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Improvement on Adhesion Properties of Insert Injection Molding Composites: Effect of Inserted Parts, Adhesive Lengths and Injection Conditions

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Abstract

The focus of this project is on the insert injection molding process, developed for merging similar or different materials by molding injected melted polymer around an inserted part and injecting in the molded cavity of the conventional injection molding machine. This method is ideal for attaching automotive parts without having to use bolts or adhesives. Glass fiber-reinforced polypropylene (GF/PP) with various adhesive lengths of 0 and 5 mm was prepared as the inserted part and injected to the mold. The effects of the inserted parts, adhesive lengths, and injection conditions on the adhesive properties were investigated. The strength of the interfacial adhesive between the insert and the injected polymer was measured by using an Intron Universal Testing machine. The effects of the material in the inserted and injected parts were analyzed. It was found that by increasing the binding area of the adhesive interface, the barrel temperature, and the mold temperature, the interfacial adhesive strength of the insert injection molded-part was improved in all tested specimens.

Keywords

Insert-Injection Molding, Adhesive Length, Adhesive Normal/Shear Load, Injection Molding Condition, Polypropylene Glass Fiber Composite

1. Introduction

Fiber-reinforced polymer composites (FRP) are widely applied to automotive and aircraft interior panels. They have overall excellent properties, particularly dimensional stability, elevated temperature, creep resistance and applications requiring heat resistance by injection molding [1]. Automotive parts are mostly bolt joining and using an adhesive. Insert-injection molding process is an advanced injection molding technology that uses dissimilar material to produce complex part [2] [3]. This unique manufacturing process combines metal and plastic, ceramics, or multiple combinations of materials, components and plastic into a single unit. The insert injection molding process is molded specimen by injecting melted polymer to the inserted part that placed in the injection molded cavity then an adhesive single bonding between the inserted part and the injected polymer [4] [5] [6]. Hence, the insert-injection molding is introduced for adhering automotive parts without using bolts or the adhesive. On the other hand, the insert-injection molding, also called two stages sequential insert molding, is the injection molding process using rigid substrate or the flexible material. The insert can either be incorporated at the time of the molding process or can be inserted as post molding operation. However, there is less information on the insert-injection molding process.

In this study, the insert injection molding was used in order to evaluate the interfacial adhesive property of the insert injection molding samples. GF/PP was applied as the inserted part with several adhesive lengths. The effects of the adhesive lengths and injection molding conditions on the adhesive properties of the insert-injection molded parts were characterized by tensile testing and morphology observations.

2. Experimental

2.1. Materials and Sample Preparation

The Dumbbell specimens were fabricated from 25 wt% glass fiber-reinforced polypropylene (GF/PP, GWH42, Sumitomo Chemical Co., Ltd.) by the injection molding process. GF/PP was fabricated to dumbbell specimens, which had dimensions of 150 × 10 × 3.5 mm according to ASTM standard D638 by injection molding (TOYO MACHINERY & METAL CO., Ltd., TI-30F6, Japan). The barrel temperature was set at 200˚C - 230˚C. The dumbbell specimens were cut into a half dumbbell shape as the inserted part. Then, the inserted parts were prepared by polishing with sand paper at (grit number R220) in order to achieve the different length of the adhesive interface of 0 and 5 mm before insert injection molding, as shown in **Figure 1**. **Table 1** summarizes the length of bonding area and processing conditions for the insert-injection molded specimens.

The inserted part was placed into the mold cavity before starting the injection molding machine (TOYO MACHINERY & METAL CO., Ltd., TI-30F6, Japan) and forming the insert injection molded dumbbell specimens. The barrel temperature was set at 200, 230, and 260˚C and the mold temperature at the nozzle was set at 40˚C and 80˚C. The holding pressure and cooling time were 20 MPa and 20 s, respectively **Figure 2** and **Figure 3** show photographs of the insert-injection molded at various adhesive lengths and various inserted and injected parts with a front view and a side view.

