

Study of Bending Strength for Aluminum Reinforced with Epoxy Composite

Saida Khan, Santosh Kumar Sarang, and Ichiro Hiratsuka
Aisin Technical Center of America

ABSTRACT

Fiber reinforced composite-metal hybrids are of great interest in automotive industry because of their excellent mechanical properties and light-weighting potential. Adhesive bonding is a preferred joining technique for manufacturing fiber reinforced composite metal hybrids. Metal surface due to the presence of process contaminants (oil, dirt, oxide layer etc.) is difficult to bond. The surface prior to adhesive application needs to be cleaned or modified using surface pretreatment methods. Especially for adhesive bonding of multimaterial joining, surface treatment is a very important step. In this paper, 7xxx series extruded aluminum alloy surface was treated using different conventional surface treatment methods and bonded with glass fiber reinforced epoxy tape/mat (FRP). The intent is to stiffen aluminum with lightweight FRP for energy absorbing part application.

The treated surface was characterized using water contact angle measurement for surface energy, optical profilometry for surface roughness, SEM for surface features and Auger electron spectroscopy for chemical analysis of surface. The adhesion strength between Aluminum and continuous glass fiber reinforced epoxy mat was evaluated by lap shear test. The bending strength of aluminum reinforced with epoxy composite was also evaluated to understand the relation between bonding mechanism and mechanical properties. We observed that surface treatment improves adhesion between aluminum and the epoxy composite and thereby results in higher mechanical properties and energy absorption.

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INTRODUCTION

7xxx aluminum alloys are relatively new in automotive industry. They are extensively used in aerospace because of high strength to weight benefit. Automotive industry is also getting more and more interested to utilize 7xxx series aluminum alloys to meet the increasing demand of vehicle light-weighting. Fiber reinforced plastic (FRP) is another avenue of light-weighting that is becoming popular in automotive. An exciting opportunity to design efficient and lightweight vehicle part is to utilize local reinforcement of FRP in metal part or vice versa. This paper presents a study involving a hybrid laminate of 7xxx aluminum alloy and glass fabric reinforced epoxy tape. Five different types of common surface treatment were applied on aluminum surface prior to tape application. The effect of surface treatment on adhesion strength and bending strength of the hybrid laminate were studied.

Fiber reinforced plastic and metal hybrids are used in aerospace industry for decades [1,2]. Automotive industry also uses FRP tape materials to locally stiffen a metal part, especially to reinforce thin metal sections. On the other hand, thin metal sheets are sometimes used to co-mold or bond with plastic parts for providing enhanced strength and crash resistance. The typical applications of these metal/FRP hybrid materials are in body parts, such as door module, roof module, front end carrier module etc. The performance of the part depends on the proper bonding between the metal and the plastic composite. Since,

most of the commercially available fiber reinforced tape materials are developed to adhere onto steel, it is worth investigating their bond performance with extruded aluminum specially 7xxx aluminum alloy that is utilized for crash absorbing components in vehicles such as bumper beam, door beam and so on [3].

Surface preparation is an important prerequisite for adhesive bonding. The purpose of surface preparation is either or a combination of the following:

1. to clean the surface from contamination that is detrimental to adhesion,
2. to abrade or roughen the surface to create sites for mechanical interlocking with the adhesive,
3. to raise the surface-free energy of the substrate to enhance wetting of the surface,
4. to change surface chemical composition in order to facilitate molecular (chemical) attachment of adhesive to the surface

Aerospace industry have developed and optimized a wide variety of surface treatment methods for aluminum bonding [4,5,6]. The surface treatment methods (Table 1) utilized for this paper were selected based on extensive literature review and ease of adoption in automotive industry [7,8,9].

MATERIALS AND METHOD

Materials

Test coupons of dimensions shown in figures 1 and 2 were sectioned from extruded aluminum part. Composite tapes of similar dimensions were then applied on aluminum surface. The test pieces were cured at 165° C for 35 minutes. The aluminum parts used for this study are produced by Aisin Light Metals. The alloy is similar to 7003-T5 in composition. The composite tape is a magnetic, heat curing epoxy sealant laminated to a 0-90 woven fiberglass reinforcing layer from Henkel Corporation (TeroCore 16005™) available in 1-2 mm thickness.

Methods

Surface Pretreatment

The common aluminum surface pre-treatments classified as [4,5]:

1. Mechanical: Grit blasting, sanding
2. Etching: Alkaline, acid, other
3. Anodizing: DC, AC etc.
4. Coupling: saline, sol gel, conversion coating
5. Physical: Plasma, laser etc.

