Test Results of Fasteners for Structural Fiberglass Composites

ED (AHMED) MORSI AND J. LARRALDE

Reinforced plastic (RP) materials have been widely used for corrosion control and are rapidly gaining acceptance as the construction material of choice for a cost-effective, high-quality product. Commercially available RP materials have been developed to maximize the properties of resins and glass fiber reinforcements that characterize them: corrosion resistance, high ratio of strength to weight, and dielectric properties. Certain design aspects still need to be resolved. The technical and structural integrity of fiberglass connections have been the least understood and have caused the most concern among engineers, designers, and construction personnel. Extensive analysis of the connections should be considered when designing and selecting the material and fasteners to ensure product and structural reliability. RP connection hardware such as self-tapping screws, bolts, nuts, rivets, and adhesives are the most commonly used connection hardware in RP construction. Although steel connection design and performance are well established and well known to engineers and designers, the behavior of RP connections is not yet fully understood. The complexity of the RP material composition, such as types and ratios of fibers and resins, can greatly influence the performance of the connection. The test results of RP connection fasteners and some insight into the behavior of various types of material and fasteners are presented. The test results are compared with the allowable strengths of the various types of fasteners.

The use of reinforced plastic (RP) structural shapes has increased in the last decade, primarily in the construction of wastewater, seawater, and chemical plants and the electronic industry. RP structural material has advantages over conventional construction materials (steel, aluminum, and wood) in corrosive environments because of its high resistance to corrosion and high ratio of strength to weight. However, the most difficult part for the engineer and designer of RP structures is the connections.

Steel detailing is well established, whereas RP connection detailing is not fully understood because of several factors, such as orientation of glass fibers in the RP structural members, percentage and type of glass in the composite, creep deformations, and effect of elevated .emperatures on the viscoelastic modules. Therefore, developing efficient techniques and reliable data for RP connection fasteners is necessary. Limitations of RP connection size, shape, and number and size of bolts permitted within the connection will add to the complexity of the system (*1–3*).

There are two main types of RP connections (*4*): (a) adhesives bonding mainly for nonrigid structure joints and (b) mechanical fasteners, which are the most reliable and controlled technique for connecting RP structures. When designing RP connection systems the following must be considered: thickness of RP material to be connected, number and size of bolts required, surrounding environment, surface temperature, and accessibility to inspect the connection. Several research projects and tests have been conducted in the last decade to determine the allowable tension and shear stress for RP fasteners and connections (*5,7,9*).

A. Morsi, IMCO Reinforced Plastics, Inc., Moorestown, N.J. 08057. J. Larralde, Civil Engineering Department, Drexel University, Philadelphia, Pa. 19104.

The behavior of RP connection fasteners is different from that of the conventional material fasteners. In the case of RP mechanical fasteners, the RP material thickness and the orientation of fibers have been found to be the most critical aspect in the design of the connection. Furthermore, it was also found that the distance between the beam web and the fastener is important because the beams failed in bending instead of shear. The RP material also will determine the capacity and strength of the connection rather than the bolt or fastener allowable load alone.

This paper presents the results of several tests aimed at investigating the effect of various types of fasteners in RP connections where bending, pull-out, and punch-out failures may occur. The tests were conducted on three types of fasteners: standard stainless steel (SS) bolts and nuts, self-tapping screws, and flat-head screws.

TEST PROCEDURE

RP Material with Standard SS Nuts and Bolts

Wide-flange RP pultruded beams were used for testing this type of fastener. This type of beam represents the most commonly used type in RP construction. RP beams are manufactured as follows: the reinforcement materials are in continuous strands of glass fibers roving and bidirectional mats that have been wet in a resin bath and pulled through a heated die. Because most glass fibers roving is in the longitudinal direction, the beams are stronger lengthwise (30,000 psi) than crosswise (7,000 psi).

The test beams were cut into 6-in.-long sections and were tested with the fasteners at various distances from the web, and as close as possible to the web face, to determine the maximum load. The following three beam sizes were tested: W 8 × 8 × ½ in., W 6 × 6 × ⅜ in., and W 6 × 6 × ¼ in. using an SS bolt ¼ in. in diameter and 2 in. long with washer and nut, as shown in Figure 1. The beam flanges were drilled to produce holes 5/16 in. in diameter for ¼-in. bolts and at a distance indicated in Figures 1 and 2. After the bolts were fastened in the flanges, the pull-out load was applied gradually at a rate of 0.1 in./min.

RP Material with Self-Tapping Screws

RP plates cut from pultruded beam flanges were used in this test. Test specimens were 2 ½ in. wide × 6 in. long with different thicknesses: ¼, ⅜, and ½ in. each. The self-tapping screws used in the tests were of various types, that is, self tapping for steel, concrete, and wood. All the screws were ¼ in. in diameter and 1 ½ in. long.

