CONCENTRATION OF THE NORMAL STRESSES IN THE ADHERENDS OF ADHESIVELY-BONDED DOUBLE LAP STEEL JOINTS DUE TO REDUCING THE WIDTH OF THE BONDED AREA

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Abstract
The purpose of this paper is to highlight the changes in the normal stresses acting along the adherends when are assembled together, like double lap joints, by bonding them using incomplete width of the adherends to reduce the bonded area.
Three-dimensional finite element model using ABAQUS® software was developed to simulate a double lap shear joint composed of galvanized steel sheets assembled by using a structural epoxy adhesive (DP490).
Shear-by-tension tests on specimens, which bonded using only 40% of the full width of the adherends, were carried out to validate the model which was provided with necessary data including the boundary conditions and displacement rate that were used during the test. Afterwards, this model was used to evaluate the cases of using variant widths (40,50,60,70,80,90, and 100%) of the adherends width with the same overlap length. For the sake of comparison, all cases were studied under a constant tension load which was just under the load causes the yielding in the adhesive layers obtained from the tests.
Normal stresses acting along the steel adherends as well as the shear and peeling stresses over the bondline (in the longitudinal and transverse directions) for each case were plotted. The results were compared with the case of the full width (100%). The main results and findings are here presented.

***Key words**: Structural adhesives, double lap shear joints, bonded area, concentrated stresses*

1. Introduction

Since the concentration of the stresses can be a critical condition in engineering structures, the effect of it has been highlighted for few decades. The stresses can be concentrated in a structural member due to different reasons, for example in the joints where two or more members are overlapped connected by bolts or rivets, the normal stresses, developed in the connected adherends resulted from an applied tension load, are concentrated at the edges of the holes due to the decrease of the cross sectional area of the connected adherend, see for example [1].

In adhesively-bonded joints, unlike to the previously mentioned connecting ways, no reduction in the cross sectional area is existed, therefore, no concentrated stresses occur in the joined adhenends. However, the concentration of the shear and peeling stresses will

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occur at the ends of the adhesive bondline [2]. In the case of two or more unequal-width adherends have to be overlapped joined, the concentration of the stresses might occur. However, this time not only in the adhesive layer but also in the wider adherends, where the increase of the normal stress would be probable. This concentration of the adherends stresses might be a critical condition and has to be taken into account when designing such joint.

In this paper, the normal stress developed in the thin-gauged galvanized steel adherends is investigated. The steel plates are assembled by a structural adhesive (epoxy DP490) to form a double lap shear joint loaded by a tension load. The joint is symmetric, and studied for seven cases of the bonded area which has the same overlap length but different widths that were selected as percentages of the width of the steel plates width.

2. Model building

When modelling by the use of the finite element method, great care has to be given to represent the structure including its geometry, mechanical properties of the materials, loading and boundary conditions in order to best simulate the structure and the conditions applied during the test. Hence, getting results identical with those gotten from the test is possible. Analysis type selected as well as tolerances made to facilitate the modelling process and to save the time needed for the completion of the analysis have to be judged and then to be determined.

A finite element model using ABAQUS software [3] is considered in the present work. This model is a double lap shear joint which represent the joint tested at room temperature and taken from [4]. Fig. 1 shows the geometry of the joint.

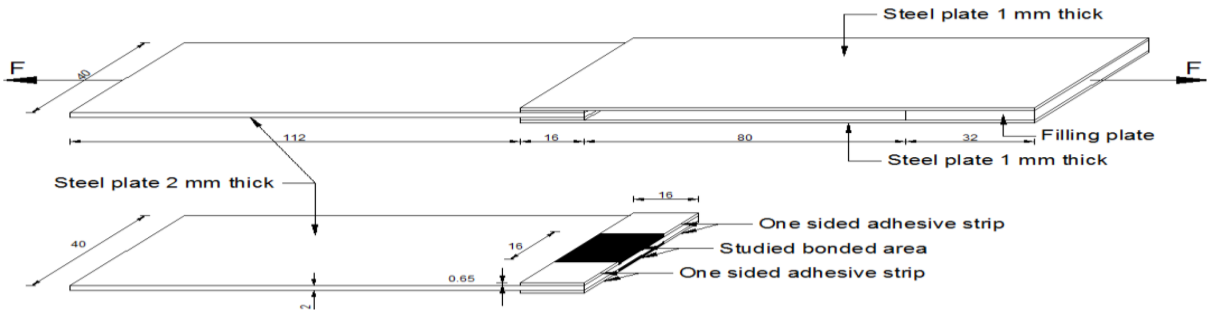

Fig. 1. Double lap shear joint, black areas represent the bonded areas, [4]

Similar to the boundary conditions applied during the real test, one side of the joint is fully constrained over an area of 32 mm x40 mm, while an equal area on the other side is allowed to move only in the longitudinal direction.

