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Experimental Investigation of Strain Rate Effects on PC and PC Blends

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Abstract: **Thermoplastic materials are increasingly used as a light weight replacement for metal, especially in automotive applications. Typical examples are mobile casings, laptop covers, headlight of vehicles etc. The loads on these structures are very often impulsive, for example in a crash situation. A high rate of loading causes a high strain rate in the material which has a major impact on the mechanical behavior of thermoplastic materials. Polycarbonate (PC) is a typical engineering polymer which is commonly used in automotive, sheet glazing, medical appliance, packing, and some electrical applications because of its high tensile strength, good electrical properties, lower coefficient of thermal expansion, clarity, dimensional stability, and high-heat deflection temperature. However, the PC resin as a synthetic plastic is hard to be rapidly decomposed which is considered as the main reason to cause the environmental pollution. Poly (L-lactide) (PLA) is a green, renewable, biodegradable, and environmentally friendly polymer. One disadvantage of this polymer is its brittleness, which limits its applications. In this work attempt was made to study the effect of addition of PLA in Polycarbonate. The strain rate was measured at room temperature, 60oC, and 80oC and result are compared with pure PC. The results showed slight improvement in the strain rates of PLA/PC blend.**

Keywords: **PC, PLA, Strain rates etc.**

1. Introduction

Nowadays if look around our environment most of the things are made up from the plastic materials because plastic materials having some unique properties as compare to the metallic material. Some of them are low weight, low cost, good finishing, availability in more than one color and easy replacement. These properties make plastic material more popular than the other material. Before 5 to 7 years ago most of the part of automobile was made from the metallic material. Now slowly plastics are replacing the traditional materials giving good combination in the properties as well as in the performance. Nowadays there is need to improve the properties of plastic by making the blends of polymers for suitable application. Yield behavior of polymers is affected by temperature and strain rate, and given by the Eyring equation:

$$\sigma yT = 2/\gamma V[\Delta H - 2.303RT\log\left(\frac{\grave{\dot{\varepsilon}}0}{\dot{\varepsilon}}\right)]$$

With tensile yield stress σyT, ΔH is the activation energy, activation volume V, and R is the gas constant. If a secondary phase is present, the stress concentration factor, γ, takes into account the dependence of yield stress on second phase content and can be calculated by using the Ishai-Cohen relation

$$\frac{1}{\gamma} = 1 - 1.21\Phi^{2/3}$$

Where Φ is the volume fraction of soft particles. Poly (L-lactide) (PLA) is a green, renewable, biodegradable, and environmentally friendly polymer. One disadvantage of this notable polymer is its brittleness, which limits its applications. Another drawback is its low melt strength, due to the lack of viscoelasticity, limiting its applications in packaging and film production. PLA is an aliphatic bio-polyester that has outstanding advantages not only over commodity polymers but also over many other bio-polymers. PLA is biodegradable, biocompatible, and recyclable, and its production consumes 25 to 55% less fossil energy compared with the petroleum-based polymers. It has also several advantages over other biopolymers since their monomers are obtained by fermentation of corn, sugar beets, wheat, and rice.

Strain rate as name indicated rate of change of strain with respect to time. The unit for this parameter is per second. The important thing about the strain rate is that while conducting the experiments with the help of Universal Testing Machine one has to maintain constant cross head velocity to achieve definite strain rate.

For known gauge length strain rate can be measured for that divide the cross head velocity of UTM by gauge length. Another formula is given as follows.

$$\dot{\epsilon}(t) = \frac{d\epsilon}{dt} = \frac{d}{dt}\left(\frac{L(t) - L_0}{L_0}\right) = \frac{1}{L_0}\frac{dL}{dt}(t) = \frac{v(t)}{L_0}$$

2. Problem definition and objective of the project

A. *Brief review of literature*

Kan et al. studied effects of strain rate and temperature on the tension behavior of polycarbonate. Polycarbonate (PC) is a high performance amorphous engineering thermoplastic possessing outstanding thermal stability, heat distortion temperature (HDT) and optical transparency. The thermal and mechanical properties of polymers are reported to be increased on incorporating inorganic fillers into the polymer matrix. If it can be done without significant loss in optical transparency, PC based composites can be used in a wide application areas. Erfan

Oliaei et al, in his study, poly(L-lactide) (PLA) is melt-blended with thermoplastic polyurethane (TPU) to modify the brittleness of PLA. The various analyses confirmed interactions and successful coupling of two phases and confirmed that melt-blending of PLA with the aliphatic ester-based TPU is a convenient, cost-effective, and efficient method to conquer the brittleness of PLA. The prepared blends are general-purpose plastics, but PLA25 showed an optimum mechanical strength, toughness, and biocompatibility suitable for a wide range of applications.

