Mechanical properties study of polycarbonate and other thermoplastic polymers

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Abstract. The polymeric materials in this study underwent mechanical tests (tensile test, impact resistance and hardness), which explained the use of polymeric materials in engineering and industrial applications that need good mechanical properties compared to metals, ceramic materials and woods, and this is a good thing because it is characterized by low cost and high efficiency with application performance. In this study, the polycarbonate polymer was characterized by its high tensile strength in the event of breakage, but the elongation values decreased compared with the polypropylene and polyethylene polymers, which were characterized by high elongation at the expense of tensile strength, as the polycarbonate polymer acted as a brittle material as for resistance to shock, which reflected the amount of energy absorbed. From the striking hammer, the impact resistance of high-density polyethylene increased compared to other polymers, as well as the hardness whose values were close to the three types of polymers used, which confirms the importance of these types in the application used in engineering.

Keywords: mechanical properties (tensile strength, impact resistance, hardness), thermoplastic polymers (polycarbonate, polypropylene, high density polyethylene)

1. Introduction

The apparent development of polymers used for medical applications has made them of great importance, as their high ability to withstand the thermal gradient drives the optimum use under temperature ranges, which are easy to form within these degrees, making them mature during application in many cases. Also, the development in the industry allows us to use thermoplastic materials with wide applications. The study identified many properties and recorded a high rise in the
values of both hardness and durability, providing the safe mechanical limits within the application of the intended working range for these materials, and the results showed the high values of mechanical resistances, which determines the values of tensile resistors in an estimative manner. [1].

The interpretation of what polymeric materials are originally depends on a set of common properties of these materials. The basic explanation for the physical behavior of polymers molecules during the heating process is that the polymer is formed according to its type and the temperature that the engineering or internal composition of the polymers bear. This is an accurate description, the thermal polymer is also characterized by being a viscous liquid that has no known shape or flow, and that the freezing occurs after a clear temperature drop, and the mechanical, chemical, thermal, or physical properties are determined. The behavior followed showing the type of polymer and its internal structure is deformation under the influence of irreversible applied load. Since the solid polymer is able to return to its normal position even after the effective load is removed, the type of bonding between the polymer molecules is also determined because the thermoplastic polymer resin binds its molecules as long polymers and cannot bind to other components, while the other materials act according to the arrangement of their molecules that may be They are regular and perfect or random combinations, and with this representation the distinction of the material will be according to its internal structure, which is a reflection of the expected properties Therefore, polymers are described by the process of melting and then hardening for a number of times and in a programmed manner within the mechanisms of heating and cooling and in the production of granules or strips in thermoplastics, as for thermosetting polymers, the formation takes place by cooling in which there is no melting after forming when the temperature is raised[2].

The polycarbonate symbol is PC, which is classified under thermoplastic polymers, as they can be easily molded and thermoformed. Due to these properties, polycarbonate has many applications. The main unit of polycarbonate is Bisphenol A, which is itself the unit that forms epoxy resins. Polycarbonate is a durable material, although it has a high impact resistance property, but it has a low resistance to scratching, so it is coated with other materials when used in areas such as eyeglass lenses and car exterior components. Polycarbonate is similar to PMMA, but it is stronger and usable over a wide range of temperatures. Unlike other thermoplastic polymers, polycarbonate undergoes major plastic deformations without breaking or collapse. With these properties, polycarbonate can be used in a wide range of applications, such as electrical insulation in electronic circuits, building materials, aircraft components, food packaging, and medical applications. It is clear that every person has dealt with polycarbonate in one form or another, that is, he is susceptible to contact with it, especially when buying prepackaged food. But recent studies have shown that it is possible for permanent exposure to polycarbonate to cause disruption in the work of the endocrine glands in humans, as it is possible to decompose polycarbonate in the presence of water or moisture at high temperatures, and the World Health Organization (WHO) has studied the vital activity of Bisphenol A derivative. From polycarbonate, as it was found to be endocrine disruptor, when it entered the body, it could mimic the estrogen hormone, which showed negative results in animals [3].

