REINFORCING BOLTED LAP SHEAR JOINTS OF LIGHT GAUGE COLD-FORMED STEEL MEMBERS

Fathy Abdelmoniem Abdelfattah
Civil Eng. Dept.
Zagazig University, Zagazig, Egypt.

Aly A.H. Aly Abdo
Structural Eng. Dept. Faculty of Engineering,
Alexandria university, Alexandria, Egypt.

ABSTRACT

This research proposes a method for reinforcing bolted lap shear joints of light gauge cold-formed members. The study investigates experimentally the behavior of this reinforced joint and obtains its yielding and ultimate loading capacities and compares them with those of bolted joints and with the design values calculated using the AISI specifications. The results show 27.6% improvement in the yielding load of reinforcing joints compared with that of bolted joints.

Keywords: Joints-bolted, Joints-lap shear, Joints-reinforcing, Joints-cold formed members, Adhesive

INTRODUCTION

Members of cold-formed sections are used in construction industry as beams, columns, sheds, portal frames, roof purlins and others. Cold-formed sections offer great variety of shapes and are often very thin. This allows considerable savings in the material weight. The research in the behavior of cold-formed sections and their connections started as early as 1939 in the United States of America by professor Winter G. A review of research developing is presented by Descude, (1974). Bakker and Stark, (1974) described the European research programme on the joining of thin cold rolled sections.

Bolts, screws, rivets, welds and adhesives are the different fastening systems for joining members of thin cold rolled sections. Adhesives are not commonly used in structure engineering. However, the hope of finding an easy and efficient alternative to traditional mechanical fastening methods in the industry of light gauge steel fabrications intensifies the interest in adhesives. Kozma and Olefjord (1987) presented the different types of adhesives for joining steel and reviewed the methods of surface preparations of steel for bonding. Gasparini (1990) examined the feasibility of connecting steel to steel with adhesives. The mechanical properties of structural adhesives, fabrication procedures and properties of bonds are discussed. Mays (1985) reviewed the use of adhesives in civil engineering considering typical applications. Fatigue strength of adhesively bonded joints was studied by Albrecht (1987) and Martin (1992).

Welding and bolting are commonly used for structural connections. In this case connections should satisfy the required strength and rigidity in addition to economy and durability. These requirements are formulated in specifications and codes of practice. The American Iron and Steel Institute Specifications for the design of cold-formed steel structural members AISI (1986) applies when the thickness of the thinnest part of the joint is less than 3/16 inch. The specification makes no differentiation between bearing and friction type joints. Joint loading capacity is calculated considering the edge distance, bearing and nominal strength and the yield load of the joint net section. Bolt allowable shear loading capacity is another factor. The Swedish code for light - gauge metal structures (1982) provides two formulas to determine bolt loading capacity. The first is related to bolt shear failure. The second is applied when high strength friction grip bolts are used. It determines the joint slip load depending on the friction coefficient values for different surface treatments. Another formula for bearing failure is provided. The use of these formulas is limited to bolts of size M10 to M16 and of grades 8.8 and 10.9.

In bolted shear lap joints, the thickness of the steel of light gauge cold-formed members in comparison to bolts diameter provides poor values of bolts in bearing, Harold (1974). Another value that may determine the joint failure is the yielding load of the joint net cross section. The research presented herein proposes a method for reinforcing bolted lap shear joints of light gauge cold- formed members. This is expected to elevate the joint strength and stiffness. The study investigates experimentally the behavior of the proposed reinforced lap shear joints and determines its yielding and ultimate loading capacities. The results are compared to bolted joints and to values calculated using AISI specifications.

REINFORCING BOLTED LAP SHEAR JOINTS

Packing plate of the same steel type, width and thickness of the joint plate is prepared. This plate is called herein the " reinforcing plate ". It should contain the same number of bolts holes having the same diameter and in the same positions as in the joint plate, Figure (1). The reinforcing plate length is limited to the joint length. Both the joint plate and the reinforcing plate are bonded using structural adhesive so that the centers of the bolts holes in the two plates become typical. After the required curing time for the adhesive, the two plates become one unit. Bolting this unit to another one would form a joint that has relatively high stiffness and strength. This joint is called herein a reinforced joint.

TEST PROGRAMME

A total number of 33 lap joints were tested. These are 15 bolted joints and 18 reinforced joints. Due to symmetry of lap joints only one plate is made from cold rolled steel having different details as described below, Table (1). This is considered the test specimen. The second plate is made from hot rolled steel of 10.0 mm thickness, Figure (2a). Five pieces of the second plate were prepared for the use several times in the test programme.

DESCRIPTION OF SPECIMEN

All the specimens were cut from one cold rolled steel sheet having a thickness of 2.0 mm. Specimens length was made equal to 600.0 mm. The width was made equal to 60.0 mm in case of joints with one row of bolts and 120.0 mm in case of joints with two rows of bolts, Figure (1). Reinforcing plates, in case of reinforced joints, were cut from the same cold rolled steel sheet having the same width values of the specimens but different lengths as shown in table 1. Bolts holes were made by drilling having a diameter of 13.0mm.

MATERIAL PROPERTIES

(i) *Steel*

Three tensile tests were carried out to define the yield and ultimate tensile strength values of the virgin steel. Flat elements of width 60.0 mm were cut from the same cold rolled steel sheet of the specimens. The relationship between the applied load and deformation was found. The results of the three tests were nearly identical. The average values of the yield and ultimate tensile strength are 232.0 N/mm^2 and 349.0 N/mm^2 respectively. This steel can be classified according to the American specification for the design of cold- formed steel structural members, AISI, as cold rolled carbon steel ASTM A611 85 grade C.

(ii) *Bolts*

Bolts were supplied in grade 8.8 and size M12 complying with DIN 931. The nuts used were of grade 8, DIN 931. The minimum yield and ultimate tensile strength values specified in DIN 18800 of this grade of bolts are 640.0 N/mm^2 and 800.0 N/mm^2 respectively. Ordinary black bolts of grade 4.6 were used in some joints. The yield and ultimate tensile strength values for this grade of bolts are 240.0 N/mm^2 and 400.0 N/mm^2 respectively, DIN 18800. Godley and Needham (1982) found that the average ultimate shear strength value of the bolts of grade 8.8 is 680.0 N/mm^2. This is 85% of the minimum specified tensile strength and 69% of the tensile strength values obtained in their experimental work. Fisher and Struik (1974) found that the ultimate shear strength of a bolt is equal to 62% of the tensile strength of the bolt considering its nominal area. They reported that this percentage is independent of bolt grade. However, when the shear plane passes through the threaded portion of the bolt, it becomes 47%. In the Swedish code for light - gauge metal structures (1982) , this percentage is taken equal to 40% .

