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THE MECHANICAL PROPERTIES OF TOUGHENED POLY(METHYL METHACRYLATE) SHEET MATERIALS (Part 1)

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ABSTRACT

The project was concerned with structure-property relations toughened grades of poly(methyl methacrylate), PMMA sheet with various weight fractions of rubber particles. The deformation and fracture behavior of rubber-toughened PMMA cast sheet materials have been studied using tensile testing. There were found that the Young's modulus , yield stress and ultimate tensile strength of the rubber-toughened PMMA materials decreased as weight fraction of the rubbery phases increase, but nevertheless the ultimate strain increases with an increase in the percentage rubber particle.

INTRODUCTION

Stress-strain measurements are probably the most widely used mechanical method for determining the mechanical properties of materials(1). These measurements are generally made in tension by stretching the specimen at a uniform rate and simultaneously measuring the force on the specimen. The test is continued until the specimen breaks.

Certain material properties such as Young's modulus, yield stress and fracture stress and strain can be calculated by analyzing the stress-strain curves obtained from the test. The Young's modulus is determined from the initial slope of the stress-strain curve. The fracture stress is the ultimate stress that the specimen can sustain, and the fracture strain is the elongation at break.

Carswell and Nason (2) have divided the types of stress-strain curves obtained with polymers into five classes. These classes are: (a) soft, weak; (b) hard, brittle; (c) hard, strong; (d) soft, tough; and (e) hard, tough. The various types of stress-strain curves of polymers are shown in ***Figure 1.*** (2)

Soft weak materials have low moduli, low tensile fracture stresses and only moderate value of fracture strain. Hard brittle polymers have high moduli and relatively high fracture stresses but break at very low strains without yield. Hard strong materials have high moduli, high fracture stresses and low strain. Soft tough polymers exhibit low moduli, low yield stresses, but very high fracture strains and moderate fracture stresses. Hard tough polymer materials show high moduli, high yield stresses and high fracture stresses and strain.

The shape of the stress-strain curves are dependent on the rate and temperature of testing. Basically as temperature increases both the rigidity and the yield strength decrease while the elongation generally increases.

MATERIALS

Sheets of rubber-toughened PMMA materials with different weight fraction were supplied by Imperial Chemical Industries, (ICI) in the form of 3mm and 6mm thick sheets. The weight percentages of particles in the materials supplied were 0%, 1%, 2%, 4% and 8%.

The matrix material used in the toughened sheets of PMMA were poly (methyl methacrylate) similar to commercial 'Perpex'. The toughening particles comprise three radially-alternating rubbery and glassy layers, the outer layer being of glassy polymer.

'Diakon' LG-156 is another commercially-available matrix material used in rubber-toughened PMMA produced by ICI. It was chosen for comparison with the properties of 'Perpex' used in the project. It is thought to be a copolymer of methyl methacrylate and n-butyl acrylate.

The weight fraction of methyl methacrylate present in the copolymer is thought to be 0.9[3]. Since 'Diakon' LG-156 was supplied in spherical bead form, rectangular plaques of LG-156 in the form of 3mm and 6mm thick sheets were prepared by compression moulding at 220 °C in order to eliminate any effects due to orientation which may be induced by injection moulding.

THE TESTING TECHNIQUE

Rectangular strips (150mm x 25mm x 3mm) were cut from the Perspex sheets provided by ICI and were machined into dumbbell shaped tensile specimens by using a router equipped with the appropriate tensile template. The rectangular strip was cut into required shape and dimensions (corresponding to BS 2782 Method 320 C) using a high-speed cutter driven by compressed air. Finally, the specimen was polished to remove surface flaws using a series of grades of silicon carbide paper followed by a metal polish (Brasso) before testing.

The dimensions of each specimen were measured using a micrometer to an accuracy of 0.01 mm. The thickness and the width of the gauge length were measured at three different points and mean values were obtained.

The specimens were tested on an Instron Universal Testing Machine Model 1211 at 21 °C ± 1 °C, using a cross-head speed of 5 mm min^{-1}. An extensometer was used to measure the strain up to 10% and any strains beyond this limit were determined from the change in grip separation and the load-time chart recorder.

Ten specimens were tested for each type of material and the mean and standard deviations of the tensile properties were obtained.

