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Strength Analysis of Resistance Spot Weld and Weld-Bonded Single Lap Joints

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Abstract: **In this study, an experimental tests and numerical analysis is carried out on hybrid/ weld-bonded single-lap joints, in comparison with the spot welded and adhesively bonded joints. A low carbon steel D513 and EDD materials are used. Experimental tests have been carried out for spot weld, adhesive bonded and weld bonded specimens to find the tensile –shear strength of the joints. Epoxy adhesive Terokal 4555B is used to fnd out the maximum load bearing capacity of adhesive bonded and weld bonded joints. Same models are modeled in hyper mesh and analysed with the Ls-Dyna software to validate the experimental results. Using this finite element model, the stress distributions were simulated in terms of Von mises stress in the overlap region. The force–displacement curves of the test results are compared with those of the simulation results.. The effect of changing overlap length showed different strength advantages, upto 26% compared to the spot welded joints and 4% over the adhesive bonded joint.**

Keywords: **Spot-Welded joint, Epoxy adhesive, Weld-Bonded joint, finite element Stress Analysis, Steel.**

1. INTRODUCTION

Weld-bonding technology is an advanced hybrid joining method, in which resistance spot-welding is combined with adhesive bonding. Corrosion at the inner surface of the spot welded joints is avoided and stress concentration around the spot welds is reduced by the application of adhesives, for this reason, the tensile-shear strength of weld-bonded structures being superior to that of spot-welded joints. The conventional joining process increase the weight of the structure by adding extra material such as bolt, screws, extra filler material. If you want to joint two plates by bolting then hole is created in the plate which result in stress concentration or if you joint by weld then there is localized heating of the component take place which alter its mechanical properties. Present work investigates the tensile shear strength obtained by weld bonding technique and compares to the traditional resistance spot welding in mild steel based. A hybrid joint has the advantages of both the adhesively bonded and spot-welded joint. The application of such a joint are: reduces the stress concentration in the spot-weld, increases the strength and the total destruction energy absorption, improves the tightness and the corrosion resistance of spot- welded joints and reduces the vibration of the components.

2. EXPERIMENTAL WORK

A. ***Adhesive and Adherend materials:*** Low carbon steel was selected for the adherents, characterized by good weld ability, ductility and low cost, which makes it a good option for many engineering applications. In the experimental part, the adherents were D513 mild steel of thicknesses (t) 0.96 mm, 1.5 mm and 1.95 mm respectively. The sheet types are increasingly used in car body structures. Their chemical composition and mechanical properties are presented in Table 1 and Table 2.

TABLE 1: Chemical composition of steel sheets

Young's modulus, E [MPa]	Poisson's ratio,μ	Lap shear strength, [MPa]	Density [kg/m^3]	Tensile strength, [MPa]
1887	0.417	20	1070	28.711

TABLE 2: Mechanical properties for steel D513

Material	Yield stress σ_y [MPa]	Tensile strength [MPa]	% Elongation
D513	270-370	280	23.0

A single part epoxy adhesive was used, Terokal 4555B from Henkel Adhesives. The material properties of Terokal 4555B, from the Henkel data sheet, are listed in Table 3. This is an adhesive that has been developed for use in the structural bonding of car body panels. The sheets were slightly preheated before the adhesive application to improve the metal surface wet ability. The adhesive was also preheated to decrease its viscosity and to promote its application on the surface. Thus enabled to achieve a relatively uniform and adhesive thickness of tg=0.2mm The joint faying surfaces were prepared by Sand Grit blasting machine. Then the specimens for adhesive bonding were chemically degreased with acetone. Then, the faying surfaces were put in proper position (lap shear joint) after the application of adhesive with uniform thickness layer of 0.2 mm applied manually on the overlap length. Finally the joints were cured in an oven at 200^{o}C for 30 minutes to obtain cohesive joints.

The weld-bonded joints were fabricated by the weld-through technique, with the welding operation taking place at a maximum of 10 minutes after bonding. The weld – bonded specimen are prepared, from the cleaned low carbon steel sheets, using the same technique of the adhesive –bonded joints followed immediately by resistance spot welding and subsequent curing as stated above.

B. Specimen Geometry

Fig.1 shows the geometry of the joints, for the weld-bonded joints (combination of spot welding and adhesive bonding). Steels D513 were used in experimental tests when reinforcing the adhesively-bonded joint with spot-welding. The specimens were fabricated from 30 mmx100 mm steel sheets. The dimensions were defined as length L=100mm, width, b=30mm, adherent thickness t_P= 1.5 mm. and adhesive layer thickness t_A =0.2 mm for the bonded and weld-bonded joint.

