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An Experimental Investigation of Adhesive Bonded Single-Lap Joints

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Abstract: Now day's use of adhesive-bonding technique is increased in manufacturing structures. For designing adhesive-bonded structure Stress and strain analyses of joints are necessary. The durability of single-lap adhesive joint is affected by adhesive design of joints. The tensile-shear test and finite element calculation are performed on single-lap specimens for various joint parameters. Effect of overlap length and adhesive-bonding thickness on adhesive strength and stress distribution of the joints is investigated. It is observed that overlap length and thickness can be important parameters for design of adhesive bonding structure.
Keywords: Adhesive Bonding, Adhesive Thickness, Overlap Length, Tensile-Shear Strength, Finite Element Analysis

I. INTRODUCTION

Stress and strain analyses of joints are essential to design adhesive-bonded joints structure. In general ,real stress of the adhesive bonded joints under definite load is in the complex state of shear stress and tensile stress, and the factors like non uniformity of the material, stress concentration, partial creep ,yield, fracture and so on have an effected on stress and strain, therefore stress analysis and strength distribution are very complicated. We had been analyzing stress of adhesive bonding, by theoretical method and finite element method. At first analysis of stress distribution of single-lap bonded joint.

The bonding Strength with tensile test was investigated for the purpose of finding out the effect of various factors in adhesive bonding part. These factors are overlap length, overlap width, curing pressure and surface treatment. Optimum adhesive thickness overlap length can be calculated from these experimental and analytic results for design of adhesive bonded joint, and results can be the base data to design the adhesive structure. The optimum condition determined for experimental factors can improve the bonding technique and design a high strength.

II. EXPERIMENTAL DETAILS

Specimens were manufactured which varied overlap length, overlap width, curing pressure and Surface treatment to find the effects on strength and durability according to ASTM D1002-94 [5]. First, the overlap length of the adhesive bonded part in the specimen was divided into five and the divided surface was polished with 2000 grit abrasive papers. The adhesive thickness was obtained b getting 10 points as the same distance on the divided surface with image analysis program, the numerical means of these values were considered as the thickness. The error range of thickness was about ±2%. Table 1 shows the curing condition of specimens. Fig. 1 shows the configuration of specimen used in this study. Tensile-shear test was conducted with a hydraulic material testing machine (8516, Instron Co., USA) in this experiment. The crosshead speed was maintained constant speed of 0.2 mm/min. To calculate where the stress concentrates on from the stress distribution applied to adhesive bonding and to measure the change of stress concentration rate due to adhesive thickness and overlap length as tensile-shear stress is subjected to adhesive bonded specimen, we made the model for FEM specimen like Fig. 2. In Fig. 2, X, Y and Z mean the direction of length, normal, and parallel direction respectively. Properties of material shown in Table 2 such as Young's modulus, Poisson's ratio and so on is applied for this FEM model from results of testing Tensile-experiment of adhesive and adhered. This calculation has 8 nodes on the model, degree of freedom is the displacement for the direction of axis. To get good analysis results, 2-dimensional solid model has 445 elements and 1465 nodes; 3-dimensional solid model has 3520 elements, 4617 nodes. Many small elements are supposed to be located on where the stress concentrates. A linear analysis of Elastic area is considered within the fracture load of adhesive.

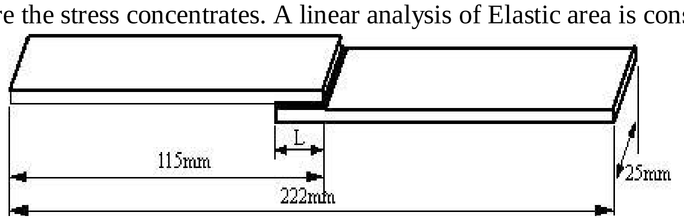

Fig. 1. Adhesive bonded specimen

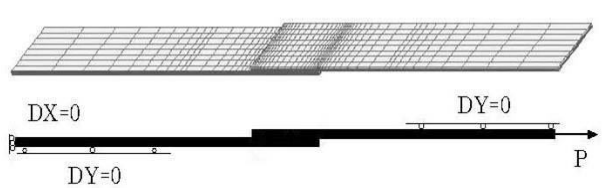

Fig. 2. FEM model and boundary condition

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Table 1. Adhesive conditions for curing

