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Effects of surface treatment on the critical energy release rates of welded joints between glass fiber reinforced polypropylene and a metal

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ABSTRACT

Fiber reinforced plastics (FRPs) are in high demand as a means to reduce the weight of vehicle structures. When utilizing FRPs with other materials, the joining technology between them is a key technical issue because the joining methods are related to the safety of the vehicle and also restrict the vehicle design.

Polypropylene (PP) is a widely utilized thermoplastic material in the automotive industry because of its reasonable price and high resistance to water absorption. Therefore, PP has a potential to be applied to a matrix resin for FRPs. When PP is utilized as a matrix resin for FRPs, welding is a joining method that has a low cost and high productivity between fiber reinforced polypropylene (FRPP) and metals. However, the welding strength between a FRPP and a metal does not have sufficient strength to be used in the structures. Therefore, in this paper, a chemical etching treatment and sandblasting treatment were applied to the surfaces of metal adherends that were used to increase the welding strength to verify the effect of mechanical interlocking, and the critical energy release rates of the welded joints were measured on welded double cantilever beam (DCB) specimens.

The experimental results indicate that the chemical etching treatment is a very effective surface treatment method, with the resulting metal surface exhibiting a drastic increase of welding strength because the treatment made the surface morphology complex enough to enhance the effect of mechanical interlocking and obtain a higher bonding strength compared to the morphology produced via sandblasting. In addition, the employed chemical etching methods increase the bonding strength between GFRPP and metal to a level that exceeds the interlaminar strength of GFRPP. Therefore, the chemical etching depth did not affect the welding strength, and the maximum bonding strength only depends on the interlaminar strength of the GFRPP.

1. Introduction

Fiber reinforced plastics (FRPs) have a higher specific strength and stiffness than metals such as steel and aluminum alloy. Utilizing FRPs reduces the weight of vehicle structures. However, it is difficult for the vehicle structures to be composed only FRPs because of the poor temperature resistance and low interlaminar strength of FRPs. Combining the structures of FRPs and metals is an effective approach to address these issues and provides reduced weight while maintaining the stiffness of the structure. For the use of FRPs and metals in the structure of a vehicle, the joining technology between them is an important issue; adhesive bonding and welding are the primary joining technologies used [1–5]. Welding is a method which can bond FRPs to metals with curing the melted FRP matrix resin at the bonding surface.

The type of matrix resin used to produce the FRPs influences the bonding strength because chemical and physical interactions must be established for bonding to occur between these materials [6,7]. Because polypropylene (PP) is a widely utilized material in the automotive industry due to its reasonable price and high resistance to water, the material has the potential to be applied to FRPs as a matrix resin. However, PP does not have a polar group on its surface, which leads to poor chemical interaction; as a result, fiber reinforced polypropylene (FRPP) joints have weak bonding strength. In the case of adhesive bonding, much research has been conducted to increase the bonding strength of thermoplastics, including PP, via surface treatment methods such as with plasma, flame, laser, and ultraviolet treatments [8–13]. In the case of welding between FRPP and metals, however, these treatment

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methods that are applied to the FRPP surface cannot improve the bonding strength because the resin of the FRPP is melted and the activated polymers do not remain at the interface during the welding process. Alternatively, surface modification of the metal can be used to improve the bonding strength. When the metal surface is roughened by chemical treatments or mechanical treatment, the melted resin can be inserted into pits in the metal surface and become cured [5,14]. These types of treatments are intended to increase the mechanical interlocking effect. Therefore, in this research effort, the effects of the surface modifications of a metal on the welding strength between a FRPP and the metal were experimentally investigated. Sandblasting (SB) and chemical etching (CE), both of which can roughen the metal surface, were selected as the surface modification methods. Glass fiber reinforced polypropylene (GFRPP) and an aluminum alloy were selected as the FRPP and metal, respectively. GFRPP was selected because the material has a high resistance to the galvanic corrosion that may occur when carbon fiber composites are directly joined to metals [15–17]. An aluminum alloy was chosen because it is a candidate material for lightweight car structures.

The mode I critical energy release rates of the welded joints were measured using double cantilever beam (DCB) tests. The mode I critical energy release rates, which are defined as the bonding energy per unit area, are widely utilized as a bonding strength parameter of joints. The DCB test is one of the testing methods used to measure the mode I critical energy release rete [18–21]. Fig. 1 shows the illustration of the DCB test. The DCB specimen, which consists of the bonded plates, has applied tensile forces at the edge, and the forces propagate the crack. The mode I critical energy release rates can be calculated using the values of the tensile force, crack length, specimen dimensions and material properties.

