

POLİETİLEN KATKILI POLİPROPİLEN BORULARIN
MEKANİK ÖZELLİKLERİNİN İNCELEMESİ

İ.T.Ü MERKEZ KÜTÜPHANESİ

Demirbaş No:

Küt. Giriş No :

YÜKSEK LİSANS TEZİ

Enise Selcen UYGUR

(515011009)

FBE
U2 88
UYG

Tezin Enstitüye Verildiği Tarih : 5 Mayıs 2003

Tezin Savunulduğu Tarih : 30 Mayıs 2003

Tez Danışmanı : Prof. Dr. Ayşen ÖNEN

Diğer Jüri Üyeleri Prof.Dr. İ. Ersin SERHATLI (İ.T.Ü.)

Doç.Dr. Yüksel GÜVENİLİR (İ.T.Ü.)

Ayşen
Serhatlı
Güvenilir

MAYIS 2003

ACKNOWLEDGEMENTS

I am primarily grateful to my thesis supervisor, Prof. Dr. Ayşen Önen, for her continuous encouragement and helpful suggestions.

INVESTIGATION ON MECHANICAL PROPERTIES OF
POLYETHYLENE BLENDED POLYPROPYLENE PIPES

I am also very thankful to my General Manager Dr. Samet Sametli for his guidance and understanding.

I wish to especially thank Quality Control Manager Dr. Mustafa Kaya for their patience and help during the testing stages of the project.

Sincerely thanks to Prof. Dr. İ. Ersin Serhatlı, Prof. Dr. Ali Şahin and Ali Şahin for their help during production stages and Dr. Mustafa Kaya for their patience and help during the testing stages of the project.

My appreciation is also extended to my friends, M. Anıl Taşdelen and Ahmet Meriç for their help and advice.

I am highly indebted to my family for their financial and moral support during all my educational life.

I.T.Ü MERKEZ KÜTÜPHANESİ
Doküman No: 96244
Küt. Giriş No :

M. Sc. Thesis by
Enise Selcen UYGUR
(515011009)

Date of Submission : 5 May 2003
Date of Defence Examination : 30 May 2003

Supervisor (Chairman): Prof. Dr. Ayşen ÖNEN
Members of the Examining Committee Prof. Dr. İ. Ersin SERHATLI (I.T.U.)
Assoc. Prof. Dr. Yüksel GÜVENİLİR (I.T.U.)

(Signatures)

May 2003



ACKNOWLEDGEMENTS

I am primarily grateful to my thesis supervisor, Prof. Dr. Ayşen Önen, for her continuous encouragements and helpful suggestions.

I am deeply indebted to my company, Novaplast Co. Ltd., where this study was carried out.

I am also very thankful to my General Manager Dr. Samet Samedi for his guidance and understanding.

I wish to especially thank Quality Control Manager, Devrim Sezen, for his recommendations and encouragement during all stages of my study.

Sincerely thanks to Plant Manager, M.Ali Şeker, Adnan Geçir, and Ali Şanlı for their help during production stages; and Murat İntepe, Gürsel Kaya for their patience and help during the testing stages of my study.

My appreciation is also extended to my friends, M. Atilla Taşdelen and Ahmet Meriç for their help and advices.

I am lastly indebted to my family for their encouragement, patience, financial and moral support during all my education life.

May 2003

Enise Selcen UYGUR

TABLE of CONTENTS

ACKNOWLEDGEMENTS	ii
LIST of ABBREVIATIONS	vi
LIST of TABLES	vii
LIST of FIGURES	viii
LIST of SYMBOLS	x
SUMMARY	xi
ÖZET	xii
 1. INTRODUCTION	 1
 2. THEORETICAL PART	 3
2.1 Polypropylene Random Copolymers	3
2.1.1 Chemistry	4
2.1.2 Manufacture	5
2.1.3 Properties	6
2.1.3.1 Physical Properties	6
2.1.3.2 Chemical Resistance	6
2.1.3.3 Barrier properties	6
2.1.3.4 Electrical Properties	7
2.1.4 Applications	7
2.2 PP-RC Pipes	7
2.3 Low Density Polyethylene	9
2.3.1 Manufacturing	11
2.3.1.1 Autoclave Reactors	11
2.3.1.2 Tubular Reactors	12
2.3.2 Properties	12
2.3.2.1 Crystallinity and Transition Temperatures	12
2.3.2.2 Physical Properties	12
2.3.2.3 Chemical Properties	12
2.3.2.4 Electrical Properties	13
2.3.2.5 Rheological Properties	13
2.3.3 Applications	14
2.4 Polymer Blends	14
2.5 Polymer Processing	15
2.6 Extrusion	16

2.6.1 Basic Extruder Types	18
2.6.2 Single-Screw Processing	20
2.6.3 Feeding and Solids Conveying	22
2.6.4 Melting	24
2.6.5 Melt Pumping and Metering	26
2.6.6 Design of Single-Screw Extruders	26
2.6.7 Heating and Cooling	28
2.6.8 Dies and Auxiliary Equipment	29
2.6.8.1 Die Design	29
2.6.8.2 Downstream Auxiliary Equipment	30
2.7 Pipe Extrusion	31
2.7.1 Raw Materials Handling	32
2.7.2 Drying	33
2.7.3 Extrusion Principles	33
2.7.4 Pipe Extruders	33
2.7.4.1 Breaker Plate/Screen Pack	34
2.7.4.2 Die Design	34
2.7.5 Pipe Sizing Operation	37
2.7.5.1 Internal Pressure Calibration	37
2.7.5.2 Vacuum Calibration	38
2.7.6 Cooling	39
2.7.7 Pullers	40
2.7.8 Cut-Off Units	41
2.7.9 Saw Equipment and Bundling	41
2.8 Testing	41
2.8.1 Workmanship, Finish and Appearance	42
2.8.2 Dimensions	43
2.8.3 Mechanical Properties	43
2.8.3.1 Impact Properties	43
2.8.4 Thermal Properties	49
2.8.4.1 Thermal Expansion	50
2.8.5 Material Characterization Tests	50
2.8.5.1 Melt Index Test	51
2.8.6 Burst Strength Test	54
2.8.6.1 Quick-burst Strength Test	54
2.8.6.2 Long-Term Burst Strength Test	55
2.8.6.3 Developing Long-Term Hydrostatic Design Stress Data and Pressure Rating	56
2.8.7 Quality Assurance	57
3. EXPERIMENTAL WORK	58
3.1 Materials and Chemicals	58
3.1.1 Polypropylene Random Copolymer (PP-RC) (Vestolen P 9421)	58
3.1.2 Low Density Polyethylene (LDPE) (PETKİM- G 03-5)	59
3.1.3 Ethyl Alcohol	59
3.2 Equipments	59

3.2.1 Extruder	59
3.2.2 Pendulum Impact Testing Machine	60
3.2.3 Cooler	60
3.2.4 Melt Flow Rate Apparatus	60
3.2.5 Oven	60
3.2.6 Hydraulic Burst Strength Tester	60
3.3 Sample Preparation and Testing	60
3.3.1 Pipe Extrusion	60
3.3.2 Melt Flow Rate (MFR)	61
3.3.3 Impact Strength Test	62
3.3.4 Burst Strength Test	63
3.3.5 Heat Reversion Test	64
3.4 A Word of Caution	64
4. RESULTS and DISCUSSION	66
4.1 Effects of Blend Composition on Extruder Performance	67
4.1.1 Die Pressure	67
4.1.2 Screw Torque	68
4.1.3 Mass Flow Rate	69
4.1.4 Puller Speed	71
4.2 Effects of Blend Composition on Mechanical Properties	72
4.2.1 Melt Flow Rate	73
4.2.2 Impact Strength	74
4.2.3 Quick-Burst Strength	75
4.2.4 Heat Reversion	76
5. CONCLUSION	78
REFERENCES	79
AUTOBIOGRAPHY	81

LIST of ABBREVIATIONS

PP	: Polypropylene
PE	: Polyethylene
PP-RC	: Polypropylene Random Copolymer
LDPE	: Low Density Polyethylene
HDPE	: High Density Polyethylene
LLDPE	: Linear Low Density Polyethylene
PVC	: Polyvinylchloride
L/D	: Barrel Length / Barrel Diameter Ratio
SDR	: Standard Dimension Ratio
QC	: Quality Control
MFR	: Melt Flow Rate
RT	: Room Temperature
ISO	: International Organization for Standardization
VDE	: Verband Deutscher Elektrotechniker
DIN	: Deutsches Institut für Normung
ASTM	: American Society for Testing and Materials

	Page No
Table 2.1. Propylene-Ethylene copolymerization	3
Table 2.2. MFR test conditions.....	52
Table 3.1. Mechanical and thermal properties of Polypropylene Random Copolymer	58
Table 3.2. LDPE specifications.....	59
Table 3.3. Specifications of extruder Weber NE 7.....	59
Table 3.4. Temperatures around the barrel.....	61
Table 3.5. Constant parameters during extrusion.....	61
Table 4.1. PP-RC/ LDPE blend compositions in extruded samples.....	66

LIST of FIGURES

	<u>Page No</u>
Figure 2.1 : Growth of PP-R vs. galvanized steel sanitary systems in Turkey.....	8
Figure 2.2 : Gain in market share of plastic systems in Germany.....	8
Figure 2.3 : Growth of plastic pipes for potable water systems- Europe 1992-2000.....	9
Figure 2.4 : A single screw extruder model.....	17
Figure 2.5 : Basic components of an extrusion line.....	18
Figure 2.6 : Different types of extruders	19
Figure 2.7 : Configurations of twin screws.....	19
Figure 2.8 : Typical Single-Stage Extruder.....	21
Figure 2.9 : A screw design with the standard nomenclature used to describe design features.....	22
Figure 2.10 : Idealized melting model.....	25
Figure 2.11 : Aerial view of typical conventional extrusion line.....	32
Figure 2.12 : Typical Resin Mixing Devices (a) Mixing Pins (b) Helical Mixer (c) Fluted Mixer.....	34
Figure 2.13 : Typical Resin Mixing Devices (a) Pipe die with spider for pipe dimensions up to 250 mm $\varnothing$ (b) Egan system (Reifenhäuser design) spiral melt distributor (c) Pipe die with breaker plate-type mandrel support.....	35
Figure 2.14 : Sizing Systems (a) Pressure sizing for small and medium pipe diameters (b) Vacuum tank sizing.....	39
Figure 2.15 : Pendulum impact tester.....	48
Figure 2.16 : A melt index apparatus.....	51
Figure 2.17 : A hydraulic burst-strength tester.....	54
Figure 3.1 : Pipe sections mentioned in DIN 8078.....	63
Figure 4.1 : Die pressure as a function of LDPE content in PP-RC/ LDPE blends.....	67
Figure 4.2 : Screw torque as a function of LDPE content in PP-RC/ LDPE blends.....	68
Figure 4.3 : Mass flow rate as a function of LDPE content in PP-RC & LDPE blends.....	69
Figure 4.4 : Mass flow rate as a function of die pressure.....	70
Figure 4.5 : Mass flow rate as a function of screw torque.....	70
Figure 4.6 : Puller speed as a function of LDPE content in PP-RC/ LDPE blends.....	70

	blends.....	71
Figure 4.7	: Mass flow rate as a function of puller speed.....	72
Figure 4.8	: Average MFR values of pipe samples as a function of LDPE content.....	74
Figure 4.9	: Impact strength as a function of LDPE content in PP-RC/LDPE blends.....	75
Figure 4.10	: Burst pressure as a function of LDPE content.....	76
Figure 4.11	: Heat reversion as a function of LDPE content.....	77

θ	: Test Temperature
m	: Average Mass
P_{nom}	: Nominal Load
t_{off}	: Cut-off time Interval
t_{ref}	: Reference Time
σ	: Hoop Stress
P	: Internal Pressure
D	: Average Outside Diameter
e	: Minimum Wall Thickness
$\bar{e}$	: Average Wall Thickness
d	: Average Inside Diameter
d_m	: Mean Diameter
d_o	: Pipe Outside Diameter
L_0	: Distance Between the Gauge Marks Before Thermal Treatment
L_1	: Specimen Length
L_2	: Length Required for Fixing the End Sealing Devices
L_3	: Distance Between the Gauge Marks After Thermal Treatment and Cooling

INVESTIGATION ON MECHANICAL PROPERTIES OF POLYETHYLENE LIST of SYMBOLS

Θ	: Test Temperature
m	: Average Mass
m_{nom}	: Nominal Load
t	: Cut-off time Interval
t_{ref}	: Reference Time
S	: Hoop Stress
P	: Internal Pressure
D	: Average Outside Diameter
s	: Minimum Wall Thickness
s_1	: Average Wall Thickness
d	: Average Inside Diameter
d_1	: Mean Diameter
d_2	: Pipe Outside Diameter
l_0	: Distance Between the Gauge Marks Before Thermal Treatment
l_1	: Specimen Length
l_5	: Length Required for Fixing the End Sealing Devices
l_{min}	: Distance Between the Gauge Marks After Thermal Treatment and Cooling

INVESTIGATION ON MECHANICAL PROPERTIES OF POLYETHYLENE BLENDED POLYPROPYLENE PIPES

SUMMARY

Polypropylene Random Copolymer (PP-RC) has become the most demanded raw material for sanitary installation systems with its high resistance to crack growth and high temperatures, long service life, low cost and safety for human contact (consumption with potable water) especially in the last 20 years. The installation systems that are made of this material have been rapidly replacing with the traditional metal sanitary installation systems and the big corrosion problems associated with this. Turkey, with an average of 50 million meters pipe production, is one of the pioneer countries in this evolution.

Low Density Polyethylene (LDPE) is also one of the raw materials used for its various features in pipe production like high impact strength, flexibility, and easy processability. In this study, in order to develop new applications for PP-RC piping systems by improving mainly the impact strength, LDPE compounded PP-RC pipes were prepared and all mechanical properties required for sanitary installation systems were observed.

In the first step, different compositions of PP-RC and LDPE blends were extruded as pipes and the performance of the extruder was examined during this process.

In the second step, the pipe specimens with different compositions were subjected to MFR (melt flow rate) test in accordance with ISO 1133; impact strength test according to DIN 8078 and DIN 51 222; and burst strength, heat reversion tests according to DIN 8078 to be able to make comparison between the mechanical properties of different pipe samples with different compositions.

POLİETİLEN KATKILI POLİPROPİLEN BORULARIN MEKANİK ÖZELLİKLERİNİN İNCELENMESİ

ÖZET

Polipropilen Random Kopolimerler (PP-RC), çatlamaya ve yüksek sıcaklıklara karşı direnci, uzun servis ömrü, düşük maliyet ve hijyenik özellikleriyle, soğuk ve sıcak su borularının imalatı için en uygun özelliklere sahip malzeme olup, özellikle son 20 yıldır sıhhi tesisat sistemlerinde en çok tercih edilen hammadde haline gelmiştir. Bu polimerlerle üretilen tesisat sistemleri, tüm dünyada, korozyon problemleri yaşanan geleneksel metal sıhhi tesisat sistemlerinin yerini hızla alırken, Türkiye de yılda ortalama 50 milyon metre boru üretimiyle, bu geçişte en çok payı olan ülkeler arasında yer almaktadır.

Alçak Yoğunluklu Polietilen (AYPE) de, yüksek darbe dayanımı, esneklik, ve kolay işlenebilirlik gibi özelliklerinden dolayı boru imalatında yaygın olarak kullanılan bir hammaddedir. Bu çalışmada PP-RC bazlı boru sistemlerinin özellikle darbe dayanımını arttırarak kullanım alanlarını genişletmek amacıyla, AYPE katkı PP-RC borular hazırlanmış ve sıhhi tesisat sistemleri için gerekli tüm mekanik özellikleri detaylı olarak incelenmiştir.

İlk aşamada değişik oranlarda PP-RC ve AYPE içeren polimer karışımları hazırlanarak ekstrüderde boru halinde getirilmiş ve bu işlem sırasında ekstrüder performansı incelenmiştir.

İkinci aşamada ise elde edilen farklı bileşimlerdeki boru numuneleri, ISO 1133' e göre MFR (Kütlesel Erime Akış Hızı); DIN 8078 ve DIN 51 222'e göre darbe dayanımı; ve DIN 8078' e göre patlatma basıncı ile termal çekme testlerine tabi

tutulup, mekanik ve termal özelliklerinin polimer bileşimine göre davranışı belirlenerek, bir karşılaştırma yapılmıştır.

1. GİRİŞ

For over half a century, polymers have played an increasing role in the global economy. In the past, polymers were considered as simple materials, but today they are regarded as one of the most important materials in the world. The development of polymers has been a continuous process, and it is expected that this process will continue in the future. The development of polymers has been a continuous process, and it is expected that this process will continue in the future. The development of polymers has been a continuous process, and it is expected that this process will continue in the future.

Polymers are materials that are made of long chains of repeating units. They are found in many forms, such as plastics, rubbers, and fibers. Polymers are used in many different ways, and they are becoming more and more important in our lives. The development of polymers has been a continuous process, and it is expected that this process will continue in the future. The development of polymers has been a continuous process, and it is expected that this process will continue in the future.

There are many different types of polymers, and each type has its own unique properties. Some polymers are very strong, while others are very soft. Some polymers are very durable, while others are very biodegradable. The development of polymers has been a continuous process, and it is expected that this process will continue in the future. The development of polymers has been a continuous process, and it is expected that this process will continue in the future.

1. INTRODUCTION

For over sixty years, polymers - commonly known as plastics - have played an increasing role in the global standard of living by providing new consumer and industrial markets with practical, modern, economic products in elegant designs that were not possible in earlier years. By the turn of the century, global thermoplastics consumption had reached 115 million tons per year, without counting the further large number of engineering and textile resins that are available. Without a doubt, the usefulness of polymers and plastics, and their profound impact on modern technology and way of life, are due just as much to the versatility and flexibility of the available shaping methods as to their inherent properties.

Polymer processing deals with the conversion of polymeric raw materials into finished products. The objective of this process is undoubtedly *shaping polymer products*. The field of polymer processing has been traditionally and consistently analyzed in terms of the prevailing processing methods, that is, extrusion, injection, molding, blow molding, calendaring, mixing and dispersion, rotational molding, and so on. These processes have been viewed as the "*unit operations*" of polymer processing [1].

Over 60% of the world's output of plastic is processed by extrusion. The products include tubing, pipes, profiles, film, sheet, monofilament for extrusion blow molding, and insulated wire for electrical use. These have one thing in common, which is that the extrusion process manufactures an endless product of constant cross-section that is cut, sawed, chopped, rolled, or otherwise reduced to a portable length. The function of the extruder is to convert solid feed stock into a homogenous melt and pump it through a die at a uniform rate. Following the die, a train of equipment handles the molten extrudate in order to ensure that it cools to precisely the right shape and with the required molecular orientation.

With the advent of science and technology, the concept of testing is an integral part of research and development, product design, and manufacturing. The manner in which we do things today is emphasized on automation, high production, and cost reduction. While designing a machine or a product, the first order of priority in most cases is safety and health. Manufacturers and suppliers are now required to meet a variety of standards and specifications [2].

A specification for a plastic material involves defining particular requirements in terms of density, tensile strength, thermal conductivity, and other related properties. The specification also relates standard test methods to be used to determine such properties. Thus, standard methods of test and evaluation commonly provide the bases of measurement required in the specification for needed or desired properties. The ultimate purpose of a standard is to develop a common language, so that there can be no confusion or communication problems among developers, designers, fabricators, end-users, and other concerned parties. The benefits of standards are innumerable. Standardization has provided the industry with benefits such as improved efficiency, mass production, superior quality goods through uniformity, and new challenges [2].

This study is on Polypropylene Random Copolymer (PP-RC) pipes. PP-RC has a long and successful tradition as a raw material for domestic hot and cold water piping applications. PP-RC offers resistance to high temperatures, easy processability, proprietary colors, weldability, no taste and odor influence, and high resistance to slow crack growth which is an important characteristic for the long-term performance under mechanical stress for plumbing and heating applications [3].

Polymer blending has become an important field in polymer research and development. The composition and the morphology of the blend determine the mechanical properties of the resulting polymer. In order to develop new applications for PP-RC piping systems by improving the mechanical properties, blends containing PP-RC and Low Density Polyethylene (LDPE) resins were compounded at different ratios and subsequently extruded as a pipe form. Once the product has been produced, it undergoes a series of quality control tests to ensure that it meets the minimum specifications as required by the appropriate standard.

2. THEORETICAL PART

2.1. Polypropylene Random Copolymers

Polypropylene random copolymers are a type of polypropylene in which the basic structure of the polymer chain has been modified by the incorporation of a different monomer molecule. Ethylene is the most common comonomer used. Table 2.1. shows the propylene-ethylene combinations most frequently used in practice [4]. This causes changes to the physical properties of the PP. In comparison with PP homopolymers, random copolymers exhibit improved optical properties (increased clarity and decreased haze), improved impact resistance, increased flexibility, and a decreased melting point, which also results in a lower heat-sealing temperature. At the same time they exhibit essentially the same chemical resistance, water vapor barrier properties, and organoleptic properties (low taste and odor contribution) as PP homopolymer.