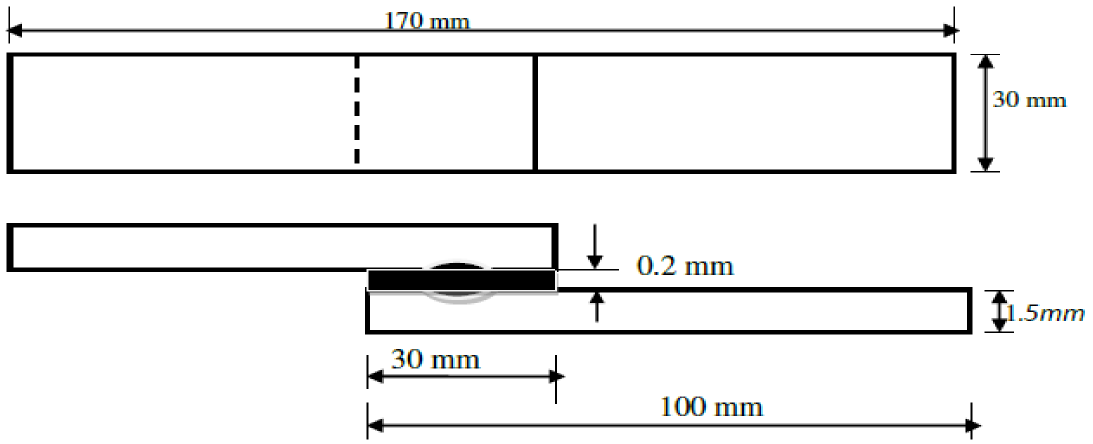

Fig.1: The configuration and dimensions of the weld bonded model

The spot welding machine used for the preparation of spot welded specimen joints is Resistance Spot Welding Machine (90 kVA). The welding electrodes are water-cooled conical copper alloy electrodes, with contact surface of 5.0 mm in diameter. The welding parameters used to fabricate the spot welded joints are as shown in Table 3. The tests were carried out in a Shimadzu AG-I 100 Universal Testing Machine with a 100 kN load cell, at room temperature and under displacement control (1.3 mm/ min) and the and the working area diameter was d=4√t (t=sheet thickness).Fig.2 shows the specimen mounted on Universal testing machine with the specimen clamped in the tensile testing machine jaws. Destructive testing is carried out until the final failure of the joints.

TABLE 3: Welding parameters

Squeeze time cycles	Weld time cycles	Hold time cycles	Off time cycles	% Heat (kA)
35-45	7-13	12-18	15-21	9.5

Fig.2: Specimen mounted on UTM

C. Strength Prediction of Spot welded, adhesively bonded and weld-bonded joints

Fig.3 shows the load –displacement curves for the pure spot- welded and adhesive bonded joints.

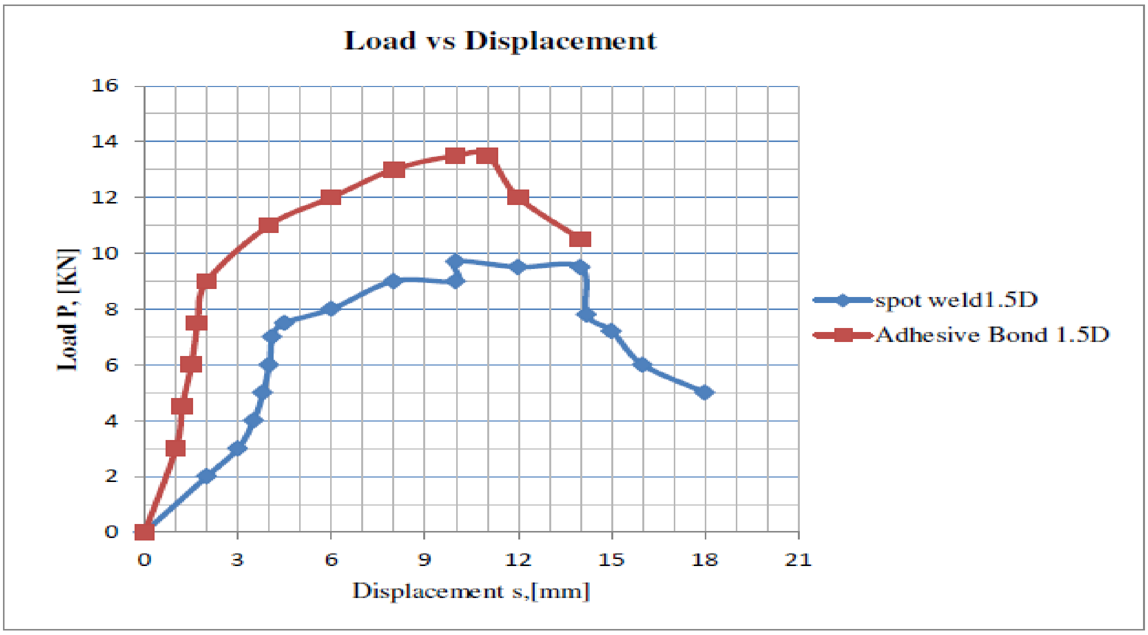

Fig.3: Load –Displacement curves for Spot- welded and adhesive- bonded joints (Material: D513)

In spot welded joints, after reaching the peak force, the force decreases gradually with the tearing process of the base metal around the weld nugget. When the single lap-joints are joined by spot weld, the joint can withstand a maximum load of 10 kN at a displacement of 13 mm, whereas for the adhesive bonded joints it was equal to 13.2 kN with a displacement of 10 mm.