Haitao Wang et al, performed a combined experimental and analytical investigation of the compressive mechanical behavior of a PC and ABS blend.They utilized the Split Hopkinson Pressure bar technique to obtain stress strain responses. The compressive experimental results showed that the total stress at high strain rate increases more rapidly than that at low and moderate strain rates. Jae Bok Lee et al, studied the mechanical rheological properties of PC/PLA blend with three different compatibilizers. They suggested that the SAN-g-MAH is the most effective compatibilizer to improve the mechanical strength of PC/PLA blend.

B. Problem definition

This project work is the extension of all these studies by creating PC/PLA blend in the composition 30:70, 40:60 (by wt/wt, % of PC/PLA) and finding out its behavior at different strain rates and temperatures and comparing its property with the PC. One important point about these studies is there is no idea about the biodegradability of the said composites.

C. Objectives of the project

- To find engineering stress-strain curves at different strain rate (0.001/s, 0.01/s, and 0.1/s) and at temperature of (a) R.T. (b) 60^0C (c) 80^0C and study mechanical properties.
- To find out relationship between yield stress and strain rate.
- To predict suitable material at different environmental conditions by mechanical properties, cost considerations.
- To increase biodegradability.

3. Methodology

A. Design of experiment

This is a systematic method to determine the relationship between factors affecting a process and the output of that process. It is used to find the cause-and-effect relationships between input and output. This information is needed for inputs in order to optimize the output. Design of experiments determines the pattern of observations to be made with minimum of experimental efforts. To be specific DOE offers a systematic approach to study the efforts of multiple variables / factors.

B. Taguchi technique

A full factorial design will identify all possible combinations for a given set of factors if an experiment consist of m number of factors & each factor at levels, then number of trails possible (Treatment Combination) = Xm. As the number of factors considered at multi-levels increases, it becomes increasingly difficult to conduct the experiment with all treatment combinations to reduce the number of experiments to practical level only a small set from all the possibilities is selected .This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting the minimal number of experiment, which could give the full information of all the factors that affect the performance parameters. The crux of the orthogonal arrays method lies in choosing the level combinations of the input design variables for each experiment.

4. Experimental set up

A. Material and specimen preparation

A 3 mm sheet of Polycarbonate was purchased from Pune Polymer. The specimens were machined directly from sheet stock and kept at room temperature for more than 4 days prior to testing. The blends of PC/ PLA in the composition 30/70 and 40/60 (by wt./wt., % of PC/PLA) was prepared by melt mixing the components in counter rotating twin screw extruder and then injection molded at GLS polymer Pvt. Ltd., Bangalore.

B. Tension testing

Uniaxial tension tests were conducted at three temperatures (R.T, 60ºC, 80ºC) over range of strain rates (0.001 s^{-1}, 0.01 s^{-1}, 0.1s^{-1}). The tests were performed on electro-mechanical machine, Instron 5582 model universal tester to obtain the stress-strain relations.

Fig. 1. INSTRON 5582 model universal tester

C. Specimen design

The rectangular dog-bone samples in accordance with ASTM D638 were used for testing as shown in Fig. 2. The specimens were rectangular dog-bone shape with the thickness 3mm. The gauge length, width and fillet radius of the specimen were 57mm, 13mm and 76mm respectively. The width of the connection part was 19mm and the total length of the specimen was 165mm.

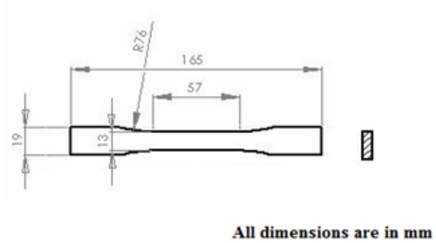

Fig. 2. Rectangular Dog-Bone Shape specimen

5. Results and discussion

Uniaxial tensile experiments were conducted at the strain rates of 0.001, 0.01 and 0.1s^{-1} respectively on PC and PC/PLA blend specimens.

