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Tension Behaviour of PC and PC/TPU Blend With Effects of Temperature and Strain Rate

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ABSTRACT

This work deals with the study of temperature and strain rate effects on tensile behavior of opaque thermoplastic polycarbonate and PC/TPU blend in the composition 90/10 (by wt. /wt., % of PC/TPU). The range of variation of parameters in experiment was linked to in service conditions of components manufactured with this material. Tensile stress-strain responses of PC and PC/TPU blend are presented for quasi-static (0.001 s^{-1}, 0.01 s^{-1}) and moderate (0.1 s^{-1}) strain rate and temperature ranging from -20 °C to 80 °C. The tension tests are performed using electro-mechanical machine, Instron 5582 model, equipped with a static clip on strain gauge extensometer was used. The influence of strain rate and temperature on tension behavior of PC and PC/TPU blend is investigated. Experimental results indicate that the values of yield strength increases with the decreasing temperature. PC/TPU blend shows increase in % elongation property in addition with tensile strength as temperature decreases which means that TPU can effectively enhance the toughness of the PC/TPU blend which indicate it's suitability for low temperature application.

Keyword: **Polycarbonate; strain rate; Tension; Thermoplastic; yield strength.**

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I. INTRODUCTION

Because of improved quality and cost competitiveness, plastic materials are displacing traditional materials in a myriad of diverse and demanding industries. Today, engineering plastics can be found in virtually every aspect of our lives. From food containers to automobiles, appliances, toys, office equipment, and life-saving medical devices, plastics affect each and every one of us. Product designers and consumers alike acknowledge that today's advanced plastics, in tandem with proper design, add to product value and versatility. Amorphous polymeric materials have been widely utilized as a structural material due to their excellent combination of mechanical property, low production cost and light weight. It is well known that the mechanical behaviour of polymers exhibit an obvious strain rate and temperature sensitivity and it has been found that the deformation, damage and failure process under tension and compression loadings vary considerably[1].

As an opaque or translucent thermoplastic polymer, polycarbonate is currently being employed in many applications such as architectural roofing, automotive trays (emballage) casing of cell phones and laptops, machine guards, aero plane interior. The tension behaviour of transparent polycarbonate has been studied over a wide range of strain rates (0.001 s^{-1}-1700 s^{-1}) and temperature up to 1200C[2].But at actual applications of opaque polycarbonate is likely to be subjected to deform at low to moderate strain rates under the extreme temperature environments as compared to transparent polycarbonate. Therefore it is important to study the low impact responses of opaque PC for scientific research and engineering structural design.An important parameter in the fracture of semi-ductile polymer is the brittle-to-ductile transition.This transition is described by the Ludwig-Davidenkov-Orowancriterion by looking at the influence of strain rate on yield stress as well as fracture stress. Yield stress increases with strain rate, more than the fracture stress changes with strain rate. At a certain point, yield stress becomes higher than fracture stress and brittle fracture occurs. Increasing the strain rate and decreasing the temperature leads to the brittle-ductile transition taking place earlier [3]. Most of the research performed on the high impact responses of PC has focused on the compression properties and the split Hopkinson pressure bar (SHPB) has been commonly used to measure the compressive stress-strain responses. For example, Richeton et al. performed SHPB experiments on polycarbonate to study the rate-temperature influence on the compressive yield behaviour of polycarbonate [4]. Siviour et al. performed SHPB experiments on polycarbonate to study the rate-temperature sensitivity of yield responses [5]. In contrast, few researchers on high rate tension behaviour of polycarbonate are reported due to the technical complexity and difficulty in Split Hopkinson tension bar testing system[6].Owing to the fact that there exist differences in tensile and compressive deformation behaviour, it is therefore necessary to study the quasi static and moderate tension behaviour of opaque polycarbonate at various temperature as lot of tension and compressive behaviour studies of transparent polycarbonate are carried out at high strain rates. Siddaramaiah et al studied on Blends of poly (methyl methacrylate) (PMMA) and thermoplastic polyurethane (TPU) in different compositions viz., 95/5, 90/10, 85/15 and 80/20 (by wt./wt., % of PMMA/TPU) were blended by melt mixing using a twin-screw extruder. All the PMMA/TPU blends have been characterized for physico-mechanical properties such as density, melt flow index, tensile behaviour and izod impact strength [7].Kameshwari Devi et al investigates the effect of TPU content on PC reinforced with and without MMT and observed that there is an improvement in mechanical properties like tensile, flexural, hardness, and abrasion resistance in case of PC/TPU blends filled with MMT [8]. Shrivastava et al studied the mechanically improved and optically transparent polycarbonate/clay nano composites using phosphonium modified organoclay and carried out tension test to find out its properties [9].

