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IMPACT VELOCITY DEPENDENCE OF THE FRAGMENTATION OF SHOCK-RESISTANT PMMA

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ABSTRACT

This work aims at studying the conditions for fragmentation and further crack arrest capability of shock-resistant PMMA under impact loading. Kalthoff and Winkler (KW) impact tests, which consist in impacting the edge of a double-notched plate, were carried out at various impact velocities. It is notably shown that the higher the impact velocity the larger the number of fragments. Moreover, depending on the impact velocity, changes in the crack path can be seen and thus in the mechanisms controlling the PMMA fracture can be further understood. Effect of impact velocities on PMMA fractography was then analysed using scanning electron microscope (SEM) which managed to observe different patterns of crack propagation.

Keywords: PMMA, impact, fragmentation, crack arrest.

INTRODUCTION

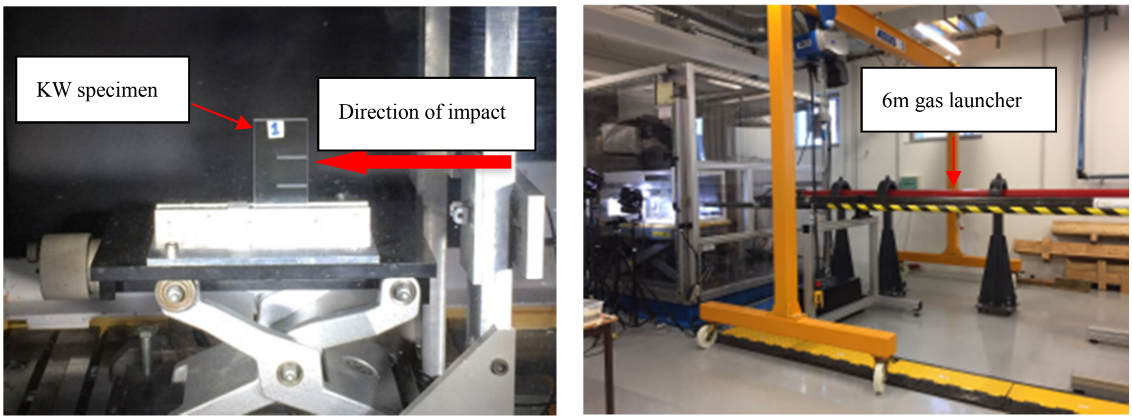
The Polymethylmethacrylate (PMMA) is a thermoplastic polymer that is extensively used in many applications such as automotive, medical, industries and consumer markets. It is a structural polymer that is lightweight and has good impact resistance with low production cost, see Jin et al. (2015). It can be easily fabricated by various techniques such as injection molding, extrusion as well as vacuum forming. Regarding its transparency, it is widely used as a substitute for inorganic glass due to its shatter, scratch and weather resistance while exhibiting favorable processing conditions, see Ali et al. (2015). This makes PMMA a suitable material for protection windows against bullet and blast, see Moy et al. (2011). Regarding its suitability in many applications, PMMA is exposed to many types of environmental and loading conditions which requires for better understanding of its mechanical behavior, see Adel et al.(2017). Therefore it is crucial to investigate its damage and fracture mechanisms in order to develop a better design for specialized tasks. Fracture process of many glassy polymers is usually associated with craze formation and governed by craze growth and breakdown. Depending on the loading conditions, one can observe several distinct patterns on fracture surfaces, such as radial striations, regularly spaced 'rib' markings and conic-shaped patterns, etc, see Wenbo et al.(2013).

The present work aims at studying the conditions for fragmentation and further crack arrest capability of shock-resistant PMMA under impact loading. Kalthoff and Winkler (KW) impact tests, which consist in impacting the edge of a double-notched plate, were carried out at various impact velocities. Effect of impact velocities on PMMA fractography is then analysed using scanning electron microscope (SEM) which managed to observe patterns of crack propagation.

EXPERIMENTS

The PMMA under consideration in the present work is the shock-resistant Plexiglass Resist®. Kalthoff and Winkler (KW)-type impact tests, which consist in impacting the edge of a double-notched plate, see Roux et al. (2015), were carried out using Institut Clément Ader Lab. Impact facility at different impact velocities comprised between 50 and 100 m/s, in order to study the effect of the impact velocity on the crack arrest capability of the PMMA under consideration. The plate dimension was 40x80x6mm^3 with notches of 300µm-thickness and 20mm-length. It was placed inside a closed chamber as can be seen in Figure 1(a). A 6m-length gas launcher was used to launch a 20mm-diameter cylindrical steel projectile (Figure 1b). A Photron SA5 high speed camera was used to observe the projectile/plate interaction at 10^{5}fps (frame per second) and 320x192pixel^2 spatial resolution.

Fracture surface morphology analysis, using scanning electron microscopy (SEM), is one of the important methods to study the polymer fracture mechanism. Fragments from impacted specimens were collected in order to investigate the difference of fracture morphology between the different impact velocities. Fragments were coated with gold for better conductivity before observation.

