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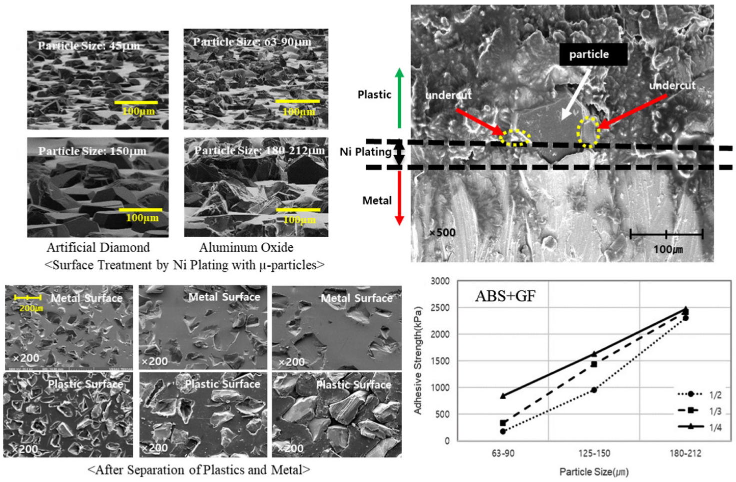
The irregular embossing of the metal surface was completed by nickel plating using micro particles of artificial diamond and aluminum oxide to improve the adhesive strength between metal and acrylonitrile butadiene styrene (ABS) resin. During insert molding, the resin solidified in the undercut area, which increased the adhesive force. As the undercut size was different depending on the plating height and particle size, the adhesive strength varied, and as the particle size increased, the adhesive strength increased.



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Adhesive Strength Between Metal Sheet Plated Using Micro Particles and ABS Resin

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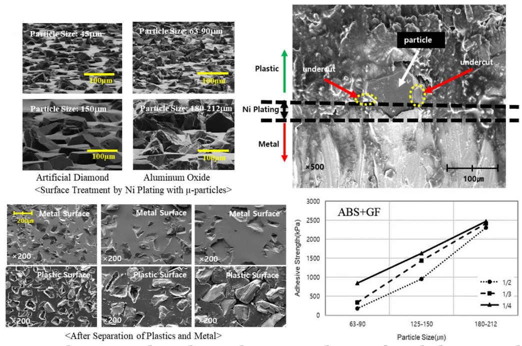
Abstract: To improve the adhesive strength between metal and acrylonitrile butadiene styrene (ABS) resin, a metal surface was embossed with an irregular shape, and then we studied the bonding between different materials by insert molding. The irregular embossing of the metal surface was completed by nickel plating using micro particles of artificial diamond and aluminum oxide. Particles of various sizes were used, and the plating height was set at 1/2, 1/3, and 1/4 of the particle size. When the embossed surface was implemented on the metal surface through the particles, an undercut area was formed on the metal surface. During insert molding, the resin solidified in the undercut area, which increased the adhesive force. As the undercut size was different depending on the plating height and particle size, the adhesive strength varied, and as the particle size increased, the adhesive strength increased. The adhesion strength was higher in the plated specimens using aluminum oxide particles than those with artificial diamond particles. Moreover, the adhesive strength was better with ABS resin containing glass fiber than with pure ABS resin.



Keywords: adhesive strength, metal insert molding, metal surface treatment, nickel plating height, artificial diamond particle, aluminum oxide particle.

1. Introduction

Recently, many studies on product weight reduction have been conducted for energy efficiency, focusing on the manufacturing method.[1-3] In particular, plastic materials are lighter than metals, so they can lower the weight of products, which has great advantages in product development.[4-7] However, plastics have poor mechanical properties such as strength, stiffness, and hardness compared to metal materials. To compensate for this, glass fibers or carbon fibers are added to plastics to improve their mechanical properties. In addition, by assembling or bonding plastic materials and parts with different physical and chemical properties, it is possible to realize weight reduction of products through a hybrid system.[8-10] When the plastics and metal materials are bonded with an adhesive or by welding, a chemical bond is not formed and the bonding strength is weak.[11] In order to compensate for these shortcomings, research on insert molding in which thermoplastic resin is injected and bonded to metal materials is being conducted.[12-14] Insert molding has a great advantage in bonding different materials based on the same productivity as conventional injection molding. This method can be applied to various products in which plastics and metal materials are bonded, such as home appliances, interiors and exteriors of automobiles, *etc.*[15,16]

Figure 1 schematically shows the process of combining different materials by insert molding after treating the metal surface by a conventional physical method. In the process of insert molding, a metal sheet is blanked, formed, and then an adhesive is applied to it and the product is injection molded after the metal is inserted in the cavity.[17] The nature of the interface between the plastic and metal is an important factor in insert molding.[18,19] In order to increase adhesion, insert molding may be performed after an adhesive is applied to the interface. In many cases, a high-temperature polymer resin melts the adhesive component, so that adhesion performance is not greatly improved.[8,20] There are studies that analyze the adhesive strength by making a metal surface in various forms without using an adhesive and performing insert molding.[13,14]

In this study, we used insert molding to study the bonding of metal and plastic, which we confirmed to be an improved method over previous studies. We produced a metal with new surface characteristics by dispersing micro-sized particles while electroplating nickel on the metal surface. After that, ABS resin was injected by insert molding and then we measured the adhesive strength between the metal and plastic. The type and size of the microparticles and the height of the plating layer relative to the size of the particles are factors that affect the adhesive strength. Adding glass fiber (GF) to ABS resin, we also investigated the effect of glass fiber on adhesive strength.

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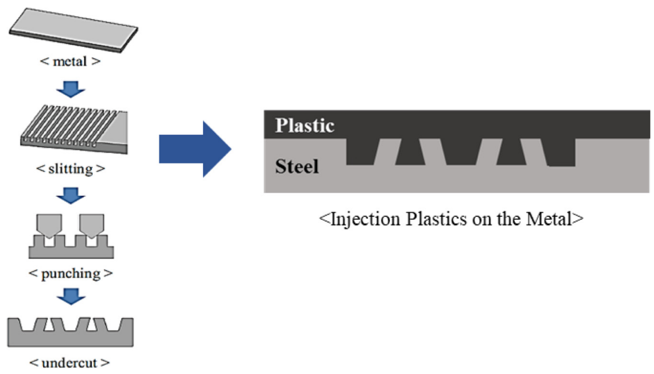


Figure 1. Bonding plastic and metal with insert molding.

