Tensile Properties of Polyethylene Composites Based Kaolin Geo-Filler

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Abstract. The current work studies the tensile properties of polyethylene composites-based kaolin geo-filler. Polyethylene composites was prepared based on kaolin geo-filler at different loading content varies from 0, 2, 4, 6, 8 and 10 wt%. The optimum results were compared with polyethylene composites based on raw kaolin to study the effect both filler on tensile properties. Tensile test was conducted according to ASTM D638. Based on these research studies, the use of kaolin geo-filler is effectively improved the tensile properties of polyethylene as compared to the raw kaolin filler. As the result, 8% of kaolin geo-filler content demonstrate the optimum formulation to enhance the tensile properties of polyethylene composites.

1 Introduction

According to survey analysis from Plastics Europe Market Research Group (PEMRG), there are around 49.9 metric tons of plastic usage in 2016. Polyethylene (PE) shows the highest percentage of usage compared to other plastic. However, poor mechanical and physical properties of polyethylene can limit their large application. During the fabrication process of polyethylene industry, high operating speed can even more significantly degrade and leads to deterioration in its mechanical and physical properties [1]. This issue may influence the long-term use of polyethylene in the structural application. Therefore, polyethylene has been improved by addition of several fibrous and/or particulate filler to develop better properties [2-4]. Incorporation of kaolin as a filler is very common in polymer composites to any matrix of polymers since it has improved the mechanical properties of the polymer composites [5-6]. However, addition of kaolin based on geopolymerization process as a filler is rarely reported.

Kaolin geo-filler is an inorganic alumino-silicate structure which synthesized from predominantly silicon and aluminum material of geological in alkaline environment condition. Kaolin geo-filler is amorphous three-dimensional ceramic-like materials. It is

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like natural zeolite except the amorphous microstructure. The alkaline environment allowed the geopolymerization to occur through poly-condensation process. Kaolin acts as main role in this process due to their highest SiO$_2$ and Al$_2$O$_3$ chemical composition. Under alkaline conditions, the geopolymerization occurs when the alkali hydroxide and silicate solution react to each other. It is essentially to prefer as low alkalinity system which high alkalinity may lead the common ions effect, and dissolution of C-S-H may be introduced [7-12]. Geopolymer based materials contribute to excellent mechanical properties, high early strength, abrasion resistance and thermal stability that lead to many application fields such ceramics, binder, matrices for hazardous waste stabilization, fire resistance and for high tech materials [13-16]. Therefore, in this study an attempt has been made to study the effect of geo-filler and polyethylene based on its tensile strength and modulus properties.

2 Experimental

2.1 Materials

Polyethylene pellets were sourced from Lotte Chemical Titan Holding Sdn. Bhd. with density 0.92 g/cm$^3$ and melting point 115 °C. Kaolin was supplied from Associated Kaolin Industries Sdn. Bhd. Malaysia. The chemical composition of kaolin from non-destructive analytical technique, X-ray Fluorescence shows as in Table 1.

| Chemical Composition | SiO$_2$ | Al$_2$O$_3$ | K$_2$O | Fe$_2$O$_3$ | TiO$_2$ | ZrO$_2$ | MnO$_2$ | LOI |
|----------------------|--------|-----------|-------|-----------|--------|--------|--------|-----|
| Mass (wt. %)         | 54.50  | 32.40     | 5.58  | 4.32      | 1.33   | 0.08   | 0.10   | 1.69|

12 M of sodium hydroxide solution was prepared by using the sodium hydroxide pellets which supplied by HmbG Chemicals. The molar mass of sodium hydroxide is 40 g mol$^{-1}$. The density of sodium hydroxide is 2.13 g cm$^{-3}$. Sodium silicate pellets are used to prepare the sodium silicate solution with the molarity of 12 M. The sodium silicate pellets were sourced from the Sigma-Aldrich (M) Sdn. Bhd. The molar mass of sodium hydroxide is 122 g mol$^{-1}$. The density of sodium hydroxide is 2.4 g cm$^{-3}$.