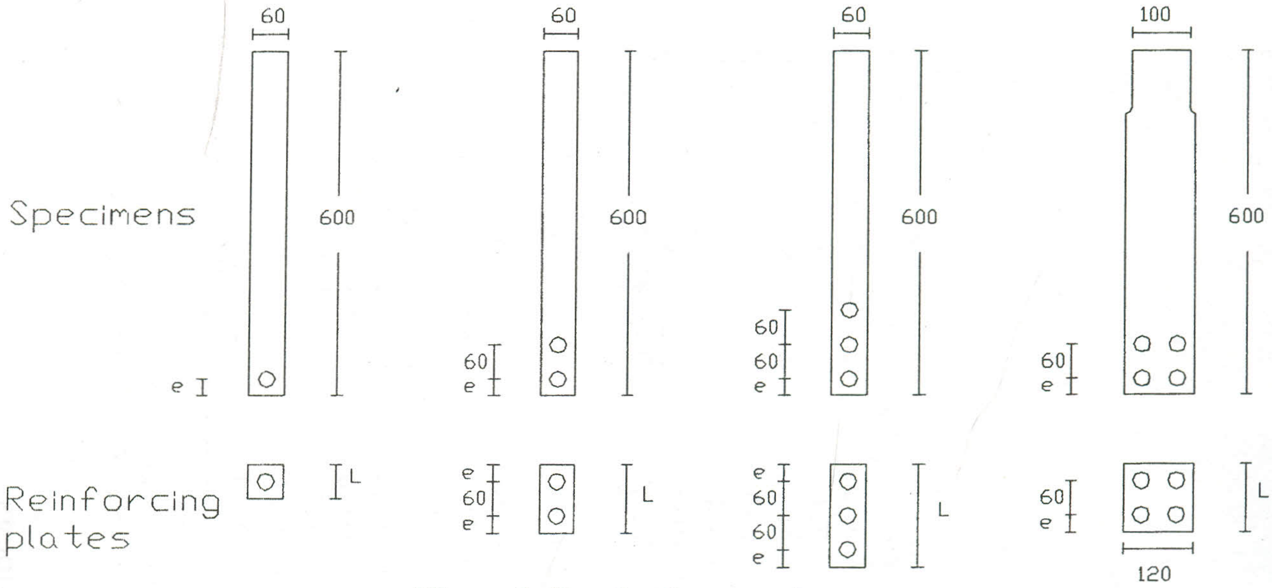


Figure 1. Details of test specimen

(iii) *Adhesive*

Two-component epoxy resin was used in this study. It is supplied by CIBA-GEIGY Egypt with the commercial names Araldite AV 1344 and Hardener HV 1344. It is a cold curing thixotropic adhesive for bonding metals, and other materials. It has good resistance to water and most commonly used solvents. The curing time is 8 hours at 25° C or 3 hours at 40° C. The average lap shear strength of metal to metal joints at 25° C is 15 N/mm^2 .

ASSEMBLY OF BOLTED JOINTS

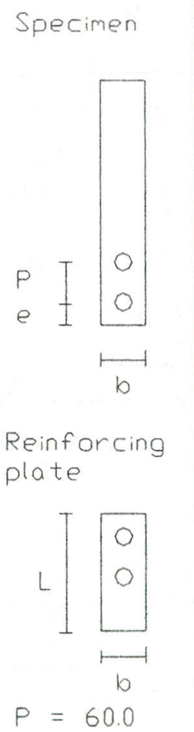
Each specimen was connected to another plate having the same length but cut from hot rolled steel sheet made from steel 37. The plate has a thickness of 10.0 mm and a width of 60.0 mm in joints of one row of bolts and 100.0 mm in joints of two rows of bolts, Figure (2a). It was used to increase the grip length of the joints material. Bolts were placed in their holes so that their heads were placed on the specimen side. Washers were placed under both the bolts heads and nuts. Tightening was carried out from the nut side using hand spanner. In friction type joints, torque wrench was used to provide a torque of 8.4 Kg.m for tightening the bolts of grade 8.8.

ASSEMBLY OF REINFORCED JOINTS

Abrasive cleaning was carried out to both the specimen and the reinforcing plate surfaces to remove oxide layer and rust that formed during processing, handling and storing. This would increase the surface roughness and consequently, the effective area for bond formation, Kozma and Olefjord (1987). Decreasing of the surfaces was carried out by Acetone. The two- component epoxy resin were mixed thoroughly in the specified ratio, 1 to 1 by volume , at room temperature which is about 20° C. The resin / hardener mix was applied with a spatula to the pretreated dry surfaces of the specimen and the reinforcing plate. The specimen and reinforcing plate were adjusted so that the centers of the bolts holes in the two plates become typical. The reinforced specimens were left for at least 10 days at 20° C for curing. The remaining steps for assembling reinforced joints are typical as described before for bolted joints.

TEST PROCEDURE

The joints were placed in the testing machine as shown in Figure (2). The specimens of 60.0 mm width were tested in a 300.0 KN. universal testing machine and those of 120.0 mm width were tested in a 1000.0 KN universal testing machine. The latter machine allows the use of specimens with maximum width of 100.0 mm only. This necessitates the modification of the specimen width ,120.0 mm, as shown in Figure (1). The load - deformation relationships and ultimate loads of the joints were recorded.

Bolted joints [1]					Reinforced joints [1]						Notes
Name	Bolts [2]			b	Name	Bolts [2]			Adhesive [3]	b	
	No.	e	grade			No.	e	grade	L X b		
Bb1e20	1	20	4.6	60	Rb1e20	1	20	4.6	40X60	60	
Bb1e30	1	30	4.6		Rb1e30	1	30	4.6	60X60		
Bb1e30'	1	30	4.6		Rh1e30	1	30	8.8	60X60		
Bb1e30''	1	30	4.6		BN1e30	1	30	4.6	60X60 N		
Bh1e30	1	30	8.8		BN1e30'	1	30	4.6	60X60 N		
Bb1e40	1	40	4.6		Rb1e40*	1	40	4.6	40X60		
Bb1e40'	1	40	4.6		Rh1e40	1	40	8.8	80X60		
Bb2e30	2	30	4.6		Rb2e30	2	30	4.6	120X60		
Bh2e30	2	30	8.8		Rh2e30	2	30	8.8	120X60		
BH2e30	2	30	8.8 f		RH2e30	2	30	8.8 f	120X60		
Bb3e30	3	30	4.6		Rb3e30	3	30	4.6	180X60		
Bh3e30	3	30	8.8		Rh3e30	3	30	8.8	180X60		
BH3e30	3	30	8.8 f		RH3e30	3	30	8.8 f	180X60		
Bb4e30	4	30	4.6	120	Rb4e30	4	30	4.6	120X120	120	
Bh4e30	4	30	8.8		Rh4e30	4	30	8.8	120X120		
					Rh4e30'	4	30	8.8	120X120		
					Rh4e30*	4	30	8.8	180X120		
					Rh4e30*'	4	30	8.8	180X120		

