EFFECT OF ANNEALING ON THE FRACTURE BEHAVIOR OF POLYSTYRENE

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The effect of annealing on the fracture properties of polystyrene was studied by changing annealing temperature and time. Polystyrene specimens were annealed at six different temperatures for 5 h and 72 h. Untreated and annealed polymers were subjected to tensile tests with a strain rate of $\dot{\varepsilon}$=0.3 min^{-1}. The yield strength, the elongation at break and the fracture energy values were discussed.

INTRODUCTION

Polystyrene is one of the most important commercial polymers and is often used mainly because of its good molding properties and transparency. For this reason much attention has long been paid to the fracture behavior and deformation of polystyrene, which can be varied by permanently changing the polymer microstructure by annealing, irradiation or prestraining, after crystallization (1). As it is known, the processing conditions and thermal hisquent thermal treatments which determine the termal history of a polymer affects greatly the mechanical properties of the polymer. One of possible thermal treatments, annealing, is the most common used. A number of extensive studies on the effect of annealing process on the deformation behavior and fracture of polymers have been carried out (2-8). LeGrand (4) was the first to note that an annealing process can cause embrittlement in the polymer.

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This study will deal with the effect of annealing temperature and time on the mechanical properties of polystyrene processed by injection molding.

EXPERIMENTAL DETAILS

Material and Specimens

The polystyrene (PS) used in this work was a general purpose homopolymer, kindly supplied by Bayer Turkish Chemistry Industry Co. Ltd. Test specimens were prepared using the specifications in ASTM D638 Type 1. Prior to deformation, annealing of the specimens was carried out in air oven at 40, 60, 85, 100, 120 and 140°C for 5 and 72 hours. At the end of period the oven was turned off and the specimens were slowly furnace cooled. Five replicates were run at each temperature and all five specimens were put into the oven at one time.

Tensile Tests

The tensile properties of non-annealed and annealed specimens were measured on an Instron Universal testing machine (Model 1195) equipped with a strain gage extensometer. The tensile tests were performed at room temperature and using a crosshead speed of 15mm/min. The measured load and elongation data were evaluated in the form of the stress-strain curve and the fracture energy with the aid of a computer. The program gave the values of the yield strength and elongation at break and fracture energy was calculated by integrating the stress-strain curve up to the fracture point using the equation:

$$E = \int_{\varepsilon}^{\varepsilon_F} \sigma(\varepsilon)\,d\varepsilon \qquad (1)$$

RESULTS AND DISCUSSION

The results were represented as yield strength-temperature and elongation at break-temperature diagrams. In both diagrams the ordinates indicate the properties of untreated specimens.

Figure 1 shows the yield strength as a function of the annealing temperature and annealing time. Each point represents the average of 5 results. As can be seen, the yield strength of the annealed PS is higher than that of the non-annealed PS at almost every temperature; furthermore the yield stress values increase slowly up to an annealing temperature of 85°C and after higher annealing temperatures these values increase definitely with annealing temperature. At the same time, we can see that the yield strength values obtained after 72 h are higher than those obtained after 5 h. When annealing takes place at temperatures higher than 85°C, the yield stress values increase definitely with annealing time.

Another important property obtained from tensile test was elongation at break. As can be seen in Figure 2, the deformation at break decreases slowly with temperature of annealing when the annealing temperature is lower than 85°C. But a clear decrease (approximately by one-half) is observed for annealing temperatures above 85°C both after 72 h and 5 h annealing time.

The fracture energy values of annealed polystyrene are some times lower than those of the untreated polystyrene; furthermore the fracture energy decreases with the increase of the annealing temperature. The fracture energy values of samples annealed for 72 h are higher than those annealed at the same temperature for 5 h. This result may be related to results obtained for yield strength and elongation at break. As was reported, yield strength values are higher for a 72 h annealing time, whereas elongation at break is nearly constant irrespective of the time of annealing. Thus the area under the stress-strain curves is greater for specimens annealed for 72 h, in close agreement with the fracture energy values.