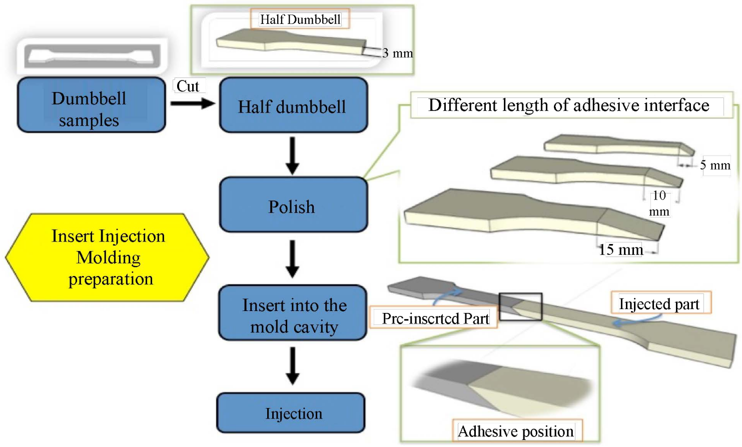

Figure 1. Preparation of the insert-injection molded.

Figure 2. Photographs of the insert-injection molded (front view).

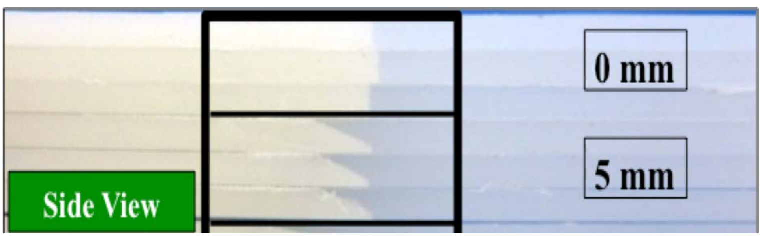

Figure 3. Photographs of the insert-injection molded (side view).

2.2. Characterization

Tensile test was carried out by using Instron universal testing machine (Instron model 4206) at 115 mm of grip distance with testing speed of 1 mm/min.

Tensile strength of was calculated by following equation.

$$\sigma = L/A \tag{1}$$

where L is a load; A is a cross sectional area of the specimen; σ is a tensile stress.

Morphology of fractured surface of the insert-injection molding specimens

Table 1. Specimen designation.

Code	Length of adhesive interface (mm)	Mold temperature (˚C)	Barrel temperature (˚C)
0-40-200			200
0-40-230	0	40	230
0-40-260			260
0-80-200			200
0-80-230	0	80	230
0-80-260			260
5-40-200			200
5-40-230	5	40	230
5-40-260			260
5-80-200			200
5-80-230	5	80	230
5-80-260			260

was observed by scanning electron microscopy (SEM) (JSM 5200, JEOL).

3. Results and Discussion

3.1. Effect of Length of Adhesive Interface on the Adhesive Properties

Figure 4 presents the load-displacements of insert injection of all specimens significant increased when increased the length of the adhesive interface. As a comparison for alternative insert molding between high barrel temperature and low barrel temperature, the maximum load of high barrel temperature was higher than that of low barrel temperature as shown in Figure 4, It was considered that high barrel temperature of insert injection molding was better adhered with injected high barrel temperature, which yielded a good mechanical interlocking between the interface of the inserted part and the injected part. In addition, the increment of the high mold temperature showed an improvement in the maximum load resulting in better adhesive property of this molding when compared with the low mold temperature.

Figure 5 illustrates tensile strength of the insert injection molded of all specimens as function of the lengths of adhesive interface. Tensile strength of the insert-injection molded specimens significantly increased with increasing the length of adhesive interface, which was due to higher interfacial adhesion between the inserted part and the injected part as well as the higher load to break either the inserted part or injected polymer.

The inserted part and the injected material were broken at the adhesive interface. It can be noted that all injected material presented as a melted polymer like an adhesive resin. Higher values in maximum load as well as in tensile strength were considering as good adhesive strength between the inserted part and the injected part.