After extensive literature review the following surface treatment methods (Table 1) were selected based on two criteria: 1) Proven method for aluminum adhesion bonding, and 2) Feasible and low cost process for high volume automotive application.

Table1. A summary of the pretreatment steps studied in this paper.

Pre-treatment	Treatment Type	Description
Grit Blasting	Mechanical	Pressure: 0.4 MPa; Approach angle: 45°; Distance: 60 mm; Grit: 180 mesh Aluminum oxide
Sulfo-ferric etching (P2)	Acid Etching	• Degreasing: Bonderite C-AK 4335 (2min @ RT) followed by DI Rinse • P2 solution etch[1]: 8min @ 145° F • DI water rinse: 2–3 min @RT • Oven dry: 30min @ 60°C
Sulphuric acid anodizing	DC anodizing	• Cleaning: Bonderite C-AK 298 (10 min @ 140° F) followed by DI Rinse • Etch: Bonderite C-AK ALUM ETCH 35 (5 min @ 143° F) followed by DI Rinse • De-smut: SC-592 (10.5/to visual de-smut @RT) followed by DI Rinse • Anodizing: Bonderite M-ED 730 Additive to Sulfuric Acid (15wt%/12V/12A/15 min @68° F) followed by DI Rinse
Plasma	Ablation /Oxidation	PlasmaTreat Openair plasma; Distance: 6mm and Speed: 2m/min
Adhesion promoter	Chemical coupling	• Degreasing: Bonderite C-AK 4335 (2min @ RT) followed by DI Rinse • De-oxidizing: Bonderite HX-357 (1 min @ RT) followed by DI Rinse • Coating: Bonderite M-NT 5200 (1.5 min @ RT) followed by DI Rinse

Surface Characterization

Aluminum surface after each surface treatment was characterized to measure water contact angle and surface roughness. The oxide layer chemical composition was studied using Auger Electron Spectroscopy (AES). Plasma treated surface was evaluated within 3 hours of treatment.

Contact Angle Measurement

Contact angle is a measure of wettability of the surface. Water contact angle was measured on each treated aluminum surface and the untreated surface as the control using a Rame-hart 200-F1goniometer.

Surface Roughness

Surface roughness was measured using an Olympus LEXT OLS4000 laser microscope. An arithmetic average height roughness (Ra) was measured over an area of 640um×640 um.

Auger Electron Spectroscopy

Auger electron spectroscopy data were collected on PHI 680 Auger nanoprobe equipped with a field emission electron gun and a cylindrical mirror kinetic energy analyzer. All samples were measured using a 5kV10nA beam with a beam cross section of about 35 nm on the sample surface under ultra-high vacuum better than 1X10⁻⁹ torr. Typically 25 scans were averaged to achieve good signal-to-noise ratio. The surface elemental compositions were calculated from the first order derivative of the averaged data by using the sensitivity factors in the MultiPak software V.9.6.0.15.

Scanning Electron Microscopy

Scanning electron microscopy was performed to observe differences in surface profile and cross-section observation. A Joel JSM-6480LV system was used for SEM measurements.

Mechanical Testing

Lap Shear Test

Lap Shear Test was performed according to ASTM D5868 with some modifications in the sample preparation as shown in Figure 1.

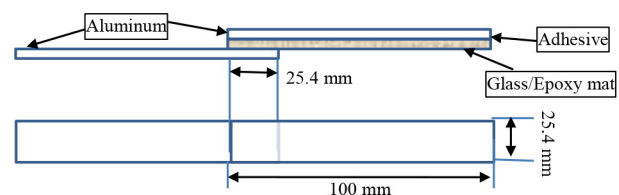


Figure 1. Lap Shear test sample dimensions according to ASTM D5868.

The cured glass epoxy mat was bonded with another piece of aluminum coupon using a structural adhesive. Emery cloth was used to protect the epoxy mat in the grip area during lap shear test.

3-Point Bend Test

3-point bend test was performed according to ASTM D7264 with some modifications in the sample preparation as shown in Figure 2.

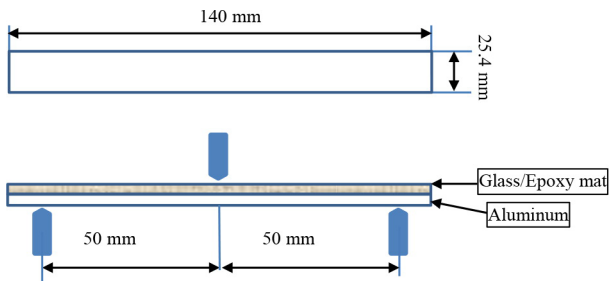


Figure 2. 3-point bend test sample dimensions according to ASTM D7264.

