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Effects of residual oils on the adhesion characteristics of metal-CFRP adhesive joints

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ABSTRACT

Although proper surface treatment is very important in adhesively bonded joints, perfectly clean surfaces have been considered in previous studies. Making the surface of an adherend clean is generally very difficult in real fields. In order to identify the minimum surface treatment that can achieve the required adhesion strength, we investigated the effects of residual oils on the adhesion characteristics of metal-carbon fiber-reinforced epoxy composites adhesive joints. We found that the amount of residual oils on the metal surfaces should be controlled to be less than 1.0 g/m^2, and that enough adhesion strength could be obtained if the flame treatment followed. Experimentation also suggested that three or four cycles of ethanol cleansing and five seconds of flame treatment was the minimum surface treatment easily adoptable in industrial fields.

1. Introduction

The demands of automobile consumers have increasingly expanded from safety to high-quality, electronic equipment, convenience, and design. As automobile makers have developed various options for satisfying consumer's needs, the average weight of vehicles has increased by about 15 kg between 1990 and 2010. However, the environmental regulations of each country enforce the improvement of fuel efficiency required of automobile industries according to simultaneous raised concerns about environmental pollution. Many efforts, such as those aimed at enhancing engine efficiency, decreasing drive resistance, and reducing weight, have been attempted. Weight reduction using advanced materials has become mainstream since the efficiency of power-generating components has peaked due to their technical limitations. For this reason, polymeric composite materials, which have previously been used in very specialized fields, such as air vehicles, aerospace equipment, and military goods, have become new candidates for use as structural materials in automobile industries, broadening their importance [1–4].

Polymeric composite materials have comparative mechanical properties, lower density, and higher specific strength and durability against metallic materials, so they can be used as structural materials for main bodies and other parts of automobiles, as well as improve fuel efficiency through weight reduction. Although these have various advantages, they also have some unclear issues of damages by foreign objects or environments and repairs, which have led to metal-composite hybrid structures. For fabricating metal-composite hybrid structures, adhesively bonded joints are generally adopted, due to their load distribution, impact or vibration mitigation, and the absence of stress concentration caused by hole drilling. Examples of metal-composite adhesive joints can be easily found, such as in BMW i3 or 7-series [5–10].

Surface treatment is most important for improving adhesion characteristics between metal-composite adhesive joints. In particular, various oils used in the machining process essentially remain on metal surfaces, and it is well known that residual oils weaken adhesive joints. Therefore, surface cleaning is critical to adhesion as well as welding, and many studies have been conducted for the purpose of finding the appropriate conditions of each surface treatment on adherends. For example, Kozma and Olefjord [11], Commercon and Wigtman [12], and Hong and Boerio [13] compared adhesion strengths between various steels with and without residual oils and reported that residual oils considerably decreased adhesion strength. They also suggested chemical and physical treatment, such as plating and various coatings, for the enhancement of adhesion strength. Other surface treatments using flame and plasma on metals as well as polymers and composites can change their surface characteristics and improve their adhesion strengths [14–18].

These studies were conducted in a well-organized laboratory for the purpose of comparing the adhesion characteristics of oily surfaces with

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Table 1
Mechanical Properties of adherend materials.

Adherend material	SPFC980Y [Steel]	6061-T6 [Aluminum]	CU190L38/FC702T [CFRP]
Young's modulus (GPa)	200	69	135
Yield strength (MPa)	490	270	400
Tensile Strength (MPa)	980	310	2550
Elongation (%)	18	12	1.7
Density (kg/m^3)	7860	2700	1810
CTE (μm/m°C)	17	25	−1.2

Table 2
Specifications of epoxy adhesive film (from L&L Products data sheet).

Color	Green
Type	Dry-to-touch adhesive film (preventing galvanic corrosion)
Curing conditions	30 min at 130–190 °C
Tensile properties	
modulus	> 2,800 MPa
strength	> 28 MPa
elongation	~2%
Lap Shear Strength	> 30 MPa
T-Peel Strength	> 5 N/mm

both very clean and surface-treated surfaces of adherends with a near-zero amount of residual oil. The derived results were realized in an ideal environment and thus have some limitations in being applied in industrial sites since cleaning and surface treatments similar to those in the laboratory are very difficult in industrial sites. If it is difficult to perfectly remove residual oils on metal surfaces in factories, we have to control the amount of residual oils in order to guarantee sufficient adhesion strength. However, there have not been any reports examining the relationship between adhesion strength and the amount of residual oils. This is the motivation of our research. The objective of this research is to find out the appropriate surface treatment method to control the amount of residual oils for guaranteeing the sufficient adhesion strength of metal-CFRP hybrid joints under the assumption that metal surfaces have residual oils. To control the amount of residual oils of metal surfaces for having required adhesion characteristics, we should know not only the effects of residual oils on the adhesion strength of metal-CFRP adhesive joints but also the effects of surface treatments on the residual oils on metal surfaces. From these two relations, we can establish the optimal surface treatments to give the required adhesion strength.

