Effects of kaolin and maleic anhydride contents on melt elasticity and flexural behaviour of polypropylene/kaolin and unplasticised poly(vinyl chloride)/kaolin composites

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Abstract: Polypropylene/kaolin and unplasticised poly(vinyl chloride)/kaolin composites were prepared by directly melt mixing polypropylene (PP) and unplasticised poly(vinyl chloride) (UPVC) with maleic anhydride (MAH) and low cost kaolin via in situ extrusion process. The influences of kaolin particles and MAH in PP and UPVC matrix were discussed through investigating the flexural and morphological properties of filled PP and UPVC composites. The extrudates obtained from the extrusion process were carefully collected in order to investigate the elastic properties (extrudate swell and melt fracture). Results revealed that the above mentioned properties are strongly dependent on the presences of kaolin and MAH in both composite systems. Observation on scanning electron microscopy (SEM) analysis showed that the kaolin books (stacks of kaolin particles) were successfully delaminated thus lead to a well dispersed of kaolin particles in PP and UPVC matrix.

Key words: polypropylene, unplasticised poly(vinyl chloride), kaolin, maleic anhydride, extrudate swell, melt fracture, sharkskin, flexural behaviour.

Introduction

The widespread use of polymer materials has created variety of new polymers with good performance and low cost [1]. Therefore, the production of new materials derived from polymer blends or alloys and composite materials have been extensively studied [2]. Fillers and additives are commonly used in the control of producing these desired materials [3]. Kaolin has been selected as filler in this study because of its potential to exfoliate in polymer matrix as single nanometric platelets leading to markedly superior mechanical properties. Kaolin is a typical clay mineral which composed of an octahedral alumina layer joined to a tetrahedral silica layer by shared apical oxygen. These layers formed structures, overlapped one another thus produced stacks of kaolin particles (called kaolin books) bound via hydrogen bonding [4-5]. The main challenge of using kaolin as filler in polymer matrix is the success of separating the kaolin books [6] in the matrix.

It is also known that in polymer/clay composites, the addition of compatibilizer can greatly affect the matrix morphology and usually leads to better clay dispersion in the matrix, resulting better filler-matrix interactions which leads to significant improvement in the strength of the polymer composites [7]. In this work, MAH were added into two different polymer systems, one being polymer with nonpolar group
(PP) and the other being those with polar group (UPVC). The study of Ismail et al. [8] reported that PPgMAH (MAH grafted to PP) acts as an effective linkage to promote better filler-matrix interaction via hydrogen bonding and Van der Waals attractions. The anhydride from PPgMAH will interact with hydroxyl group on the surface of filler through hydrogen bonding. Whereas, the PP segment interaction of PPgMAH with PP matrix is through Van der Waals bonding (molecular entanglement). However, the use of ungrafted MAH in PP/kaolin composites has not drawn any attention to researchers. It is strongly believed that due to heating and shearing during processing could lead to the scission of molecular chains. Subsequently, giving rise for the grafting of MAH with PP matrix and introducing strong interfacial interaction between filler and matrix.

On the other hand, PVC system is thermally unstable and can easily undergo degradation process, the HCl originating from the dehydrochlorination of PVC chains is believed to be the main reason of this process [9-10]. At present, compounds such as cadmium, lead and calcium stearate are used as stabilizers that bond to the HCl thus prevent the degradation process from occurring [11]. Nevertheless, alternative is required in order to find the best compound that could inhibit dehydrochlorination and in chorus, improve compatibility between mineral filler and PVC matrix.

Therefore in this paper, compatibilizer MAH was used, aimed at enhancing the compatibility between kaolin and PP or UPVC matrix. Addition of very small amounts of any filler or additive (in this case, kaolin and MAH), can deeply cause significant changes in the polymer molecules movement [12]. The molecules movement scenario in the melt is closely related to the elastic properties of the base polymer. In order to introduce these new polymeric products to the outside world, it is vital to understand not only the mechanical properties but also the elastic nature of the melt. This study focusing on the elastic properties in a class of extrudate swell and melt fracture as they have great influence on the product quality and processing applications. Further investigations on flexural and morphological properties will also be discussed to evidence the effect of melt elasticity on the properties of the end products.