The filler can be add into the polymer to raise certain properties which will be helpful to design certain application, for example ABS, PMMA, TPU can be add in to the polycarbonate to raise their mechanical property. The objective of the present paper is to investigate the effects of strain rate and temperature on the tension behaviour of opaque polycarbonate and PC/ TPU blend in the composition 90/10 (by wt. /wt., % of PC/TPU). Quasi-static (0.001 s^{-1}, 0.01 s^{-1}) and moderate (0.1 s^{-1}) strain rate tension tests were performed at temperature ranging from -20°C to 80°C.

II. EXPERIMENTAL DETAILS

A.Material and specimen preparation

A 3 mm sheet of opaque Polycarbonate of Lexan™ manufactured by Sabic Innovative Plastics purchased from Pune Polymer. Specimens were machined directly from sheet stock using VMC machine and kept at room temperature for more than 3 days prior to testing.PC/ TPU blend in the composition 90/10 (by wt./wt., % of PC/TPU) is to be prepared by melt mixing the components in counter rotating twin screw extruder and then injection moulding at GLS polymer Pvt. Ltd., Bangalore

B.Tension testing

Uniaxial tension tests were conducted at five temperature (-20°C, 0°C, R.T, 60°C, 80°C) over wide range of strain rates. Quasi-static (0.001 s^{-1}, 0.01 s^{-1}) and moderate (0.1 s^{-1}) strain rate tension tests were performed on electro-mechanical machine, Instron 5582 model universal tester to obtain the stress-strain relations using constant cross-head velocity mode. A liquid CO_2 cooled environmental chamber was used to create the testing temperature below room temperature which is shown in Fig.1

Fig.1. Instron 5582 model with environmental chamber

C. Specimen Design

The rectangular dog-bone samples are machined in accordance with ASTM D638-02a were used for tension testing **[10].** As shown in Fig.2 specimen 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.

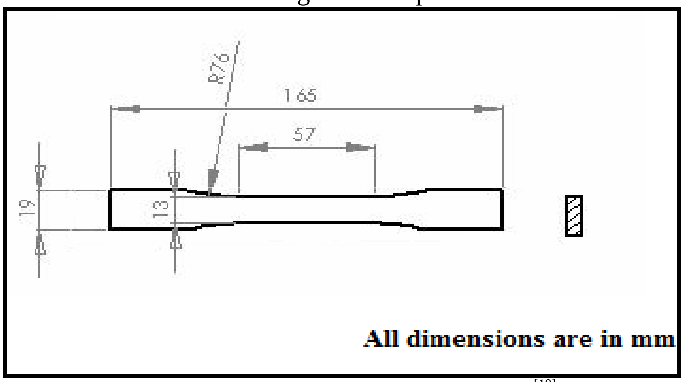


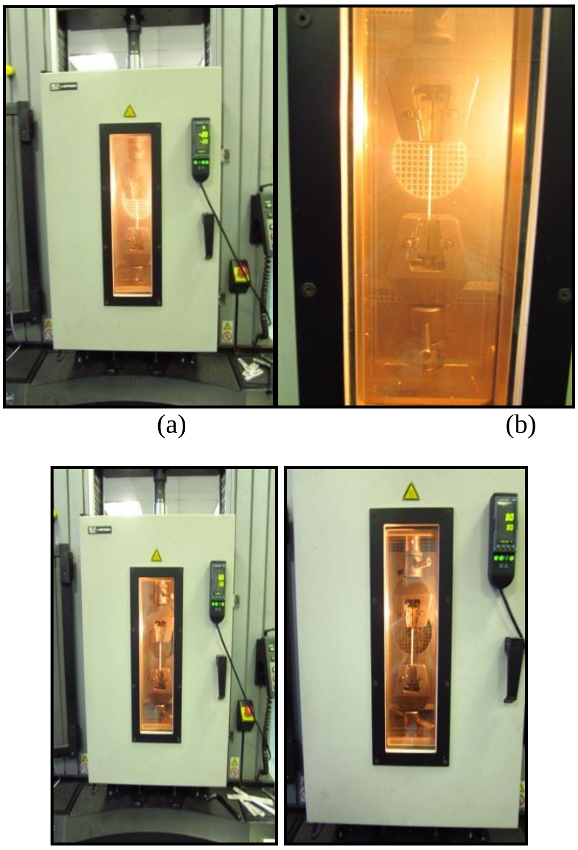
Fig.2 Specimen geometry as per ASTM D638-02a [10]