Polypropylene is a white natural substance obtained by polymerizing propylene particles obtained from "oil", which in turn is considered a derivative of crude oil (through the process of obtaining large particles by adding particles longitudinally) . And in order that the derivatives obtained from crude oil are used by an average of 97% when producing them, the availability of that material and its prices are fully linked to the global crude oil reservations and prices. In other words, when global petroleum ends, so too will polypropylene. As a result of a matrix of complex chemical processes and procedures in terms of being suitable for different places of use and purposes of use, developments can be made on the physical properties of polypropylene such as stiffness, elasticity, heat resistance and brittleness, by placing ethylene molecules within polypropylene molecules. An example of this is: Propylene gas is introduced in a reaction with ethylene gas inside a reactor under very special conditions, so that the fixation positions between the ethylene molecule and the propylene molecules in a ratio of 1-7 determine the physical properties of the material being obtained. In this way, a raw material is obtained that can withstand extremely high pressure and very high temperatures. Today, containers made of propylene can be used to withstand temperatures of 1200 degrees Celsius in cooking ovens [4].
High-density polyethylene (HDPE) is a type of high-density plastic. HDPE is stiffer than other types of polyethylene, and is heavier and stiffer compared to low-density polyethylene (LDPE). HDPE is lighter than water. It is made by casting technique or by extrusion method. It can be processed into machine tools and joined using special welding methods. And it is very difficult to be attached using adhesives. It has a natural appearance and a beeswax-like poultice. And there is no harm in contact with foodstuffs. In the 1950s (1950), low-density polyethylene (PE 32) was developed and used for the first time in drinking water networks. Later on, polyethylene (PE 63) was developed in the manufacture of pipelines for natural gas networks, with an internal pressure level of 4 bar. The manufacturers realized how easy it is to use this material, so they developed it within a short period of time. At the beginning of the 1990s (1990) polyethylene type (PE 80) was developed, then PE 100 was developed. HDPE pipes were first used in America and Canada in the 1960s (1960)[5]. The projects that were realized on that date are still working today without any problem. The materials used in polyethylene pipes are rated MRS. The MRS property is the internal resistance applied to a material below 20 °C over a period of 50 years. The features and characteristics of polyethylene can be arranged as follows: It is anti-aging and has been calculated to be at least fifty (50) years old, however its true performance is much more. They are great at resisting stress cracking and providing that cracking or cracking. Polyethylene has good flexibility, which gives it ease and durability under the worst working conditions. Light and easy to conduct when compared to steel, wood and aluminum. And it gives ease of forming all kinds of structures. Thanks to the corrosion-resistant property of polyethylene, it maintains its resistance and performance in all working conditions. It has high impact resistance, and is resistant to breakage even at low temperatures. It is not easily contaminated, does not contain toxic substances and is very easily cleaned. High resistance to freezing. It is not affected by the freezing of the liquid inside. In addition to all these properties, in terms of raw materials it is more economical than steel, aluminum and wood. [6]

J. roh, et.al. [7] Studied the comparison between two types of polymeric products reinforced with long carbon fiber over the type of polymer resins, where they produced five polymer resins such as polyamide 6, polyamide 6, polycarbonate, high density polyethylene and polypropylene reinforced with 30% carbon fiber. The mechanical properties of the individual resins were examined once and when reinforcing again, and it was found during the analysis that the polymeric materials with their five resins had improved mechanical resistances values after the long carbon fiber cementing process due to the load distribution on the reinforced material that absorbs the energy released from the loads during the testing process.

J vácha, M borůvka [8] study The measurement of mechanical properties in this paper, including mechanical properties tests and for reinforced polymeric materials with the base material without reinforcement, comparing the effect of reinforcement on the mechanical properties of the polymer material with carbon nanotubes and without fillers, as it emphasized the importance of adding nanomaterials. Which showed a clear improvement in the properties of polymers. The current work also studies the mechanical properties of thermoplastic polymer matrix compounds such as nanotubes, and to find out the true behavior of the reinforced polymers, they were examined microscopically under stresses and found that the phases formed during manufacturing exhibit extremes in the work of polymeric chains where the polymers tend to be highly durable with the presence of filler support materials.