Table 2.1. Propylene-Ethylene copolymerization

Monomer sequences	Products
PPPPPPPPPPPPPPPP	homopolymer polypropylene
PPPEPPPPPPPEPPPP	polypropylene randomly modified with ethylene
EPEPPEEPEPEPEPE	elastomer
EEEEPEPEPEEEEEEP	thermoplastic elastomer
EEEEEPPEEEEEPEEE	polyethylene randomly modified with propylene
EEEEEEEEEEEEEEEEEE	homopolymer polyethylene

P = propylene, E = ethylene

Random copolymer PPs were developed to combine improved clarity and impact strength, and are used in piping applications, blow molding, injection molding, and film and sheet extrusion applications. They are used in food packaging, medical packaging, and consumer products [5].

2.1.1. Chemistry

Random copolymer PP typically contains between 1 and 7 wt.-% of ethylene molecules and 99 to 93 wt.-% propylene molecules. The ethylene molecules are inserted randomly between the propylene molecules in the polymer chain. In such random or statistical copolymers the majority (usually 75%) of the ethylene is incorporated as single molecular insertions termed X_3 groups (these have three consecutive ethylene $[\text{CH}_2]$ molecules in sequence in the polymer chain). These also can be viewed as one ethylene molecule inserted between two propylene molecules.

About 25% of the ethylene is incorporated in multiple molecular insertions. These are called X_5 because there are five methylene groups in sequence (two ethylenes inserted together between two propylenes). It is difficult to distinguish between X_5 and higher groups (X_7 , X_9 , etc.). Because of this, the content of multiple ethylene insertions for X_5 and higher groups is usually reported as $>X_3\%$. The randomness ratio (X_3/X_5) also can be determined. A large percentage of $>X_3$ groups will significantly decrease the crystallinity of the resulting copolymer. This has important effects on the final properties of the random copolymer. Very high levels of ethylene in the copolymer have similar effects on the crystallinity of the polymer, as do high levels of atactic PP.

Random PP differs from homopolymer because the ethylene molecules randomly inserted into the polymer backbone hinder the crystal-type arrangement of the polymer molecules. This reduction in copolymer crystallinity is responsible for the modification of physical properties: random copolymers have reduced stiffness, higher impact resistance, and much better clarity than homopolymer PP. Ethylene copolymers also have lower melting temperatures which give them advantages in some applications.

Random copolymers also have higher levels of extractable materials and atactic PP, and polymer chains with much higher levels of ethylene (to 15wt. - %). These higher extractable levels occur to one degree or another with all commercial copolymer materials (depending on the polymerization process), and can cause problems in meeting food contact regulations for some applications [4, 5].

2.1.2 Manufacture

Ethylene/propylene random copolymers are produced by the simultaneous polymerisation of propylene and ethylene molecules in the same reactors used to produce homopolymer PP. Ethylene molecules are smaller than propylene molecules, and react faster (they are about ten times more reactive). This makes the catalyst less stereospecific but more active, which results in an increased production of atactic PP. To reduce such atactic production, the temperatures at which the reaction is carried out are reduced. This lowers the activity of the catalyst and so reduces the eventual atactic content, resulting in the production of a copolymer product with a better balance of properties.

Random copolymers with high levels of ethylene (>3%) are more difficult to handle in production. Polymerizing high ethylene copolymers in hexane diluents is more difficult because of the solubility in hexane of the secondary by-products of the reaction (atactic PP and copolymer with very high ethylene content). This also is true in bulk polymerization with liquid propylene, although the solubilities are lower. Thus, the hexane diluents process produces a large amount of by-product that must be separated in a hexane recycle stage, adding to the overall manufacturing cost. It does, however, result in cleaner polymer with lower levels of extractable components.

In a bulk process, these residues tend to stay in the polymer and cause handling problems with flake materials. Also, the final copolymer product tends to have higher residual extractable components. Secondary washing steps that use organic solvents can remove a large part of these residues, but this also serves to increase the overall cost of manufacturing the copolymers. Generally, random copolymer flakes are stickier because of these high level of by-product materials, and this problem becomes critical when ethylene levels are greater than 3.5 wt.-%.

Increased handling problems and lower reactor temperatures lead to lower production rates for random copolymers. Also, random copolymers usually are produced in much shorter runs. These factors contribute to the overall higher production cost for random copolymers compared to homopolymers, especially for the higher ethylene types.

Reduction of the copolymer's melting point is directly related to ethylene content. Thus, melting point values as low as 60°C. have been reported with copolymers with 7 wt.-% ethylene. The X_3 content has a greater effect on the copolymer melting point than the content of X_5 and higher sequences. It also depends on the catalyst itself and its ability to incorporate ethylene as X_3 sequences instead of as X_5 sequences [4].

2.1.3 Properties

2.1.3.1 Physical properties

Generally, random co-polymers are more flexible and less stiff than homopolymer PP. They have moderately better impact strength at temperatures down to 0°C, and they have limited utility down to -25°C. The molecular weight of the material has a greater effect on the stiffness for homopolymers than it does for copolymers [4, 5].

2.1.3.2 Chemical resistance

Random copolymers are highly resistant to attack by such chemicals as acids, alkalis, alcohols, low-boiling hydrocarbon solvents, and many inorganic chemicals. At room temperature, PP copolymers are essentially insoluble in most organic solvents. Also, they are not susceptible to environmental stress cracking failures when exposed to soaps, soap solutions, wetting agents, and alcohols, as are many other polymers. Contact with some chemicals-particularly liquid hydrocarbons, chlorinated organic compounds, and strong oxidizing acids-can cause surface crazing or swelling. Generally, non-polar compounds are absorbed more easily by PP than are polar chemicals [4, 5].

2.1.3.3 Barrier properties

Both homopolymer and copolymer PP have very low water vapor permeability. Resistance to permeation by gases is fair to moderate. These can be improved through orientation.

Stretch-blow molded PP bottles improve the moisture vapor resistance and the O_2 permeability.

2.1.3.4 Electrical properties

Generally, PP has excellent electrical properties-including high dielectric strength, low dielectric constant, and low dissipation factor. However, homopolymers are the usual choice for electrical applications [4, 5].

2.1.4 Applications

Random copolymer PP is mainly used in piping applications, film, blow molding, and injection molding applications where high clarity is a requirement. Because of their lower sealing initiation temperatures, higher-ethylene copolymers find wide use as special sealing layers in coextruded film structures.

2.2 PP-RC Pipes

PP-RC has a long and successful tradition as a material for domestic hot and cold water piping applications. PP-RC offers resistance to high temperatures, easy processability, proprietary colors, weldability, no taste and odor influence, and high resistance to slow crack growth which is an important characteristic for the long-term performance under mechanical stress for plumbing and heating applications [3].

The success has documented itself by the rapid world-wide market growth to today 60 ktons since the introduction of PP-RC systems for heating and plumbing in Germany more than 15 years ago. In countries with a large use of traditional galvanized steel pipes and the big corrosion problems associated with this, the substitution has been particularly dramatic. Turkey (see Figure 2.1), Italy, Argentina and eastern Europe are good examples of this where also the key value chain member, the plumbers, have appreciated maintaining the traditional straight pipe and welding installation techniques [6].

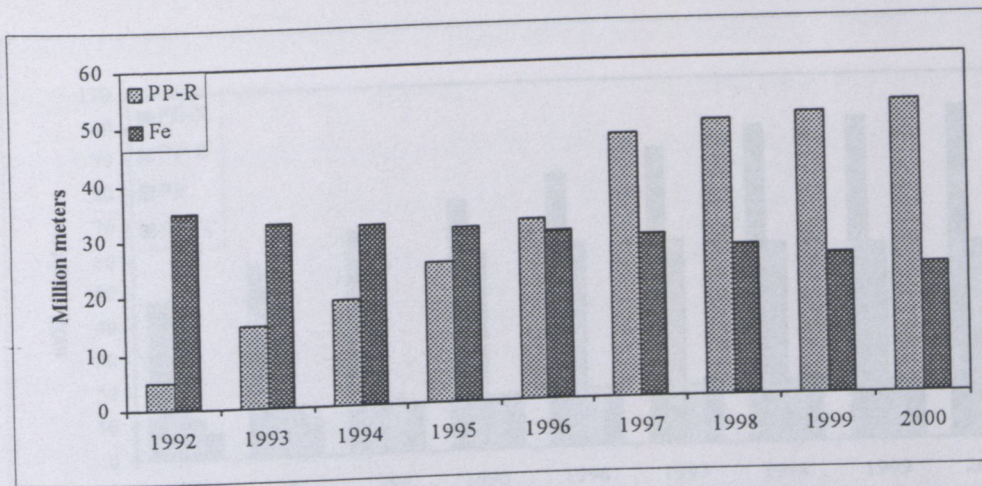


Figure 2.1 Growth of PP-R vs. galvanized steel sanitary systems in Turkey

But also copper pipes have been receiving some serious competition from plastics, especially in areas where the acidic water quality can quickly cause pitting corrosion and there is concern about the impact of copper emissions on the environmental office and health institute have jointly issued a health warning against using copper pipes for water with pH values below 7.3 as there is a risk of dangerously high copper concentrations [6]. Market growth trends eg. for Germany demonstrate the general recognition of plastic systems (see Figure 2.2). Growth of plastic pipes for potable water systems in Europe between 1992 and 2000 is also given in Figure 2.3

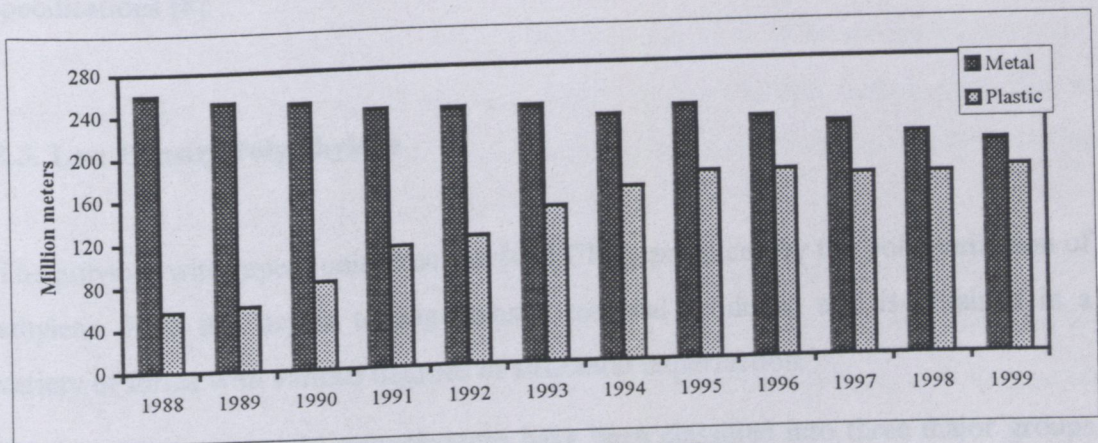


Figure 2.2 Gain in market share of plastic systems in Germany

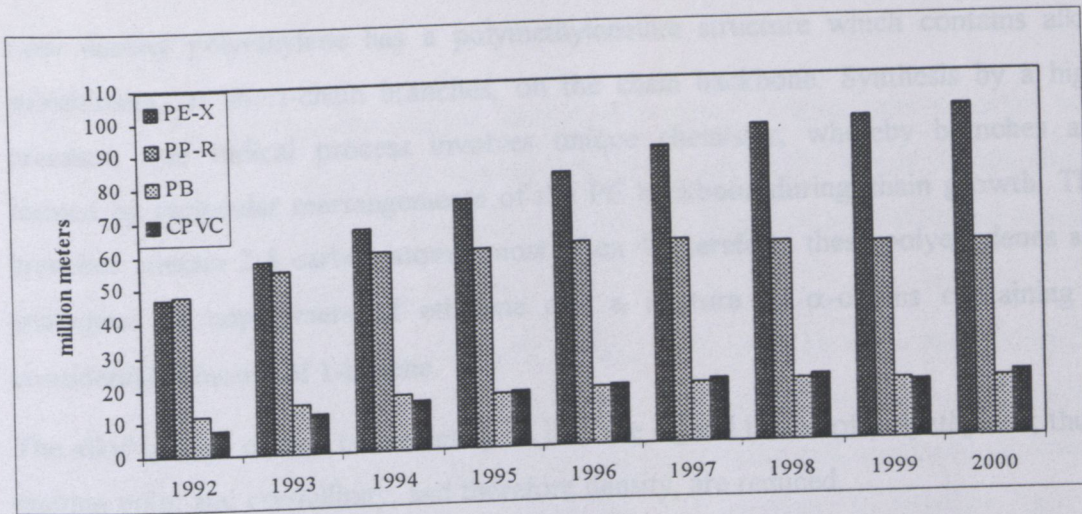


Figure 2.3 Growth of plastic pipes for potable water systems- Europe 1992-2000

PP-R and the other plastic raw materials commonly used in hot and cold water application have had an impressive growth, winning in most cases against traditional metal alternatives. Different plastic systems all have their strengths and shortcomings, but their common success factor has been fulfilling the needs of the key players in the value chain and building up an impressive track record over more than 25 years. For PP-R and all plastic systems it remains critical to have a very high level of requirements and formalize these through corresponding standards and specifications [8].

2.3. Low Density Polyethylene

The polymer with repeat unit structure $[\text{CH}_2\text{CH}_2]_n$ produced by the polymerization of ethylene. It is the largest tonnage plastic material produced and is obtained in a variety of forms with various degrees of structural imperfection.

Traditionally, commercial polyethylenes have been classified into three major groups based on both the manufacturing process and the polymer properties:

- Low Density, or LDPE
- High Density, or HDPE
- Linear Low Density, or LLDPE.

For many end uses, these polymer groups are not fully interchangeable [7].

Low density polyethylene has a polymethylenelike structure which contains alkyl substituents, or short-chain branches, on the chain backbone. Synthesis by a high pressure, free radical process involves unique chemistry, whereby branches are formed by molecular rearrangements of the PE backbone during chain growth. The branches contain 2-8 carbon atoms, most often 4; therefore, these polyethylenes are analogous to copolymers of ethylene and a mixture of α -olefins containing a considerable amount of 1-hexene.

The alkyl groups cannot conveniently fit into the crystal lattice of polyethylene; thus, melting point and crystallinity, and therefore density, are reduced.

Densities may vary from 0.910 to 0.955 g/cm³, compared with 0.960-0.970 for linear, ie, unbranched, PE. The homopolymers produced under the reaction conditions available in commercial processes usually have densities of 0.916-0.930 g/cm³; they are called LDPE. Homopolymers of density 0.930-0.935 have been produced, but with low efficiency; some were blends of low and high density PE. Products with density as low as 0.912 have been made. Typical commercial products have a degree of crystallinity of 45-55% and melting points of 105-115°C, compared with 70-90% and 135°C for unbranched PE. These products contain 15-25 short-chain branches per 1000 carbon atoms.

In addition to alkyl substituents, long-chain branches as long as the backbone chain are formed by the grafting of polymer chains to inert chains before they can be removed from the reactor. Such chains broaden molecular weight distribution and have a pronounced affect on rheological properties.

Additional substitutents can be introduced by copolymerisation with polar monomers, such as vinyl acetate or ethyl acrylate, which reduce crystallinity further and improve flexibility and impact strength. PE with polar groups and long-chain branches cannot be prepared with the help of Ziegler and Phillips catalysts, which are used to produce high density (HDPE) and linear low density polyethylene (LLDPE).

The structural features of LDPE can thus be varied widely by a careful choice of reaction conditions and type and amount of comonomer, resulting in a broad spectrum of physical properties and an extremely wide range of applications [12].

2.3.1 Manufacturing

LDPE is produced by a free-radical catalyzed reaction using oxygen or other free radical initiators such as organic peroxides or azo compounds. Synthesis conditions are usually 250-300 °C outlet temperature, 120-280 MPa pressure. Nominal reactor residence times are about 10-50 seconds.

Heat of polymerization is about 800 Kcal/gm, which must be removed during the short residence time available. Only a small part of this heat can be removed through the reactor walls because of their comparatively limited area and necessary thickness. In addition, the polymer tends to deposit on cool surfaces. In practice, heat is removed by recirculating excess cool monomer and the system operates essentially adiabatically. Therefore, production rates vary directly with the ethylene recirculation rate and the allowable temperature rise through the reactor. Heat balance limits conversion to ~15-20 % on each pass.

Reactors are of two general types, autoclaves and high pressure tubes. Each of these types produces slightly different polymers, primarily because of differing temperature profiles through the reactors. In many cases, commercially similar polymers can be produced in either type of reactor [8].

2.3.1.1 Autoclave Reactors

These are well mixed vessels which may be subdivided into one to six separate reaction zones. Frequently, different catalysts are employed in each zone so that each catalyst is essentially consumed in its own zone. This allows a choice of zone temperatures by matching the zone residence times to an appropriate catalyst half-life. Because temperature determines many of the physical properties of polymers, this zoning allows a wide range of polymers to be produced.

In general, lower, more uniform temperatures give better optical properties as well as lower melt flow indexes. Higher exit temperatures give higher conversions and, therefore, lower production costs. There is, however, an upper limit to reactor temperature- that is, the temperature at which ethylene violently decomposes. This temperature is approximately 360°C at reaction pressures [7].

2.3.1.2 Tubular Reactors

These reactors consist of long, jacketed high pressure tubes with perhaps a midpoint addition point for the injection of the catalyst and/or monomer. An alternative configuration is the use of two half-reactors operating in parallel rather than in series.

Because of the smaller diameter and larger heat transfer area, a part of the heat of polymerization can be removed through the reactor walls. This allows a slightly higher conversion for the same overall temperature rise. A multizone autoclave can be simulated by injecting mixed catalysts that are activated at different temperatures along the reactor length [7].

2.3.2 Properties

2.3.2.1 Crystallinity and Transition Temperatures.

Unbranched PE is 90-70% crystalline, depending on molecular weight, annealing technique, and other factors; it has a melting point of 135°C. The unit cell contains four ethylene units in which the PE chains are in a linear zigzag form, with a repeating unit of only one ethylene unit [8].

2.3.2.2 Physical Properties

LDPE has a unique combination of properties: toughness, high impact strength, low brittleness temperature, flexibility, processability, film transparency, chemical resistance (especially to polar compounds), low permeability to water, stability, and outstanding electrical properties [8].

2.3.2.3 Chemical Properties

Although PE is highly stable and inert, it is affected by certain chemicals. Although it is highly resistant to water and many aqueous solutions, even at high temperatures, it is slowly attacked by oxidizing agents, and aliphatic, aromatic, and chlorinated solvents cause swelling at room temperature. At 70°C, at which the melting process begins, swelling increases; at higher temperatures, solution occurs. However, PE remains sparingly soluble in many polar liquids such as alcohols, esters, ketones, etc.

Some chemicals pass through PE film at rates which vary widely. The permeability constants for nitrogen, oxygen, and carbon dioxide are very high compared with those for poly(vinylidene chloride) or nylon. Permeability to water is low compared with that of most polymers. The permeability of polar organic compounds such as alcohols or esters is much lower than that of nonpolar organic compounds such as heptane or diethyl ether [8].

2.3.2.4 Electrical Properties

The insulating properties of PE compare favorably with those of any known dielectric material. The outstanding electrical properties of LDPE were the basis for its initial commercialization and use as radar insulation during World War II. Today, various types of PE are the principal material used for power and communications cable insulation.

The electrical properties are defined primarily by the dielectric constant, the dielectric-loss index, and the dielectric strength. The dielectric constant for LDPE is very low because it is essentially nonpolar, although branches are believed to introduce slight polarity. The dielectric constant for nonpolar materials is nearly independent of frequency, and varies from material to material more or less proportionately to variations in density. The dielectric constant of PE increases slightly with density, eg, from 2.273 to 2.338 as density increases from 0.918 to 0.951. It varies only slightly with temperature; the variation can usually be accounted for by variations in density [7, 8].

2.3.2.5 Rheological Properties

Above its melting point, PE is highly viscous; the viscosity at any temperature depends on average molecular weight, the molecular weight distribution, and shear rate or shear stress. Molten PE may be classified as a pseudoplastic fluid. Typically, the melt viscosity at 200°C drops almost two orders of magnitude as the shear rate is increased nearly four orders of magnitude.

Differences in the molecular characteristics cause differences in shear-thinning behavior. Therefore, the melt viscosity, at any shear rate is not reliable in predicting melt viscosity at other shear rates. Polyethylenes are generally compared at the same melt index, which is measured at a low shear rate. However, the shear rate, under practical processing conditions may be 500-2000 times as great [8].

2.3.3 Applications

Applications for polyethylenes are many and varied, including: packaging films; trash, garment, grocery and shopping bags; molded housewares; toys; containers; pipe; drums; gasoline tanks; coatings and many others.

Film for packaging is one of the largest markets for low density polyethylene. Low cost, ease of sealing and good product protection have helped to make film the largest polyethylene market.

2.4 Polymer Blends

Polymer blends are one of the most active areas of growth in polymer materials over the last ten years or so. A polymer blend is a physical mixture of two, or sometimes more, different polymers. The term is usually used to refer to mixtures in which the polymers are of different chemical types [9].