2. Experimental

2.1. Experiment method

After fixing the surface treated metal sheet in the cavity of the mold, the mold was closed and a molten plastic resin was injected onto the metal sheet. After the molding was completed, the adhesive strength of the specimen to which the two materials were bonded was measured through a tensile test.

To improve the bonding between the metal sheet and the plastic resin, we applied a special treatment to the surface of the metal sheet. The purpose of the special surface treatment was to disperse microparticles during nickel plating on the metal sheet. During the nickel plating on the surface of the metal sheet, the micro particles embedded in the plating layer form an embossed protrusion on the metal surface, thereby enhancing the adhesive strength with the plastic resin.[14,21,22] The adhesive strength between the metal and plastic was analyzed by controlling the type and size of particles and the plating height.

2.2. Materials

The resin used in this study was ABS (STAREX HG-780, supplied by Cheil Industries Inc.) and the ABS resin contained 30 wt% of glass fiber (STAREX GR-4030, supplied by Cheil Industries Inc.). The metal sheet specimen was a Steel Use Stainless (SUS) sheet with a thickness of 0.4 mm.

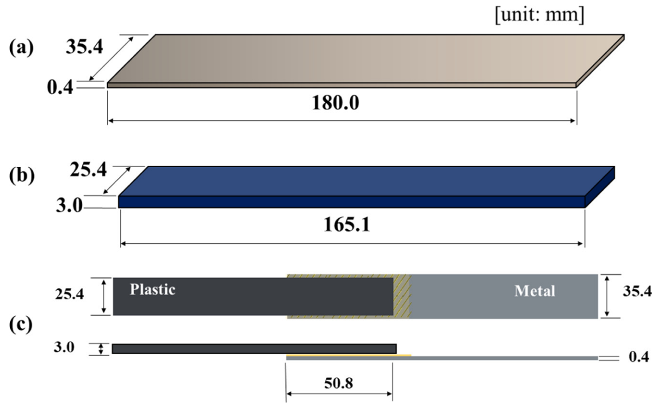


Figure 2. Specimen for metal-plastic adhesion test. (a) Surface treated metal sheet to be inserted into a cavity, (b) plastic shape to be injected, and (c) overall shape of insert molded tensile specimen for lab-shear test.

2.3. Preparation of tensile specimen

To measure the adhesive strength between the metal and plastic, we used a specimen of ASTM D1002 standard. Figure 2 shows the metal sheet with an embossed surface for bonding to plastic and a metal-plastic bonded specimen made by insert molding. The surface of the metal specimen as shown in Figure 2(a) was plated with nickel using micro particles, and the ABS resin was injected on it in the shape shown in Figure 2(b). The final specimen molded by insert molding is shown in Figure 2(c). The area where the two materials are bonded is 25.4 mm in width and 50.8 mm in length.

2.4. Surface treatment of metal sheet

The surface treatment method of the metal sheet used in this study was nickel electroplating. The process of plating on a metal sheet is schematically shown in Figure 3. To proceed with the plating, the metal specimen was first dipped in a 1.3 wt% NaOH solution at 45 °C for 1 minute, and then in a 35% HCl solution at 20 °C to remove oil. Subsequently, the metal specimen was dipped in a solution containing $NiSO_4$, $NiCl_2$, and H_3BO_3, and after spraying the particles to be treated with the embossed surface in the solution, plating was performed.

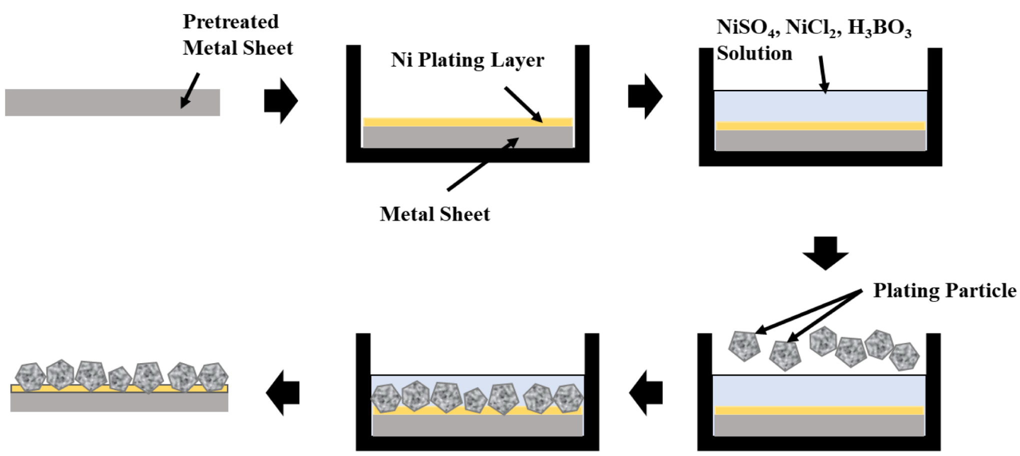


Figure 3. Schematic drawing of plating process using micro particles.

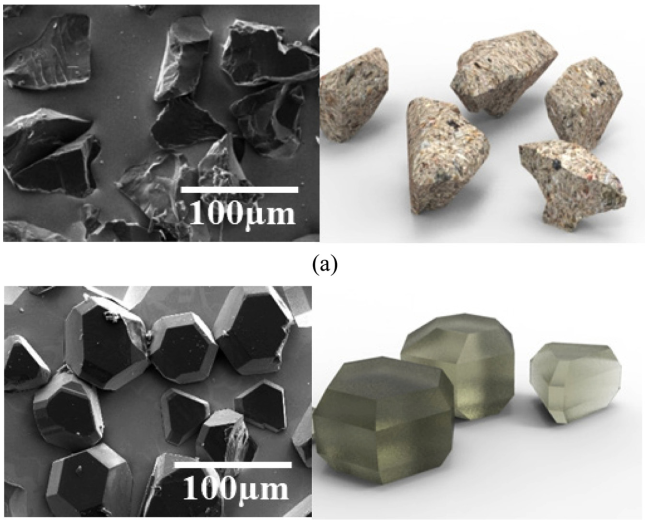


Figure 4. Particles used in the experiment. (a) Artificial diamond and (b) aluminum oxide.

