# Measurement of J-Integral Values of Adhesive Joints between CFRP and Aluminum Alloy by Digital Image Correlation Method under Mixed-mode Loadings

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## 1. Introduction

In recent years, further weight reduction of the vehicle body is required in the automobile industry due to strict fuel consumption regulations. Therefore, at present, weight reduction by thinning using high strength steels is being achieved. On the other hand, attempts have also been made to apply nonferrous metals and resin materials such as thermoplastic CFRP (Carbon Fiber Reinforced Plastic), which has high specific strength and high specific rigidity, and is excellent in recyclability.

The challenge in advancing multi-materialization of automobile body is the bonding between dissimilar materials. In particular, conventional welding techniques can not be applied to resin materials such as CFRP. On the other hand, adhesive bonding is a method often used for bonding different materials, and it is possible to prevent stress concentration because surface bonding can be performed at low cost, and it is expected as a bonding method for different materials. However, when adhesive bonding is actually used for car bodies, it is necessary to consider strength reliability in various load modes. Shimizu et al. [1] constructed a method to obtain the *J*-integral values by digital image correlation (DIC) method under mixed mode loading, using single edge adhesive joints of aluminum alloy A5052. However, there are few studies on dissimilar material adhesive joints.

Therefore, in this study, we aim to develop the method to obtain *J*-integral values from displacement and strain distribution around adhesive joints between thermoplastic CFRP and aluminum alloy A5052 under mixed mode loadings.

## 2. Theories

### 2.1 Displacement and strain measurement method by digital image correlation method

Digital image correlation method can extract displacements of the object surface by comparing random pattern images before and after deformation drawn on the object surface. As shown in Fig. 1, random patterns were created on the surface using black toner. When this image is enlarged, it is information with a luminance value for each pixel as shown in Fig. 2. Using this information, displacements and strains are determined by finding out the area in the image after deformation that has the same distribution of luminance values as the subset in the image before deformation.

### 2.2 *J*-integral value calculation

In this study, an arbitrary path surrounding the edge of adhesive joint is created as shown in Fig. 3 and the stress is calculated using the generalized Hook's law from the displacements and strain distributions obtained by DIC. The *J*-integral values were calculated from

$$J = \int_{\Gamma} \left( W dy - T_i \frac{\partial u_i}{\partial x} d\Gamma \right) = \int_{\Gamma} \left( W dy - \left( \sigma_x \frac{\partial u_x}{\partial x} + \tau_{xy} \frac{\partial u_y}{\partial x} \right) dy + \left( \tau_{xy} \frac{\partial u_x}{\partial x} + \sigma_y \frac{\partial u_y}{\partial x} \right) dx \right) \quad (1)$$

where, $W$ is strain energy density, $T_i$ surface force acting on the path $\Gamma$, $u$ displacement, $\sigma$ normal stress, $\tau$ shear stress.

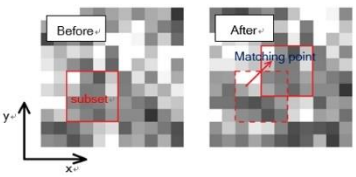



Fig. 1 Random pattern Fig. 2 DIC method

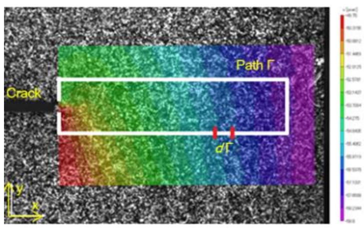



Fig. 3 Path integral

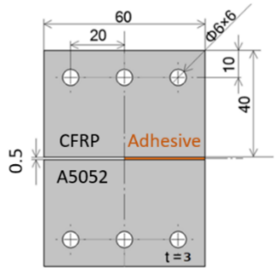



Fig.4 Adhesive joint

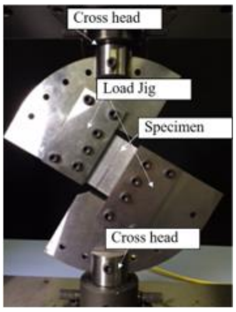



Fig.5 Mixed mode jig

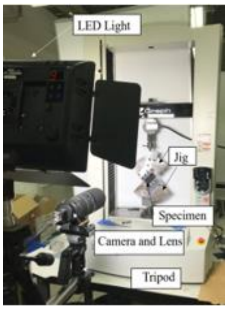
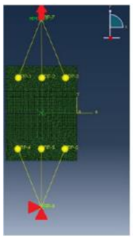
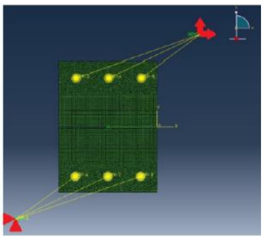