The properties of a polymer blend depend on several factors which are themselves interdependent. These include:

- choice of polymers;
- composition;
- compatibility of the polymers;
- phase morphology;
- method of blend preparation.

It is often the case that the properties of a blend do not depend in a simple manner on its composition. A property may reach some maximum and minimum value as composition varies. Such behavior often can be correlated with a change in phase

structure at the behavior often can be correlated with a change in phase structure at the composition where the maximum or minimum value or other discontinuity occurs.

The most important change in phase morphology that can occur is phase inversion, when the blend structure changes from that of a matrix of polymer A containing dispersed phase polymer B to that of A dispersed in B. In general, it is the matrix phase polymer which is more important in determining the blend properties, even if it is present in the lower amount.

The phase morphology, and hence blend properties, is often determined in practice by the method of blend preparation, which is normally melt mixing. The general aim is to achieve as fine a dispersion of the minor component as possible. This frequently means the use of high shear compounding equipment and long mixing times. Frequently, the dispersion consists of spherical particles of the minor component, though roughly shaped torn particles may result when the dispersed phase has a very high viscosity. The lower melt viscosity component is more likely to form the continuous phase.

The compatibility of the polymer components is crucial in determining the blend properties, most importantly the strength properties. As explained above, it is the limited compatibility of most polymer pairs that has until recently restricted the commercial use of blends. At one extreme, if the polymers are so compatible that they are completely miscible, forming a single-phase blend, then the properties may be related to blend composition in a simple manner. However, most polymer blends are two-phase systems, one characteristic of each separate component. At the opposite extreme, when the two polymers are so completely incompatible that there is no interfacial adhesion between two faces, no stress transfer to the dispersed phase is possible on stressing. The dispersed polymer particles therefore act as if they are holes and the blend has very poor strength properties as a consequence [14].

2.5 Polymer Processing

Polymer processing is defined as the *"engineering specialty concerned with operations carried out on polymeric materials or systems to increase their utility"*.

Primarily it deals with the conversion of polymeric raw materials into finished products.

The field of polymer processing has been traditionally and consistently analyzed in terms of the prevailing processing methods, that is, extrusion, injection, molding, blow moulding, calendaring, mixing and dispersion, rotational molding, and so on. These processes have been viewed as the "*unit operations*" of polymer processing [1].

The objective of polymer processing is undoubtedly *shaping polymer products*. The shaping operation may be preceded and followed by many manipulations of the polymer to prepare the polymer for shaping and to modify its properties and improve its appearance. Nevertheless, the essence of polymer processing remains the shaping operation. The selection of the shaping method is dictated by product geometries and sometimes, when alternative shaping methods are available, by economic considerations.

Polymeric materials possess a surprisingly useful combination of chemical, physical, and electrical properties, rendering them probably the most versatile raw materials available to mankind. Moreover, the "plastic" deformable state achieved by thermoplastic polymers at elevated temperatures, and possessed by thermosetting polymers before being chemically "set," allows them to be shaped into a myriad of finished products, some of them of great geometrical complexity. The shaping operations used are relatively quick and easy, and are superbly fitted for mass production without necessarily sacrificing quality and aesthetics. Without a doubt, the usefulness of polymers and plastics, and their profound impact on modern technology and way of life, are due just as much to the versatility and flexibility of the available shaping methods as to their inherent properties [1].

2.6 Extrusion

The word "extrusion" is derived from the Latin words *ex* and *trudere* meaning, respectively, "out" and "to thrust" or "to push." These words describe literally the process of extrusion, where a polymer melt is pushed across a metal die that continuously *shapes* the melt into the desired form. Polymer products that are

"infinite" in one direction are manufactured by the extrusion process. These include wires, cables, rods, tubes, pipes, and a variety of profiles, which include filaments, films, and sheets that are products of great volume and importance; with ingenious engineering, even nets and corrugated tubes can be continuously extruded [1].

The feed stock may enter the extrusion device in the molten state, but more commonly it consists of solid particles that must be subjected in the extruder to melting, mixing, and pressurization. The solid feed may be in the form of pellets, powder, beads, flake, or reground material. It may also be a combination of any of these with or without liquid additives, all of which may be premixed or fed separately at one or more feed ports. Before the existence of the thermoplastics industry, extrusion devices were applied to rubber, clay, and ground meat. Today, extrusion has been extended to other food processing, machines designed to injection-mould plastics, and blow-mould plastic bottles. Extruders of some type are required to process almost all thermoplastics. Many plastics are first extruded in polymer manufacturing plants and in compounding operations before reaching the final extrusion device used to make fabricated products [8].

Most plastics extruders incorporate a single screw rotating in a horizontal cylindrical barrel with an entry port mounted over one end and a shaping die mounted at the discharge end as shown in the following Figure 2.4.

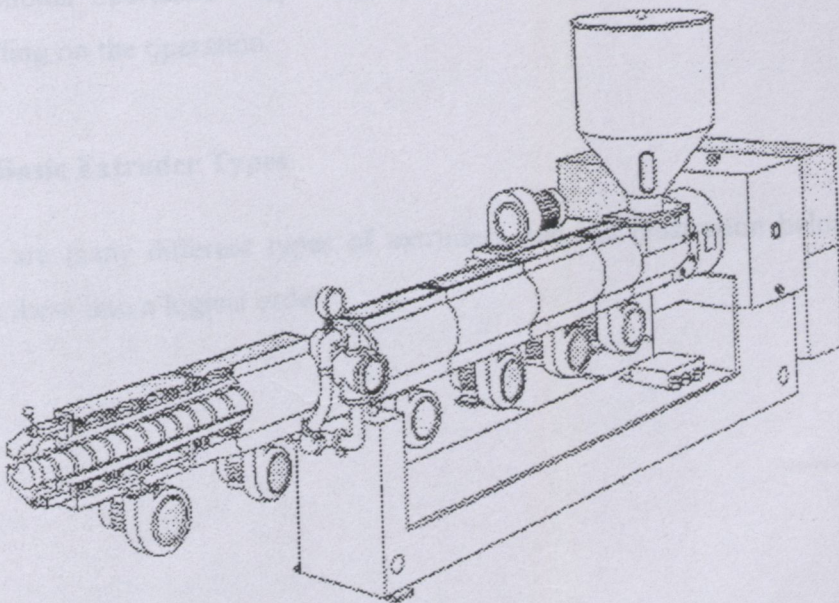


Figure 2.4 A single screw extruder model.

The basic components of an extrusion line are shown below:

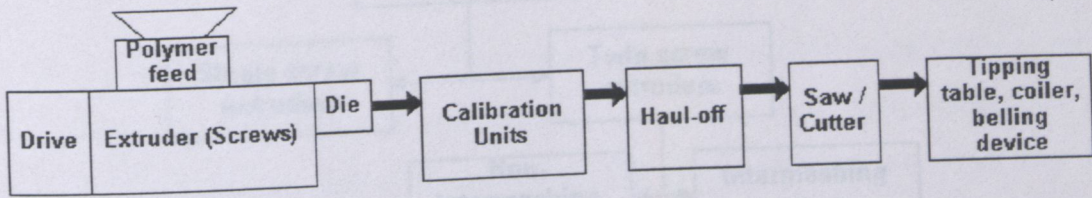


Figure 2.5 Basic components of an extrusion line.

- The extruder drive is electrical in operation and is geared via a thrust bearing to produce the rotational movement of the extruder screw.
- The polymer feed to the screw is from the feed hopper and the feed may be by gravity, metering screw or simple conveying spiral.
- The barrel and screw are zoned into between 3 and 7 sections which are individually heated and cooled depending on the material and process parameters.
- The die channels the polymer melt from the front of the screw to form the basic shape of the desired product.
- The calibration units stabilize the form of the output to the detailed shape whilst the polymer is being cooled.
- The haul-off provides the dragging force to overcome the frictional forces in the calibrators and to pull the profile through the calibrators.
- The saw / cutter cuts the profile to the desired length.
- Additional operations may be performed in the line or at the end of the line depending on the operation.

2.6.1 Basic Extruder Types

There are many different types of extruders and the illustration below attempts to divide these into a logical order.

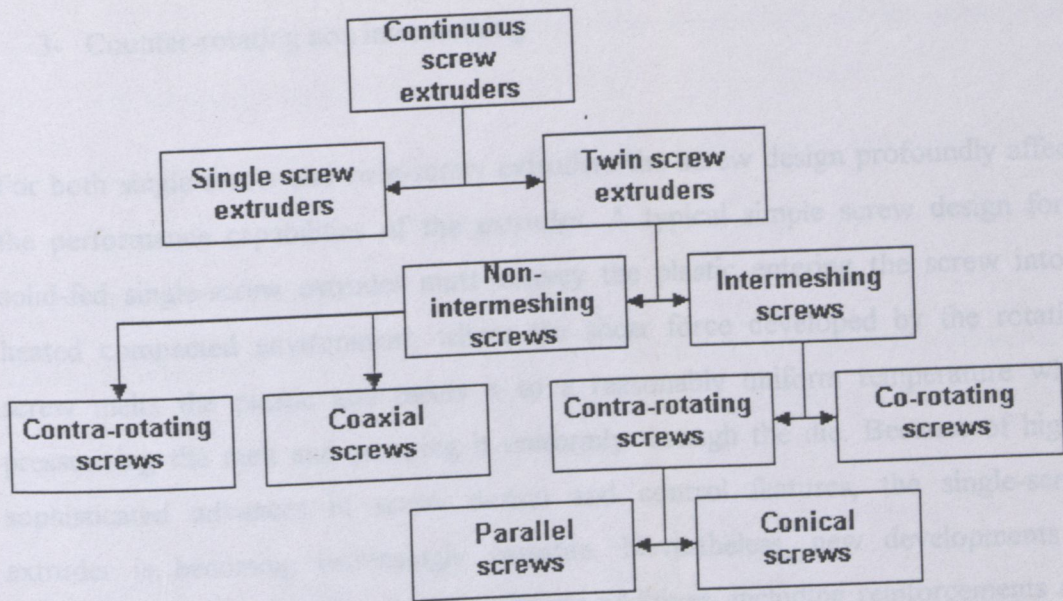


Figure 2.6 Different types of extruders

In addition to single screw extruders, there are twin and multiscrew extruders performing essentially the same functions. Among these, the intermeshing twin screw extruders are the most important ones. They partly compete with single screw extruders and partly expand screw extrusion potential. For example, polyvinylchloride (PVC) powder, regrind scrap, and other difficult-to-feed materials are easier to process with twin extruders than with single screw extruders. There are notable differences in the pumping, melting, and mixing mechanisms of single screw and twin screw extruders, as well as among the various types of twin screw extruders [1].

Some different configurations of the twin screws are shown in the following Figure 2.7.

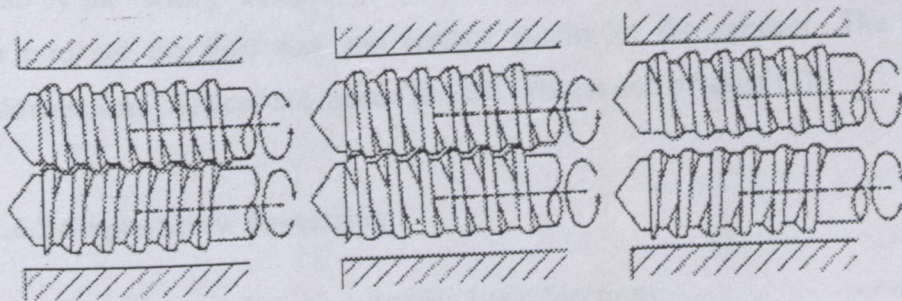


Figure 2.7 Configurations of twin screws.

- 1- Counter-rotating intermeshing
- 2- Co-rotating intermeshing

3- Counter-rotating non intermeshing

For both single-screw and twin-screw extruders the screw design profoundly affects the performance capabilities of the extruder. A typical simple screw design for a solid-fed single-screw extruder must convey the plastic entering the screw into a heated compacted environment, where the shear force developed by the rotating screw melts the plastic and mixes it to a reasonably uniform temperature while pressurizing the melt and pumping it uniformly through the die. Because of highly sophisticated advances in screw design and control features, the single-screw extruder is becoming increasingly versatile. Nevertheless, new developments in combining plastics and incorporating various additives, including reinforcements and fillers, are placing more demands than ever before on twin-screw extruders and devices with unique rotors, thus assuring their expanded use. Both single-screw and twin-screw extruders can be designed with one or more vents to remove volatiles and with additional feed ports downstream of the first feed port. Sometimes extruders are arranged in tandem or as coextruders to produce different layers of molten polymers through the same die. At the extruder exits, melt filtration may be provided, usually by screen packs. Sometimes a gear pump may precede the die to assure a more consistent output rate. The possibilities for die design are almost unlimited and cover many applications, such as compounding (coloring and blending of melts, additives and fillers), cross-head extrusion (wire, garden hose); sheet, film, coatings, pipe, tubing, rod, profiles, and coextruded products [8].

The finished product of the extrusion process is determined not only by the die but also by the "sizing" equipment, the cooling system, and the cutting equipment, which in turn set the final size and surface quality of the product. The postextrusion (downstream) devices are unique to each process and product [1].

2.6.2 Single-Screw Processing

The extruder screw has the following basic functions:

- To bring the feedstock into the extruder and to move the material along the screw whilst at the same time compressing it and removing volatiles.

- To soften the melt by heating it (both from internally generated shear forces and externally applied heat).
- To mix the melt and produce a homogeneous melt without impurities.
- To apply the constant pressure (free of pulsation) required to force the material through the die.

These functions, at least for the single screw extruder, are generally achieved at different sections of the extrusion screw as the material progresses along the barrel and the functions are illustrated below in Figure 2.8.

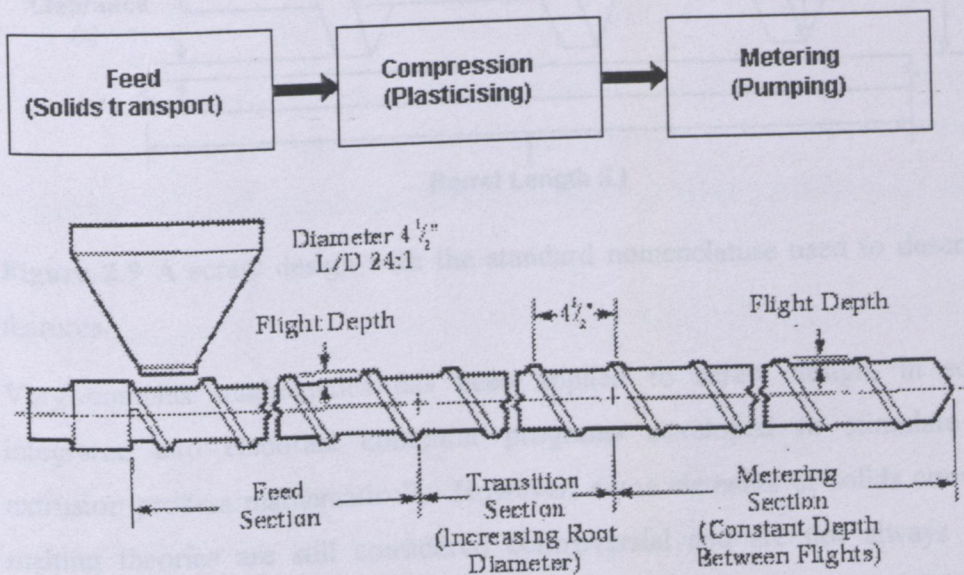


Figure 2.8 Typical Single-Stage Extruder

Although many applications justify highly sophisticated extrusion equipment and controls, numerous applications are well served by the simple screw design shown in Figure 2.9 which also gives the standard nomenclature used to describe design features. The so-called conventional screw, as illustrated, has a relatively deep feed section, followed by a tapered transition section and comparatively shallow constant-depth meter section. The length and depth of these three sections greatly affect performance, which depends on the frictional and melting characteristics of the polymer and the rheology of the polymer melt. Minimum clearances between screw and barrel promote efficient melting and good heat transfer, but the fit must not be tight enough to risk binding. The optimum radial clearance between the screw and barrel is approximately 0.1% of the barrel diameter. Usually the helical flight

advances one turn per unit of length equal to the screw diameter. This is called a square-pitch, where the helix angle is 17.7° at the outside of the screw [8].

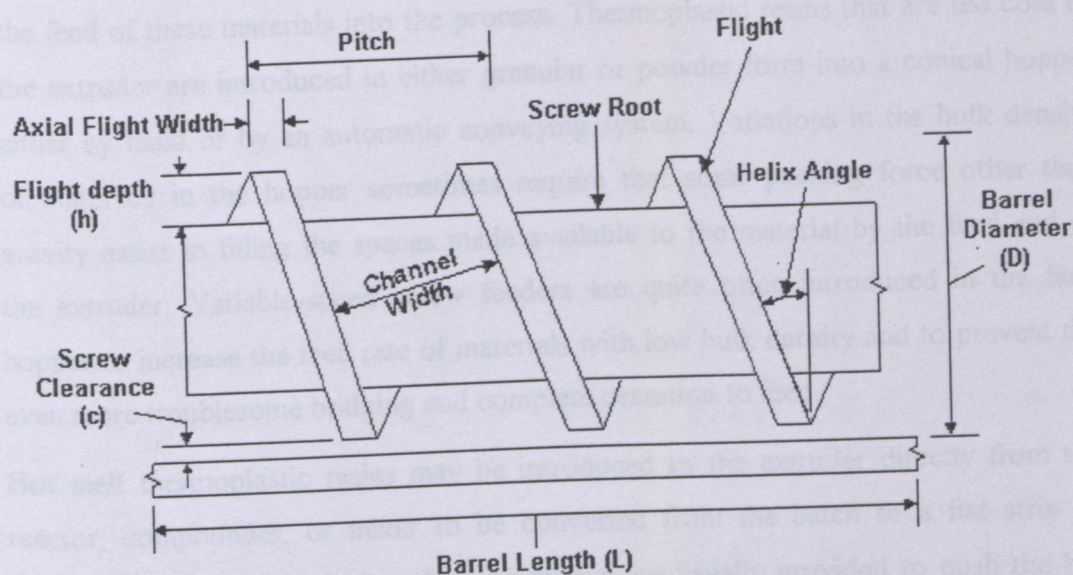


Figure 2.9 A screw design with the standard nomenclature used to describe design features.

Very complex mathematics has been applied to screw design, in some cases integrated into elaborate computer programs developed to stimulate the total extrusion process mathematically. However, some elements of solids conveying and melting theories are still considered controversial and are not always applicable. Furthermore, some advantageous design features are not incorporated in computer models, and therefore mathematical computations alone are not adequate to optimize screw design. Where high performance screws are needed, experimental evaluation of design features is highly beneficial. Nevertheless, mathematical models have been invaluable as diagnostic tools to aid in optimizing extruder operation and design, including scale up, to promote better melting and mixing [8].

2.6.3 Feeding and Solids Conveying

The feed throat is connected to the feed hopper and the extruder barrel. The feed hopper holds the plastic pellets or powder and discharges the materials into the feed throat. The hopper should be designed to allow a steady flow of material through the hopper. Steady flow is best achieved with a circular hopper with a gradual transition in the conical section of the hopper.

The success of any continuous extrusion process depends not only on the uniform quality and conditioning of the raw materials but also on the speed and continuity of the feed of these materials into the process. Thermoplastic resins that are fed cold to the extruder are introduced in either granular or powder form into a conical hopper either by hand or by an automatic conveying system. Variations in the bulk density of materials in the hopper sometimes require that some packing force other than gravity assist in filling the spaces made available to the material by the feed end of the extruder. Variable-speed screw feeders are quite often introduced in the feed hopper to increase the feed rate of materials with low bulk density and to prevent the even more troublesome bridging and complete cessation to feed.

Hot melt thermoplastic resins may be introduced to the extruder directly from the reactor, compounder, or mixer to be converted from the batch to a flat strip or pelletized form. Mechanical pushers or pumps are usually provided to push the hot bulky mass into the feed opening.

Almost all pelletized feed stocks can be gravity fed, but material that does not flow freely frequently requires forced feeding. Metered feeding, at a rate lower than the pumping capacity of the screw, is widely used for twin-screw extruders, partly to avoid high torque loads. This technique also increases the versatility of single-screw extruders. In gravity feeding, the problem of bridging and erratic solids flow to the feed throat can be overcome by vibrating the feed hopper or installing a slowly turning agitator. The actual feed opening should be designed to minimize resistance to material flow into the feed flights. A good design is a top rectangular opening symmetrical with the vertical centreline of the screw, each side tapering down to the full width of the screw.

In the first few flights of the screw feed section (upstream of where a melt film develops at the barrel wall), the frictional characteristics of the solids feed stock greatly influence the feed capability. Most high performance screws build pressure rapidly and friction characteristics usually do not remain constant in the feed section. During solids conveying, temperature and pressure may rise considerably moving down the channel. Changes in pressure and coefficient of friction drastically affect the solids-conveying rate because these changes drastically affect the angle of advancement of the solid plug.

