

Comparison and Analysis Dissimilar Joint Strength of Pultrusion GFRP Composites

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ABSTRACT

Under the premise of maximum connection intensity, the composites plate and metal plate connected through three ways using adhesive bonding, bolt connection and mixed connection, comparing and analysing the joint strength of these two, the result of the research showed that mixed connection's strength is the largest, the second one is adhesive bonding. The composite-metal's connection strength is significantly higher than the composite-composite's under the different connection ways, but its ductility is slightly worse than that of the latter.¹

INTRODUCTION

Fiber-reinforced polymer (FRP) composites have been used as a new structural material with low carbon, energy saving and good design ability in civil engineering, such as full GFRP composites bridge structure, application of FRP composites for maintenance and reinforcement, etc. [1-4]

The biggest technical difficulties in the design and construction of FRP composites are joint connection, the node problem of FRP composites have been researched by the academic circles, the cementation strength is mainly affected by lap length, nature and thickness of the glue, etc. Additionally, the cementation strength increases with the increase of lap length within the effective lap length[5-9]. The main failure modes of bolt connection are shear failure, splitting failure, crushing failure and tensile failure, which are significantly affected by geometry size and connection form, during designing process, the ratio of plate thickness (t) to hole diameter (D) is 1, and that of end distance(E) to hole diameter(D) is 3-4 [10-13]. The strength that mixed

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connection is mainly decided by geometry size, connection form and the nature of glue, and its transfer mechanism is complex. Additionally, its strength is better than that of the bolt connection [14-16].

The research on the influence parameters of the joint strength is more complete currently, however, for the connection between composite plate and dissimilar materials (such as steel plate) is less, there is also lack of comparative analysis test now. The study based on the existing research, the connection strength and connection efficiency of the composite plate were analyzed through the test, and providing advice for further study the connection between composite materials and dissimilar materials.

EXPERIMENT IN DIFFERENT SPECIMENS

Test Summary

The specimens were prepared based on standard ASTM 5961/D5961M-13 [17] and standard GB/T7559-2015[18]. The Pultrusion GFRP Composites and Q235 steel plates were employed in the test, and the bolt was A2-70 full stainless steel bolt ($\sigma_s=450\text{MPa}$), the acrylic adhesive modified was also employed in the test. The plates connected through three ways using adhesive bonding, bolt connection and mixed connection, the single lap and double lap were only considered in the test, the specimen connection of the test as shown in Fig.1.

Materials test [19] was performed on six samples, which were cut from the tested GFRP composites to measure σ_x and modulus E, the test results were 430 Mpa and 25.9 GPa, respectively.

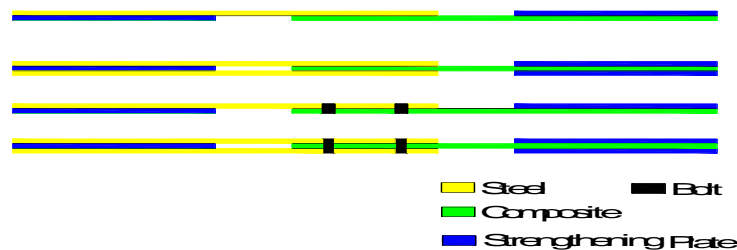


Figure 1. The specimen connection of experiment.

Tension Test

The tension test conducted using a 30T electro-Hydraulic servo Universal Tester, loading was performed at a displacement rate of 1.0mm/min, the specimens were preloaded ($\varepsilon=3000\mu\varepsilon$) before the official test. 12 conditions were designed in order to compare and analyse the joint strength of different connection modes, and each condition was triplicate, in which the final specimen was reserved as a spare in the event that other specimens were damaged or improperly tested. The conditions of the test as shown in Table I, the tension test as shown in Fig.2.

TABLE I. THE CONDITIONS OF THE TEST.

Connection modes	Numbering	Plate size (mm×mm)	Lap length (mm)	End distance (mm)	Bolt spacing (mm)
Adhesive Bonding	A-FF-D	210×36	72		
	A-FS-D	210×36	72		
	A-FF-S	210×36	72		
	A-FS-S	210×36	72		
Bolt Connection	B-FF-D	210×36		18	36
	B-FS-D	210×36		18	36
	B-FF-S	210×36		18	36
	B-FS-S	210×36		18	36
Connection modes	Numbering	Plate size (mm×mm)	Lap length (mm)	End distance (mm)	Bolt spacing (mm)
Mixed Connection	M-FF-D	210×36		18	36
	M-FS-D	210×36		18	36
	M-FF-S	210×36		18	36
	M-FS-S	210×36		18	36
Where B=bolt connection, M=Mixed connection, A=adhesive bonding FS=FRP-Steel, FF=FRP-FRP; S=single lap, D=double lap					



Figure 2. The tension test.

