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Evaluation of Flexural and Flame Retardant Properties of Recycled Polyethylene Terephthalate – Silica Sand Composites

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Abstract: This research focuses on the evaluating the mechanical properties of the polymer composites made with recycled polyethylene terephthalate (PET) and silica sand. The mechanical testing focuses in this research are bending test and fire retardant test. The objectives of this research are to produce a composite material from mixture of PET and silica sand and also to evaluate the mechanical properties of PET-silica sand composites. The materials used in this researcher PET and silica sand where PET can be obtained from the recycled plastic bottles. Several parameters were considered such as varying the sand particle weight percentage such as 20 %, 30 %, 40 % and 50 %. The results for bending test and fire retardant test were obtained, however, they do not verify by the previous research. It can be concluded that the mechanical properties of PET-silica sand composite was successfully evaluated.

Keywords: PET, Silica Sand, Mechanical Properties, Bending Test, Fire Retardant Test

1. Introduction

Polyethylene terephthalate (PET) is a polymer. This means that it is a macromolecule consisting of thousands of repeating units. In order to produce PET, two different monomers are used which is terephthalic acid and ethylene glycol. A reaction called esterification is undergone by both units, where and organic acid and an alcohol combine to form an ester and water. PET is a thermoplastic polymer resin. Thermoplastics has the simplest molecular structure, with chemically independent macromolecules. They are softened or melted by boiling, and shaped, formed, welded, and solidified when cooled. Thermoplastic matrix composites have distinct benefits over thermoset matrix composites in terms of recyclability, with a high precision, power and specific stiffness, corrosion resistance, improved strength, cost effectiveness and structural flexibility.

The next raw materials used in this research is silica sand. Silica sand will be used as the filler in the composite. Silicon dioxide is an organic substances also known as silica. Silica sand is a type of sand that often consists of tiny quartz granules. Silica, or silicon dioxide (SiO_2) is a term used in a mineral family containing quartz, cristobalite, tridymite and Tripoli [1]. In recent years, much attention

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has been paid to the use of silica particles as a reinforcement in polymers. The silica used differs from being used as an extenders to a practical filler. In plastics, it is used to increase abrasion, flame, corrosion and scratch resistance, to improve compressive, flexural and dielectric properties [2]. Filler additive is recorder to improve properties such as mechanical, thermal characteristics and conductivity so applications favour the use of polymer composite materials rather than pure polymers [3]. Besides, the addition of rigid silica particles to the polymeric matrix will quickly improve the elastic modulus of the composites. The tensile strength of the composites decreased by increasing the size of the particles, reducing the interfacial adhesion of the particle of matrix and increasing the fractional mass of the particle from a critical value [4].

Composite products are composed of two or more constituent materials with substantially different physical or chemical properties, which when mixed, create a composite with net superior characteristics that vary from the individual components. Meanwhile, a polymer composite is a multi-phase substance in which the reinforcement fillers are combined with a polymer matrix, resulting synergistic mechanical properties that cannot be obtained by any part alone. The mechanical and physical properties of polymer composites materials are defined by their constituent properties and by their microstructural structure [5]. Polymer composite materials possess a valuable complex of properties, the most important being low density and associated high specific strength, specific stiffness, corrosive resistance and the capacity to withstand sustained static and dynamic tension, as well as ability to work at a wide temperature range, under alternating stress and high humidity [6]. Besides that, polymer composites are ideal for use as high-performance composites, where the reinforcing characteristics are significantly different or greater than those of the matrix. This is due to they have a very high mechanical strength and stiffness, along with corrosion resistance [7].

2. Materials and Methods

2.1 Materials

This part explains the details and the list of raw materials that were used in the preparing and producing of the PET-silica sand composite. Firstly, 30 pieces of 1500 ml recycled PET were obtained by picking up waste PET bottles and washed them. Then, the PET bottles were cut according to a width of about 3 mm and a length of about 5 mm. The next raw materials is silica sand. The silica sand was obtained by collecting in on the beachfront and filtered using a filter. The raw materials is then weighted according to their desired mass referred to the sand particle weight percentage for every samples. Table 1 shows the designation of the sample.