It seems clear that annealing the polystyrene about 85°C causes some internal rearrangement in the material which is reflected in the yielding properties of the polymer. According to Feldman et al (9), this suggest that the motion of the structural units becomes more restricted due to changes in the internal structure. At higher temperature these structural changes dominate over the softening effect of temperature. It is claimed in the literature that the annealing process has long been associated with the molecular relaxation transition as measured by conventional dynamic-mechanical or dielectric methods (10-11). However, it is more difficult to explain what are the micromechanism responsible for the annealing effects. Despite the numerous studies on annealing in the past 25 years (12), there remains a lack of agreement concerning underlying molecular mechanism. It is beyond the scope of this work to discuss the problem in detail.

CONCLUSIONS

All the results reported indicate that the annealing of polystyrene increase the yield strength by about 20 percent. The annealing cause a degree of embrittlement in the polymer which is also manifested as a decrease of elongation at break and fracture energy at all annealing temperatures. Internal arrangement and the relaxation theory support each other rather well.

SYMBOLS USED

E = fracture energy (J/mm^3)

ε = strain at break (%)

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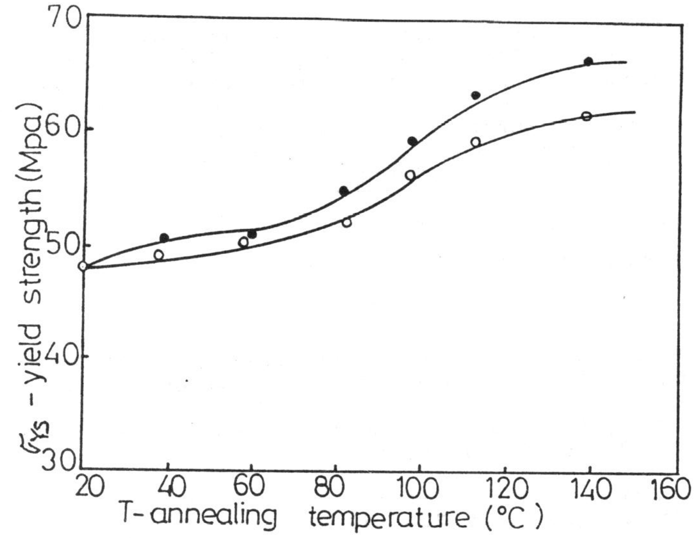

Figure 1. Effect of annealing on yield strenght. Annealing times of 5 hours (o) and 72 hours (•)

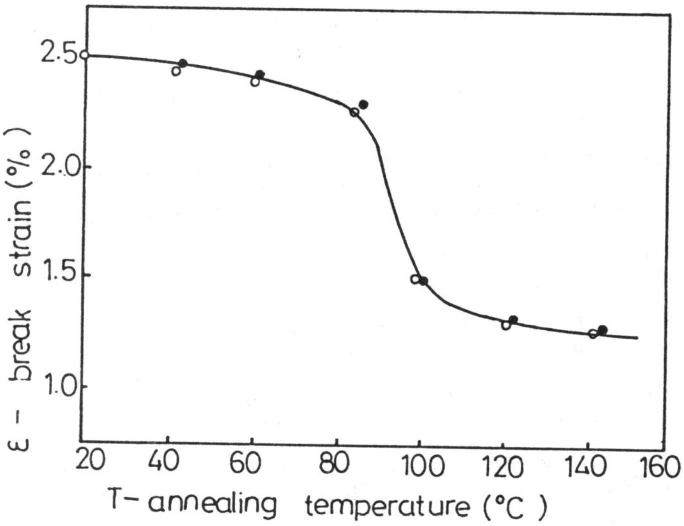

Figure 2. Effect of annealing on elongation at break. Symbols are as in Figure 1.