Results and discussion

Extrudate swell studies

-Effect Of Kaolin Content

Figure 1 presents the dependency of extrudate swell ratio towards the kaolin content in PP/kaolin and UPVC/kaolin composites. Both composites consist of 8 php of MAH content. As can be seen from the graph, an addition of kaolin content causes a reduction in swell ratio for both composites. From a careful examination of the data in Figure 1, it appears that the reduction of PP/kaolin composites is continuous until a plateau level is attained at kaolin content of 25 php. This can be interpreted as a result of decreased entanglement of polymer molecules as reported by several investigators [12-13]. On loading the extruder’s hopper with PP matrix, the PP starts to melt and as the mixing of matrix and filler continues, the viscosity of PP melt is reduced until it is believed to be fully melted. In a molten state of a polymer, the molecules start to mobilize and in a random configuration. This molecules’ movement is closely related to the elastic properties of the base polymer. When the melt emerges out of the die, the elastic property gives rise to an increase in the degree of
entanglements. This entanglement scenario can be evidenced in the swell of the extrudates [13]. On the other hand, for PP/kaolin composites, the presence of fillers have delayed the movement of PP molecules which lead to less entanglement level and giving more aligned structures. Therefore, reduces the swell of the extrudate by decelerating the elastic memory.

![Graph showing swell ratio vs kaolin content for PP/Kaolin and UPVC/Kaolin composites.](image)

**Fig. 1.** Effects of kaolin content on swell ratio of PP/kaolin and UPVC/kaolin composites.

For UPVC composites as illustrated in Figure 1, the swell ratio values are less than 1. This indicates that UPVC composites have undergone shrinkage, which is opposite to the trend observed in PP composites showing swelling phenomenon. A comparison was made between V0K8M and P0K8M samples (in the absence of kaolin filler) giving a result that V0K8M shows lower swell ratio if compared to that of P0K8M. This fact is attributed to the presence of MAH in V0K8M. As reported by Montrikool et al. [14] that during thermal processing, MAH can be used as a chemical to react with the polyene of PVC and generated new polymeric structures. A shrinkage in extrudate diameter is believed to appear when the polymer chains motion as well as the entanglement of the polymer chains are reduced due to the formation of these new polymeric structures. On the contrary, the evidence for interaction of MAH with PP matrix resulted in the swelling of extrudate. It will be described later in the effect of MAH content section. In the case of UPVC/kaolin composites, there is a slight dependence of extrudate’s shrinkage on the kaolin content. A similar scenario is believed to occur in UPVC/kaolin composites. The movements of molecules, entangled and realigned of polymer chains due to the elastic recovery and delaying of the molecules’ movements by fillers discussed earlier are few scenarios which arise in the capillary die. Nevertheless, these composites exhibit only a minor decrease in the shrinkage of extrudate diameter when the kaolin content increases. The composite with 10 php of kaolin content having an increase in shrinkage ratio of approximately 9.18% with respect to that of V0K8M and the plateau level can be observed at 10 php of kaolin content. This scenario is owing to the fact that at 10 php and above of kaolin content, the reduction of extrudate diameter almost reach the limit. The system is believed to be heavily crammed with interaction of PVC molecules with either MAH or filler and restricted
the molecule-molecule interactions. Thus, giving no effect on the shrinkage of UPVC/kaolin composites containing 10 php and above of kaolin content.

-Effect of MAH content

The measurements on swell ratio against MAH content of PP/kaolin and UPVC/kaolin composites are illustrated in Figure 2. Both composites consist of 5 php of kaolin content. The introduction of MAH into both composites has shown significant effect in the extrudate swell ratio. It can be seen that the incorporation of MAH content has increased the swell ratio of PP/kaolin composites. Assumption made is regarding to the ability of MAH in allowing more polymer molecules interactions. An ease in the molecules interaction enhances entanglement level and elastic property of PP melt therefore affecting the deformation rate (in this case referring to the extrudate swell). In this situation, when the external shear stress is released from the system, the elastic memory in the PP system dictates the polymer molecules back to the original configuration and PP/kaolin composites exhibit larger diameter from the die diameter. This scenario explains the influence of MAH in the composites as Figure 2 showing that the swell ratio of PP/kaolin composites increases with an increase in the MAH content.