A. K. Bhowmick [9] For the study presented on the tests of the mechanical and dynamic properties of different types of polymers, where the fracture was described in the polymeric materials during the examination process, and by using the prediction of the stress and strain curves of the polymers by examining the tensile property to reach the state of fracture and failure, as it was a clear indicator of the polymers durability, which was represented by measuring the polymer hardness.

P hariprasadarao [10] Thermoplastic polymers are used in medical, industrial and food applications. The properties of materials change due to environmental changes, and here the need arises for applications designed in use, as well as in engineering applications. At a higher temperature to study
the effect of age on mechanical properties and fatigue, various types of polymers are studied and applied to nanomaterials used medically in dental fillings that are oxides. Nano cement, which acts as a filler for polypropylene and high-density polyethylene base polymers, the thermal aging and evolution of the polymer time as the mechanical resistance values are kept in the same period that they were manufactured and tested at the same time.

S.I.Ibrahim [11] study the materials as matrix reinforced with flexible polyethylene and poly oxy ethylene primer, and micro-filters were examined in various shapes such as short carbon fiber (SCF prepared), silicon carbide (SiC) and alumina. (Al2O3). And the manufactured by smelting method using double extruder made standard models to measure variable properties according to the force of force where the results of The results obtained during the examined tests showed an increase in the mechanical properties of the glass fiber reinforced materials for the principle of the distribution of the loads imposed on the reinforced materials, while the ceramic reinforced polymeric materials showed greater tensile and bending results at the same time. In hybrid compounds there is less tensile strength with higher strength in the mixing method.

S. Iwamoto et.al. [12] in this paper, study the effects of filler materials with polymer poly amid 6 ,The reinforcement ratios of the filler were in lower proportions, which led to a decrease in the values of mechanical resistances due to the low physical properties. While the stiffness and impact strength increased by more than 1%, due to the phase dispersion formed in the ceramic material inside the polymeric material, which led to a clear change in the physical behavior and thus reflected on the mechanical properties as the loading of nanoparticles from graphene benefited from other, also increases when compared to the results with polymers reinforced with short shredded glass fiber, which showed a decrease in the values with the reinforcement of graphene in relation to the studied properties. It was used in many applications that were subjected to different mechanical loads. The surfaces were examined by a scanning optical device, which revealed the dispersion with variable phases and according to the added proportions.

T. Quazi et.al.[13]in this study, two types of polymers were combined with an ethylene-butene polymer with wood flour or cellulose fiber nanofibers to prepare different main compounds. The sample preparation process included polypropylene to obtain the final compounds despite the fact that the ethylene-butene co-polymer is considered a rubber material, and that the combination with this material increases the strength values while reducing the hardness, while the compounds reinforced with cellulose nanofibers and wood flour showed high resistance values. Very with respect to the base material for the different mechanical resistances with advancement in addition to cellulose with the polymeric material, in which the different properties decreased with a clear gradient relative to the substrate.

R., S. Shamsuria et.al. [14] Thermoplastic polymers are used in medical, industrial and food applications. The properties of materials change due to environmental changes, and here the need arises for applications designed in use, as well as in engineering applications. At a higher temperature to study the effect of age on mechanical properties and fatigue, various types of polymers are studied and applied to nanomaterials used medically in dental fillings that are oxides. Nano cement, which acts as a filler for polypropylene and high-density polyethylene base polymers, the thermal aging and evolution of the polymer time as the mechanical resistance values are kept in the same period that they were manufactured and tested at the same time.

B. Kusuktham · P. Teeranachaideekul [15] The current study examines the change in the added percentages of natural rubber on polypropylene Where different blends were prepared by melting the Natural Rubber Compound (ENR). The PP / ENR blends were prepared by compound smelting using an internal mixer and smelted through vulcanization. Mechanical tests such as tensile test, hardness test and impact test are performed To analyze the results of properties that showed an improvement in strength and elongation upon tensile strength, and a decrease in the values of hardness and tensile strength, as this decrease was related to the amount of changes transmitted by the elastic chains.
M. Tasyurek, S. E. Murat Mirik [16] In this study, high-density polyethylene (HDPE) was used with calcium silicate, where the samples were made by injection. The reinforcement process led to a significant increase in the yield and tensile stresses, and a decrease in the amount of elongation was observed at the fracture stages. For composites, it can be concluded that the modified calcium silicate played a role in enhancing the mechanical properties of HDPE, which was represented by a slight improvement in properties and reduced other properties, the main objective of which is to provide a wide range of materials that are used in many applications.

