Effects of glass scraps powder and glass fiber on mechanical properties of polyester composites

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Abstract. One concern in bus manufacturing is the high cost of glass fiber reinforced in polyester composites parts. The composites of glass fiber and polyester are low elongation and high strength, and glass scraps powder displays high hardness and good chemical compatibility with the polymer matrix and glass fiber. This research aimed to study the effects of glass scraps powder and glass fiber on mechanical performance of polyester composites. Glass fiber was randomly oriented fiber and used as new. Glass scraps were obtained from a bus factory and crushed to powder sizes of 120 and 240 µm by a ball mill. Polyester composites were prepared using Vacuum Infusion Process (VIP). Polyester reinforced with 3 layers of glass fiber was an initial condition. Then, one layer of glass fiber was replaced with glass scraps powder. Flexural strength, tensile strength, impact strength and hardness of the polyester composites were determined. Hardness was increased with a combination of smaller size and higher volume of glass scraps powder. Pictures of specimens obtained by using scanning electron microscope (SEM) confirmed that the powder of glass scraps packed in the layers of glass fiber in polyester composites.

1. Introduction
A composite, one of the most significant inventions of the materials sciences (matrix and reinforcement), is made from distinct materials combined to make a better material [1]. Composite materials are used in assembly boards, furniture, fencing, paneling to civil constructions, automobile and even space or aircraft manufacturing. Composite materials can also be used in many fields with high quality and low cost applications [2]. Fiber restressing techniques were developed to improve the properties of continuous fiber reinforce composites [3, 4]. Fiber reinforced composites were successfully used for many decades in engineering applications. In this study, the matrix was polyester resin and the reinforcements were glass fiber and glass scraps powder. The glass fiber was chopped mat No. 450. The glass scraps powder were laminated glass recycling which obtained from terminated buses or crack during operation in bus fleet and manufacturing. Then, the scraps were grinded and passed through sieve mesh No. 60 and 140. The glass fiber had the density of 450 g/m².

Vacuum Infusion Process (VIP) is an efficient manufacturing process for complex laminates with many plies of fibers and core materials. The method is used for producing composites and has many advantages over hand lay-up method such as higher quality, higher specific strength and stiffness, better consistency, good interior finish, faster cycle time and lower cost [5].

Mechanical property of a combination of glass fiber and polyester is characterized by high toughness leading to resistance to crack propagation [6].
The main objective of this research was to study the mechanical properties of the polyester composites reinforced with glass fiber and the powder of glass scraps which the composites were fabricated using VIP. Initial composite material composition was polyester resin matrix reinforced with 3 layers of glass fiber. Next, one layer of glass fiber was replaced by glass scrap powder. The weights of one layer of glass fiber and glass scrap powder were identical. Tests were performed to determine flexural, tensile, impact and hardness properties of the polyester composites.

2. Methods
2.1. Materials
Materials used for this project were:
- Matrix: Polyester resin
- Catalyst: Methyl Ethyl Ketone Peroxide Norox KP-100
- Reinforcements: Glass fiber chopped stand mat No. 450 and glass powder sizes of 60 and 140 Mesh.
- Others: Gel coat, Styrene monomer and Cobalt in solution as accelerator.

Glass scraps were milled into powder by using a ball mill and screened with sieves No.60 and 140 Mesh where it was decided that the particles could be filled in between the fibers. The sizes were measured by a laser particle counter before used. The results of size measurement are shown in Table 1 and Figure 1. Table 2 show sample preparation that was PGF, polyester resin reinforced with 3 layers of pure glass fiber, and D12/W45, D12/W55, D24/W45, D24/W55, the resin reinforced with 2 layers of glass fiber and the amount of glass powder. Initially, one layer of glass fiber had weight of 450 g/m². Therefore, the weight of the glass scraps powder in the experiment were 450 and 550 g/m² which the former was identical with the weight of one layer of glass fiber and the latter was expected to have more glass powder compacted in the composite.