![Effects of MAH content on swell ratio of PP/kaolin and UPVC/kaolin composites.](image)

However, under the same amount of MAH contents, the swell ratio of UPVC/kaolin composites displaying a sharp decrease at the early experiment (from 0 – 2 php of MAH content) and then remain almost constant once it reaches 2 php of MAH content. A reduction in swell ratio for UPVC/kaolin composites with the value of less than 1 is due to the shrinkage behavior of the extrudate diameters. At temperature well above the melting point, dehydrochlorination (as can be seen in Figure 4, the colour of sample V5K8M has changed from white to brownish red (sample V5K0M)) of PVC molecules occur for UPVC/kaolin composite without MAH. At this phase more polyenes are created [14]. The rapid and random movements of these polyenes have restricted the disordered (entanglement) configuration of the PVC chains thus allowing a reduction in its extrudate to take place. On the other hand, when MAH content is added to UPVC/composite, the presence of MAH has reacted with the
polyenes and retarded the dehydrochlorination in UPVC system. The PVC chains entanglement become limited, hence, there is no recovery of elastic property and resulting higher extrudate shrinkage. This scenario suggests that MAH is more competent in reducing the extrudate diameter of the UPVC system if compared to that of kaolin effect. At 2 php of MAH content and beyond, the shrinkage of extrudate is almost independent from MAH content signifying that the shrinkage phenomenon has reached the limit. This result adheres to the trend observed in the effect of kaolin content (extrudate swell studies). That is, the shrinkage of extrudate has almost reached the limit at 10 php of kaolin concentration.

Flow Instability Studies

-Effect of kaolin content

The photograph (Figure 3(a)) of unfilled PP (pure PP) sample showing near the onset of instability which occurs due to the pressure applied exceeded the critical shear stress. Figures 3(b) and 3(c) illustrate smooth surfaces of PP/kaolin composites with the presence of filler. In a molten state of PP/kaolin composite, when the melt heading towards the die exit, the entangled polymer chains and kaolin particles align according to the flow direction. The presence of kaolin particles has hindered the mobility and deformability of PP molecules subsequently increasing the melt strength of P5K0M and P5K2M. For this reason, higher critical shear stress is needed to create flow instabilities in P5K0M and P5K2M with respect to that of unfilled PP.

![Fig. 3. Flow patterns of extrudate surfaces for (a) unfilled PP; and PP/kaolin composites (b) P5K0M; (c) P5K2M; and (d) P5K8M.](image)

Figure 4 shows the extrudate surfaces of UPVC/kaolin composites. As illustrated in Figure 4(a), a rough surface of V0K8M extrudate can obviously be seen. This class of surface roughness corresponds to the flow instability which is in a form of sharkskin. In contrast, Figure 4(b) presents extrudate surface of V5K8M which exhibits better flow pattern with a decrease in its surface roughness if compared to that of V0K8M. The reduction of flow instability in this case can be seen clearly by the addition of 5 php kaolin content in V5K8M therefore preventing from the appearance of melt fracture in filled PP. However, the introduction of kaolin particles in V25K8M has shown significant effect in the surface roughness. It can be seen that the incorporation of 25 php of kaolin content has increased the sharkskin’s level and most of the extrudate surface is severely damaged. Assumption made regarding this scenario was due to the presence of overloaded kaolin fillers in V25K8M which creates stiffer environment for the system. Thus, it is suggested that V25K8M melt is more elastic than viscous. At this stage, the stiffer melt increases the deformation rate by reducing the melt strength and increasing the elastic property. Furthermore, judging from the SEM result (refer to SEM analysis section) the size of kaolin agglomerates increases with an increase in its content. High content of kaolin
particles revealed poor interaction of kaolin particles with UPVC matrix by the formation of larger agglomerates. Poor filler-matrix interaction and agglomerations of particles contribute to the growth of deformation rate which lead to die swell [15-16] and flow instabilities [17-18] to the system. Nonetheless, this fact can only be applied to UPVC/kaolin system as PP/kaolin system shows normal flow even if kaolin concentration is added up to 30 php in the PP system. In the investigations of melt elasticity of PP composites done by Ariffin et al. [12] using talc and calcium carbonate as fillers, it has been concluded that filler is capable of preventing from the appearance of flow instability in PP composites. When the external force is released from the system, the presence of filler has delayed the movement/interaction of polymer molecules and decelerated the elastic recovery. Subsequently, leaving the PP chains as it is, giving more oriented and aligned structures, produced PP composite with smooth surface extrudate.

