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# Effect of ABS Content on Thermal Stability, Tensile Strength, Friction, and Wear of PMMA/ABS blends

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A B S T R A C T

*The effect of ABS content on the thermal stability, tensile strength, and wear resistance of polymethyl-methacrylate (PMMA)/acrylonitrile-butadiene-styrene (ABS) (PMMA/ABS) blends was systematically investigated. The thermal stability of the PMMA/ABS blends became higher with higher ABS content due to the increased fraction of higher thermal resistant ABS componen in the blends. However, the increased ABS content in the PMMA/ABS blends from 10 to 70 wt.% resulted in a 17.9% decrease in their tensile strength while the wear volume of the PMMA/ABS blend with 70 wt.% ABS content was 39.5 times larger than that of the one with 10 wt.% ABS content. The PMMA/ABS blend with 10wt.% ABS content had the highest tensile strength and wear resistance among the samples used in this study because of its best miscibility and processability. It could be concluded that the ABS content had a significant effect on the thermal stability, tensile strength, and wear resistance of the PMMA/ABS blends.*



## 1. INTRODUCTION

PMMA is an engineering thermoplastic that has been widely used in modern industrial products such as vehicle windows, contact lenses, smartphone screens, LCD screens, micromolds, bone cement, etc. because it is a strong, rigid, lightweight and transparent material in addition to its biocompatibility, high chemical resistance, high resistance to UV light, low thermal conductivity, etc. [1]. PMMA is also used as a low cost alternative to polycarbonate (PC) when the mechanical strength, UV tolerance, and light transmissibility are preferred [2]. However, PMMA has a significant challenge to be applied in high temperature environments because of its low heat resistance [3]. In addition, PMMA has poor notch and impact resistance due to its brittleness, which leads to cracking over time under stress [4]. ABS is known for its low cost, high notch and impact resistance, high toughness, good dimensional stability, ease of molding, high quality surface properties, poor flame, chemical and wear resistance, etc. [5].

ABS has been a widely used engineering thermoplastic in electronic housing, auto parts, consumer products, tool handles, pipe fittings, etc. [5]. Engineering thermoplastics have different advantages and disadvantages so individual thermoplastics cannot fulfil all desired properties for specific applications.

Polymer blending is a traditional, low cost and sustainable method to modify various polymer properties such as rheological, morphological, thermal, mechanical and tribological properties [6,7]. Bano et al. [8] investigated the hardness of PC/ABS blends with a decrease in their hardness with increased ABS content. Khun et al. [7] successfully prepared PC/ABS blends with different ABS contents to study their thermal, mechanical and tribological properties. Poomali et al. [9] found that the tensile strength and wear resistance of PMMA/polyurethane (PU) blends decreased with increased PU content. Therefore, it is expected that blending of PMMA and ABS is an effective way to develop a PMMA/ABS blend with the most desirable properties of both components, such as high mechanical strength and wear resistance of PMMA and high notch and impact resistance and high thermal stability, flexibility and processability of ABS [7,10]. PMMA/ABS blends are used in a wide range of applications such as auto parts, electronic parts, telecommunication parts, computer peripherals, etc. which demand their high mechanical strength and abrasive wear resistance [11]. The wear resistance of PMMA/ABS blends is relatively important since their wear greatly contributes to a financial loss in various industries. Kuleyin et al. [11] investigated the effect of ABS fraction on the fatigue resistance of PMMA/ABS blends. Ueda et al. [12] evaluated the internal morphology and mechanical properties of PMMA/ABS blends. Available data are mostly for the structural, thermal and mechanical properties of PMMA/ABS blends. It is clear that studies on the tribological properties of PMMA/ABS blends have not been widely reported in the literature yet. It is essentially necessary to investigate the thermal, mechanical and tribological properties of PMMA/ABS blends for their successful applications.

In this study, PMMA and ABS were blended with different ABS content to investigate the effect of ABS content on their thermal stability, tensile strength, and wear resistance.