In commercial practice, the feed section for many screws has been designed empirically. Recently, axial grooves have been investigated at the feed end of extruder barrels. If the feed pellets are completely protected from circumferential slippage at the barrel wall as the screw rotates, the maximum theoretical throughput is the volume of feed packed into one turn of the screw times the rotational speed. The maximum theoretical throughput was almost always obtained with a grooved barrel in the absence of pressure build-up and minimal frictional drag on the screw root. In commercial extrusions with a grooved-barrel feed section, the amount transported is less because of slippage and, in some cases, because of partial melting or breakage of particles in the grooves. With fairly long grooves, extending several turns of the screw, which are externally cooled, very high compression forces can be developed in the feed section, and output is governed by the solids conveying. Under these circumstances, a very low compression screw is employed, often designed with mixing elements; a shallow meter section is frequently not safe. Shorter grooves are sometimes used with conventional metering screws when the feed stocks are highly lubricated. Ideally, with a smooth barrel it is the best to have considerable frictional drag at the surface and minimal frictional drag at the screw root [8].

2.6.4 Melting

The energy required to melt polymers in single-screw plasticating extruders is derived primarily from viscous dissipation and to a lesser extent from heat transfer through the barrel wall. The tapered transition section (Figure. 2.8) serves to promote melting. The melting mechanism is described as follows:

" Particles are conveyed rapidly along the screw surface until they become subjected to shearing action between the root of the screw and a thin skin of molten material along the barrel. They are then smeared around the barrel in a direction normal to the screw axis until they meet the leading edge of the advancing thread. Here they are mixed with previously molten material, forced downward into the channel initiating a helical circulating path. This circulating flow is confined to the rear portion of the channel in each turn, the forward portion being filled largely with unfluxed material. The width of the fluxed and circulating band gradually increases toward the exit end of the screw. Under ideal conditions, this mechanism produces complete fluxing and

a homogeneous product before discharge from the screw, but this condition frequently is not realized particularly if the channel is too deep at the exit end."

The melting-rate is highly dependent on the physical and rheological properties of the polymer. It rises with increasing values of melt density, thermal conductivity, and melt viscosity, but decreases with increasing specific heat or heat of fusion. More viscous materials and amorphous materials melt faster. The melting rate then becomes highly dependent on whether the screw design promotes mixing of melt and unmelted solid.

None of the mathematical melting models appear adequate when break-up of the solids bed has occurred prematurely. An idealized cross section of the screw channel in the melting zone shown in Figure 2.10. A visual analysis procedure has been followed for numerous commercial-scale extrusions producing high quality melts when the break-up of solids bed occurred before melting was more than 25% complete. In such situations, it is frequently beneficial to design mixing elements in the screw to increase the heat transfer between the molten and solid fractions in the screw channel. On the other hand, some screws are designed with an undercut extra barrier flight inserted between the primary flights in the melting zone to keep the solid bed and melt pool separated, thus avoiding the break-up of the solids bed.

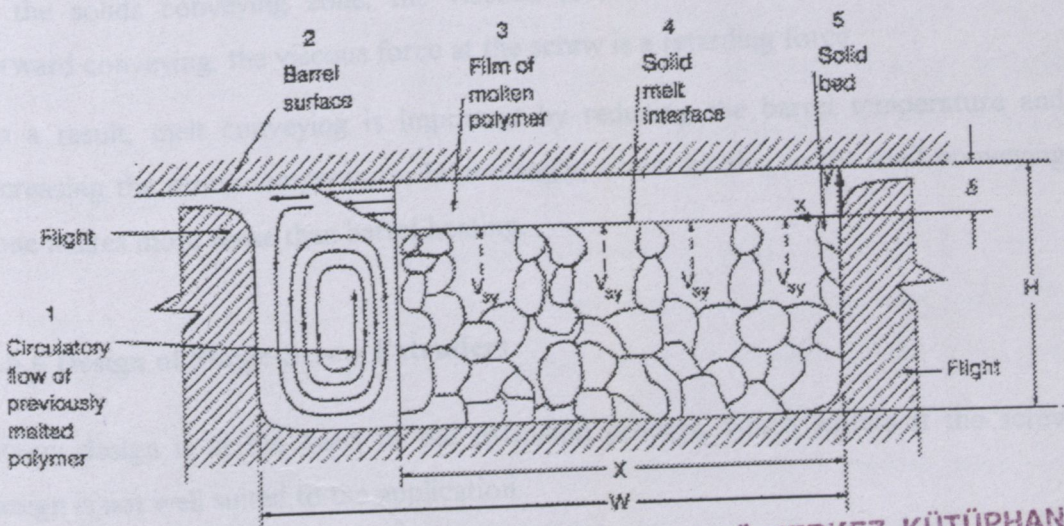
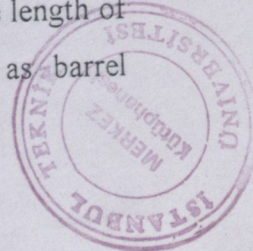


Figure 2.10 Idealized melting model

Some computer programs have been developed that generate tabulations of all important conditions predicted to exist at various locations along the entire length of the extruder screw and barrel. When inputs to the program, such as barrel

I.T.Ü MERKEZ KÜTÜPHANESİ
Demirbaş No: 96244
Küt. Giriş No :



temperature, screw rpm, and polymer properties are changed, it can be enlightening to examine computer predictions [8].

2.6.5 Melt Pumping and Metering

In a conventional single-stage metering screw, the meter section depth and length are of major importance in determining the output per screw revolution, as well as the melt temperature and flow stability. Mathematically, the metering section can be considered as a melt pump for purposes of estimating output and output sensitivity of head pressure at the screw tip [8].

Although the extruder may be called on to serve a wide variety of functions, depending on the polymer being conveyed and the application, the prime requirement is that it be a pump. The extruder must usually be capable of providing a uniform pressure or a uniform flow rate to a sufficiently large or continuous supply of polymer so that a more or less continuously formed product or extrudate will emerge [1].

The mechanism of melt conveying is viscous drag. In other words, the viscous forces acting on the plastic melt are responsible for the forward conveying of the melt. As in the solids conveying zone, the viscous force at the barrel is responsible for forward conveying, the viscous force at the screw is a retarding force.

As a result, melt conveying is important by reducing the barrel temperature and increasing the screw temperature. Interestingly, screw heating in the melt conveying zone makes more sense than barrel heating.

2.6.6 Design of Single-Screw Extruders

Screw design is at the heart of the extrusion process, which suffers if the screw design is not well suited to the application.

High performance screws can be classified as follows: screws with localized-mixing sections, long mixing sections, and controlled-melting barriers. Mixing in the extruder screw produces a homogeneous melt temperature and accelerates the final melting process after break-up of the solid bed. However, frequently the feed stock itself is not homogenous, and the screw must be designed to promote intensive

mixing. Solid and liquid additives often must be incorporated and the polymer itself may consist of both virgin and reground resin. In the extruder itself, meter-section depth and screw speed limit the maximum shear stress and shear rate unless special close-clearance mixing sections are incorporated [8].

Unfortunately, poor mixing ability is typical of single screw extruders with straight conveying screws, i.e. without mixing sections. The best method to really improve mixing in single screw extruders is to incorporate mixing sections. Mixing sections are also useful in reducing the large variations in melt temperature that can occur in screw extruders. If a melt with non-uniform melt temperatures is discharged into an extrusion die, a number of problems can occur that affect the quality of the extruded product.

For special applications employing grooved feed sections in the extruder barrel where the grooves are several screw diameters long and well cooled, the output may be controlled by feed-section performance. In these cases, the customary meter section may be replaced by a long mixing section or a series of short mixing sections, such as mixing teeth, ring barriers, and a mixing section in various combinations. None of these mixing elements need contribute to the pumping action because the feed section itself can develop enough pressure to pump melt through the die. Mixing-element combinations are selected to promote melting through energy transfer between the coexisting melt and solids to provide the required dispersive mixing [8].

Recently, some barrier screws are designed to prevent solid bed break-up, thereby improving melting rate and control of the melting process. Melting takes place over many screw turns, especially for crystalline polymers at high speeds; only long continuous undercut barrier sections in the melting zone of the extruder belong in this category. Many different designs, often with unique patented features, have been developed. All these designs have advantages over conventional screws in some applications. However, there is no universal screw design which is the best for all applications and it cannot be demonstrated that any one design is universally superior to others. Nevertheless, it is well established that break-up of the solid bed can greatly retard melting in the channel of a conventional screw. Furthermore, an improved melting rate would be expected for designs that maintain a wide solid bed

until melting is completed, even when break-up would not have occurred in conventional screws.

The tapered transition section of a conventional screw is replaced by a long double-flighted melting zone, where the secondary flight is undercut and more steeply pitched than the primary flight. The solid bed is preserved in a progressively narrower channel as the melt pool widens during the melting process. The melting rate may be increased, as follows: As the traveling flight moves forward it forces the unmolten or solid-bed portion into a narrowing channel, increasing the melting rate by compressing the solids against the inside diameter of the barrel. Presumably, this would thin out the melt film, thus increasing the shear rate and temperature in the melt film, thereby increasing the melt rate. If carried to extreme, the increased temperature in the melt film, caused by high shear rate over the solid bed, might lead to degradation. Therefore, a controlled- melting barrier screw should be reasonably well matched to the application [8].

2.6.7 Heating and Cooling

Control of the temperature along the length of the barrel is extremely important. In some operations, the screw is temperature controlled by hot oil or water circulating through a center bore, which is frequently drilled to the full length of the screw. The temperature is controlled in zones along the length of the barrel, usually three to seven separate zones depending on extruder size and L/D ratio; liquid and air-cooling are used. For liquid cooling cast aluminum shells are clamped around each barrel zone with electrical resistance heating elements and liquid cooling coils embedded in the castings. Solenoid valves automatically control the flow of coolant to each zone. Usually the coolant is water, treated to remove hardness, in a closed-loop system containing a heat exchanger, centrifugal pump, reservoir, and inlet and outlet manifolds. Microprocessor-based extrusion control systems are increasingly used; they accept input-sensor signals and interpret the requirements for heating and cooling.

Although liquid cooling is preferred for many applications, particularly at high extrusion rates, air cooling is adequate for a number of applications, e.g., low-melt-viscosity polymers extruded at moderate speeds. At very high barrel temperatures, e.g., 300°C and above, liquid cooling is rarely required, and ceramic-type electrically

heated bands may be preferred. For air-cooled extruders, an air blower mounted under each zone heater often is adequate. To increase cooling capacity, the external surface of cast aluminum heaters can be finned to increase the surface area in conjunction with using larger capacity blowers.

Although about 10-20% of the total energy requirement for plastic extrusion is typically derived from barrel heating, supplying energy is not the primary purpose of barrel temperature control. Instead, it is more important to control the temperature of the inside barrel wall. As feed stock passes from the housing into the barrel, solids-conveying characteristics, pressure development, and melt-film formation are strongly influenced by the wall temperature. Near the exit end of the barrel, the wall temperature may affect the melt temperature uniformity, and efficient heat removal in this region is often desirable [8].

2.6.8 Dies and Auxiliary Equipment

2.6.8.1 Die Design

The extrudate entering the die is typically a polymer melt that can be characterized rheologically [8]. Dies, as used in polymer processing, are metal flow channels or restrictions that serve the purpose of imparting a specific *cross-sectional shape* to a stream of polymer melt that flows through them. They are primarily used in the extrusion process to *continuously* form polymer products such as tubes, films, sheets, fibres, and profiles of complex cross-sectional shapes [1]. Dies are positioned at the exit end of the melt generating or conveying equipment and, generally speaking, can be divided into three functional zones: material inlet, mandrel support and die gap, which are considered separately for die design.

The engineering objectives of die design are to achieve the desired shape within set limits of dimensional *uniformity* and at the *highest* possible *production rate* [1]. Consequently classic theoretical equations for flow through various sections of the die and adapter aid die design and indicate die performance at different throughput rates and with different polymer melts.

For dies of complex geometry the viscosity term is reasonably correct only for those points at which the shear rate can be estimated accurately. Mathematical expressions

would be needed in which the terms are continuously varied which relate to the geometry of the passage and to the viscosity. Designs must be derived which give the desired production rate at an acceptable pressure. Furthermore, shape and dimensions must be established which impart the desired shape and size to the finished product. For complex profile shapes, the extruded profile may differ considerably from the shape of the die opening. For example, if thick and thin sections of a shape were produced by openings of equal die land length, polymer in the thicker sections would flow more rapidly than in the thin ones [8].

2.6.8.2 Downstream Auxiliary Equipment

For quality products, polymer melt filtration is very important. Simple melt-filtration procedures employ coarse mesh-screen packs mounted in front of a breaker plate at the end of the extruder barrel to separate metal scraps, dirt, or other solids. Contaminants are more likely to be present, if reprocessed scrap resin is incorporated into feed stock.

Several screen layers in combination are called a screen pack; these are employed in a fixed position ahead of a breaker plate at the end of the barrel or in a separate screen-changer apparatus. Except for a clean, gel-free polymer melt, a screen changer is usually installed at the end of the barrel.

The screen pack also promotes breaking up particle agglomerates.

A gear pump, installed between extruder and die, assures uniform output and permits operation at lower back pressure. However, a gear pump requires elaborate electronic controls and can be very expensive, often 50% of the cost of the extruder. In addition, it is easily damaged by metal scraps and some fillers, and its use should be confined to installations where it can be economically justified.

In a typical gear-pump installation the cavities between the teeth of the two intermeshing counterrotating gears on the inlet side must be filled with polymer under sufficient pressure to avoid cavitation. The precision fit of the gear teeth and close tolerances between the gears and the housing assure metering accuracy through high and low pressure dies. Accuracy is only slightly affected by pressure on the inlet side, melt temperature, or viscosity. Precisely machined, the gear pump is a positive displacement device.

Dependable pressure sensors are employed in commercial practice because extruder output must be closely synchronized to the gear pump. Constant pump speed assures constant output if the pump inlet pressure is continually monitored and maintained by a feedback control loop that continually monitored and maintained by a feedback control loop that continually adjusts screw speed. The operation of the extruder and, if desired, of the downstream equipment, is controlled by the pump. Its speed determines the volumetric output in straight-line fashion. A well-designed extruder screw under steady-state operation may deliver output proportional to screw speed, but extruder output is more dependent on back pressure and affected by variations in feed. Consequently, the extruder is not a true positive displacement device, but is controlled by the pump inlet pressure while maintaining a reasonably stable screw speed.

A gear pump does not improve mixing or equalize temperature but many eliminate the need to pump against high back pressure, thus making it possible to replace part of the meter section with mixing elements. However, the gear pump cannot correct all deficiencies, and being expensive, should not be used with worn or poorly designed equipment [8].

2.7 Pipe Extrusion

The principal aspect of a solid wall plastic pipe manufacturing facility is presented in Figure 2.11. Production of pipe includes raw material handling, extrusion, sizing, cooling, printing, and cutting, through finished product handling.

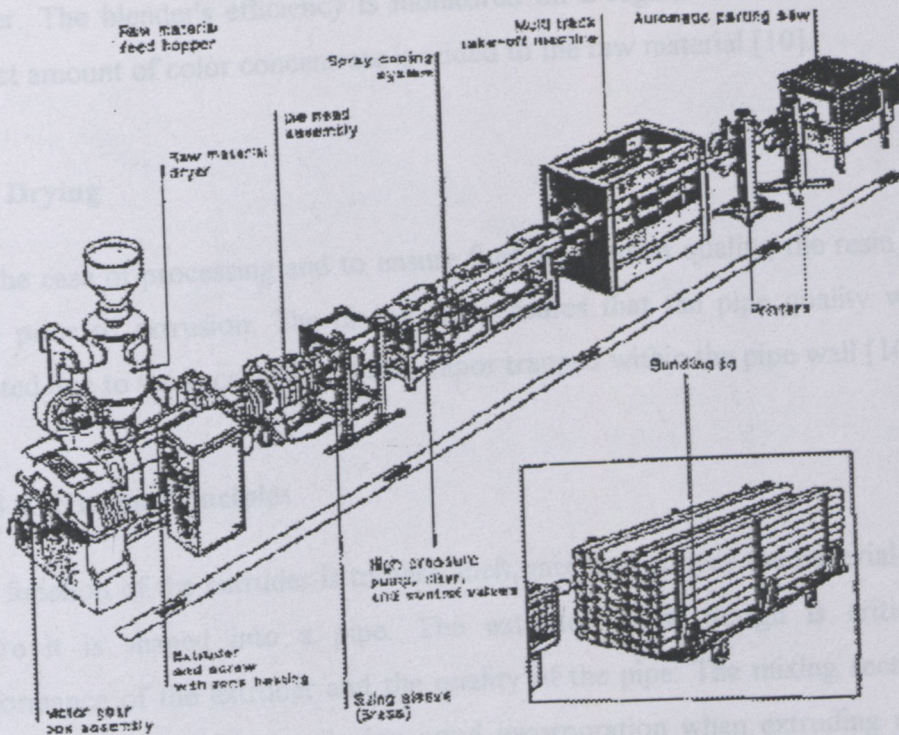


Figure 2.11 Aerial view of typical conventional extrusion line

2.7.1 Raw Materials Handling

Each pipe producing plant establishes quality control procedures for testing incoming resin against specification requirements. The parameters that are typically tested include: melt index, density, tensile strength, and environmental stress crack resistance.

The raw materials used to manufacture plastic pipe are generally supplied as pellets. The resin is supplied in either the natural state (milky white) or in a precolored form. If the resin is supplied as a natural pellet, the pipe producer will blend a color concentrate with the resin prior to extrusion.

The resin is then transferred to the pipe extruder by a vacuum transfer system. Precolored materials can be moved directly into the hopper above the extruder.

If a natural material is used, it must first be mixed homogeneously with a color concentrate. The resin may be mixed with the color concentrate in a central blender remote from the extruder or with an individual blender mounted above the extruder.

hopper. The blender's efficiency is monitored on a regular basis to ensure that the correct amount of color concentrate is added to the raw material [10].

2.7.2 Drying

For the ease of processing and to ensure finished product quality, the resin should be dried prior to extrusion. The drying step ensures that the pipe quality will not be affected due to voids caused by water vapor trapped within the pipe wall [10].

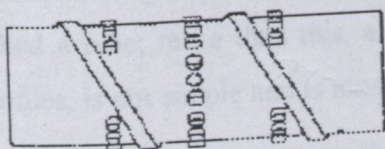
2.7.3 Extrusion Principles

The function of the extruder is to heat, melt, mix, and convey the material to the die, where it is shaped into a pipe. The extruder screw design is critical to the performance of the extruder and the quality of the pipe. The mixing sections of the screw are important for producing good incorporation when extruding natural and concentrate blends and to produce a homogeneous melt.

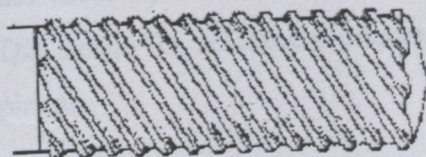
If a natural resin and concentrate blend is used, the screw will also have to incorporate the colorant into the natural resin. Various mixing devices are used for this purpose as shown in Figure 2.11. They include mixing rings or pins, fluted or cavity transfer mixers, blister rings, and helix shaped mixers, which are an integral part of the screw [1,10].

2.7.4 Pipe Extruders

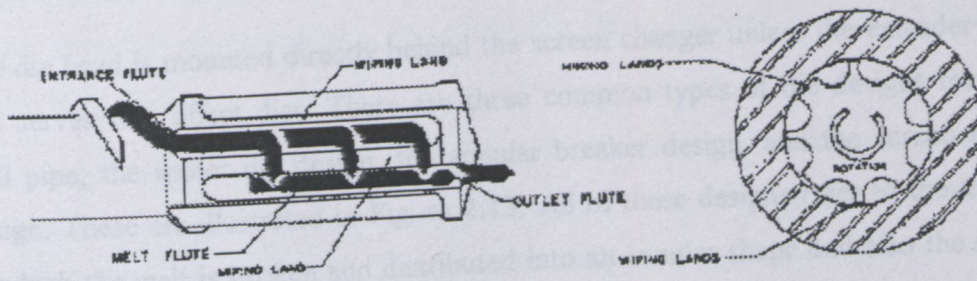
The pipe extrusion line generally consists of the extruder, die, cooling systems, puller, printer, saw, and take-off equipment.



(a)



(b)



(c)

Figure 2.12 Typical Resin Mixing Devices (a) Mixing Pins (b) Helical Mixer (c) Fluted Mixer

The single-screw extruder is generally used to produce polypropylene pipe.

2.7.4.1 Breaker Plate/Screen Pack

The molten polymer leaves the extruder in the form of two ribbons. It then goes through a screen pack which consists of one or more wire mesh screens, positioned against the breaker plate. The breaker plate is a perforated solid steel plate. Screen packs prevent foreign contaminants from entering the pipe wall and assist in the development of a pressure gradient along the screw. This helps to homogenize the polymer. To assist in the changing of dirty screen packs, many extruders are equipped with a screen changer device. It removes the old pack while it inserts the new pack without removing the die head from the extruder [10].

2.7.4.2 Die Design

Pipe, tube, and profile extrusion operation of outstanding practical importance. It is usually distinguished between pipes and tubes by size below 1.25 cm diameter is called a tube; more than this, a pipe. Die design for all these products, in particular profiles, is not simple and is mostly empirical.

