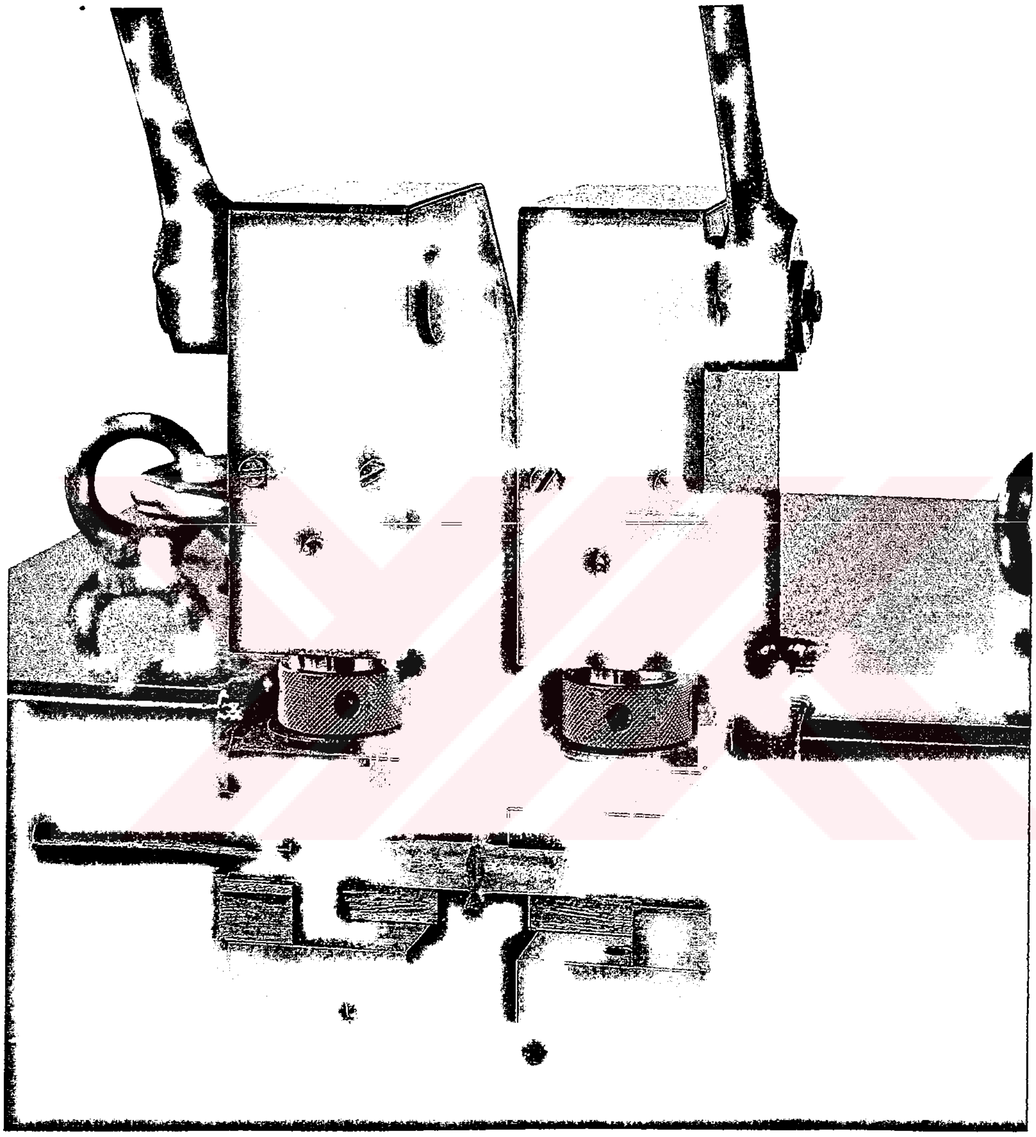


Fig. 3.3 Resistance butt welding of a rod [11]

The majority of butt welders presently used in the wire industry are for welding either prior to or during the drawing operation. Other manufacturers can, of course, use butt welding equipment for product manufacturing, for continuous processing and to provide customers with larger coil bundles. By simply changing the clamping members of the welder, many shaped materials of hexagonal, flat and square from may be welded [10].

3.3.1. Principles of Operation

In butt welding by electrical resistance methods, the feed stock is changed from assolid to a plastic state and back to a solid within a few cycles or seconds. This is much faster than the usual metallurgical practices. It causes a change in grain structure of the parent metal within the weld and the zones immediately adjancent to the bond. Consequently when welding hard-drawn nonferrous stock, annealing of the joined area is necessary to normalize the heat-affected welded section. It provides ductility for subsequent handling of stock and recudes strains incident to drawing oparetions such as severe twistting, bending or straightening procedures. Of course, by annealing, the tensile strength of welded wire or rod will be reduced at the annealed section, but tensile strength will be almost entirely regained during the subsequent drawing operation. The length of time the current is applied depends upon the type and size of the stock.

This operation may be performed manually by an operator observing the color of annealing heat on stock. If uniform control of annealing cycle is required to eliminate human errors of judgement, an automatic timer control may be used. For fine wire annealing, the wire is placed in a preheated trough of a heating element. The element has an indicating heat meter to identify the temperature of the element and consequently the annealing temperature of the wire. This is called annealing by heat transfer [10].