## 2. EXPERIMENTAL DETAILS

Commercially available PMMA and ABS pellets were blended in a Teflon mold using a Carver 3856 hot press machine to produce PMMA/ABS blends with different ABS contents of 10-70 wt.%. The PMMA/ABS blends with ABS contents of 10, 30, 50 and 70 wt.% were designated as PMMAABS10, PMMAABS30, PMMAABS50, and PMMAABS70, respectively.

The thermal stability of the PMMA/ABS blends was evaluated using a TA 2950 thermogravimetric analyzer (TGA) by heating them in a nitrogen gas chamber from room temperature (RT, ~22-24˚C) to 800˚C at a heating rate of 10 ˚C/min.

A TA Q200 thermal analyzer was used for differential scanning calorimetric (DSC) measurements of the PMMA/ABS blends with two times scanning in aluminium pans from an equilibrium temperature of RT to 225˚C at a heating rate of 10˚C/min with an interim cooling at a cooling rate of 10˚C/min. Glass transition temperature ($T_g$) was taken from the inflection point of heat capacity curve on each second scan.

The surface topographies of the PMMA/ABS blends were captured via Talyscan 150 surface profilometry with a 4 μm diamond stylus. Their surface roughness was measured in terms of an average root mean square roughness ($R_q$). Three random measurements on each blend were carried out to get an average $R_q$ value.

An Instron 5565 universal tensile tester was used to measure the tensile strength of the PMMA/ABS blends in a standard dog-bone shape with a guage length of 25 mm and a cross-section of 5 mm × 3 mm (Figure 1) at a cross-head speed of 0.01 mm/s. An average tensile strength was taken from five measurements per blend.

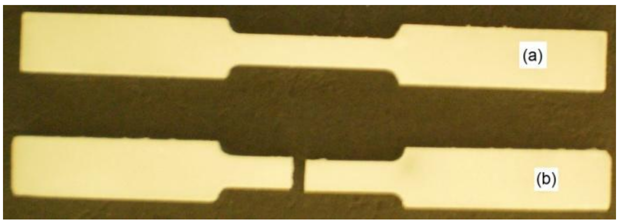



**Fig. 1.** Tensile PMMAABS30 specimens in a dog-bone shape (a) before and (b) after tensile test.

A CSM ball-on-disc micro-tribometer was used to measure the friction coefficients of the PMMA/ABS blends by rotating them against fixed 6 mm 100Cr6 steel balls in a circular path of 3 mm in diameter for 30 m sliding distance at a sliding velocity of 3 cm/s under a normal load of 1 N. Their wear tracks were scanned via Nikon L150 white light confocal imaging profilometry to measure their wear widths and depths and calculate their wear volumes. Three random measurements on each blend were carried out to get average friction coefficient and wear volume. Their wear morphologies were observed via JEOL JSM5600LV scanning electron microscopy (SEM).

## 3. RESULTS AND DISCUSSION

Figure 2 presents the thermal stability of the PMMA, ABS, and PMMA/ABS blends with different ABS contents. The temperature that is responsible for 50% weight loss is used as a measure to evaluate the thermal stability of the PMMA/ABS blends. The 50% weight loss temperatures of the PMMA, PMMAABS10, PMMAABS30, PMMAABS50, PMMAABS70, and ABS are 356, 369, 379, 391 and 401 ˚C, respectively. The 50% weight loss temperature of the ABS is 12.6% higher than that of the PMMA, which means that the ABS requires higher temperature for its 50% weight loss. As a result, the PMMA/ABS blends with higher ABS content require higher 50% weight loss temperatures as found in Figure 2 [11]. It can be deduced that the higher ABS content gives rise to the higher thermal stability of the PMMA/ABS blends.