2. Experiments

2.1. Materials

Glass fiber reinforced polypropylene (TEPEX dynalite 104-RG600(6), BOND LAMINATES, Brilon, Germany), which has roving glass with 2/2 twill in 47% of the volume, was used. Its melting point is 163 °C. In the configurations referred to hereafter, GFRPP and aluminum alloy A6061 were selected as the materials for the DCB specimens. The material properties are shown in Table 1.

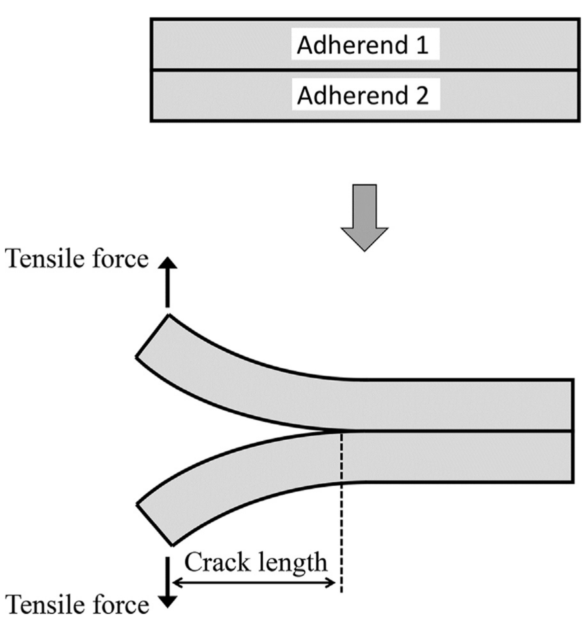

Fig. 1. DCB test that determines the mode I critical energy release rate.

Table 1
Material properties.

	Coefficient of thermal expansion ($\times 10^{-6}\,K^{-1}$)	Young's modulus (GPa)	Plate thickness (mm)	Bending stiffness ($N\,m^2$)
GFRPP	8.84	21.5	3.00	1.21
Aluminum alloy	23.6	68.0	2.00	1.13

2.2. Surface treatments

To increase the welding strength, two types of surface treatment were applied on the surface of the aluminum alloy: sandblasting and chemical etching.

2.2.1. Sandblasting

Sandblasting, which is one of the most widely used treatment methods, roughens the surface of a material via the impact of grit that is accelerated using air pressure. The roughened metal surface can increase the welding strength due to the enhanced mechanical interlocking effect. Alumina (SG-118-120, Hozan Tool Industrial Co. Ltd., Osaka, Japan) was utilized to perform the sandblasting and was also applied to the GFRPP to remove the release agent on the surface. The air pressure was set at 0.5 MPa and was generated by a compressor (SLP-37CD, ANEST IWATA COMPRESSOR Corporation, Yokohama, Japan).

2.2.2. Chemical etching

Chemical etching roughens the surface of a metal via a chemical reaction. The AMALPHA treatment, which is a proprietary metal surface treatment technology developed by (MEC Co. Ltd., Hyogo, Japan), was utilized for the experiments. The AMALPHA treatment was developed for the purpose of plastics–metal joining. This treatment can roughen various metals, such as copper, stainless steel, and aluminum alloys with no voltage application. Fig. 2 shows images of these metals taken with a scanning electron microscope (JSM-7000F, JEOL Ltd., Tokyo, Japan). It was confirmed that each surface is roughened by this treatment. Fig. 3 shows the side views of the welded joints between thermoplastics and metals treated with AMALPHA. Melted resin can be intruded into the pits on the surface of the metal generated by chemical etching; as a result, mechanical interlocking between the resin and metal surface occurs, thereby increasing the bonding strength. In this study, the treatment was applied to the surface of the aluminum alloy, resulting in etching depths of 2 and 15 μm.

2.3. Specimens preparation

The configuration and dimensions of the DCB specimens utilized in this study are shown in Fig. 4. Two different thicknesses of the adherends, 3 mm for the GFRPP and 2 mm for the aluminum alloy, were selected for the study to ensure that their bending stiffness values were similar. The surface treatments described in Section 2.2 were applied to the materials, and three types of specimens shown in Table 2 were prepared. The specimens are denoted as follows:

(1) SB specimen: The aluminum alloy and GFRPP were treated by sandblasting with #120 Al_2O_3 grit.
(2) CE (2 μm) specimen: The aluminum alloy was chemically etched by the AMALPHA treatment to a depth of 2 μm, and the