The pipe extrusion die supports and distributes the homogeneous polymer melt around a solid mandrel, which forms it into an annular shape for solid wall pipe. The production of a profile wall pipe involves extruding the molten polymer through a die which has a certain shaped profile.

The die head is mounted directly behind the screen changer unless the extruder splits and serves two offset dies. There are three common types of die designs for solid wall pipe; the spider die design, the annular breaker design, and the screen basket design. These are illustrated in Figure 2.13. All of these designs refer to the manner in which the melt is broken and distributed into an annular shape and also the means by which the mandrel is supported [1, 10].

The function of the mandrel support is to keep the spreader body in the centre of the die. The incoming melt flow is split by it into several streams which are brought together again after passing over it. Where these streams recombine, weld lines form which under some circumstances may be visible on the pipe and may represent mechanical weakness. In order to ensure the best possible fusion of the streams, the material is compressed after the mandrel by a reduction in the channel cross section.

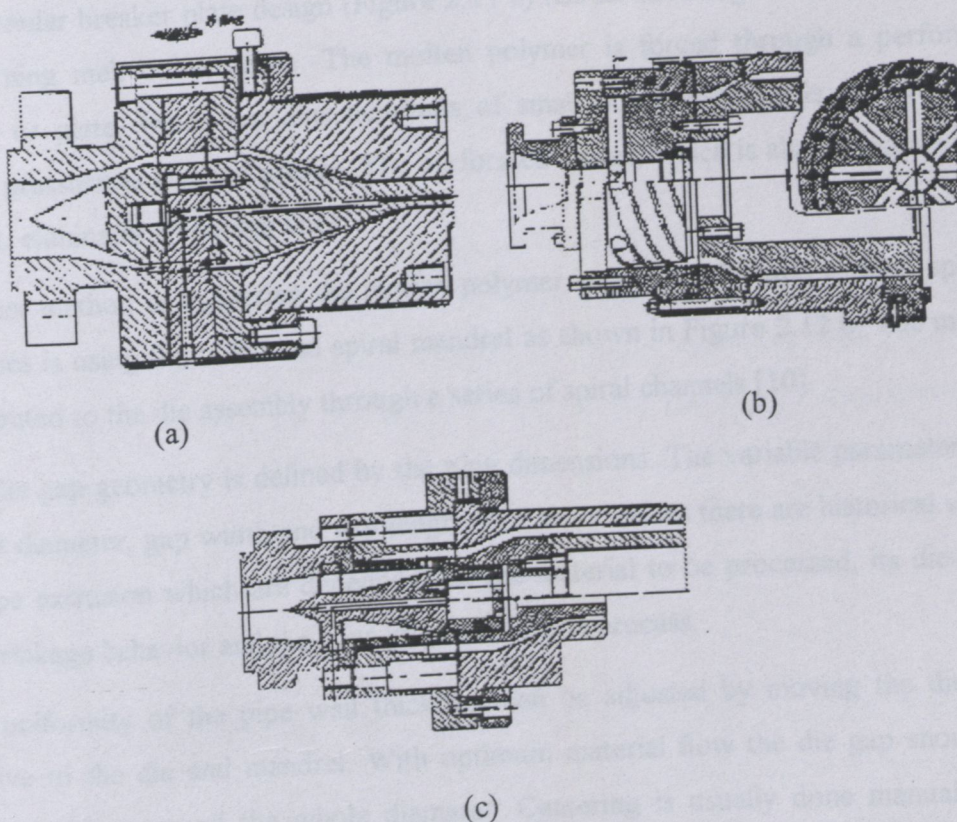


Figure 2.13 Typical Resin Mixing Devices (a) Pipe die with spider for pipe dimensions up to 250 mm ø (b) Egan system (Reifenhäuser design) spiral melt distributor (c) Pipe die with breaker plate-type mandrel support

In the spider die (Figure 2.13 a), the melt stream is distributed around the mandrel by a cone which is supported by a ring of spokes. Since the melt has been split by the spider legs, the flow must be rejoined.

Flow lines caused by mandrel supports should be avoided. This is done by reducing the annular area of the flow channel just after the spider legs to cause a build-up in die pressure and force the melt streams to converge, minimizing weld or spider lines. After the melt is rejoined, the melt moves into the last section of the die, called the land.

The land is the part of the die that has a constant cross-sectional area. It re-establishes a uniform flow and allows the final shaping of the melt and also allows the resin a certain amount of relaxation time. The land can adversely affect the surface finish of the pipe if it is too short in length. Typical land lengths are 15 to 20 times the annular spacing.

The annular breaker plate design (Figure 2.13 c) has an advantage over the spider die concerning melt convergence. The molten polymer is forced through a perforated sleeve or plate, which contains hundreds of small holes. Polymer is then rejoined under pressure as a round profile. The perforated sleeve, which is also called a screen basket, eliminates spider leg lines.

Another method of delivering the molten polymer into a round shape without spider-leg lines is using the radial and spiral mandrel as shown in Figure 2.12 b. The melt is distributed to the die assembly through a series of spiral channels [10].

The die gap geometry is defined by the pipe dimensions. The variable parameters are outlet diameter, gap width and gap length. For these values there are historical values in pipe extrusion which are dependent on the material to be processed, its die-swell or shrinkage behavior and the connected calibration process.

The uniformity of the pipe wall thickness can be adjusted by moving the die ring relative to the die and mandrel. With optimum material flow the die gap should be the same size around the whole diameter. Centering is usually done manually via adjusting screws. Alternatively there are the possibilities of thermal and motorized centering. Thermal centering is controlled by using the differential temperature effect of the material flow on the circumference of the die outlet. The die circumference is divided into several thermally separate segments which are separately heated. If the

pipe wall is too thin at a particular position, then the temperature in the corresponding segment will be slightly raised. Because of the local change in viscosity in this area, the flow rate in relation to the rest of the circumference is slightly higher which leads to an increase in wall thickness.

A definite disadvantage of thermal centering is its very long reaction time since the temperature takes effect only slowly. Motorized centering is far quicker.

The die ring and the die body are connected by a spherical joint the die ring can be brought to any desired specific and repeatable position relative to the die body by four adjusting motors. From the outside the two support plates, adjustable relative to each other, and the motors are visible. By moving the die ring, the gap at the die outlet is altered. By reason of its fast reaction and the possibility to connect it to a computer, this design lends itself to the automation of pipe manufacturing lines. Combined with a powerful control system it is possible to centre even thick walled pipe to within a few tenths of a millimeter, which signifies a considerable saving in material for the pipe manufacturer.

2.7.5 Pipe Sizing Operation

The dimensions and tolerances of the pipe are determined and set during the sizing and cooling operation. The sizing operation holds the pipe in its proper dimensions during the cooling of the molten material. For solid wall pipe, the process is accomplished by drawing the hot material from the die through a sizing sleeve and into a cooling tank. Sizing may be accomplished by using either vacuum or pressure techniques [10].

2.7.5.1 Internal Pressure Calibration

In internal pressure calibration the material is pressed against the sizing sleeve by a pressure excess inside the tube. This is achieved by a compressed air supply through the mandrel (0.2 to 1.0 bar). In order to hold the pressure the pipe must be sealed inside. With small pipe sizes the pipe end is closed; with large pipes sealing is affected by a floating plug which is attached to the mandrel. To prevent the still plastic pipe from bulging, the sizing sleeve in this process is fixed directly on to the

die. The die diameter is smaller than the sizing sleeve in order to guarantee reliable transport (see Figure 2.14 a).

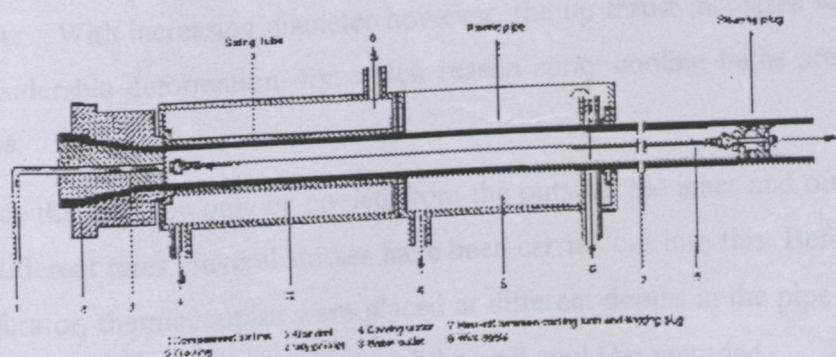
2.7.5.2 Vacuum Calibration

In vacuum calibration too there is a pressure difference between the inside and outside of the pipe. This is produced not by raising the pressure inside the pipe but by a partial reduction in the pressure surrounding the outside of the pipe. A reduced pressure is produced in a vacuum tank so that as the pipe passes through this tank atmospheric pressure within the pipe presses the melt on to the inside of the sizing sleeve and thus takes up its shape.

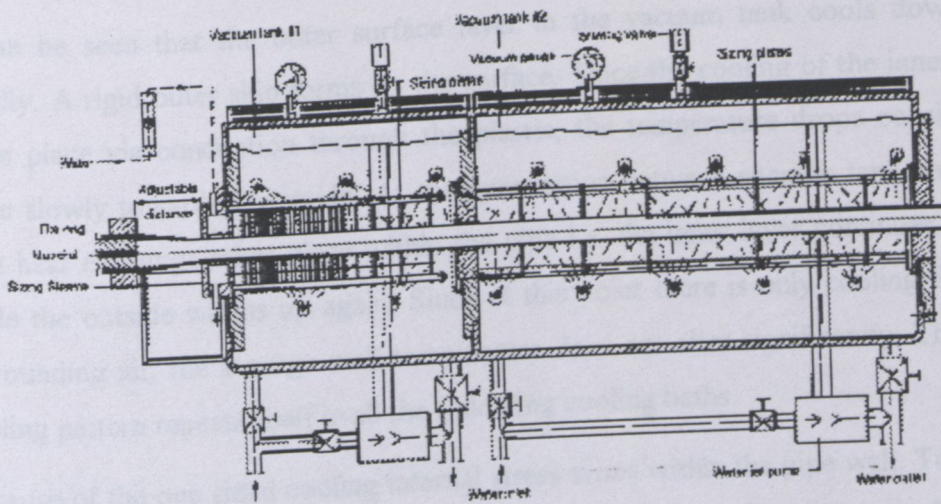
In contrast to pressure calibration, the die diameter is greater than the sizing sleeve so that as soon as the pipe enters the calibrator it contacts the sizing sleeve and thus provides a seal to the tank. The distance of the calibrator from the die is generally greater than for a pressure calibrator. For high product quality it is important to hold the vacuum constant. Pressure variations, such as those which arise from pumping out the cooling water, must be compensate for. In modern lines therefore, the vacuum system and the cooling water circulation comprise two separate circuits (see Figure 2.14 b).

While pressure calibration was always used previously, vacuum calibration has quite clearly replaced it in the current technology.

After the pipe exits the vacuum sizing tank, it is moved through a second vacuum tank or a series of spray or immersion cooling tanks



(a)



(b)

Figure 2.14 Sizing Systems (a) Pressure sizing for small and medium pipe diameters
(b) Vacuum tank sizing

In the pressure sizing system, a positive pressure is maintained on the inside of the pipe by the use of a plug attached to the die face by a cable or, on very small bore pipe, by closing or pinching off the end of the pipe. The pressure on the outside of the pipe remains at ambient and the melt is forced against the inside of the calibration sleeve with the same results as in the vacuum system

2.7.6 Cooling

Further down the line the pipe is cooled. At the end of the cooling run it should be cold enough that no further deformation occurs under outside influences e.g. the pull of the haul-off.

Small sizes can be run in immersion baths, i.e., the whole pipe is surrounded by water. With increasing diameter however, the up thrust increases which can lead to considerable deformation, for which reason spray cooling baths are used for larger sizes.

Since the pipe can only be cooled from the outside, the inner and outer surfaces cool at different rates. Several studies have been carried out into this. Before entry into the calibrator, thermocouples were placed at different depths in the pipe wall. In this way the cooling rate in different layers of the wall could be recorded.

It can be seen that the outer surface layer in the vacuum tank cools down very rapidly. A rigid outer skin forms on the surface. Since the cooling of the inner layers takes place via conduction through the plastic, the temperature drops considerably more slowly towards the inside. At the intersection between vacuum tank and spray bath heat exchange takes place within the pipe i.e. the inner layer continues to cool while the outside warms up again. Since at this point there is only cooling from the surrounding air, the average wall temperature does not alter significantly. This basic cooling pattern repeats itself in all the following cooling baths.

Because of the one sided cooling internal stress arises within the pipe wall. To reduce this internal cooling could be used but so far suitable systems for high performance extrusion have not proved practical.

The required length of a cooling line depends on several factors. These are:

- Throughput
- Wall thickness/diameter ratio (pressure class)
- Material properties such as thermal conductivity, specific heat, enthalpy and density
- Heat transfer into the cooling medium (heat transfer coefficient)
- Temperature of cooling medium
- Entry temperature and required final temperature of pipe

For accurate calculation of the cooling rate a knowledge of all the above values is required. Since the material values are functions of temperature, it is a difficult calculation. Finite element analysis however yields a very good simulation of the actual situation. This was demonstrated amongst others in the above study.

2.7.7 Pullers

The puller must provide the necessary force to pull the pipe through the entire cooling operation. It also maintains the proper wall thickness control by providing a constant pulling rate. The rate at which the pipe is pulled in combination with the extruder screw speed determines the wall thickness of the finished pipe. Increasing the puller speed at a constant screw speed reduces the wall thickness, while reducing the puller speed at the same screw speed increases the wall thickness.

Standards of the many standardization bodies and other specifications require that the pipe be marked at frequent intervals. The markings include nominal pipe size, type of plastic, SDR and/or pressure rating, and manufacturer's name or trademark and manufacturing code. The marking is usually ink, applied to the pipe surface by an offset roller. Other marking techniques include hot stamp, ink jet, and indent printing. If indent printing is used, the mark should not reduce the wall thickness to less than the minimum value for the pipe or tubing, and the long-term strength of the pipe or tubing must not be affected. The mark should also not allow leakage channels when gasket or compression fittings are used to join the pipe or tubing [10].

2.7.8 Cut-Off Units

Up-stroking saws, automatic cutting units and planetary saws are available as cutting-off devices. Application criteria such as pipe diameter, material and additional operations are critical to the selection. Equally important are the extrusion speed and the cut length and accuracy of cut length. Depending on the task, mechanical, pneumatic, hydraulic and electromotive drive designs are used. When considering the cost/utilization ratio special emphasis was placed on easy maintenance. So, for electrical feed drives and tool advance drives, and three-phase motors are used.

2.7.9 Saw Equipment and Bundling

The pipe is usually bundled before it is placed on the truck or railcar. Bundling provides ease of handling and safety during loading and unloading [10].

2.8 Testing

With the advent of science and technology, the concept of testing is an integral part of research and development, product design, and manufacturing. The manner in which we do things today is emphasized on automation, high production, and cost reduction. While designing a machine or a product, the first order of priority in most cases is safety and health. Manufacturers and suppliers are now required to meet a

variety of standards and specifications. The following are some of the major reasons for testing:

- 1- To prove design concepts.
- 2- To provide a basis for reliability.
- 3- Safety.
- 4- Protection against product liability suits.
- 5- Quality control.
- 6- To meet standards and specifications.
- 7- To verify the manufacturing process.
- 8- To evaluate competitors' products.
- 9- To establish a history for new materials [2].

Quality is engineered into the pipe product during the entire manufacturing process. The three phases of quality control for the pipe manufacturer involve the incoming raw material, the pipe production, and the finished product. The combination of all three areas ensures that the final product will fulfill the requirements of the specification to which it was made.

Testing the incoming resin is the first step in the quality control program. It is usually checked for contamination, melt index, density. Any resin that does not meet the raw material specification is not used for the production of specification-grade pipe.

During the manufacturing step, the pipe producer routinely performs quality assurance tests on samples. This verifies that proper production procedures and controls were implemented during production.

Once the product has been produced, it undergoes a series of quality control tests to ensure that it meets the minimum specifications as required by the appropriate standard.

The manufacturing specifications for piping products list the tests that are required. There are several quality control tests that are common in most polypropylene standards. The typical QC tests found in most standards are described below [10].

2.8.1 Workmanship, Finish and Appearance

According to product specifications, the pipe, tubing, shall be homogeneous throughout and free of visible cracks, holes, foreign inclusions, blisters, and dents or

other injurious defects. The pipe tubing and fittings shall be as uniform as commercially practicable in color, opacity, density, and other physical properties. Pipe ends shall be cut as square as possible to the pipe axis [10].

2.8.2 Dimensions

Pipe diameter, wall thickness, ovality, and length are measured on a regular basis to insure compliance with the prevailing specification. The outside diameter and wall thickness shall comply with the specifications [10].

2.8.3 Mechanical Properties

The mechanical properties, among all the properties of plastic materials, are often the most important properties because virtually all service conditions and majority of end-use applications involve some degree of mechanical loading.

The material selection for a variety of applications is quite often based on mechanical properties such as tensile strength, modulus, elongation, and impact strength. These values are normally derived from the technical literature provided by material suppliers. A thorough understanding of mechanical properties, tests employed to determine such properties, and effect of adverse conditions on mechanical properties over along period is extremely important [2].

2.8.3.1 Impact Properties

The impact properties of the polymeric materials are directly related to the overall toughness of the material. Toughness is defined as the ability of the polymer to absorb applied energy. Impact strength is a measure of toughness. The higher the impact strength of a material, the higher the toughness and vice versa. Impact resistance is the ability of a material to resist breaking under a shock loading or the ability of a material to resist breaking under a shock loading or the ability of a material to resist the fracture under stress applied at high speed.

The theory behind toughness and brittleness of the polymers is very complex. The molecular flexibility plays an important role in determining the relative brittleness or toughness of the material. For example, in stiff polymers, the molecular segments are

unable to disentangle and respond to the rapid application of mechanical stress and the impact produces brittle failure. In contrast, flexible polymers have high-impact strength due to the ability of the large segments of molecules to disentangle and respond rapidly to mechanical stress.

Most polymers, when subjected to the impact loading, seem to fracture in a characteristic fashion. The crack is initiated on a polymer surface due to the impact loading. The energy to initiate such a crack is called the crack initiation energy. If the load exceeds the crack initiation energy, the crack continues to propagate. A complete failure occurs when the load has exceeded the crack propagation energy. Thus, both crack initiation and crack propagation contribute to the measured impact strength. There are basically four types of failures encountered due to the impact load.

BRITTLE FRACTURE: In this type of failure the part fractures extensively without yielding. A catastrophic mechanical failure is observed.

SLIGHT CRACKING: The part shows evidence of slight cracking and yielding without losing its shape or integrity.

YIELDING: The part actually yields showing obvious deformation and stress whitening but no cracking takes place.

DUCTILE FAILURE: This type of failure is characterized by a definite yielding of material along with cracking.

The distinction between the four types of failures is not very clear and some overlapping is quite possible.

Impact properties of the polymers are often modified simply by adding an impact modifier. The addition of a plasticizer also improves the impact strength at the cost of rigidity. Material such as nylon, which has relatively fair impact strength, can be oriented by aligning the polymer chains to improve the impact strength substantially. Another way to improve the impact strength is to use fibrous fillers that appear to act as stress transfer agents [2].

a) Factors Affecting the Impact Strength

I. Rate of Loading

The speed at which the specimen or part is struck with an object has a significant effect on the behavior of the polymer under impact loading. At low rates of impact, relatively stiff materials can still have good impact strength. While at high rates of impact, even rubbery materials may exhibit brittle failure. All materials seem to have a critical velocity above which they behave as glassy, brittle materials [2].

II. Notch Sensitivity

A notch in a test specimen or a sharp corner in a fabricated part drastically lowers the impact strength. A notch creates a localized stress concentration and hence the part failure under impact loading. All plastics are notch-sensitive. The degree of sensitivity varies with the type of plastic. Both notch depth and notch radius have an effect on the impact strength of materials. For example, a larger radius of curvature at the base of the notch will have a lower stress concentration and, therefore, a higher impact strength of the base material [2].

III. Temperature

The impact strength of plastic materials is strongly dependent upon the temperature. At lower temperatures the impact strength is reduced drastically. The reduction in impact is even more dramatic near the glass transition temperature. Conversely, at higher test temperatures, the impact strength is significantly improved [2].

IV. Orientation

The manner in which the polymer molecules are oriented in a part will have a major effect on the impact strength of the polymer. Molecular orientation introduced into drawn films and fibers may give extra strength and toughness over the isotropic material. However, such directional orientation of polymer molecules can be very fatal in a molded part since the impact stresses are usually multiaxial. The impact strength is always higher in the direction of flow [2].

V. Processing Conditions and Types

Processing conditions play a key role in determining the impact resistance of a material. Inadequate processing conditions can cause the material to lose its inherent toughness. Voids that act as stress concentrators are created by poor processing conditions. High processing temperatures can also cause thermal degradation and, therefore, reduced impact strength. Improper processing conditions also create a weak weld line that almost always reduces overall impact strength [2].

