Tensile deformation mechanisms of ABS/PMMA/EMA blends

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Abstract. The tensile deformation mechanisms of acrylonitrile–butadiene-styrene (ABS) / polymethyl methacrylate (PMMA) blends toughened by ethylene methacrylate (EMA) copolymer was investigated by analysing the fracture morphology. ABS/PMMA was blended with EMA copolymer by melt mixing technique using co-rotating twin extruder. Tensile tests show that the elongation at break of ABS/PMMA blends can be efficiently improved with the increase in EMA content. Fracture morphology of ABS/PMMA/EMA blends reveals that the material yield induced by hollowing-out of EMA particles and its propagation into yield zone is the main toughening mechanism. Moreover, the appearance that EMA particles in the central area are given priority to hollowing-out may be related to the skin-core structure of the injection moulded parts caused by the different cooling rate between surface and inside in the process of injection moulding.

1. Introduction

Blending of polymers to achieve better comprehensive properties than those of individual components is of practical importance. Acrylonitrile-butadiene-styrene (ABS) resin itself is a kind of multiphase polymer, and it is very blendable with many other polymers like nylon, polypropylene and styrene-co-maleic anhydride (SMA) [1-3]. ABS blends with poly (methyl methacrylate) (PMMA) can provide ABS with improved surface characteristic, and ABS/PMMA blends have been used where good surface appearance is desired.

However, the addition of PMMA to ABS leads to a low toughness of ABS/PMMA blends, which is a certain limitation on its practical use [4]. In the past decades, the researches about ABS/PMMA blends were mostly focused on its composition and the performance of itself [1, 5]. Very recently, there appeared researches on the modification of ABS/PMMA blends. Zhang [6] and Tayebe [7] investigated the modification of nano-calcium and organoclays on ABS/PMMA blends, respectively. In general, brittle polymers are blended with elastomer particles to improve their fracture toughness. The elastomer particles act as stress concentrators under the action of external force, thereby induce crazes and shear deformation [8]. Poomalai [9] used Ethylene methacrylate (EMA) copolymer toughened PMMA, and conducted studies on physical-mechanical and optical properties. The toughness of the blends was improved significantly with the addition of EMA content, without affecting the optical properties significantly. It was also revealed that the EMA phase dispersed as domains in the continuous PMMA matrix at 5 and 10 wt% [9]. The same methyl methacrylate (MMA)
structure may contribute to the good miscibility of PMMA/EMA blends. In addition, EMA and ABS may also have anticipated compatibility for the vinyl structure in EMA and butadiene composition in ABS.

The objective of this article is to obtain information concerning the nature of toughening mechanisms of ABS/PMMA blends toughened by EMA. The toughening mechanisms will be revealed according to the fracture morphology of specimens that fully deform in a low strain rate.

2. Experimental

2.1 Materials

The ABS matrix polymer (757K) was obtained from Zhenjiang Chimei Chemical Co., Ltd, with Vicat softening temperature of 105°C and flow coefficient of 1.8g/10min. PMMA resin, CM-211, with flow coefficient of 16g/10min and Vicat softening temperature of 102°C, were purchased from Taiwan Chimei Chemical Co., Ltd. EMA was provided by Dongguan AnChen plastic technology co., with Vicat softening temperature of 59°C.

2.2 Preparation

The ternary blends of ABS, PMMA and EMA were prepared by melt mixing technique using co-rotating twin extruder (L/D ratio 40:1) with a screw diameter of 21.7 mm. The ABS/PMMA blends composition was 80/20, with the EMA content of 0, 4wt%, 6wt% and 8wt% of ABS/PMMA/EMA blends. Prior to mixing, ABS and PMMA were pre-dried in an air circulating oven at 80°C for 12 h, as well as EMA, which was dried at 50°C for 4 h. The pre-dried granules of ABS, PMMA and EMA were mixed homogeneously and fed into the extruder. The processing temperature range of 200°C-225°C and screw speed of 21 rpm were used. The extruded strands were quenched subsequently in water and cut into pellets, and then dried again in the hot air oven at 80°C for 12 h for further study.

2.3 Measurements

The dumbbell-shaped test specimens (150 mm in gauge length, 10 mm in width, and 4 mm in thickness) for tensile tests were prepared by a 68 tons injection molding machine with a 6 MPa injection pressure and a 5.5 MPa package pressure. The tensile tests were performed on a CMT 5305 electrical testing machine at room temperature with a crosshead speed of 4 mm/min.

The specimens were broken in the tensile tests, and the fracture surface was coated with a thin layer of gold. They were then examined in a scanning electron microscope (VEGA 3 SBH).

3. Results and discussion

3.1 Tensile deformation

The measured tensile strength and elongation at break of ABS/PMMA blends and EMA toughened ABS/PMMA are presented in figure 1. The percentage elongation at break for ABS/PMMA blends is found to be substantially increased with the addition of EMA. Meanwhile, it is seen that as the EMA content increases, the elongation at break gradually increases. When EMA content of the blends increases from 0 to 8wt%, a large variation of elongation at break from 11.38% to 28.38% are observed, with an increase of 149.4%. On the contrary, tensile strength decreases as EMA content increases, but the drops are not big, as shown in figure 1.

