EFFECT OF SURFACE ROUGHNESS ON ADHESIVE STRENGTH OF HEAT-RESISTANT ADHESIVE RTV88

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Abstract

In this study, effects of surface roughness on adhesive strength of heat-resistant adhesive RTV88 were examined. Sandblast was used to generate rough surfaces on aluminum adherends, and then tensile-shear tests of Al/RTV88 single lap joints were performed. The shear strength was shown to be affected by the surface roughness. Effective area, peel failure area, and cohesive failure area were introduced to explain the effects of surface roughness on the adhesive strength. An empirical relation for the failure force was proposed based on these parameters and verified by the test results.

INTRODUCTION

Adhesive joint is a kind of structural connecting method and has been used in various areas. The use of adhesive joints has increased day by day, especially in aero space industry, because geometrically simple shapes reducing the aero dynamic resistance can be made, the weight of flying objects can be decreased, and stress of the connecting area can be distributed uniformly by using adhesive joints. The heat-resistant adhesive RTV88 is a silicone rubber compounds for high temperature and is used as thermal insulation, sealing, and shock-absorbing material in aero space industry. RTV88 is applicable from room temperature to high temperature because the material properties of RTV88 don't vary significantly in spite of high relative temperature difference. So RTV88 is used to flying objects subjected to rapid temperature change.

Adhesive joints are required to maintain adhered state to given loading conditions. Adhesive strengths are highly affected by the surface roughness of adherends, so it is important to investigate it and there have been a lot of researches on adhesive strengths of adhesive joints composed of various adhesives and adherends. Shahid and Hashim[1] presented experimental and numerical results on the effect of surface roughness on the cleavage strength of standard steel/steel cleavage specimen. Kim and co-workers[2] searched suitable conditions for surface treatments such as plasma surface treatment, mechanical abrasion, and sandblast treatment to enhance the mechanical load capabilities of carbon/epoxy composite adhesive joints. Seo and co-workers[3,4] made single lap joints composed of polycarbonate adherend and epoxy resin adhesive and performed shape designs of adhesive joints for strength improvement. Uehara and Sakurai[5] found an optimum value of surface roughness with respect to tensile strength of butt joints and single lap joints composed of steel and a few adhesives. Prolongo and co-workers[6] investigated effects of adherend surface roughness on epoxy bonded aluminum joints. They measured surface roughness by Environmental Scanning Electron Microscopy(ESEM). Also they found an optimum value of surface roughness for adhesive strength of single lap joints.

Adhesive RTV88 is known that it is similar to hyper elastic materials. So, the material properties of RTV88 are quite different from the previously studied adhesive, epoxy resin. So far, there have been little researches on the adhesive joints using RTV88, so it is necessary to study it. In this study, effects of surface roughness on adhesive strength of heat-resistant adhesive RTV88 were investigated. First, sandblast is used to generate rough surfaces on the aluminum adherends. After measuring surface roughness, Al/RTV88 single lap joints were prepared and then tensile-shear tests were performed. Effective area, peel failure area, and cohesive failure area were introduced to explain the effects of surface roughness on the adhesive strength and an empirical relation for the failure force was proposed as a function of these parameters.

EXPERIMENT

The single lap joint specimen used in this study was manufactured in accordance with ASTM D1002[7] and shown in Figure 1. Aluminum 2024-T3 was used as the adherend. Milling machining and sandblast were used to generate different levels of surface roughness on the adherends. The grit numbers of sandblast particle were #150, #120, #80, and #46, respectively. Aluminum oxide(Al_2O_3) was used as the sandblast particle and jetted to the adherends at a pressure of 0.5MPa. The surface roughness of adherends was measured by Form Talysurf Series II, a kind of contact type surface roughness testers. Three specimens were tested for each level of surface roughness and six regions per specimen were measured. The surface roughness were obtained by averaging the measured data and the results were 1.83μm, 2.49μm, 3.55μm, and 6.82μm, respectively, when the grit number of sandblast particle were #150, #120, #80, and #46, respectively. The surface roughness of milling machining specimen was 0.32μm. After measuring the surface roughness, adhesive RTV88(GE Bayer Silicones) was spread on aluminum adherends using an appropriate jig. The material properties of RTV88 are shown in Table 1. Adhesive thickness and length were 0.3mm and 20mm, respectively. Since RTV88 is a kind of two-part room temperature cured types, the single lap joints were cured at room temperature for more than one week.

The tensile-shear test was performed in accordance with ASTM D1002[7] to estimate the shear strength of Al/RTV88 single lap joint. As shown in Figure 2, INSTRON 4206 was used to the test and loading rate was 0.5mm/min. Five specimens were tested for each level of surface roughness. The maximum and the minimum data were discarded, then the failure load and the shear strength were averaged by using the middle three data. Test results were shown in Table 2. As the surface roughness increases, the shear strength also increases then slightly decrease at roughness of 6.82μm.