D. Experimental accessories

A liquid-CO_2 cooled environmental chamber and a resistance-wire heated temperature chamber were used to create the testing temperatures below and above the room temperature, respectively. Static clip on extensometer was used to determine strain having 50 mm gauge length to hold 0-12.5 mm thick specimen. Mechanical wedge action grips were used to hold the specimen having rated capacity 100 kN.

III.EXPERIMENTAL RESULTS & DISCUSSION

Quasi-static and moderate uniaxial tensile experiments were conducted at the strain rates of 0.001, 0.01 and 0.1s^{-1} respectively on opaque polycarbonate and PC/TPU Blend specimens. The test temperature were 20,0,R.T (27°C),60 and 80°C below the glass transition temperature Fig.3 shows specimens in environmental chamber at these different temperature soaked at least for 10 min to give actual environmental effect.



(a) (b)

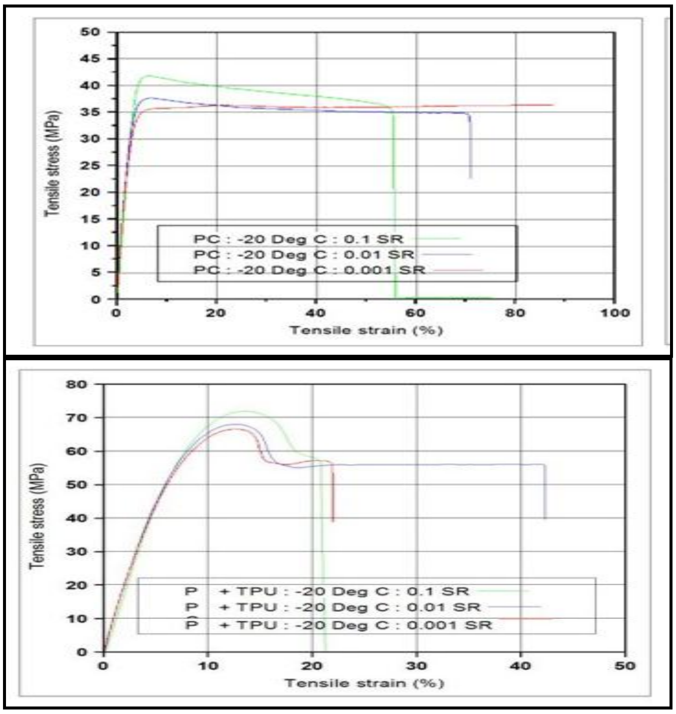
(c) (d)

Fig.3 Specimens in environmental chamber: (a) -20^{0}C (b) 0^{0}C (c) 60^{0}C (d) 80^{0}C