**Effect of MAH content**

An extensive work has been done in order to understand the limitations and advantages of adding MAH in PP and UPVC matrix. As shown in Figure 3(c), the addition of MAH presents extrudate surface of P5K2M which exhibit smooth surface comparable to the surface of P5K0M. However, when MAH content is increased, the onset of flow instability is affected, subsequently the critical shear stress is reduced to lower value. Therefore, sample P5K8M exhibits severely distorted extrudate. This reflects to the weak distribution of MAH which caused chaotic situation between arranging and rearranging of polymer melt. This scenario leads to substantial changes in the melt flow [13] hence contributes to the melt fracture shown by the sample (Figure 3(d)).

**Fig. 4.** Flow patterns of extrudate surfaces for (a) V0K8M; and UPVC/kaolin composites (b) V5K8M; (c) V25K8M; (d) V5K0M; and (e) V5K2M.

Reduction in sharkskin for UPVC composites with the presence of MAH are presented in Figures 4(d), 4(e) and 4(b). These figures illustrate that without the presence of MAH, UPVC/kaolin composites have underwent dehydrochlorination. This behaviour was found related to the changes of colour, from white (V5K8M) to brownish red (V5K0M). This result is in good agreement with the work done by Montrikool et al. [14] that dehydrochlorination of PVC was inhibited by the presence of MAH. The extrudate texture surfaces have also improved with the presence of MAH. V5K0M shows a rough surface with an exfoliated skin (without MAH in the system) and then, as the content of MAH is increased, the rough surface of the extrudate was diminished (at 8 php of MAH content). This effect is explained by the presence of MAH which improved the melt strength of the system. Therefore, when the melt strength of UPVC/kaolin composite is higher than the external force subjected to the system, the system exhibits better texture in its extrudate surface.
Flexural Behaviour

Effect of kaolin content

Figures 5 and 6 show results of flexural strength and flexural modulus for PP/kaolin and UPVC/kaolin composites as a function of kaolin content. It can be seen that the optimum values of flexural strength for both composites lie at 5 php of kaolin content and declined gradually as the kaolin content increased. Similar improvements in mechanical properties of PP/nano-SiO2 were also reported by Huang et al. [19] that this composite reached its optimum value of strength between 4 % - 5% of filler loading. Above 5 % of fillers, the mechanical properties of PP/nano-SiO2 composites show a decrease in its value.

![Fig. 5. Effects of kaolin content on flexural strength of PP/kaolin and UPVC/kaolin composites.](image)

![Fig. 6. Effects of kaolin content on flexural modulus of PP/kaolin and UPVC/kaolin composites.](image)

The reinforcement effect of 5 php kaolin content is possibly due to the degree of exfoliation and well distribution of fillers in matrix (as evidenced in Figure 9(a)(ii)). Consequently, the high aspect ratio of plate-like structure of kaolin enhances the interaction between silicate layers and polymer matrix. Furthermore, the observations in SEM results have clearly shown that the presence of MAH has increased the interaction between fillers and matrix as fillers are deeply embedded in polymer matrix. On the other hand, beyond 5 php of kaolin content, the appearance of fillers’
agglomerates in polymer matrix and interfacial defects could be the main causes of the reduction in flexural strength. All these factors would have hindered the stress transfer from polymer to kaolin particles during testing. Figure 6 indicates that flexural modulus of both composites increase gradually with increase of kaolin content. This could be attributed to the presence of high content of kaolin in the composite system, creating stiffer and more rigid environment due to the ability of fillers to promote stiffness in the composite. This scenario introduces higher flexural modulus as the kaolin content increases in the system.