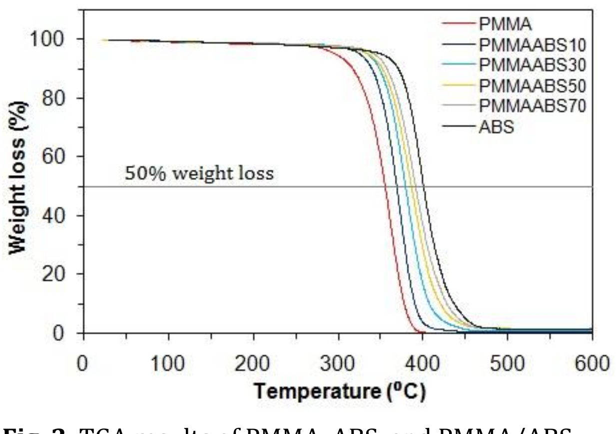



**Fig. 2.** TGA results of PMMA, ABS, and PMMA/ABS blends with different ABS contents.

Figure 3 presents the DSC results of the PMMA, ABS, and PMMA/ABS blends with different ABS contents. The $T_g$ (about 123˚C) of the ABS is higher than that (about 101˚C) of the PMMA. The PMMAABS10 does not show two $T_g$ values, indicating its complete miscibility [7,8,11]. However, the PMMA/ABS blends with ABS contents of more than 10 wt.% apparently show two $t_g$ values attributed to the $t_g$ values of the PMMA and ABS components [7,10,13]. The $t_g$ ranges of the PMMA and ABS components of the PMMA/ABS blends become more apparent with their higher fractions. It can be deduced that the PMMAABS10 has the best miscibility among the PMMA/ABS blends used in this study.

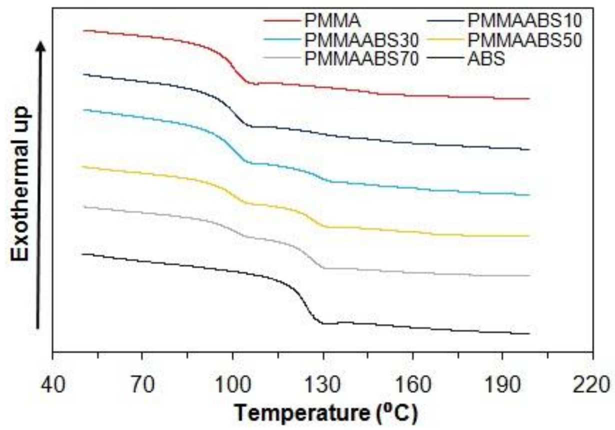
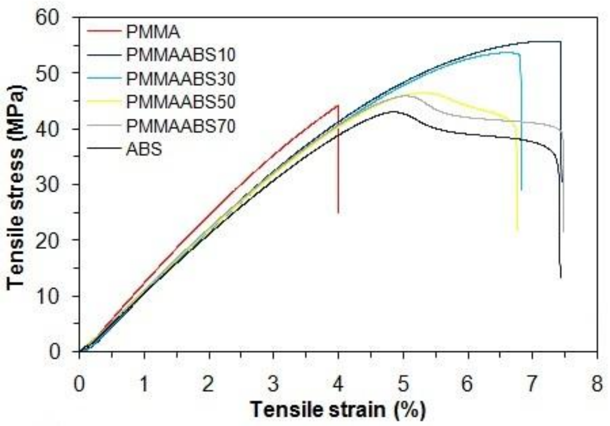


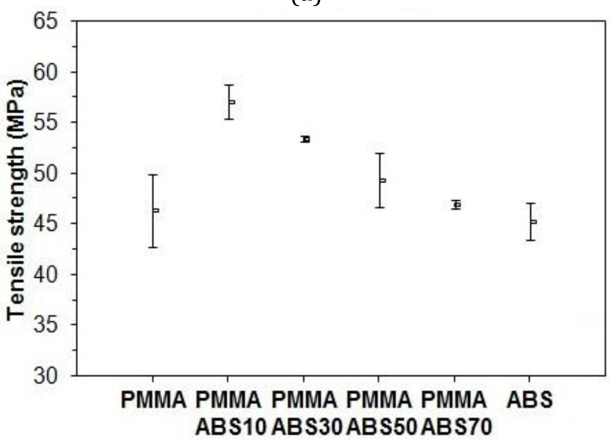

**Fig. 3.** DSC results of PMMA, ABS, and PMMA/ABS blends with different ABS contents.

Figures 4a and b show the tensile stress-strain curves and tensile strength of the PMMA, ABS, and PMMA/ABS blends different ABS contents. In Figure 4a, the ABS breaks with long necking at its breaking point. However, the PMMA exhibits a brittle fracture without any apparent necking at its breaking point. The tensile strength (46.3 MPa) of the PMMA is 2.4% higher than that (45.2 MPa) of the ABS (Figure 4b) probably due to its structural defects such as pores, inhomogeneity, etc. associated with its less processability [14,15].