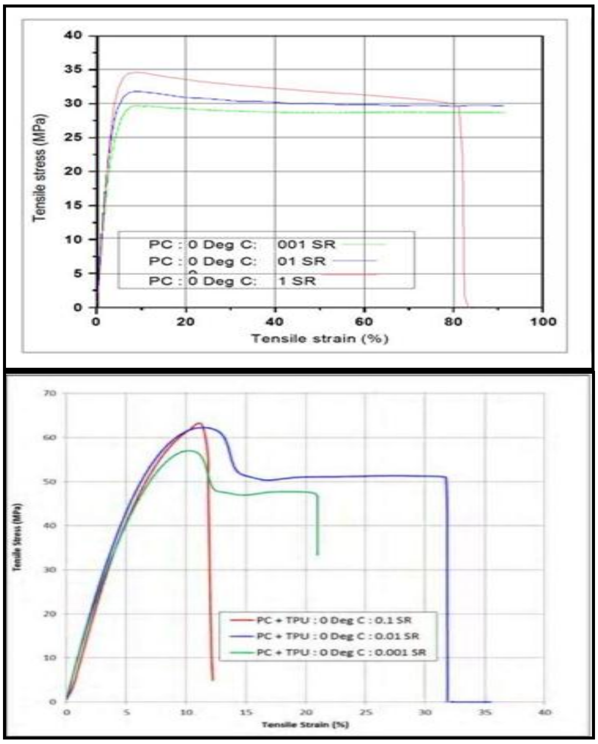
A.Tensile stress-strain responses

Fig.4 illustrates the tensile stress-strain responses of opaque polycarbonate and PC/ TPU blend in the composition 90/10 (by wt./wt., % of PC/TPU) as a function of strain rates at different temperatures the responses of the material are clearly shown to be strongly dependent on the strain rate at all testing temperature An obvious stress drop occur following a plastic flow platform when the stress reaches the peak point in the case of quasi-static and moderate loading, the typical tensile response of opaque polycarbonate includes the linear elastic and non-linear homogeneous deformation stages and the strain softening and plastic flow inhomogeneous deformation stages corresponding to the shear band forming, necking generation and propagation which can be observation within the gauge length of the specimen through the naked eye observation. In considering the deformation of polymers the yield stress or tensile strength is generally define as the stress at the peak point on the stress-strain curve. Compared with the isothermal quasi-static & moderate loading process it is worth noticing that the deformation process at high strain rate for transparent polycarbonate can be considered as an process because the heat generated in the specimen has no sufficient time to dissipate although existing the adiabatic temperature rise in the specimen the tensile responses at high strain rate for transparent PC are similar to quasi-static and moderate responses of opaque PC [11]. As temperature consideration of the tension behavior it is observed that the yield and post yield behavior of PC is sensitive to temperature. The values of yield stress and strain at yield decrease with the increase of temperature. In addition there is a change in initial young's modulus within temperature. Tension stress and strain response of the PC at various strain rates shown in Fig.4 is similar to crystalline thermoplastic polymers presented in the literatures [12].

For comparative study of the opaque polycarbonate and PC/ TPU blend in the composition 90/10 (by wt./wt., % of PC/TPU) it is observed in the tensile stress-strain graph that for polycarbonate plastic deformation zone is very less after yielding above room temperature which shows ductility at high temperature. For PC/TPU blend after after yielding it shows little plastic deformation zone and suddenly brittle fracture. This indicate hard and tough behavior of PC/TPU blend.



(a)



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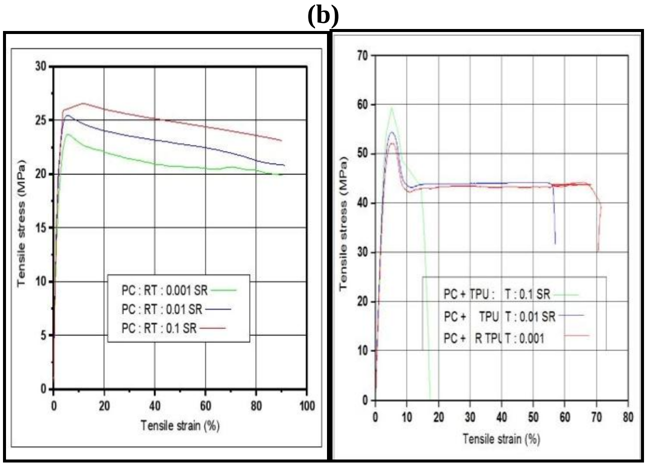