DISCUSSION OF SHEAR STRENGTH

In this study, we introduced effective area and cohesive failure area to explain the effect of surface roughness. The effective area was already proposed in study of Shahid and Hashim[1]. The effective area defined by ISO 4287 is calculated by Equation (1) and (2). In other words, the effective area is the square of actual length considering surface roughness as shown in Figure 3. It is known that adhesive strengths are increased as the effective area is increased[1]. The length ratio and the effective area ratio can be obtained by dividing the average profile length and the effective area by nominal length and area, respectively. The estimated length ratio and the effective area ratio of aluminum adherends were shown in Table 2.

$$\text{Average profile length} = \int_0^L \sqrt{1+\left(\frac{dy}{dx}\right)^2}\,dx \tag{1}$$

$$\text{Effective area} = \left(\text{average profile length}\right)^2 \tag{2}$$

From Table 2, the length ratio and the effective area ratio are increased as the surface roughness increases. After performing the tensile-shear test of single lap joint, the failure surfaces were photographed as shown in Figure 4. The interface failure occurs with separation between aluminum and RTV88 when the surface roughness is low, whereas the area of the cohesive failure area by adhesive fracture is increased as the surface roughness increases. Since the cohesive failure area is dependent on the surface roughness and also affects the shear strength, the cohesive failure area ratio was calculated from image processing of the failure surface and shown in Table 2. The cohesive failure area ratio is the ratio of the cohesive failure area in the nominal bonding area. As the surface roughness increases, the effective area, the cohesive failure area, and shear strength are also increased. And the cohesive failure area is increased as the effective area increases.

ESTIMATION OF FAILURE FORCE

Estimation equation of failure force

Through the tests of Al/RTV88 single lap joint, it was observed that the failure force was affected by the effective area and the cohesive failure area. Therefore if the total failure surface is divided into the peel failure surface and the cohesive failure surface, the failure force can be expressed as a function of the force inducing peel failure and the force inducing cohesive failure as shown in Equation (3).

$$F_{failure\_predicted} = \underbrace{\left(A_{peel}\tau^{c}_{peel}\right)A_E}_{\text{Peel failure term}} + \underbrace{\left(A_{cohesive}\tau^{c}_{cohesive}\right)}_{\text{Cohesive failure term}} \tag{3}$$

Where A_{peel}, $A_{cohesive}$, and A_E incidates the peel failure surface, the cohesive failure surface and the effective area, respectively and the values to different roughness levels are shown in Table 3. τ^{c}_{peel} is the critical shear stress for the peel failure. In this study, the apparent shear stress of milling machined surface specimen, mainly fractured by peel failure, is used for it. From the tests, $\tau^{c}_{cohesive}$ is obtained as 1.21MPa. $\tau^{c}_{cohesive}$ is the critical shear stress when material bulk failure occurs. In this study, it is calculated from the ultimate tensile stress that is applied to von Mises failure criterion as shown in Equation (4).

$$\tau^{c}_{cohesive} = \frac{\sigma_{ultimate}}{\sqrt{3}} \quad (4)$$

In the empirical relation of failure force, the peel failure term includes the effective area since it increases the size of the peel failure area. However, the cohesive failure term doesn't include the effective area because the cohesive failure occurs only in the inside of adhesive.

Tensile test of adhesive RTV 88

The ultimate tensile stress must be measured from the tensile test to obtain the critical shear stress , $\tau^{c}_{cohesive}$, showed in Equation (4). The tensile test for adhesive RTV88 was performed in accordance with ASTM D412 which specifies test methods for RTV. The tensile test specimen is shown in Figure 5. The gauge length of the specimen was 50mm and loading rate was 5mm/min. The measured true stress-true stain curve was shown in Figure 6. From the tests, the true ultimate tensile stress was measured as 8.31MPa and $\tau^{c}_{cohesive}$ was calculated as 4.80MPa subsequently.

Estimation of failure force

The predicted failure forces, the peel failure area, the cohesive failure area and the effective area as variation of surface roughness are listed in Table 3. As surface roughness increases, the peel failure area and the peel force are decreased, whereas the cohesive failure area and the cohesive force are increased. There are substantial discrepancies between the predicted force and the experimental result in the specimen of surface roughness 1.83μm and 2.49μm. It is thought that the cause of error is to use the constant value for the critical shear stress for the evaluation of the peel failure irrespective of surface roughness. Actually, it is reported in study of Kim and co-workers[8] that the peel stress varies as variation of surface roughness. It is also known that the peel stress decreases at higher surface roughness than specific level. Consequently, to estimate the failure force accurately, further study has to be performed to express the critical shear stress for the evaluation of the peel failure as a function of surface roughness.

