Abstract

The purpose of this research paper was to enhance the properties of Poly Propylene Random Copolymer (PPRC) pipes using poly olefins polymers such as Polyethylene (PE).

Three types of polymers were used; High Density Poly Ethylene (HDPE), Low Density Poly Ethylene (LDPE) and Linear Low Density Poly Ethylene (LLDPE); each additive was used in percentages of 10%, 20% and 40%, added to the PPRC.

This was done using an extruder where the raw material of PPRC and the additive were inserted directly and let to heat and mix, then a sample of 2m was taken out of each to perform tests on it and based on those tests the optimum case was obtained.

From the samples of the HDPE polymers the best one was the 10%, as it showed 24% increase in strength, only 6% decrease in toughness and a 50% increase in ductility.

From the LDPE samples also the sample with 10% polymers showed the best results as it had a 14% increase in tensile strength, 11% increase in toughness and an 88% increase in ductility.

But the ultimate best sample was the 10% polymers in HDPE compared to the others, and it is the recommended additive percentage to be used in future work in the company.

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# Chapter 1

# Introduction

Polymers are substances with high molar masses and are composed of a large number of repeating units. There are both naturally occurring such as proteins, starches, cellulose, and latex, and synthetic polymers which are produced commercially on a very large scale and have a wide range of properties and uses such as plastics.

Polymers are formed by chemical reactions in which a large number of monomers are joined sequentially; one, two or three different monomers may be combined, forming a chain. Polymers are classified by the characteristics of the reactions by which they are formed. [1]

After 1920’s Staudinger proposed molecular weights were made up of macromolecules composed of 10,000 or more atoms. He formulated a polymeric structure for rubber, based on a repeating isoprene unit (referred to as a monomer). The terms polymer and monomer were derived from the Greek roots poly (many), mono (one) and mers (part).
Recognition that polymeric macromolecules make up many important natural materials was followed by the creation of synthetic analogs having a variety of properties. Indeed, applications of these materials as fibers, flexible films, adhesives, resistant paints and tough but light solids have transformed modern society. [2]

Polymers are divided into two main groups, thermosets and thermoplastics Polyethylene and Polypropylene are examples of the latter, and they are both used in different applications as engineering polymers.

One of these applications is using them in piping systems, mainly for the transportation of water, while polyethylene is used to transport cold water; polypropylene is used for the transportation of both hot and cold water.

Polypropylene is a thermoplastic belonging to the polyoleﬁn group which has a semi-crystalline material and a density lower than that of other well-known thermoplastics.

Its mechanical characteristics, chemical resistance and its relatively high heat deﬂection temperature have made it one of the most important materials used in piping installations today.

Polypropylene is manufactured from low molecular weight [natural gas](http://www.wisegeek.com/what-is-natural-gas.htm) components or petroleum distillation byproducts. As polypropylene pipes possess less density than other thermoplastics and certainly much less dense than steel, iron, or [copper](http://www.wisegeek.com/what-is-copper.htm) pipes, transportation costs are lower. [3]

Properties of Polypropylene:

1. Polypropylene is a lightweight material.
2. Its tensile strength is quite high. It shows strong resistance towards stress and cracking.
3. Polypropylene is crystalline in nature and possesses a regular geometrical shape.
4. It acts as an excellent insulator. That means, it prevents flow of electricity through it.
5. Polypropylene does not get damaged by water exposure because its moisture absorption is very low.
6. Melting point of polypropylene is 160°C. Therefore, unlike other polymers like polyethylene, it is capable of being operational at a very high temperature.
7. This polymer remains unaffected when it comes in contact with chemicals such as alkaline substances, acids, de-greasing agents, electrolytic attacks, etc. However, its resistance towards aromatic or aliphatic hydrocarbons, chlorinated solvents and ultraviolet radiation is not very strong.
8. Other Useful Properties:
9. It is a non-toxic substance.
10. It does not get stained very easily.
11. It can be easily fabricated.
12. It can retain its stiffness and flexibility intact even at very high temperatures. [4]

Polypropylene can be formed using two methods; the first one is by using the same monomer which is then called a homopolymer the other one is by using a mixture of two monomers and that is called a copolymer.

**Polypropylene Homopolymer (PPH)** is the most widely utilized. PPH offers a high strength to weight ratio and is stiffer and stronger than copolymer, this combined with good chemical resistance and weld ability allows this material to be used in many corrosion resistant structures.