-Effect of MAH content

Figure 7 represents the effect of MAH content on the flexural strength of PP/kaolin and UPVC/kaolin composites. It was found that the flexural strength of both composites is dependent on the MAH content. For PP/kaolin composites, with the MAH content increasing up to 4 php, the flexural strength reaches a maximum value and then decline. A decrease in flexural strength beyond 4 php of MAH content may be explained in relation to the effectiveness of MAH. During extrusion process, certain amounts of MAH are needed to promote strong interfacial interaction between kaolin filler and the matrix, resulting in better interfacial bonding. As seen in SEM results that fillers are deeply embedded in PP matrix compared to that without the presence of MAH. However, it is only effective when using 4 php of MAH content, above this amount, MAH had probably not been used and the leftover MAH then introduced more filler agglomerates to the composite (refer Figures 9(a)(i) and 9(a)(ii)) systems. This might be the reason for a decrease in flexural strength (beyond 4 php of MAH content) of PP/kaolin composites with increasing concentration of MAH.

![Graph](image)

**Fig. 7.** Effects of MAH content on flexural strength of PP/kaolin and UPVC/kaolin composites.

A reduction in PVC strength is widely associated with thermal degradation during processing due to the inappropriate amount of stabilizer or processing temperature
Flexural strength of UPVC/kaolin composites as a function of MAH is illustrated in Figure 7. At low MAH content (from 0-4 php), the flexural strength values increased only from 16 to 29 MPa. At this stage, the composites have undergone degradation (Figures 4(d) and 4(e)), resulting in an increase in the cleavage of Cl atoms in PVC and reducing the molecular stability [21]. This fact enhances the ability of polymer chains to slip past each other and more slippage of the molecular chains, causing a reduction in flexural strength. The flexural strength started to increase drastically giving the optimum value of 91 MPa (at 6 php of MAH concentration). The enhancement of flexural strength became less significant as the MAH content increased (at 8 php). A reduction in flexural strength at this phase is believed due to the excess of MAH which led to formation of fillers’ agglomerates as mentioned in the preceding paragraph and acted as defects in UPVC/kaolin composite.

**Fig. 8.** Effects of MAH content on flexural modulus of PP/kaolin and UPVC/kaolin composites.

PP/kaolin composites showing different trend in flexural modulus compared to that of UPVC/kaolin composites, is revealed in Figure 8. The flexural modulus of PP/kaolin composites exhibits an increase in increasing MAH content. Obviously, the addition of MAH in the system contributes to better interfacial interaction between filler and PP matrix as discussed in the above paragraph. Furthermore, the presence of well-distributed rigid kaolin particles (as seen in SEM results) restricts the mobility and deformability of the matrix by introducing a mechanical restrain [22-24]. Nevertheless a maximum value of flexural modulus is achieved with the addition of 2 php of MAH content. The reduction of modulus property is believed due to the agglomeration of kaolin filler that act as a microcrack initiator for the composite to fracture. Furthermore, the presence of excess MAH in the system:

(i) enhances the tendency of kaolin fillers to agglomerate
(ii) increases the plasticity of PP matrix and
(iii) reduces the rigidity or stiffness of the matrix,

giving less value in its flexural modulus. Whereas, UPVC/kaolin composites show a slight increase in flexural modulus with increasing MAH content. A factor that contributes to this scenario is the strong interfacial interaction and better wetting between kaolin and UPVC matrix, reflected by fewer microvoids observed in SEM
result with an increase in MAH concentrations. The increase in flexural modulus of UPVC/kaolin composite up to 6 php of MAH content does not sacrifice the strength of the composites as shown in Figure 7 that the flexural strength increase with an increase in MAH concentrations. Good wetting of fillers [25] by UPVC matrix with the presence of MAH results in less porosity which would not only enhances the flexural modulus but also the flexural strength of UPVC/kaolin composites.