Table 1: The designation of the sample

No.	Designation	PET (%)	Silica Sand (%)
1.	S20	80	20
2.	S30	70	30
3.	S40	60	40
4.	S50	50	50

2.2 Methods

In preparing the of PET-silica sand composite, the first process that took place is the milling process by using the Laboratory Rotor Mill Pulverisette 14 machine at Polymer Laboratory Faculty of Mechanical and Manufacturing Engineering UTHM. Rotor mill is used to grind the silica sand as it is suited for pre-crushing and fine comminution of soft to medium-hard, brittle, fibrous, and temperature sensitive materials. The silica sand were milled into sized less than 63 µm.

After the milling process take place, the raw materials is then undergo the next step which is mixing. The mixing process is done by suing Brabender Plastograpgh machine, also located at the Polymer

Laboratry UTHM. The temperature were set at 250 ℃ as the melting point of PET is 260℃. The PET is first fed into the mixer. When the PET is fully melted, the silica sand were added gradually according to their preference sand weight percentage which is 20 %, 30 %, 40 % and 50 % into the brabender mixer. A mix of PET-silica is the result obtained from this mixing process.

Due to the current situation of COVID-19, the production of sample cannot be done at the laboratory. By that, the concept of brabender mixer were applied at home. Kitchen stove, a 22 cm diameter frying pan and a stainless steel spatula that can be obtained in the kitchen at home were used. The main component for the melt and mix of PET and silica sand is heat so, the PET is first melt in the frying pan and once it melted, silica sand were added into it. The temperature was approximately 250 ℃ as the PET able to melt on the stove.

After the mixing process done, the next step is to shape the sample. Initially, hot press method was chose but it could not be done due to the restrictions. So the sample shaping also were done at home. The PET-silica sand mixture which in the solid slated is placed in a desired shape mould and heated on the stove. By heating, the state of the PET- silica sand mixture will change into a liquid. Once the mixture is completely in liquid state, put the mould aside and let them air dried. Figure 1 shows the outcomes of the sample shaping.

Figure 1: The samples according to their designation

Moving on to the mechanical testing on the PET-silica sand composite sample. The first testing is bending test. Bending test is known as the flexural testing or transverse beam testing, assesses the performance of materials subjected to basic beam loads. Due to the current condition, bending test cannot be performed in the laboratory. Hence, the testing were carried out at home. The sample was tied with a string that attached with a bucket and let them hanging on a higher place. A 1 kg load was loaded in the bucket repeatedly for every 10 seconds until the sample was fractured.

Next, fire retardant test is the second test tested on the PET-silica sand composite. One of the principle of retardation is when combustible gases are created by thermal breakdown of flammable material, fire retardant release and emit inflammable gases in the heat interval. The indicator used in this testing are the weight of sample and the time taken for the sample to burn. The sample is first weighted to compare the weight before and after the testing occur. After that, the sample were exposed to the fire and the time taken for the sample to burn were taken. The test was hold on a kitchen stove.

When using the brabender mixer, the sample weight must be calculated first by using equation shown in Eq 1. Sample weight should be calculated first as to know the capability of the mixer to mix the raw materials evenly.

$$m = v \times l_c \times k \quad \text{Eq 1}$$

Where,

m = sample weight (g)

v = mixer chamber volume (55cm^3)

l_c = total composite density (g/cm^3)

k = constant (0.7 @ 0.8)

In bending test, the weight needed for the sample to break is considered as the maximum load. Maximum load exerted on each specimen was recorded and the flexural strength, σ was calculated in MPa. The greatest stress in the outermost sample is known as the flexural strength. Flexural can be calculated from the equation shown in Eq 2.

$$\sigma = \frac{3FL}{2BH^2} \quad \text{Eq 2}$$

Where,

F = maximum load (N)

L = distance of the sample (mm)

B = width of the sample (mm)

H = height of the sample (mm)

3. Results and Discussion

In this research, there are two testing that were conducted which is bending test and fire retardant test. Here, a detailed discussion has been made based on the results obtained from the testing and experimentation that is available and listed in the scope of study. This tests were performed at home based on their preference concept. By that, the results of the test might not be as accurate as testing that can be done in the laboratory.