The particles used together for plating were micro-sized artificial diamond and aluminum oxide. For this study we used the following principles. When metal is precipitated during the electroplating process, foreign substances in the solution are mixed and plated together on the metal surface. Particles sprayed on the metal surface in the nickel plating bath stick together when nickel is plated on the metal surface and form an embossed metal surface. Because the height of the plating layer is lower than the particle size, particles appear to rise above the plating layer. The shapes of the two particles mentioned above were realized through 3D modeling and are shown in Figure 4. The plating height (H) for each particle was adjusted as shown in Figure 5. Tables 1 and 2 show the particle size and plating height used in the experiment. For artificial diamond, particles of 45, 106, and 150 μm were used, and for aluminum oxide, particles of 63-90 μm (mesh #180), 125-150 μm (mesh #100), 180-212 μm (mesh #80) were used. The plating height was set to 1/2, 1/3, and 1/4 of the particle size.

Table 1. Particle size and plating height for treating metal surfaces with artificial diamond particles

Particle	Polymer	Plating height[a]	Patricle size (μm)
Artificial diamond	ABS	1/2	45
			106
			150
		1/3	45
			106
			150
		1/4	45
			106
			150
	ABS+GF (30%)	1/2	45
			106
			150
		1/3	45
			106
			150
		1/4	45
			106
			150

[a]Plating height: Relative ratio to particle size.

Table 2. Particle size and plating height for treating metal surfaces with aluminum oxide particles

Particle	Polymer	Plating height[a]	Patricle size (μm)
Aluminum oxide	ABS	1/2	63-90
			125-150
			180-212
		1/3	63-90
			125-150
			180-212
		1/4	63-90
			125-150
			180-212
	ABS+GF (30%)	1/2	63-90
			125-150
			180-212
		1/3	63-90
			125-150
			180-212
		1/4	63-90
			125-150
			180-212

[a]Plating height: Relative ratio to particle size.

Figure 6 shows the shape of the plated surface using artificial diamond and aluminum oxide particles of various particle sizes on the surface of a metal sheet. It can be seen that the particles are embedded in the plating layer so that the surface irregularly protrudes and a rough surface is formed by the particles. The larger the particle, the rougher the surface looks.

2.5. Insert molding condition

Using the surface treated metal sheet, a tensile specimen for testing adhesive strength between the metal and plastic was prepared by insert molding. Figure 7 shows the molding conditions for the insert molding. Filling was set at 4 levels of speed and packing was set at 3 levels of pressure. The injection molding machine used in this study was an 80 ton injection molding machine (TE110, Woojin Plaim). The injection temperature was set to 260 °C, the mold temperature was set to 80 °C by installing a cartridge heater on the stationary side and room temperature on the movable side.

2.6. Tensile test

A tensile test was performed to measure the adhesive strength of the specimen bonded with metal and plastic made by insert molding. Figure 8 shows the tensile test for measuring the adhesive strength of the specimen bonded with different materials. The tensile tester used in this study was EZ20 (AMETEK Sensors,

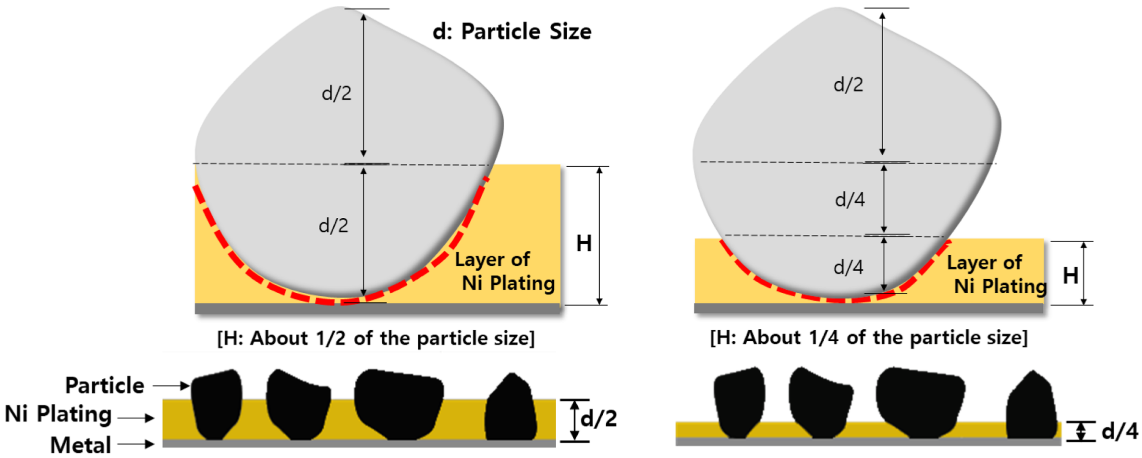


Figure 5. Metal sheet surface shape according to plating height.