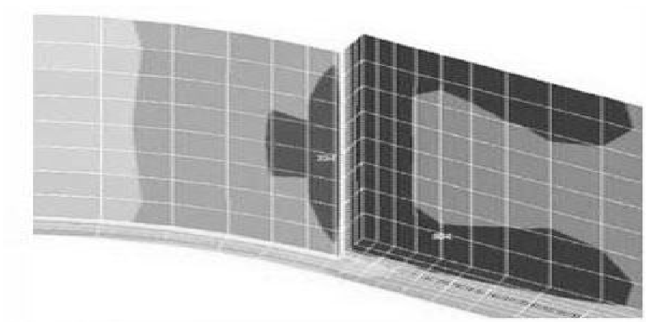
Adhesive thickness [μm]	118	112	106	98	92	88	86
Applied pressure [MPa]	0.012	0.025	0.049	0.074	0.098	0.29	0.59
Overlap length [mm]	8	12	18	25	-	-	-

III. RESULTS AND DISCUSSION

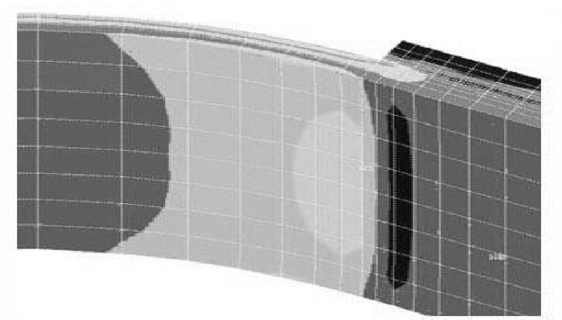
1. FE Analysis of Adhesive Joints. Bending deformation breaks out along the opposite sides of each other in the centre of adhesive bonding part due to effect of moment to be subjected to singled-lap specimen. The stress concentrates more on adhered part than on adhesive bonding part when considering of the end side of overlap. This stress distribution may be caused by different deformation rates between adhesive bonding part and adherend part when specimen subjected to tensile load. In the area range to be restrained, deformation ratio of adherend is small, however that in the area not to restrain is big. Wider overlap length means to be able to support heavier load under definite range, crease of deformation ratio of adherend to be close to the end of overlap part makes strain distribution, because of much heavier load. Fig. 3 shows that there is strain distribution area like a Utype as a result of FE calculation with 3 dimensional models in the figure, (a) and (b) shows stress Distribution states with deformation ratio distribution in the front side of adhesive layer and the other side respectively. Fig. 4 illustrates distributions of σx, axis directional stress between adhesive and adherend σy, laminar stress to be normal to adhering layer and τxy, shear stress inner adhering surface. In the area of the one-fourth from the ends of both sides of the adhesive bonded part, stress concentrates on that area and the edges of the adhesive bonded part have the maximum stress. Besides overlap center part has much less stress than the end of the sides, almost of single overlap typical adhesive bonded little distributes on load resistance comparing with the strength of adhesive and adhesive bonded part layer. The stress σx subjected to the same direction of the load is the biggest stress among the stresses subjected to adhesive bonded part layer along the directions, therefore σx ismajor stress to make an influence to adhesive strength

Table 2. Material properties used in this study

	Young's modulus (Gpa)	Poisson's ratio	Yield strength (Mpa)	Tensile strength (Mpa)
Adherend	210	0.3	120.8	300
Adhesive	2.7	0.33	56.7	61.3



a) Front view



(b) Rear view

Fig. 3. Stress intensity contour by 3D FEM model

A. *Effect of Adhesive Thickness on Strength.*

Relationship between bonding real strength of specimen and adhesive thickness is considered by tensile-shear test. Fig. 5 is the diagram of load and deformation with 4 different thicknesses. As seen in Fig. 5, the increase of the adhesive thickness from 98 to 118 μm reduces the maximum load. However the reduction of the adhesive thickness to limitation, the strength not increases but reduces on the contrary. Fig. 6 shows that the increase and reduction of adhesive thickness have the limit strength corresponded to the thickness to make an contrary influence, therefore in this study the limit thickness of adhesive and adherend is in 95-100μm. It's thought that the strength is reduced because frailest boundary layer in the case that the adhesive thickness is too thin might be the layer of adhesive and adherend.

