# The effect of Titanium dioxide on the tensile properties of Polycarbonate and Polystyrene Polymers

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**Abstract**

This research study the effect of Titanium dioxide on the tensile properties of Polystyrene (PS) and Polycarbonate (PC) polymers. The stress – strain curve for pure PS and pure PC, shows that Young modulus for PS is higher than Young modulus for PC, because PS have higher ultimate strength than PC.

The addition of $TiO_2$ to PS and PC will reduce the Young modulus and ultimate stress, because the $TiO_2$ particles will reduces or freeze the orientation of these molecular chain and reduced the toughness of PC, while when the $TiO_2$ were added to PS, the value of toughness will be stabilized because $TiO_2$ particles make these chains interlocked and the mobility of the chains will be restrict.

## تأثير ثاني أوكسيد التيتانيوم على خصائص الشد لبوليمرات البولي الكاربونيت والبولي ستايرين

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**الخلاصة**

تم في هذا البحث دراسة تاثير ثاني اوكسيد التيتانيوم على خصائص الشد لبوليمري البولي ستايرين والبولي كاربونيت ، يوضح منحني اجهاد – انفعال لهذين البوليمرين ان معامل يونك واقصى شد البولي ستايرين هو اعلى من بوليمرالبولي كاربونيت وذلك لان البولي ستايرين يملك معامل شد اعلى من البولي كاربونيت. ان اضافة ثاني اوكسيد التيتانيوم الى بوليمري البولي ستايرين والبولي كاربونيت تؤدي الى نقصان في معامل يونك والشد الاقصى، وذلك لان جزيئات ثاني اوكسيد التيتانيوم تسبب اعاقة في دوران السلاسل الجزيئية وتقلل من متانة البولي كاربونيت، بينما تسبب اضافة ثاني اوكسيد التيتانيوم الى البولي ستايرين في تغير طفيف لان جزيئات ثاني اوكسيد التيتانيوم تكون مقيدة وان حركة السلاسل البوليمرية تكون محددة.

## Introduction

Mechanical properties provide a measure of a materials ability to resist deformation when subjected to externally applied loads. The relationship between the applied load and the observed displacement is dependent on two factors: the material being tested and the size and shape of the specimens.

Polycarbonate is an amorphous plastic with very high impact strength, good ductility and high stiffness. It is very difficult to break and the material is therefore considered fracture-proof (e.g. bullet-proof glass).

Light transmission is 85-90% but depends on the thickness. It has good outdoors resistance in the UV-stabilized form, but it tends to turn yellow by long exposition to sunlight. PC is transparent and can be dyed in many colors. PC has a relatively good chemical resistance.[1].

Polystyrene is an inexpensive amorphous thermoplastics that has good mechanical

properties. Foamed PS is used for packaging and insulation purposes [2].PS is not weather resistant, and therefore not suitable for outdoor uses. PS is transparent (it transmits about 90% of the sunlight) and has unlimited dyeing possibilities. Assembly can be done with gluing.
Color pigments are used in the plastics industry to enhance the aesthetic appeal of plastics products and in some cases, to color-code some plastics products used in specific applications. There are three types of colorants. These are dyes, organic, and inorganic pigments [3].

A number of inorganic pigments provide color to paint. Titanium dioxide in both the rutile and anatase forms is the most popular white pigment because of its high refractive index and excellent hiding power (the ability to render a paint opaque). Rutile titanium has the highest refractive index and the best tinting strength of all other pigment types. (Tinting strength is the ease by which color pigments can be mixed with another pigment to color the paint.) Other pigments, both organic and other pigments; they are used in conjunction with more expensive pigments to reduce costs. The use of extender pigments reduces shrinkage stresses within the paint film, giving it strength, and “extending” the pigment volume content at relatively low cost. Extender pigments include those based on carbonates, silicates, sulfates, barytes, and mica.