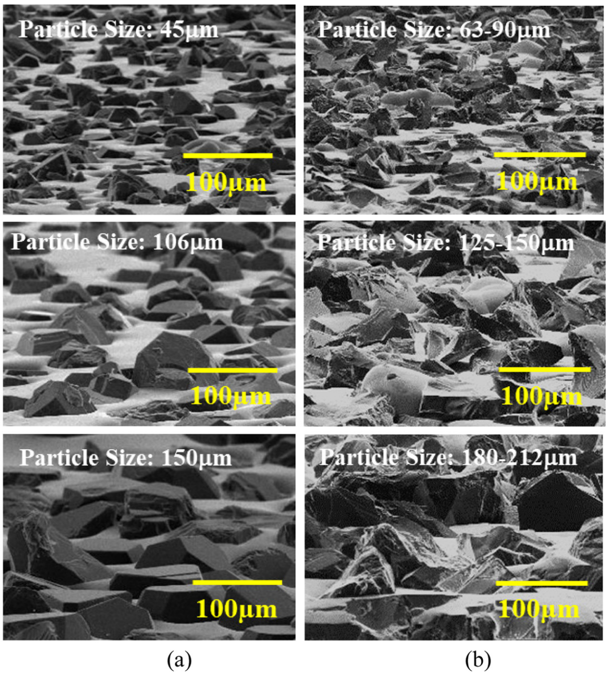


Figure 6. SEM images of the metal surface treated by plating using micro particles (× 500 view). (a) Artificial diamond and (b) aluminum oxide.

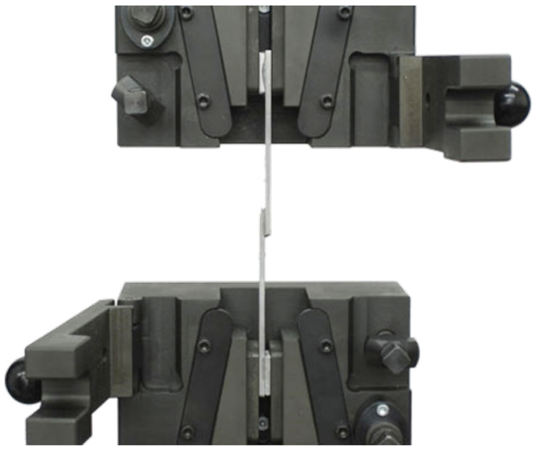


Figure 8. Tensile test for measuring the adhesive strength of metal sheet and plastic bonded specimen.

Test & Calibration). The tensile speed was set to 1 mm/min, and the tensile force was measured while stretching until the bonding surface was separated. The adhesive strength was calculated by dividing the measured maximum tensile force by the area of the surface (25.4 mm by 50.8 mm) where the metal sheet and plastic were bonded.

3. Results and discussion

3.1. Adhesive strength of specimens surface-treated with artificial diamond

A specimen was fabricated by over-molding ABS resin by insert

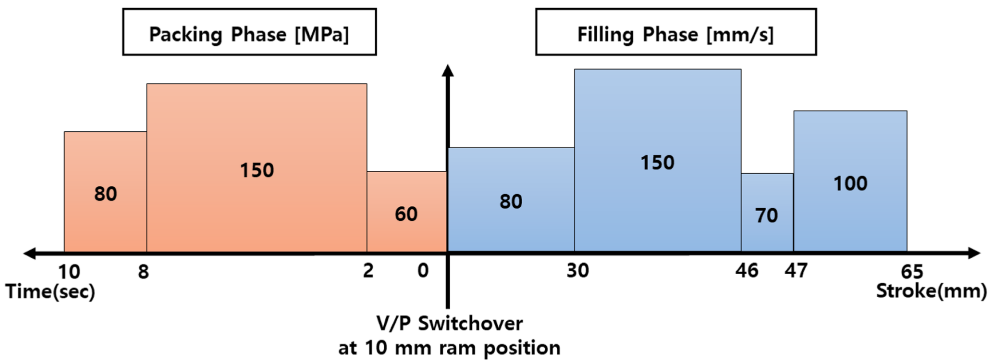


Figure 7. Metal insert molding conditions.

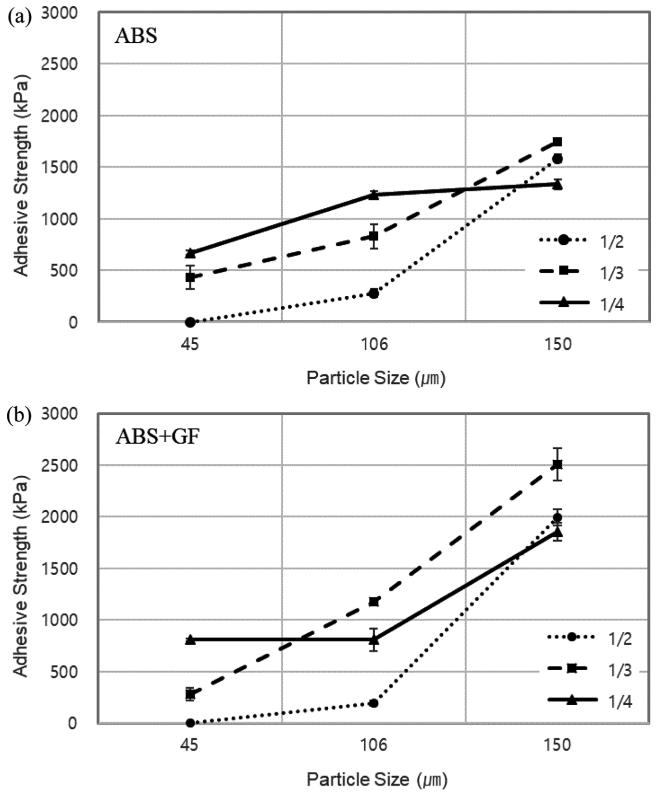


Figure 9. Adhesive strength of the metal sheet surface-treated with artificial diamond particles and the ABS resin bonded specimen according to particle size and plating height. (a) ABS and (b) ABS+GF (30%).