**Properties: -** Resists most acids, alkalis and solvents, thermoforming performance,

Chemical- and corrosion-resistant, No moisture absorption.

Applications**: -** Homopolymers are mainly used in the following applications**,** orthotic and prosthetic devices, valve bodies, plating and anodizing process equipment, pump components, storage tanks, carpet backing, fiber bags, fiber and tape and in rope and cordage twine. [5]

**Polypropylene copolymer (PPC**) is a bit soft but has better impact strength, is tougher and more durable than PPH. Copolymer polypropylene tends to have better stress crack resistance and low temperature toughness than homopolymer at the expense of quite small reductions in other properties.

**Properties: -** High impact resistance strength, better resistance to cracking at low temperatures than other materials, no moisture absorption, more pliable than homopolymer, chemical- and corrosion resistant.

Application**; -** Thick extrusion, die cutting pads, fire Plating and anodizing process equipment, truck water and foam tanks, tanks - secondary containment, pipes and finally injection molding (caps & closures, batteries, pails, automotive).

Copolymer is divided into four groups, depending on the way the monomers are arranged to form the copolymer chain, there are four ways of doing so and they are:

1-Block copolymer**: -** is a polymer consisting of multiple sequences, or blocks, of the same monomer alternating in series with different monomer blocks. The blocks are covalently bound to each other such as AAABBBAAA fashion (A and B are different types of monomers). Block copolymers are classified based on the number of blocks they contain and how the blocks are arranged.

2-Graft copolymer**: -** Graft copolymers belong to the general class of segmented copolymers and generally consist of a linear backbone of one composition and randomly distributed branches of a different composition.  They have been prepared for many decades and have been used as impact resistant materials, thermoplastic elastomers, compatibilizers or emulsifiers for the preparation of stable blends or alloys.

3-alternating copolymer: - An alternative copolymer is a type of [polymer](http://chemistry.about.com/od/chemistryglossary/g/polymerdef.htm) consisting of two different repeating units in which the units alternate positions within the chain of the [molecule](http://chemistry.about.com/od/chemistryglossary/g/moleculedef.htm).

4- Random copolymer**: -** 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. [6-9]

The development of efficient thermo pipes since the mid of 1980s resulted in a worldwide rapid increasing use of these pipes for domestic and industrial applications. Hence the development of Polypropylene Random Copolymer or PPRC for short.

Polypropylene Random Copolymer (PPRC) Thermo-pipes have proved to be ideal for plumbing, heating, air conditioning and for a wide range of industrial and medical uses. PPRC system has been improved with the additional of a full range of PPRC fittings that can be poly-welded to thermo-pipe system creating fully watertight systems even under most severe conditions of use.[10]

Thermo pipes are made of high quality raw materials using some of the most advanced production techniques in the world. Also, engineers are required to develop piping systems for special needs.

The workability of these pipes, due to lightness (low density ρ = 898 kg/m) and flexibility is fast and easy. Together with its wide range of fitting, lightness and flexibility of thermo pipes permit an easy, stable, and fast construction of hydro thermo sanitary installations compared to conventional pipes of steel or copper. The fitting used for the pipes are brass fittings. There are some installation instructions that must be taken into consideration when installing pipes, pipes and fittings should not be directly exposed to UV radiation. Ultimately, this will lead to crystallization of its material. [11]

When using thermo pipes in space heating, hot water of changeable temperature flows within pipes; and hence raises the temperature of these pipes. The temperature variations occur in longitudinal and radial directions with destroying effect on the pipes. Because such a distribution leads to local deformations and stress concentrations, cracks will initiate at such locations. In other words, local temperature gradients will result in generating thermal stresses in the pipe. Pipe aging and pipe failure can be considered as a direct result of thermal stresses.[12]

Heating systems are one of the most important applications at homes, companies, school, universities, and other facilities. Best materials for space-heating pipes are Polypropylene Random Copolymer (PPRC) and Cross-Linked Polyethylene (PEX). These two types of thermo pipes are widely used in heating systems due to convenient properties. [13]

Thermo Pipes are important because of the following qualities:

• Low heat dissipation and energy saving:

Due to low thermal conductivity, thermo pipe systems reach their operating temperature much faster than metal piping systems do. Thus, less energy is wasted in heating the pipes and less insulation is needed.