B. Suresha ,et.al. [17] The development in the use of nanomaterials has prompted many researchers to study the ability of nanomaterials to be supported with various incubators, especially thermoplastic polymers Addition ratios change when reinforcing for multi-walled carbon nanotubes with high-density polyethylene nanocomposites (MWCNT / HDPE). Multi-walled carbon nanotubes (MWCNTs) were incorporated into a high-density polyethylene (HDPE) matrix using twin-screw extrusion and injection technology. High-density polyethylene, which was reinforced with different proportions (1%, 3% and 5%), was produced from the carbon nanotubes in the form of rods and the best results were for the reinforcement ratios (3%). Where the results showed the ability of the compounds to improve the mechanical properties clearly.

S. A. Hafad [18] The use of fibers as a product development material has significantly improved due to its importance in reinforcing thermoplastic polymeric compounds used in a wide range of economical products due to their low costs. Where the fibers of all types are used to support the base material in the thermoplastic polypropylene (PP) matrix for the preparation of composite materials used in the development of the variable polymeric product with the addition ratios, as the polypropylene was supported with the carbon fibers cut and through the results obtained from the variable tests as analyzed, which show an improvement in properties The mechanics that can be developed through the strength of adhesion and coalescence between the fibers and the incubator. It is also benefited from the use of nanomaterials with polymers, especially thermoplastics.

2. Experimental

Materials
In this research the following materials were used
Thermoplastic polymers:

1- Polycarbonate: This type of thermoplastic is used distinctively because of its physical properties, it is transparent, has thermal stability up to a temperature of 130 degrees Celsius and withstands up to 150 degrees Celsius without any elastic stabilizer. It has a low ability to absorb water, acids and oil, but it absorbs Air humidity is greater. Its resistance to mechanical loads is high and its chemical resistance is relatively high compared to other polymers [19].
It is used in thermal resistance applications due to its high temperature stability up to 155 ° C due to the type of chains that this type of polymer possesses under difficult conditions. It is characterized by its chemical resistance, which makes it safe for applications in preserving food and medicine. It is characterized by the ability to be mixed with colors due to its high transparency.

2- High-density polyethylene: It is characterized by its, but its composition affects the changing properties and has crack resistance as it is considered relatively more elongated than polycarbonate [20]. Table (1) shows the characteristics of HDPE [21].

3- Polypropylene: It is a polymer that has the advantage of good heat and electricity insulation, as well as good chemical resistance to corrosive solutions. It is not affected by any type of compounds except for (hydrocarbon compound), where the swelling of the polypropylene surface causes its dissolution and the breakdown of the bonds between the polymeric chains [22].

Preparing methods
The methods used to produce the panels used in the manufacture of standard models of polymer granules are above Extrusion method: a programmed heating method for thermoplastic polymeric granules only and is single-screw, which pushes the electrostatic polymer from the specified molds that are cooled with water during the drawing process, [23].

**Table (1):** Properties of polymer used for Research extrusion

| properties                  | Poly carbonate | Poly propylene | High density polyethylene |
|-----------------------------|----------------|----------------|---------------------------|
| Density (Kg/m³)             | 2.3            | 0.96-0.98      | 0.900-0.91                |
| Ultimate T.S (Mpa)          | 42.01          | 34             | 30                        |
| Tensile modulus (Mpa)       | 35             | 17             | 22                        |
| Impact strength izod (KJ/m²)| 13-19.5        | 1.3-9.1        | 2-8                       |
| Hardness ,Rockwell          | M70,R118       | R85-110        | D45-50                    |

![Fig.(1) photo of extruder machine](image)

**Table (2)** Samples dimensions and standard specifications for the testing specimens. According standardization

| Test      | Sample dimensions | Standard Specifications |
|-----------|-------------------|-------------------------|
| impact    | ![Sample](image)  | ISO-179                 |
| tensile   | ![Sample](image)  | ASTM-D638               |