VI. Degree of Crystallinity, Molecular Weight

Increasing the percentage of crystallinity decreases the impact strength and increases the probability of brittle failure. A reduction in the average molecular weight tends to reduce the impact strength and vice versa [2].

b) Types of Impact Tests

In the last two decades, attempts have been made to develop different types of impact tests by organizations throughout the world. The specimens have been subjected to a variety of impact loads including tensile, compression, bending, and torsion impacts.

An impact test can be divided into six major classes and subdivided into many different types having slight variations.

1. Pendulum impact tests.
 - a) Izod impact test.
 - b) Charpy impact test.
 - c) Chip impact test.
 - d) Tensile impact test.
2. High-rate tension test.
3. Falling weight impact test.
 - a) Drop weight impact test.
4. Instrumented impact tests.
5. High-Rate impact testers.

a) High-speed ball-impact tester.

b) High-speed plunger-impact tester.

6. Miscellaneous impact tests [2].

I. Pendulum Impact Tests

• Izod-Charpy Impact Test

The objective of the Izod-Charpy impact test is to measure the relative susceptibility of a standard test specimen to the pendulum type impact load. The results are expressed in terms of kinetic energy consumed by the pendulum in order to break the specimen. The energy required to break a standard specimen is actually the sum of energies needed to deform it, to initiate its fracture, and to propagate the fracture across it, and the energy needed to throw the broken ends of the specimen. This is called the 'toss factor'. The energy lost through the friction and vibration of the apparatus is minimal for all practical purposes and usually neglected.

The specimen used in both tests is usually notched. The reason for notching the specimen is to provide a stress concentration area that promotes a brittle rather than a ductile failure. A plastic deformation is prevented by such type of notch in the specimen. The impact values are seriously affected because of the notch sensitivity of certain types of plastic materials.

The Izod test requires a specimen to be clamped vertically as a cantilever beam. The specimen is struck by a swing of a pendulum released from a fixed distance from the specimen clamp. A similar set-up is used for the Charpy test except for the positioning of the specimen. In the Charpy method, the specimen is supported horizontally as a simple beam and fractured by a blow delivered in the middle by the pendulum. The obvious advantage of the Charpy test over the Izod test is that the specimen does not have to be clamped and, therefore, it is free of variations in clamping pressures [2].

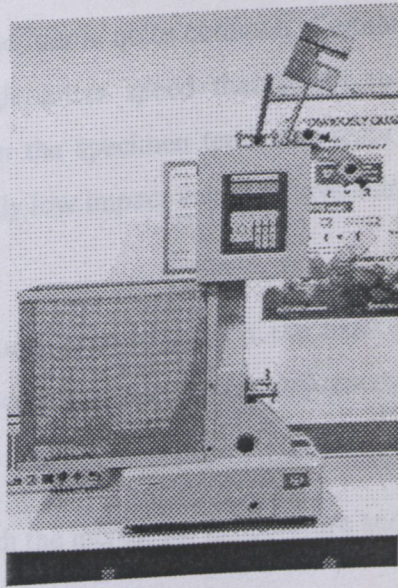


Figure 2.15 Pendulum impact tester.

- **Apparatus and Test Specimens**

The testing machine consists of a heavy base with a vise for clamping the specimen in place during the test. A pendulum type hammer with an antifriction bearing is used. Additional weights may be attached to the hammer for breaking tougher specimens. The pendulum is connected to a pointer and a dial mechanism that indicates the excess energy remaining in a pendulum after breaking the specimen. The dial is calibrated to read the impact values directly in Joules. A hardened steel-striking nose is attached to the pendulum. The Izod and Charpy tests use different types of striking noses. Figure 2.15 illustrates a typical pendulum-type impact testing machine. The test specimens can be prepared either by molding or cutting them from a sheet. A notch is cut into a specimen very carefully by a milling machine or a lathe [2].

- **Effect of Test Variables and Limitations**

Notch

A slight variation in the radius and depth of a notch affects the impact strength results. Many other variables such as the cutter speed, sharpness of the cutting tooth, feed rate, type of plastic, and quality of the notch cutting equipment, all seem to have a significant effect on the results. Such variations are difficult to control and

nonuniformity between the lots is quite common. Certain heat sensitive polymers are also affected by the high cutter speed that seems to contribute to the thermal degradation. The notch in the specimen tends to create a stress concentration area that produces unrealistically low impact values in crystalline plastics.

Specimen Thickness

Although the impact values reported are on the basis of standard specimens, the actual thickness of the specimen used in the test influences the test results.

Temperature

Impact values increase with the increasing temperature and vice versa.

Fillers and Other Additives

Fillers and reinforcements have a pronounced effect on the test results. Fillers and pigments generally lower the impact strength.

Limitations

The results obtained from the Izod or Charpy test cannot be directly applied to part design since these tests do not measure the true energy required to break the specimen. The notched Izod impact test measures only the notch sensitivity of the different polymers and not the toughness [2].

2.8.4 Thermal Properties

Thermal properties of plastic materials are equally as important as mechanical properties. Unlike metals, plastics are extremely sensitive to changes in temperature. The mechanical, electrical, or chemical properties of plastics cannot be looked at without looking at the temperature at which the values were derived. Crystallinity has a number of important effects upon the thermal properties of a polymer. Its most general effects are the introduction of a sharp melting point and the stiffening of thermal mechanical properties. Amorphous plastics, in contrast, have a gradual softening range. Molecular orientation also has a significant effect on thermal properties. Orientation tends to decrease dimensional stability at higher temperatures. The molecular weight of the polymer affects the low-temperature flexibility and low-temperature brittleness. Many other factors such as intermolecular bonding, cross linking, and copolymerization all have a considerable effect on thermal properties. It

is very clear that the thermal behavior of polymeric materials is rather complex. Therefore, in designing a plastic part or selecting a plastic material from the available thermal property data, one must thoroughly understand the short term as well as the long-term effect of temperature on properties of that plastic material [2].

2.8.4.1 Thermal Expansion

The coefficient of thermal expansion is defined as the fractional change in length or volume of a material for a unit change in temperature. Plastics tend to expand and contract anywhere from six to nine times more than materials such as metals. This difference in the coefficient of thermal expansion develops internal stresses and stress concentrations in the polymer, and premature failures occur. The use of a filler such as fiberglass lowers the coefficient of thermal expansion considerably and brings the value closer to that of metal and ceramics [2].

2.8.5 Material Characterization Tests

In order to understand the phenomenon of batch-to-batch variation, the polymerization process must be understood. The polymerization mechanism can often be very complex. Basically, it involves adding a monomer or a mixture of monomers into a reaction kettle along with several other ingredients such as a catalyst, an initiator and water, depending on the type of polymerization process. The contents are agitated at a specific speed. The time, temperature, and pressure are carefully controlled. During this process, the monomer is converted into a polymer. The properties of the final product depend on several factors such as the monomer to water ratio, if the water is present, the degree of agitation, the removal of exothermic heat generated during the polymerization, and the ability of the polymer to dissolve in monomer. This is further complicated by the fact that different polymerization techniques are used to form the same chemical type of polymer. Since it is difficult to manufacture a monodispersed polymer (a polymer in which all molecules have the same size) commercially, we are forced to live with variations in the size and weight of molecules in a polymer. Such variations in the size and the weight of the polymer molecules are also extremely difficult to control. The relative proportions of molecules of different weights within a polymer comprise its molecular weight distribution. Depending on the range of distribution (narrow or broad), the

processability and the properties of a polymer vary significantly. The basic nature of the polymerization process creates a need for material characterization test that can be used as an insurance against variations in the characteristics of the polymer [2].

2.8.5.1 Melt Index Test

The melt index tests measures the rate of extrusion of a thermoplastic material through an orifice of specific length and diameter under prescribed conditions of temperature and pressure. This test is primarily used as a means of measuring the uniformity of the flow rate of the material. The reported melt index values help to distinguish between the different grades of a polymer. A high molecular-weight material is more resistant to flow than a low molecular-weight material [2].

a) Test Procedures

The melt index apparatus (Figure 2.16) is preheated to a specified temperature. The material is loaded into the cylinder from the top and a specified weight is placed on a piston. The most commonly used test conditions are shown in Table 2.2 [11]. The material is allowed to flow through the die. The initial extrudate is discarded since it may contain some air bubbles and contaminants. Depending on the material or its flow rate, cuts for the test are taken at different time intervals. The extrudate is weighed and melt index values are calculated in g/10 min [2].



Figure 2.16 A melt index apparatus.

The melt index value is calculated by using the following formula [11]:

$$\text{MFR } (\Theta, m_{\text{nom}}) = (t_{\text{ref}} / t) * m \quad (2.1)$$

Where

- Θ is the test temperature, in degrees Celsius;
- m_{nom} is the nominal load, in kilograms;
- m is the average mass, in grams, of the cut-offs;
- t_{ref} is the reference time (10 min), in seconds (600 s);
- t is the cut-off time interval, in seconds.

Table 2.2. MFR test conditions [11].

Conditions (code letter)	Test temperature, Θ	Nominal load (combined), m_{nom}
	°C	kg
A	250	2.16
B	150	2.16
D	190	2.16
E	190	0.325
F	190	10.00
G	190	21.60
H	200	5.00
M	230	2.16
N	230	3.80
S	280	2.16
T	190	5.00
U	220	10.00
W	300	1.20
Z	125	0.325

b) Factors Affecting the Test Results

I. Preheat Time

If the cylinder is not preheated for a specified length of time, there is usually some nonuniformity in temperature along the walls of the cylinder even though the

temperature indicated on the thermometer is close to the set point. This causes the flow rate to vary considerably [2].

II. Moisture

Moisture in the material, especially a highly pigmented one, causes bubbles to appear in the extrudate which may not be seen with the naked eye. Frequent weighing of short cuts of the extrudate during the experiments reveals the presence of moisture. The weight of the extrudate is significantly influenced by the presence of the moisture bubbles [2].

III. Packing

The sample resin in the cylinder must be packed properly by pushing the rod with substantial force to allow the air entrapped between the resin pellets to escape. Once the piston is lowered, the cylinder is sealed off, and no air can escape. This causes variation in the test results [2].

IV. Volume of Sample

In order to achieve the same response curve repeatedly, the volume of the sample in the cylinder must be kept constant. Any change in sample volume causes the heat input from the cylinder to the material to vary significantly [2].

c) Interpretation of Test Results

The melt index values obtained from the test can be interpreted in several different ways. First of all, a slight variation in the melt index value should not be interpreted as indicating a suspect material. A significantly different melt index value than the control standard may indicate several different things. The material may be of a different grade with a different flow characteristic. It also means that the average molecular weight distribution of the material is different than the control standard and may have different properties [2].

Melt index is an inverse measure of molecular weight. Since flow characteristics are inversely proportional to the molecular weight, a low molecular-weight polymer will have a high melt index value and vice versa.

2.8.6 Burst Strength Test

Plastics are used in a variety of applications requiring internal stresses applied by the transporting fluid. Plastic pipes, fittings, valves, tanks, and containers are some of the typical examples of pressure vessels [2].

Two basic tests of primary interest are:

- Quick-burst strength test.
- Long-term burst strength test.

2.8.6.1 Quick-burst strength test

This method was developed to determine the ability of a plastic pressure vessel to resist rupturing when it is pressurized for a short period of time. Surging is a common phenomenon in a fluid transfer system. Surging is a pressure rise in a pipeline caused by a sudden change in the rate of flow or stoppage of flow in the line.

In such cases, pressure vessels are subjected to very high internal pressures for a relatively short period. The short-time rupture strength of pressure vessels is determined by continuously increasing internal hydraulic pressure while immersed in a controlled temperature environment until rupture occurs [2].

A hydraulic burst-strength tester such as the one shown in Figure 2.17 is employed

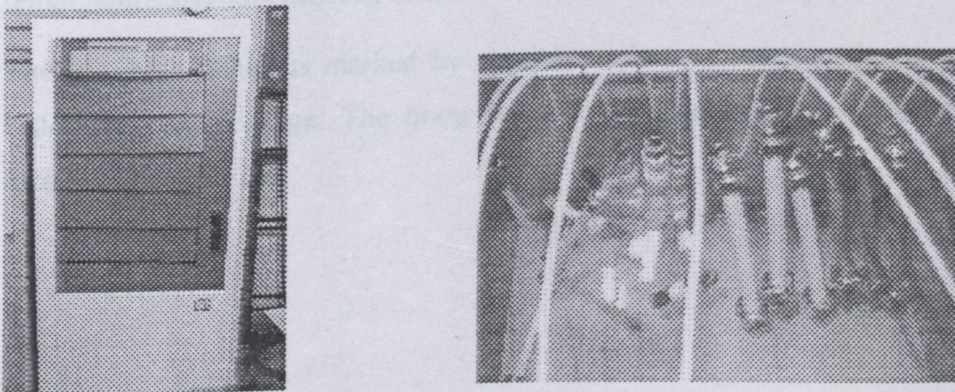


Figure 2.17 A hydraulic burst-strength tester

This test is carried out by simply pressurizing the specimen and uniformly increasing the pressure until the failure occurs.

The Hoop stress can be calculated as follows:

$$S = P * (D - t) / 2st \quad \text{or} \quad S = P * (d + t) / 2s \quad (2.2)$$

Where

S = Hoop stress (N/mm^2)

P = Internal pressure (N/mm^2)

D = Average outside diameter (mm)

d = Average inside diameter (mm)

s = Minimum wall thickness (mm)

Hoop stress is defined as the circumferential stress in a material of cylindrical form subjected to internal or external pressure [12].

2.8.6.2 Long-Term Burst Strength Test

The long-term burst strength of plastic pressure vessels is determined by subjecting the pressure vessels to constant internal pressure and observing time-to-failure. This test is a static pressure test as opposed to the dynamic quick-burst test described earlier.

The specimens are filled with test fluid or gas, and pressure is applied to produce the desired loading. The timers are started immediately after reaching the desired pressure. A constant temperature system may be employed if so desired. The test must be carried out in a standard laboratory atmosphere since any variation in temperature and humidity can cause results to change drastically [2].

The specimen failure is marked by continuous loss of pressure, bursting, abnormal ballooning, and leakage. The hoop stress in the specimens is calculated by using formula Equation 2.2.

2.8.6.3 Developing Long-Term Hydrostatic Design Stress Data and Pressure Rating

The plastic Pipe Institute of the Society of the Plastic Industry has developed a method of obtaining a long-term hydrostatic design stress and pressure rating a thermoplastic pressure pipe. Hydrostatic design stress is defined as the estimated maximum tensile stress in the wall of the pipe in the circumferential orientation due to internal hydrostatic pressure that can be applied continuously with high degree of certainty that failure of the pipe will not occur. Pressure rating is the estimated maximum pressure that the medium in the pipe can exert continuously with a high degree of certainty that failure of the pipe will not occur.

Long-term hydrostatic design stress is obtained by essentially extrapolating the stress-time regression line on data obtained in long-term burst strength test. The following is a summary of procedures used to obtain long-term hydrostatic design stress.

1. Specimens of plastic pipe are subjected to constant internal water pressure at different levels of pressure and the time to rupture is measured. Stress on each specimen is calculated by means of formula applicable to plastic pipe:

$$S = (P * d_I) / 2s_I \quad (2.3)$$

Where

S = Hoop stress (N/mm^2)

P = Internal Pressure (N/mm^2)

d_I = Mean diameter (mm)

s_I = Average wall thickness (mm)

The specimens are tested for 10,000 hrs under specified conditions and a linear plot of hoop stress versus to rupture on log-log coordinates is generated

The stress rupture data is analyzed by statistical regression to generate a hoop stress versus time equation. This equation is extrapolated mathematically one decade of time to 100,000 hrs (approximately 11.4yr) to obtain a 100,000 hr design stress.

2. Next, the entire design stress scale is divided into continuous increments, each of which is approximately 25 percent larger than the one below it. Each material is arbitrarily assigned the threshold value of the increment in which its 100,000 hr

design stress falls. The working stresses are calculated from this fundamental stress called hydrostatic design basis [2].

A safety factor, depending upon temperature and type of service, is applied to the hydrostatic design basis to obtain a working stress. This value is then substituted in the pipe design equation to obtain pressure rating or required wall thickness.

2.8.7 Quality Assurance

Through the constant updating of industry standards, the quality performance of the pipe and fitting industry is continually evolving. Each year, standardization bodies work to improve standards on plastic pipe which include the latest test methods and recommended practices. Resin producers, pipe extruders, and fittings manufacturers incorporate these revisions into their own QC practices to insure compliance with these standards. In this way, the exceptional performance and safely record of the pipe industry is sustained [10].

Property	Test Method	Unit	Value
Main Flow Rate	MFR 1900	g/10 min	8.43
	MFR 2300 10	g/10 min	9.3
	MFR 2300	g/10 min	1.5
Density at 23°C	ISO 1183	g/cm ³	0.944
Crystalline Melting Temperature	DIN 51756 B1	°C	130-134
Tensile Stress At Yield	ISO 527	MPa	25
Modulus of Elasticity	Speed 50 mm/min	MPa	870
Elongation at Yield	Test Specimen 1B	%	10
Impact Strength	21	kJ/m ²	no failure
(Charpy)	0°C	kJ/m ²	no failure
	-10°C	kJ/m ²	no failure
Coefficient of Linear Thermal Expansion	YDA 234-74m 100	1/°C	1.5x10 ⁻⁴
Thermal Conductivity at 23°C	DIN 51755	W/mK	0.24
Specific Heat at 23°C	ASTM D 1268	J/kgK	2.0

3.1.2 Low Density Polyethylene (LDPE) (PETKIM-G 83-5)

It was supplied in the form of pellets, and used as one of the components in the extruded polymer blend.

3. EXPERIMENTAL WORK

Table 3.2. LDPE specifications

Property	Test Method	Unit	Value
Melt Flow Rate	ASTM D-1238	g/10 min	0.43
Density at 23°C	ASTM D-1505	g/cm ³	0.919 - 0.922

3.1 Materials and Chemicals

3.1.1 Polypropylene Random Copolymer (PP-RC) (Vestolen P 9421)

It was supplied in the form of pellets, and used as one of the components in the extruded polymer blend.

Table 3.1. Mechanical and thermal properties of Polypropylene Random Copolymer (PP Type 3)

Property	Test Method	Unit	Value
Melt Flow Rate MFR 190/5	ISO 1133 Condition 18	g/10 min	0.43
MFR 230/2.16	ISO 1133 Condition 12	g/10 min	0.3
MFR 230/5		g/10 min	1.5
Density at 23°C	ISO 1183	g/cm ³	0.898
Crystalline Melting Temperature	DIN 53736 B2	°C	150-154
Tensile Stress At Yield	ISO 527	N/mm ²	25
Modulus of Elasticity	Speed 50 mm/min	N/mm ²	850
Elongation at Yield	Test Specimen 1B	%	12
Impact Strength RT	ISO 179/1eU	kJ/m ²	no failure
(Charpy) 0°C		kJ/m ²	no failure
-10°C		kJ/m ²	no failure
Coefficient of Linear Thermal Expansion	VDE 0304 Part 1&4	K ⁻¹	1.5x10 ⁻⁴
Thermal Conductivity at 20°	DIN 52612	W/mK	0.24
Specific Heat at 20°C	Adiabatic Calorimeter	kJ/kg K	2.0

3.1.2 Low Density Polyethylene (LDPE) (PETKİM- G 03-5)

It was supplied in the form of pellets, and used as one of the components in the extruded polymer blend.

Table 3.2. LDPE specifications

Property	Test Method	Unit	Value
Melt Flow Rate (MFR 190/2.16)	ASTM D-1238	g/10 min	0.2 - 0.4
Density at 23°C	ASTM D-1505	g/cm ³	0.919 - 0.923

3.1.3 Ethyl Alcohol

It was used as an anti-freeze agent in Charpy Impact Test.

3.2 Equipments

3.2.1 Extruder

Pipe samples were extruded with a grooved feed extruder, Weber NE 7 007-1994

Table 3.3. Specifications of extruder Weber NE 7

Screw diameter- Ø mm	75
L:D ratio	30
Extrusion height	1000 mm
Heating zones	6+1
Cooling zones	5
Drive	D.C. drive approx. 38 kW
Net weight	3200 kg

3.2.2 Pendulum Impact Testing Machine

The relative susceptibility of the standard test specimens to the pendulum type impact load was measured. Charpy Method was used with Zwick pendulum impact testing machine with 15 J and 50 J rated initial potential energies.

3.2.3 Cooler

Specimens used for the impact tests were kept at 0 ± 2 °C and -10 ± 2 °C with Nüve ES 500 cooler.

3.2.4 Melt Flow Rate Apparatus

Melt flow rates of both raw materials and all pipe samples with different compositions were measured with a Zwick melt flow rate apparatus.

3.2.5 Oven

Kerman oven was used for heat reversion tests at 135 ± 2 °C.

3.2.6 Hydraulic Burst Strength Tester

IPT 1568/1575 hydraulic burst strength tester was used to determine the ability of a plastic pipe to resist rupturing when it was pressurized for a short period of time.

3.3 Sample Preparation and Testing

3.3.1 Pipe Extrusion Process

20 kg blends of PP-RC and LDPE with different compositions were extruded as pipe samples with an outer diameter of 20 mm and wall thickness of 3.4 mm.