Fabrication Process

The FRP composites are known to brittle materials, drilling will lead to fiber breakage at the opening, at the same time, it results in the destruction of the resin structure and cracking, therefore, the aluminum plate was under the composite plate when drilling, that can avoid the split phenomenon and ensure drilling quality. When the bolt is contacted with the composite plate, the stress on the surface of the bolt is serious, and the resin structure would easily damaged, the glue seal was performed in the surface of the bolt.

TEST RESULTS AND ANALYSIS

Experimental Phenomena

When the adhesive bonding specimens were drew, the dislocation occurred in the node accompanied by sporadic "hiss" when the load reaches 50 percent of the ultimate load. The specimen damaged with a loud bang, where the load reached ultimate load, this failure mechanism can be completely attributed to adhesive shearing.

In the course of the experiment has been accompanied by the sound of "hiss" when drawing the bolt connection specimens. From the point of view of failure mode, the end orifice member of the single lap specimens where destroyed by splitting among the orifice connection, however, the shear failure appeared at the end orifice member of the double lap specimens, and a splitting crack appeared behind the second orifice, as shown in Fig.3.

The dislocation occurred in the node accompanied by sporadic "hiss" when drawing the mixed connection specimens, the glue line destroyed with a loud bang. Then, the phenomenon and failure mode were similar to the bolt connection, as shown in Fig.4.

COMPARISON ANALYSIS

The experimental results in table 2 demonstrate different specimens, from the point of view of bearing capacity, the mixed connection's strength is the largest, the second one is adhesive bonding; The bearing capacity of FS group is significantly higher than that of FF group, and the largest one is M-FS-D($F=8720.21N$). From the point of view of deformation, FF group is higher than that of FS group.



Figure 3. The Failure Mode of Bolt connection. Figure 4. The Failure Mode of mixed connection.

Fig.5 presents the load-deflection curves for different adhesive bonding specimens, as we can see, the trend of the cures are similar between FF group and FS group. The plate is in the elastic stage during initial loading phase, and

the curve is oblique line. As the displacement increases, the slope of the curves and the load both increase, but the slope is smaller than that of the initial loading phase, this is mainly due to the dislocation occurred in the node. The specimens damaged after the peak, the bearing capacity of FS group is significantly higher than that of FF group.

Fig. 6 presents the load-deflection curves for different bolt connection specimens, the trend of the cures are similar between FF group and FS group. The load is mainly borne by friction during initial loading phase, and the curve is oblique line. Because there is a gap between the bolt and the bolt hole, and curve is horizontal line until the bolt is in contact with the plate. When the splitting cracks occurred at the end orifice member, the load will drop. From the point of view of ductility, FF group is higher than that of FS group. This is mainly because the difference between the GFRP plate and steel plate's stiffness and linear expansion coefficient.

TABLE II. THE EXPERIMENTAL RESULTS OF DIFFERENT SPECIMENS.

Connection modes	Numbering	Load (N)	Failure stress (MPa)	Displacement (mm)
Adhesive Bonding	A-FF-S	3813.08	26.48	0.67
	A-FS-S	5555.39	38.58	0.95
	A-FF-D	6262.33	43.49	1.24
	A-FS-D	6849.62	47.57	0.97
Bolt Connection	B-FF-S	2778.42	19.29	2.19
	B-FS-S	3063.81	21.28	1.08
	B-FF-D	3257.51	22.62	2.37
	B-FS-D	3892.11	27.03	2.09
Mixed Connection	M-FF-S	4763.78	33.08	1.38
	M-FS-S	6598.75	45.82	1.32
	M-FF-D	7868.91	54.65	1.73
	M-FS-D	8654.15	60.10	3.47