The PMMAABS10 has the tensile strength of 57.1 MPa that is 23.3% and 26.3% higher than those of the PMMA and ABS, respectively. Since the poor miscibility of a polymer blend can result in its low tensile strength as a result of the weak interfacial bonding between its components, the higher tensile strength of the PMMAABS10 than those of its two components confirms its complete miscibility [14,16]. The enhanced processability of the PMMA/ABS blend associated with 10 wt.% ABS content suppresses its structural defects to promote its tensile strength [12,17]. Since the PMMA component of the PMMA/ABS blend serves as a brittle phase for readily cracking during the tensile test, the complete miscibility of the blend effectively prevents readily initiation and propagation of brittle cracks in it under the tensile stress and thereby promotes its tensile strength [11,17]. Therefore, the good miscibility and processability of the PMMAABS10 result in its higher tensile strength than those of its two components [7,17]. However, the PMMAABS10 still shows a brittle fracture without any apparent necking at its breaking point as found in Figure 4a.



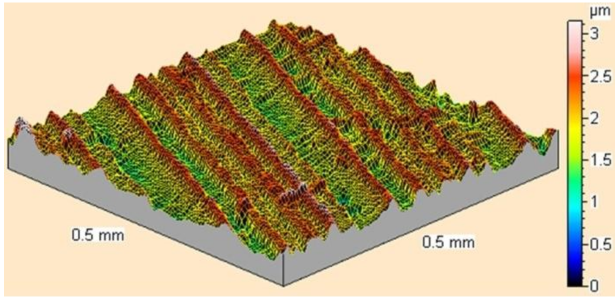

(a)



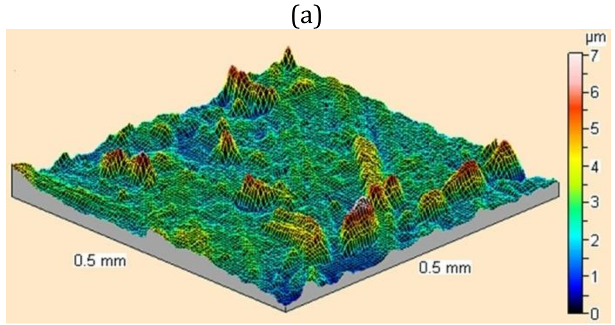

(b)

**Fig. 4.** (a) Tensile stress-strain curves and (b) tensile strength of PMMA, ABS, and PMMA/ABS blends with different ABS contents.

It is found that the PMMAABS30 shows a brittle fracture without any apparent necking at its breaking point (Figure 1 and 4a), but has the lower tensile strength of 53.4 MPa that is 6.5 % lower than that of the PMMAABS10 due to its higher ABS content and less miscibility [7,11,17]. Therefore, the further increased ABS content to 70 wt.% further decreases the tensile strength of the PMMA/ABS blend to 46.9 MPa that is 17.9 % lower than that of the one with 10 wt.% ABS content in Figure 4b [7,11,17]. In Figure 4a, the PMMA/ABS blends with ABS contents of more than 30 wt.% break with longer elongation for higher ABS contents at their respective breaking points. It can be deduced that the higher ABS content results in the lower tensile strength of the PMMA/ABS bends as the highest tensile strength of the blend is found at the ABS content of 10 wt.%.




(a)