## Theoretical Part

### Tensile Test

Tensile test is a measurement of the ability of a material to withstand forces that tend to pull it a part and to determine to what extent the material stretches before breaking.
The tensile strength (stress) σ of a material is the ratio of the load (force) applied to the material at rupture to its original cross – sectional area. This property is typically called the rupture tensile strength, that is the strength at break, can be expressed as follows [4].

$$\sigma = F/A \qquad \text{------- (1)}$$

where F is the load (N), and A is the cross section area ($m^2$) so we can calculate the tensile strength at yield $\sigma_y$, and at break $\sigma_b$ as shown below:

$$\sigma_y = F_y / A \qquad \text{------ (2)}$$

$$\sigma_b = F_b / A \qquad \text{------ (3)}$$

where $F_y$: is the maximum load recorded, and Fb is the load record at break.
Strain ε is given by the following expression:

$$\varepsilon = \text{change in length/original length} = (L - L_o)/L_o \qquad \text{----- (4)}$$

where L is the final length (m) and $L_o$ is the gauge length (m) .
The modulus may also be obtained from the stress – strain or load deformation curve. The modulus value most frequently used in design is Young modulus E or modulus of elasticity, which represents an indication of the relative stiffness of a material and can be determined from the initial slope of the curve below the proportional limit of materiel
E = Difference in stress ($N/m^2$)/ Difference in corresponding strain

$$E = \varepsilon/\sigma \qquad \text{----- (5)}$$

The transition point between the elastic and plastic regions of the stress – strain curve is referred to as the elastic limit. Because it is difficult to pinpoint the end of the elastic region, the proportional limit or yield point may be used instead. This point is determined by the intersection of the stress – strain curve and a line parallel to the linear portion of the curve with an arbitrary defined strain offset, typically 0.2%. The stress value corresponding to the proportional limit is referred to as the (offset) yield stress [5].
Ultimate stress or strength is defined as the maximum stress that a material is able to withstand prior to failure. The failure point corresponds to the stress value at which failure actually occurs, depending on the material and the failure criteria imposed (and the definition of stress and strain), the failure point may coincide with the ultimate stress or may occur at a lower stress and higher strain than the ultimate

stress. Because elastic recovery occurs following fracture, the elongation at failure is less than the maximum strain attained immediately prior to failure.

***Toughness***

Toughness is a measure of the energy expended in deforming a material to failure and is equal to the area under both the elastic and plastic portions of the stress – strain curve. Toughness has the dimensions of work or energy per unit volume (Newton –meters per cubic meter = joules per square meter) and is therefore also refer to as strain energy density. Although different materials may exhibit dramatically different behavior in response to the same applied load, the areas under their respective stress- strain curves may be similar [6].

**Experimental Parts**

***Materials:***

Two polymers were used, polystyrene and Polycarbonate polymers.

***Fillers:***

The material used as fillers throughout this study is Titanium dioxide ($TiO_2$).

***Samples preparation:***

1. A weight amount of the polymer was then mixed with $TiO_2$ powder in different percentages (0,0.5,1 and 1.5 wt%). To obtain 5gm of the total weight for polymers and filler until homogenized mixture attained.
2. The prepared samples were left at room temperature for 24 hours.
3. The samples were shape according to the ASTM standard of tensile test specimens [7], as shown in fig (1).

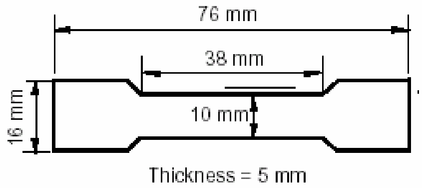


Fig. 1. The dimension of composite sample for tensile testing

**Tensile test**

Instron testing machine model (Inst. 1122) was used in its tensile mode of full scale 5KN. At first requirements of tensile test were adjusted .The values of cross head speed and chart speed were fixed to 0.5 mm/ min. and 20 mm/min. respectively. The test specimen was positioned vertically with the aid of the grips of the testing machine which were tightened evenly and firmly to prevent any slippage during the tension processes. During loading processes, the load value (force) and displacement were recorded with the y-t and x-t recorder attached to the instrument. The processes of elongation of the specimen continued until a rupture of the specimen was observed.