Test procedure
The Charpy method was used: (Charpy test) to measure shock resistance using the device manufactured by IMI from Amityville / New York. The factory model is placed within the standard
specifications as in (Table No. 2) and found amount of resistance of the material to shocks, as shown in Figure (2). As shown in Equation No. 1 [24]

\[ \text{I.S.} = \frac{UC}{A} \quad \cdots \cdots \cdots \cdots (1) \]

While:
UC: is the fracture energy (KJoule), which is determined by the Sharpy Impact Test tool.
A: It is the cross-section area of the sample.

**Figure (2) Sharpy Effect tool [24]**

Tensile test instrument tensile tester:
The device used is (Instron) and the programmed in which the model is modified for installation after its standard manufacture, as shown in Table 3. The longitudinal fixation of the sample is carried out by the upper and lower jaws of the equipment, and certain loads are exerted at a maximum and a load (500 kg), at a velocity rate (2 mm / min). The relationship obtained during this test is strain strain (-) through a relationship (P) - (l) as shown in Figure (3). Equations 2 and 3 to estimated ultimate tensile strength [25]

\[ \sigma = \frac{P}{A} \quad (2) \]

Where: P: load (N) A: cross-sectional area

\[ \varepsilon = \frac{\Delta l}{l} \quad (3) \]

A. Location: \( \Delta l \): change length, \( l \): original length

**Figure (3): photo of Tension Tool [25]**

Hardness test:
Shore d method
The device used for this type of polymer is a standard model D-39576 manufactured by the German company Sendle. The tool needle is stitched on the surface of the manufactured pattern, which gives an indication of the value and amount of stiffness as shown in the figure. (4)

![hardness shore D instrument](image)

**Fig. (4) hardness shore D instrument**

3. Results

Tensile Test Results:
Fig.(5) The tensile strength of polymers was measured according to international standards.) respectively, that the known behavior is Polycarbonate polymer as a hard, but brittle polymer, made the lipo fracture optimized as glass, meaning that it is weak for tensile loads compared with compressive loads as it is a material that can withstand high compressive forces, and it not observed stress of other polymers, as shown by the polymer Polypropylene behaves more flexible than high-density polyethylene and has less tensile strength, less elongation and greater than, which explains the real behavior of the physical interconnection between the formed polymeric chains that show reflection. Actual behavior after applying tensile loads Ref. [26]

In Figure (6), the tensile strength is compared with the shear resistance of the models used, which was 8% less than the amount of tensile strength values, the engineering behavior of the single polymer chains and how they slip on vertical or shear loads where it was found that the amount of shear resistances is less than the tensile resistors and the behavior The real-time loads will be simultaneously compared with the shear resistance [26][27].

![Tensile (stress- strain) Curves of Plain Polymers.](image)
Impact results:
the analysis of absorbed energy results of the three polymers, where the results of the shock resistance of the polypropylene polymer is less than that of polycarbonate and high-density polyethylene, which absorb part of the hammer energy at high speed and weak the bonds and bonding forces in it, which reduces the occurrence of fracture through growth Initial cracks due to shock stresses resulting from breaking bonds or polymeric forces, fig.(7) [29].

Hardness shore D:
the measures of polymer surface hardness, and by measuring the hardness of the surface of a model. The relationship between plastic hardness and elasticity is related to similar materials as in the value of (PC) which upper values of the other polymers. And the shear, and the hardness values appear close to the polymers under test due to the nature of the bonding and the physical behavior that varies with the temperature in place and application, fig. (8) [30].
4. Conclusions

1. Through tensile testing of polymers, the polycarbonate polymer showed a tensile strength higher than that of polypropylene and high-density polyethylene.
2. Apparent elongation of the polymers was the share of polypropylene and high-density polyethylene.
3. Different mechanical properties of thermoplastic polymers according to the nature of the polymer and the strengths of the polymer chains.
4. Some properties are related to each other and are an indication of resistance to each other.
5. Hardness values affect the bending strength values of the polymer surface.

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