The quantity of heat required to raise a section of wire or rod to a specific welding temperature depends upon the size of the material, conductive heat losses through clamping electrodes, and the type of material being welded.

Time control and current termination for the welding process are accomplished by adjustable limit swicthes or electronic programming.

Welding pressure may be exerted by mechanical, pnuematic or hydrolic upset. Welding pressure applied through clamping jaws to the ends of rod or wire assists in welding by forcing the ends into intimate contact and maintaining constant pressure during the welding cycle. This allows the stock itself, to a great excent, to control forging action and the fusion point [10].

Good maintenance procedures will both increase the operating life of a machine and improve the quality of the finished product. While in specific practice the operator should follow the instructions provided by the manufacturer.

3.3.2. Weldable Metals

Almost all types of steels can be successfully flash-butt-welded, and most of the combinations, such as high-speed tool steel and low-carbon steel, are satisfactorily flash-butt-welded even though it is often necessary to employ special procedures to equalize the differences in hardness, fusion temperature, electrical and thermal conductivity, physical geometry, and crack sensitivity [9].

Most of the nonferrous metals, such as copper and coper alloys, can be flash-welded in condensed sections-tubings, rods, sheets, etc.-as long as a very short flashing period is used, together with a very quick push up as soon as the abutting ends become molten. This is owing to the lower range of plastic and fusion temperatures of copper as compared with steel.

Brass and aluminum alloys such as 2S, 3S, 53S and 61S in thicknesses over 0.050 inch can also be flash-butt-welded [9].

Dissimilar combinations of nonferrous metals, such as aluminum to copper or copper to brass, can be widely employed. The stainless-steel alloys, the high-alloy steels, nickel and nickel alloys can be very satisfactorily flash-butt-welded as can types of coated or plated steels and in fact, even rare metals such as gold, platinum, silver as well as magnesium, beryllium, copper, bronze and many others [9].

The material will simply cover briefly the following groups which have been successfully resistance-welded;

- Low-carbon steels
- High-carbon and low-alloy steels

- Stainless and high-alloy steels
- Aluminum and aluminum allyos
- Copper and copper-based alloys
- Zinc die castings
- Lead alloys
- Magnesium alloys
- Nickel and nickel alloys
- Dissimilar and refractory metals

CHAPTER 4. EXPERIMENTAL STUDIES

4.1. Material and Welding Operations

The wires used in this study were 99,99% pure electrolytic copper. The samples, which were in the range of 1.6-3.6 mm. diameter, were supplied from AKSEKİ BAKIRCILIK A.Ş. Fig. 4.1 shows the process flow chart of copper wire production at AKSEKİ BAKIRCILIK A.Ş.

The wires were drawn from 8 mm diameter rod in the sequence of cold drawing and annealing stages. Annealing of the wires were achieved at;

500°C for 4:00 hours for 1,60 – 1,80 mm
530°C for 4:00 hours for 2,00 – 2,25 mm
550°C for 4:30 hours for 2,50 – 2,60 mm
580°C for 5:00 hours for 3,00 – 3,60 mm

These wires were welded by cold pressure and resistance welding techniques. Cold pressure welding was achieved at SARKUYSAN A.Ş. with a M101 P.W.M. cold pressure welding machine. Resistance welding was done at AKSEKİ BAKIRCILIK A.Ş. with a DSH 070 IDEAL resistance butt welding machine.

4.2. Tensile Tests

Non welded, resistance welded and cold pressure welded wires were subjected to tensile test at SARKUYSAN A.Ş. Tensile tests were carried out on ZWICK Z010 Tensile