**Results and Discussions**

***Stress- strain curve results***

The mechanical properties of polymers depend on many parameter like type of polymer and method of preparation [8]. In this work, it found that the strain- stress curve behavior of PS and PC change. $TiO_2$ was added with different percentages Fig (2), Fig (3). Fig (1) shows the stress – strain curve for pure PS and pure PC, which shows that Young modulus for PS is higher than Young's modulus for PC, as shown in table (1) because PS have higher ultimate strength than PC, because the back bone of PS would carry more loading than PC and the chain of PS contains in each side a benzene ring which interlock between them, so when the chain were stressed, the mobility of these chains will restrict and the strain of this polymer will be reduced.

**Table (1) : Ultimate strength and Young modulus for Polycarbonate**

| material | Ultimate strength (MPa) | Young modulus (MPa) |
|---|---|---|
| PC pure | $x10^{6}3.2$ | $x10^{6}347$ |
| 0.5% $TiO_2$ | $0.82x10^{6}$ | $x10^{6}115$ |
| 1% $TiO_2$ | $0.81x10^{6}$ | $x10^{6}17$ |
| 1.5% $TiO_2$ | $0.62x10^{6}$ | $x10^{6}148$ |

The addition of $TiO_2$ to PS and PC will reduce the Young modulus and the ultimate stress as shown in fig (4) and Fig (5) respectively, this is attributed to the distribution of $TiO_2$ particles between the chain of these polymers Table (2), (3), because these particles will give more spacing between these fold chains and this reflect to make stretch mobility of main chain interaction of applied stress of these specimens will reduce, when these chains where stressed and the aggregation of some of these particles in local area will decrease the strength of these polymers, because these particles will be as a weakness points. These weakness points will accumulate a stress around these area and the crack will be propagate causes a failure in the polymers [9].

**Table (2) : Ultimate strength and Young modulus for Polystyrene**

| Materials | Ultimate strength(MPa) | Young modulus (MPa) |
|---|---|---|
| PS pure | $75x10^6$ | $4687x10^6$ |
| 0.5% $TiO_2$ | $46x10^6$ | $333x10^6$ |
| 1% $TiO_2$ | $57x10^6$ | $3073x10^6$ |
| 1.5% $TiO_2$ | $56x10^6$ | $3500x10^6$ |

### *Toughness Results*

In pure PC, the stress- strain curve, fig (1) indicates that this polymer have higher strain value compared with pure PS, because the chain molecule of PC will oriented with axial load direction easily than PS molecules so that, the toughness of pure PC is higher than PS. The addition of $TiO_2$ to PC will reduce the strain because, the $TiO_2$ particles will inhibited the orientation of these molecular chain and reduction the toughness of PC [10].

when the $TiO_2$ was added to PS the value of toughness may be stable, because the $TiO_2$ particles will cram between the back bonds of the PS polymer of the branch benzene ring, fig (6), which make these chains interlocked and the mobility of the chains will be restrict .

## Conclusion

1- The stress – strain curve for pure PS and pure PC shows that Young modulus for PS is higher than Young modulus for PC, because PS have higher ultimate strength than PC.

2- The addition of $TiO_2$ to PS and PC will reduce the Young modulus and the ultimate stress, this is attributed to the distribution of $TiO_2$ particles between the chain of these polymers.

3- The toughness of pure PC is higher than PS. The addition of $TiO_2$ to PC will reduce the strain because, the $TiO_2$ particles will inhibited the orientation of these molecular chain and reduction the toughness of PC.

4- When the $TiO_2$ was added to PS the value of toughness will be stable, because the $TiO_2$ particles will cram between the back bonds of the PS.

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