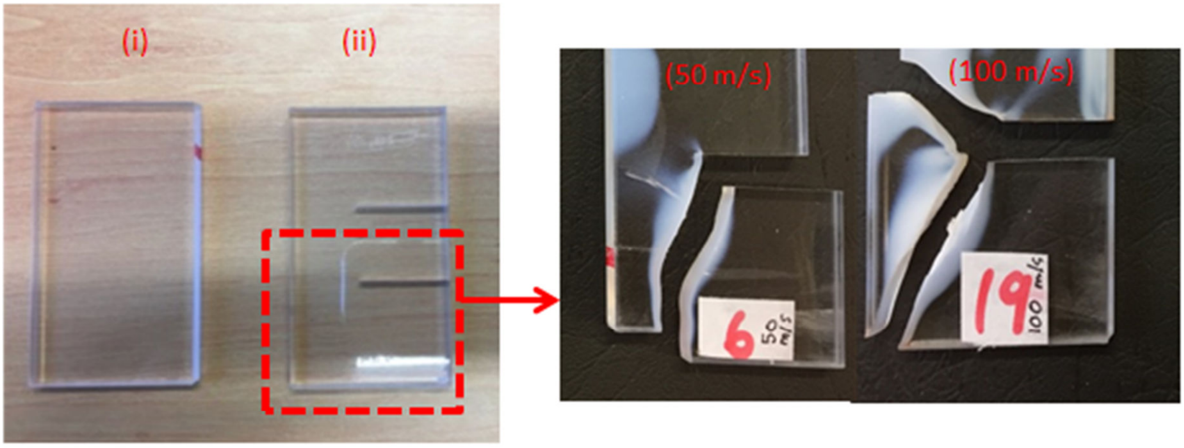


(a) (b)

Fig. 1 - (a) KW-impact type specimen was placed in the chamber to be impacted by a steel projectile; (b) 6m gas launcher which launches the projectile at various impact velocities

RESULTS AND CONCLUSIONS

Figure 2(a) shows the specimens of the shock-resistant Plexiglass Resist® before impact test. The fragmented specimens after impact test are shown in Figure 2(b) for two impact velocities, namely 50 and 100 m/s. According to Figure 2(b) and a complementary campaign of impact tests (not shown here), it can be seen that the higher the impact velocity the larger the number of fragments. The total energy imparted to PMMA is expected to be mostly absorbed either as elastic strain energy or as fracture energy or combination of these two energies, see Acharya (2014). On the other hand, under high strain rates, a part of the energy brought to the material is dissipated as heat causing a thermal softening, see Chou et al. (1973) and Richeton et al.(2006). However the brittleness of PMMA which increases with increasing strain rate seems to overcome the thermal softening effects.

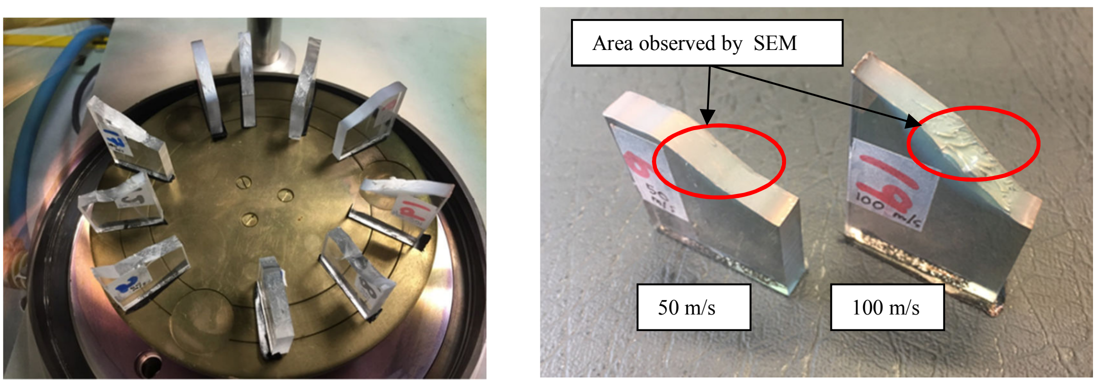


(a) (b)

Fig. 2 - (a) Unimpacted specimen of shock-resistant PMMA (i) without notch (ii) with 2 notches (KW-type specimens); 1(b) Fragmented KW specimens after different impact velocities

There are also significant differences in the fracture pattern depending on the impact velocity magnitude. In particular, at the lower impact velocity, the fragmentation occurs by the propagation of two symmetric cracks initiated from both notch tips and results in a single fragment. At the higher impact velocity, there seems to be a competition between the aforementioned Mode I-controlled crack propagation and a (near) Mode II-controlled crack propagation in the extended inelastic/damaged (opaque, white) zone. As a consequence, different mechanisms of failure are activated depending on the impact velocity magnitude.