RESULTS AND DISCUSSION

The stress-strain curves of rubber-toughened PMMA materials are similar to those obtained by Bucknall et. al.[4] and Frank and Lehmann[5]. The stress-strain curves of LG-156, PMMA and the rubber-toughened PMMA cast materials obtained from the appropriate load-displacement plot are shown in ***Figure 2***. The initial region of the stress-strain curves of all the rubber toughened PMMA materials are linear, although the modulus is lower compared with PMMA due to the presence of the disperse rubbery phase. The results for the tensile properties of LG-156, PMMA and the rubber-toughened PMMA materials are given in ***Table 1.***

Table 1. Results from Tensile Testing

Sample	Modulas E (GPa)	Yield stress (MPa)	Ult.Tensile strength (MPa)	strain %
LG-156	3.16 ± 0.56	63.9 ± 9.2	63.9 ± 9.2	5.3 ± 1.1
0 %	3.38 ± 0.44	81.1 ± 1.8	81.1 ± 2.4	8.7 ± 0.6
1 %	3.35 ± 0.34	79.8 ± 1.9	79.8 ± 2.0	9.0 ± 3.2
2 %	3.30 ± 0.68	78.5 ± 11.6	78.2 ± 12.0	10.4 ± 2.9
4 %	3.28 ± 0.30	74.5 ± 5.2	74.3 ± 5.2	11.1 ± 2.2
8 %	3.08 ± 0.36	66.8 ± 6.2	66.2 ± 6.2	13.6 ± 1.6

The effect of weight fraction, w_p upon the tensile Young's modulus, E of rubber toughened materials is illustrated in ***Figure 3.*** The figure shows that a linear relationship exists between E and w_p. It was found that the pure PMMA cast material has the highest modulus which drops gradually as the percentage of particles increases. This observation suggests that it thought to be due to the presence of the rubber particles in the matrix PMMA which was later confirmed by transmission and scanning electron micrographs. It was also reflected in the stress-strain data but nevertheless it can be seen that the ultimate strain increases with an increase in the percentage of rubber particles, which is shown in ***Figure 4.***

Figure 5 shows the effect of w_p upon the yield stress of rubber toughened PMMA materials. The figures indicate that a linear relationship exists between the yield stress and w_p, which is observed to decrease with increasing w_p. Yield was observed for the pure PMMA material which was thought to be rather unusual. This might be due to the high molar mass(6) of the cast sheet. Alternatively it might be due to the presence of the unpolymerised monomer acting as a plasticiser in the polymer as in the case of water in nylon(7).

Stress-whitening was observed as a 'milky white' haze which intensified continuously as the stress and strain increased. It started to appear at strains of 2-3% in the rubber-toughened PMMA materials. At low or moderate strains, stress-whitening was concentrated in broad diffuse shear bands lying at angles of about 45° to the tensile axis. Eventually, at very high strains, the entire gauge length of the specimen was intensely whitened. The intensity of stress-whitening at failure depended on the amount of the rubber particles present and increased with increasing w_p.

The ultimate tensile strength was found to be slightly lower than the yield stress as there was a yield drop and no induced molecular orientation during the process of yielding. It was also observed that the ultimate tensile strength decreases as the w_p increases.

CONCLUSIONS

The importance of w_p was demonstrated by the mechanical properties of rubber-toughened PMMA. Stress-strain curves revealed that the modifier particles induced macroscopic yielding in the matrix PMMA. The Young's modulus, E was observed to decrease from 3.38 GPa to 3.08 GPa as w_p increased from 0% to 8%.