RESULTS

Surface Characterization

The most important variables that affect bonding are: wettability, surface micro-roughness, oxide-layer chemistry, and chemical groups present on the surface [4-5].

Aluminum has a thick native oxide layer that prevents corrosion. However, the native oxide layer may be contaminated, too thick or loosely bound to the bulk material [12-13]. Therefore, surface treatment attempt to remove the native oxide layer and form a new and clean oxide layer with controlled thickness, physical and chemical structure [4,13,14]. The following sections provide the surface characterization results.

Contact Angle Measurement

Water contact angle measurement helps to determine the relative surface energy of surfaces with different pretreatment. The method measures the contact angle between a droplet of water and the surface. If the surface has higher energy than the surface tension of water (~ 72 dyne/cm), the droplet will wet the surface. As a result, the contact angle will be lower than 90° . Similarly, if the surface energy is low, the water droplet will not spread or wet the surface. As a result, the contact angle will be higher than 90° . By measuring the contact angle, it is possible to determine if the pretreatment helped to increase the surface energy and provide better wetting. Better wetting of the surface by the adhesive is required for better adhesion. However, water contact angle is not always an accurate prediction of adhesive wetting or adhesion strength. There are other factors such as polarity and roughness of the surface that also affect the wetting. Also, the surface energy of epoxy adhesive is between 39-46.8 dyne/cm at room temperature which is much lower than the surface tension of water [11]. Therefore, epoxy should be able to wet a surface with surface energy higher than ~ 47 dyne/cm. It is also found that during curing at high temperature, the surface tension of epoxy gets as low as 0.4 dyne/cm [10,11]. Table 2 presents the contact angle data on the pretreated aluminum surfaces with different treatment methods. It is observed that only plasma treatment increase the surface energy and make the aluminum surface hydrophilic. Since, the surface treatment methods were developed to address durability of the bonded joints in corrosive environment, surface hydrophobicity will play an effective role in long term durability of the joints [15].

Table 2. Results for contact angle measurement on surface treated aluminum.

Pretreatment	Water Contact Angle
No Treatment (Control)	82.9
Grit	114.7
Etch	112.1
Anodize	98.0
Coating	94.5
Plasma	64.5

Surface Roughness

Surface roughness helps adhesion by providing larger surface area and sites for mechanical interlocking between the adhesive and the metal surface. Therefore, certain degree of roughness is desirable. However, the benefit of surface roughness on adhesion always depends on the specific surface and adhesive type. Table 3 lists the roughness values for different surface treatments on aluminum.

Table 3. Results for surface roughness measurement on surface treated aluminum.

Pretreatment	Average Roughness, μm
Control	0.43
Grit	0.79
Etch	0.36
Anodize	0.65
Coating	0.44
Plasma	0.34

Figure 3 presents the surface profilometry pictures of Aluminum surface treated with different methods showing comparison of 3D profile taken by laser profilometer.

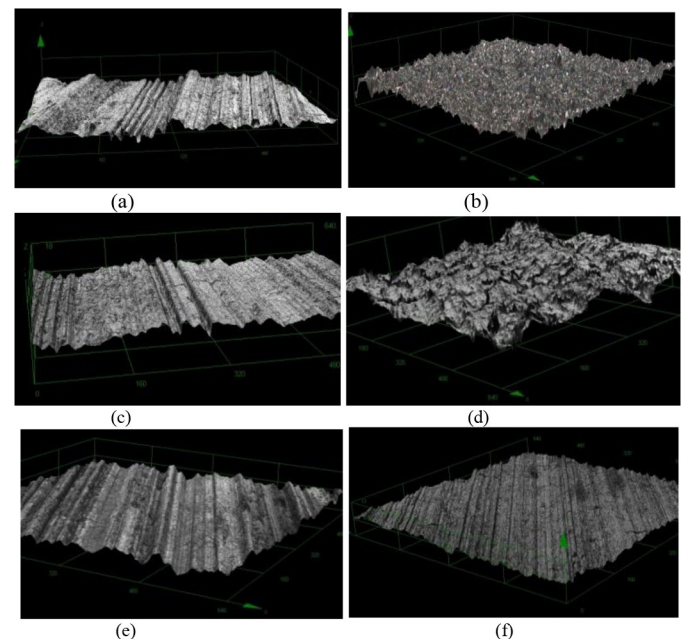


Figure 3. Surface profile as seen in 3D laser micrograph: a) Control, b) Grit, c) Etch, d) Anodize, e) Coating, and f) Plasma treated. The figure shows the difference in topography for different surface treatments.