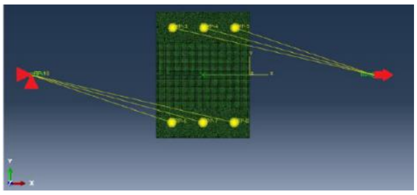

Fig.6 Tensile test



(a) 0 deg



(b) 45 deg



(c) 90 deg

Fig.7 FEM analyses

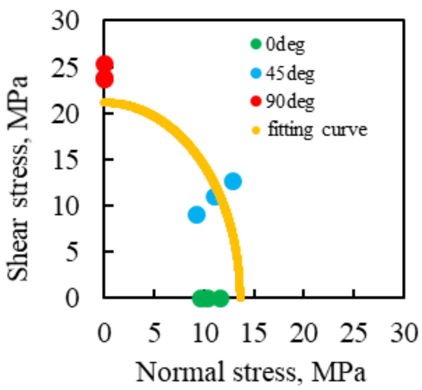



Fig.8 Normal stress and shear stress at break

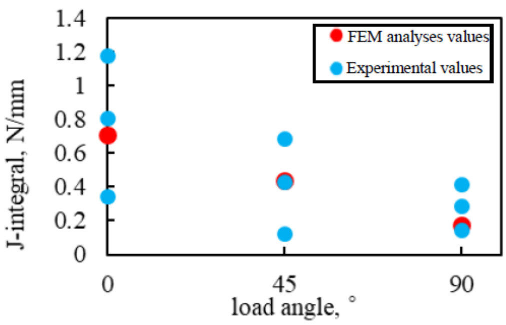



Fig.9 *J*-integral for Adhesive Joints at 0.5 kN

## 3. Experimental methods

### 3.1 Mixed mode tensile tests of adhesive joints[2]

As shown in Fig. 4, adhesive joints were prepared using CFRP and A5052. After that, the substrate was coated with white lacquer spray, black toner powder was applied, and a random pattern as shown in Fig. 1 was produced.

Specimen was attached to a jig that can change the load angle as shown in Fig. 5, and tensile tests were carried out as shown in Fig. 6. The crosshead speed of tensile testing machine was 1 mm/min, the flame rate of CCD camera was 5 fps, and the loading angle was 0°, 45°, and 90°. The recorded movies were converted to images, and the displacements / strain distributions around the adhesive joint was measured by DIC using Correlated Solutions VIC-2D. After that, based on Eq. (1), the *J*-integral values were obtained.

### 3.2 FEM analyses

The validity of the *J*-integral values obtained from experiments were compared with finite element analyses. Figure 7(a)-(c) show the boundary conditions. Pin holes of specimen were connected to load point and fixed point by upper and lower beam elements.

## 4. Results

### 4.1 Stresses at break

Figure 8 shows the normal and shear stresses at break for each load angles. As a result of approximation by the elliptic formula, the shear stress showed a high value compared with the normal stress.

### 4.2 J-integral values

Figure 9 shows the *J*-integral values at 0.5 kN. The *J*-integral values calculated from the experimental results shows the same tendency as the FEM analyses.

## 5. Conclusions

In this study, J-integral values of adhesive joints were calculated with displacements measured by digital image correlation method. By comparing with finite element analyses, it was confirmed that the experimental results show the same tendency as numerical results.

## References

[1] S. Shimamoto, K. Shimizu, M. Omiya and S. Yoneyama, "Fracture Mechanics Evaluation of Adhesive Joints Using Image Correlation Method," *The Japan Society of Mechanical Engineers 2018 Annual Meeting*, No. 18-1, (2018).

[2] S. Yoneyama, S. Arikawa, S. Kusayanagi and K. Hazumi, “Evaluating J-integral from Displacement Fields Measured by Digital Image Correlation”, *Strain*, Vol. 50, (2014), pp. 147-160.