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Investigation about the effect of previous impacts on the impact behavior of high impact polystyrene (HIPS)

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A process of adding rubbers to rigid plastics in order to increase their fracture resistance was first used commercially in 1948, with polystyrene being the matrix. The early success of high impact polystyrene (HIPS) led to the development of similar blends based on other rigid polymers, giving rise to the rubber-toughened grades, which are now available for most commercial plastics and thermosets of any significance [1–4].

Rubber toughening causes extensive plastic deformation at crack tips and leads to a considerable increase in impact strength. The initiation and propagation of cracks in glassy thermoplastics is essentially a competition between crazing and shear yielding. In brittle polymers, such as PS, crazing is the dominant mode whereas in more ductile materials, such as PC or PES, plane-stress shear yielding plays a more important role and, indeed, is responsible for the ductile fracture. The rubber particles not only initiate multiple crazing at low applied stresses, but also extend and deform with the crazed matrix, providing stability against premature fracture. Rubbers are unique in their ability to perform both functions, and therefore can toughen brittle PS. Other types of particles, including glass beads, can accelerate crazing sufficiently to cause yielding, but only well-bonded rubber particles enable essentially brittle polymers to reach large strains [5–9].

It is known that micro voids form in the polymer during deformation and they can grow and coalesce to form larger cavities and crazes, which can be observed by the naked eye. Eventually fracture will occur, at least in a glassy polymer, by the breakdown of crazes into a crack. In these materials, the impact energy is most effectively dissipated by the formation of large craze envelopes at the crack tip. The dispersed impact modifier must arrest these crazes and must be sufficiently large so as not to be engulfed by the approaching craze. The rubber particle size must exceed the craze thickness and the interfacial adhesion must be sufficient to permit the effective transfer of stress to the rubber inclusion to blunt the craze. The required size is of the order of microns. The interparticle distance must be sufficiently small to prevent the occurrence of a catastrophic crack [5–7].

A number of quite different mechanisms for toughening have been proposed but they all rely on the dispersion of rubber particles within a glassy matrix. These include energy absorption by rubber particles, debonding at the rubber-matrix interface, matrix crazing, shear yielding or a combination of shear yielding and crazing, fracture of rubber particle, trans-particle failure, crack deflections by particles, plastic zone at crack tip, stretching and tearing of rubber particles. More energy is being absorbed than for an equivalent volume of the polystyrene matrix. The amount of energy absorbed in impact is attributed to the sum of the energy to fracture the glassy matrix and the work to break the rubber particles [5–7].

HIPS polymer is used in mechanical engineering applications where machine parts are subjected to impact loading. In fact, most of the machine parts are subjected to impact loading repeatedly during their service life. This study is aimed to investigate the repeated impact behavior and the crack initiation and propagation mechanism of the HIPS material.

The test material HIPS was kindly supplied by PETKIM (The Turkish Petrochemical Company). “A-825 E” is the commercial name of the styrene—butadiene blend. Instrumented Charpy impact tests were performed on a Ceast pendulum type tester (Resil 25). A charpy hammer having a strike range of 1.08 kN was used. Hammer length and mass were 0.327 m and 1.254 kg, respectively. Sampling time was 8 μs. At a falling angle of 35 °, impact velocity was 0.93 m/s, and maximum available energy was 0.54 J. Impact test samples were prepared according to ASTM D 256 standard. Notched samples with dimensions of $3.2 \times 12.7 \times 138$ mm were used. The span was 63.5 mm. For each parameter, 10 experiments were performed and the average is reported. Preliminary experiments were performed in order to find the appropriate falling angle, which was chosen to be 35 ° in order to reduce the inertial oscillations in the contact load between striker and sample. Before discussing these results, it is important to understand the approach used in the analysis of force-time curves, which is critical in determining the impact characteristics of materials. Upon impact of the pendulum the force rises sharply to a maximum value ($F_{\max}$) and then gradually falls to zero due to catastrophic failure. The total area under a force-time curve gives the impact energy for the system ($E_{\max}$). This curve can be divided into two regions. These regions give the energies of crack initiation (E_{i}) and crack