1 All dimensions in millimeters
2 Bolts of size M12
3 Minimum curing time is 10 days at 20 C°

f Friction type joint
N Reinforcing plate not adhesived

Table 1 : Details of bolted and reinforced joints

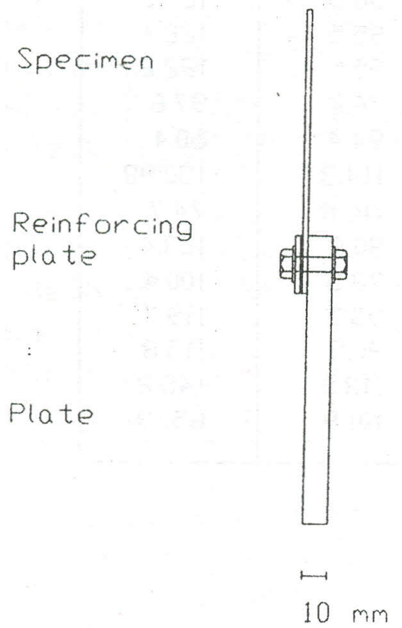


Figure 2a. Assembly of test joints

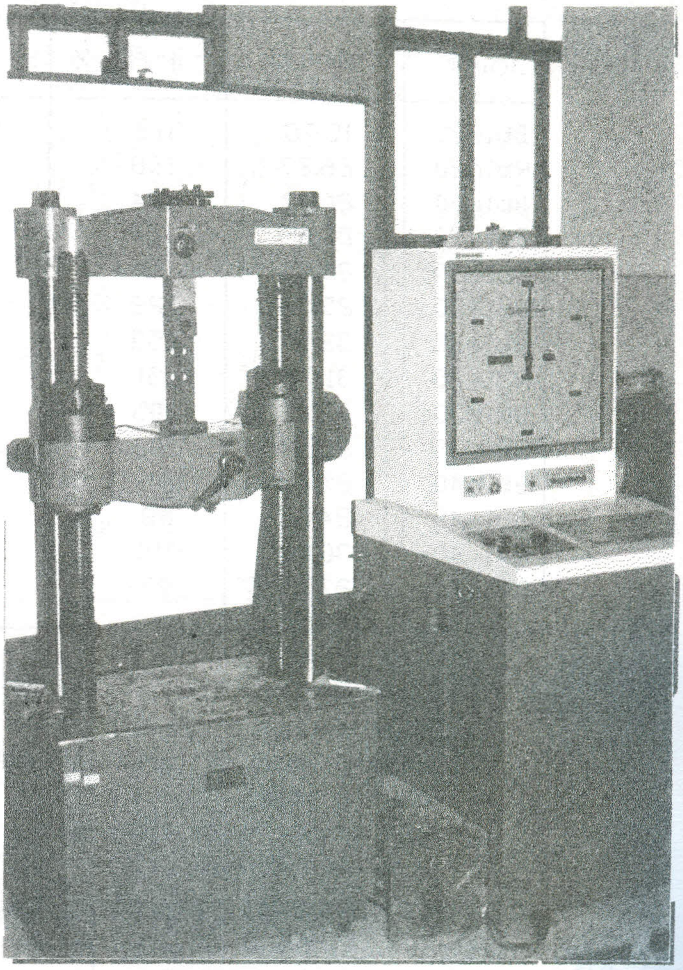


Figure 2b. Test arrangements

RESULTS

The ultimate loads of the specimens tested were obtained . Other four values for each joint were calculated using AISI. They are the ultimate loads of the joints when considering the edge distance, net section, bearing and bolts shear capacity. The experimental values and their percentages to these four values are presented in Tables (2) to (4). The results of the joints with single bolt are presented in Table (2). Figures (3-5) show their load -deformation relationships. The results of the joints with two and three bolts are presented in Table (3). Figures (6-9) show the load-deformation relationships obtained. Figures (10-11) show the behavior of friction type lap joints. Table 4 and Figures (12) and (13) present the results of the joints with four bolts. Figures (14) and (15) show the different failure modes of reinforced and bolted joints.

The load - deformation relationships of joints Rb1e20 and Bb1e20 are presented in Figure (3). The two joints have the same details except the first is reinforced as described above. Joint Rb1e20 shows a stiffer behavior and higher loading capacity. At load 26.27 KN the test was stopped, due to out of hand reasons. This value equals 166% of joint Bb1e20 ultimate load and 94% of the yield load of the gross cross section of the specimen. At this load both the reinforcing plate and the joint plate were acting together as one unit. No slip between the two plates occurred. They deformed at the bolt hole as shown in Figure (14a). Joint Bb1e20 failed by bearing and cracking of the specimen, Figure (14a).

Bolted joints Bb1e30, Bb1e30`, Bb1e30`` and Bh1e30 have the same details.

Table 2. Results of joints with single bolt.

Joint	F KN	F/P_e %	F/P_n %	F/P_r %	F/P_b %
Bb1e20	15.78	113	68.7	57.9	74.2
Rb1e20	26.27 S	188	114.4	96.5	123.5
Bb1e30	26.03	124	113.3	95.5	122.4
Bb1e30′	26.0	124	113.2	95.5	122.2
Bb1e30″	20.75	99	90.3	76.2	97.6
Bh1e30	25.70	122	111.9	94.4	60.4
Rb1e30	32.10	153	139.8	114.3	150.98
Rh1e30	31.78	151	138.4	116.8	74.7
BN1e30	22.0	105	95.8	80.8	103.4
BN1e30′	21.36	102	93.0	78.5	100.4
Bb1e40	25.45	91	110.8	93.5	119.7
Bb1e40′	24.62	88	107.2	90.5	115.8
Rb1e40*	30.88	110	134.4	113.5	145.2
Rh1e40	27.72 S	99	120.7	101.9	65.19

- F Experimental failure load in KN
- P_e Edge distance ultimate load
- P_n Yielding load of joint net section
- P_r Bearing load
- P_b Bolt shear load failure
- S Test is stoped

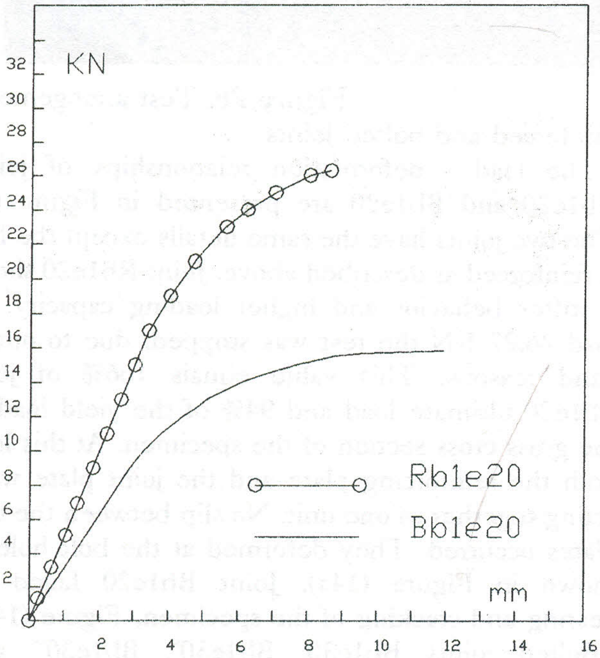


Figure 3. Load-deformation relationship of joints Rb1e20 and Bb1e20.