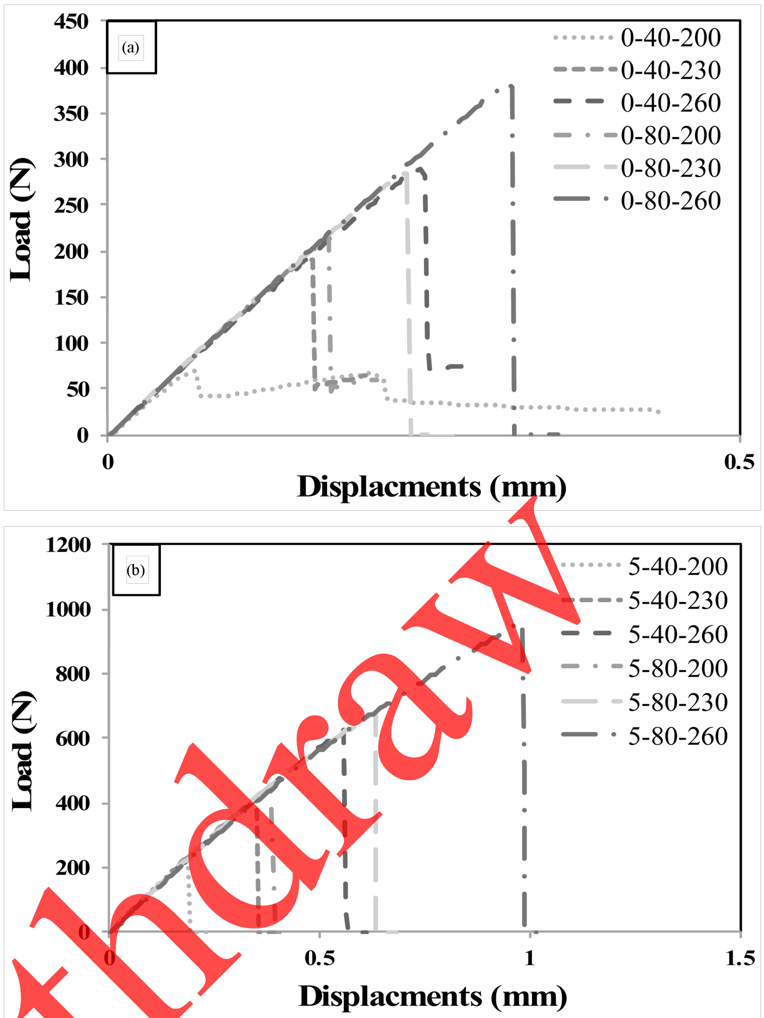

Figure 4. Load-displacement curves of adhesive samples at different barrel and mold temperatures. (a) Adhesive length 0 mm; (b) Adhesive length 5 mm.

3.2. Adhesive Normal Load and Adhesive Shear Load

In fact, both shear effect and stretch effect exist in the interface of the adhesive dumbbell samples and the schematic of load analysis in the adhesive interface is shown in Figure 6. The adhesive normal stress and the adhesive shear stress can be calculated by following equations:

$$\sigma_{\text{insert}} = L_N / \text{Area} \tag{2}$$

$$t_{\text{insert}} = L_S / \text{Area} \tag{3}$$

L_N and L_S are the adhesive normal stress and adhesive shear stress, respectively as shown in Figure 6. Adhesive normal stress and adhesive shear stress were divided by the cross-sectional area of the specimens to obtain the adhesive normal stress and adhesive shear stress of the insert injection molded specimens.