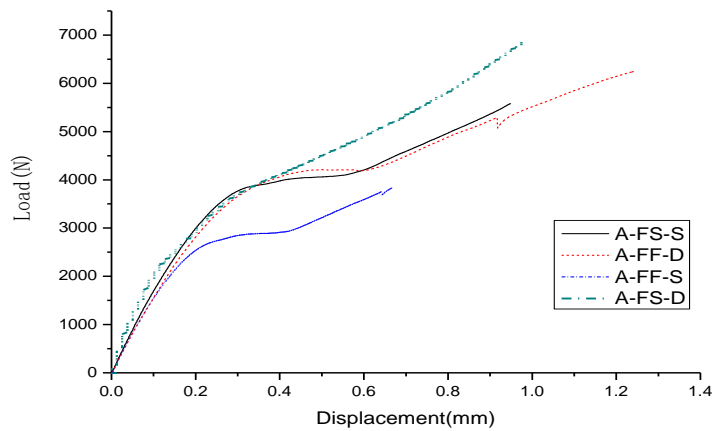


Figure 5. Load-deflection curves for different adhesive bonding.

Fig. 6 presents the load-deflection curves for different bolt connection specimens, the trend of the curves are similar between FF group and FS group. The load is mainly borne by friction during initial loading phase, and the curve is oblique line. Because there is a gap between the bolt and the bolt hole, and curve is horizontal line until the bolt is in contact with the plate. When the splitting cracks occurred at the end orifice member, the load will drop. From the point of view of ductility, FF group is higher than that of FS group, This is mainly because the difference between the GFRP plate and steel plate's stiffness and linear expansion coefficient.

Fig. 7 presents the load-deflection curves for different mixed connection, the most noticeable of which is when the glue line stripped and the load will suddenly drop, the curve is similar to the bolt connection then. From the load value, FS group is significantly better than that of FF group.

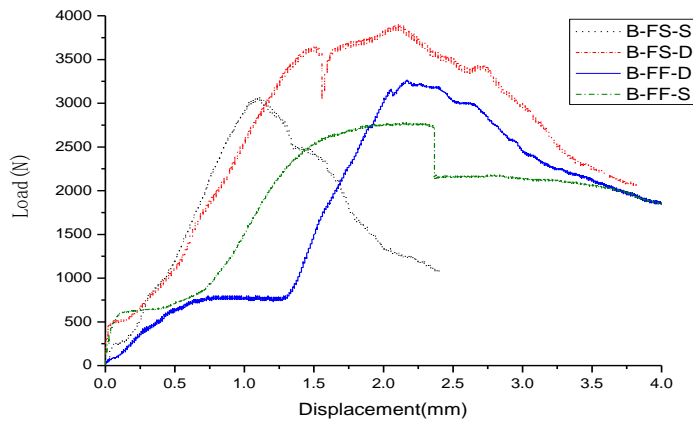


Figure 6. The load-deflection curves for different bolt connection.

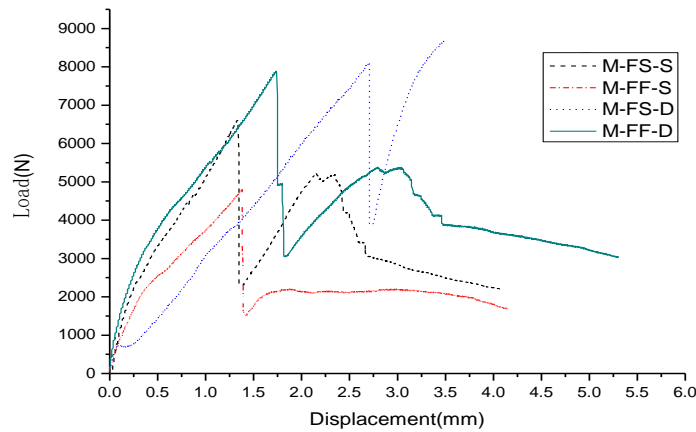


Figure 7. The load-deflection curves for different mixed connection.

CONCLUSIONS

This paper presents the results of tension test on pultruded GFRP

composites and steel plates at different connection mode. Based on these testing results and those of previous studies the following conclusions can be drawn from this study:

1. From the point of view of bearing capacity, the mixed connection's strength is the largest, the second one is adhesive bonding; The bearing capacity of FS groups are significantly higher than that of FF group at different connection mode, but its ductility is slightly worse than that of the latter.
2. From the point of view of failure mode, the end orifice member of the single lap specimens were destroyed by splitting among the orifice connection, however, the shear failure appeared at the end orifice member of the double lap specimens, and a splitting crack appeared behind the second orifice, the failure mode is related to the vertical restraint.
3. It is difficult to achieve the ideal extrusion failure mode for pultruded FRP composites.

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