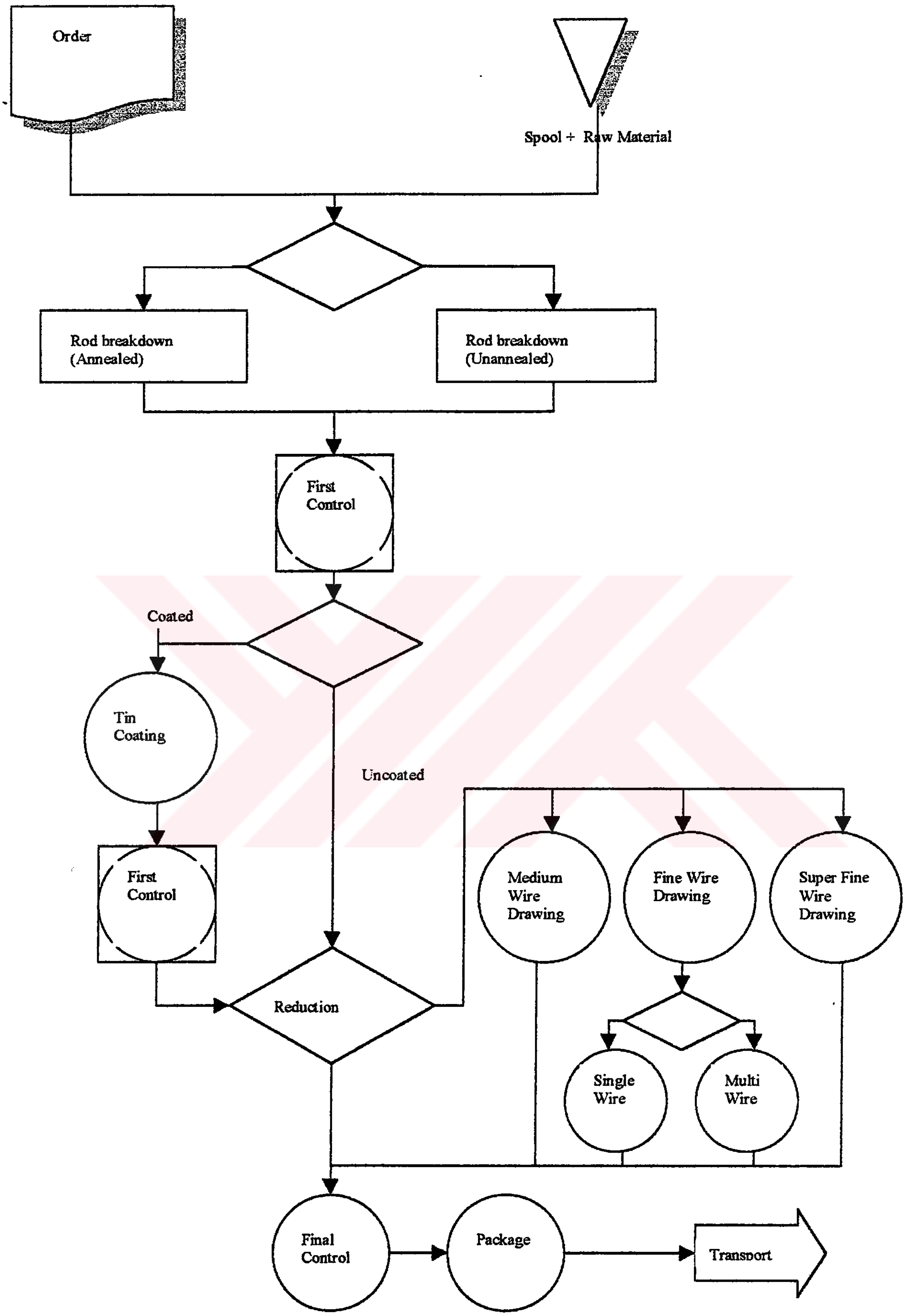


Fig. 4.1 The process flow chart of copper wire production at AKSEKİ BAKIRCILIK A.Ş.

Testing Machine with a cross head speed of 100 mm/minute. The gauge length of the samples were taken as 250 mm.

4.3. Microstructural Examinations

The microstructures of the welded wires were examined by optical microscope after polishing and etching the metallographic samples by standard manner. After polishing by diamond powders, the specimens were etched with a solution of 5 g $FeCl_3$ + 95 ml alcohol + 2 mg HCl.

4.4. Hardness Tests

Micro hardness measurements were carried out on metallographic samples. 100 gr. of test load were applied by a Vickers indenter. Hardness measurements were done around weld regions to determine the hardness distribution.

CHAPTER 5. RESULTS AND DISCUSSION

5.1. Tensile Tests

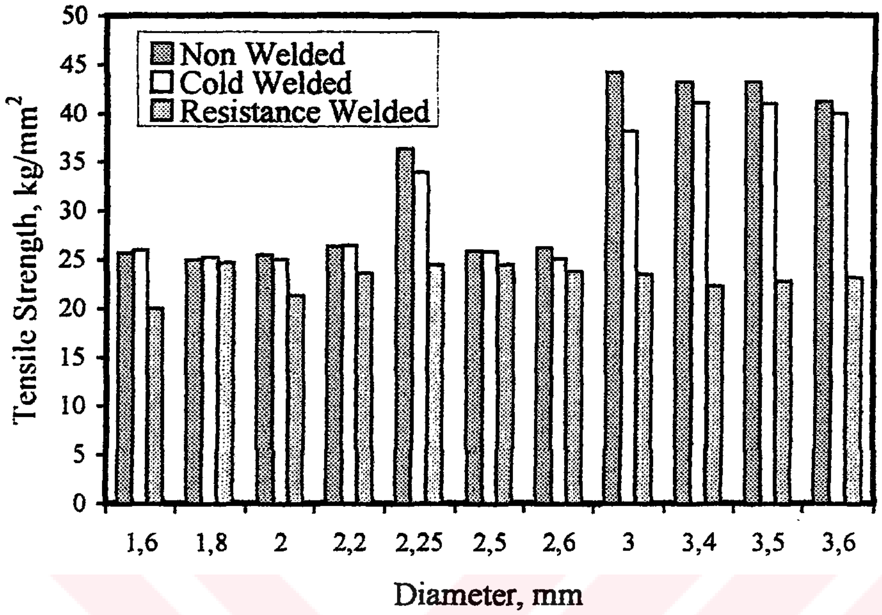
Ultimate tensile strength and elongation at fracture values of the investigated copper wires are given in Fig. 5.1. These results are the average values of the two tests for each condition. The results of tensile tests shown in Fig. 5.1 indicate that;

i. In the non-welded condition; the low values of ultimate tensile strength is due to the annealing heat treatment applied to the wires after cold drawing operations. Thus, in this study copper wires were examined in as-drawn (dia: 3.6 mm, 3.5 mm, 3.4 mm, 3 mm and 2.25 mm) and as-annealed (dia: 2.6 mm, 2.5 mm, 2.0 mm, 1.8 mm and 1.6 mm) conditions.