• Low Friction Loss:

The smoothness of internal surface of pipe with no porosities leads to low friction coefficient which results in low friction loss with high velocities.

• No Corrosion Resistance:

Thermo pipes don’t rust given that their chemical resistance for most chemicals and all water types.

• Thermal Memory:

In practice, any incorrect bend or twist can be easily rectified.

• Hygienic and NontoxicThermo pipe systems are not toxic in line with current international standards, and they meet international standards for drinking water systems.

• Frost Resistance

Thermo pipe will not burst in cold weather. The elasticity of thermo-pipe material allows the pipe to increase in cross-sectional diameter according to volume of the frozen material.

• Long Life

The molecule structure of thermo-pipes material and special additives ensure a high mechanical resistance and a long life depending on operating temperature and pressure. A thermo pipe system can be expected endure for 50 years.

• Abrasion Resistance

Abrasion resistance of thermo piping is four times equal to that of metal piping, allowing higher water velocities up to 7 m/s without corrosion problems. [14]

**Literature review:**

The history of man-made fibers began at the end of the 19th century with the first semi-synthetic or regenerated materials (van Oosten 2002) and although completely synthetic polymers were developed in the early 20th century, many fibers that are now in common use were not fully exploited until the 1960s and 1970s. Isotactic polypropylene was successful from the early 1960s due to the new catalysts for polymerization developed by Ziegler and Natta in 1954 (Brydson 1999). It became an important plastic being used in many different forms and applications through a range of manufacturing processes.

Propylene was first polymerized to a crystalline isotactic polymer by Giulio Natta as well as by the German chemist Karl Rehn in March 1954.[15] This pioneering discovery soon led to large-scale commercial production of isotactic polypropylene (PP) by the Italian firm Montecatini from 1957 onwards.[16] Syndiotactic polypropylene was also first synthesized by Natta and his coworkers.

Others claimed the discovery, as often occurs when a general body of knowledge is used, and this litigation was not resolved until 1989. This very popular plastic is one that many different manufacturers use for a number of different products.[17]

Since the 1980s the production, consumption and applications of Polypropylene have increased through the application of even more efficient catalysts and property enhancements and today PP is the most common fiber used all over the world.

Moreover, Polypropylene is the second most important plastic with revenues expected to exceed US$145 billion by 2019. The demand for this material was growing at a rate of 4.4% per year between 2004 and 2012.

A large proportion of PP is used in fibers as constituents of fabrics, upholstery and carpets. Many industrial uses involve ropes, woven and non-woven fabrics and reinforcements.

The usefulness of PP depends on the retention of its properties during a prolonged service life. For instance, under mild conditions, unsterilized PP will retain its properties for long periods of time. However in most applications, exposure to heat and light will occur which accelerates oxidative degradation. The properties that make PP widely used as a fiber do not prevent the fiber from deteriorating over time when exposed to daylight and UV radiation (Lemaire et al. 1988).[18]

After searching the open literatures many studies were found. These studies could be described as the following:

1. Senol Sahin and Pasa Yayla studied the effects of processing parameters on the mechanical properties of polypropylene random copolymer, the mechanical tests showed that both the type and content of master batches in PPRC influence the degree of crystallinity and the mechanical properties of the polymer.[19]
2. H.B Chen et al researched about the fracture toughness of alpha and beta-phase polypropylene homopolymer random and block copolymer, and it was concluded from the research that first beta-crystallinity strongly increases the toughness of PP-H and PP-B. And the Beta-crystallinity may suppress the effect of rubber dispersion in PP-R however, without affecting the overall toughness response.[20]
3. In a research by Andrzej Galeski about the strength and toughness of crystalline polymer systems the researcher proved that in most polymer systems toughening relies on mechanisms promoting energy dissipative processes, also proved that toughening phenomena in crystalline polymers are believed to arise from percolation of the material with enhanced molecular mobility in layers around rubber or solid inclusions.[21]

###

# Chapter 2

# Extruder

# Extruder:

### Extrusion

Extrusion is a plastic deformation process in which a polymer melt is forced to flow by compression through the die opening of a smaller cross-sectional area.

Many materials such as polystyrene, nylon, polypropylene and polyethylene can be used in extrusion process. That means when they are heated and then pressured in a mould they can be formed into different shapes and sections.[22]

* Classification of extrusion process:

1- By direction: Direct / Indirect extrusion, Forward / backward extrusion.