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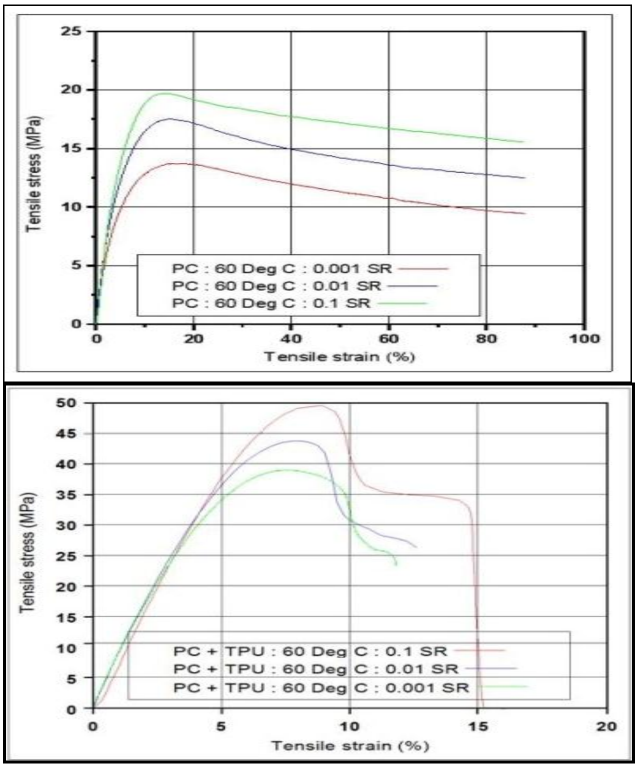
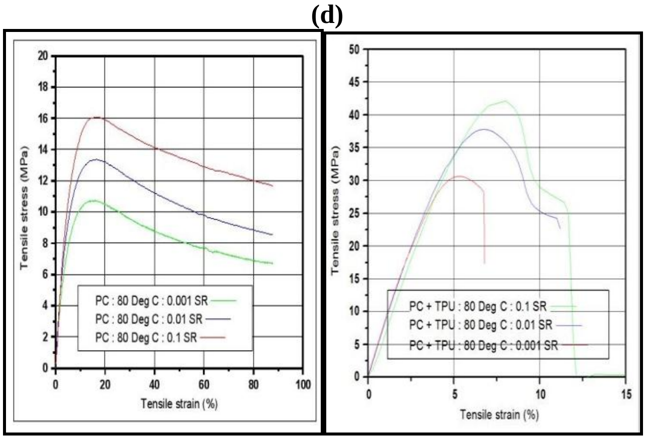


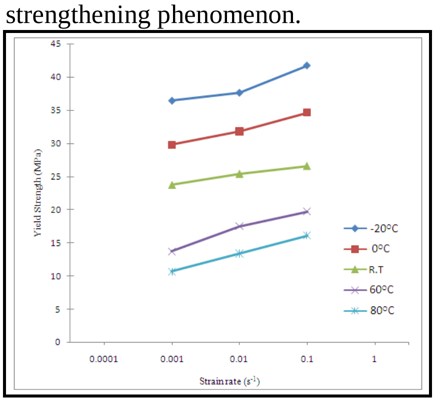
(d)



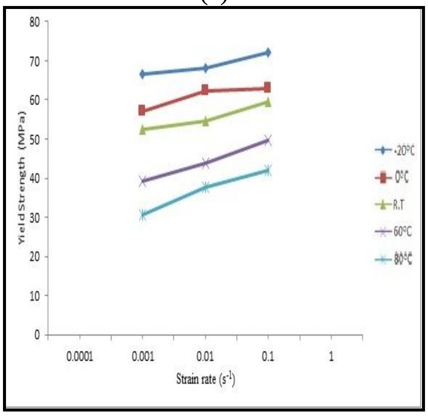
(e)

Fig.4 Tensile stress-strain curves at different strain rates and at temperature of (a)-20°C (b) 0°C (c) RT (d) 60°C (e) 80°C

The graph of yield stress plotted against the strain rate at different temperature is shown in Fig.5. It can be seen that the tension yield stress of PC amc PC/TPU blend are sensitive to the strain rates and temperature. The values of yield stress at moderate strain rates ($0.1s^{-1}$) are greater than that under quasi-static loading which presents considerable strain rate strengthening phenomenon.



(a)



(b)

Fig.5 Effect of strain rate and temperature on the yield stress of(a) polycarbonate(b) PC/TPU blend.