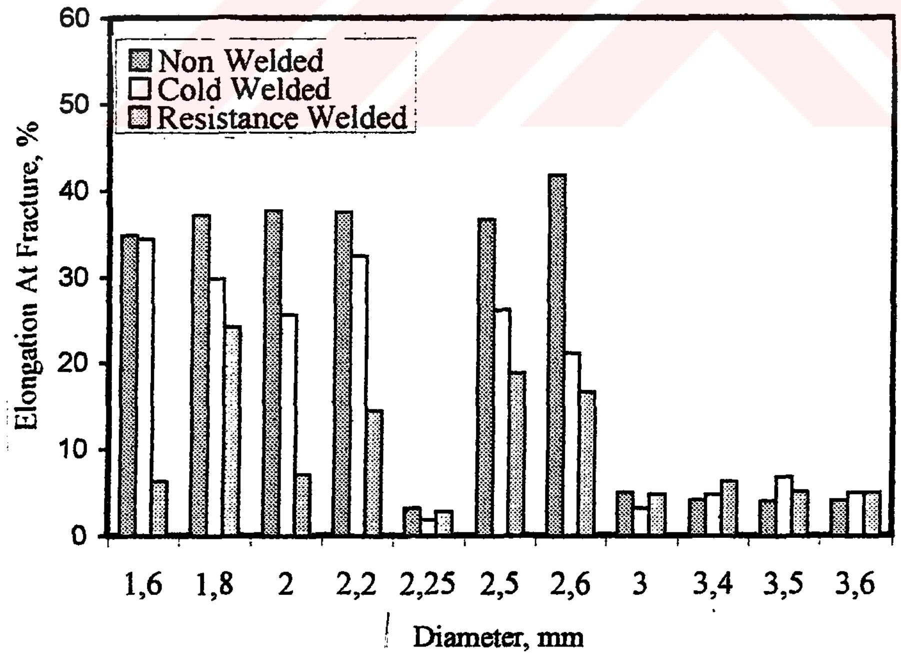
ii. The mechanical properties of the cold welded wires are almost similar to the non welded wires. During the tensile test, all the cold welded wires have been fractured from the outside of the welded area.

iii. Some of the resistance welded wires exhibited almost similar strength to the non welded wires and cold welded wires. However some of them exhibited extremely low strength and ductility values and fractured from the weld region. The mechanical behaviours of the wires which were not fractured from the weld region are almost same with that of the cold pressure welded and non-welded wires.

iv. In the present study, 11 wires with different diameters were tested. All of the cold pressure welded wires fractured from outside of weld region. However six of the resistance welded wires were fractured from weld region. These test results


Non Welded
Cold Welded
Resistance Welded
Tensile Strength, kg/mm^2
0
5
10
15
20
25
30
35
40
45
50
1,6
1,8
2
2,2
2,25
2,5
2,6
3
3,4
3,5
3,6
Diameter, mm

(a)


Non Welded
Cold Welded
Resistance Welded
Elongation At Fracture, %
0
10
20
30
40
50
60
1,6
1,8
2
2,2
2,25
2,5
2,6
3
3,4
3,5
3,6
Diameter, mm

(b)

Diameter (mm)	Fracture Zone	
	Cold Welded	Resistance Welded
1,60	BM*	WR**
1,80	BM	BM
2,00	BM	BM
2,20	BM	BM
2,25	BM	WR
2,50	BM	BM
2,60	BM	BM
3,00	BM	WR
3,40	BM	WR
3,50	BM	WR
3,60	BM	WR

*BM Base Metal **WR Welding Region

(c)

Fig. 5.1 The results of tensile tests of non-welded, cold pressure welded and resistance welded wires (a) ultimate tensile strength values (b) elongation at fracture values and (c) fracture region of the welded wires

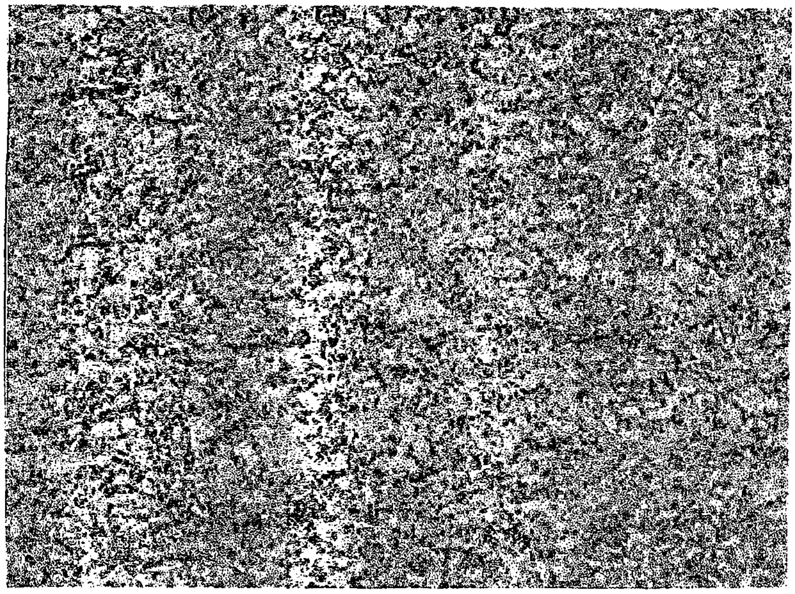
showed that the efficiencies of cold pressure welding and resistance welding are 100 % and 45 %, respectively.