A displacement rate applied in the test (1.27 mm/min) is simulated by applying a constant velocity at the moveable side of the joint, this procedure was done by [5]. Based on the fact that the joint fails cohesively [4], i.e. the failure happens in the adhesive layer not at the interfacial surfaces, the two layers of the adhesive are connected with the steel adherends by an appropriate definition of contacts based on the theory of the so-called slave and master surfaces. A specific tie constraint, that ties two separate surfaces together so that there is no relative motion between them, is used [3,5,6].The selection of the element type and the mesh size is based on the ability of representing the model accurately. Therefore, the middle area of the joint is meshed finer than the rest areas. For the whole model, the mesh is generated using eight-node linear hexahedral elements of type C3D8. Non-linear analysis was done. Fig. 2 displays the constraints, loading, and meshing used in the FE model.

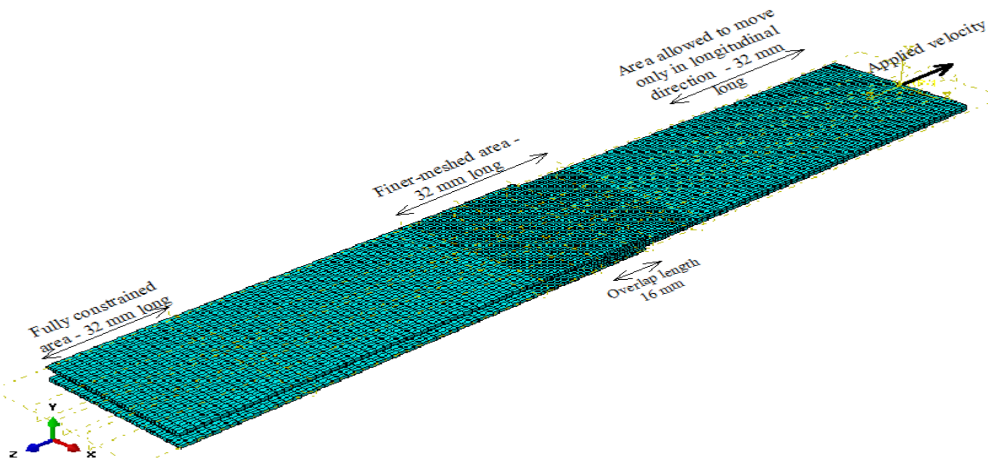

Fig. 2. Boundary conditions, loading, and meshing of the model

The material properties were obtained from tests carried out by the author. Fig. 3 displays the material properties for the steel adherends where true stress and strain are used for the model. The adhesive material is considered as linear elastic isotropic material (E = 875.21 MPa, $\sigma_y = 41.38\ MPa$, ν = 0.378)

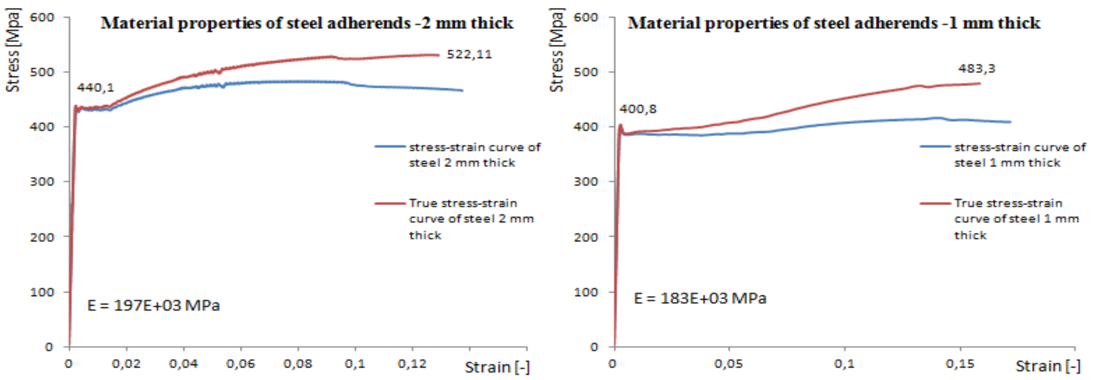

Fig. 3. Engineering and true tensile stress - strain curves of the used steel adherends