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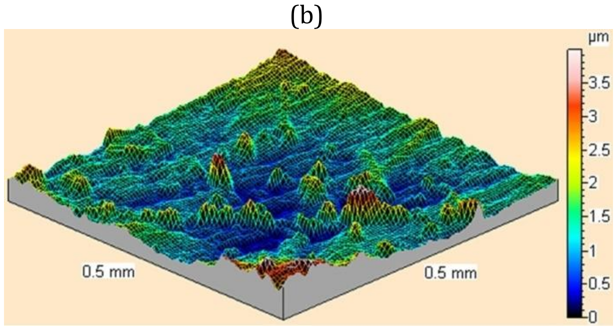
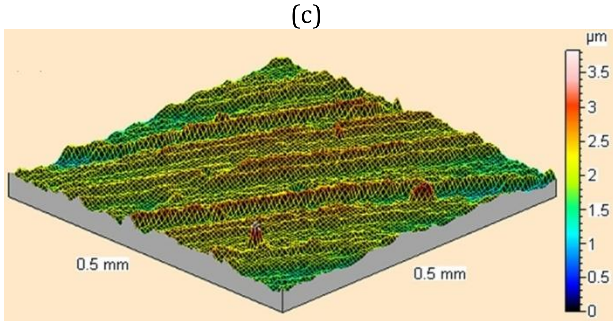



(c)




(d)

**Figure 5:** Surface topographies of (a) PMMA, (b) PMMAABS10, (c) PMMAABS70, and (d) ABS.

Figures 5a, b, c and d illustrate the surface topographies of the PMMA, PMMAABS10, PMMAABS70, and ABS, respectively. The surface topographies of the PMMA and ABS shown in Figures 5a and d have protruded surface patterns left by their manufacturing molds. However, the ABS has a smoother surface than the PMMA, which is confirmed by its smaller $R_q$ value of 0.31 μm compared to that (0.41 μm) of the PMMA. In Figures 5b and c, the PMMAABS10 and PMMAABS70 have rougher surfaces attributed to highly protruded surface asperities than the PMMA and ABS, which are confirmed by their larger $R_q$ values of 0.76 μm and 0.55 μm, respectively.

Figure 6 shows the wear volumes of the PMMA, ABS, and PMMA/ABS blends with different ABS contents. The wear volumes of the PMMA and ABS are $14\times10^{-4}$ $mm^3$ and $636.3\times10^{-4}$ $mm^3$ (45.5 times larger), respectively, indicating that the ABS has much lower wear resistance than the PMMA. The PMMAABS10 has a 2.5 times smaller wear volume of $5.5\times10^{-4}$ $mm^3$ than the PMMA due to its promoted mechanical strength [7,9]. However, increasing the ABS content to 70 wt.% increases the wear volume of the PMMA/ABS blend to $222.7\times10^{-4}$ $mm^3$ that is 39.5 times larger than that of the PMMAABS10, which indicates its apparently increased wear with the increased fraction of its lower wear resistant ABS component [7,9]. The wear volumes of the PMMA/ABS blends are apparently smaller than that of the ABS, which reveal that the higher wear resistant PMMA component is responsible for their lower wear [18]. It can be deduced that the higher ABS content lowers the wear resistance of the PMMA/ABS blends although their highest wear resistance is found at the ABS content of 10 wt.%.

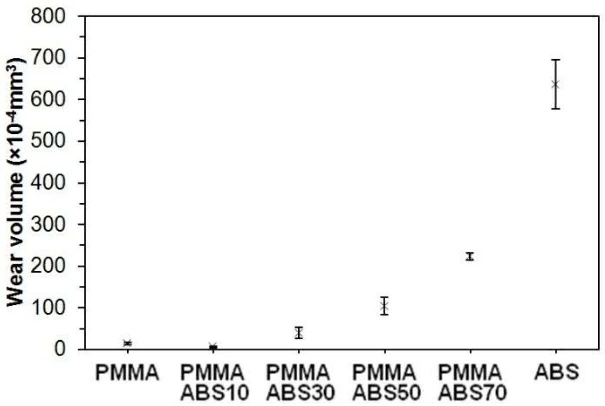
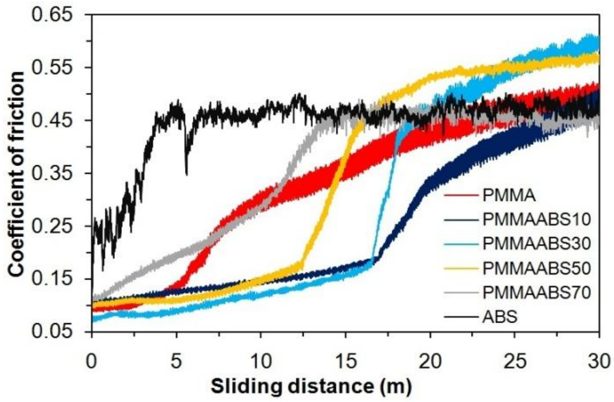
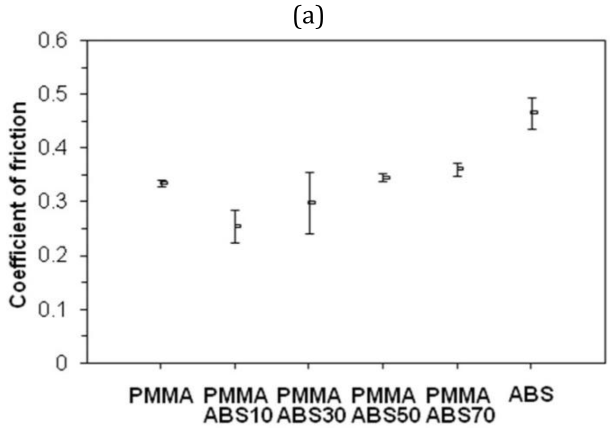