Table 1. Sizes of glass scraps powder.

| Particle sizes of glass scraps powder (µm) | Mean size | Std. Dev. | Median size |
|-------------------------------------------|-----------|-----------|-------------|
| Mean size                                 | 240.66    | 100.60    | 221.35      |
| Std. Dev.                                 | 120.45    | 47.02     | 117.03      |
| Median size                               | 120.45    | 47.02     | 117.03      |

Figure 1. Particle size distribution of glass scraps particle through sieve (a) No. 60 (240 µm) and (b) No. 140 (120 µm).
Table 2. Samples preparation.

| Sample | Polyester resin (g/m²) | Catalyst (g/m²) | Gel coat (0.5 mm thick) (g/m²) | Glass fiber (No. of layer) | Glass scraps powder Size (µm) | Weight (g/m²) |
|--------|---------------------|----------------|---------------------------------|--------------------------|-------------------------------|---------------|
| PGF    | 2,430               | 24.3           | 815.1                           | 3                        | -                            | 450           |
| D12/W45| 2,430               | 24.3           | 815.1                           | 2                        | 120                           | 450           |
| D12/W55| 2,430               | 24.3           | 815.1                           | 2                        | 120                           | 550           |
| D24/W45| 2,430               | 24.3           | 815.1                           | 2                        | 240                           | 450           |
| D24/W55| 2,430               | 24.3           | 815.1                           | 2                        | 240                           | 550           |

2.2. Fabrication using VIP

The VIP was used as a manufacturing technique in this study. The technique applies vacuum to pull resin into a laminate (Figure 2). The fabric fibers and core materials are loaded into the mold. Then, a vacuum bag is covered on the top to close the mold and creates a vacuum seal. After that, a vacuum pump is used to remove all of the air in the cavity and consolidate the fiber and core materials. Finally, resin is infused under vacuum into the mold cavity to wet out the fiber.

In the present study, the process was followed the practical steps. The glass powder was sprayed after laying the fiber layer by layer. The glass powder was sprayed with a controlled feed flow rate. The graphic of rectangular mold used in the experiment is presented in Figure 3. The locations of the vacuum ports and the resin insertion points need to be carefully planned to ensure full resin infusion. Thus, the resin infusion inlet and vacuum outlet were placed at the mid edge of the mold.

![Figure 2. Vacuum infusion process (VIP).](image2)

![Figure 3. Composite plate forming of VIP.](image3)

2.3. Mechanical properties testing

Each composition in Table 2 was fabricated with a size of 50x50 cm² then cut into small specimens as shown in Figure 4 for determining mechanical properties effected by longitudinal (L) and transverse (T) infusion flow, and locations at the edge (E), middle (M) and corner (C) on the workpiece.

Flexural and tensile tests were performed using a universal testing machine, with a speed of 5 mm/min at room temperature. The test was according to ASTM D790 [2, 3] and ASTM D3039, respectively.

Izod impact test (unnotched) was conducted using INSTRON (CEAST)/CEAST 9050 impact according to ASTM 4812 apparatus with a hammer of 11 J, at room temperature. Then, the fracture surfaces of the specimens subjected to Izod impact test were taken to scanning electron microscope (SEM) to analyze their microstructure which the specimens were coated with gold [1].

Hardness test was carried out using the shore D hardness according to ASTM D2240 during 10s [1].
3. Result and discussion
The test results were graphically and statistically analyzed and discussed as following.

3.1. Flexural test
Figure 5a shows that either the directions of infusion flow or locations of the specimens had no effect with the flexural strength. The diverse compositions affected the strength. The strengths obtained from D24/W45 and D24/W55 were only slightly lower than PGF, see Figure 5b, that might be resulted from the larger particle size in the matrix.

![Figure 5a](image1)
![Figure 5b](image2)

**Figure 5. Flexural test results.**

3.2. Tensile test
The results indicate that the directions of infusion had no effect on the tensile resistance (Figure 6). The tensile strength diminished with adding glass scraps powder weight of 450 g/m² into the glass fiber and polyester.
3.3. Impact test

As well as in the flexural test, the infusion directions had no effect on the impact resistance (Figure 8a). All proposed composite compositions showed significantly lower impacting energy absorption (Figure 8b). Averagely, impacting energy was absorbed by PGF 39%, composition, D12/W45 22%, D12/W55 19%, D24/W45 28% and D24/W55 26%. That might be the consequence of reinforcement with short and tiny particles instead of long and strong fibers.