3.1 Result of Bending Test

Tensile tension is generated on the convex side of the specimen while compression stress is generated on the concave side. This results in a shear stress zone along the midline. Initially, the purpose of a real bending test performed in the laboratory were to deform the sample into a certain shape rather that to load the material till failure but in order to gain a result through the modified version of bending test, the test were performed until the sample fractured.

The parameters used in the bending test is weight needed and the time taken for the sample to break off. Table 2 shows the weight and the time taken respectively to their designations. From the mass obtained, the flexural strength can be calculate. Figure 2shows the graph of flexural stress against the designation of the sample.

Table 2: Weight needed and time taken for the sample to break off

Designation	Weight (kg)	Time taken (s)
S20	2	20
S30	4	40
S40	8	80
S50	12	120

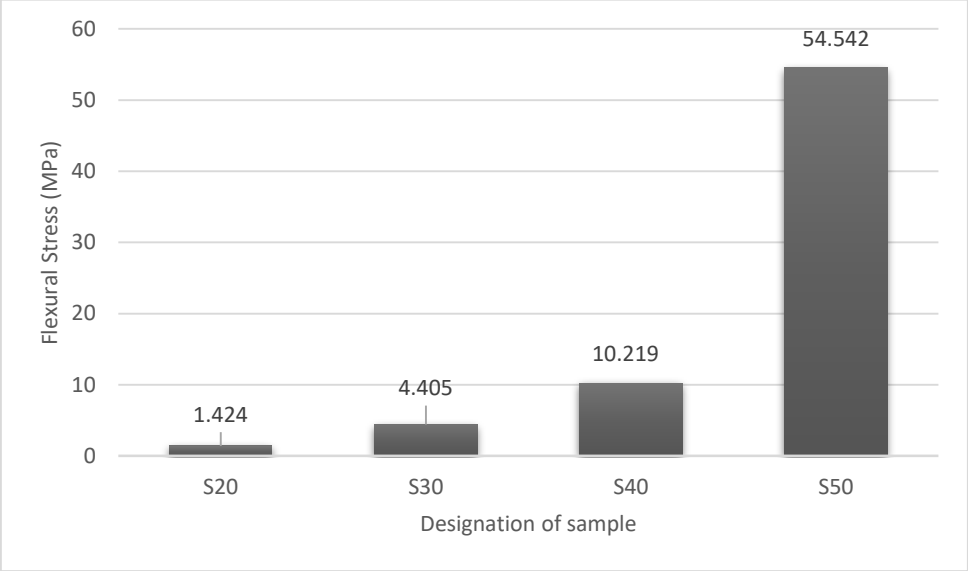

Figure 2: Graph of flexural stress against designation of the sample

As shown in the Figure 2, the flexural stress increase as the sand weight percentage increase. The flexural stress for 20 & sand weight percentage is 1.424 MPa while for 30 % sand weight percentage, the flexural stress is 4.405 MPa. For 40 % sand weight percentage, the flexural stress is 10.219 MPa. There is a huge increment for 50 % sand weight percentage where the flexural stress is 54.542 MPa.

By comparing the result obtained in Figure 2 with previous research by [8], the result obtained is very contradicts with the result obtained by the researcher. Quitero et al (2009) stated that the compressive strength reading fall significantly with the increasing of sand addition. This might be attributed to sand overpopulation, which results in a poor contact between the sand and the PET matrix and inefficiencies in stress transmission.