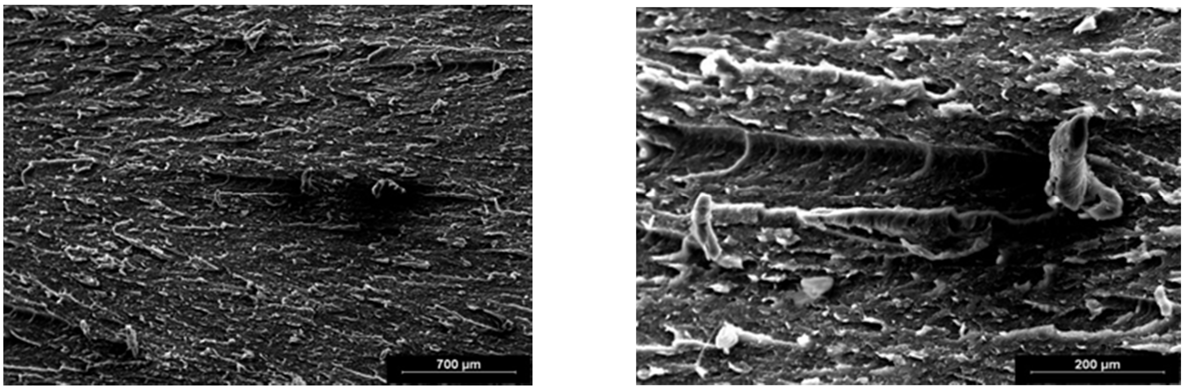
Figure 3a shows the fragments of PMMA placed in a gold sputter machine to coat the top surface of fracture. As can be seen in Figure 2, the surface roughness of fragments after two different impact velocities shows different patterns of fractures. Fragment from lower impact velocity shows continuous smooth finishing while interrupted surfaces with steps are observed on fragments impacted at higher impact velocity. These fragments were then placed in the SEM for fracture analysis.



(a) (b)

Fig. 3 - (a) Fragments were coated using a gold sputter machine; 1(b) Fragmented KW specimens after different impact velocities (with gold coating on surface)

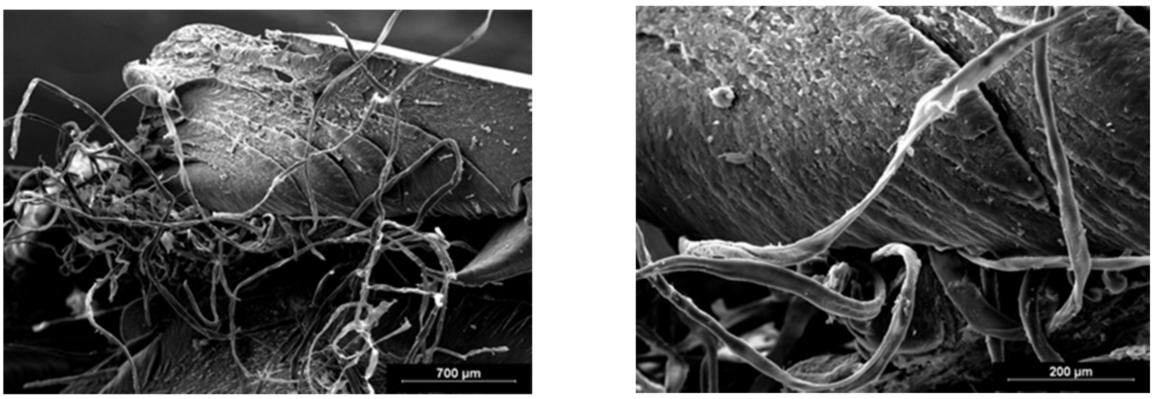
The effect of impact velocity on PMMA was analyzed by scanning electron microscopy. SEM fractography of PMMA after impact at 50m/s is depicted in figure 4. It exhibits a conic shape pattern which features fracture surface when relatively slow crack growth has taken place, see Wenbo and Tinqing (2003). The whitening characteristics that can be seen in figure 4 (b) represent the crazing effect on the PMMA that alter the optical properties due to light scattering, see also Farias (2015).



(a) (b)

Fig. 4 - The SEM picture of PMMA at 50m/s (a) 50Xmagnification (b) 200X magnification

Fractography images from PMMA impacted specimen at 100m/s can be seen in figure 5. The images (a) and (b) correspond to the images at magnification of 50X and 200X respectively. By increasing the impact velocity, the dissipation induced temperature also increased leading to local melting, see Ghorbel (2014). This can be seen from the SEM image in figure 5 for the impact at 100 m/s, where fibrous structure can be observed in the PMMA under consideration. It is to be noted that this structure is not observed at lower velocity. Further microscopic investigation is in progress in order to interpret these results.



(a) (b)

Fig. 5 - The SEM picture of PMMA at 100m/s (a) 50X magnification (b) 200X magnification

CONCLUSION

The investigation concerns the effect of impact velocity on the fragmentation of shock-resistant PMMA and its fracture behavior. It is demonstrated that the higher the impact velocity, which means the higher the strain rate, the large the number of fragments. Multi-fragmentation is accordingly increasing with increasing impact velocity. Crazing effects can be seen on the fracture surface using the Scanning Electron Microscope (SEM) by the presence of white regions. Furthermore, high impact velocities lead to local melting of PMMA as can be observed in the SEM images.

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