**Fig. 6.** Wear volumes of PMMA, ABS, and PMMA/ABS blends with different ABS contents.

Figures 7a and b present the friction coefficients of the PMMA, ABS, and PMMA/ABS blends with different ABS contents. In Figure 7a, the friction of the ABS dramatically increases with increased sliding distance at the beginning as a result of its immediate wear and then becomes stable at about 5 m sliding distance to reach its steady state throughout the wear test due to its steady wear. However, the friction of the PMMA slowly increases with increased sliding distance as a result of its high resistance to surface wear, then quickly increases with further increased sliding distance at about 5 m sliding distance, starts to become stable at about 20 m sliding distance, but never reaches its steady state during the entire 30 m long sliding where the ABS has experienced, indicating its higher wear resistive behaviour than the ABS. Since a larger contact between two rubbing surfaces gives rise to higher friction via a larger number of contact junctions between them [19], the lower wear of the PMMA results in its lower friction via its smaller contact with its counter steel ball. As a result, the friction coefficient of 0.33 of the PMMA is 29.8% lower than the 0.47 of the ABS as found in Figure 7b.




(a)




(b)

**Fig. 7.** Friction coefficients of PMMA, ABS, and PMMA/ABS blends with respect to (a) sliding distance and (b) ABS content.

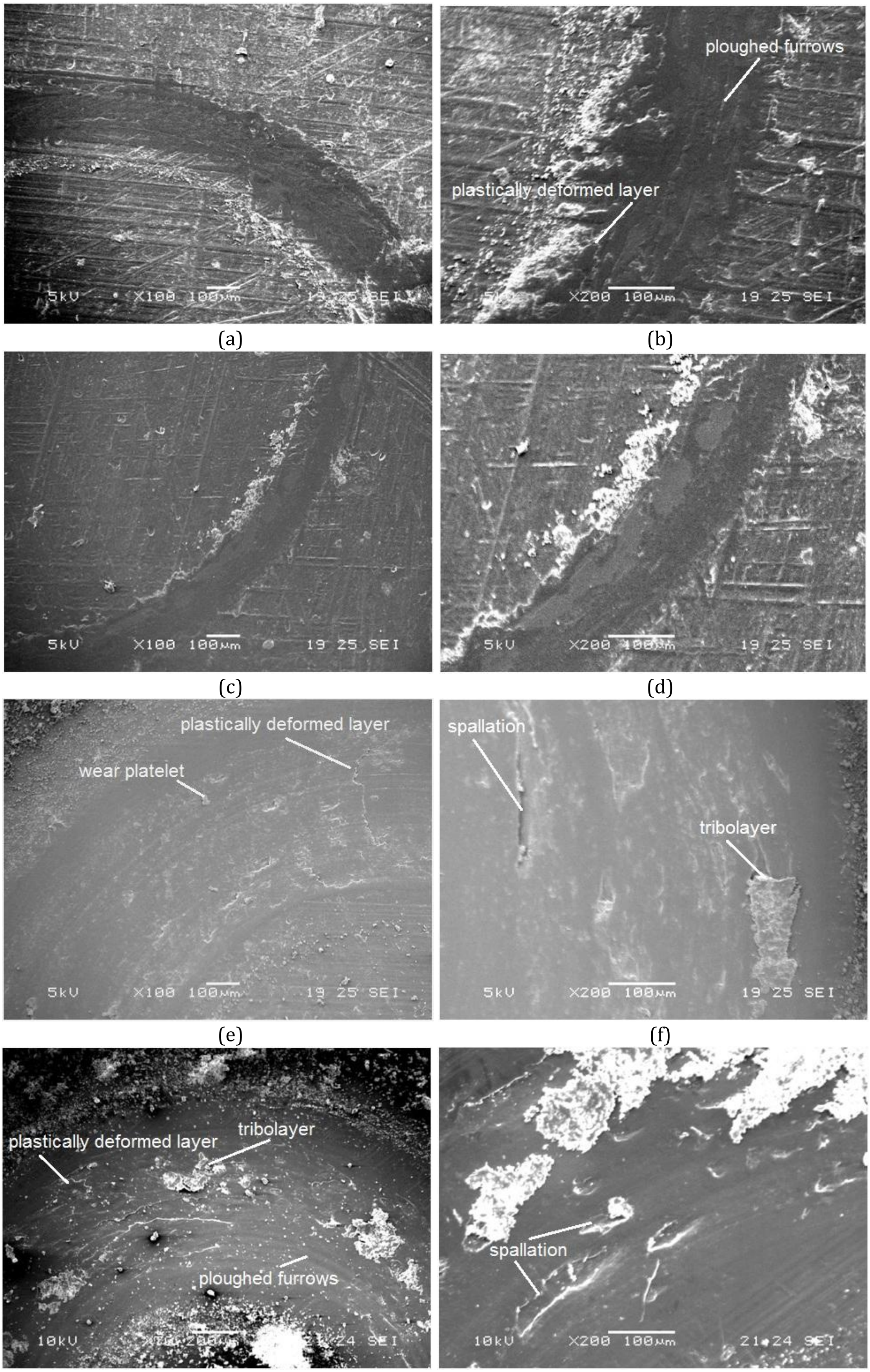
The PMMAABS10 has an even slower increase in its friction up to the about 17.5 m sliding distance via its higher resistance to surface wear and a more significant delay to reach its steady state compared to the PMMA as shown in Figure 7a. Therefore, the friction coefficient of 0.26 of the PMMAABS10 is even 44.7% lower than that of the PMMA (Figure 7b). It indicates that the PMMAABS10 has higher resistance to abrasive wear than the PMMA.