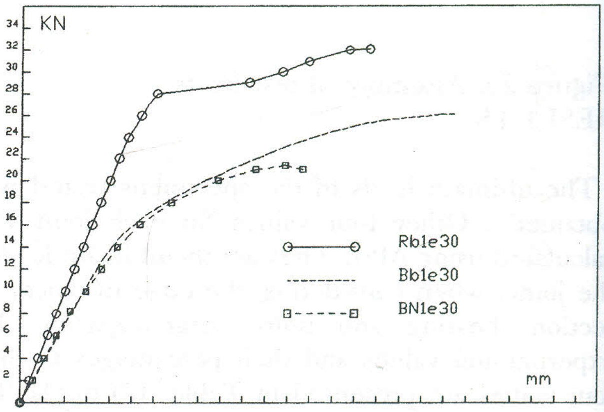


Figure 4. Load-deformation relationship of joints Rb1e30, Bb1e30 and BN1e30.

Joint	F KN	F/P_u %	F/P_n %	F/P_r %	F/P_b %
Bb2e30	32.58	99.3	149.4	119.7	76.6
Bh2e30	33.44	101.8	153.3	122.9	39.3
BH2e30	32.92	100.3	151.0	121.0	38.71
Rb2e30	33.74	102.8	154.7	124.0	79.35
Rh2e30	32.5	99.0	149.0	119.4	38.2
RH2e30	32.78	99.9	150.3	120.5	38.5
Bb3e30	33.08	100.8	151.7	121.6	51.8
Bh3e30	33.50	102.1	153.6	123.1	26.2
BH3e30	33.96	103.5	155.7	124.8	26.6
Rb3e30	33.18	101.1	152.2	121.9	52.0
Rh3e30	33.10	100.9	151.8	121.7	25.9
RH3e30	33.96	103.5	155.7	124.8	26.6

- F Experimental failure load in KN
- P_u Ultimate load of joint net section
- P_n Yielding load of joint net section
- P_r Bearing load
- P_b Bolts shear load failure

Table 3 : Results of joints with 2 and 3 bolts

Joint	F KN	F/P_u %	F/P_n %	F/P_r %	F/P_b %
Bb4e30	68.80	104.8	157.7	126.3	80.9
Bh4e30	68.40	104.2	156.8	125.6	40.2
Rb4e30	69.85	106.4	160.2	128.3	82.1
Rh4e30	70.70	107.7	162.1	129.8	41.5
Rh4e30′	67.90	103.5	155.7	124.7	39.9
Rh4e30*	69.05	105.2	158.3	126.8	40.6
Rh4e30*	70.65	107.6	162.0	129.7	41.5

- F Experimental failure load in KN
- P_u Ultimate load of joint net section
- P_n Yielding load of joint net section
- P_r Bearing load
- P_b Bolts shear load failure

Table 4 : Results of joints with 4 bolts

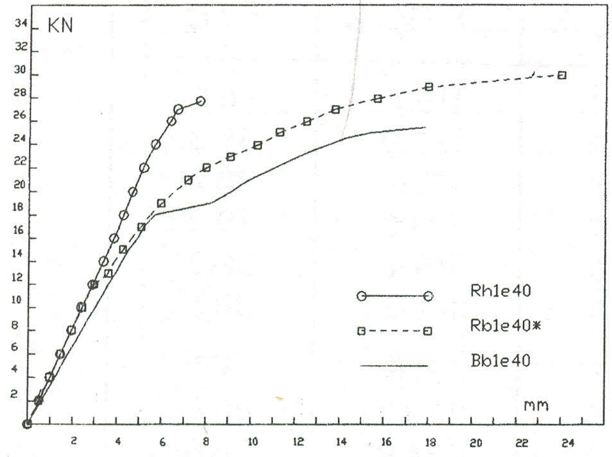


Figure 5. Load-deformation relationship of joints Rh1340, Rb1e40* and Bb1e40.

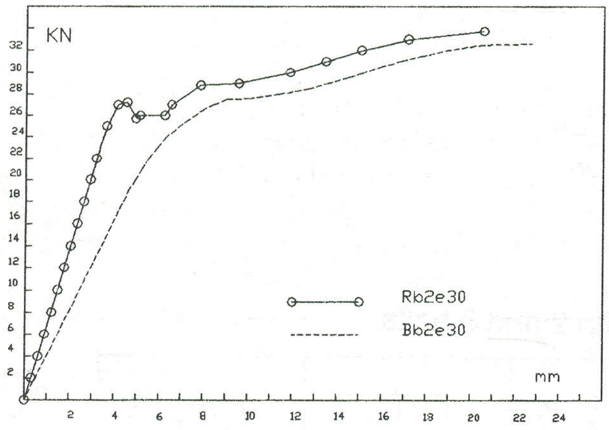


Figure 6. Load-deformation relationship of joints Rb2e30 and Bb2e30.

The bolts in Bh1e30 were of grade 8.8. The joints failed nearly at the same load, Table (2). They failed by bearing and pilling of the thin plate at the edge of the specimen, Figure (14b). Joint Bb1e30`` showed lower ultimate loading capacity and failure mode similar to that of Bb1e20. The reinforced joints Rb1e30 and Rh1e30 showed the same behavior and failed at the same load, Table (2). Joint Rb1e30 behaved in a linear manner until a load of 28.0 KN, Figure (4). This equals the yield load of the gross cross section of the joint plate. The ultimate capacity of the joint is equal to 122% of that of joint Bb1e30 and 98% of the ultimate load of the joint plate net cross section. At failure, slip occurred between the reinforcing and joint plates. Bearing occurred mainly in the joint plate, Figure (14-b). Joints BN1e30 and BN1e30` have the same details as Rb1e30 except the reinforcing plates were not adhesived to the joint plates. The joints failed at load lower than that of Bb1e30 and with different mode. The reinforcing plate, served in this case as a packing plate, prevented the joint plate pilling and promoted crack initiation and propagation at the plate edge, Figure (14b).

Joint Rh1e40 showed stiffer behavior than Bb1e40, Figure (5). At a load of 27.72KN, the test was stopped. Both the reinforcing and joint plates were acting as one unit and deformed by bearing at the bolt position. Joint Rb1e40* failed at load of 30.88 KN due to shear failure of the bolt,
Figure (14c).

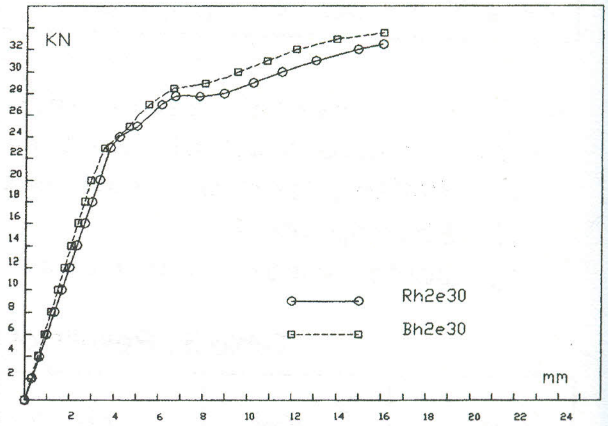


Figure 7. Load-deformation relationship of joints Rb2e30 and Bb2e30.