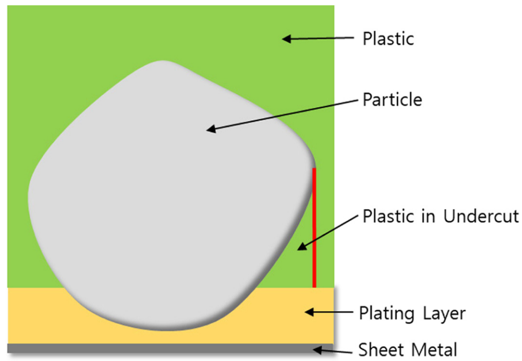


Figure 10. Schematic drawing of solidified plastic in the undercut area between the surface of the plating layer and the particles.

molding to a metal sheet that was embossed by plating using artificial diamond particles on the surface. Figure 9 shows the results of the adhesive strength of the metal sheet and the ABS resin bonded specimen. When the metal sheet was not subjected to surface treatment, ABS and metal sheet were not bonded by insert molding. In the case of pure ABS resin (Figure 9(a)), as the size of the artificial diamond particles increased at all plating heights, the adhesive strength increased. When the particle size was small (45 μm, 106 μm) and the plating height was 1/4 of the particle size, the adhesive strength was greater than that when the plating height was 1/2 and 1/3 of the particle size. However, when the particle size was as large as 150 μm, the adhesive strength was lower when the plating height was 1/4 of the particle size than when plated with 1/2 and 1/3 of the particle size. In other words, the lower the plating height, the greater the adhesion strength. However exceptionally, when the particle size was 150 μm, the lowest adhesive strength was shown when the plating height was the lowest. When the plating height was low, a large undercut shape formed between the plating surface and the particles. In addition, as the size of the particle increased, the area of the undercut increased proportionally, so the larger the particle size and the lower the plating height, the greater the adhesive strength.

Figure 10 schematically shows the layers of metal, plating, particles, and plastic resin. A space formed from the surface of the plating layer to the largest width of the particle. This space was undercut and the resin was solidified in it, acting as an anchor, showing great adhesion between the metal and plastic. When the particle size was 45 μm and the plating height was 1/2 of the particle size, adhesion was not well made and the adhesive strength was not detected. It appeared that the undercut was not formed and showed weak bonding strength. When the particle size was 150 μm and the plating height was 1/4 of the particle size, the undercut formed the largest, and the resin was deeply filled in the undercut area to be firmly bonded. In this situation, when shear force was applied, the particles separated from the plating layer rather than the particles being separated from the resin, resulting in a phenomenon in which the

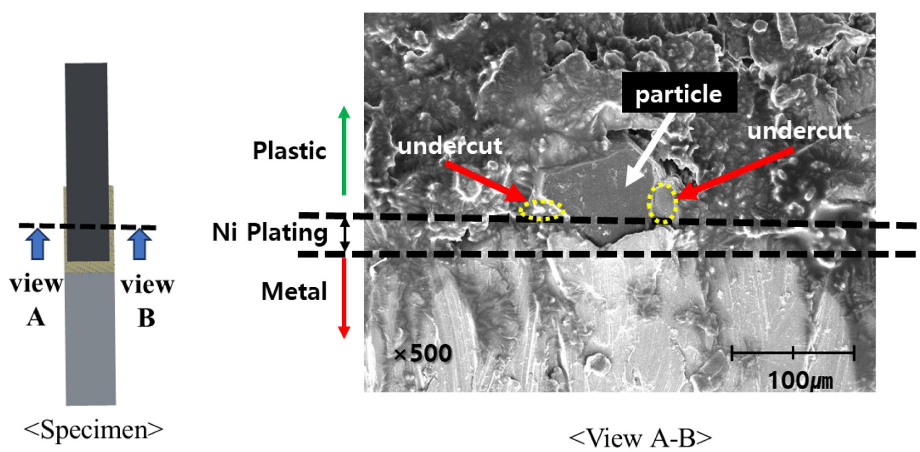
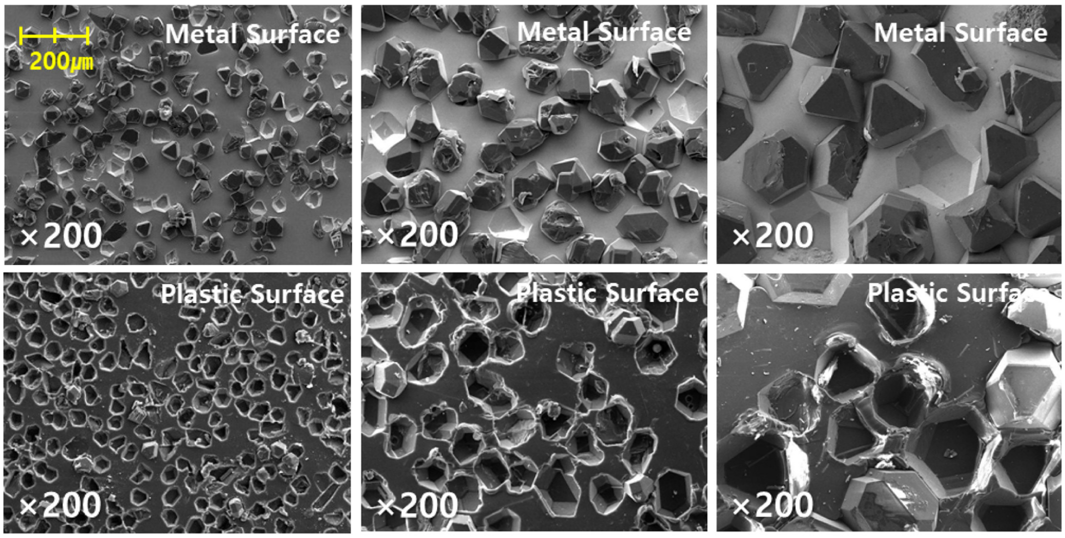


Figure 11. SEM images of cross section of tensile specimen showing plastic and metal (× 500 view).