3. Model validation

The created model was validated by comparing the maximum shear strength over the adhesive bondline τ_{max} and the shear elasticity modulus G of the adhesive. Table.1 exhibits the model factors that show high agreement between the results of FE model and those of the real test.

Table 1. Comparison between FE-model and test results

	FE-Model	Test	Model factor* (%)
Maximum shear strength τ_{max} [MPa] over the adhesive bondline	23.85	23.89	99.8
Shear elasticity modulus G [MPa] of the adhesive	323.84	317.59	102

* Model factor (%) = [(Model value)/ (Test value)] x100

4. Parametric study

After the model has been validated and adopted, the parametric study can be done by changing only the width of the bonded area used in the model in order to get results regarding how the normal stresses in the steel adherends change for each considered width. The bonded area width was determined to be 40,50,60,70,80,90, and 100% of the adherends width (40 mm) i.e. the bonded area widths studied are 16,20,24,28,32,36, and 40 mm respectively. The length of the bonded area is constant and equal to 16 mm. For the sake of comparison, all cases were studied under a constant tension load (12000 N) which is just under the load causes the yielding in the adhesive layers obtained from the tests. A general overview of the shear and peeling distributions over the adhesive bondline is also reported.

5. Results

Fig. 4 shows the difference between the distribution of the normal stresses in the steel adherends in the case of the full width is bonded and the concentrated normal stresses, in the area just after the overlapped area, when only 40% of the width is bonded. Due to symmetry of the joint, the normal stress developed in the middle steel plate at specified tension load (12000 N) is obtained. The stress is determined in two paths that are defined in both longitudinal and transverse directions. The shear and peeling stresses, developed in one adhesive layer in two directions, are also determined along two paths defined for the adhesive layer. , Fig. 5 shows the paths defined for the steel adherend and the adhesive layer.

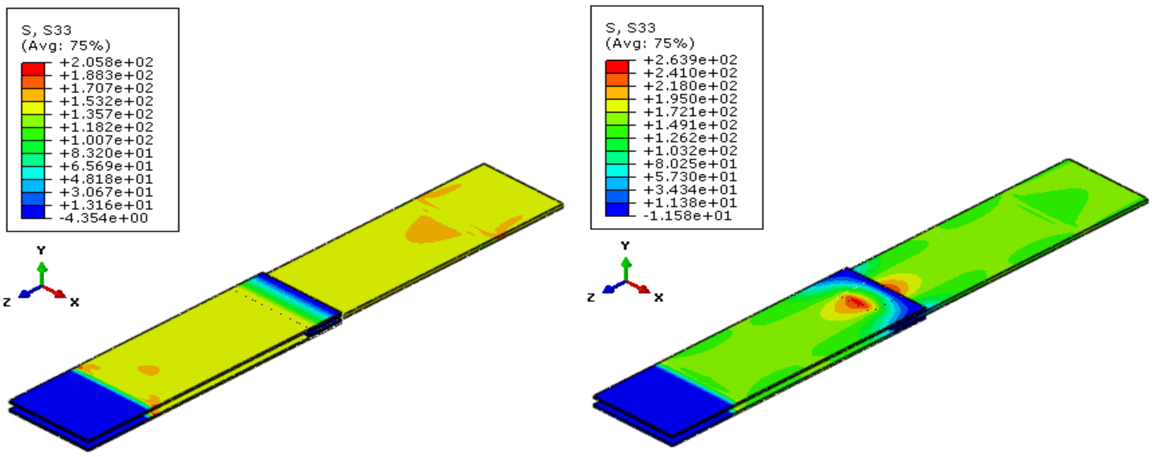

Fig. 4. Difference between the distribution of the normal stresses for complete width bonded (left) and 40% of the width bonded (right)