**SEM Analysis**

Fig. 9. SEM micrographs showing cross sections of surface morphologies of (a) PP/kaolin; and (b) UPVC/kaolin composites. Arrows show kaolin particles whereas circles show agglomerations of particles.
-Effect of kaolin content

In order to identify kaolin influences on the microstructures of both PP/kaolin and UPVC/kaolin composites, the fractured surfaces of P5K8M, P30K8M, V5K8M and V30K8M were examined by means of SEM. SEM micrographs of P5K8M and V5K8M shows fillers were uniformly distributed and dispersed, suggesting improved mixing which justify significant improvement in flexural strength. In contradiction to P30K8M and V30K8M samples which exhibit agglomerates formations hence creating weak filler-matrix interaction. The size of kaolin agglomerates increases with an increase in its content. This would be the reason for lower flexural strength in both composites compared to that of composites with 5 php of kaolin content.

-Effect of MAH content

The delamination and dispersion of kaolin books into individual particles can be evidenced in Figures 9 (a)(i) and 9(b)(i). However, these figures show poor interaction of kaolin particles with polymer matrix. The kaolin particles tend to be exposed and loosely distributed on the fractured surfaces. In contradiction to Figure 9(a)(ii) and 9(b)(ii) which further revealed that kaolin is deeply embedded in polymer matrix due to the wetting phenomenon attained with the presence of MAH, thus, giving rise to filler-matrix interaction. The only disadvantage of adding MAH in PP and PVC matrix is MAH causes agglomerate formations. As can be seen in Figures 9(a)(ii) and 9(b)(ii) that the individual particles of kaolin (refer Figures 9(a)(i) and 9(b)(i)) have shifted into stacks of particles. It is also interesting to note that the powdery state of the starting material for both PP and PVC matrix is the main reason for delamination and dispersion of kaolin books in both composite systems (samples P5K0M and V5K0M). Assumption made is implied to the high surface area of both polymer and kaolin particles therefore improving the dispersion and affinity of kaolin in both polymer.

Conclusions

The method of direct melt mixing has become a mainstream for preparation of polymer/clay composites because of its convenience in industrial practices. The formulations discovered in this work represent a simple route to reinforced PP/kaolin and UPVC/kaolin composites with considerably higher flexural strength and smooth extrudate surface.

The presence of kaolin particles and MAH in filled PP and UPVC composites gives significant effects in the extrudate swell and flow instabilities of the systems. The results showed that the addition of kaolin particles to PP and UPVC causes a decrease in swelling and flow instabilities of both composites compared to the unfilled systems. However, the introduction of more than 5 php of kaolin content in UPVC composites increases the deformation rate by reducing the melt strength. Thus, increasing the sharkskin level and the extrudate surface is severely damaged (V25K8M sample). Eventhough MAH formed strong bonds between filler and both PP and UPVC matrix. This work has evidenced the limitations of adding MAH in PP matrix as it could cause an increase in the swell ratio. Furthermore, the melt fracture could be observed if adding 8 php of MAH content to the PP system. Whereas, UPVC/kaolin composites showed different trend, the shrinkage of extrudate can be observed with the addition of MAH. Other advantages of adding MAH to UPVC matrix, is that, MAH exhibited excellent properties as a secondary stabilizer for PVC when used in combination with CaSt₂. Secondly, MAH prevented flow instability
(V5K0M) from appearing in UPVC composites, giving better texture in its extrudate (V5K8M). The variations in extrudate swell and flow instabilities of PP/kaolin and UPVC/kaolin composites are strongly related to the entanglement level of polymer chains in the systems.

It was demonstrated in the results and discussion section that the incorporation of the starting material for PP and UPVC matrix which is in powder form leads to well dispersed of kaolin particles with high density of nano-level particles and in some cases micro-level particles. The microscopical evaluation showed fillers tend to be loosely exposed on the fractured surface in the absence of MAH. All the composites’ flexural moduli were increased with increasing in kaolin and MAH content. Nevertheless, this is incomparable to the effect of MAH content on UPVC composites which shows an optimum value of flexural modulus lies at 2 php of MAH content. In the case of flexural strength, it was revealed that 4 php of MAH concentration giving the maximum value is 49 MPa for PP/kaolin composites. Whereas, UPVC/kaolin composites achieved the maximum value of flexural strength at 91 MPa with 6 php MAH concentration. The excess of MAH was found to be one of the crucial parameters to be taken into account as it introduces filler agglomerates to PP/kaolin and UPVC/kaolin composites thus reducing the flexural strength.