The deformation in the adhesive-bonded joint tests is mainly due to the adherend extension. Failure occurs near the end of each curve. Once it occurs, the force drops rapidly with very little deformation in the adhesive zone. Comparing the specimens test results of the adhesive-bonded joint with those of the spot welded joint, it is found that the adhesive-bond is able to bear relatively larger force inthe lap-shear coupon test.

Two peaks loads are observed in this (fig.4) load-displacement curve. The first peak value corresponds to the load under which the adhesive layer fails, and the second is the maximum force developed when only the spot weld bears load. The symmetric stress conditions developed in the weld-bonded joint make the joint rotate and the tensile-stress is concentrated at the edges of the overlap. When the single lap-joints are joined by spot weld, the joint can sustain a maximum load of 10 kN at a displacement of 13 mm, whereas for the weld- bonded joints it was equal to 13.4 kN with a displacement at ultimate load of 5 mm.

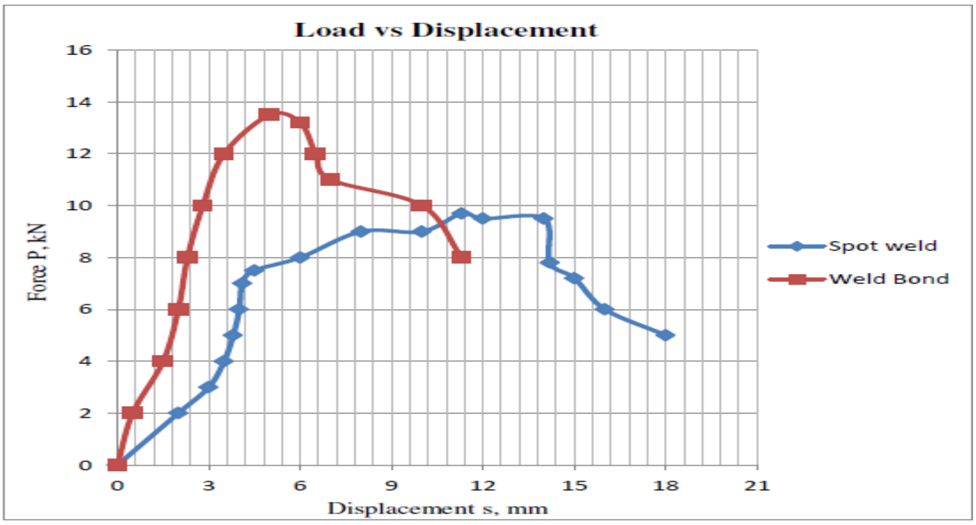

Fig.4.: Load –Displacement curves for spot- welded and weld- bonded joints

Fig.5 shows the comparison of load-displacement curves for spot weld, adhesive bond and weld- bonded joints. In spot welded joints, after reaching the peak force, the force decreases gradually with the tearing process of the base metal around the weld nugget. The loading capacity of the spot welded joints was approximately 10 kN, whereas for the hybrid joints it was 13.4 kN. The introduction of the adhesive layer leads to a significant increase of the maximum force that can be carried by the joints. The maximum load carried by the adhesively bonded joints is nearly equal to that of weld- bonded joints i.e 13.2 kN with a displacement of 10 mm.

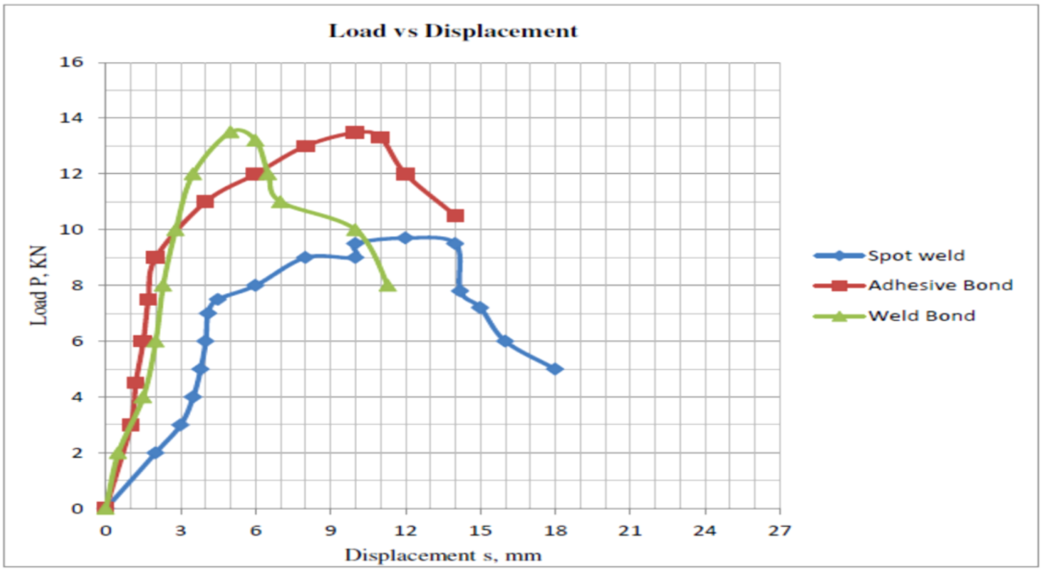

Fig.5: Comparison of Load-Displacement curves for Spot-welded, adhesively-bonded and weld-bonded joint