2-By operating temperature: Hot / cold extrusion.

3- By equipment: Horizontal and vertical extrusion.

Extrusion equipment mainly includes dies and tooling.

The principal variables influencing the force required to cause extrusion:- Type of extrusion (direct / indirect), Extrusion ratio, Working temperature, Deformation, Frictional conditions at the die and the container wall.[23]

The figure (1) shows the extruder parts and how the pellets enter the hopper then to the screw passing through heaters to exit from the nozzle as polymer.



Figure 2.1: extrusion process.

## Types of Extruder

Plastic extruders are used to create a wide range of items, including plastic tubing, trims, seals, plastic sheets and rods. Extruder is the machine for producing more or less continuous lengths of plastic sections out of a selected type of plastic resin. There are a number of extrusion techniques available such as co-extrusion, offset extrusion, oriented extrusion, overcoat extrusion, cold extrusion, ram extrusion and much more.

The essential elements for a thermoplastic extruder are a tubular barrel, usually electrically heated; a revolving screw, ram or plunger within the barrel; a hopper at one end from which the material to be extruded is fed to the screw, ram or plunger; a die at the opposite end for shaping the extruded mass.

Extruders may be divided into two general types:

* Single Screw Extruder.
* Twin or Multiple Screw Extruders. [24]

### Single Screw Extruder

By far the most common and most versatile extruder in use today is the single-screw extruder. Single-screw extruders are characterized by two dimensions; the bore diameter (D), and the length of the barrel in bore diameters or L/D ratio. Extrusion of PPRC in the single extruder.

The extruder function is to mix and plasticize the granule or powder plastic into melting, extrude the melted material out barrel under the suitable pressure and temperature.

The extruding system of single screw extruder is composite of one screw and one barrel, electric heater, and forming mould.

Single screw extruder is applicator widely. By changing the screw structure type, it can extrude and mold different raw material plastic products.

Single screw extruder has a characteristic of low cost, simple operation, easy maintenance and convenience checking and repairing.

 In the Single screw extruder:

* Screw diameter means the outer diameter of screw parts, usually use D to represent.
* Screw L/D, it is the value that screw length/screw diameter.
* Screw rotating speed range: it means the min. speed and the max. Speed when working.
* Motor power: mean the driving motor power which drives screw to rotate the unit is Kw.
* Barrel heating power: it is the electric consumption power when heating the barrel.
* Heating zone: it is the temperature controlling zone numbers.
* Extruder capacity: it is the plasticization capacity in unit time.[25]

****

Figure 2.2: extrusion process.

### Twin Screw Extruder

Twin screw extrusion is used extensively for mixing, compounding, or reacting polymeric materials. The flexibility of twin screw extrusion equipment allows this operation to be designed specifically for the formulation being processed. For example, the two screws may be co-rotating or counter rotating, intermeshing or no intermeshing. In addition, the configurations of the screws themselves may be varied using forward conveying elements, reverse conveying elements, kneading blocks, and other designs in order to achieve particular mixing characteristics. [26]

 Although twin screw extruders can be used with any thermoplastic, their added complexity is normally acceptable only when required for special characteristics such as lower sheet heat. Common multi-screw applications include e.g. large diameter rigid PVC pipe, compounding of certain polymers, and processing of heat-sensitive materials or materials that must leave the die at relatively low temperatures.

PPRC pipe production/extrusion line/PPRC pipe making machinery is used to produce PPR pipes for cold and hot water supply. It's composed of vacuum feeding machine, hopper dryer, single screw extruder, mould, make line co-extruder, vacuum calibration and cooling tank, extended spraying cooling tank, haul off machine, cutter and stacker. PPRC cool and hot water pipe extrusion line is used by single screw extruder for extruding the pipes with various tube diameters and the wall thickness. [27]

# Chapter 3

# Modification of Polypropylene products

### Modification of Polypropylene products:

Without the use of the proper additives, polymers will not have the required characteristics; each type of polymer needs different groups of additives to enhance and to prolong the polymer lifecycle.

For polypropylene pipes we mainly need to enhance the hardness and the outdoor stability where the continuous exposure for light and the interaction with oxygen can cause significant degradation of the pipes. [28]

One must recognize additives may have a negative effect on material processing or application properties such as mold plate out, high water carryover, interference with colors or pigments, etc. Some of the more commonly used additives include:

* High density polyethylene
* Low density polyethylene
* Linear low density polyethylene

**Low density polyethylene**

It has many properties such as highly branched, though the branching is short, tough, and chemically inert and it is a poor conductor of electricity.