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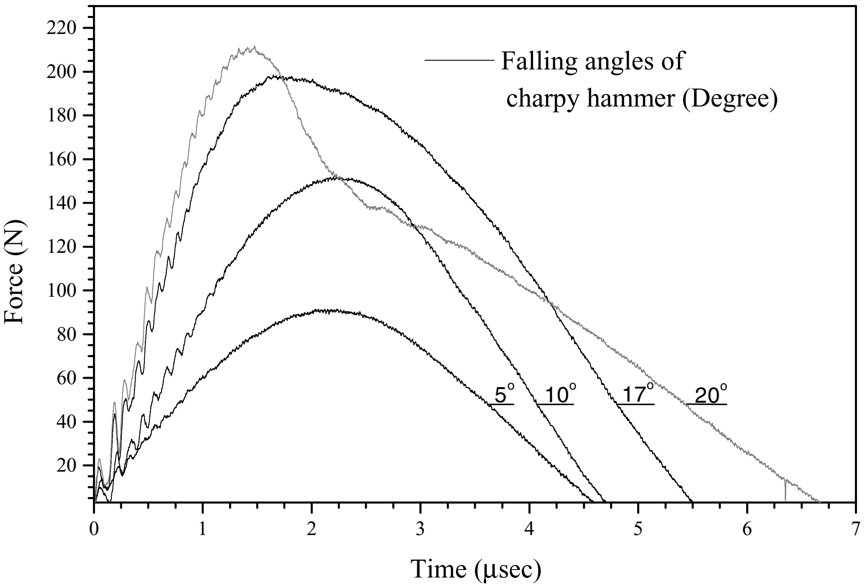


Figure 1 Force-time curves of previous impacts.

propagation (E_p). The first region is the crack initiation region, which extends up to F_{max} in the force—time curve. The second region is the crack propagation region, which starts from F_{max} and ends at the fracture of the sample. The spikes seen in the first region are due to inertial oscillations of the sample.

The samples were placed into the instrumented impact tester and struck with the pendulum hammer, at small falling angles. These falling angles were not big enough to fracture the samples but they were big enough to cause elasto-plastic deformation in the material. The falling angles of charpy hammer were chosen as 5, 10, 13, 15, 16, 17, 18, 19 and 20 °. The hammer struck each sample only one time. The samples were preserved from additional strikes of the hammer. These samples were called "previously impacted samples" and their force-time and energy-time curves were carefully investigated (Fig. 1). It was observed that there was remarkable crack propagation at 20 ° which was the maximum falling angle used for these samples (Fig. 1).

As shown in both Fig. 1 and Table I, up to a falling angle of 16 °, crack initiation in the material was not observed. Previous impacts caused crazes at the crack tip. A stressed material that contains a high density of crazes is said to have "stress whitened" because of its appearance as a result of this scattering. The crazing formations at the crack tips were observed by the naked eye. The crazed area was very small, especially at 5 °. Increases in the falling angle up to 16 ° caused larger crazed areas and the crack initiation was observed at 16 °. The amount of crack propagation and total fracture energy increased with the increase of falling angle.