When a unidirectionally fiber-reinforced composite is exposed to a compressive stress, many primary failure modes are founds, including matrix yield followed by fiber microbuckling, local fiber microbuckling with an elastic matrix, shear failure and pure fiber compression failure. Composites with low, moderate and high degree of fiber or matrix adhesion were linked to such failure mechanisms. It is an important to note that the fibers in composites are not all precisely aligned in a uniaxial orientation. Furthermore, these cellulosic fibers are flexible, particularly after grafting, lowering their effective elastic modulus. Many fibers will then be bent across distances that are far larger than their diameters. The matrix also helps to strengthen the composite by preventing fiber bending and buckling by impeding their capacity to bend. As a results, when the matrix begins to give, the misaligned fibers will bend, but the matrix surrounding then will strain harden, and the specimen will be able to take greater load [9]. This explained why the compressive strength should be increase when the sand particle weight decrease.

3.2 Results of Fire Retardant Test

The next test occurred to test the mechanical properties of the sample is fire retardant test. The purpose of this test is to observe the duration for the sample to burn. The benchmark for the test is when soot were produces when the sample in on fire. The parameters of this sample is the weight of the sample before and after the test and the time taken for the sample to burn. Apparently, the mass loss of the PET-silica sand composites is to measure the amount of the thermal decomposition and subsequent volatilization. Due to the improper and insufficient equipment, the thermal decomposition could not be detected. Figure 3 shows the weight of the sample before and after the testing.

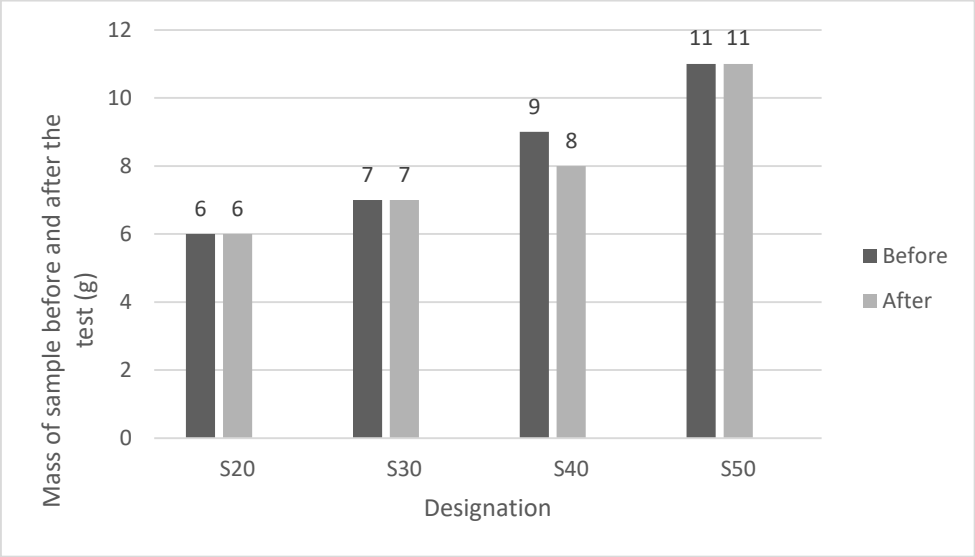

Figure 3: Graph of mass of sample before and after testing against designation of sample

Based on the Figure 3 above, it is observed that the mass of the sample unchanged except for 40 % sand weight percentage where it was 9 g before the testing and 8 g after the testing. Moving on to the next parameter which is the time taken for the sample to burn. The trends of the time taken obtained can be seen in Figure 4 where the time taken decreased gradually as the sand weight percentage increased.