The PMMA/ABS blends exhibit the similar frictional behaviour of the both PMMA and ABS components depending on the ABS content. As shown in Figure 7a, the PMMA/ABS blends have a faster increase in their initial friction within a shorter sliding distance via their lower resistance to abrasive wear and a less significant delay to reach their steady states with their higher ABS contents. Therefore, the friction coefficients of the PMMA/ABS blends become higher with their higher ABS contents (Figure 7b), which is confirmed by the 38.5% higher friction coefficient (0.36) of the PMMAABS70 than that of the PMMAABS10. Normally, mechanical interlocking between mating asperities of two rubbing surfaces can give rise to high friction during a dry sliding [20,21]. However, no correlation between the surface roughness (Figure 5) and friction (Figure 7b) of the PMMA/ABS blends indicates that the effect of surface roughness on their friction is not significant in this study as a result of the more significant effect of their wear.

Figure 8 shows the wear morphologies of the PMMA, ABS, and PMMA/ABS blends with different ABS contents. In Figures 8a and b, the PMMA has an apparent wear track on which ploughed furrows resulted from abrasive wear and plastically deformed layers (plastic flow) formed by the sliding of the steel ball are found [7,22,23]. In Figures 8c and d, the PMMAABS10 has a smaller wear track than the PMMA, confirming that it has the higher abrasive wear resistance.