B. Fracture Analysis by Optical Microscopy

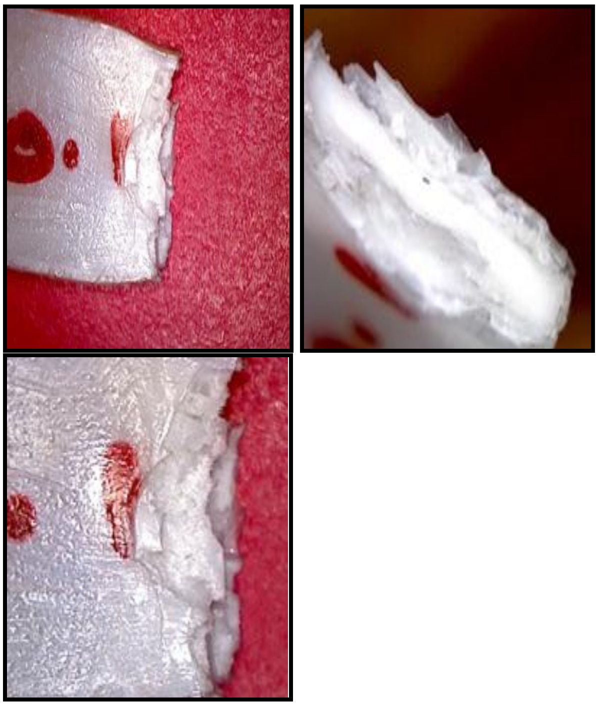
It is observed that the fracture surface of opaque polycarbonate under quasi-static and moderate tensile loading is characterized by brittle fracture manner at -20°C and 0°C. Comparatively at high temperature above room temperature at 60°C and 80°C the fracture is characterized by ductile manner.Fig.6. Shows the fracture appearance of polycarbonate at -20°C temperature.Fracture shows brittle fracture showing no fibrous structure. This fracture is exhibiting very low elongation.

Fig.6.Fracture appearance of polycarbonate at -20°C

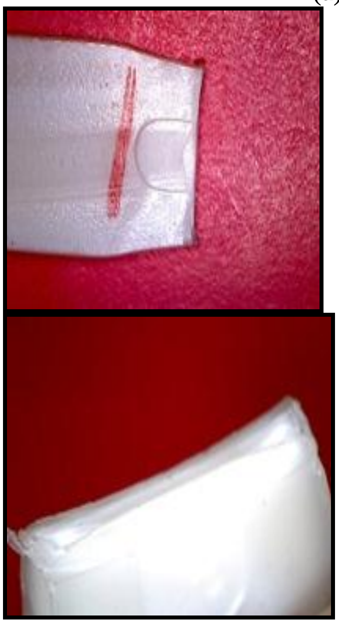
An important parameter in the fracture of semi-ductile polymers is the brittle-to-ductile transition. This transition is described by the Ludwig-Davidenkov-Orowan criterion by looking at the influence of strain rate on yield stress as well as fracture stress. Yield stress increases with strain rate, more than the fracture stress changes with strain rate. At a certain point, yield stress becomes higher than fracture stress and brittle fracture occurs. Increasing the strain rate and decreasing the temperature leads to the brittle-ductile transition taking place earlier. With increasing test speeds the materials are expected to fracture in a more brittle manner. However, the combination of a higher fracture stress and a slightly lower fracture strain surprisingly resulted in a more ductile behavior of the material.

Blending two or more polymers offers yet another method of tailoring resins to your specific application. Because blends are only physical mixtures, the resulting polymer usually has physical and mechanical properties that lie somewhere between the values of its constituent materials. For instance, an automotive bumper made from a blend of polycarbonate resin and a thermoplastic polyurethane elastomer gains rigidity from the polycarbonate resin and retains most of the flexibility and paint ability of the polyurethane elastomer. For business machine housings, a blend of polycarbonate and ABS resins offers the enhanced performance of polycarbonate flame retardance and UV stability at a lower cost. In this seminar PC/ TPU blend in the composition 90/10 (by wt./wt., % of PC/TPU) was studied and the fracture appearance is shown in Fig.7.

It can be observed from the fracture appearance in Fig.7 and tensile stress-strain curve the tensile strength for the PC/TPU blend at lower temperature is more than pure PC. Also tensile strain or % of elongation value is decreases as temperature increases which is opposite behavior of pure PC. At lower temperature somewhat ductile behavior is observed in tension loading.Fig.7(a) shows the fracture appearance of PC/TPU blend at -20°C temperature, shows very ductile fracture showing fibrous structure.The fracture is comparable to cup and cone fracture exhibiting higher elongation. This behavior indicates hard and tough property of PC/TPU blend. Fig.7(a) shows the fracture appearance of PC/TPU blend at -20°C temperature, shows less ductile fracture as compared to sample 1 showing no fibrous structure.Fracture is comparable to cup and cone fracture exhibiting some elongation but is less ductile as compared to sampleThe main reason for this unique behavior of PC/TPU blend is it's processing to prepare this blend. The processing of a plastic material can alter the capacity of the molecule structure to damp energy resulting from impact loading. Essential aspects of the processing include Discontinuities, Fusion, Orientation, Molded-in stress.