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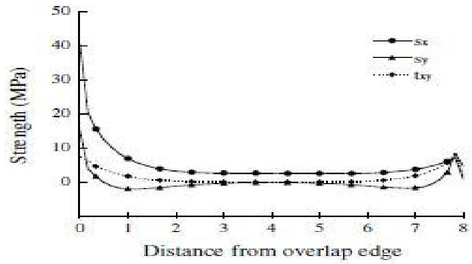

Fig. 4. Stress distribution as function of distance from the edge of the overlap

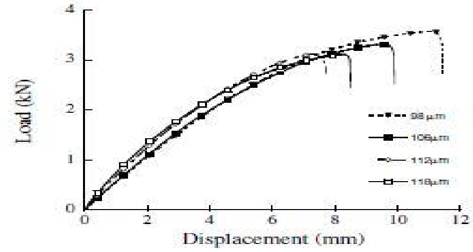

Fig. 5. Fracture behaviors according to various adhesive thickness

FE analysis is processed with 50, 100, 150 and 200 µm thickness model to analyse the relationship between adhesive thickness and strength as the stress distribution and stress concentration rate. Fig. 7illustrates the state and the magnitude of the stress distribution of σx to make a great influence on the fracture of the adhesive bonded part under the same load. The σx max is distributed on the end of overlap part, as the stress concentration, and the stress concentration is severe in 50 µm, as the
maximum stress intensity. Fig. 8 shows the relationship between the stress intensity and adhesive thickness along the direction of x. The stress intensity is expressed as the ratio of σx max, the maximum tensile stress over σ0, the average tensile stress to be distributed over overlap part. The strength of adhering has to increase because thicker adhesive thickness it gets, less stress intensity gets in the Fig.8. Actually, the strength of adhering increased according to increasing of thickness under 98 µm likeFig. 5. However if thickness excesses the limitation, the increase of deficiency in adhesive makes the crack, therefore not a stress intensity but inner deficiency causes strength reduction primarily. Fig. 5and Fig. 6 show the tendency of that over 98 µm of adhesive thickness

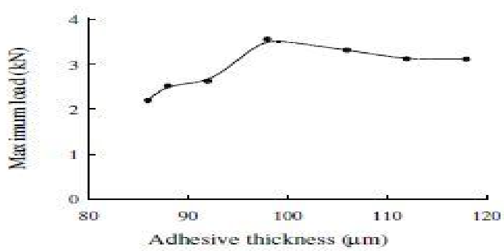

Fig. 6. Relation between maximum load and adhesive thickness

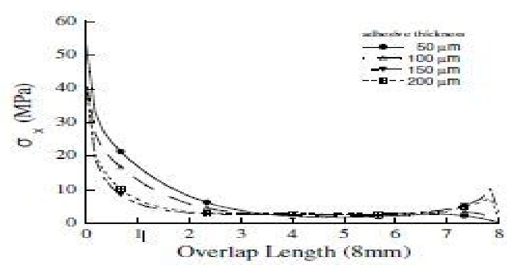

Fig. 7. Relation between stress distribution and adhesive thickness

B. Effect of Overlap Length on Strength.

The experimental results on the specimens to be changed with overlap length are arranged in Fig. 9. The pressure on the adhesive bonded part is controlled with0.098, 0.29 and 0.59 MPa to obtain different adhesive thickness, the overlap length is put up with 8,12, 18, and 25 mm according to setting pressure. Fig. 9 shows that shear strength has increased a little from 8 to 12 mm in the case of 0.59 MPa pressure, and there is no large change in the case of other pressure. However if the overlap length is over 12 mm, shear strength fell down rapidly. The strength of adhesive bonded part is affected by the adhesive strength of the end of side, and the increase of the bonded area cannot increase the adhesive strength proportionally.