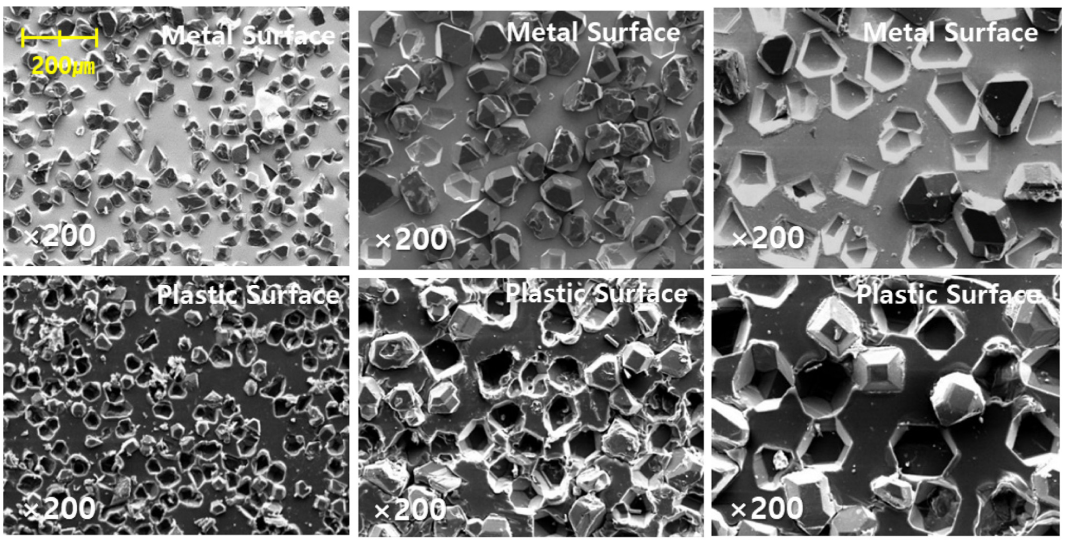
adhesive strength was decreased. There is an appropriate plating height depending on the size of the particles. Figure 11 shows the cross section of a specimen made by insert molding using a metal sheet plated to a height of 1/4 of the particle size. It can be seen that the undercut formed by the plated particles is filled with resin, forming a bond between the metal and plastic.

Figure 9(b) shows the adhesive strength of the specimen insert molded with ABS resin containing 30 wt% GF. It was the same as the ABS that did not contain GF: the larger the particle size, the greater the adhesive strength. When the particle size was 150 μm, ABS containing GF had greater adhesive strength than ABS containing no GF. Regardless of the size of the particles, the adhesion strength was greater when the plating height was 1/3 that when the plating height was 1/2 of the particle size. Looking at the case where the plating height was the lowest, 1/4 of the particle, the adhesive strength was greater than other plating heights when the particles were small, that is, 45 μm. However, when the particle size increased to 106 μm, the adhesive strength was less than 1/3 of the plating height. And, when the particle size was 150 μm, the adhesive strength was smaller than that of other plating heights. When the plating height was 1/4 of the particle size, for a large particle size, the undercut area was large and GF also helped the anchor role, so the adhesion between the particles and the resin was strong. In this environment, when a large external force was applied, that the particles were separated from the plating layer before the resin was separated from the particles plated on the metal. The low plating height allowed the resin to adhere well, but the low plating height provided that the particles were more easily separated from the plating layer. When the particle size was 150μm, it exhibited



(a) (b) (c)

Figure 12. SEM images of separated surfaces after the tensile test when the plating height is 1/2 of the artificial diamond particles for 30 wt% GF contained ABS (× 200 view). (a) 45 μm particle size, (b) 106 μm particle size, and (c) 150 μm particle size.



(a) (b) (c)

Figure 13. SEM images of separated surfaces after the tensile test when the plating height is 1/3 of the artificial diamond particles for 30 wt% GF contained ABS (× 200 view). (a) 45 μm particle size, (b) 106 μm particle size, and (c) 150 μm particle size.

great adhesive strength as in ABS that did not contain GF, and when the height of the plating was 1/3, it possessed the greatest adhesive strength.

Figures 12, 13, and 14 show the separated surfaces of metal and plastic after the tensile test. When the plating height is 1/2 of the particle size (Figure 12), it can be seen that most of the particles are separated from the plastic and attached to the metal surface. This shows that the particles are cleanly separated from the plastic surface, which is why the adhesive strength is low. When the particle size is 150 μm, the particles adhere to the metal surface of a relatively small area compared to the small size particles, by which we inferred that the adhesion between the plastic and the particles worked somewhat strongly. When the plating height is 1/3 of the particle size (Figure 13), the marks where the particles are separated from the plastic surface appear rough. Here we assume that the adhesion between the plastic and the particles was strong. When the particle size is 45 μm and 106 μm, most of the particles are attached to the metal surface. However when the particle size is 150 μm, many particles are attached to the plastic surface, which shows that the bond between the particles and the plastic is very strong. When the plating height is 1/4 of the particle size (Figure 14), most of the particles are attached to the plastic surface. We considered that the particles are thinly embedded in the plating layer and thus easily separated from the metal surface. Even if the particles are easily separated from the plating layer, the adhesive strength is not high. When the particles are 150 μm, it can be seen that the particles are coarsely separated from the metal surface and the plastic surface, which is different compared to the particles of 45 μm and 106 μm. In this case, the adhesive strength was measured to be high.

3.2. Adhesive strength of specimens surface-treated with aluminum oxide

Figure 15(a) is the result of the adhesive strength test of pure ABS resin and a metal surface treated by plating with aluminum oxide. In the case of plating embossed with aluminum oxide particles, as in the case of artificial diamond particles, the adhesive strength increased as the particle size increased. Plating with aluminum oxide particles generally shows greater adhesive strength than plating with artificial diamond particles because the surface of the aluminum oxide particles is rougher than with artificial diamond particles as shown in Figure 4. Thus, the contact area with the resin is large. When the plating height is 1/2