Figure 7 presents the adhesive shear load increase significantly with increase length of adhesive length. It can be seen that the adhesive normal load and adhe-

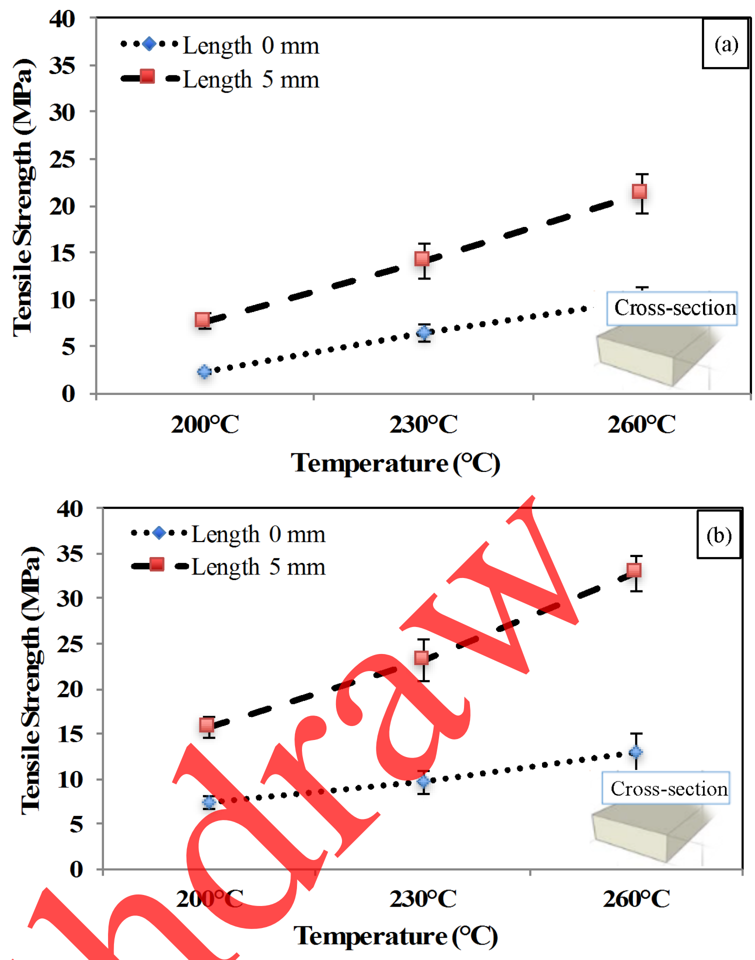

Figure 5. Tensile strength of adhesive interface. (a) Mold Temperature 40˚C; (b) Mold Temperature 80˚C.

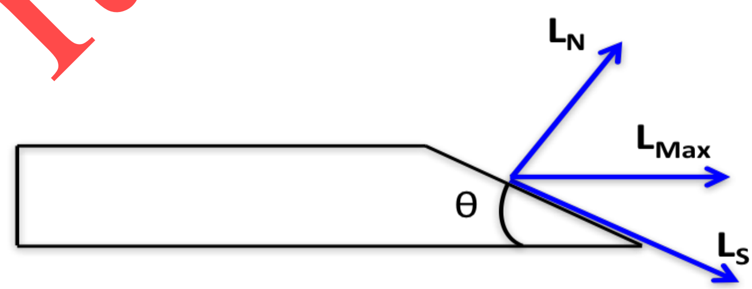

Figure 6. The schematic of load analysis in the adhesive interface.

sive shear loads also increased with increasing barrel temperature. At higher temperatures, a better interface adhesion is obtained. It can be noted that the specimens molded with a barrel temperature of 260˚C and mold temperature 80˚C have the highest values, due to greater interaction and adhesion of the inserted part and the injected resin.