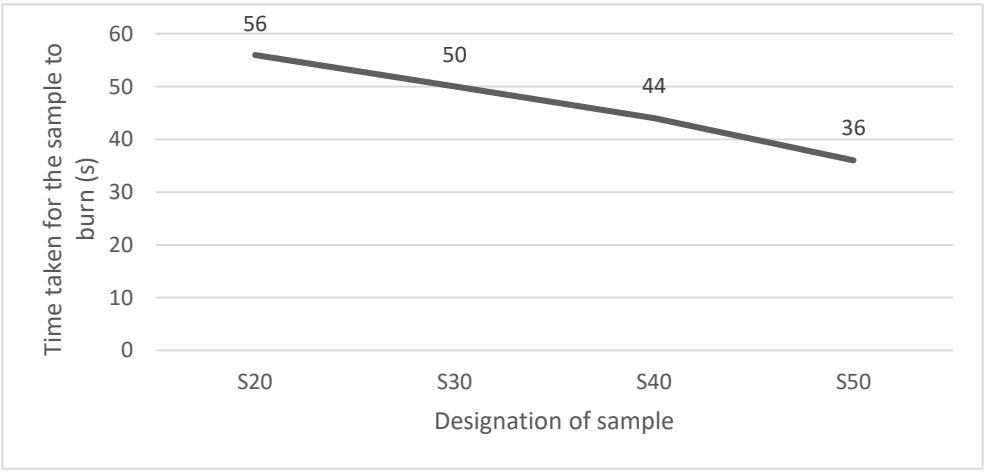

Figure 4: Graph of time taken for the sample to burn against designation of sample

Most of the fire retardant test studies (particularly for heat release rate and smoke density) have the constraint of ignoring the impacts of fire development. Another problem is that utilizing fire retardant techniques to recreate actual flames is difficult, if not impossible. For example, the heat release rate, air motions, and oxygen/fuel ratio seen in actual flames are frequently different from those found in fire retardant test, and this can have a significant impact on the observed fire response characteristics. Another disadvantages of fire retardant test is where the entire sample is frequently burned, but in real fires, this may not occur due to the lower oxygen levels found within confined, unventilated rooms.

Many forms of polymer composites produce dense smoke, which reduces visibility and can create confusion among those trying to flee a fire. Fine soot particles (usually less than 2 μm) are generated by the heat breakdown of the polymer matrix and organic fibers, resulting in smoke. Smoke can also contain tiny shards of non-combustible fibers, albeit they make up a minor portion of the smoke composition.

The combustibility of polymer composites is one of the most serious safety problems. When subjected to high heat flux, many polymer composites burn, producing heat that can contribute to the spread of the fire in some cases, significant amounts of smoke and poisonous gases may also be produces, obstructing vision and constituting a health risk respectively. Polymers and organic fibers commonly employed in composites have endothermic reactions, which absorb heat [10]. The heat created by the decomposition reactions of the volatiles released by the dissolving composites less the heat absorbed by the endothermic breakdown processes of the polymer matrix and organic fibers determines the net release rate, which is a complicated characteristics.

4. Conclusion

The presented research is about the mechanical testing of the polymer composite made with polyethylene terephthalate (PET) and silica sand. Multiple changes have been made during the PET-silica sand composite sample making. This is due to the few restrictions of the equipment and also due to the current situation happen to the country not that enable to complete the experiment as planned earlier. Despite that, the process of making PET-silica sand composite sample has succeed based on the desired sand weight particle percentage which is 20 %, 30 %, 40 % and 50 %. It is proven that the sample making can be done at home with proper understanding towards the concept.

Bending test and fire retardant test has been chose to test the sample as it is easy to be conducted at home. During the bending test, the load were applied to the sample until the sample break off. From the testing, flexural stress can be measured. The results shows that the highest the sand particles weight percentage, the highest the flexural stress of the sample. Unfortunately, the result obtained contradicts to the result that has been done by previous researchers. The next test that were carried out in order to the mechanical properties of the sample is fire retardant test. Sample was put on the fire and the time taken for the sample to burn were taken. The results shows that the highest the sand particles weight percentage, the longest the time taken for the sample to burn out.

From the objectives of this study, the PET-silica sand composite were succeed to produce and the mechanical properties of the PET-silica sand composite can be evaluated through bending test and fire retardant test. Unfortunately, the best PET-silica sand composite cannot be determined due to the misleading of the results obtained.

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