5.2. Microstructural Examination

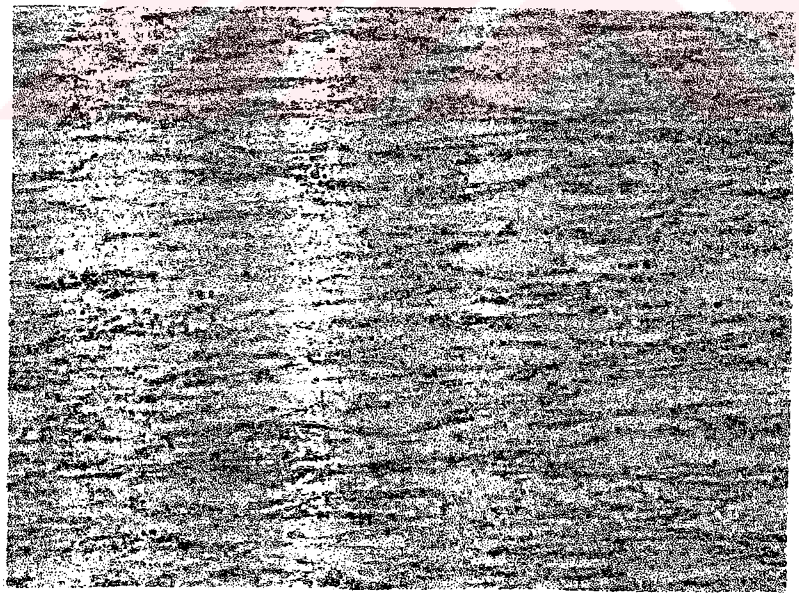
The microstructures of the base metals and weld regions of resistance and cold pressure welded wires are given in Fig. 5.2-5.4 respectively.

The following results can be withdrawn from the metallografic examinations;

i. The microstructurers of the 1,60 mm and 3,60 mm diameter wires are different (Fig. 5.2). 3,60 mm diameter wire has characteristic cold drawn microstructure



(a)

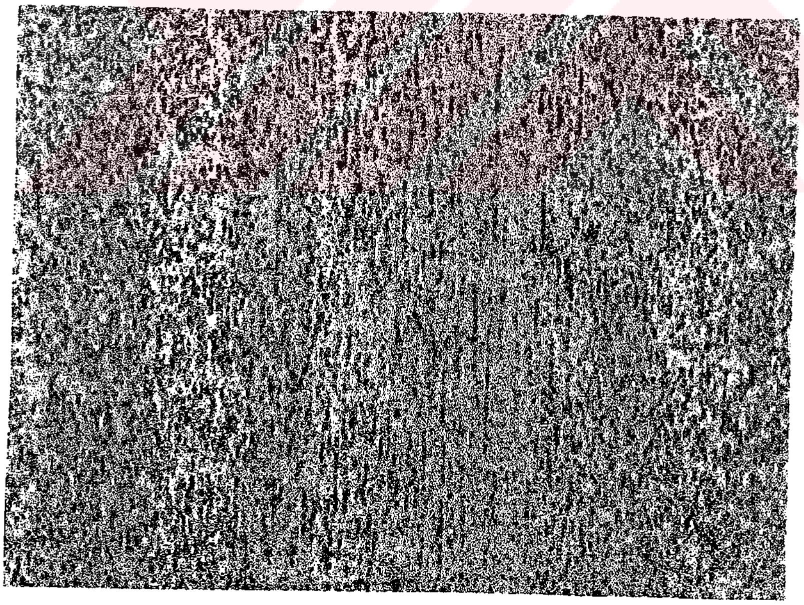


(b)

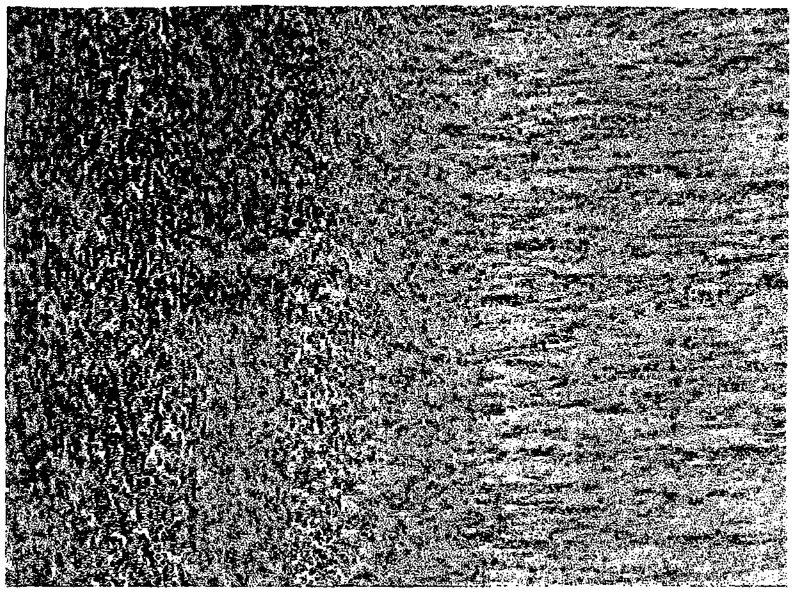
Fig. 5.2 Microstructures of the base metals (a) ∅ 1,60 mm (b) ∅ 3,60 mm

(Fig. 5.2b). On the other hand Fig. 5.2a indicates that 1,6 mm diameter wire was subjected to annealing treatment after drawing.

