Experimental investigation on different patterned bolted/welded structural connection in steel and GFRP plates

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Abstract: The experimental investigation is explained different structural connection like various patterned single shear lap bolted connections and slot complete penetration welded connection. Totally 12 numbers of 300 x 50 x 4 mm steel connections made by lap joint as per IS800: 2007 provisions. The patterns are linear, diamond and staggered for the bolted and slot complete penetration welded connections, 4.6 grade bolt and tungsten electrode rods are used for structural slot complete penetration welded connection conforming to IS 800: 2007. And 6 numbers of 300 x 50 x 6mm Glass fibre reinforced polymer (GFRP) plate with bolted connection was casted, shear resistance capacity is considerably higher in the staggered pattern structural connections then the linear and diamond pattern connections. The connection which is made by GFRP, failure occurred in the plate itself and the shear resistance capacity is lowered 60% then the steel plate even though GFRP plate high resistivity against aggressive environment

Keywords: lap joints, single shear failure mode, bolt, fasteners arrangement and slot complete penetration weld.

1. Introduction

A steel structure is an assemblage of beam, column and tension members. These different members have to be connected properly by means of fasteners in order to act as a single composite unit. Facilitating flow of forces and moments from one member to another is not the only function of connections but it also allows transfer of forces up to foundation level[1]. The performance of a structure depends upon behaviour of joints so before analyzing the structure it is important to analyze the joints within them .In order to avoid connection failure proper design and detailing is needed otherwise it results in a weaker connection. Safe, economical and simple are the basic goal of connection design to produce a joint so that without any difficulty it can be manufactured and assembled at site. A connection failure should not occur before a member failure because it may lead to failure of whole structure and steel member failure is more ductile when compared with connection failure. There are different failure modes in which a bolted connection may fail such as shear failure of bolt, shear failure of plate, bearing failure of bolt, bearing failure of plate, tensile failure of bolts, bending of bolts and tensile failure of plate. Any one of the above mentioned following modes controls the strength of bolted connections [2-4].

In steel structures different types of simple connections are used such as lap joint, butt joint, truss joint connections, connection at beam column junctions, tension and flange splices. For the members, which are composed of plate elements lap joints are often used to connect. In case of lap joint two members are simply overlapped or connected together by means of bolts or welds[5]. Different types of fastener patterns are available for connecting plate members such as linear, diamond and staggered or chain connection. In the case of linear pattern, fastener holes are located in a straight line and in the case of diamond pattern, fastener holes are located in diamond shape and for staggered pattern fastener holes are arranged in a zigzag pattern[6].

Heating two pieces of metal to a plastic or fluid state for the occurrence of fusion to connect them is called welding. To join various metals there are several welding processes available today. Different types of welds are available for jointing; they are groove welds, fillet welds slot or plug and slot complete penetration welds. In steel construction slot complete penetration welds are widely used nowadays. In slot complete penetration welding, weld metal is used to fill the hole completely or partially. Slot complete penetration welds are used when it is not possible for fillet welding to fill up the holes in connections[7]. The design strength of slot complete penetration weld is similar to that of fillet weld and also they assumed to fail in shear [8]. In preventing overlapping parts from buckling slot complete penetration welds are useful [9-10]. Bolts have many advantages such as simple mechanism, high bearing ability and anti-fatigue behaviour.

2. Experimental procedures

2.1 Materials

Steel: IS2062 – E415 mild steel flat section is used for the bolted and welded connections, 300x50x4mm thick flat strip used for the lap joint, similarly 300x50x6mm size manufactured glass fibre reinforced polymer flat strip connected by lap joint using E4.6 grade bolts. Table1 shows the mechanical properties of IS2062 steel and GFRP

Table 1. properties of the materials

Material	Elastic modulus (MPa)	Poisson ratio	Yield strength (MPa)	Ultimate tensile strength (MPa)	Percentage elongation (%)
Steel	2×10^5	0.30	312	423	52.05
GFRP	0.26×10^5	0.25	360	385	5.13

2.2 Specimens

Totally 18 numbers of specimens are casted to conduct experimental study. Each pattern 2nos of specimen fabricated in linear, diamond and staggered; for analysing mechanical property coupon test was conducted separately results are mentioned in Table1. Out of 18numbers of specimen 12 numbers fabricated by using steel flat strips and 6 numbers of specimen casted in GFPR flat strips. Table 2 shows the number of experiment conducts for different pattern. 6mm diameter with 4.6 grade bolts is used for all bolted connections. Fabrication done with provisions in IS800:2007. Bolted and slot complete penetration welded connections made 7.2mm diameter (d_o) bolt clearance provided as specified in IS800.

