Steel fiber/polyethylene terephthalate composites

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Abstract

Currently, lightweight materials with high performance have been strongly needed to meet the requirements of advanced structural materials. One of the promising lightweight materials is the metals fiber reinforced plastic composite, which usually gives good specific strength and high toughness. However, de-bonding between metal fiber and plastic is the main problem in the production and utilization of the composite. Recently, Katayama, et., al studied the dissimilar materials joining between plastics and metals such as PET/SUS 304 and so on. The joint was succeeded with the reaction between the metal oxide and functional group in the molecule of the polymer. The possibility to join metal/plastic may provide the new approach to produce new design composites. Thus, the objective of the study is to investigate the feasibility to produce stainless steel fiber reinforced PET plastics composite (SFRP). In experiments, stainless steel mesh and PET sheet with 0.5 mm of thickness were used as materials to fabricate the SFRP composite. The hot pressing of sandwich stacks with inserted SUS304 wire mesh between two PET sheets was performed at 120°C. Results indicated that high strength composite without de-bonding could be obtained.

Keywords: Polyethylene terephthalate (PET), Stainless Steel grade 304 (SUS 304)

1. Introduction

Automotive part manufacturers have been challenged by new technologies concerned with manufacturing electric vehicles. In order to increase the distance of driving per charge, the application of lightweight materials to reduce the energy consumption rate of electric vehicles, is needed [1]. In the past 30 years ago, lightweight materials have been rapidly developed from high strength steel, to aluminum alloy, and then composites materials. Various composites materials have been developed based on using the difference of the raw materials used such as CFRP composites that are produced with carbon fiber and plastic. However, carbon fiber reinforced plastic provides low toughness, new fiber-reinforced plastic has been needed to be developed in order to improve toughness. The metal fiber-reinforced materials exhibit a 3 to 5 times higher elongation than typical continuous carbon and glass fiber composites and can therefore provide an answer to improve toughness [2-3]. However, the plastic matrix and metal reinforcement are difficult to bond. Therefore, after production, delamination between plastic matrix and metal fiber is easily found [4]. In order to solve the problem, using the compatibility
between steel fiber and plastic to make fiber reinforced plastic composites will provide the opportunity to obtain high quality materials. Katayama et al. [5] applied the laser bonding for stainless steel/PET composite fabrication. They succeeded in producing good bonding between stainless steel and PET by the reaction between a functional group in the molecule of the PET and the chromium oxide film on the stainless-steel surface. Therefore, in this work, new composites materials developed by using PET as a matrix, and stainless-steel as fiber have been studied in order to study the feasibility of producing new composites materials.

2. Materials and Methods

2.1 Materials
Stainless steel fiber reinforced plastic composite (SFRP) was produced from stainless steel meshes and polyethylene terephthalate (PET) plastic. The stainless-steel wire meshes as reinforced materials were cut to a size of 70x20 mm. For the plastic matrix, the polyethylene terephthalate (PET) sheets with the size of 60x190x0.5 mm were used. The material characteristic and their mechanical properties of both materials are expressed in Table 1.

| Materials        | Wire Ø (mm) | Opening (mm) | Maximum Load at 15 mm of the width of the specimen (N) |
|------------------|-------------|--------------|-----------------------------------------------------|
| PET              | -           | -            | 169                                                 |
| SUS304 mesh 60   | 0.15        | 271.0        | 485                                                 |
| SUS304 mesh 100  | 0.10        | 0.153        | 386                                                 |
| SUS304 mesh 200  | 0.055       | 0.432        | 314                                                 |

2.2 Experimental procedures
SFRP composites were produced by using the compression molding technique with the MODEL PR2D-W3tech00L350 PM-WCL machine as shown in Figure 1. The sandwich stack of stainless-steel mesh in the middle between the PET sheets was performed as shown in Figure 2. The compressive molding process was performed at a mold temperature of 120 OC, the pressure of 60 psi, and a curing time of 5 minutes. After curing, the mold was opened and the sandwich stack was cooled by dipping into the water.

![Figure 1. Compression Moulding machine](image1)

![Figure 2. Schematic of SFRP composites stack layer. (PET/SUS304 mesh /PET)](image2)
The integrity of SFRP composites was then investigated by visual inspection, macrostructure observation. The macrostructure observation of SFRP composite cross-section was performed under the stereo microscope and scanning electron microscopes (SEM). Moreover, SFRP composites were cut to the tensile specimens as shown in Figure 3. The tensile testing was performed by Instron 4505 with a crosshead moving speed of 2 mm/min. After tensile testing, the failure samples were characterized under SEM observation.