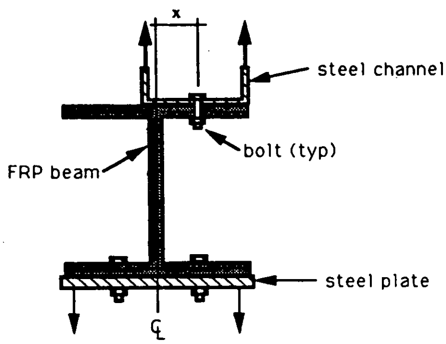

FIGURE 1 Test procedure for FRP beams with stainless steel nuts and bolts.

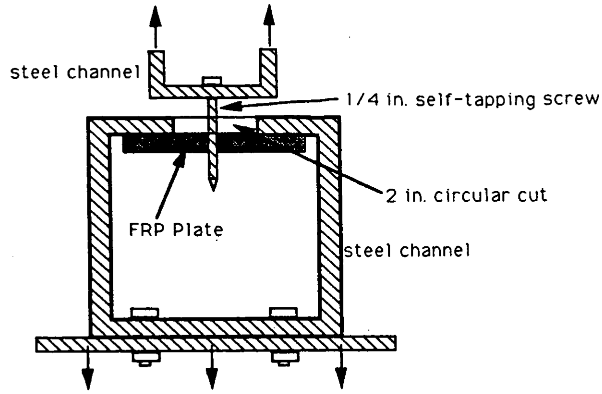

FIGURE 3 Test procedure for FRP plates with self-tapping screws.

The plates were predrilled at pilot holes 3/16 in. in diameter. The plates were held down on the test machine with steel plates, as shown in Figures 2 and 3. The load was applied gradually by pulling out the fasteners from the RP plates at a rate of 0.1 in./min. The test was repeated in three different plate thicknesses: 1/4, 3/8, and 1/2 in. using the three different types of screws.

RP Material With Flat-Head Screws

Flat-head screws can be used where the field conditions do not permit using standard nuts and bolts. The RP material used in this test was cut from pultruded flat sheets 3 in. wide × 12 in. long with various thicknesses of 1/4, 3/8, and 1/2 in. The flat-head screws used in the tests were of three different diameters: 1/4, 3/8, and 1/2 in. The plates were drilled for each screw size with countersunk holes, as indicated in Figures 2 and 4. In addition, two holes were drilled close to the main countersunk hole, about 1 1/4 in. center to center, to hold down the plate on the testing machine. The load was applied gradually at 0.1 in./min until the screw was pulled out completely from the plate.

RESULTS AND DISCUSSION

In the first series of tests, RP beams with standard nuts and bolts, the beam flanges failed first. However, the distance between the bolt and web was kept to a minimum. In most cases, the flanges failed first at the joint between the flange and web. The failure load was proportional to the flange thickness. Failure occurred either as cracking at the flange/web joint or as bolt punching through the flange. The failure type depended on the distance from the bolt to the web (*x*). Test results are given in Table 1.

In the second series of tests, RP plates with self-tapping screws 1/4 in. in diameter (Figure 3), the screws failed by pulling out from the plate. The maximum pullout load for self-tapping screws for steel and concrete was very close in each test, as shown in Table 2. However, the maximum load in the self-tapping screws for wood was comparable in 1/4-in.-thick plate, but in thicker plates (3/8 and 1/2 in.), the wood screws themselves failed in tension (Figure 2, Failure Type 1). These failure loads show an increase in load-carrying capacity of RP material 1/2 in. thick at about 75 percent over 3/8 in. thick and 120 percent over 1/4 in. thick. Failure loads of the second test group are summarized in Table 2.

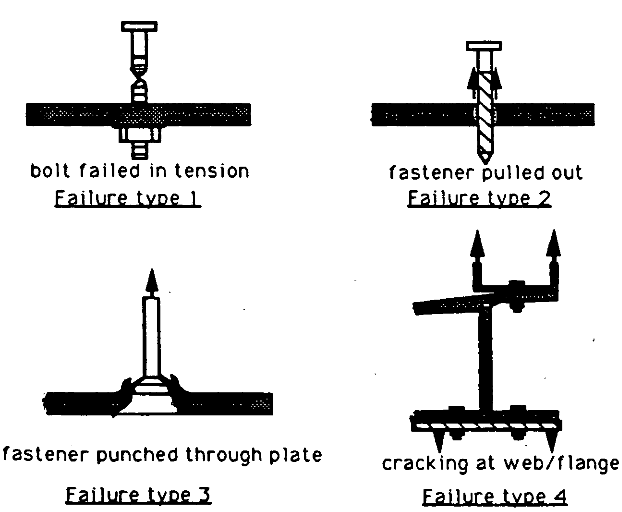

FIGURE 2 Failure types.