3.4. Hardness test

From statistical analysis, it was found that the hardness of the specimens at the corners was significantly lower than at the edge or in the mid plate (Figure 7) but not so affecting with PGF. This may result from the flow at the corner not so compromise as other positions. Though, the D12/W55 (the mix between smaller particle size and higher weight) gained a higher hardness than, and D12/W45 (the mix between smaller particle size and an identical weight of glass fiber), PGF resulted by the rigid and a numbers of particles spreading thoroughly over the work to absorbing the compression.
3.5. **SEM analysis**

The fracture surfaces of the specimen subjected to impact test were analyzed using SEM. Figure 8 presents the proof that particles of glass scraps trapped as expected in the space between the glass fabrics to reinforce the composite.

![SEM images](Image)

**Figure 9.** SEM photomicrographs of impact test fractured surfaces (70X).

Table 3 shows the summary of test results obtained by flexural, tensile, impact and hardness tests on polyester composites reinforced with pure glass fiber and glass scraps powder. The values shown in the table was averaged from the total numbers of all specimens in each type of tests. The point estimation in the table agreed well with the graphical and statistical analysis.

| Sample | Particles size of glass scraps powder (µm) | Weight of glass scraps powder (g/m²) | Flexural strength (MPa) | Tensile strength (MPa) | Impact Strength (kJ/mm²) | Hardness (Shore D) |
|--------|-------------------------------------------|-------------------------------------|-------------------------|------------------------|--------------------------|-------------------|
| PGF    | -                                         | -                                   | 121.52                  | 74.56                  | 106.85                   | 74.6              |
| D12/W45| 120                                       | 450                                 | 40.71                   | 53.79                  | 61.05                    | 75.7              |
| D12/W55| 120                                       | 550                                 | 72.90                   | 60.32                  | 53.56                    | 77.3              |
| D24/W45| 240                                       | 450                                 | 98.12                   | 53.28                  | 77.06                    | 71.0              |
| D24/W55| 240                                       | 550                                 | 101.38                  | 61.33                  | 70.92                    | 75.2              |
4. Conclusion

From the results and discussion, the conclusion can be made here.

- The resistance to bending, flexural strength, was maintained comparing to composite reinforced with pure glass fiber by composing the glass scraps powder size of 240 μm.
- Adding glass scraps powder weight of 450 g/m² decreased the tensile strength.
- Absorbed energy, impact strength, of the composite samples was reduced according with powder reinforcement as oppose to fiber strengthening.
- Hardness was increased through spreading of glass particles over the composite by increasing proportion of glass powder together with a refinement of particle size.
- Pictures from SEM shows that the powders of glass scraps were inserted in the gap of glass fibers.

References

[1] Araújo E M, Araújo K D, Pereira O D, Ribeiro P C and Melo T J A 2006 Fiberglass wastes/polyester resin composite: Mechanical properties and water sorption Polímeros: Ciência e Tecnol 16 pp 332–335

[2] Elahi A H M F, Hossain M M, Afrin S and Khan M A 2014 Study on the mechanical properties of glass fiber reinforced polyester composites Int. Conf. on Mechanical Industrial and Energy Engineering

[3] Cao Y and Cameron J 2006 Flexural and shear properties of silica particle modified glass fiber reinforced epoxy composite J. Reinf. Plast. Comp. 25 pp 347–359

[4] Cao Y and Cameron J 2006 Impact properties of silica particle modified glass fiber reinforced epoxy composite J. Reinf. Plast. Comp. 25 pp 761–769

[5] Performance Composites Inc Vacuum Infusion Process Guide Technical Information California USA http://www.performancecomposites.com

[6] Aramide F O, Atanda P O and Olorunniwo O O 2012 Mechanical properties of a polyester fiber glass composite International Journal of Composite Materials 2 pp 147–151