3. Results and discussion

3.1 Visual Inspection of SFRP composite

The visual inspection results of the SFRP composite samples with the different wire sizes of stainless-steel mesh were shown in Figure 4. Two layers of PET and stainless-steel mesh were perfectly welded into a single sheet of SFRP composites. The width at the end of all SFRP samples as indicated by the red dash line rectangular was wider than the width at the center of the SFRP sample. Moreover, in SFRP composites with #200 of stainless-steel wire mesh, the tearing of stainless-steel wire mesh was found at the edge of the sample as indicated in Figure 5. The tearing of stainless-steel wire at end of the SFRP sample was caused by that the pressing process was carried out with no constraint. Thus, in order to avoid such ending effect on the tensile test result, the tensile samples were cut only from the center of the SFRP composite sample.

Figure 4. The SFRP composites formed with different stainless-steel wire mesh sizes (a) SFRP SUS304 mesh 60 (b) SFRP SUS304 mesh 100 (c) SFRP SUS304 mesh 200

Figure 5. Defect on the sample SFRP with SUS304 mesh 200 composites.
3.2 Cross-sectional observations.
Figure 6 shows the cross-section observation of the SFRP composites reinforced with various stainless-steel mesh sizes. From Figure 6, it could be realized that the PET was fully filled into the gaps between the stainless-steel wire mesh. No porosity and gaps between the steel wire mesh and the PET matrix were found under optical microscope observation. However, at higher magnification observation of cross-section of SFRP composites, porosity, and PET unfilled in the hole between the stainless-steel wire mesh were observed as indicated in the dark spots in Figure 6. Although porosity and gaps were present, good bonding between PET stainless steel was achieved as realized in Figure 7(c), Figure 7(g), and Figure 7(j).

![Figure 6](image)

Figure 6. Macrostructure of a cross-section of the SFRP composites, difference stainless-steel wire mesh, (a) SFRP SUS304 mesh 60 (b) SFRP SUS304 mesh 100 (c) SFRP SUS304 mesh 200 composites.

![Figure 7](image)

Figure 7. Shows the cross-section of the SFRP composites by SEM.

3.3 Tensile testing
Figure 8 shows the maximum tensile resistance loads of SFRP composites with different mesh sizes and the theoretical maximum tensile resistance load of SFRP composites. The theoretical maximum tensile resistance loads of SFRP composites were calculated from the summation of maximum load capacity of
each material that were used to fabricate the SFRP composites. From Figure 8, the experimental maximum tensile resistance loads of the SFRP composites were better than that of the theoretical ones. Moreover, the maximum tensile load of SFRP composites decreased with the lower load capacity of stainless-steel wire mesh used as reinforcement. The elongation of SFRP with different stainless steel wire mesh was shown in Figure 9. It could be recognized that the SFRP composites were ductile materials due to high elongation. Using a larger stainless-steel wire mesh increased the elongation of the SFRP. Moreover, the overview of fracture specimens after the tensile test were shown in Figure 10. The stainless-steel wire was broken in the perpendicular direction to tensile loading. SEM micrographs as shown in Figure 11 reveal the ductile fracture of stainless-steel wire. Furthermore, the de-bonding of PET and stainless-steel wire after the tensile test was observed. Based on the above results, it could be inferred that new SFRP composites have good mechanical properties. Delamination of PET and stainless steel in the fracture samples occurred during tensile testing.

Figure 8. The Maximum tensile loading of SFRP in three different stainless-steel wire mesh sizes fiber in the PET matrix.

Figure 9. The % elongation at break of SFRP composites in three different stainless-steel wire mesh fiber size in the PET matrix.
Figure 10. Fracture surface of the SFRP composites, three different stainless-steel wire mesh fiber size in the PET matrix.

Figure 11. Fracture surfaces of the SFRP composites, (a, d) SFRP SUS304 mesh 60, (b, e) SFRP SUS304 mesh 100, (c, f) SFRP SUS304 mesh 200 composites by SEM.

4. Conclusion
According to the results, SFRP composites made by stainless steel wire mesh and PET were successfully produced by using a compressive molding process. Although some defects, such as porosities and no fill with PET, were found the mechanical properties of developed the SFRP composites were still better than that of raw materials. Moreover, good bonding between PET and stainless-steel wire mesh was achieved, after production. However, after the tensile test, de-bonding between the PET and the stainless-steel wire was still found. Ductile fracture of stainless-steel wire was also observed. The de-bonding between the PET and stainless steel after the tensile test will be possibly solved by refining the compressive molding process conditions in future work. Finally, it could be inferred that SFRP composites between PET and stainless steel are the potential candidate list as a new composite material used in lightweight structures.
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