Adhesive Shear Strength Improvements of Metal/CFRP Laminated Ply Joints Irradiated by EB with Low Dose Prior to Assembly and Hot-Pressing

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Keywords: *Electron beam irradiation, Metal, CFRP, Adhesion*

Abstract

Adhesive 2-layer lamination plies (Metal/CFRP) of metals (18-8, Al and Cu) and carbon fiber reinforced epoxy polymer (CFRP) were prepared using a new adhesion method consisting of applying low dose of less than 0.3 MGy of homogeneous low energy electron beam irradiation (HLEBI) to connecting surfaces of the metals and CFRP prior to assembly and hot-pressing. Application of each HLEBI dose apparently improved the adhesive shear strength.

1. Introduction

Techniques to increase the strength of metal/composite joints are highly sought after. CFRP is typical light structural materials with high strength utilized for aerospace technology. In addition, recyclable metals with their low cost also used for aerospace are not only aluminum (Al) with being a traditionally used light metal with successful record of safety, but also stainless steels such as 18-8 (18mass% Cr-8mass% Ni) austenite with their high corrosion resistance and high fracture toughness, and copper (Cu) with its high electrical conductivity to avoid lightening impact damages. However, the two major methods of joining different materials: mechanical fastening and adhesive bonding although having their advantages, possess their shortcomings.[1] Mechanical fastening uses bolts and rivets, whereas adhesive bonding methods range from applying an adhesive, brazing or welding.

This research shows a joint of metal and CFRP was achieved without the use of fasteners, chemical treatment, or external adhesive by a new adhesion method; a double-step treatment consisting of applying low dose of homogeneous low energy electron beam irradiation (HLEBI) to connecting surfaces of the CFRP and metal, respectively prior to lamination assembly and hot-pressing. The HLEBI is a quick and safe adhesion method applied in very short bursts of ~0.20 s to laminate metal with epoxy CFRP without adhesive or heating the materials. Therefore, the purpose of the present work was to investigate effects of HLEBI prior to hot-pressing on the adhesive shear strength of adhesion of Metal/CFRP.

2. Experimental Procedure

2.1 Preparation of Metal/CFRP

As shown in Fig. 1, the Metal/CFRP laminated joints with and without HLEBI prior to assembly and hot-pressing in vacuum below 1 Pa for 2 h at 401± 0.5 K. were constructed from their separate components of: (1) 18mass%Cr-8mass%Ni austenite (18-8) stainless steel, Aluminum (Al) and copper (Cu) with dimensions [10mm × 40mm × 2.0mm], and (2) cured CFRP (carbon fiber reinforced polymer) with dimensions [10mm × 40mm × 0.25mm] being 1 ply 0.25mm in thickness.

2.2 Homogeneous low voltage electron beam irradiation (HLEBI)

The connecting surfaces of metal and CFRP sheets were homogeneously irradiated by an electron-curtain processor (Type CB250/15/10mA, Energy Science Inc., Woburn, MA, Iwasaki Electric Group Co., Ltd., Tokyo).[2]-[6] The samples were homogeneously irradiated with an electron beam through a titanium window attached to a 24cm-diameter vacuum chamber. A tungsten filament in a vacuum was used to generate the electron beam with an electric voltage of 0.17 MeV and an irradiating current of 2.0 mA. To prevent oxidation, the samples were kept in a N_2 atmosphere of 0.10 MPa with a residual O_2 concentration of less than 0.040%. The flow rate of the N_2 was 1.5 L/s.

2.3. Adhesive shear strength

As shown in Fig. 1, the adhesive shear strength test of the Metal/CFRP laminated joints was performed by an Instron type tensile machine at a constant strain rate of 1 mm/min on the samples as illustrated where the joint was pulled in tension, a shim being added with the thin CFRP sheet in the grips.

2.4 Dangling bond effects and electron spin resonance (ESR)

ESR is utilized to detect unpaired electrons, i.e. dangling bonds by their spins (m_s=+/¹1/2) since electrons have a magnetic moment and spin quantum number. When electrons are unpaired, their magnetic moments either align themselves parallel or anti-parallel to an induced magnetic field producing a peak at a particular magnetic field, B.

3. Result

Figure 1 shows tensile shear stress – strain curves of Metal/CFRP joints with and without 0.22 MGy-HLEBI prior to assemble and hot press at low accumulative probability of tensile shear strength of 0.15. 0.22 MGy-HLEBI improves the tensile shear strength of adhesion for all Metal/CFRP laminated sheets. The adhesive shear strength values for all Metal/CFRP laminated sheets with optimal dose of HLEBI are always higher than that without HLEBI, although the additional dose of HLEBI decays the adhesive strength because of radiation damage. HLEBI mainly enhances the stiffness for Cu/CFRP, ductility for Al/CFRP and both for 18-8/CFRP, respectively.

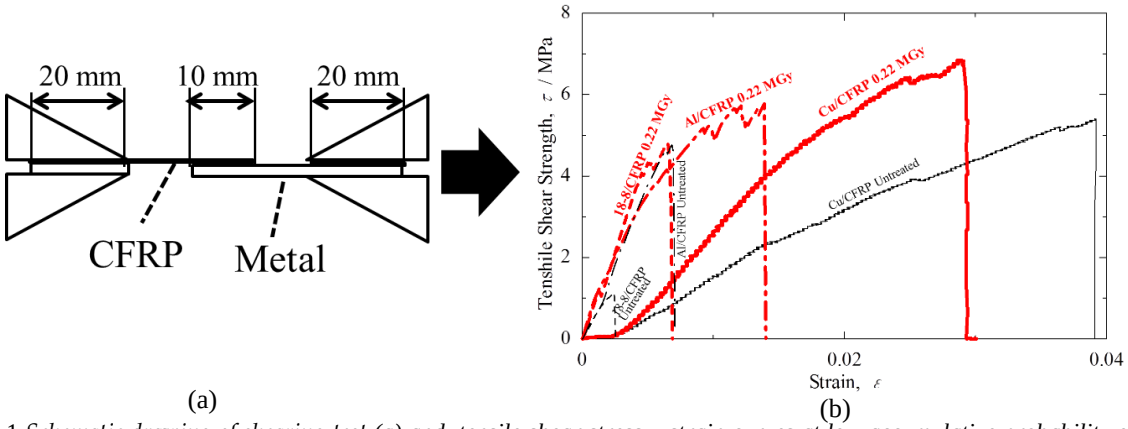

Fig. 1 *Schematic drawing of shearing test (a) and tensile shear stress – strain curves at low accumulative probability of the shear strength (P_s=0.15) of CFRP/Metals (Cu, Al and 18-8) laminated sheets with and without 0.22 MGy-HLEBI (b).*

4. Discussion

HLEBI enhances the height of ESR signals, although ESR signals, indicating dangling bonds, have not been observed in epoxy sample without HLEBI. When HLEBI cuts the chemical bonds and generates active terminated atoms with dangling bonds in epoxy polymers, the electrons probably activate the surface. HLEBI inducing strong adhesive force can be explained by the chemical bonds at interface between Metal and epoxy.

5. Conclusion

Up to now, adhesion of 2-layer laminated Metal/CFRP sheets without our treatment of homogeneous low energy electron beam irradiation (HLEBI) prior to hot press has not been observed in the literature. However, strong adhesion of the Metal/CFRP was created from the new treatment applying low dose ≦0.43 MGy-HLEBI to the CFRP and metal prior to hot-pressing in vacuum below 1 Pa for 2 hr at 401±0.5 K.

References

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