The elongation at break is one of the most important parameters to estimate the toughening effect of rubber particles in modified plastics. Therefore, the addition of EMA toughened ABS/PMMA blends efficiently. This may be due to the good adhesion of EMA with ABS and PMMA, which may improve the compatibility of ABS and PMMA, and improved interface adhesion may prevent the
emergence and development of cracks to a certain extent. The linear increase in figure 1 may also involve the optimum composition, as 4wt% to 8wt% EMA is such a limited range that can hardly express the nature and amount of the elastomeric phase. More importantly, the rubber particles generally act as stress concentrators in the tensile process and hence promote the development of crazes at the periphery of rubber domains [10]. It is worth noting that neck-down is observed and stress whitening propagated through the entire gauge portion during the necking process. To obtain the details of the toughening mechanism, SEM images were used for further study.

![Figure 1](image_url)

**Figure 1.** Effect of EMA content on the tensile strength and elongation at break of the blends.

3.2 Fracture morphology of the blends

Figure 2 shows the tensile fracture morphology of ABS/PMMA/EMA blends with EMA content of 6wt%. It can be seen from the overall morphology presented by figure 2(a) that the blends exhibited very complicated localized strain behaviour in low-speed stretching with the addition of EMA. Figure 2(b) shows the typical hollowing-out phenomenon of EMA particles under continuous stretch. The article considers that the hollowing-out of EMA induces a yield band that radiates to the surrounding gradually until being blocked by the crazing, as showed in figure 2(c). Figure 2(d) illustrates that the continuous crazing will cause fracture eventually. The hollowing-out of elastomer particles, the yield band, and the crazing are believed to participate in energy dissipation, thus improving the ductility of the blends.

From figure 2(a) and (b) it can be noticed that a set number of hollowing-outs will be induced in the interior of the specimens under the effect of tensile force. EMA particles act as the stress concentrators when ABS/PMMA/EMA blends are subject to external forces and gradually generate cavity inside. The continuous extend of the cavities in EMA particles largely depends on its energy, which is mainly from the additional internal stress of specimens that caused by the different cooling rates between surface and inside in the process of injection moulding. As injection mouldings are known to exhibit anisotropic skin-core morphological behaviour [11], EMA particles in different regions will suffer from different internal stresses. The internal regions will have a set amount of shrinkage during the slow cooling process, and the internal stress of the tensile direction caused by shrinkage makes EMA particles in the core a higher cavitation energy, especially in the central area. Therefore, the EMA particles in the central area are given priority to hollowing-out.

The material deformation resistance is reduced by the hollowing-out of EMA particles, and hence allowing matrix resin yield. The yield tends to be localized and formation of yield zone is the result of
strain softening. Furthermore, the strain softening of elastic deformed materials in the surroundings of each peneplain zone causes the plane expansion of the yield zone, and finally forms the oval flat yield zone around the central b point, as shown in figure 2(a). Meanwhile, from figure 2(c) it can be noticed that EMA particles and the rubber composition of ABS resin in the skin area induce crazing deformation under the action of external force. The strain hardening produced by orientation of crazing chain eventually limits the degree of strain, embodied in the crazing voluntary termination and terminating the yield zone. Finally, the end and the fibre of crazes give rise to strain softening of polymer surrounded, and thus can efficiently improve the resin volume that involve into absorbing energy. As discussed above, the transition of strain softening to stain hardening happens in the highly tensile area when it reaches critical elastic deformation determines the toughness of the blends. Moreover, yield may occur a little earlier than crazing in ABS/PMMA/EMA blends, which allows the blends to seem too prone to yield.

![Figure 2](image-url)

**Figure 2.** Fracture morphology of ABS/PMMA/EMA (EMA=6wt%) blends.

Figure 3 shows the tensile strength at yield caused by low-rate stretching as a function of EMA content. Virgin ABS/PMMA has the highest tensile strength at yield in comparison with the toughened blends by EMA. It is observed that with the increase in EMA content, the tensile strength at yield gradually decreases, especially when the EMA content is more than 8wt%. Polymer blends are easier to be induced to yield when in a lower tensile strength at yield, which may relate to the phenomenon that the toughened ABS/PMMA blends appear sufficient yield at a low strain rate.
From the discussion above, it can be observed that ABS/PMMA/EMA blends show better elongation at break compared to the virgin ABS/PMMA. The toughen mechanism is mainly due to the tensile yield, which can dissipate a large amount of energies while it is induced and in the process of propagation. The characteristics of being prone to yield may be associated with the reduction of tensile strength at yield caused by the addition of EMA content. Therefore, EMA particles in ABS/PMMA blends may play the role of stress concentrators that can induce yield through the hollowing-out instead of the rubber particles in ABS resin.

![Figure 3. Effect of EMA content on the tensile strength at yield of ABS/PMMA blends.](image)

4. Conclusions

The tensile deformation of ABS/PMMA blends toughened by EMA copolymer and its toughening mechanisms were obtained in this investigation. The elongation at break of ABS/PMMA blends was found to substantially increase with the addition of EMA. When EMA content of the blends increased from 0 to 8wt%, the elongation at break increased by 149.4%. The toughening mechanism for ABS/PMMA by EMA might be due to the reduction in tensile strength at yield, thus the material was easier to be induced to yield by the hollowing-out of EMA particles, especially in the central area. Meanwhile, a large amount of energies would be dissipated in the process of inducement and the formation of yield zone.

Acknowledgments

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