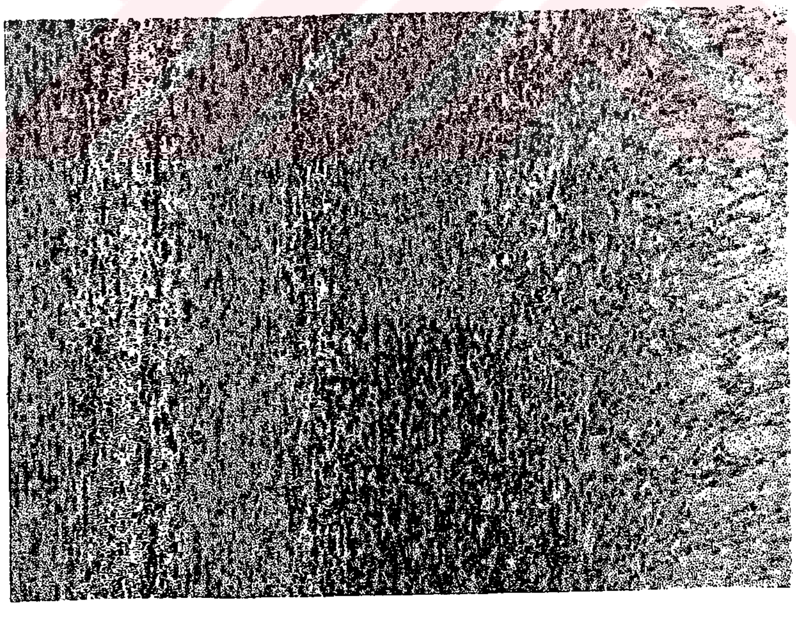
ii. It was observed that, in cold pressure welded wires, the weld region is subject to heavy plastic deformation, and there is an outward material flow due to the pressure applied . The microstructure of the cold welded wires exhibited that in butt joints, the lateral flow of metal between the dies during upset produces a cross-grained structure adjacent to the interface of the weld. This cross-grained material is essentially a narrow transverse section in the weld (Fig. 5.3a and 5.3c). In Fig. 5.3b the transection can be seen from the base metal through welding region clearly.



(a)



(b)

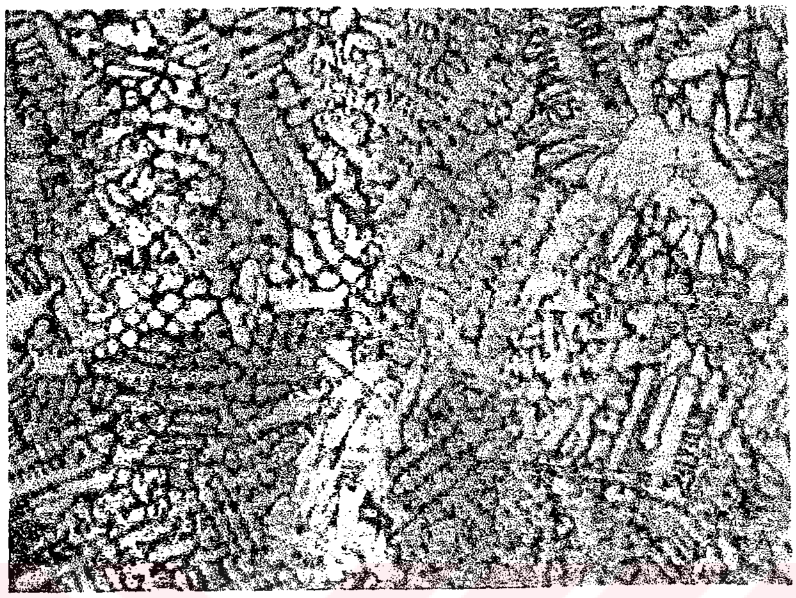


(c)

Fig. 5.3 Weld region microstructures of cold pressure welded wires (a) ∅ 1,60 mm (b) ∅ 3,40 mm (c) ∅ 3,60 mm .

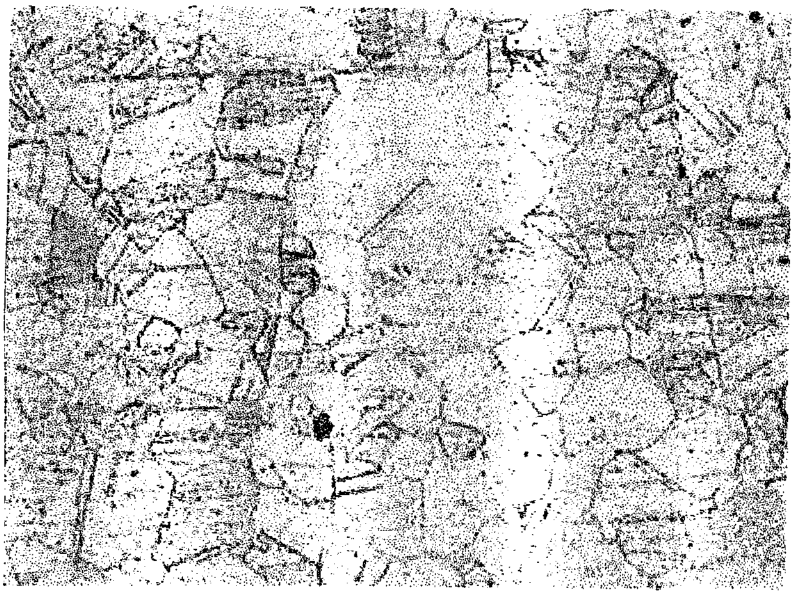
iii. Welding region of the resistance welded wires exhibited equiaxed grain structure. Thus, recrystallization process had taken place during welding. However, high welding temperature caused grain growth (Fig. 5.4a, 5.4c and 5.4d). Overheating caused melting in the weld region which resulted with a dentritic microstructure (Fig. 5.4b)