 Also it may be applied in making films, molded toys and articles of domestic use, pipes and squeeze bottles.

**High density polyethylene**

It has linear molecules, chemically inert, greater tensile strength and high softening temperature (l35 C).

 The applications of HDPE are used for making polyethylene coated papers and for making flexible bottles and pipes. [29]

**Linear low density polyethylene**

LLDPE liners are the ideal choice for applications which require significant material flexibility, in addition to strength and durability. Our LLDPE liners have the ability to elongate under stress, allowing them to maintain their integrity under localized differential settlement conditions without puncturing, tearing, or cracking.

 The application of LLDPE is Secondary containment for above ground storage tanks, Tank linings and Waste water treatment lagoons.[30]

###

# Chapter 4

# Experimental Work

The raw material was used in this project:

* Polypropylene random copolymer (PPRC) supplied by Carmel olefin.
* High density polyethylene (HDPE) supplied by Sabic.
* Low density polyethylene (LDPE) supplied by Westlake.
* Liner low density polyethylene (LLDPE) supplied by Carmel olefin.

This table show the percentage of row material used, that the screw extruder was used to prepare these samples and produce pipes

Table4.1: Sample Preparation.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **%LLDPE** | **%LDPE** | **%HDPE** | **%PPRC** | **Sample number** |
| 0 | 0 | 0 | 100 | **1** |
| 0 | 0 | 40 | 60 | **2** |
| 0 | 0 | 20 | 80 | **3** |
| 0 | 0 | 10 | 90 | **4** |
| 0 | 40 | 0 | 60 | **5** |
| 0 | 20 | 0 | 80 | **6** |
| 0 | 10 | 0 | 90 | **7** |
| 40 | 0 | 0 | 60 | **8** |
| 20 | 0 | 0 | 80 | **9** |
| 10 | 0 | 0 | 20 | **10** |

### Tests of polypropylene pipes

Many tests were conducted to choose the optimum sample that mach the ISO 4437 and PS standard they are:

1. **Melt Flow Rate (MFR) of Plastics**

The melt flow rate is measured by putting the plastic resin under test in a testing equipment called a melt low indexer, heating the plastic resin at 230 ˚C, making the molten plastic resin with 6g weight to flow putting 5 kg load above the hole, and measuring the weight of the plastic that flows out during 10 min, as an index of the melt flow rate. The method of this test has been stipulated ISO standards that is not be exceed 1.2g/10min.
so it is necessary to understand well the fact that the melt flow rate as it is does not fit in the case of injection molding.[32]

1. **Impact test**

The objective of this test to measure the ability of different types of specimens to withstand impacts using two procedures for impact tests, Izod and Charpy test methods.

Impact test is defined as the resistance of a material to rapidly sudden applied loads.

Impact testing involves the sudden and dynamic application of the load. Parts such as shafts, bolts, anvils and dies are examples of items subjected to impact loading.

Toughness is a property, which is capacity of a material to resist fracture, (crack propagation), when subjected to impact.

The machine measures the amount of energy absorbed by the specimen for the rapture in joules unit.

The amount of energy absorbed can give an indication of the toughness of a material. It can classify the different types of materials into either brittle or ductile materials.

The charpy test was used in this project , that The specimen is supported as a simple beam with the load applied at the center**,** The position of latching tube is set to140°, and The specimen is supported horizontally from two sides.[33]

1. **Tensile testing of Plastics**

The ability to resist breaking under tensile stress is one of the most important and widely measured properties of materials used in structural applications.

The combination of high ultimate tensile strength and high elongation leads to materials of high toughness. [34]
Tensile tests measure the force required to break a specimen and the extent to which the specimen stretches or elongates to that breaking point. Tensile tests produce a stress-strain diagram, which is used to determine tensile modulus. The data is often used to specify a material, to design parts to withstand application force and as a quality control check of materials. Since the physical properties of many materials (especially thermoplastics) can vary depending on ambient temperature, it is sometimes appropriate to test materials at temperatures that simulate the intended end use environment.

Specimens of 0.5m are placed in the grips of the Instron at a specified grip separation and pulled until failure; the test ends after sample break (rupture).