Both bolted and reinforced joints with two and three bolts behaved initially in a linear manner, Figures (6-9). This changed when the joint yield load was reached. This was found to be equal to the yield load of the net cross section in bolted joints and the yield load of the gross cross section in reinforced joints. This provides 27.6% improvement in the yield load of reinforced joints. The reinforcing plate in this case substituted the reductions occurred in the cross section of the joint due to bolts holes.

This improvement is not noticeable clearly in Figures (7) and (9) when bolts of grade 8.8 were used. All the bolted and reinforced joints with two and three bolts failed nearly at the same load. This equals the ultimate load of the net cross section of the joint plate. They failed by bearing and cracking at the joint net section, Figure (15a) and b.

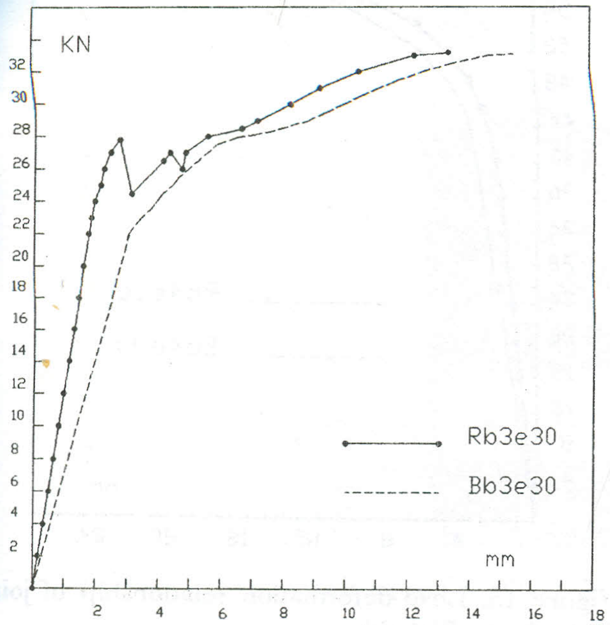


Figure 8. Load-deformation relationship of joints Rb3e30 and Bbe30.

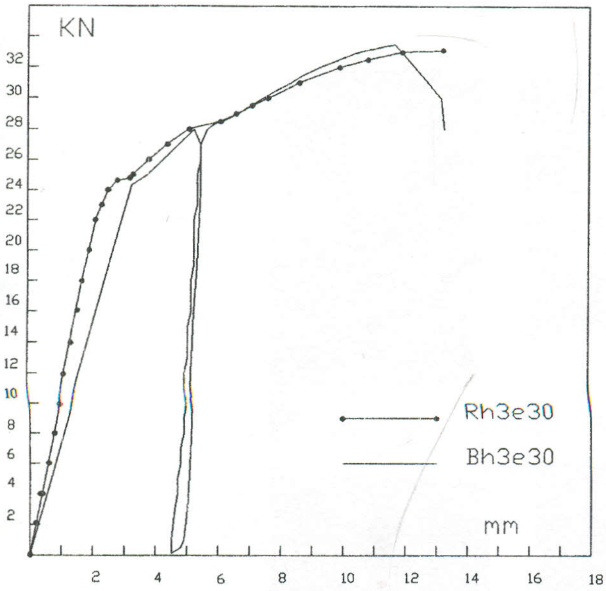


Figure 9. Load-deformation relationship of joints Rb3e30 and Rh3e30.

Figures (10) and (11) show the load - deformation relationships of friction type bolted and reinforced joints. The bolts were tightened to their full proof loads. Bolted joints show higher slip loads than reinforced joints. The slip loads of joints RH2e30 and RH3e30 are equal to 82.0% and 75.0% of those of joints BH2e30 and BH3e30 receptively. After slip, reinforced joints behaved in a linear manner. At a load nearly equal to the yield load of the gross cross section of the joint plate, the reinforced joints behaved in a similar manner to that of the bolted joints. All the joints failed nearly at the same load, Table (3). This equals the ultimate load of the joint net section.

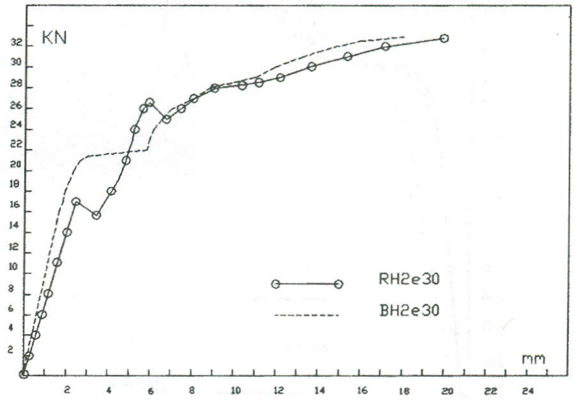


Figure 10. Load-deformation relationship of joints RHe30 and BH2e30.

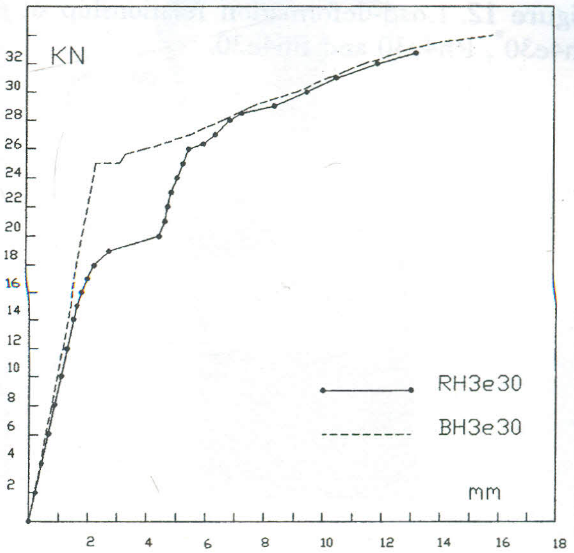


Figure 11. Load-deformation relationship of joints RHe30 and BH3e30.

Reinforced joints with four bolts behaved initially in a linear manner, Figures (12 -13). At a load of 54.0 KN, yielding occurred in joints Rh4e30 and Rh4e30* and their load - deformation relationships approached that of Bh4e30, Figure (12). This load is equal to 97.8% of the yield load of the gross cross section of the joint. Above this value , all the joints behaved in a similar manner. Again, all the joints, bolted and reinforced, failed in the same mode and nearly at the same load. This is equal to the ultimate load of the joint net cross section. Figure (15c) shows the failure modes of these joints.