(a)



(b)

(c)



(d)

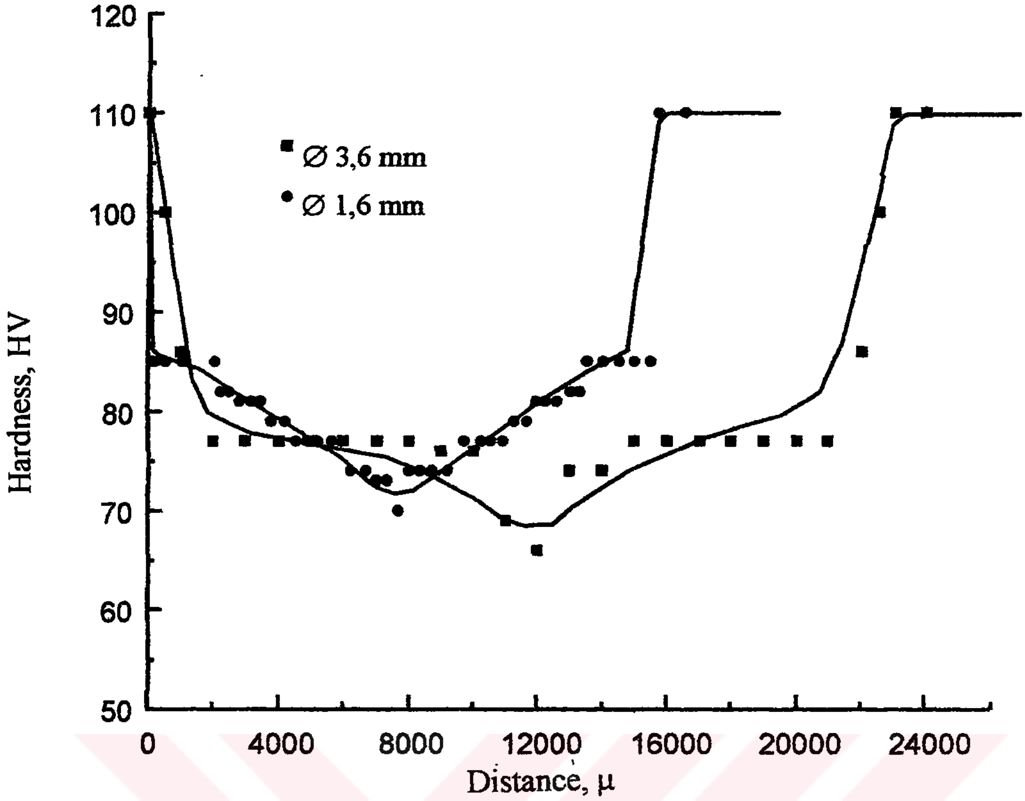
Fig. 5.4 Microstructures of resistance welded wires (a) ∅ 1,60 mm (b) ∅ 2,20 mm (c) ∅ 2,50 mm (d) ∅ 3,60 mm .

5.3. Hardness Tests

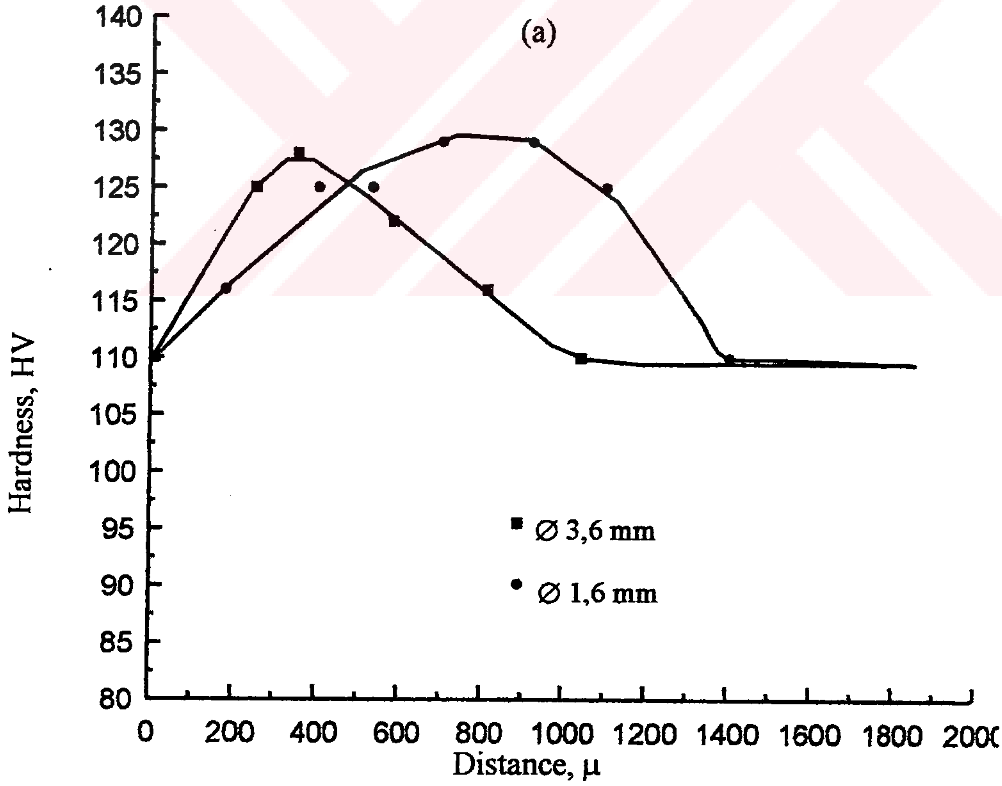
The distribution of hardness around the weld region of resistance and cold pressure welded copper wires are shown in Fig. 5.5. Hardness measurements at the weld region of resistance welded and cold pressure welded wires revealed that;