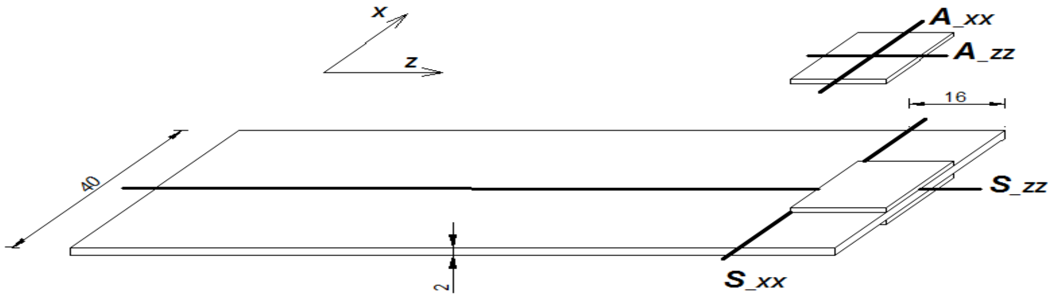

Fig. 5. The longitudinal and transverse paths defined for the steel adherend (S_ZZ and S_XX) and for the adhesive layer (A_ZZ and A_XX)

In Fig. 4, it is shown that the normal stress in the steel is concentrated over a small area which is very close to the bonded area and the peak value is at the border of the bonded area. The normal stress variation in two directions for the seven cases studied is shown in Fig. 6. The stress concentration factor, k_c is defined as follows,[1]:

$$K_c = {}^{\sigma_{\max,i}}/_{\sigma_{\max,R}}$$

where $\sigma_{\max,i}$ is the maximum normal stress of the i[th] case, while $\sigma_{\max,R}$ is the maximum normal stress of the reference case (the full width of the bonded area 40 mm). The relation between K_c and i[th] width to the reference width ratio ($^{b_i}/_{b_R}$) is illustrated in Fig. 7.

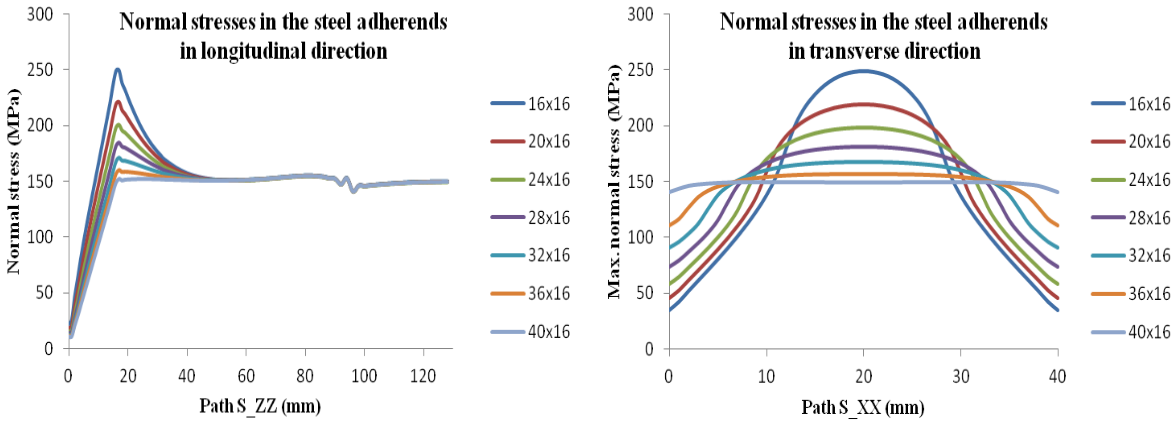

Fig. 6. The normal stress variation in Z and X directions for the seven cases studied

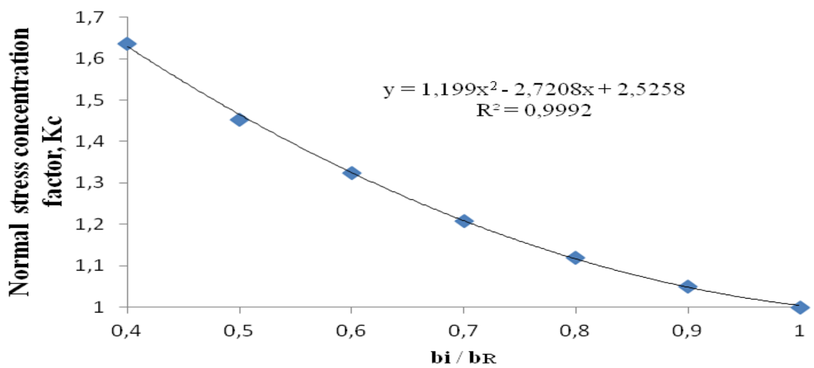

Fig. 7. Stress concentration factor K_c as a function of $^{b_i}/_{b_R}$

The distribution of the shear stress within the adhesive layer in the longitudinal and transverse directions is exhibited in Fig. 8. The concentrated shear stresses are at the ends, as it is expected, the increase of these stresses is because of the reduction of the bonded area.