3.3. Adhesive Normal Load

In this study, we focused on an adhesive length of 0 mm, where the adhesive

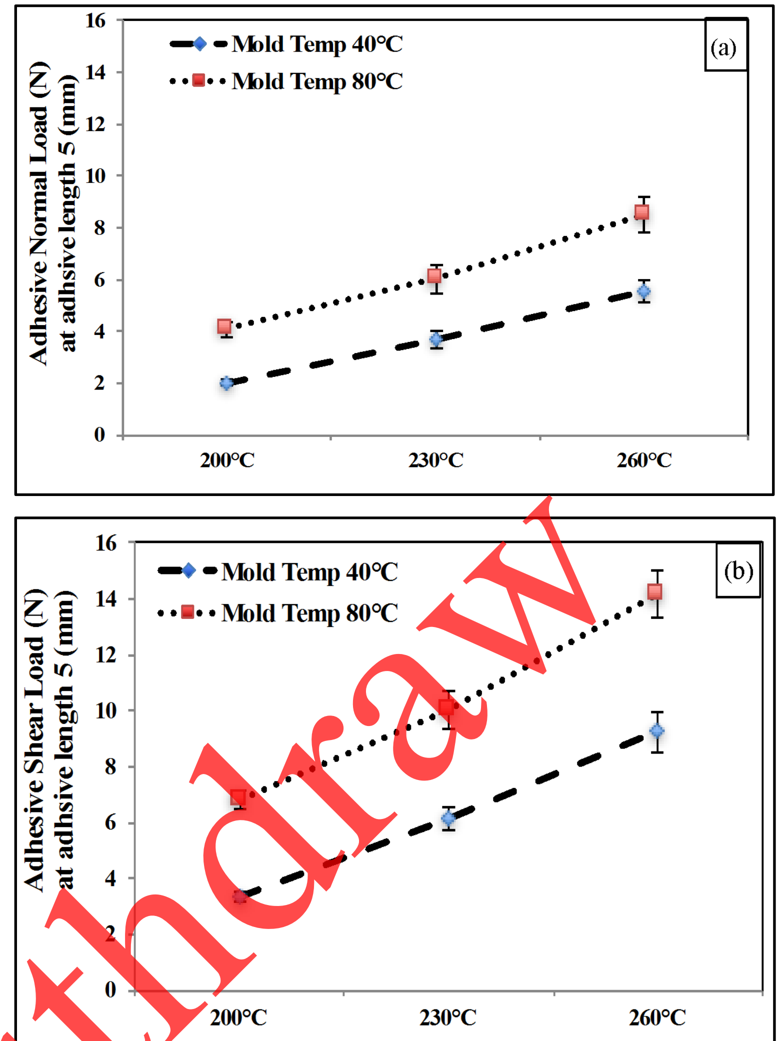

Figure 7. Adhesive normal load and adhesive shear load at different length of adhesive interface. (a) Adhesive normal load; (b) Adhesive shear load.

normal load is considered as the interfacial strength (tensile strength of the adhesive part) without the effect of adhesive shear load. The results are shown Figure 8, It can be seen that the adhesive normal load with the barrel temperature of 260˚C and mold temperature of 80˚C show the highest values. On the contrary, fracture characteristics of the specimens reveal that fracture originated at the adhesive interface, and later extended into either the injected or inserted part.

3.4. Morphology of Inserted Injection Molded

The fracture surface specimens were observed by scanning electron microscope (JEOL, JSM 5200). Figure 9 presents SEM photographs of the fractured surface morphology of inserted part from the insert-injection molded specimen before molding and after tensile testing. Figure 9(a), the inset surface roughness before insert-injection molding. Figure 9(b) and Figure 9(c), reveals the surface mor phology between barrel temperature 200˚C and barrel temperature 260˚C (L =

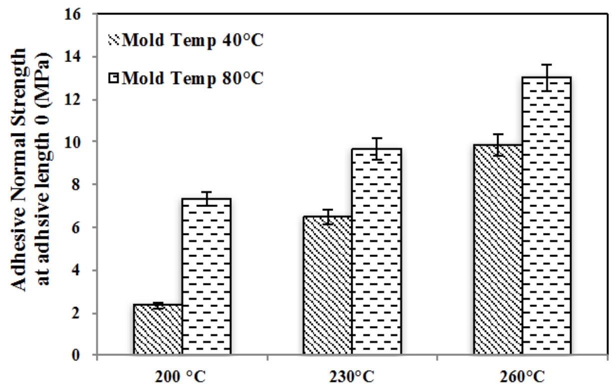

Figure 8. Adhesive normal strength (adhesive length 0 mm).