CONCLUSIONS

In this study, the effects of surface roughness on adhesive strength of heat-resistant adhesive RTV88 were investigated through experiments and analysis of parameters. The effective area, the peel failure area, and the cohesive failure area were introduced to explain the effects of surface roughness on the adhesive strength more effectively. The effective area, the cohesive failure area, and the shear strength are generally increased as surface roughness increases. Though the effective area is increased as surface roughness increases, the shear strength is decreased because the cohesive failure area is decreased when surface roughness reaches a certain critical value. The shear strength was observed as a function of the peel failure area, the cohesive failure area, and the effective area. An empirical relation for the failure force was proposed based on experiments and parameter analyses. The failure force consisted of the peel failure force and the cohesive failure force. The tensile test of RTV88 was performed to obtain the necessary material property used to the estimation formulation of the failure force. As a result, the peel failure force was evaluated to be the dominant force when the surface roughness was at low level. However the cohesive failure force was the major part of the failure force when the surface roughness was at high level. In the transition surface roughness from low level to high level, there was significant error in the failure force between the evaluated and tested failure force. Actually, the critical shear stress for the peel failure is known as a function of surface roughness and in this study, it is not considered in the evaluation of the failure force. So, additional study for it will be desirable as future works.

ACKNOWLEDGEMENT

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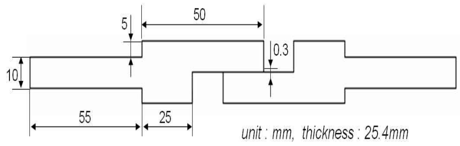

Figure 1 – Configuration of single lap shear joint specimen

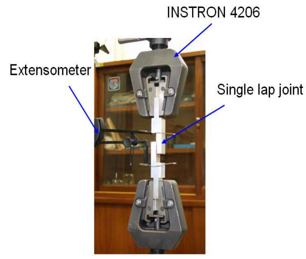

Figure 2 – Tensile-shear test of single lap joint

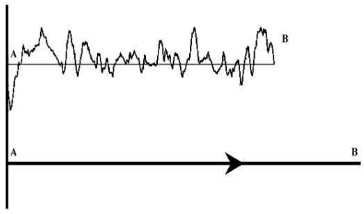

Figure 3 – Average profile length

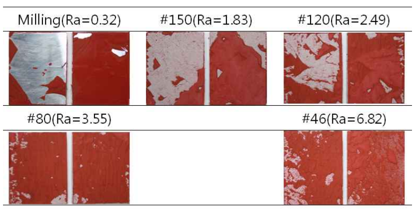

Figure 4 – Failure surface of Al/RTV88 single lap joint

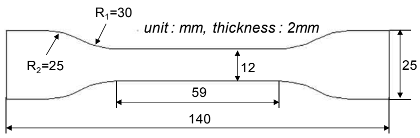

Figure 5 – Tensile specimen of RTV88

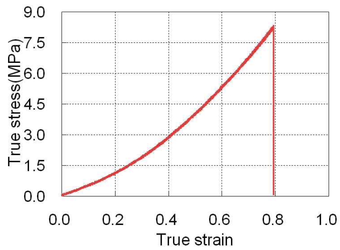

Figure 6 – Tensile stress-strain curve of RTV88

Table 1 Material properties of RTV88

Item	Data
Density	1,470kg/m^3
Viscosity	880,000mPa-s
Work time	0.75hours(at 24℃)
Cure time	24hours(at 24℃)
Hardness	58 Shore A
Elongation	120%
Tear strength	8.0kN/m

Table 2 Shear strength, effective area ratio, and cohesive failure area ratio as variation of surface roughness

Surface roughness(μm)	Shear Strength(MPa)	Effective area ratio	Cohesive failure area ratio
0.32	1.21	1.004	0.090
1.83	3.22	1.191	0.087
2.49	3.54	1.213	0.238
3.55	4.09	1.238	0.844
6.82	3.96	1.285	0.799

Table 3 Estimated parameters and evaluation of failure force

Surface roughness(μm)	Effective area ratio	Peel failure area(mm^2)	Cohesive failure area(mm^2)	Peel force (N)	Cohesive force (N)	Failure force(N)	
						Test	Predicted
0.32	1.004	462.28	45.72	473	219	614	693
1.83	1.191	463.80	44.20	564	212	1,637	776
2.49	1.213	387.09	120.90	480	580	1,796	1,060
3.55	1.238	79.25	428.75	100	2,057	2,078	2,157
6.82	1.285	102.11	405.89	134	1,947	2,011	2,082