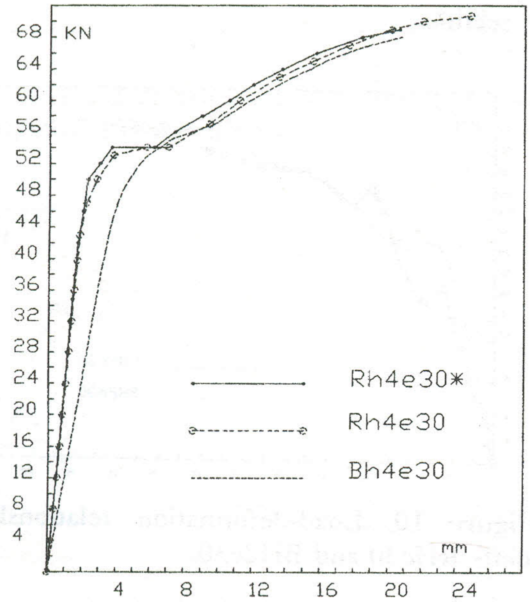


Figure 12. Load-deformation relationship of joints Rh4e30*, Rh4e30 and Bh4e30.

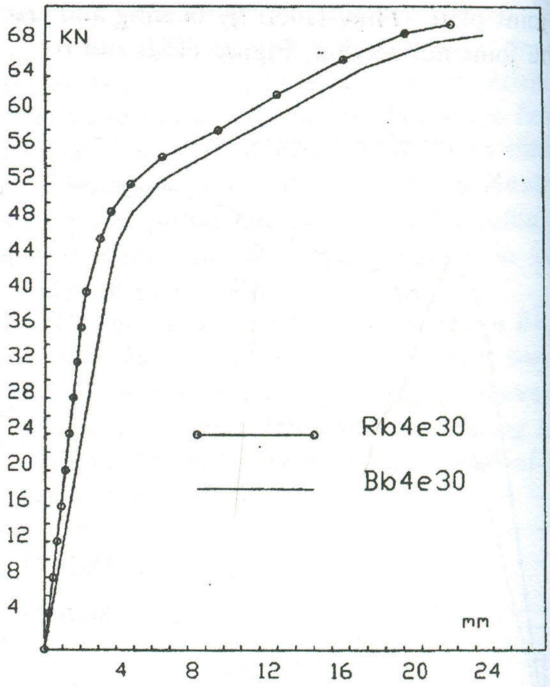


Figure 13. Load-deformation relationship of joints Rb4e30 and Bb4e30.

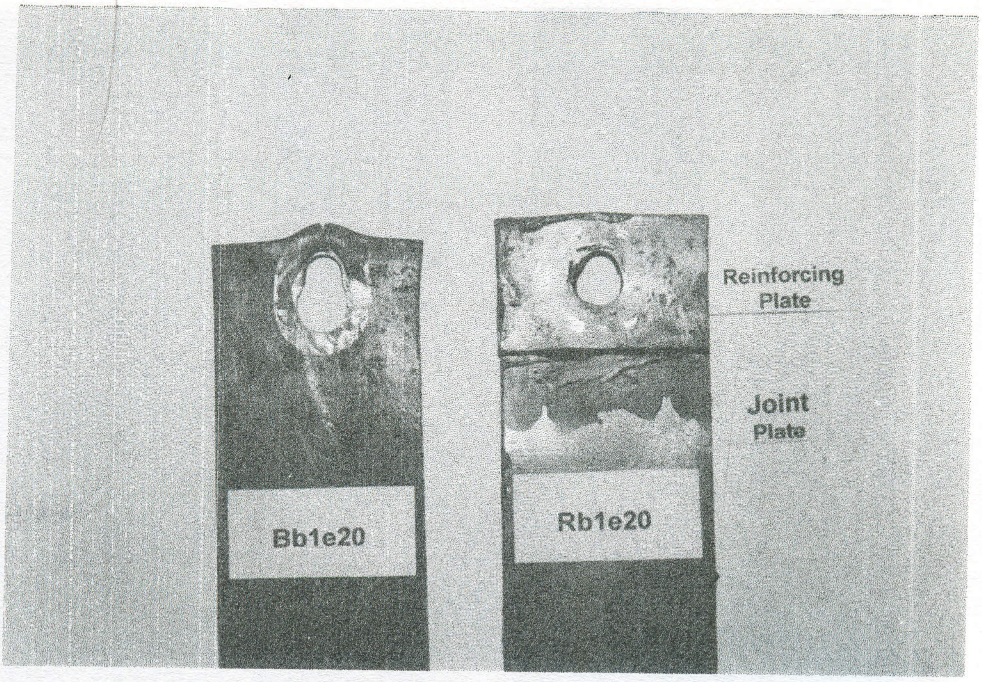


Figure 14a. Failure of bolted and reinforced joints with single blot.

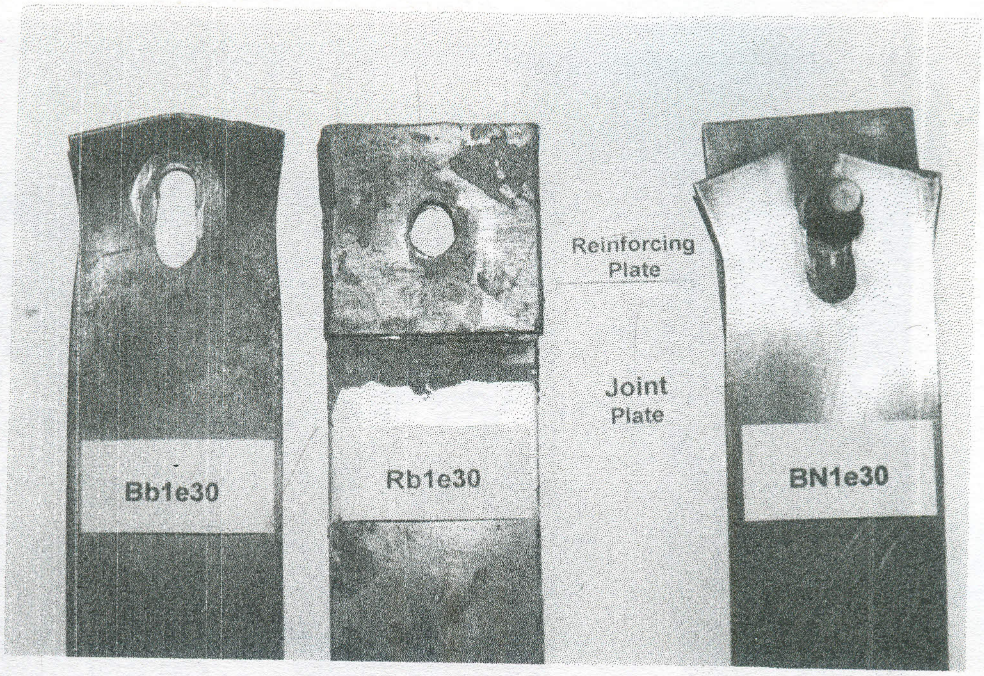


Figure 14b. Failure of bolted and reinforced joints with single blot.