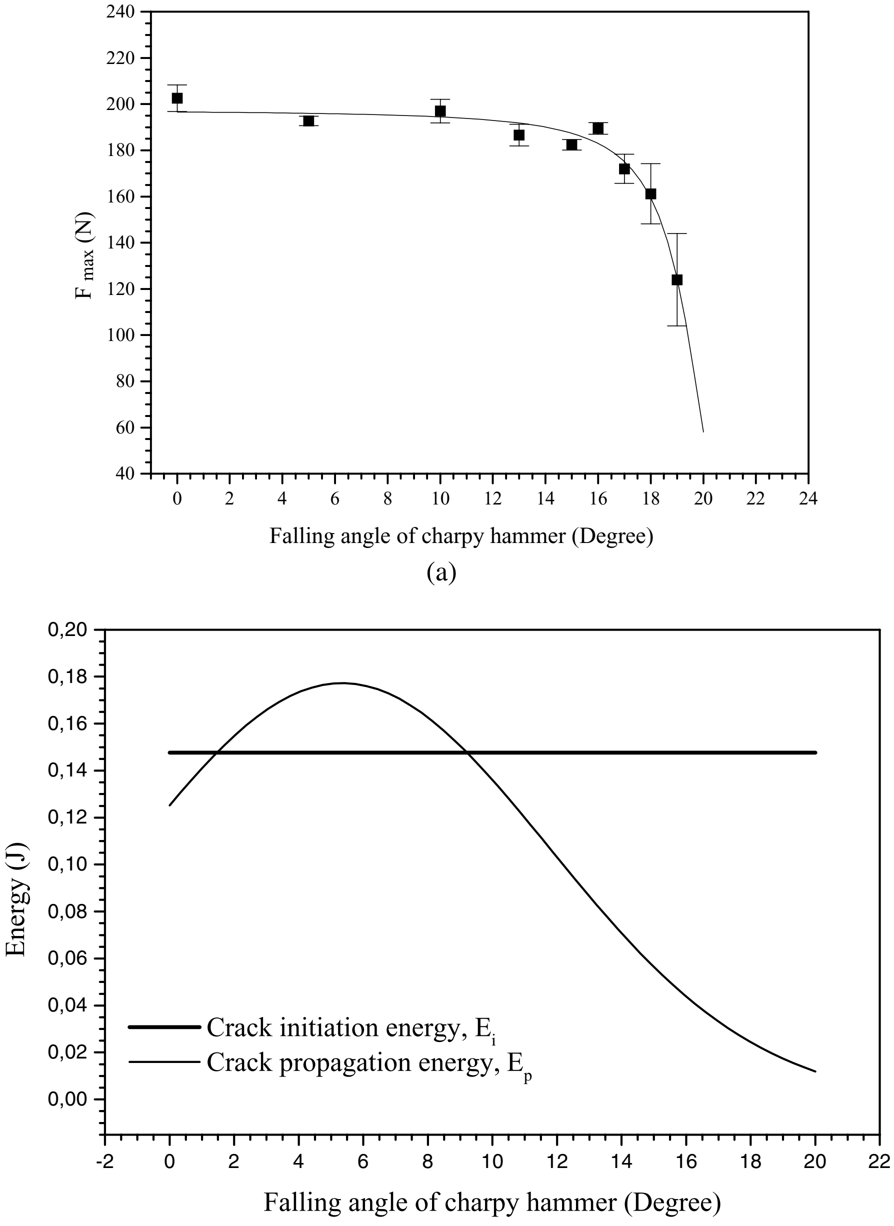
Finally, all of the previously impacted samples were put into the impact tester and fractured by the charpy hammer, at a falling angle of 35 °. This impact was called the "final impact". The sample previously impacted at 20 ° was fractured at final impact with a very small energy reading which tester could not measure. Data for both previous impacts and final impact at each falling angle are given in Table I.

As a result of the final impact, as illustrated in Fig. 2a, it was observed that there were remarkable changes for F_{max} values up to 16 ° and the F_{max} values decreased sharply between 16 and 20 °.

After final impacts, it was observed that the crack initiation energies, E_i, were nearly the same for each sample (Fig. 2b). On the other hand, crack propagation energies, E_p, increased for the samples, which were previously impacted at 5 and 10 °. An increase of 23% in E_p at 5 ° and 18% at 10 ° compared to pre-impact