Fig. 3. Specimens in environmental chamber:
(a) 60^{0}C (b) 80^{0}C

A. Tensile stress-strain responses

Fig. 4, Fig. 5, & Fig. 6 illustrates the tensile stress-strain responses of PC and PC/ PLA blend as a function of strain rates at different temperatures. Material response clearly shows to be strongly dependent on the strain rate at all testing temperatures. Stress drop occurs following a plastic flow pattern when the stress reaches its peak point. The yield behavior and after yield behavior of PC is strongly dependent on temperature. For PC/PLA blend after yielding shows very little plastic deformation zone and sudden brittle fracture. This indicates that PC/PLA blend has hard and tough behavior.

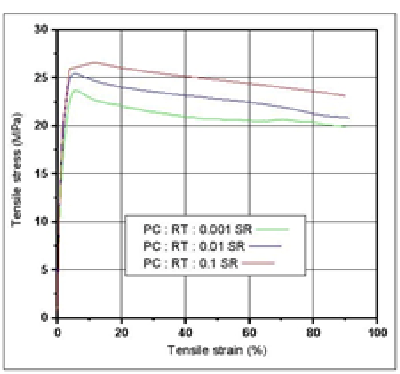

Fig. 4. Stress-Strain Relation for PC at R.T.

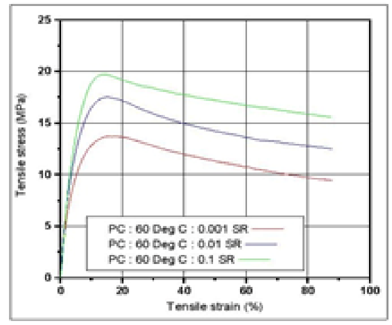

Fig. 5. Stress-Strain Relation for PC at 60oC

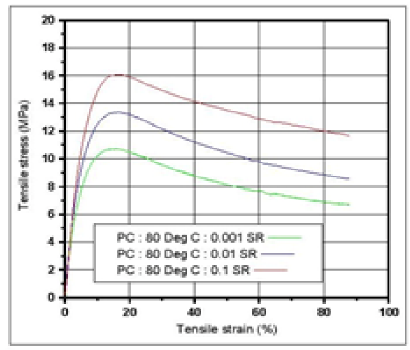

Fig. 6. Stress-Strain Relation for PC at 80oC

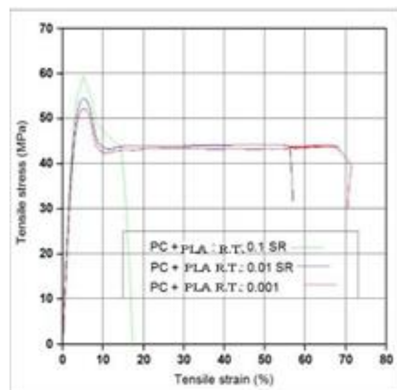

Fig. 7. Stress-Strain Relation for PC/PLA at R.T.

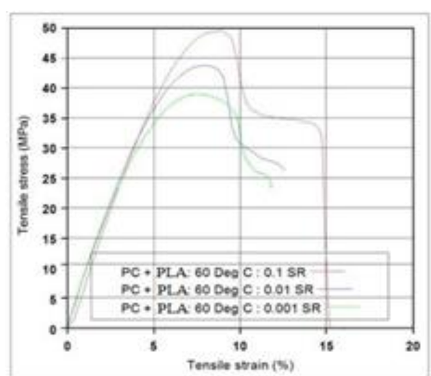

Fig. 8. Stress-Strain Relation for PC/PLA at 60oC

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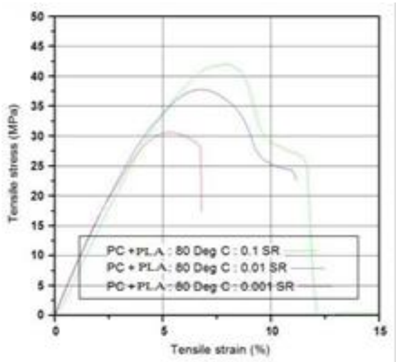

Fig. 9. Stress-Strain Relation for PC/PLA at 80ºC

It can be observed from the tensile stress-strain curves that the tensile strength for the PC/PLA blend at lower temperature is more than pure PC. Also tensile strain or % of elongation value decreases as temperature increases.

6. Conclusion

The following conclusions can be drawn based on results.

- PC/PLA blend proves to be excellent in strain resistance at room temperature.
- As the percentage of Polycarbonate is increased there is increase in strain resistance at higher temperature due to the fact that PC resist thermal deformation.
- Also PLA being a biopolymer increases the biodegradability of blend.

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