An [extensometer](http://www.ptli.com/testlopedia/tests/Tensile-Extensometers.asp) is used to determine elongation and tensile modulus. [35]

# Properties of PPRC pipes:

Polypropylene random copolymer (PPRC) has many characteristics that make it different than other types of polymers, some of these characteristics that it is a softer, more flexible plastic, which also tends to have more stress-crack resistance and has greater impact strength.

 Moreover, Copolymer polypropylene tends to have greater low-temperature endurance with only modest compromises over basic polypropylene properties.

Actually, in order to produce (PPRC) pipes with all of the above properties, many tests should be carried out for it, and the results of these tests must achieve the specific characteristics. Each of these tests will be carried out according to Iso 4437.

The following table include the tests and the desired properties that should be accomplished in order to have a (PPRC) pipe.

Table 4. 2: Tests of PPRC with their desired properties. [36]

|  |  |
| --- | --- |
| Tests | Desired properties of tests  |
| Melt flow rate (pipe) | The difference in flow rate between the compound and pipe melt flow rates should be 30% difference maximum at the same condition. |
| Melt flow rate (compound) | The melt flow rate should not be more than 1.2g/10min for PPRC at 230 °C with a mass load of 5Kg. |
| Impact resistance | 25 °C impact resistance should not break. |
| Resistance to internal pressure | PPRC pipes must withstand an internal pressure of 20 bars at 20 °C for one hour. |
| Soft texture | PPRC must be soft texture inside and out side |
| Thickness | Must be the thickness of the four points of equals, and measure the outside diameter equal (outer diameter measurement perpendicular from different destinations). |
| Tensile Test | Must take the longest time before fracture. |

# Chapter 5

# Results and Discussion

###

## Results of the Questionnaire:

A questionnaire to evaluate the desired properties of the Polypropylene Random Copolymer pipes that consumers concern in it such as toughness and outdoor stability was prepared.

This questionnaire was distributed on the traders who buy this type of pipes, in order to know whether there are any problems with PPRC type.

Moreover, this questionnaire includes many questions to discover the properties that the consumers want it to be improved in this kind of pipes.
The result of this questionnaire was collected and was taken in to consideration in order to improve the properties of this pipe.
The questionnaire was written in Arabic language in order to be easy to understand. Appendix A.

By interpretation the results of questionnaire which prepared and distributed to 8 companies which are use poly propylene pipes, the following responses which explained by tables were reported on pipes properties:

Table5. 1: Nature of installation.

|  |  |
| --- | --- |
| Company | Insulation |
| Inside | Outside |
| طبيلة | 1 |  |
| الطويل | 1 | 1 |
| عزيزة | 1 | 1 |
| محلات الاخوة | 1 |  |
| مجلس قروي صيدا | 1 |  |
| بلدية بيتا | 1 |  |
| مجلس قروي روجيب | 1 |  |
| بلدية عنبتا | 1 |  |
| Summation | 8 | 2 |
| Average | 5 |

Table5.2: Method of installation with links.

|  |  |
| --- | --- |
| الشركة | Method of installation with links |
| Mechanical | Welding |
| طبيلة |   | 1 |
| الطويل |   | 1 |
| عزيزة |   | 1 |
| محلات الاخوة |   | 1 |
| مجلس قروي صيدا |   | 1 |
| بلدية بيتا |   | 1 |
| مجلس قروي روجيب |   | 1 |
| بلدية عنبتا |   | 1 |
| Summation | 0 | 8 |
| Average | 4 |

Table 5.3: Nature of water used in pipes.

|  |  |
| --- | --- |
| الشركة | evaluation of product |
| excellent | good | bad |
| طبيلة | 1 |   |   |
| الطويل |   |   | 1 |
| عزيزة | 1 |   |   |
| محلات الاخوة |   | 1 |   |
| مجلس قروي صيدا | 1 |   |   |
| بلدية بيتا |   | 1 |   |
| مجلس قروي روجيب |   | 1 |   |
| بلدية عنبتا | 1 |   |   |
| Summation | 4 | 3 | 1 |
| Average | 2.666666667 |

Table5. 4: Customers Evaluation of the pipes.