2.2 Sample Preparation

Kaolin raw materials was placed in oven at 100 °C for 24 hours before mixed with the alkaline activator. Alkaline activator solution is prepared by using both sodium hydroxide solution and sodium monosilicate solution at 12 M with ratio 2:0. Kaolin was mixed with alkaline activator and the geopolymeric paste were placed in oven at temperature 80 °C for 24 hours. After 24 hours, the materials are crushed using ring mill and sieved by using siever size 150 μm. Polyethylene pellet and geo-filler were mixed according to Table 2. Preparation of composites was used twin screw extruder LabTech Scientific 20 mm co-rotating. The barrel, die temperature, feeder speed and screw speed are controlled according to Table 3.
Table 2: Formulations of polyethylene filled with kaolin geo-filler.

| Sample    | Polyethylene wt.% | Geo-filler wt.% |
|-----------|-------------------|-----------------|
| PE        | 100               | 0               |
| PEKG-2 %  | 98                | 2               |
| PEKG-4 %  | 96                | 4               |
| PEKG-6 %  | 94                | 6               |
| PEKG-8 %  | 92                | 8               |
| PEKG-10 % | 90                | 10              |

Table 3: Temperature and screw speed profiles of the extruder barrel

| Zone | Temperature | Screw speed |
|------|-------------|-------------|
| 1    | 115 °C      | 110 rpm     |
| 2    | 120 °C      |             |
| 3    | 125 °C      |             |
| 4    | 130 °C      |             |
| 5    | 135 °C      |             |
| 6    | 140 °C      |             |
| 7    | 145 °C      |             |
| 8    | 150 °C      |             |

2.2 Testing and Characterization

The composite sample of dumbell shape with thickness of 0.2 cm were fabricated for tensile testing using Instron Universal Testing Machine Model 5569 according to ASTM D638. The speed of testing used is 5 mm/min with the nominal strain rate of 1.5 mm/mm-minute.

3 Results and Discussion

The results of tensile strength and modulus for polyethylene composite (PEKG) with different geo-filler contents at varies loading from 0,2,4,6,8 and 10 wt. % were illustrated in Figure 1. Tensile modulus is directly proportional to tensile strength and it can be seen that tensile strength and modulus increased as geo-filler content increased up to 8 wt. % and reached the optimum tensile strength at 20.83 MPa and modulus at 476.67 MPa. However, the tensile strength and modulus has found to be decreased as the kaolin geo-filler reached 10 wt. %.

Kaolin geo-filler is an inorganic materials that acted as reinforcement in polyethylene composites and as geo-filler content increased, it will contributed to higher tensile strength. Inorganic reinforcing fillers are harder and stiffer than the matrix and deform less, causing an overall reduction in the matrix strain, especially in the vicinity of the particle as a result of the particle/matrix interface [17]. In addition, kaolin geo-filler is a concrete like materials and anticipated higher strength than matrix polymer. As the kaolin geo-filler incorporated in polyethylene matrix, these geo-filler tend to restrain movement of the matrix phase in the vicinity of each particles which bear a fraction of the load thus increase the tensile strength [18]. However, at higher geo-filler content the filler particles expected having poorly dispersed and acts as flaws in the composites structure. In addition, higher filler content
will accumulate filler at the joint interface, and insufficient thermoplastic material is present to form a strong bond. So, the tensile strength will decreased at high percentage of filler content [19].

![Fig.1: Tensile strength and modulus of polyethylene at different geo-filler content.](image)

Tensile modulus is the ratio between tensile stress and tensile strain in the linear elasticity regime of a uniaxial deformation. From Figure 1, tensile modulus was increased from the origin polyethylene to addition of 2, 4, 6 and 8 wt.% of geo-filler content. Incorporation of geo-filler and polymer matrix clearly improve the stiffness of composites, which enhance the tensile modulus as the result. Higher filler content tend to lower the chain mobility. The limitation of chain mobility is the result of external load needed to strain the bonding of polymer [20]. However, tensile modulus was found decreased as the geo-filler increase to 10 wt.%. The reason is that the more shear force generated at higher filler concentration lead the filler agglomerates and decrease the free volume. It will restrict the mobility of chain movements and tends to lower the tensile modulus [21].

The optimum kaolin geo-filler content at 8 wt% in polyethylene composites was compared at even loading with raw kaolin in polyethylene composites (PEK) to study the efficacy of geo-filler in composites system. The results was illustrated in Figure 2. From the figure, addition of geo-filler kaolin obviously improved the tensile strength and modulus as geo-filler have cementing properties through geopolymerization process. Apart from that, PEKG also have rougher surface such in Figure 3. The rougher surface needs more energy to strain which support the high tensile strength and modulus [22].
Fig. 2: Tensile strength and modulus of polyethylene based kaolin filler (8 wt%) (PEK) and polyethylene based kaolin geofiller (8 wt%) PEKG.

Fig. 3: SEM morphology cross-sectional images: (a) polyethylene based kaolin filler (8 wt%) (PEK) and (b) polyethylene based kaolin geofiller (8 wt%) PEKG.

4 Summary

In this study, kaolin geo-filler was produced from geopolymerization process using sodium hydroxide and sodium silicate was used as a filler in the polyethylene composites. Tensile properties of polyethylene composites has enhanced by addition of kaolin geo-filler with the optimum formulation of 8 wt%.
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