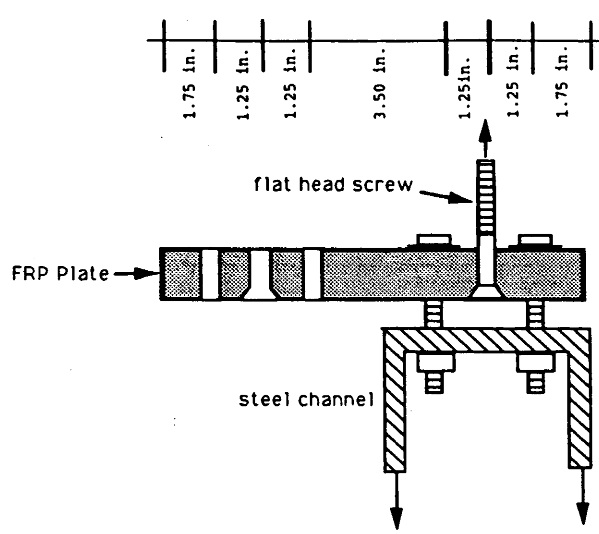

FIGURE 4 Test procedure for FRP plates with flat-head screws.

TABLE 1 Test Results of RP with Bolts

Beam Size	Test No.	Pulled Out Load	Failure Type (See Fig 2)	(x) Distance (See Fig 1)
W 8 x 8 x 1/2	G11	1,100 lb	4	1 3/4"
W 8 x 8 x 1/2	G12	3,400 lb	2	3/4"
W 6 x 6 x 3/8	G13	1,350 lb	4	5/8"
W 6 x 6 x 1/4	G14	970 lb	4	1/2"

The third series of test, RP plates with flat-head screws, the plates failed by pulling out the screws from the RP material, with the exception of the screws that were ¼ in. in diameter, which failed in tension when tested with the ½-in.-thick plate (the screw failed in tension when reaching the ultimate load of 2,400 lb). There were indications of splits occurring between the fiber layers, especially where the glass fibers run in crosswise directions. The plate thickness seemed to be the main factor for load resistance, as shown in Table 3. Also, the low ductility of RP material caused the plates to rapidly fail without advance notice. Before installation of the flat-head screw, a countersunk hole must be drilled and prepared, which will reduce the thickness of the plate to approximately 40 percent.

CONCLUSIONS AND RECOMMENDATIONS

Standard conventional bolting material is the most efficient way to connect RP structural elements. It offers a large selection of bolt sizes and types. Stiffening the flange/web area can prevent the development of cracks that reduce structural integrity.

Self-tapping screws in the RP connection provide the simplest and most economical solution to the construction technique, especially where the connections are in inaccessible locations. On the other hand, the self-tapping screws have a limited load-carrying capacity over other fasteners and limited cycles for assembly and disassembly because the screw's threads exert excessive damage to the RP holes.

The flat-head screws showed higher load capacity than the self-tapping screws. As the load increases, it tends to cause cracking in the RP material, mainly in the direction of fiber orientation. Because of the complexity of the RP connection and the wide variety of fasteners, material thickness, fastener's pattern, and spacing in the connection, the following design recommendations should be considered:

1. The anisotropic behavior of RP material limits the connection efficiency of the fiberglass composites. Therefore, to minimize stress concentration and increase connection capacities, oversize washers or combined mechanical fasteners with adhesives, or both, should be provided.
2. Connection strength can be increased by bonding RP angles to the connection members in addition to the fasteners.
3. RP materials display different strength characteristics depending on the orientation of glass fibers; thus, care should be taken when using the fasteners in directions parallel or perpendicular to the member.
4. Failure of RP material is completely different from that of other conventional materials; therefore, methods for deflection monitoring should be provided.
5. RP material can be significantly affected by elevated temperatures; thus, tight-fit fasteners and adhesive connections should be considered. In addition, engineers and designers should specify the appropriate type of fastener and resin (polyester or vinylester) as recommended on the corrosion resistance chart.
6. RP materials show a large variability because there is no RP manufacturing standardization. As a result, the designer must specify material properties and consider a large factor of safety.

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TABLE 2 Test Results of RP Plates with Self-Tapping Screws

RP Plate Thickness (in)	1/4" Dia Self-Tapping for Steel		1/4" Dia Self-Tapping for Concrete	
	Max Pull Out * Loads (lb)	Failure Type (See Fig 2)	Max Pull Out * Loads (lb)	Failure Type (See Fig 2)
1/4"	912	2	780	2
3/8"	1,100	2	1,130	2
1/2"	1,938	2	1,995	2

TABLE 3 Test Results of RP Plates with Flat-Head Screws

Plate Thkness	Screw Size	Test Max Pull Out (lb)	Failure Type (See Fig 2)	Nominal Ultimate Strength of Screws (*)	Screw Type
1/4"	1/4" dia	1,640	3	2,400 lb	Steel
	3/8" dia	2,000	3	6,240 lb	S.S.
	1/2" dia	2,890	3	11,760 lb	Steel
3/8"	1/4" dia	2,240	3	2,400 lb	Steel
	3/8" dia	3,265	3	6,240 lb	S.S.
	1/2" dia	4,700	3	11,760 lb	Steel
1/2"	1/4" dia	2,400	1	2,400 lb	Steel
	3/8" dia	4,390	3	6,240 lb	S.S.
	1/2" dia	5,410	3	11,760 lb	Steel

(*) From AISE Design Manual (1)

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