|  |  |
| --- | --- |
| الشركة | Problems |
| cant a bear the pressure | expulsion of pipes | cracking |
| طبيلة |   |   |   |
| الطويل | 1 |   | 1 |
| عزيزة |   |   |   |
| محلات الاخوة | 1 |   |   |
| مجلس قروي صيدا |   |   |   |
| بلدية بيتا | 1 | 1 |   |
| مجلس قروي روجيب |   | 1 |   |
| بلدية عنبتا |   | 1 |   |
| المجموع | 3 | 3 | 1 |
| الوسط الحسابي | 2.333333333 |

Table5. **Error! No text of specified style in document.**5:Problems that face this type of pipes.

|  |  |
| --- | --- |
| الشركة | nature of used water |
| Cold | Hot |
| طبيلة | 1 |   |
| الطويل | 1 |   |
| عزيزة | 1 |   |
| محلات الاخوة | 1 |   |
| مجلس قروي صيدا | 1 |   |
| بلدية بيتا | 1 |   |
| مجلس قروي روجيب | 1 |   |
| بلدية عنبتا | 1 |   |
| summation | 8 | 0 |

### Discussion of questionnaire:

The tables (5.1-5.5) can be summarized in the following results:

**The nature of installation**: all of these companies use this type of pipes for inside installation, and two of these companies use PPRC pipes for inside and outside installation.

**Method of installation with links**: all of the customers prefer the welding way and they think that it is the most appropriate method of installation with links, and none of them use the mechanical way.

**Nature of water**: all of customers use this type of pipes for cold water and not for hot water.

**Evaluation of the product**: half of the customers said that it is an excellent product, some of them said that it is good but it is need some modifications, and few of them said that it is bad product.

**Problems that face this type of pipes**: some of customers says that type of pipes don’t bear the pressure, so this cause expulsion of pipes. And few of them said that this type of pipes is easily to be cracked.

## Discussion of tests:

In order to select the best product, a comparison was needed between all the 10 samples produced and tested including the original one, so based on the following figures which describe the behavior of the product based on Toughness, ductility, strength and melt flow index the optimum will be selected and we start with the HDPE additive:

Table 5. 6: The result of tests for PPRC with percentages of HDPE

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sample # | % of additive | Rm | Aelongation | Toughness (kN/mm) | MFI g/min | Toughness (Mpa) |
| 10 | 100% PP | 16.54 | 42.30% | 579 | 1.91 | 0.0126 |
| 3 | 10% HDPE | 20.6 | 63.27% | 451 | 1.31 | 0.0118 |
| 2 | 20% HDPE | 23.55 | 54.47% | 380 | 1.06 | 0.0113 |
| 1 | 40% HDPE | 20.28 | 54.47% | 431 | 1.2 | 0.0091 |

Figure 5. 3: Effect of tensile strength in PPRC and different percentages of HDPE.

Figure 5. 4: Effect of toughness in PPRC and different percentages of HDPE.

Figure 5.5 : Effect of ductility in PPRC and different percentages of HDPE.

When adding HDPE to the PPRC pipes an increase in strength is noticed due to the high strength of HDPE, that can be especially noticed for the sample with 20% HDPE added to it, if anything this increase indicates that the two materials are highly compatible up to a certain percentage between 20% and 40%, this compatibility happens because in this case Random copolymer is used so it is very easy for the PE monomers to take their places in the PPRC composite and assume a better stronger composite, now when the strength increases as mentioned earlier ductility and toughness decrease and the figures above clearly show that except in the case of 40% HDPE in toughness which is because the sample shows less compatibility at high percentages of HDPE.
Now to select the optimum sample with the HDPE additive all aspects must be taken in consideration, even though the 20% sample shows the highest strength with a difference of 42% increase from the original sample, the toughness and ductility of the 10% sample are higher, where the toughness is almost the same as the original sample but the ductility showed a 42% increase where the 20% sample only showed 28%.

Figure5. 6 : Effect of MFI in PPRC and different percentages of HDPE.

As for the melt flow index all the samples fall within the range of 30% difference from the original sample so all the samples are valid and the Melt Flow Index cannot be used as a criterion here.

Table 5.7: The result of tests for PPRC with percentages of LDPE

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sample # | % of additive | Rm (N/mm2) | Aelongation | Toughness (kN/mm) | MFI g/min | Toughness (Mpa) |
| 10 | 100% PP | 16.54 | 42.30% | 579 | 1.91 | 0.0126 |
| 6 | 10% LDPE | 18.98 | 79.91% | 604 | 1.59 | 0.014 |
| 5 | 20% LDPE | 13.76 | 76.82% | 596 | 1.77 | 0.011 |
| 4 | 40% LDPE | 23.57 | 42.04% | 346 | 1.27 | 0.0094 |

Figure 5.7: Effect of tensile strength in PPRC and different percentages of LDPE.