D. Effect of Changing Overlap Length Size for Spot Weld, Adhesive Bond and Weld –Bonded Joints

Fig.6 shows the load-displacement curves of Spot weld, adhesive bond and weld –bonded joints. For spot welded joints with overlap length equal to 25 mm, the maximum load bearing capacity is 9.7 kN at a displacement of 13 mm. whereas for the weld-bonded joints with the same overlap length, the maximum load capacity was equal to 12.9 kN and the displacement reaches 11 mm.

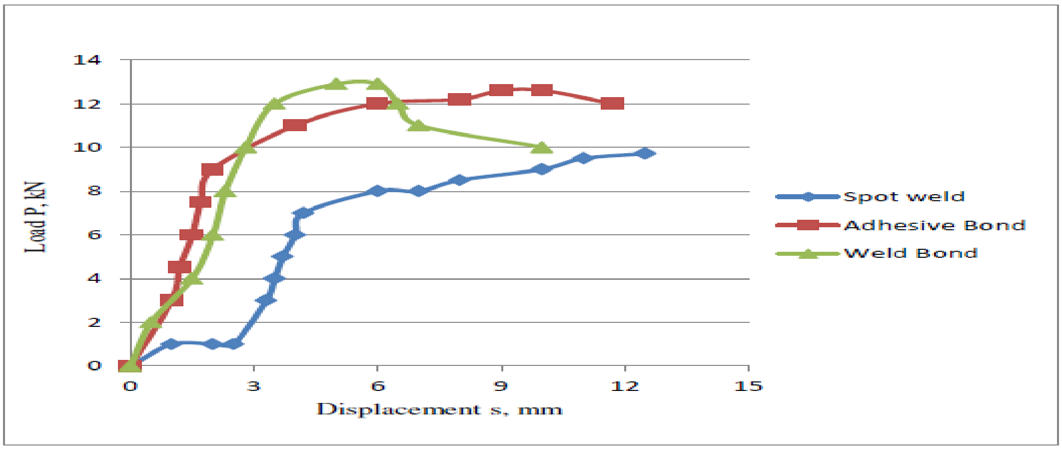

Fig.6: Load-Displacement curves of three types of joints (Lo=25 mm)

The introduction of the adhesive layer leads to a significant increase of the maximum force that can be carried by the joint. When they are joined by adhesive, the load reaches 12.6 kN and the displacement reaches 12 mm. So by decreasing the overlap length size the strength of spot welded joints is decreased by 3%.

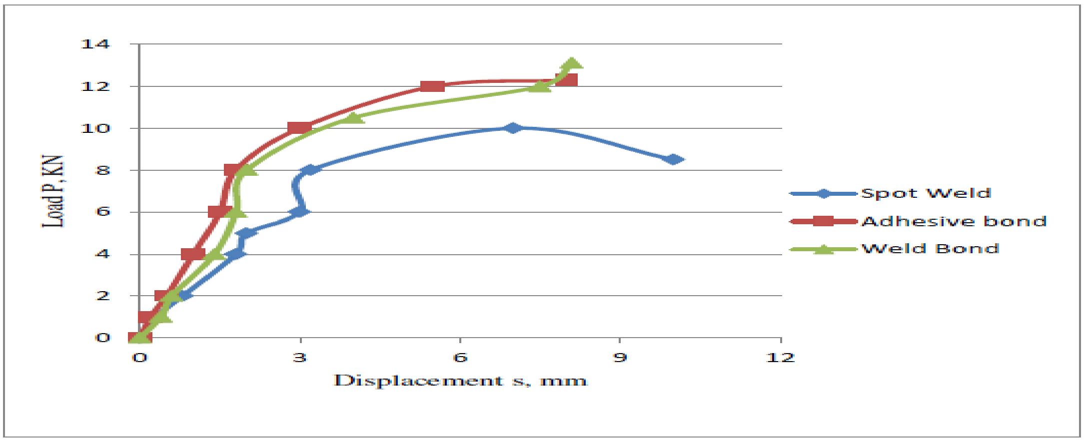

Fig.7: Load-Displacement curves of three types of joints (Lo=45 mm)

Fig.7 shows the load-displacement curves of spot weld, adhesive bond and weld-bonded joints for 45 mm overlap length. For spot welded joints with overlap length equal to 45 mm, the maximum load bearing capacity is 10 kN at a displacement of 7 mm. Whereas for the weld-bonded joints with the same overlap length, the maximum load capacity was equal to 13.1 kN and the displacement reaches 8 mm. When they are joined by adhesive, the load reaches 12.3 kN and the displacement reaches 7.5 mm. Regarding the effectiveness of the traditional joining method, the weld bonded joint surpasses the spot welded joint for Lo=45 mm. By increasing the overlap length size from 25 mm to 45 mm for spot welded joints there is non-negligible improvement in its strength.

