Strain Rate Dependency of Fracture Toughness of Al/Epoxy Resin Interface

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Introduction.

Adhesive bonding with a polymeric resin has various advantages such as reduced stress concentration and higher strength to weight ratio of component. When in use, these components are not only subjected to static loading but also the dynamic loading. Moreover, interfacial fracture or delamination is often experienced from initial defects such as micro air bubble and impurities in interface. Thus, quantitative evaluations of the static and dynamic bonding strength and fracture toughness are strongly demanded to select an adhesive. Recent previous studies reported that laser shock wave technique can load the interface locally and induce a delamination inside the sample. This is called laser spallation or laser shock adhesion test (LaSAT). In this study, we evaluated the Al/Epoxy interfacial bonding strength and fracture toughness by using LaSAT. In addition, we tried to clarify the loading rate dependence of the interfacial strength by comparing with the uniaxial tensile test (quasi-static test) and LaSAT (dynamic test).

Sample and Experimental Setup

This study used a bilayer sample composed of an aluminum substrate and an epoxy resin film to mimic the Al/epoxy resin interface. Figure 1 shows an experimental setup of the laser shock adhesion test (LaSAT). The Nd:YAG laser (Tempest 300, New Wave Research) irradiates pulsed laser (wavelength 1064nm, pulse duration 3-5 ns) towards the grease. The grease, which is composed of silicone oil and graphite powder, absorbs energy from the pulsed laser and expands rapidly due to the phase transition from the liquid phase to the gas or plasma phase (laser ablation). This phenomenon applies impulses to the substrate, and a strong shock wave occurs inside the sample. The shock wave propagates through the sample toward the epoxy resin surface. At the free surface of epoxy film, the wave mode is converted from compressive stress into tensile stress (due to free edge reflection). This converted shock wave applies tensile stress to substrate/film interface. The magnitude of the tensile stress can be controlled by the pulsed laser energy. Therefore, the laser energy where a delamination or failure is first detected is defined as the critical laser energy.

Results

In order to detect delamination or failure of epoxy film, the epoxy surface is continuously observed using a microscope. Figure 2 shows micrographs of the epoxy film surface and cross section around the pulsed laser irradiated area. We observed a white circle formed in the substrate surface (Fig.2a) through the transparent epoxy film. To verify this, the cross section of the white circle area is observed (Fig.2b), and it is proved that the white circle is regarded as a delamination.

To estimate the critical laser energy of aluminum/epoxy delamination, the laser energy is increased in a stepwise fashion with every 10 mJ until the delamination. The diameter of pulsed laser is constant value to be 3.2 mm. Pulsed laser irradiation at the energy of 190 mJ does not induce a delamination. However, a delamination occurred at the laser energy of 200 mJ (like Fig.2a). The test was conducted four times in order to confirm reproducibility. In all four tests, pulsed laser irradiation at 200 mJ induces delamination. Therefore, the energy of 200 mJ is the critical laser energy for the present specimen. We further will compute interfacial stress at the critical laser energy. The computed stress corresponds to the interfacial strength of Al/Epoxy resin. The estimated value will be compared with that of static loading.

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Fig1: Experimental setup of the Laser Shock Adhesion Test (LaSAT).

Fig2: Micrographs of the delamination induced pulsed laser irradiation (a) surface observation (b) cross section observation.