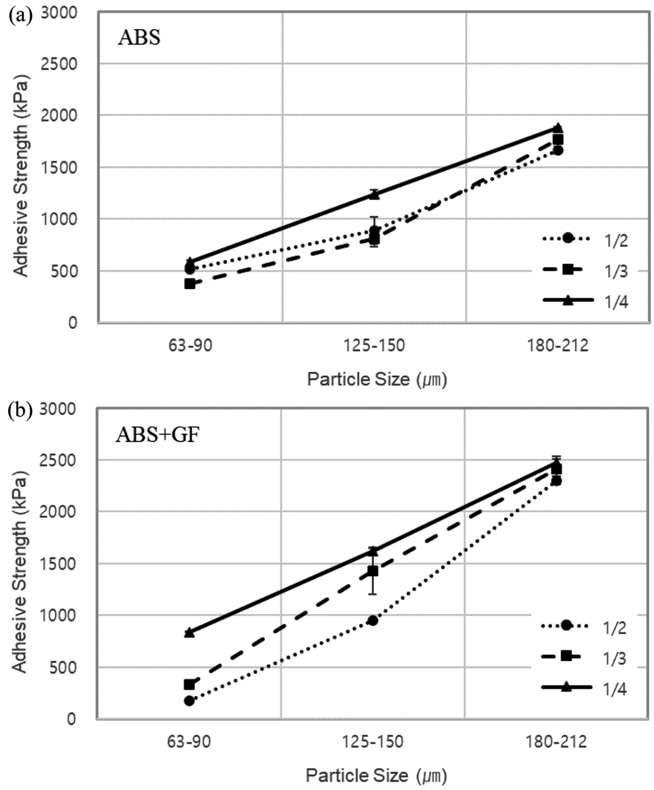


Figure 15. Adhesive strength of the metal sheet surface-treated with aluminum oxide and the ABS resin bonded specimen according to particle size and plating height. (a) ABS and (b) ABS+GF (30 wt%).

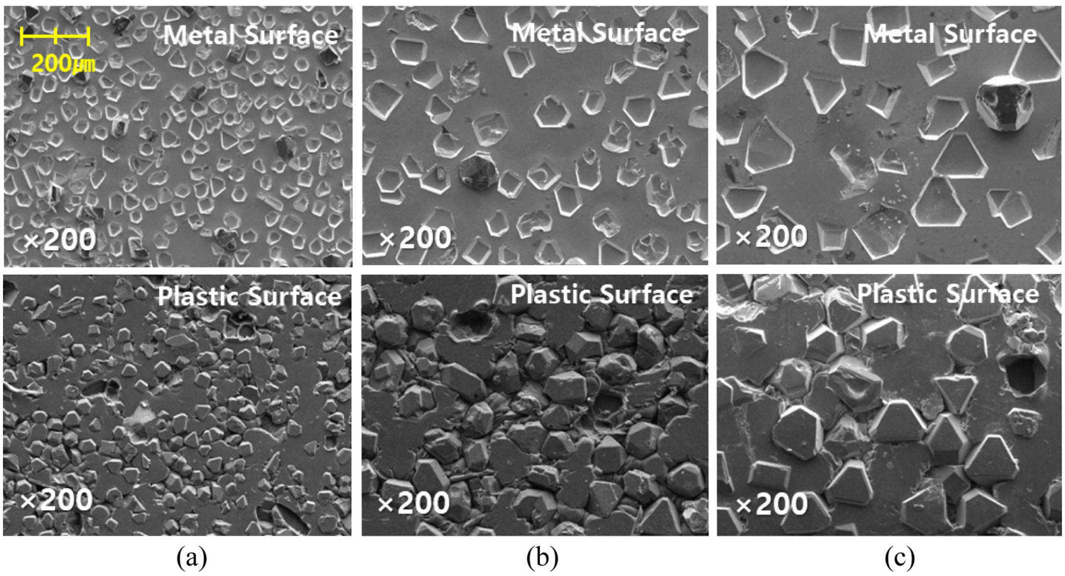


Figure 14. SEM images of separated surfaces after the tensile test when the plating height is 1/4 of the artificial diamond particles for 30 wt% GF contained ABS (× 200 view). (a) 45 μm particle size, (b) 106 μm particle size, and (c) 150 μm particle size.

and 1/3 of the particle size, there is no significant difference in the adhesive strength, but when the plating height is 1/4 of the particle size, the adhesive strength is greatly increased. We considered that when the plating height is low, an appropriate undercut is formed between the surface of the plating layer and the particles, and after the resin is solidified therein, it acts as an anchor and the adhesive strength becomes significant.

Figure 15(b) shows the adhesive strength between ABS resin containing 30 wt% of GF and metal sheet plated with aluminum oxide. Overall, it shows greater adhesive strength than pure ABS resins that do not contain GF. We believe that GF in the resin acts as a barb to prevent separation from the metal surface when shear force is present. However, when the particle size is small at 63~90 μm, the adhesive strength is lower than that of pure ABS resin at 1/2 and 1/3 of the plating height. We believe that this was caused by insufficient undercut, and GF prevented resin from flowing into the narrow undercut area rather than playing a barb role in the small undercut area. However, when the plating height is 1/4, the adhesive strength is greater than that of pure ABS resin. When the particle size is 180~212 μm, the adhesive strength is greatest when the plating height is 1/4 of the particle size, but there is no significant difference depending on the plating height.

Figure 16 shows the specimen after tensile test when the particle size is 180~212 μm and the plating height is 1/4 of the particle size. Fracture occurred in the plastic where the metal and resin were not bonded. This is considered to be fractured in a relatively weak plastic part because the bonding strength between metal and resin is very large. When the plating height is 1/4 of the particle size, the contact area between the rough aluminum oxide particles and the resin is large, and the bonding force between them is large. In addition, because of the rough surface of the particles, the contact area between the particles and the plating layer is large even in the plating layer, so that the particles are not easily separated from the plating layer. Thus, it is clear that the adhesion strength is large. Overall, it shows a greater bonding strength than when the plating is with artificial diamond particles because of irregular and rough surface of aluminum oxide.

Figure 16. Fracture after the tensile test of a specimen bonded with metal plated with aluminum oxide and ABS resin containing 30 wt% GF.

Figure 17 shows the separated bonding surface after a tensile test of a specimen in which the plating height is 1/2 of the particle size in plating with aluminum oxide particles. A large number of particles exist on the metal surface, and there are many grooves in which particles are missing on the surface of the ABS resin side. In this case, the adhesive strength was low. Figure 18 is a photograph of the bonding surface observed with SEM after the adhesive strength was measured when the plating height was set to 1/4 the size of aluminum oxide. It can be seen that the number of particles remaining on the ABS resin side is larger than the particles remaining on the metal surface. In this case, the adhesive strength was high. The marks of aluminum oxide particles escaping from the plastic or plating layer look very rough.