The weld-bonded joints shown in Fig.8 are made with D513 steel plates and epoxy-based terokal 4555B adhesive. Tests are carried on a Universal testing machine at a constant velocity rate of 1.3 mm/min. The fig. shows the prepared specimens and the tearing of the weld bonded joints.

(a) (b)

Fig.8: The weld bonded joints before tensile-shear test (a) and (b) after tensile shear test

The spot welded joints as shown below in the Fig.9 (a). For the spot welded joints a spot weld was centered on a 30 mm overlap region. Tensile-shear tests were performed at a cross head of 1.3 mm/min with a Shimadzu universal testing machine. Failure modes were determined from the failed samples.

The adhesive bonded specimens after tensile shear test are as shown in the Fig.9 (b).The adhesive layer was applied for 25 mm, 30 mm and 45 mm overlap region respectively.

Fig.9: The spot welded (a) and the (b) adhesive bonded joints after tensile shear test

3. FINITE ELEMENT MODELING AND BOUNDARY CONDITIONS

By using accurate dimensions the solid model of spot welded single lap joints is generated using Catia V5 software. Spot weld model is similar to weld-bonded except that it does not have an adhesive layer around the nugget. The total length of each model is 170 mm and width is equal to 30 mm and width is equal to 30 mm.The overlap length is 30 mm.

Symmetric boundary conditions are applied along the x-axis side. As a result of that, two constraints are imposed. The rotation and horizontal displacement at the line of symmetry are zero. The boundary conditions and constraints are shown in the Fig.10. The applied load is taken to be a small load (500 N), the displacement and accordingly the stresses are assumed to be proportional to the load. To approximate the static conditions in the solver, one end of the coupon is fixed and the other end is pulled with a constant velocity of 1 m/s in the FE simulations.

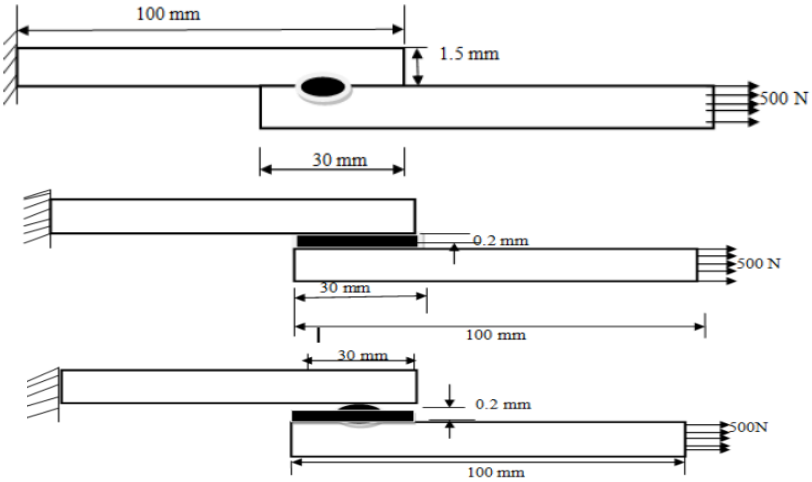

Fig.10: Finite element model for spot weld, adhesive bond and weld bonded joints

TABLE 4: Physical and mechanical properties: Terokal 4555B

Young's modulus, E [MPa]	Poisson's ratio,μ	Lap shear strength, [MPa]	Density [kg/m^3]	Tensile strength, [MPa]
1887	0.417	20	1070	28.711

A. Finite Element Mesh

The finite element computation is carried out using Hypermesh/Ls-Dyna software. For the FEM model, the elements used throughout the modeling are linear quadrilateral elements. The size and bias is applied for the whole geometry and element size is give as 10 mm. MAT_JOHNSON COOK model in LS-Dyna is used to model the adherends (i.e. metal sheets). For weld nugget the numbers of elements were 847. A fine mesh is used in the nugget of the solid element model. To create a spot weld nugget , eight rigid elements are used to represent the nugget and evenly share the cross section area of the nugget. The spot weld nugget diameter is taken as 5 mm.(d=4√t). The mesh of bonded model is straight forward and simpler because of the absence of spot welding, and it reaches mesh independent solution with a relatively coarse mesh. The adhesive layer contains 953 elements. Mat_Elastic property is used to model the adhesive layer. Single lap weld bonded joints with 3496 elements and 5914 nodes. However, the weld-bonded model needs additional finer mesh on the edges of spot weld and adhesive layer to avoid error analysis. A fine mesh is used for the solid weld nugget.