During the extrusion operation, screw speed, mass per length, cooling water temperature, vacuum pressure and temperatures around the barrel were kept constant. These constant values are given in Table 3.4. and Table 3.5.

Table 3.4. Temperatures around the barrel

Resistance Temperatures	Tset (°C)
Zone 1	26
Zone 2	185
Zone 3	190
Zone 4	195
Zone 5	195
Zone 6	197
Zone 7	198
Zone 8	201
Zone 9	202
Zone 10	205

Table 3.5. Constant parameters during extrusion.

Mass per length (kg/m)	0.167-0.169
Screw Speed (rpm)	48-50
Cooling water temperature (°C)	16-17
P vacuum (bar)	12

The effects of blend composition on die pressure, screw torque, flow rate, and puller speed were the observed variables.

3.3.2 Melt Flow Rate

Firstly, the piston was put in the cylinder and allowed to descend under gravity, until a bubble-free filament was extruded. Then, the cylinder was charged with 4 g of the pipe sample pieces according to ISO 1133 requirements. During charging, the material was compressed with a packing rod, using hand pressure. To ensure a

charge as free from air as possible for material susceptible to oxidative degradation, the charging process was completed in 1 minute.

Four minutes after completing the introduction of the test sample, during which time the temperature returned to 190°C, the 5 kg load was placed on the piston. The time for this operation did not exceed 1 minute. The extrudates were cut off with the cutting tool, and discarded. When the lower reference mark reached the top edge of the cylinder, the timer was started, and simultaneously the extrudates were cut off with the cutting tool and again discarded.

Then successive cut-offs were collected in order to measure the extrusion rate at time intervals, depending on the melt flow rate, so chosen that the length of a single cut-off was not less than 10 mm and preferably between 10 mm and 20 mm.

Cutting was stopped when the upper mark on the piston stem reached the top edge of the cylinder. Any cut-off containing visible air bubbles were discarded. After cooling, weighed individually, to the nearest 1 mg, the remaining cut-offs, which were number at least three, and their average mass was calculated [11].

Figure 3.1 Pipe sections prepared in DIN 8078.

3.3.3 Impact Strength Test

In accordance with DIN 8078, specimens were prepared from the pipes in the form of pipe sections (100mm±2 long) and were placed in a cooler at 0±2 °C for 1 hour.

Testing was carried out on ten specimens using a DIN 51222 pendulum impact testing machine with 15 J rated initial potential energy [12].

The test specimens taken from the cooler was mounted horizontally and supported at both ends. The pendulum hammer was released, allowed to strike the specimen, and swung through. The impact values were read directly in Joules from the scale. It was established whether the specimens fail. Only the specimens that break completely were considered acceptable [2].

When a result could not be obtained with the initial conditions, the test was carried out again with, firstly, increasing the rated initial potential energy to 50 J and then decreasing the specimens' temperatures to -10±2 °C.

3.3.4 Burst Strength Test

According to the DIN 8078, three sections of pipe were taken as specimens and were cut to the following lengths:

$$\text{for } d_2 \leq 250 \text{ mm: } l_1 = 3 d_2 + 2 l_5 + 250 \text{ mm;} \quad (3.1)$$

$$\text{for } d_2 > 250 \text{ mm: } l_1 = 1000 \text{ mm} + 2 l_5 \quad (3.2)$$

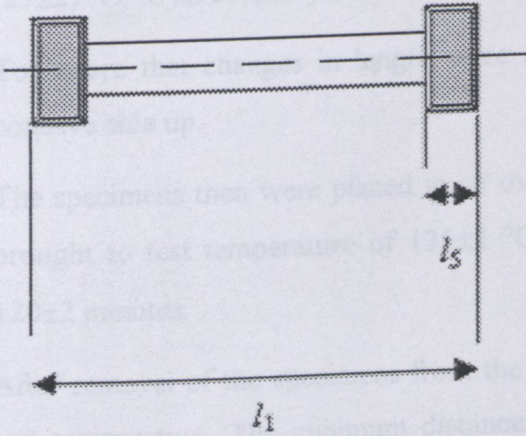


Figure 3.1 Pipe sections mentioned in DIN 8078.

In the above equations and Figure 3.1,

d_2 is the pipe outside diameter, in mm;

l_1 is the specimen length, in mm;

l_5 is the length, in mm, required for fixing the end sealing devices.

The lengths of the specimens were calculated as 34 cm, using the Equation 3.1.

Sealing devices were fitted at both ends of the specimens of 34 cm in length which were remained free to move in the axial direction during the test. Pipes were filled with water at 20 °C through an aperture in one of the sealing devices.

Finally, the pressure in the pipe then was steadily increased until the failure occurs [12].

3.3.5 Heat Reversion Test

Heat reversion test was carried out on the lines of DIN 8078. Either three complete sections of pipe, each about 200 mm long, were used as specimens.

A mark was scribed on the external surface approximately 50 mm from each end of the pieces so obtained, in the axial direction of the pipe. The distance between the two marks, l_0 (reference length), was approximately 100 mm and measured, at $(23 \pm 2)^\circ\text{C}$, to an accuracy of 0.25 mm.

To ensure that changes in length were not obstructed, the specimens were placed concave side up.

The specimens then were placed in an oven with forced air circulation that had been brought to test temperature of $135 \pm 2^\circ\text{C}$. The specimen were kept in the oven for 120 ± 2 minutes.

After removal of the specimens from the oven, they were left to cool in air down to test temperature. The minimum distance between the gauge marks, l_{min} , then were measured.

The relative change in length, ε , as a percentage, was calculated using Equation 3.3.

$$\varepsilon = [(l_0 - l_{min}) / l_0] \times 100 \quad (3.3)$$

where

l_0 is the distance between the gauge marks before thermal treatment;

l_{min} is the distance between the gauge marks after thermal treatment and cooling.

The mean of relative changes in length, ε , calculated from the above equation, were taken as the mean relative change in length, ε , for the pipe concerned. [12].

3.4 A Word of Caution

It is extremely important to understand that the majority of physical property tests are subject to rather large errors. As a general rule, the error of testing should be considered ± 5 percent. Such testing errors come about from three major areas: one from the basic test itself, the second from the operators conducting the tests, and the

third from the variations in the test specimens. While evaluating the test data and making decisions based on test data, one must consider the error factor to make certain that a valid difference in the test data exists [2].

4. RESULTS AND DISCUSSION

In this thesis, the effects of PP-RC/ LDPE blend composition on the mechanical properties of the resulting pipes were investigated.

The first step was the extrusion of the PP-RC/LDPE blends. For this purpose, different compositions of PP-RC/LDPE blends were prepared (Table 4.1). 100%PP-RC and 100% LDPE were also extruded to be able to make a proper comparison.

Table 4.1 PP-RC/ LDPE blend compositions in extruded samples

Sample No	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
PP-RC weight (%)	100	95	90	85	80	75	60	50	40	30	20	10	0
LDPE weight (%)	0	5	10	15	20	25	40	50	60	70	80	90	100

During the extrusion process, the extruder performance was examined by comparing the pressures, flow rates, screw torque and roller speeds according to the varying compositions of the blends.

In the second step, the mechanical tests required for sanitary system pipes like impact strength, melt flow rate, burst strength and heat resistance tests were carried out under standard test conditions for the extruded pipe samples in order to analyze the effects of composition on the mechanical properties of the pipes.

4.1 Effects of Blend Compositions on Extruder Performance

Extrusion performance depends on several factors which are themselves interdependent.

These include raw material, heating & cooling, screw geometry, die design, downstream auxiliary units, etc. etc. etc.

4. RESULTS AND DISCUSSION

In this thesis, the effects of PP-RC/ LDPE blend composition on the mechanical properties of the resulting pipes were investigated.

The first step was the extrusion of the PP-RC/LDPE blends. For this purpose, different compositions of PP-RC/LDPE blends were prepared (Table 4.1). 100%PP-RC and 100% LDPE were also extruded to be able to make a proper comparison.

Table 4.1. PP-RC/ LDPE blend compositions in extruded samples.

Sample No	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
PP-RC weight (%)	100	95	90	85	80	70	60	50	40	30	20	10	0
LDPE weight (%)	0	5	10	15	20	30	40	50	60	70	80	90	100

During the extrusion process, the extruder performance was examined by comparing die pressures, flow rates, screw torques and puller speeds according to the varying compositions of the blends.

In the second step, the mechanical tests required for sanitary system pipes like impact strength, melt flow rate, burst strength, and heat reversion tests were carried out under standard test conditions for the extruded pipe samples to be able to analyze the effects of composition on the mechanical properties of the pipes.

4.1 Effects of Blend Composition on Extruder Performance

Extrusion performance depends on several factors which are themselves interdependent.

These include: raw material, heating & cooling, screw geometry, die design, downstream auxiliary units, drive trains, etc.

During extrusion process, screw speed, mass per length, cooling water temperature, vacuum pressure and temperatures around the barrel were kept constant. These constant values are given in Table 3.4 and Table 3.5. The die pressure, screw torque, flow rate, and puller speed were the observed parameters during the extrusion process.

4.1.2 Screw Torque

4.1.1 Die Pressure

Extrusion die determines the dimensions and quality of the plastic extrudate from a screw extruder. Therefore, use of a well-designed extrusion die is essential to assure the quality of the extruded product. Design of an extrusion die requires an analysis of the velocity as well as pressure field for the polymeric flow inside the die. For the desired throughput, the pressure required at the die entrance should not exceed the pressure available at the screw channel exit, which depends upon the screw speed. Therefore, at a constant screw speed, an excessively restrictive flow in the die leads to a reduction in the throughput [1,8].

Die pressure was one of the observed variables during the extrusion operation. Die pressure as a function of LDPE content in PP-RC/ LDPE blends is given in Figure 4.1.

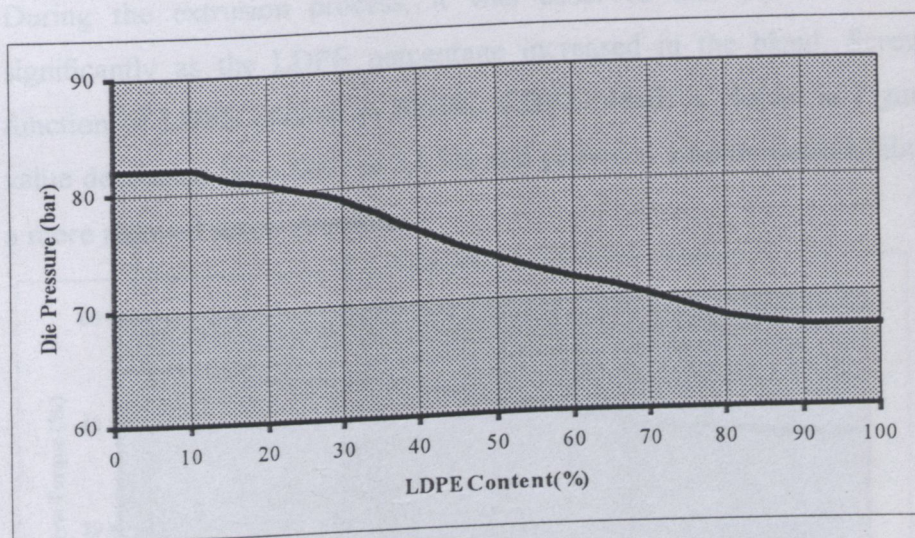


Figure 4.1 Die pressure as a function of LDPE content in PP-RC/ LDPE blends.

As the ratio of LDPE in the feed composition increased, the die pressure reduced significantly from 82 to 67 bars. Even the slightest pressure drop makes the extrusion operation more facilitated. At least it improves the wear resistance for long-term

applications. Although this decrease in die pressure ensures a lower power consumption, it must be kept within limits since the buildup of pressure is required in order to pump the melt through the die and give the desired shape and size to the finished product. In addition, a reasonable back pressure improves melt uniformity.

4.1.2 Screw Torque

Torque is a measure of how much a force acting on an object causes that object to rotate. The measurement of torque is essential in extrusion, being concerned with the transmission of power from the drive train to the extruder screw for 'pushing-in' the process material through the entire extruder length.

In extrusion process the viscosity/shear rate relationship for each polymer melt is extremely important in determining the melt temperature rise and the screw power consumed in the metering section. Good speed control is crucial to assure that adequate resin is being fed to the process.

Maintaining the required pressures to get consistent flow to reduce gauge variations and pipe imperfections is equally important. In addition, a precise motor control helps processors dramatically to reduce overhead expenses.

During the extrusion process, it was observed that the screw torque dropped significantly as the LDPE percentage increased in the blend. Screw torque as a function of LDPE content in PP-RC/ LDPE blends is plotted in Figure 4.2. Torque value decreased from 50% to 33.5% and provided a better extrudability by supplying a more relieved screw rotation.

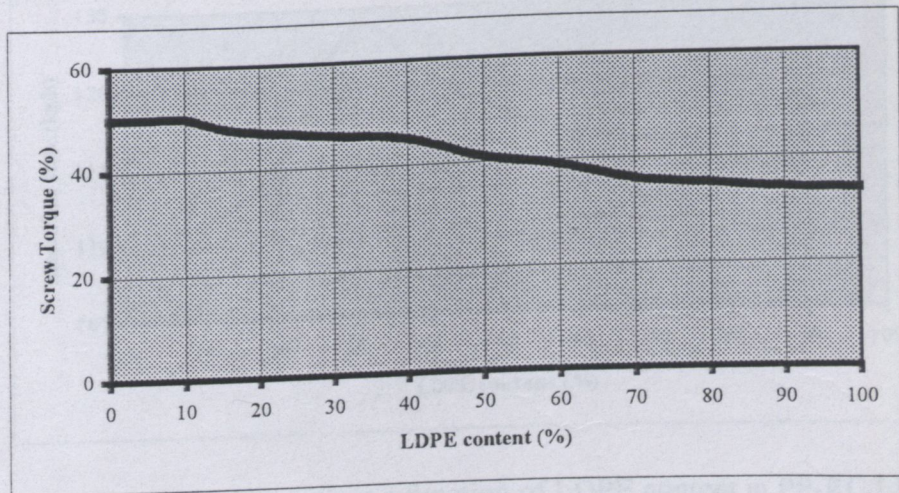


Figure 4.2 Screw torque as a function of LDPE content in PP-RC/ LDPE blends.

Although the decrease in screw torque provides a lower power consumption, it must be kept within limits to be able to push in the process material through the entire extruder length and not to lead a reduction in the output with a restrictive flow through the barrel.

4.1.3 Mass Flow Rate

Mass flow rate value is one of the main criteria for the evaluation of extruder performance since it directly shows the output rate of the process. Frequently an increase in output is required without loss in quality or quality must be improved without loss of output.

During the extrusion process while the mass per length (kg/m) value could be set, the mass flow rate could not. The mass per length value of pipe must be determined before the process to obtain standard sized pipes and the mass flow rate should be adjusted according to this value. Mass flow rate could not be set before the operation because process conditions, raw material conditions, feeding conditions could not be always kept constant. For instance, batch-to-batch variation is a common encountered problem for raw materials. During processing if a raw material with a higher viscosity than usual is employed, mass flow rate should be lower than normal values to obtain the same weighed pipes.

In Figure 4.3 mass flow rate is given as a function of LDPE content in PP-RC/LDPE blends.

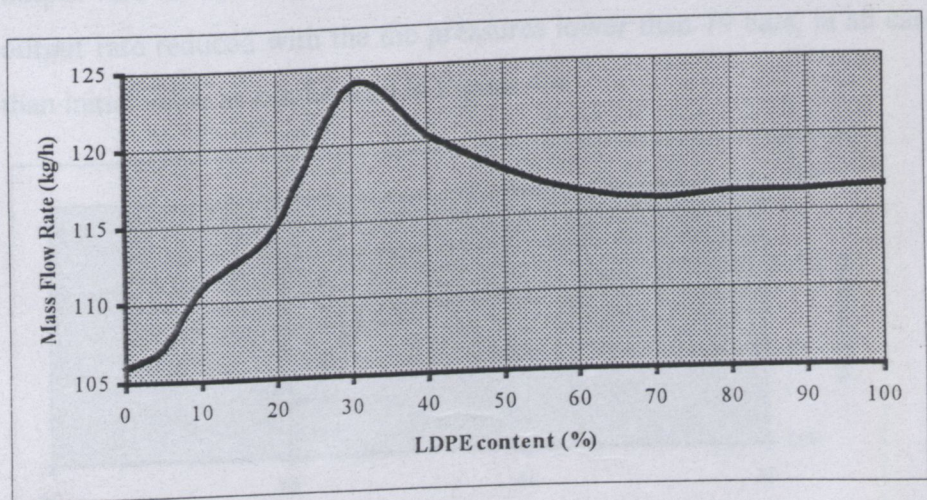


Figure 4.3 Mass flow rate as a function of LDPE content in PP-RC/LDPE blends.

The mass flow rate started to increase from the 106 kg/h up to 124 kg/h as LDPE content increased. After reaching its maximum value with S 6 (30% LDPE) blend, output rate decreased and stabilized at around 115-117 kg/h. Even though the output rate started to decrease with the S 7 (40% LDPE) blend, in all cases it is higher than initial value as can be seen in Figure 4.3

Extruder performance was analyzed by graphical studies based on die pressure and screw torque data. Output is given as a function of die pressure and screw torque in Figure 4.4 and Figure 4.5, respectively.

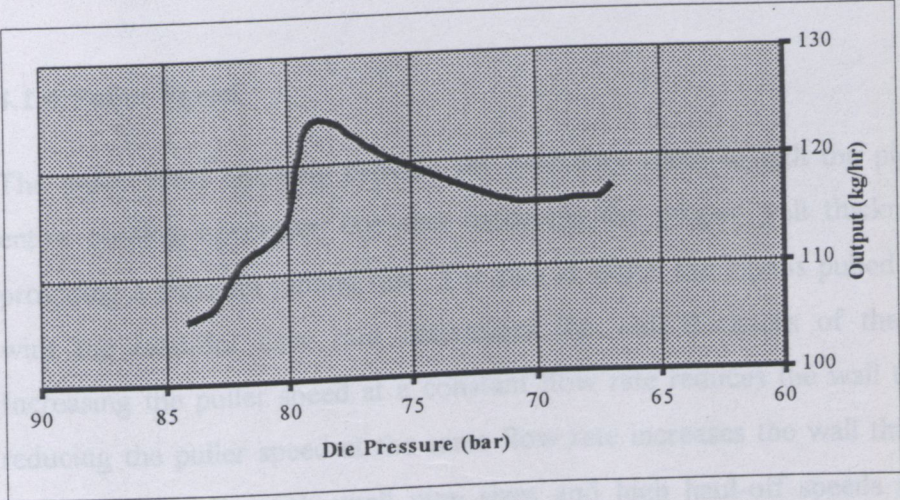


Figure 4.4 Mass flow rates as a function of die pressure.

The output rate increased as die pressure decreased from 84 to 67 bars and reached its maximum value of 124 kg/h with a die pressure of 79 bars. After making a peak, output rate lowered and stabilized with die pressures around 70-67 bars. Even if the output rate reduced with the die pressures lower than 79 bars, in all cases it is higher than initial value as can be seen in Figure 4.4.

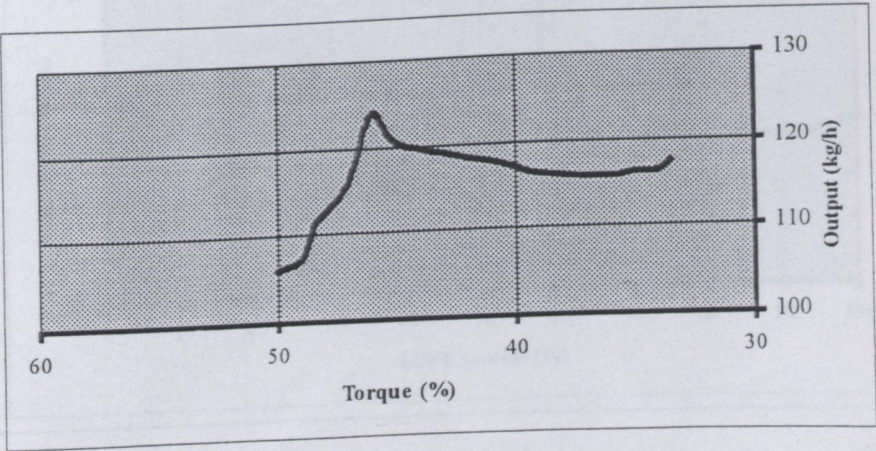


Figure 4.5 Mass flow rate as a function of screw torque.

The output rate increased as screw torque value decreased from 50% to 33.5% and reached its maximum value of 124 kg/h with a torque value of 46%. After making a peak, output rate lowered and stabilized with torque values around 39-34%. Although the output rate decreased with the torque values lower than 46%, in all cases it is higher than initial value as can be seen in Figure 4.5.

It is obvious that die pressure and screw torque values must be kept within limiting values for obtaining the highest possible performance and an operating point should be defined by considering not only the output as a function of blend composition but also the interaction with die pressure and screw torque.