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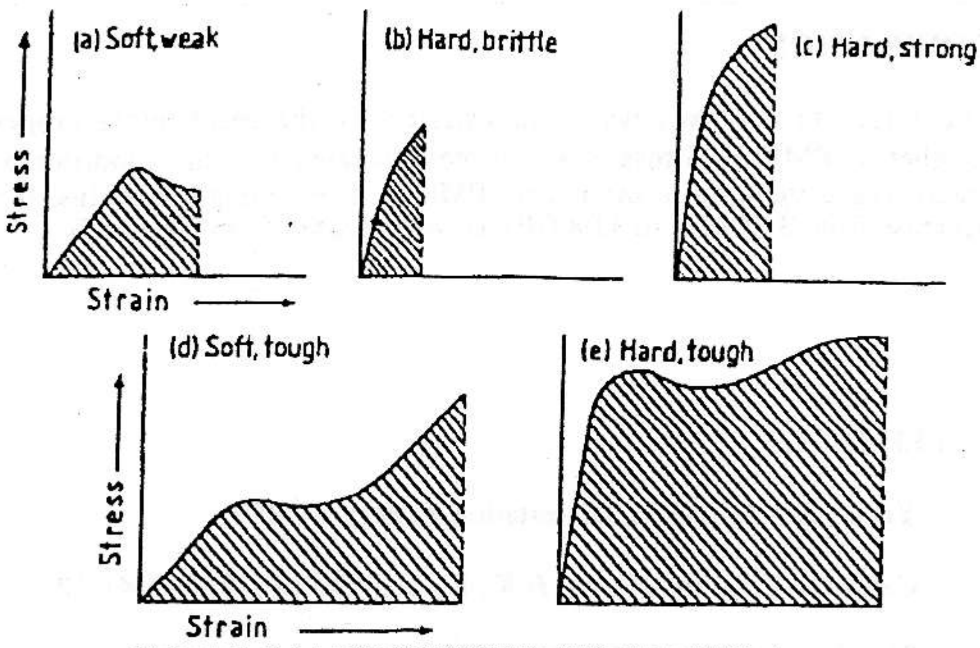

Figure 1: The various types of stress-strain curves of polymers (2)

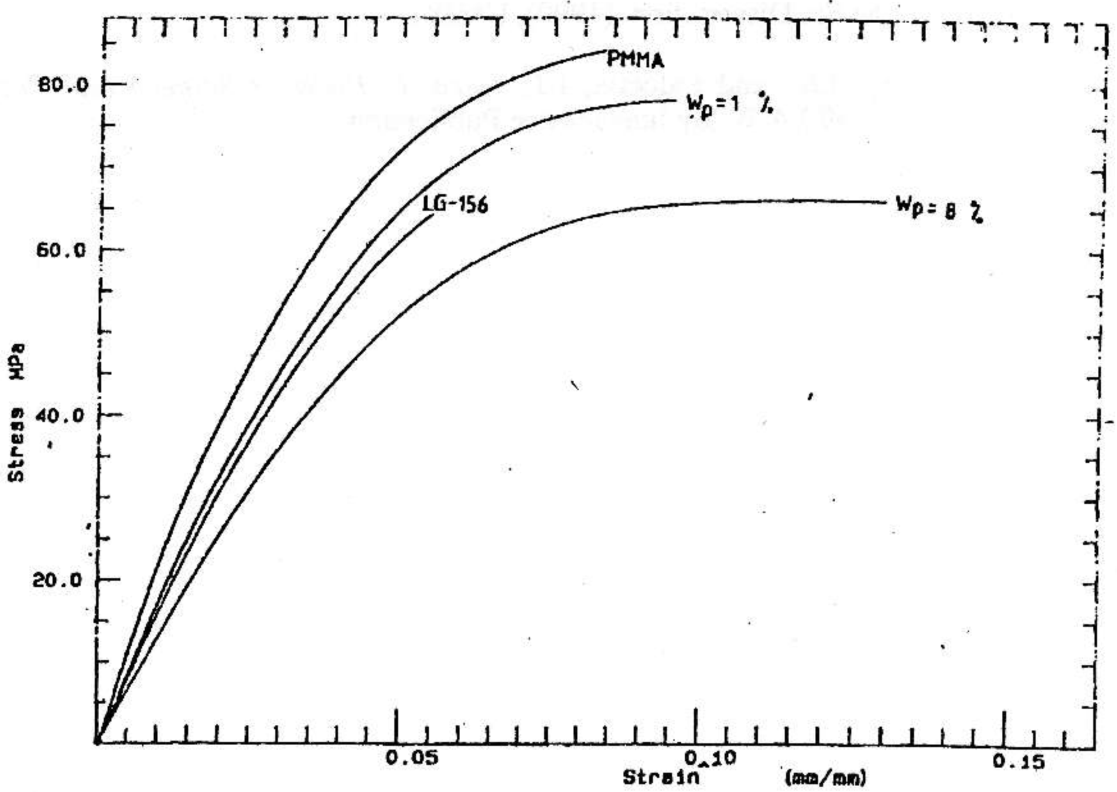

Figure 2: The stress-strain curves for LG-156, PMMA and RTPMMA materials with Wp = 1% and 8%