(a)



(b)

Fig.7.Fracture appearance of PC/TPU blend at:(a) -20° (b) 80°C

From table I it can be observed that for polycarbonate as temperature increases tensile strengh dcreases but % Elongation increases.But it is observed that for PC/TPU blend as temperature increases tensile strengh dcreases in addition with % Elongation. It showsthe trend that as quantity of TPU increases in the polycarbonate at low temperature tensile strength and % elongation properties get raised.It means that addition of TPU raised properties of polycarbonate in low temperature application. Most plastics at room temperature show their familiar properties of flexibility (a low Young's modulus) and high resistance to cracking but when the temperature decreases this can change rapidly and many common plastics become brittle with low failure stresses. Low temperatures can be more harmful to plastics than high temperatures. Catastrophic failures can occur if materials selection does not take account of the low temperature properties of plastics.

Table I
Experimental tensile strength and % elongation results for (a) Polycarbonate (b) PC+TPU blend

(a)

Temp. [^{0}C]	**0.001s^{-1}**		**0.01s^{-1}**		**0.1s^{-1}**	
	σ_s [MPa]	% E	σ_s [MPa]	% E	σ_s [MPa]	% E
-20^{0}C	36.4	87.8	37.6	71.1	41.7	56.0
0^{0}C	29.8	91.3	31.8	91.2	34.6	82.2
27^{0}C	23.7	90.0	25.4	90.0	26.6	90.0
60^{0}C	13.7	87.8	17.5	87.7	19.7	87.0
80^{0}C	10.7	87.8	13.4	87.7	16.1	87.5

(b)

Temp.[^{0}C]	**0.001s^{-1}**		**0.01s^{-1}**		**0.1s^{-1}**	
	σ_s [MPa]	% El	σ_s [MPa]	% E	σ_s [MPa]	% E
-20^{0}C	66.7	22.1	68.1	42.3	72.1	21.3
0^{0}C	57.0	21.0	62.3	31.9	63.0	26.0
27^{0}C	52.3	70.6	54.5	56.8	59.5	17.3
60^{0}C	39.1	11.8	43.9	12.5	49.6	15.0
80^{0}C	30.6	6.8	37.7	11.2	42.1	12.0

The presence of included contamination, or voids or porosity within the molded components will result in points of stress concentration. Such defects will intrinsically reduce the impact resistance of the part. Areas of poor fusion, such as a knit line, correspond to poor molecular entanglement. These regions of the molded part will essentially be more prone to disentangle, rather than yielding, upon impact loading. Orientation of the polymer molecules during molding will alter the impact response of the material. Depending on the direction of orientation relative to the impact load, the results may be an increase or decrease in the impact resistance. Internal and external stresses are additive within a formed article, thus the presence of molded-in stress can severely reduce the level of impact stress a material can accommodate.

IV.CONCLUSION

Uni-axial tension stress-strain behavior of opaque polycarbonate and PC/ TPU blend in the composition 90/10 (by wt. /wt., % of PC/TPU) was investigated at five temperatures in the range of -20^{o}C to 80^{o}C and three strain rates ranging from 0.001 s^{-1} to 0.1 s^{-1}.The experimental results indicate that the tensile response of opaque polycarbonate and PC/TPU blend is dependent on strain rate and temperature. The values of yield strength and strain at yield decreases with increasing temperature. Yield strength increases significantly with increasing strain rate. Also the fracture behavior of polycarbonate in tensile loading shows the brittle to ductile transition from low to high temperature respectively. The maximum stresses, the fracture propagation displacements and the fracture energies at high strain rates were higher than was expected based on low strain rate results. Also the size and the temperature of the deformation zone increased with strain rate. This suggests that at high test speeds a more delocalized deformation process is taking place. This delocalization might well be the result of either lowering of drawing stress due to the increased temperature. But in case of PC/TPU blend localized stress was observed leading in brittle fracture. Applications where hardness with toughness property is required we can use this PC/TPU blend with better paint ability like case cover of mobiles, radiator grills, dashboards and also in loe temperature application.

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