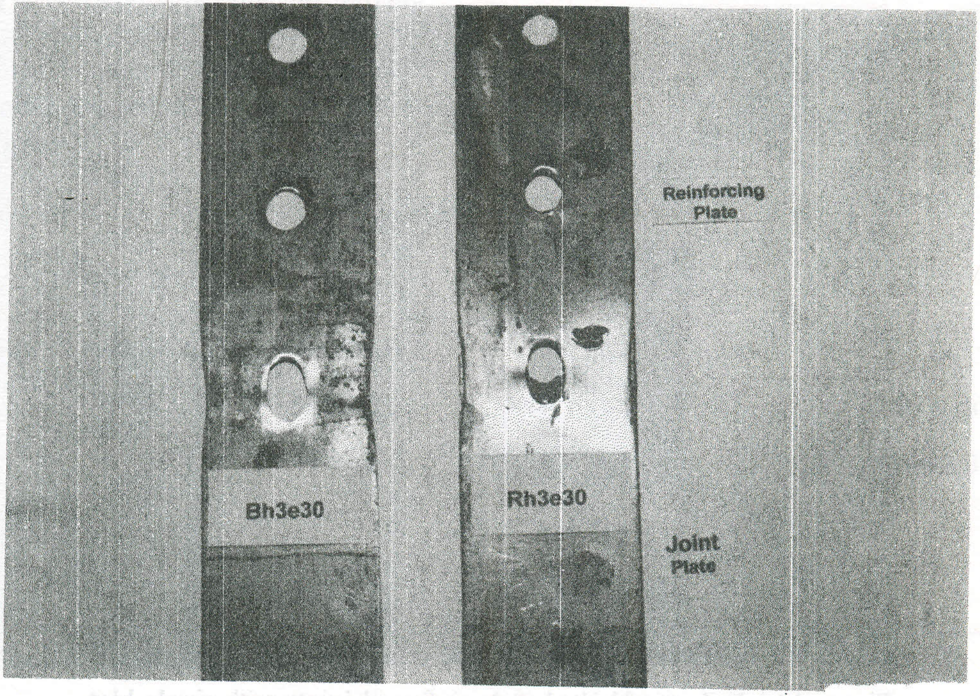


Figure 15b. Failure of bolted and reinforced joints with 3 bolts.

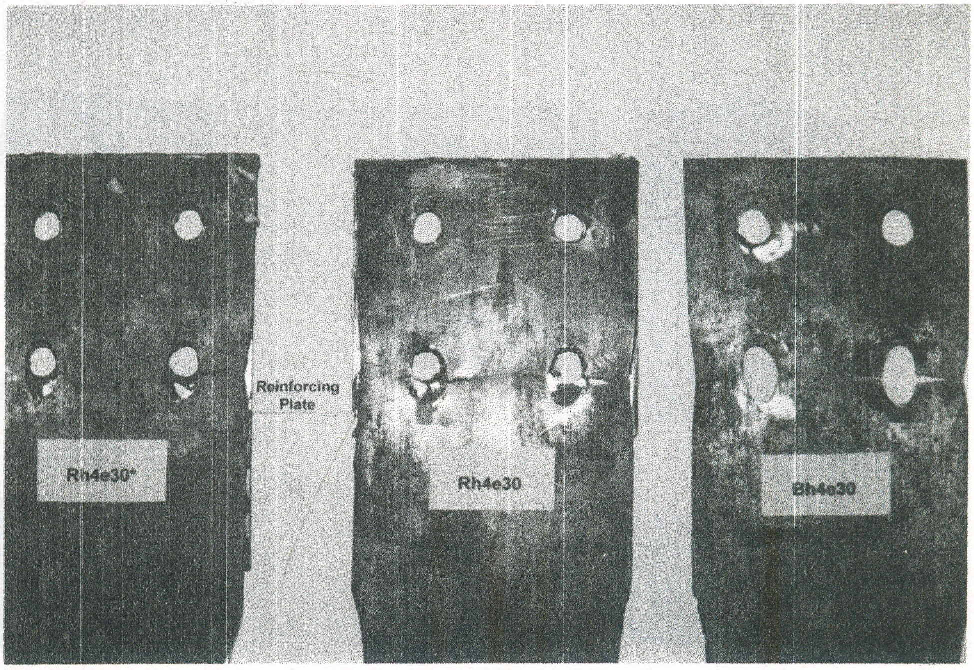


Figure 15c. Failure of bolted and reinforced joints with 4 bolts.

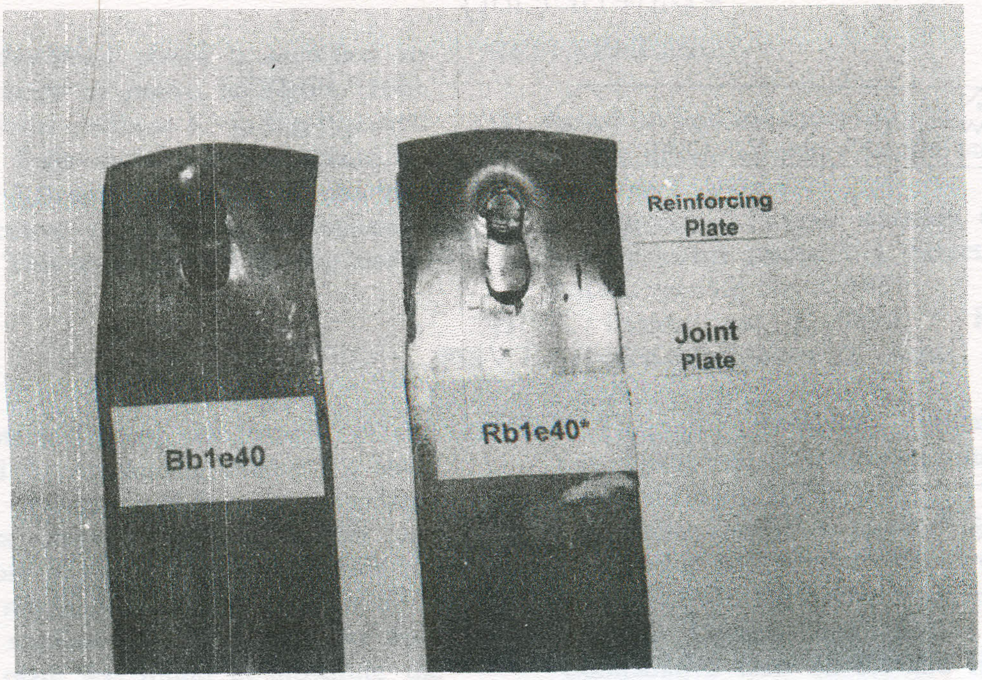


Figure 14c. Failure of bolted and reinforced joints with single blot.