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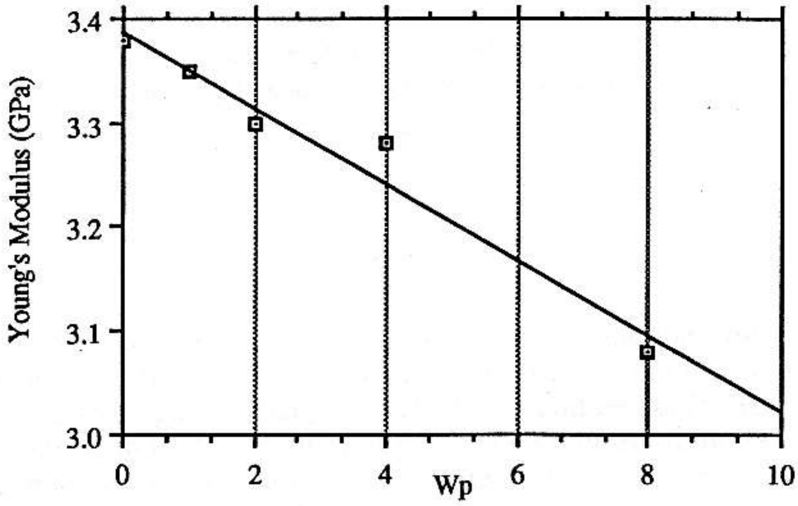

Figure 3: Young's Modulus Vs. Wp

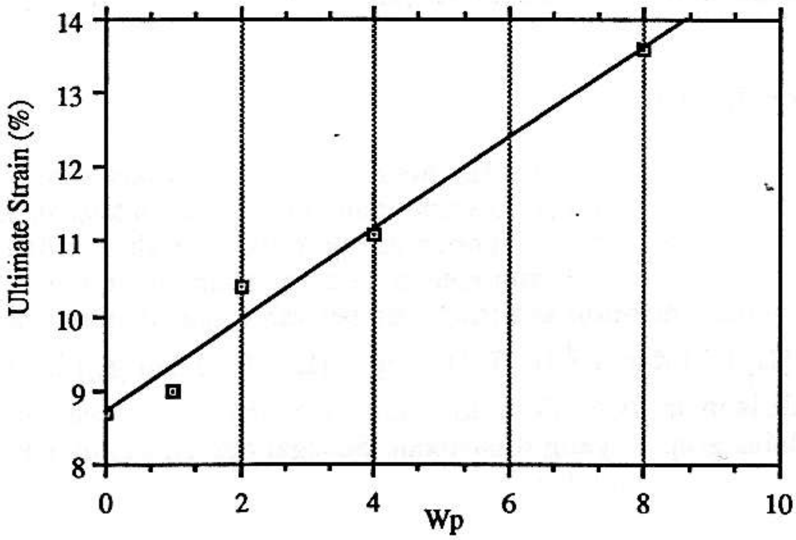

Figure 4: Ultimate Strain Vs. Wp

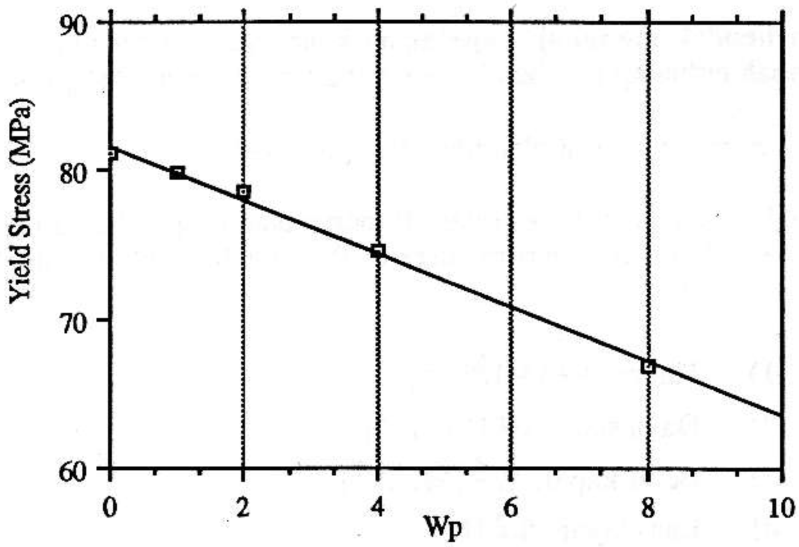

Figure 5: Yield Stress Vs. Wp