TABLE I Numerical result of instrumented charpy impact test results

Preliminary impact results					Final impact results				
Falling angle	F_{max} (N)	E_i (J)	E_p (J)	E_{max} (J)	Falling angle	F_{max} (N)	E_i (J)	E_p (J)	E_{max} (J)
0	–	–	–	–	35	202.6	0.163	0.132	0.295
5	93.4	–	–	0.016	35	192.75	0.124	0.162	0.286
10	149.75	–	–	0.060	35	197.00	0.134	0.156	0.290
13	191	–	–	0.105	35	186.60	0.153	0.091	0.244
15	199	–	–	0.139	35	182.40	0.164	0.035	0.199
16	205.4	–	–	0.157	35	189.50	0.166	0.033	0.199
17	201.2	0.157	0.019	0.176	35	172.00	0.155	0.039	0.194
18	206	0.167	0.032	0.197	35	161.20	0.149	0.027	0.176
19	200.4	0.148	0.07	0.218	35	214.00	0.120	0.025	0.145
20	200	0.154	0.087	0.241	35	–	–	–	–



(a)

(b)

Figure 2 (a) $F_{\max}$ values as a result of final impacts. (b) Energy values as a result of final impacts.

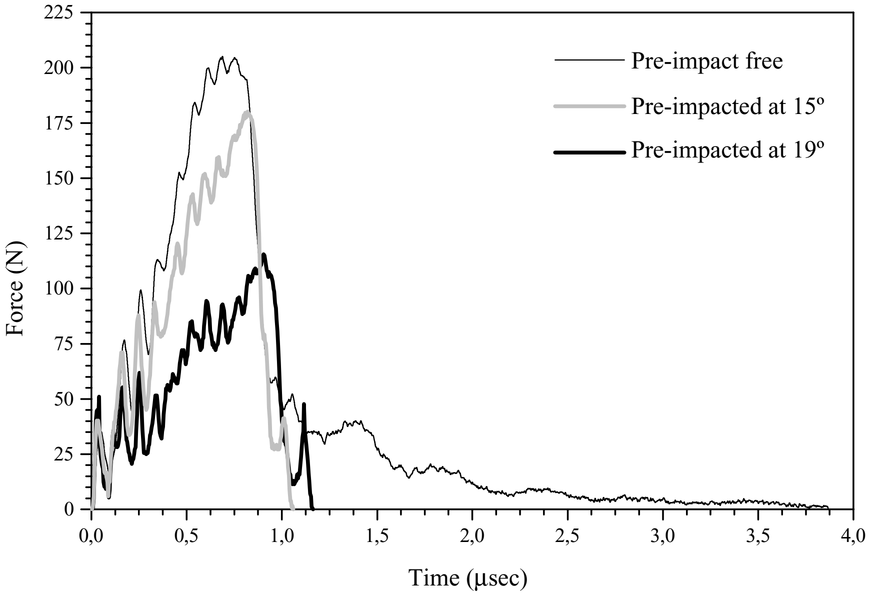


Figure 3 Force-time curves of final impacts.

free samples was obtained. It is clear that plastic deformation at the crack tip gives rise to an increase in E_p. Significant heating can take place at the tips of cracks during the tests. This may be another effect of increasing the initiation fracture energies or toughness values [5–7].

The E_p values were reduced dramatically for the samples, which were previously impacted at falling angles higher than 10°. The force-time curves of final impacts are illustrated in Fig. 3. Pre-impact free samples showed a fairly sharp increase to F_{max}, followed by a cascade type or stepwise drop with a fairly long tail. The cascade type behavior was due to the arrest of the propagating crack at the bulk. Previously impacted samples at 15° and 19° showed gradual increases until F_{max}, followed by a sudden drop due to catastrophic failure, indicating lower elasticity and poor plasticity (Fig. 3).

As a result of previous impact, many changes occurred within the material. These changes concentrated at the crack tip. There are remarkable structural and geometrical changes at the notch tip (notch tip radius changes, changes of crack shape, crazing and plastic zone formation at the crack tip etc.). Besides the mechanical changes, rapid deformation at the crack tip caused remarkable heating, which may induce morphological changes in the material [5, 6]. Structural and geometrical changes at the notch tip in the material are proportional with the strength of the previous impact. Previous impacts have an important effect on the catastrophic failure of the material. Up to a certain value there is a remarkable increase in the impact properties of the material as a result of the structural changes. The previous impacts over the certain value will result in lower crack propagation energy and catastrophic failure.

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