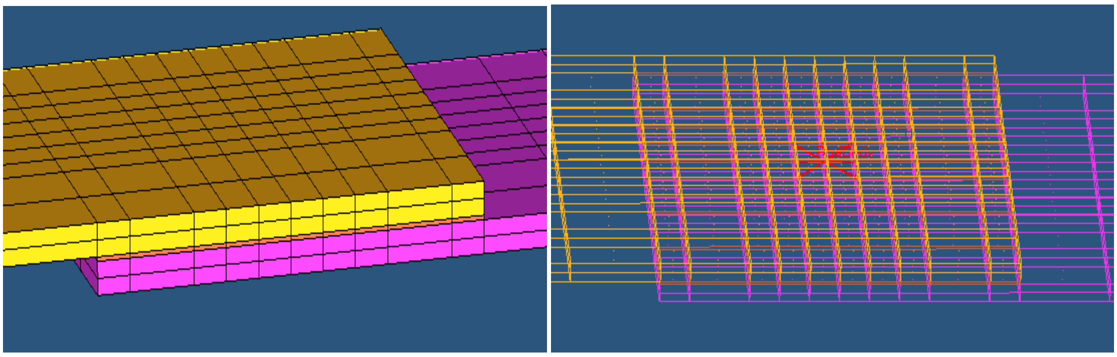

Fig.11: Meshed details of the weld bonded joints

B. Static Analysis of the Spot, Adhesive and the Weld bonded Joints

Fig. 12 shows von Mises equivalent stresses at the spot-welded joints in the overlap region, emphasizing the large joint rotation due to the loading asymmetry and peak stresses at the weld- nugget peripheryIn the analysis carried out, one end is constrained while at the other end axial load of 500 N is applied. In the overlap region, (Lo=30 mm) the stresses recorded were 765 MPa at a load of 5 kN where yielding takes place. The maximum tensile stresses recorded were 1057 MPa at a load of 8 kN. From the figure, it can be seen that the tensile-shear stresses are concentrated at the far ends of the weld nugget in case of spot-welded joint. It is worth noting that the spot-welded joint shows a 386 % higher stress concentration, when compared with the weld-bonded joint.

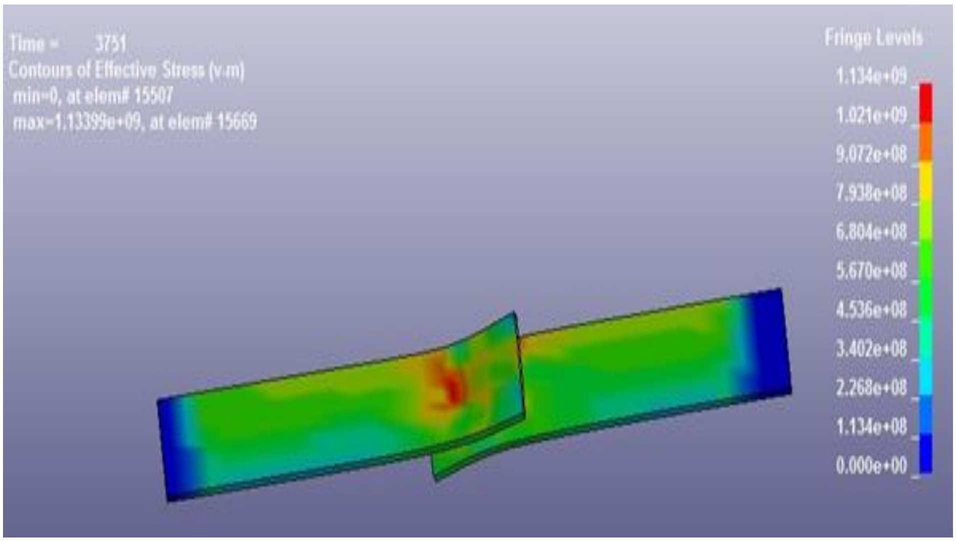

Fig.12: Von mises equivalent stress for Spot welded joints

Fig.13 shows the Von mises effective tensile stresses at the adhesive-bonded joints in the overlap region (Lo=30 mm). The stresses are concentrated at the far ends of the over- lap region in case of adhesive bonded joints. The stresses recorded were 300 MPa at a load of 7 kN which are nearly same as that of weld bonded joint.