i. The hardness of the weld region of the resistance welded wires is lower than base metal (Fig. 5.5a). This result is also in accordance with the microstructure shown in Fig. 5.4a and 5.4b. The recrystallized equiaxed grains are present in the weld region of resistance welded wires. Thus, recyrstallization process had taken place during the operation.

ii. The hardness of the weld region is higher than that of base metal (Fig. 5.5b). This result is also in accordance with microstructural examinations. The flowlines in the microstructure indicate that there is an excessive strain hardening in the welded area (Fig. 5.3a and 5.3b).



(a)



(b)

Fig. 5.5 The Distribution of Hardness Around The Weld Region of Resistance and Cold Welded Copper Wires

iii. The size of weld zone depends both on welding method and diameter of the wire. It is obvious from Table 1 that, the size of weld region is about 1/10 of resistance welded wires, in cold pressure welded wires.

Table 5.1 The length of weld region after resistance and cold pressure welding

	Wire Diameter			
	1,6 mm		3,6 mm	
Wire Type	Resistance Welded	Cold Pressure Welded	Resistance Welded	Cold Welded
Weld Zone (mm)	15	1,4	24	1

5.4. Economic Evaluation

In previous sections, technologically comparison has been made between cold pressure and resistance welding techniques for copper wires in the diameter range of 1,6 mm – 3,6 mm. Table 2 compares to investment cost of the cold pressure welding and resistance welding machines which used for investigated wire diameter range.

Cold pressure welding machine is more expensive than resistance welding machine. Also, as mentioned in Chapter 2.4. the dies of the cold pressure welding machines have special importance in welding quality and are specific for each wire diameter. On the other hand periodical renewal of the cold pressure welding machines dies is also necessary. However the dies of the resistance welding machines are used for a wide range of wire diameter. Therefore the cost of the dies also be added to the investment cost.

According to Table 2 total investment cost of the pressure welding machine is about 50 % higher than resistance welding machine.

Table 5.2 First investment costs of P.W.M. M101 Cold Pressure Welding Machine and IDEAL DSH 070 Resistance Butt Welding Machine

	COLD WELDING	RESISTANCE WELDING
Diameter Range	1,00 – 3,60 mm	1,00 – 4,00 mm
Machine Cost	5.550,00 DM	5.270,00 DM
Die Number	6	-
Die Cost	6 x 555,00 = 3.330,00 DM	-
Total Cost	8.880,00 DM	5.270,00 DM

5.5. Discussion

Tensile test results show that cold pressure welded copper wires exhibit the same strength and ductility properties with that of the base metal, while resistance welded wires seldomly exhibit such behaviour. In the investigated wire diameter range, (1,6 mm to 3,6 mm), the weld efficiency is found as 100 % and 45 % for cold pressure welding and resistance welding respectively.

The weld region is very narrow and harder than base metal in cold pressure welded wires. The length of this area is at least ten times greater in resistance welded wires. Weld region provides a perfect continuation of the base metal in cold welded wires. Coarse grains and dendritic microstructure are present in weld region of resistance welded wires which is softer than base metal.

Cold welding technique, which achieves excellent welding, has some handicaps in terms of economy. Initial investment cost of cold welding machine is about 50 % higher than resistance welding machine. Also, the dies of cold pressure welding machines are subjected to wear during service condition and requires periodical renewal.

Reliability of the resistance welding process is somewhat lower than the cold welding process, due to being dependent on the operator. In a specific practice the operator should follow the instructions to achieve the best weld quality. For this reason, wire manufacturers should choose cold welding equipment despite its higher cost.

CHAPTER 6. CONCLUSION

The following conclusion can be withdrawn from the comparison of cold pressure welding and resistance welding techniques for copper wire industry;

1. Resistance welding yields a wider welding region than cold welding. Recyrstallization and grain growth occur in the welding region of the resistance welded wire. Overheating causes a decrease in the strength and ductility. The weld region of the cold pressure welded wire has a cross-grained structure which causes the hardness of the welding region to increase. The welding region of the cold welded wires are narrow and continuation of the base metal.

2. Cold welding machine has a greater first investment cost than the resistance welding machine, and the obligation to renew dies periodically increases the total cost of the machine, which appears to be the only shortcoming of the cold welding machines. Since the quality of resistance welding depends mainly on the operator, the reliability of the resistance welding process is lower than the cold welding process.

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