4.1.4 Puller Speed

The puller must not only provide the necessary force to pull the pipe through the entire cooling operation, but also maintains the proper wall thickness control by providing a constant pulling rate. The rate at which the pipe is pulled in combination with the extruder flow rate determines the wall thickness of the finished pipe. Increasing the puller speed at a constant flow rate reduces the wall thickness, while reducing the puller speed at the same flow rate increases the wall thickness [43]. In addition especially with small pipe sizes and high haul-off speeds it can limit the output and hence has an effect on the economics of the plant.

Puller speed was also one of the variables that was adjusted according to the constant mass per length value of pipe during the extrusion operation. In Figure 4.6 puller speed as a function of LDPE content in PP-RC/ LDPE blends is plotted.

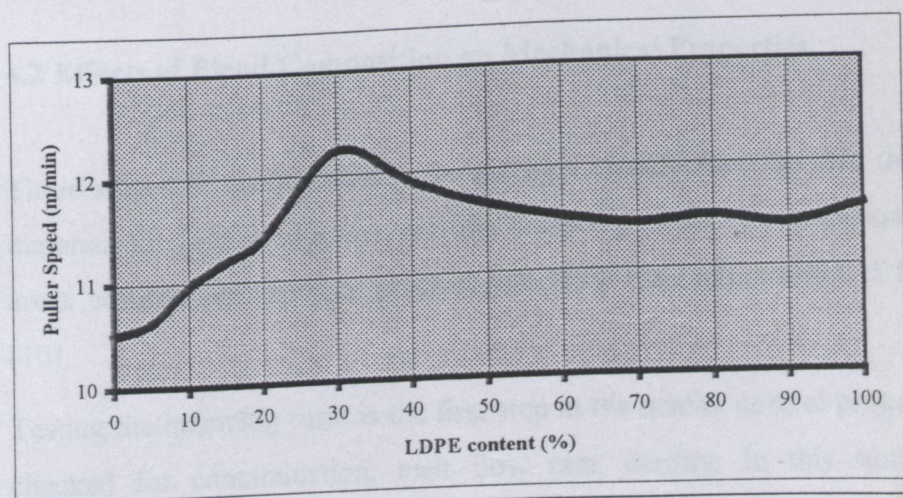


Figure 4.6 Puller speed as a function of LDPE content in PP-RC/ LDPE blends.

The puller speed increases as LDPE content increases and reaches its maximum value of 12.24 m/min with S 6 (30% LDPE) blend, as indicated also for the mass flow rate. Starting with a speed of 10.5 m/min and after making a peak, puller speed stabilized at around 11.4-11.5 m/min.

In the below graph in Figure 4.7 the combination between the extruder output rate and the puller speed can be seen.

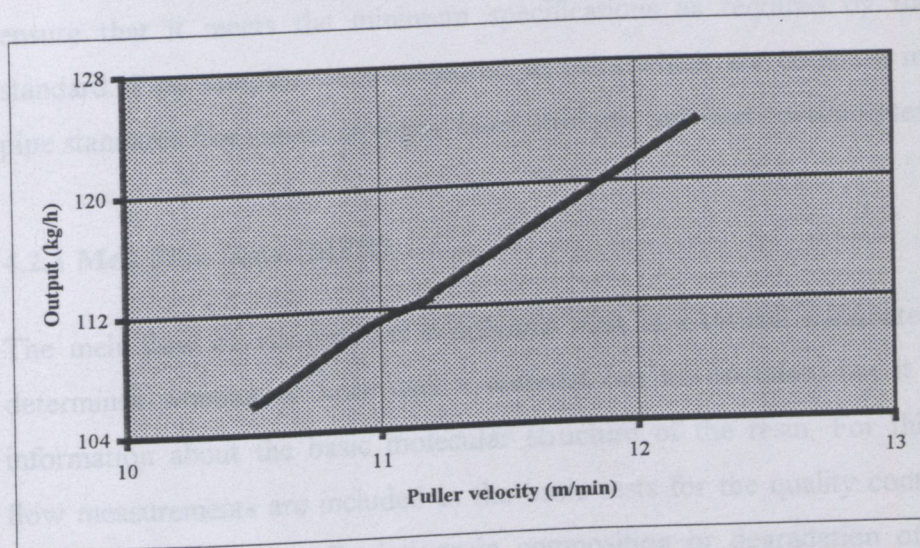


Figure 4.7 Mass flow rates as a function of puller speed.

Both of these parameters could not be set before the extrusion operation. Puller speed is dependent on mass flow rate and operates according to the variations in output rate. Both of these values adapt automatically to a variation in raw material, feeding or process conditions for obtaining standard sized pipes

4.2 Effects of Blend Composition on Mechanical Properties

Three stages of quality control for the pipe manufacturer involve the incoming raw material, the pipe production, and the finished product. The combination of all three areas ensures that the final product will fulfill the requirements of the specification [10].

Testing the incoming resin is the first step in the quality control program. It is usually checked for contamination, melt flow rate, density. In this study both of raw materials, PP-RC and LDPE, were tested for their melt flow rates in the first step.

During the manufacturing step, the pipe producer routinely performs quality assurance tests on samples. To understand how a plastic behaves during processing, plastic melt flow behaviour should be known. Melting performance influences solids conveying, temperature profile and pressure development. For this purpose, after extrusion process, pipe samples were examined for their melt flow rates.

Once the product has been produced, it undergoes a series of quality control tests to ensure that it meets the minimum specifications as required by the appropriate standard. Pipe samples were subjected to tests which are common in most plastic pipe standards like impact strength, burst strength, and heat reversion tests.

4.2.1 Melt Flow Rate (MFR)

The melt flow or viscosity of a polymer melt is a critical parameter. It not only determines whether or how well a material can be extruded, but it also provides information about the basic molecular structure of the resin. For this reason melt flow measurements are included in the basic tests for the quality control of plastics compounds and resins. Deviations in composition or degradation of the polymer, which may lead to failure of the extruded product, can be predicted by observing changes in the resin or compound's melt viscosity.

This test was carried out for both raw material, PP-RC, LDPE, and for all pipe samples for at least three times according to ISO 1133 requirements. MFR values of PP-RC and LDPE were found as 0.43 g/10 min and 1.08 g/10, respectively, under the conditions of 5 kg nominal load at 190°C.

In Figure 4.8, the graph of average MFR values of pipe samples as a function of LDPE content is plotted. MFR values increases from 0.41 g/10 min to 1.05 g/10 min with the increasing rate of LDPE content in the blend. These minimum and maximum values belong to pure PP-RC and LDPE pipes.

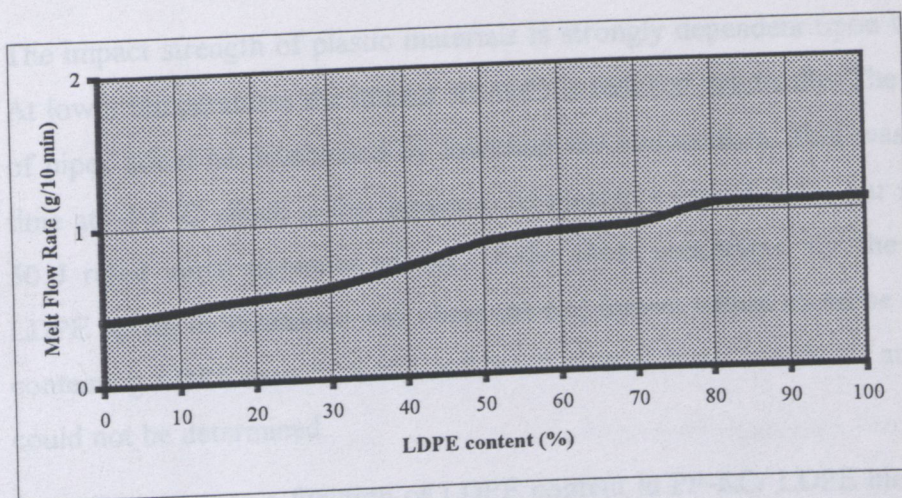


Figure 4.8 Average MFR values of pipe samples as a function of LDPE content.

In this study, the parameters determining the extrusion performance, like output rate, die pressure, screw torque and puller speed, were affected directly from the melt flow rate of the polymer blends including different amounts of LDPE.

4.2.2 Impact Strength

Impact strength is one of the most widely specified mechanical properties of the polymeric materials. However, it is also one of the least understood properties. Predicting the impact resistance of plastics still remains one of the most troublesome areas of product design. One of the problems with some earlier Izod and Charpy impact test was that the tests were adopted by the plastic industry from metallurgists. The principles of impact mechanisms as applied to metals do not seem to work satisfactorily with plastics because of the plastics' complex structure [2].

This test had to be carried out with three different conditions for each sample.

According to DIN 8078 requirements pipe samples should not break with a 15 J rated initial potential energy pendulum type impact tester at 0°C. When all pipe samples were subjected to this test under these conditions, none of them was broken.

To make a comparison and determine their impact strength, a test condition should be obtained in such a way that to break the pipes. For this purpose, the load was increased to 50 J which is given as a maximum rated initial potential energy in DIN 51 222 standards for plastics.

After the test was repeated, it was seen that the result did not change. Even with this load, impact strength could not be determined since the pipes did not break.

The impact strength of plastic materials is strongly dependent upon the temperature. At lower temperatures the impact strength is reduced drastically. The impact strength of pipes could be determined by lowering the temperature. Test was performed this time at $-10\text{ }^{\circ}\text{C}$ which is the minimum temperature provided for our system and with 50 J rated initial potential energy. Under these conditions, for the pipes including LDPE up to 50 %, failure was observed and impact values could be measured. Pipes containing LDPE over 50% did not break even at these conditions and impact values could not be determined.

Impact strength as a function of LDPE content in PP-RC/ LDPE blends is plotted in Figure 4.9.

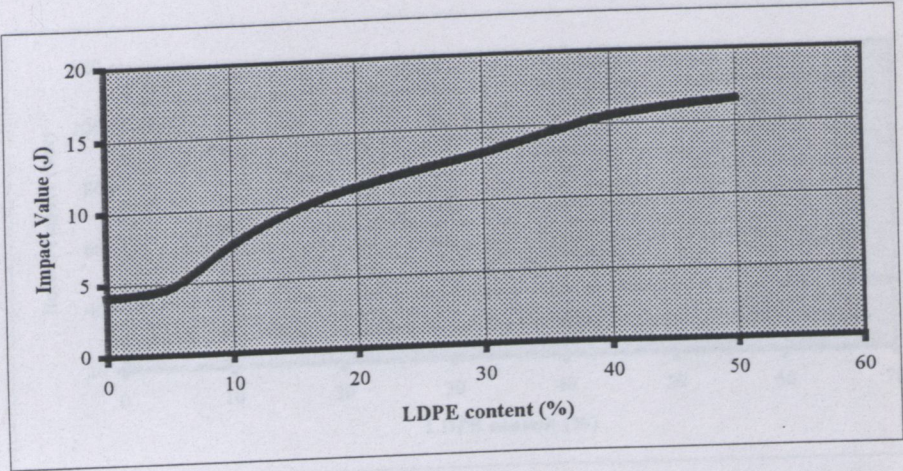


Figure 4.9 Impact strength as a function of LDPE content in PP-RC/ LDPE blends.

The impact strength increases with the increasing LDPE content in PP-RC/ LDPE blends.

4.2.3 Quick-Burst Strength

One of the most important properties of a polymer material used for hot and cold water pressure pipes is its resistance to internal pressure. It is necessary to determine the ability of a pipe to resist rupturing when it is pressurized for a short period of time to see the effects of a pressure rise in a pipeline caused by a sudden change in the rate of flow or stoppage of flow in the line [2].

This test was carried out three times for each sample by simply pressurizing the specimen and uniformly increasing the pressure until the rupture occurs.

During testing, determining the burst strength of the pipe samples with LDPE content over 50% (S 8) was difficult due to the occurring leakages. For the S 9 (% 60 LDPE) and S 10 (% 70 LDPE) pipe samples, this test had to be carried out with six samples to be able to ensure with the bursting pressure results. But for the S 11 (% 80 LDPE), S 12(% 90 LDPE) and S 13(% 100 LDPE) pipes burst pressures could not be determined since none of them could resist without leaking.

In the figure below the burst strength as a function of LDPE content is given (Figure 4.10). As the LDPE content increases, burst strength decreases from 100 bars to 42 bars. In sanitary installations, PP-RC pipes should resist to an internal pressure of around 70-80 bars.

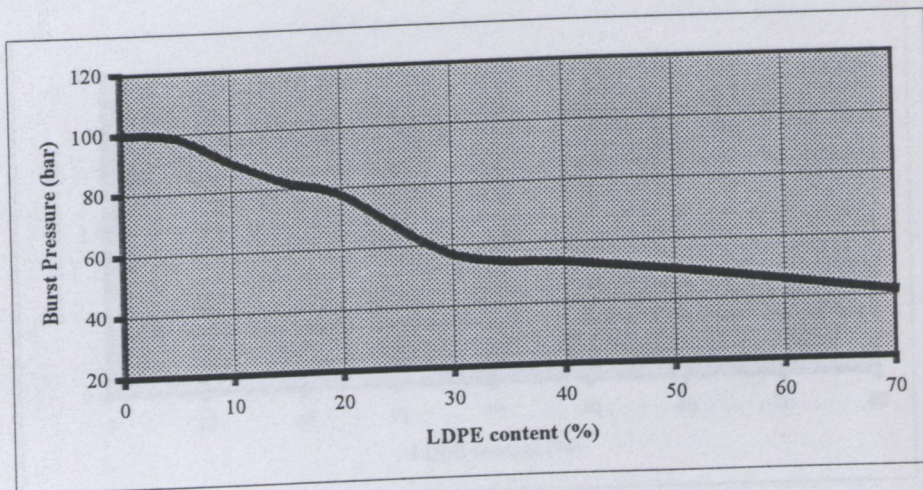


Figure 4.10 Burst pressure as a function of LDPE content.

The leakages of S 11 (% 80 LDPE), S 12 (% 90 LDPE) and S 13 (% 100 LDPE) pipe samples arose from around the welding parts and it was certain that these pipes could not be jointed properly by socket welding which is a crucial requirement for sanitary system applications.

4.2.4 Heat Reversion

The coefficient of linear thermal expansion is defined as the fractional change in length of a material for a unit change in temperature [2].

Plastics tend to expand and contract anywhere from six to nine times more than materials such as metals. This difference in the coefficient of thermal expansion develops internal stresses and stress concentrations in the polymer, and premature failures occur. For transportation of hot water we have to deal with linear expansion.

During the planning and laying of visible pipes for hot water on ceiling or walls, special attention must be given to the linear expansion due to temperature to prevent sagging and "snaking" of pipe lines. In concealed installation, for both cold or hot water pipe lines, it is not necessary to take into account linear expansion. Pipes can be encased or embedded in walls, concrete and plaster. The expansion of pipe due to temperature will not damage the wall plastering as the linear expansion is prevented by the compressive strain and tensile stress of concrete and plaster, it will be absorbed through the material itself.

Heat reversion test is carried out mainly for hot water pipes. According to DIN 8078 requirements, the mean relative change in pipe length shall not exceed 2%.

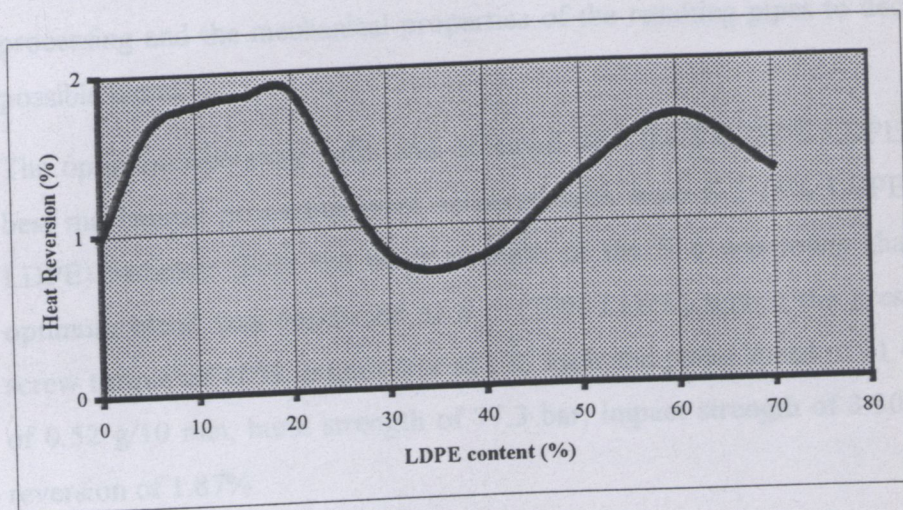


Figure 4.11 Heat reversions as a function of LDPE content.

In the graph above heat reversion as a function of LDPE content was plotted (Figure 4.11). A linear relationship could not be observed between the heat reversion values and LDPE content. For the S 11 (% 80 LDPE), S 12 (% 90 LDPE) and S 13 (% 100 LDPE) pipe samples heat reversion could not be determined since they melted and lost their shapes in the oven. The mean relative change in length of other pipe samples did not exceed 2% as required.

5. CONCLUSION

In order to develop new applications for PP-RC piping systems, blends containing PP-RC and LDPE resins with different mechanical and thermal characteristics were compounded at different ratios and subsequently extruded as a pipe form.

The main parameters that should be considered are the extruder performance during processing and the mechanical properties of the resulting pipes to decide on the best possible blend.

The optimum operating point was obtained with the S 6 (30% LDPE) blend and the best mechanical properties were achieved with from S 2 (5% LDPE) to S 5 (20% LDPE) samples. Since the burst strength of the S 6 was lower than required, the optimum blend was concluded as S 5 (20% LDPE) with a die pressure of 80 bar, screw torque of 47 %, output rate of 115 kg/h and puller speed of 11.40 m/min; MFR of 0.52 g/10 min, burst strength of 77.3 bar, impact strength of 3.30 kJ/m, and heat reversion of 1.87%.

The next level of this project should involve extrusion of this blend in different sized pipes and with incorporating additives which affect the processing characteristics of a material such as stability and flowability.

In addition it is crucial for such a product to meet the regulations for materials in contact with drinking water since pipes and fittings made of polyolefin are mainly used to transport drinking water.

REFERENCES

- [1] **Zehner Tadmor and Costas G. Gogos**, 1979. *Principles of Polymer Processing*, edited by John Wiley & Sons, New York.
- [2] **Vishu Shah**, 1984. *Handbook of Plastic Testing Technology*, edited by John Wiley & Sons, New York.
- [3] **Karl Ebner**, 2001. APPA 012: Latest trends and developments of PP for piping applications report, Stenungsund, Sweden
- [4] **Herman F. Mark, Norbert M. Bikales, Charles G. Overberger and Georg Menges**, 1988. *Encyclopedia of Polymer Science and Engineering* edited by John Wiley & Sons, New York, Volume 13.
- [5] **Joseph C. Salamone**, 1996. *Polymeric Materials Encyclopedia*, CRC Press, New York, Volume 9.
- [6] **R. Bresser and A. Sallaberger**, 2000. APPA 001: PP-R for demanding plumbing and heating applications report, Stenungsund, Sweden
- [7] **Joseph C. Salamone**, 1996. *Polymeric Materials Encyclopedia*, CRC Press, New York, Volume 3.
- [8] **Herman F. Mark, Norbert M. Bikales, Charles G. Overberger and Georg Menges**, 1986. *Encyclopedia of Polymer Science and Engineering* edited by John Wiley & Sons, New York, Volume 6.
- [9] **I.M. Ward and D.W. Hadley**, 1993. *An Introduction to the Mechanical properties of Solid Polymers*, edited by John Wiley & Sons, New York.
- [10] **The Plastic Pipe Institute**, 2000. *PPI Handbook of Polyethylene Piping*, www.plasticpipe.org
- [11] **ISO 1133**, 1997. Plastics- Determination of the melt mass flow rate (MFR) and the melt volume flow rate (MVR) of thermoplastics, *International Organization for Standardization*.
- [12] **DIN 8078**, 1996. Types 1, 2 and 3 polypropylene (PP) pipes-General requirements and testing, *Deutsches Institut für Normung*, Berlin
- [13] **ASTM Volume 08.04**, 1989. Plastic Pipe and Building Products, *American Society for Testing and Materials*, Philadelphia

- [14] **ISO 12162**, 1995. Thermoplastics materials for pipes and fittings for pressure applications- classification and designation-overall service (design) coefficient, *International Organization for Standardization*.
- [15] **ISO 4065**, 1996. Thermoplastic pipes-Universal wall thickness table, *International Organization for Standardization*.
- [16] **DIN 8077**, 1999. Polypropylene (PP) pipes-Dimensions, *Deutsches Institut für Normung*, Berlin
- [17] **DIN 51 222**, 1996. Pendulum impact testing machines with a rated initial potential energy of 50 J or less, *Deutsches Institut für Normung*, Berlin

AUTOBIOGRAPHY

Enise Selcen UYGUR was born in Gaziantep in 1979. She was graduated from Bursa Anatolian High School in 1997. She admitted to Middle East Technical University, Chemical Engineering Department and graduated as a chemical engineer in 2001.

She was registered as M.Sc. student to the Polymer Science and Technology Programme of the Institute of Science and Technology of Istanbul Technical University in 2001 under the guidance of Professor Dr. Ayşen Önen.