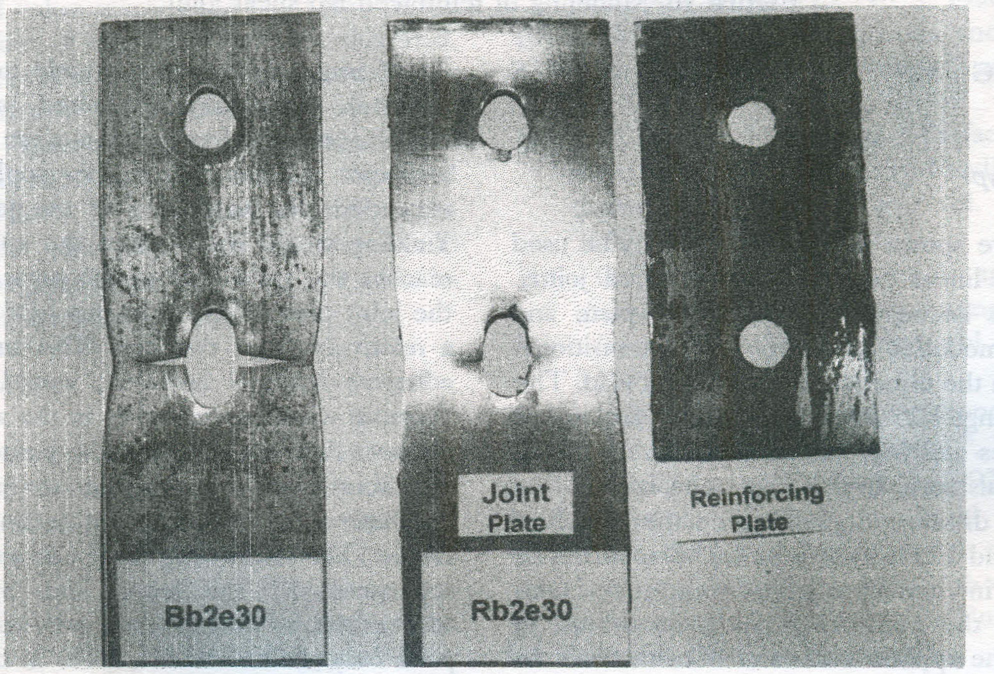
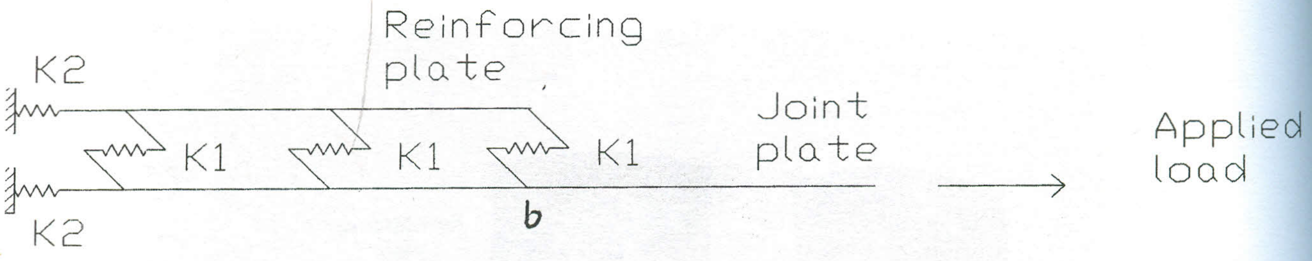
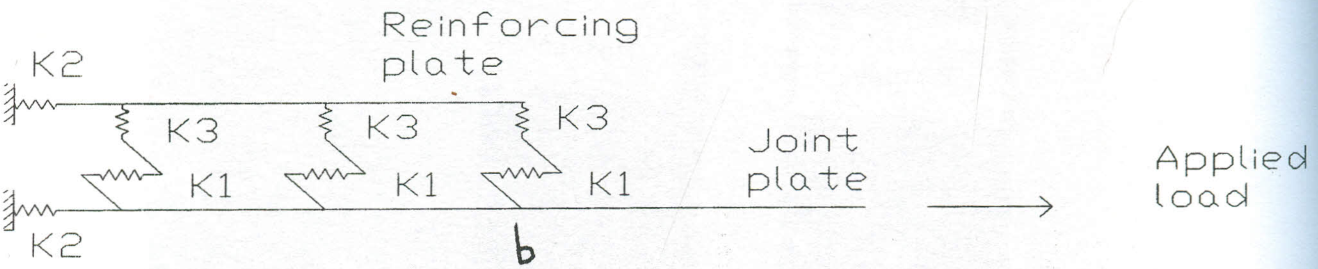


Figure 15a. Failure of bolted and reinforced joints with 2 bolts.



a - Bearing type joint



b - Friction type joint

Figure 16. Modeling of reinforced lap shear joint.

MODELLING OF REINFORCED JOINTS BEHAVIOR

(i) *Bearing type*

The structure shown in Figure (16a) may be used to model the linear behavior of reinforced joints. The adhesive between the reinforcing plate and joint plate is modelled as springs having transitional stiffness K1 in the direction of the applied load. The horizontal springs K2 model the bearing resistance of the joint plates and bolt flexure stiffness. In bolted joints K1 equals zero. In this case point b would be transmitted a distance depending on the values of the applied load and the stiffness K2. The existence of springs K1 in reinforced joints would make both the joint and the reinforcing plates contribute in transmitting the applied load to or from the bolt. In the above experiments, the reinforcing plate was found to substitute the reductions in the cross section of the joint due to bolts holes. This caused 27.6% improvement in the yield load of reinforced joints in comparison to bolted only joints. This explains why reinforced joints were still behaving in a linear manner when the applied load value exceeded the yield load of the joint net section. Yielding would occur when the applied load value reaches the yield load of the gross cross section of the joint plate. Point b in this case should transmit a relatively large distance. The brittleness of the adhesive material however, would not allow this. Fracture would occur either in the adhesive itself or between the adhesive and the joint plate surface or a combination between these two cases. The first is a cohesive failure while the second is a cohesion failure. The reinforcing plate and joint plate will be separated. In this case, the applied load is transmitted to or from the bolt through the joint plate only. Failure would occur in the joint plate at the ultimate load of the net cross section of the joint plate.

(ii) *Friction type*

The structure described above is modified by adding vertical springs as shown in Figure (16b). They have transitional stiffness K3 in the direction of the bolts axis. Bolts in friction type joints are tightened to their full proof loads. Part of this load becomes not effective according to the adhesive plastic properties. This would reduce the slip load of the joint.

CONCLUSIONS

The results obtained show the success of the proposed method for reinforcing bolted lap shear joints of light gauge cold-formed members. Reinforced joints showed higher strength and stiffness than those of bolted only joints. Both the joint and the reinforcing plates contribute in transmitting the applied load to or from the bolt. The reinforcing plate was found to substitute the reductions occurred in the cross section of the joint due to bolts holes. This caused 27.6% improvement in the yield load and caused the linear behavior even when the applied load value exceeded the yield load of the joint net section. Yielding would occur when the applied load value reaches the yield load of the gross cross section of the joint plate. At this load, fracture would occur either in the adhesive itself or between the adhesive and the joint plate surface or a combination between the two cases. The reinforcing plate and joint plate will be separated and the applied load is transmitted to or from the bolt through the joint plate only. Failure would occur in the joint plate when the ultimate load of its net cross section is reached.

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