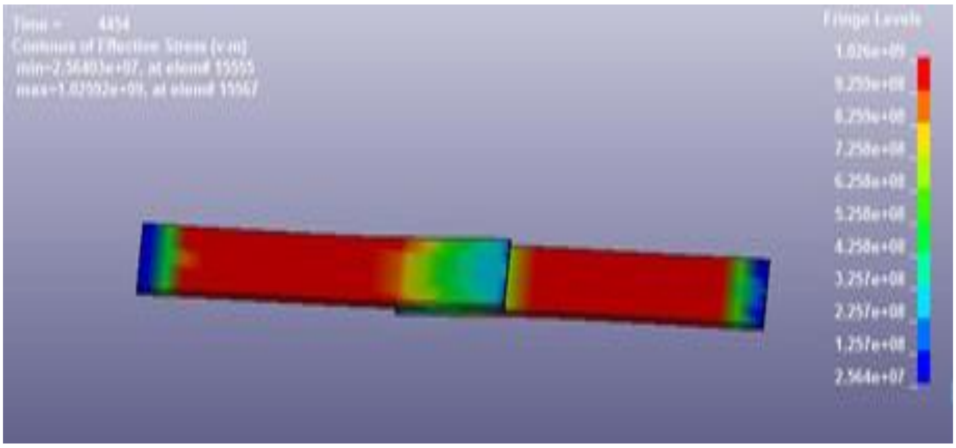

Fig.13: Von mises equivalent stress for adhesive bonded joints

Fig.14 shows the Von mises effective tensile stresses at the weld-bonded joints in the overlap region (overlap length, Lo=30 mm). The maximum tensile stresses recorded were 210 MPa at a same load of 7.4 kN as that for the spot welded joint. The stresses are considerably reduced by the introduction of adhesive layer at the mid portion. Above yielding point, i.e.at a load of 10.7 kN the stresses recorded were 340 MPa and that for spot welded joint they showed 188% higher stress concentration. The stress of the spot-welded joint is nearly five to six times, when compared to weld-bonded joints, respectively

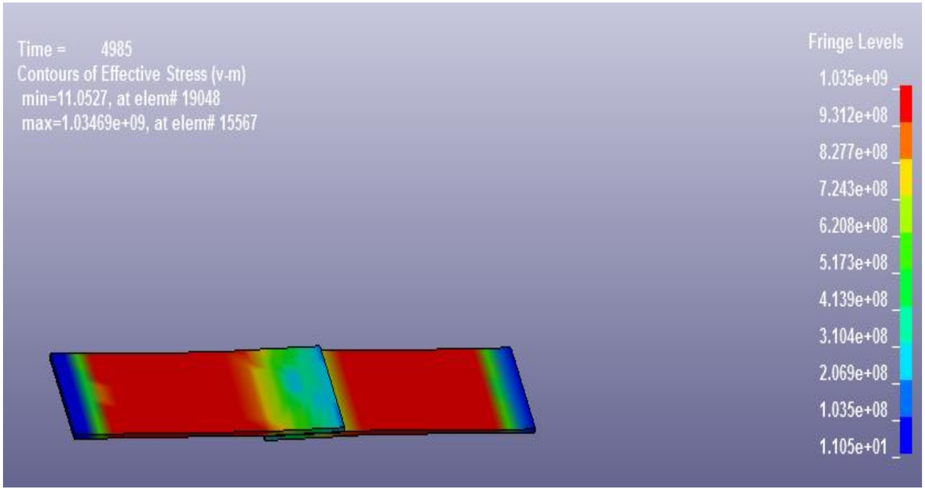

Fig.14: Von mises equivalent stress for Weld-Bonded joints

4. RESULTS AND DISCUSSION

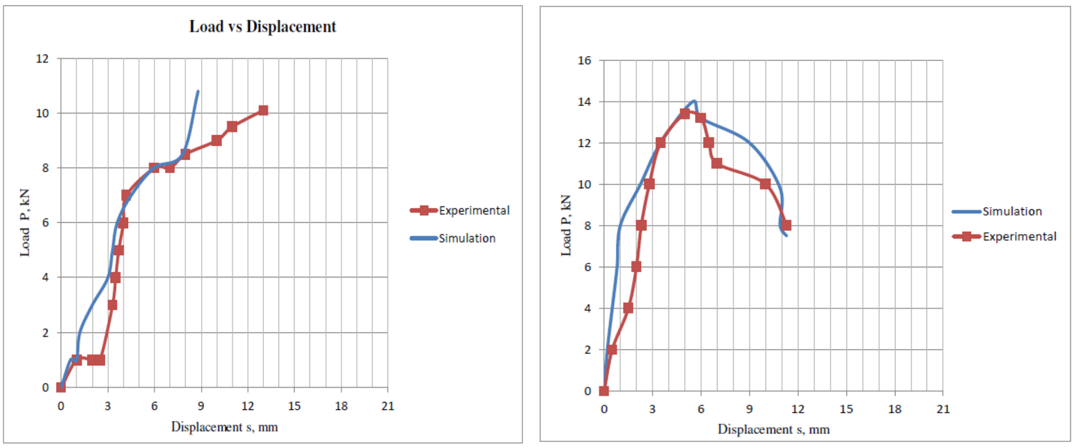

Fig.15: Experimental and simulation P–s curves for the Spot weld and Weld bonded joints (Lo=30 mm)