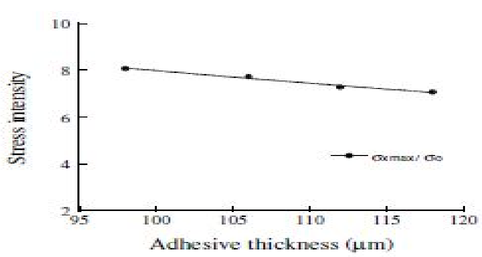

Fig. 8. Relation between stress intensity and adhesive thickness

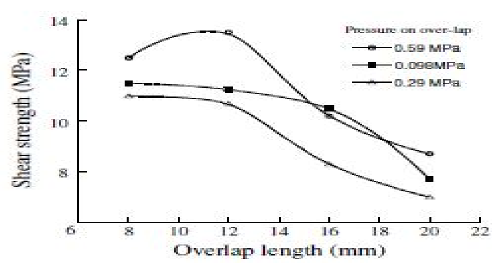

Fig. 9. Relation between maximum load and overlap length

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Fig. 10 to arrange the relationship between overlap length and stress distribution shows the stress concentrates on the part of 1/8-1/4 area of overlap part, the maximum stress of the end of adhesive bonded part has increased according to the increase of overlap length. The relationship between overlap length and x-directional stress intensity is expressed in Fig. 11. The stress intensity increases as the overlap length does. The ratio of the area increase according to the overlap length increase is bigger than that of load increase according to area increase. This relationship is analysed in general stress distribution of single overlap bonded part. Namely the stress concentrates on the both edges of adhesive layers, other parts under less stress along the longitudinal direction cannot afford to sustain the load. The bonded part would fracture, because the maximum stress which distributes on the bonded part exceeds the critical value of strength in the frail part, and this critical value is definite in the special bonded part. Therefore there is the critical overlap length (Lm) in the special part of bonded area, if overlap length(L) exceeds the critical overlap length (L>Lm), the stress goes to zero in the middle part of overlap area, and the maximum stress of the end in the overlap part can be fracture stress. In the case that the overlap length exceeds Lm, the load wouldn't increase any more, it causes the decrease of strength. Therefore it is noticed in the case of structural design for adhesive bonded part, the increase of the load by the method to increase overlap length is not efficient.

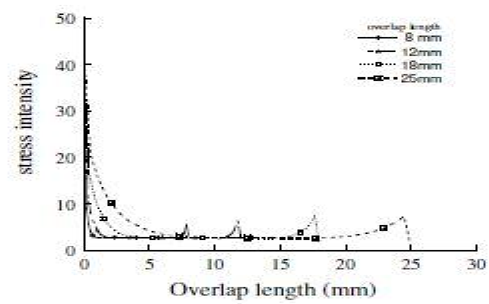

Fig. 10. Relation between stress distribution and overlap length

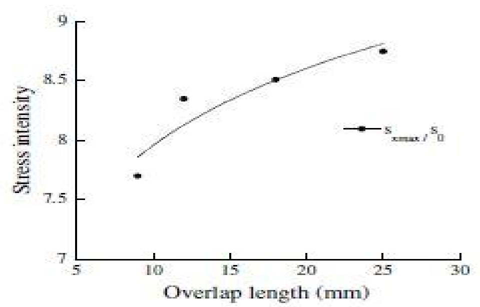

Fig. 11. Relation between stress intensity and overlap length

IV. CONCLUSIONS

Tensile-shear test and FEM analyses are accomplished about the specimens under the condition changing the single joint overlap length and the thickness of adhesive, we obtained stress distribution analyses and strength evaluation in this research. The conclusions are as following.

A. It is certified that the stress concentrates on the end part of adhesive bonding when tensile-shear load applies on the specimen, single overlap joint, by the FEM, and we can obtain the same results from tensile-shear test.
B. The load increases as the thickness increases to 100 µm, but it decrease over 100 µm contrarily. The increase of the thickness causes the increase of strength because the sicker adhesive bonding gets, the less the stress intensity gets, however the sudden increase of inner deficiency in the adhesive itself over the special thickness causes the decrease of the strength.
C. Shear strength of bonded part severely decreases over 12 µm of overlap length, therefore despite the overlap area increases, if overlap length exceeds critical length (Lm), the load cannot increase any more. This is the reason that the most of the load applies on the 1/8 - 1/4 length from the end in the overlap area, the load doesn't increase proportionally as the overlap area increases.

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