Table 2. Design of experiments

Description	pattern	Numbers of connection fabricated
Bolted connection in steel flat	linear	2
	diamond	2
	staggered	2
Slot complete penetration welded connection in steel flat	linear	2
	diamond	2
	staggered	2
GFRP with bolted connection	linear	2
	diamond	2
	staggered	2

Figure 1. (a) Bolted connection (b) Slot complete penetration welded connection (c) Bolted connection in GFRP.

Figure 2. Experimental set-up

3. Results and discussion

Experimentation result shows that tensile strength of the slot-plug welded connection and bolted is provides greater results then the codal provisions, also from different pattern of lap connection, bolt value having significant variation with same number of bolt. Table 3 shows the Experimental results for carbon steel bolted lap connection, among linear, diamond and staggered connections the bolt value of staggered one gives higher resistance comparing to other two connections. But where as in the slot welded connection linear pattern gives greater than the other two in Table 4. In GFRP strips lap bolted connections gives significant strength about 40% of steel connections strength in staggered connection pattern.

Figure 3, 4 and 5 shows the comparison between theoretical tensile strength and the experimental tensile strength of bolted and welded connections , all specimens satisfies the codal requirement and tensile strength 15-30% higher than the theoretical value in that staggered pattern connection gives better value in bolted connection and linear pattern gives better value in welded connections.

Table 3 Experimental results for carbon steel bolted lap connection

S. No.	Specimen ID	Connections	Shear strength of connections		
			Codal provisions (kN)	Experimental (kN)	Variation in percentage %
1	CS-BL-01	Bolted linear pattern	25.058	42.215	68.469
2	CS-BL-02	Bolted linear pattern	25.058	40.639	62.179
3	CS-BD-01	Bolted diamond pattern	25.058	32.217	28.569
4	CS-BD-02	Bolted diamond pattern	25.058	36.715	46.52
5	CS-BS-01	Bolted staggered pattern	25.058	44.452	77.396
6	CS-BS-02	Bolted staggered pattern	25.058	45.621	82.062

Table 4. Experimental results for carbon steel welded lap connection

S. No.	Specimen ID	Connections	Shear strength of connections		
			Codal provisions (kN)	Experimental (kN)	Variation in percentage %
1	CS-WL-01	Slot complete penetration welded linear pattern	45.238	66.352	46.670
2	CS-WL-02	Slot complete penetration welded linear pattern	45.238	69.175	52.913
3	CS-WD-01	Slot complete penetration welded diamond pattern	45.238	64.850	43.353
4	CS-WD-02	Slot complete penetration welded diamond pattern	45.238	63.342	40.020
5	CS-WS-01	Slot complete penetration welded staggered pattern	45.238	61.727	36.460
6	CS-WS-02	Slot complete penetration welded staggered pattern	45.238	59.770	32.123