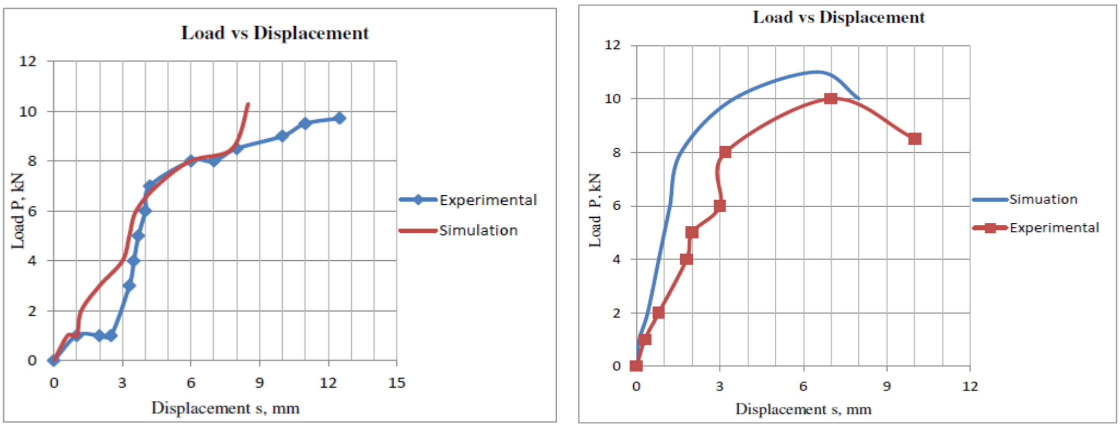

Fig.16: Experimental and simulation P–s curves for the Spot weld and Weld bonded joints (L_o=25 mm)

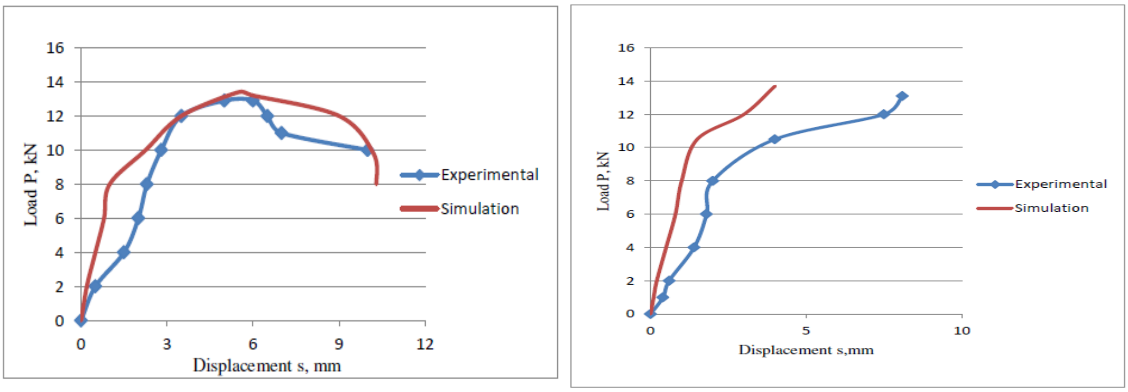

Fig.17: Experimental and simulation P–s curves for the Spot weld and Weld bonded joints (Lo=45 mm)

Fig.15 shows the load-displacement curves that were obtained from the FE modeling and corresponding experimental results from the actual spot-welded and weld bonded joint**.** The load capacity calculated in the simulation model was approximately 7 % higher in comparison to the experimental one. The results are in very good agreement with the simulation results. The strength comparisons between the three joining techniques showed a marked advantage of weld-bonding over the traditional spot welding for Lo=30 mm. For the overlap length Lo=25 mm the values of stress were lower than for a large overlap length such as Lo=45 mm. The maximum loading capacity of weld bonded joints was found to be 13.4 kN experimentally and through simulation results it was 14 kN. A good correlation is obtained between experimental tests and the simulation results with an error of 4.2 % (overlap length= 30 mm)

Fig. 16 and Fig.17 the maximum load (Pm) carried by the spot weld is 10 kN experimentally. These results are in very good agreement with the simulation results, except at the plastic region where a maximum acceptable error of 9 % was observed. By changing overlap length from L_0= 25 mm to L_0= 45 mm the tensile- shear strength of spot welded joints is improved by only 3%.

5. CONCLUSION

1. The strength comparisons between the three joint techniques showed a marked advantage of weld-bonding over the traditional spot welding for L_O=30 mm. Bigger values of Lo (i.e. overlap length) revealed a smaller influence on the strength improvement to the bonded joints ,even though they were recommended over spot welding**.**

2. The effect of changing overlap length allowed achieving different strength advantages, up to 35% compared to the spot welded joints. For overlap length Lo=30 mm, the adhesive bonded joints showed 32% increase in its tensile shear strength when compared with the spot welded joints..

3. Using the finite element model, the stress distributions were simulated in terms of Von Mises stress at several point of loads. The stresses recorded in spot welded joints (469 MPa) were three to four times higher than weld bonded joints (169 MPa) at the same joint loading.

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