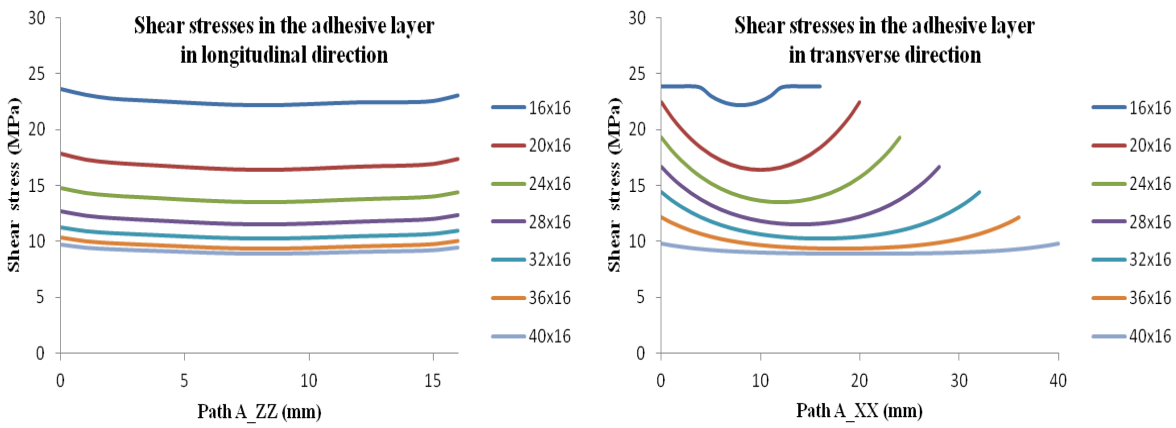

Fig. 8. Shear stresses within the adhesive layer in the longitudinal direction (left) and in the transverse direction (right)

Moreover, the plastic zone, (Fig. 8, right), is obvious in the 7^{th} case (area of 16x16 mm) where the applied load was just under the load causes the yielding in the adhesive layers. The concentration of the peeling stresses can also be observed at the ends of the longitudinal path as shown in Fig. 9.

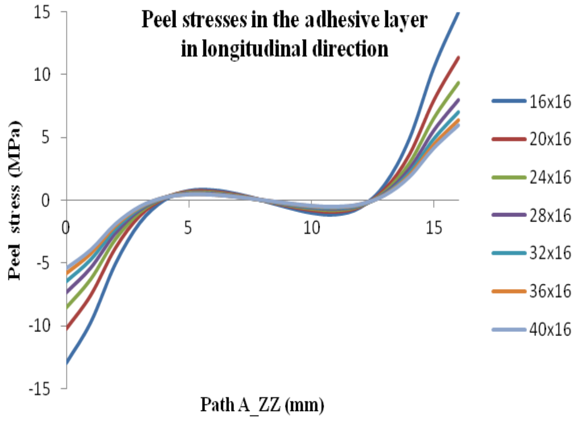

Fig. 9. Peel stresses in the adhesive layer (longitudinal direction)

Conclusion

Three-dimensional finite element model using ABAQUS® software was developed to highlight the changes in the normal stresses acting along the adherends when are assembled together in double lap joint configuration by bonding them using incomplete width of the adherends to reduce the bonded area. The double lap shear joint is composed of galvanized steel sheets assembled by using a structural epoxy adhesive (DP490). Seven cases of variant widths (40,50,60,70,80,90, and 100%) of the adherends width with the same overlap length were studied under a constant tension load. The concentration of the normal stresses along the steel adherends as well as the shear and peeling stresses over the adhesive bondline for each case were obtained. The stress concentration factor K_c due to the reduction of the width of the used bonded area was determined.

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