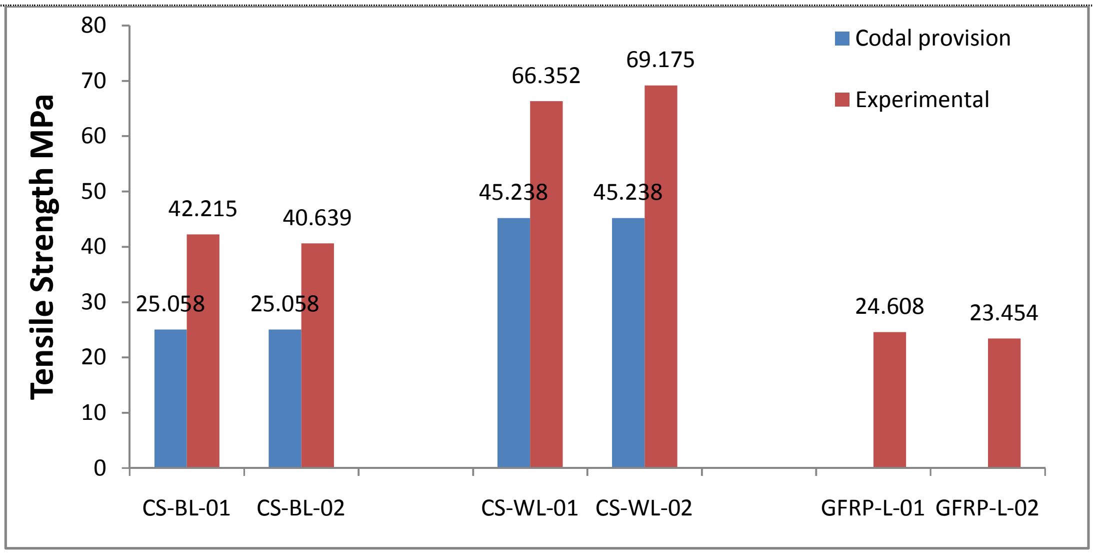

Figure 3. Comparisons of Linear pattern structural connection

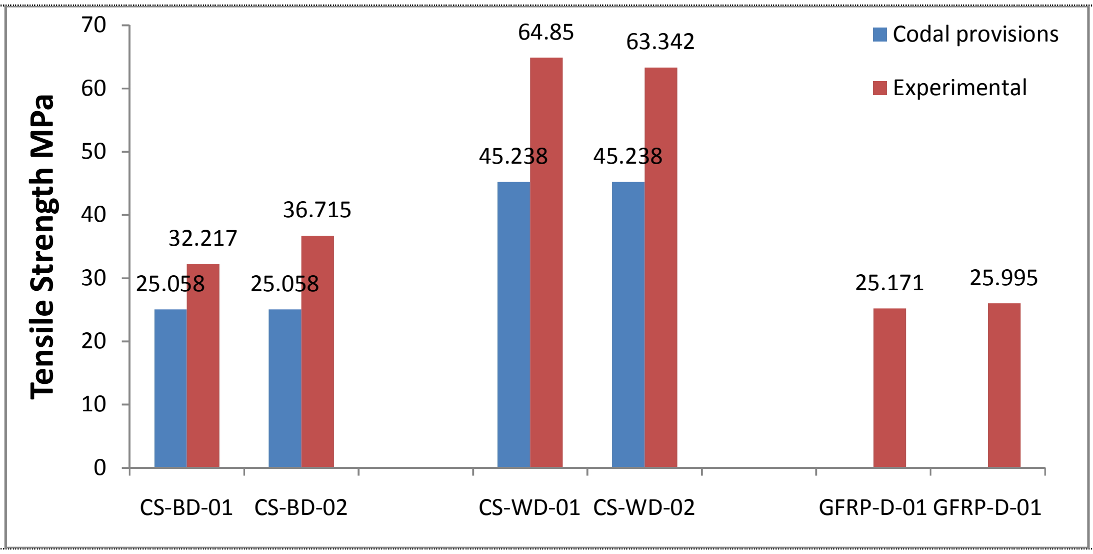

Figure 4. Comparisons of diamond pattern structural connection

Table 5. Experimental results for GFRP with bolted connections

No.	Specimen ID	Connections	Shear strength GFRP	Variation
1	GFRP-L-01	Bolted linear pattern	24.608	-1.86
2	GFRP-L-02	Bolted linear pattern	23.454	-6.838
3	GFRP-D-01	Bolted diamond pattern	25.171	+0.449
4	GFRP-D-01	Bolted diamond pattern	25.995	+3.739
5	GFRP-S-01	Bolted staggered pattern	26.854	+7.167
6	GFRP-S-02	Bolted staggered pattern	29.766	+18.788

4. Conclusion

From experimental results, linear pattern of lap joint bolted connections provides almost 65% higher strength considering provisions is made by IS800:2007, but the staggered patterned connections shows the greater shearing strength of 22.3% comparing to linear pattern in bolted connections. Comparing complete penetration of slot type welded connections shearing strength slightly lowered. GFRP plate connections are not satisfied the provisions made by IS800:2007 but the shear strength gives relatively well (-6.838 to +18.788%). GFPR connections may suitable for offshore structures, aggressive environmental conditions, freezing thawing region, low maintenance areas, low cost and where high durability required.

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