The PMMAABS70 (Figures 8e and f) has an apparently larger wear track compared to those of the PMMA and PMMAABS10, which confirms that the higher ABS content is responsible for its lower wear resistance [7]. In addition, plastically deformed layers are more apparently found on the wear track of the PMMAABS70 as a result of the higher ABS content. Besides, the repeated sliding of the steel ball on the PMMAABS70 surface generates wear debris and ploughed furrows on its wear track via abrasive wear. [22,23]. The repeated dry sliding of the steel ball initiates minute cracks in the subsurface region, propagates them parallel to a free surface to some extent, and eventually leads to a removal of surface materials as platelets [24,25]. Therefore, surface spallation is apparently found on the wear track of the PMMAABS70, which indicates that its fatigue wear also contributes to its wear [24,25].

In Figures 8g and h, the ABS has a largest wear track among the samples used in this study due to its lowest wear resistance associated with its lowest mechanical strength. The formation of plastically deformed layers is most apparently found on the wear track of the ABS while the most obvious ploughed furrows on its wear track can be related to its lowest abrasive wear resistance [7,22,23]. The highest wear of the ABS generates the largest amount of wear debris which are subsequently compacted by the repeated sliding of the steel ball to densely form tribolayers on its wear track while the detachment of thickened tribolayers is apparently found [26,27]. It is therefore supposed that the formation and detachment of tribolayers also contribute to the wear of the ABS [26,27]. The ABS has the most severe spallation of surface materials on its wear track although such spallation is not apparently found on the wear tracks of the PMMA and PMMAABS10. The PMMABS70 has more and less severe spallation of surface materials than the PMMAABS10 and ABS, respectively. It reveals that the ABS is highly susceptible to fatigue wear so that the higher ABS content in the PMMA/ABS blends makes them more susceptible to it [24,25]. The wear morphologies confirm that the wear resistance of the PMMA/ABS blends decreases with increased ABS content although their highest wear resistance is found at the ABS content of 10 wt.%.




(a) (b) (c) (d) (e) (f) (g) (h)

**Figure 8:** Wear morphologies of (a and b) PMMA, (c and d) PMMAABS10, (e and f) PMMAABS70, and (g and h) ABS observed at different magnifications.

## 4. CONCLUSIONS

The thermal stability, tensile strength, and wear resistance of the PMMA/ABS blends were systematically investigated with respect to ABS content of 10-70 wt.%.

- The higher ABS content in the PMMA/ABS blends resulted in their higher thermal stability because the ABS had higher thermal stability than the PMMA.
- Based on the DSC results, the PMMA/ABS blends with 10 wt.% ABS content had the best miscibility among the blends used in this study, which was confirmed by its single $t_g$ value.
- The tensile strength of the ABS was slightly lower than that of the PMMA. The tensile strength of the PMMA/ABS blend with 10 wt.% ABS content was apparently higher than those of the PMMA and ABS due to its enhanced miscibility and processability. However, increasing the ABS content more than 10 wt.% decreased the tensile strength of the PMMA/ABS blends as a result of the increased ABS content. During the tensile tests, the ABS and PMMA/ABS blends with ABS contents of more than 30 wt.% broke with long necking at its breaking point while the PMMA and PMMA/ABS blends with ABS contents of less than 30 wt.% showed brittle fracture without any apparent necking. The PMMA/ABS blends with ABS contents of more than 30 wt.% had longer elongation before breaking for higher ABS content.
- The abrasive wear resistance of the ABS was much lower than that of the PMMA. Blending of the PMMA with 10 wt.% ABS resulted in its higher wear resistance than the PMMA and ABS as a result of its promoted mechanical strength. However, increasing the ABS content more than 10 wt.% apparently decreased the abrasive wear resistance of the PMMA/ABS blends due to the much lower abrasive wear resistance of the ABS than that of the PMMA. The ABS was highly susceptible to fatigue wear so that the PMMA/ABS blends with higher ABS content led to their higher susceptibility to it.
- It could be concluded that the higher ABS content in the PMMA/ABS blends lowered their tensile strength and wear resistance, but promoted their thermal stability. The highest tensile strength and wear resistance of the PMMA/ABS blends among the samples used in this study were found at the ABS content of 10 wt.%. The ABS content had a significant influence on the thermal stability, tensile strength, and wear resistance of the PMMA/ABS blends.

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