Figure 5.8: Effect of toughness in PPRC and different percentages of LDPE.

Figure 5.9: Effect of ductility in PPRC and different percentages of LDPE.

It is known that when the strength increases the ductility and toughness decrease, so based on the previous figures (1, 2 and3) it is obvious that the strength is highest at 40% addition of LDPE then 10% then 20% this due to the toughness of LDPE being higher than that of PPRC, judging from the ductility and toughness figures where the toughness and ductility are higher at 10% addition of LDPE then 20% then 40% we can tell that the sample which contained 20% LDPE failed at the tensile test.

The increase in strength was about 14% for the sample which contained 10% additive of LDPE and 42% for the 40% sample, the defected sample however showed a decrease in strength which might be due to incompatibility in the structure of the material.

So as expected the toughness increased the most for the 10% additive sample which was 11% but showed a drop for the other two samples, the ductility showed an 88% increase for the 10% sample over the original PPRC sample which is a great value.

The optimum sample of the LDPE additive group is the 10% sample because it has high ductility, high toughness and even if its lower than the 40% sample its strength is still good.

Figure 5.10: Effect of MFI in PPRC and different percentages of LDPE.

According to the standard values of the melt flow index, it should be 1.91 g/10min, the samples with the polymers are not to show ±30% which in this case all the samples apply, as figure 4 shows the difference isn’t that much but the best sample is the sample with 20% polymers.

Table 5.8: The result of tests for PPRC with percentages of LLDPE

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sample # | % of additive | Rm | Aelongation | Toughness (kN/mm) | MFI g/min | Toughness (Mpa) |
| 10 | 100% PP | 16.54 | 42.30% | 579 | 1.91 | 0.0126 |
| 9 | 10% LLDPE | 22 | 84.08% | 499 | 2.6 | 0.0091 |
| 8 | 20% LLDPE | 17.85 | 56.25% | 315 | 1.84 | 0.0069 |
| 7 | 40% LLDPE | 21.01 | 73.47% | 459 | 1.6 | 0.011 |

Figure 5.11: Effect of tensile strength in PPRC and different percentages of LLDPE.

Figure 5.12: Effect of toughness in PPRC and different percentages of LLDPE.

Figure 5.13: Effect of ductility in PPRC and different percentages of LLDPE.

Adding LLDPE to the PPRC is supposed to lower its strength because the strength of LLDPE is lower than that of PPRC, and this shows in the 40% sample very good.

The LLDPE samples had some problems, even though the 10% sample had high ductility with a 98% increase, and high strength with a 33% increase, its toughness was very low where it dropped 60% from the standard value so it can’t be used.

As for the 40% sample it had good ductility (73% increases) and high toughness only 12% less than the standard sample, but it had a very low tensile strength.

The 20% sample had relatively low strength with only 8% increase from the standard sample, low toughness with almost half that of the pure sample and the lowest ductility with only 33% increase.
So in conclusion none of the LLDPE samples are recommended to be used as their properties are not very good compared to the other polymers.

Figure 5.14: Effect of MFI in PPRC and different percentages of LLDPE.

As the previous samples of the HDPE and LDPE the LLDPE samples are all within the range of a 30% difference from the original sample when it comes to the melt flow index.

Charpy impact test:

The charpy impact test came back with excellent results for all the samples except sample No.5 (20%LDPE) which was ruled out anyway comparing it to other percentages of LDPE, the impact test on the samples under the same conditions should come back with the same result which is for the sample not to break, none of the samples broke or cracked except the 20%LDPE sample, so in comparing the impact test is positive for all the other 9 samples.

Cost of polymers:
for all the samples whether it was HDPE, LDPE or LLDPE the cost is always less than that of pure PPRC because PPRC has the highest cost of all, also the more percentage of the polymers the less the cost of the pipe the difference in cost may not be very high but having a better quality with less cost to manufacture means the product can cost less and be sold for more so more income to the company.

The cost may be taken in consideration but as a last resort as the other properties such as toughness and strength are more important and the cost is dropping no matter what sample is chosen.

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