To achieve our research objective, we investigated the effects of residual oils on the adhesion characteristics of metal-carbon fiber-reinforced epoxy composites (CFRP) adhesive joints. We controlled residual oils on metal surfaces, fabricated metal-CFRP adhesive joints, and performed lap shear tests. In addition, contact angles and fracture modes were measured for analyzing surface characteristics. We then correlated the amount of residual oils with adhesion strength and surface characteristics. In addition, we experimentally studied the effects of ethanol and flame treatments on the adhesion strength and failure modes of metal-CFRP adhesive joints. We found the optimal conditions of surface treatments, which can be easily used in industrial sites of automobiles.

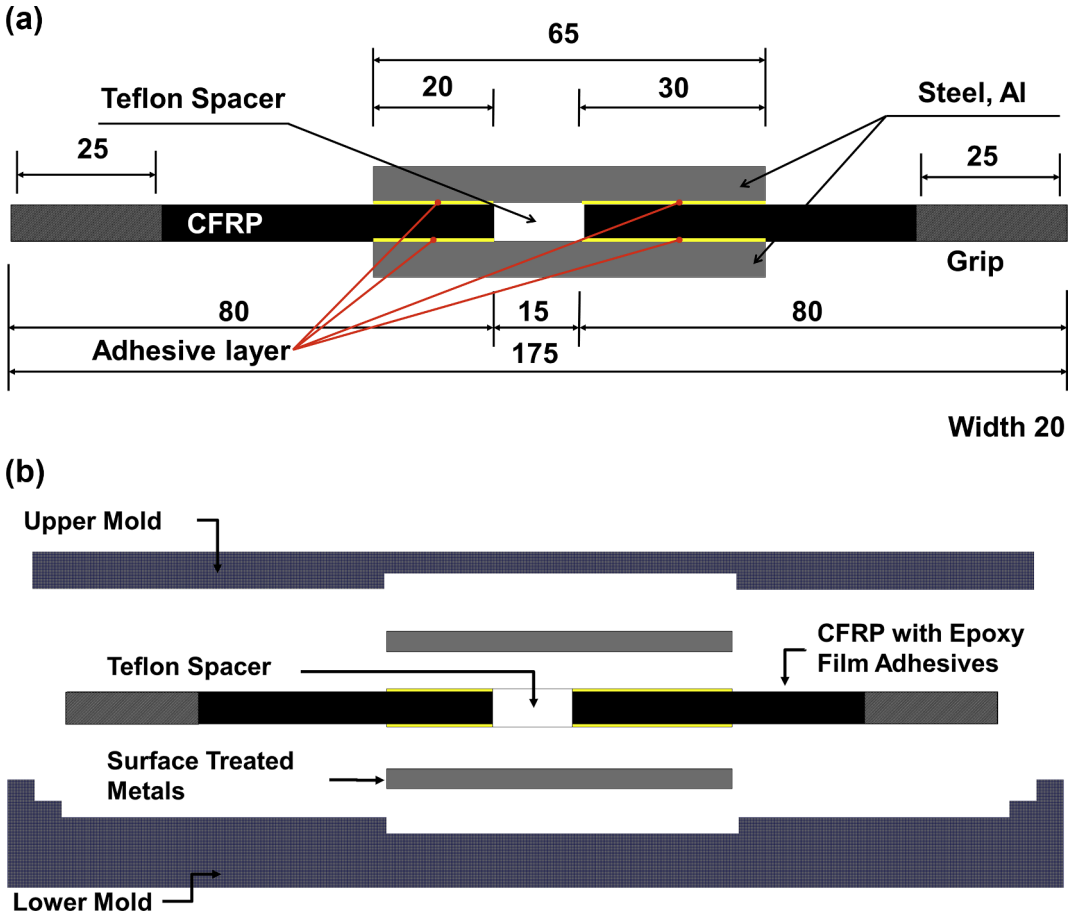

Fig. 1. (a) Dimensions of modified double lap adhesive joints and (b) schematic configuration of fabrication procedure.