When embossed with aluminum oxide particles, there was

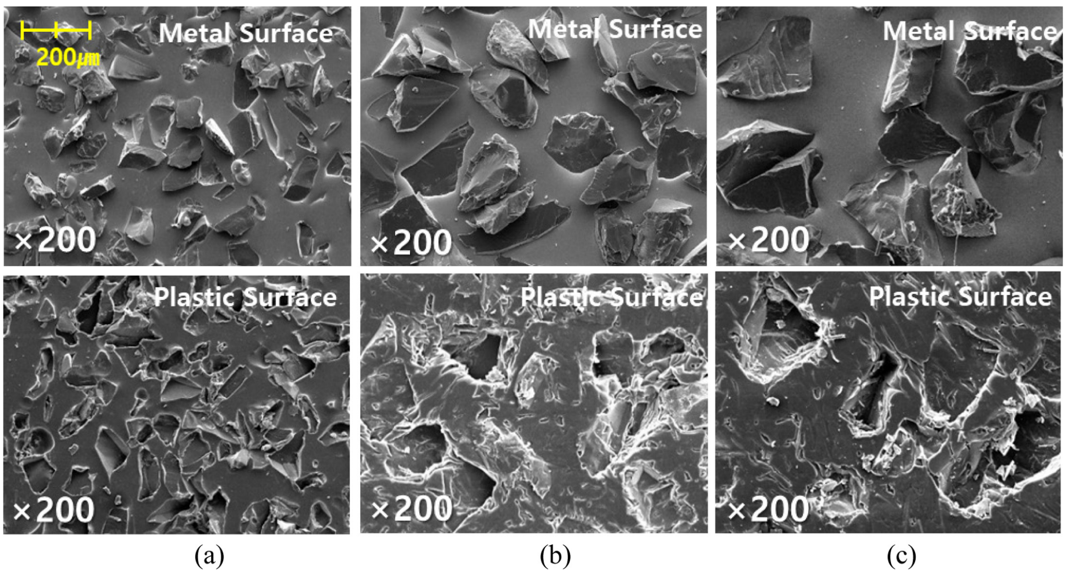


Figure 17. SEM images of separated surfaces after the tensile test when the plating height is 1/2 of the aluminum oxide for 30 wt% GF contained ABS (× 200 view). (a) Particle size 63 μm~90 μm, (b) particle size 125 μm~150 μm, and (c) particle size 180 μm~212 μm.

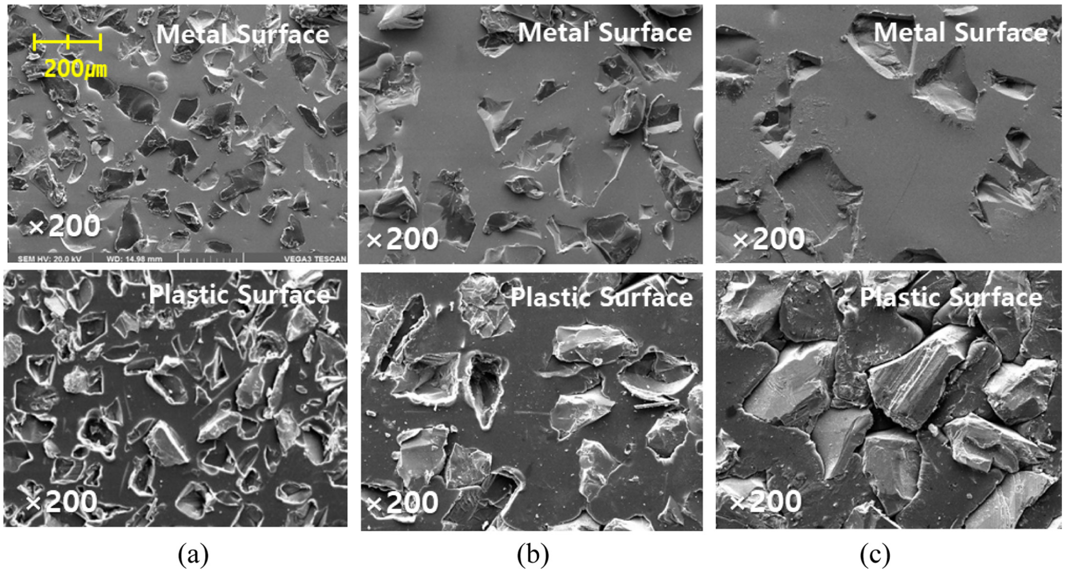


Figure 18. SEM images of separated surfaces after tensile test when the plating height is 1/4 of the aluminum oxide for 30 wt% GF contained ABS (× 200 view). (a) Particle size 63 μm~90 μm, (b) particle size 125 μm~150 μm, and (c) particle size 180 μm~212 μm.

better adhesive strength than with artificial diamond particles, which is related to the surface roughness of the particles. Aluminum oxide particles have irregular lengths in all directions in a polygonal shape, so more undercuts were formed than with artificial diamond particles.

4. Conclusions

In this paper, we described our study on the improvement of adhesive strength between metal and plastic resins. By dispersing micro-sized particles and nickel plating on the metal surface, an embossed shape was formed on the metal surface, and then the metal and plastic resin were bonded by insert molding.

Among the particles used for plating, aluminum oxide had higher adhesive strength than artificial diamond particles. The rough surface condition of the particles influenced the improvement of the adhesive strength. The adhesive strength was higher when the plating height on the metal surface was 1/4 of the particle size than when the plating was with a thicker height. Particles protruding from the plating surface formed an undercut, and the resin entered it and acted as an anchor. ABS resins containing GF had greater adhesive strength than pure ABS resins. This was because GF acted as a barb along with the undercut shape to improve the bonding force.

In this study, our novel surface treatment method improved the adhesive strength of metal and plastic resin. We examined the bonding mechanism and developed a new method that can be widely applied to the bonding of different materials.

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