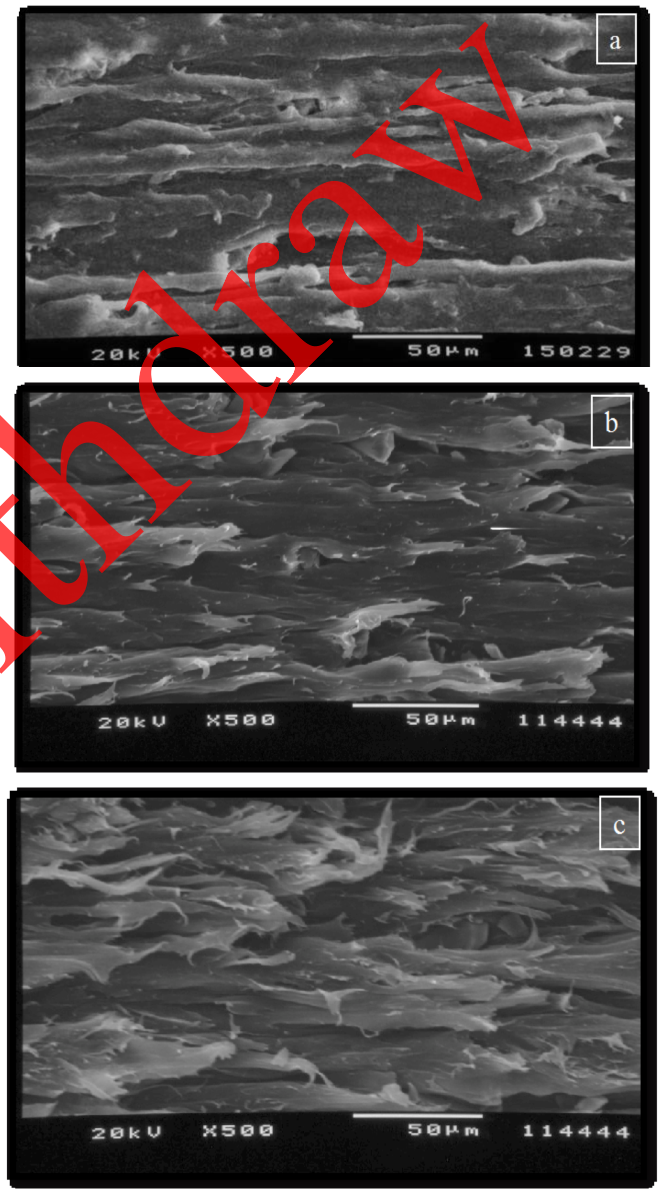

Figure 9. SEM photographs of tensile fractured surface of insert-injection molded parts. (a) Insert part before molding; (b) Barrel temperature 200˚C; (c) Barrel temperature 260˚C.

0) mm, respectively. Barrel temperatures of 200˚C and 260˚C, and differences in the GF/PP surface roughness are observed. A rougher surface (more surface damage) can be seen at a barrel temperature of 260˚C compared to 200˚C. The images show that a high barrel and high mold temperature is more efficient for producing good adhesion between the interfaces when compared with a low barrel temperature as shown in **Figure 9(c)**. It can be indicated that the insert with high barrel temperature was more efficiency for performing adhesion between the interfaces of the injected part and the inserted part as compared to low barrel temperature as shown in **Figure 9(c)**.

4. Conclusions

The effect of different length of adhesive interface, the injection molding conditions and couple of insert/injection parts on the adhesive property of the insert-injection molded can be summarized as the following:

1) The maximum load of insert injection molding specimens significantly increased when increasing the length of adhesive interface.

2) The high mold temperature of the inserted part shows better adhesive property results when compared with the high mold temperature.

3) Higher barrel temperature of the molding exhibited a great result of adhesive property and adhesive load of the specimens.

4) The highest interfacial strength (tensile strength between the adhesive parts) was found in the specimens with a high barrel temperature and high mold temperature.

5) The higher values of maximum load and tensile stress of the insert-injection molded would inform the better in adhesion property of the specimen.

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