The addition of 5 php of kaolin content in PP and UPVC matrix has the effect of progressively increasing the flexural strength of both composites compared to all composite systems. Therefore, the kaolin content should be kept at 5 php level in order to achieve optimum value in its flexural strength. It is also proven in this work that the elastic properties have significant effect on the mechanical properties of the end product. The results showed that P5K4M and V5K6M composites with good flow properties and better extrudate surfaces give the highest value in the flexural strength. It can be concluded that kaolin and MAH loading plays an important role in the formation of the final PP/kaolin and UPVC/kaolin composite structures with improved properties.

**Experimental**

**Materials**

The thermoplastics used in this study were polypropylene (PP) homopolymer powder, grade G112 supplied by Polypropylene (M) Sdn Bhd and poly(vinyl chloride) (PVC) homopolymer powder, grade MH-66 and supplied by Industrial Resin Malaysia (IRM) Sdn. Bhd. The filler used was hydrous aluminium silicate or kaolin \([\text{Al}_4\text{Si}_4\text{O}_{10}(\text{OH})_8]\) grade RC15. Maleic Anhydride \([\text{C}_4\text{H}_2\text{O}_3]\) grade 63210 which is in a crystal form was supplied by Fluka. The calcium stearate \([\text{C}_{36}\text{H}_{70}\text{CaO}_4]\) used as stabilizer in UPVC/kaolin composites was supplied by Riedel-de-Haen. The compositions for all systems studied in this work are presented in Table 1. The composites were compounded using a single screw extruder, model Betol. Kaolin particles and MAH were hand mixed with PP or UPVC and calcium stearate prior to compounding. The temperatures of the extruder zone were maintained at 140°C, 150°C, 160°C and 160°C and the rotating screw was fixed at 16 Hz. Some of the extrudates which exited through the die have been carefully collected for further investigations on extrudate swell and flow instabilities of PP/kaolin and UPVC/kaolin composites. The rest of the extrudates were subsequently pelletized and then moulded for flexural testing.
**tab. 1.** Sample compositions according to per hundred parts (php) of PP and UPVC matrix at different kaolin and MAH content.

<table>
<thead>
<tr>
<th>PP/kaolin composites</th>
<th>UPVC/kaolin composites</th>
<th>Kaolin</th>
<th>MAH</th>
</tr>
</thead>
<tbody>
<tr>
<td>P5K0M</td>
<td>V5K0M</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
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<td>V5K2M</td>
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</table>

*All UPVC/kaolin composites were prepared at calcium stearate (stabilizer) level of 2 php.

**testing**

The extrudates collected earlier were allowed to cool in air at room temperature and the diameter of the extrudate was measured after 24 hours of cooling period. Determination of extrudate swell ratio, \( B \)

\[
B = \frac{d_e}{d_d}
\]

where \( d_e \) is the equilibrium extrudate diameter and \( d_d \) is the die diameter.

The photographs of distorted extrudates for the study of flow instabilities were taken using high resolution digital camera fitted with an image analyzer. On the other hand, the micrographs of cross section extrudates were obtained using scanning electron microscope instrument, model Zeiss Supra 35VP-25-58.

The pellets of compounded PP and UPVC were compression moulded in an electric heated hydraulic press (Kao-Tieh compression moulding machine). The three-point flexural test for both PP/kaolin and UPVC/kaolin samples were implemented with the aid of INSTRON Series IX/s Automated Materials Tester-Version 8.25.00. Moulded samples were then cut into test shape specimens. The test for PP/kaolin composites were performed in accordance to ASTM D790-98. The support span was set at 50 mm and at crosshead speed of 5 mm/min. Whilst, The test for UPVC/kaolin composites were performed in accordance to ASTM D790-98. The support span was set at 50 mm and at crosshead speed of 5 mm/min. At least 5 samples for each formulation were tested to ensure persistency.

**references**