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Tensile Testing of Bolted Joints in Pultruded Glass Fibre Reinforced Plastic Profiles

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Abstract

Machine manufacturing and the automotive industry are often faced with supply chain problems for the raw materials used in the largest proportion (steel and aluminium) and the resulting large price changes. One solution to the lack of raw materials could be the introduction of new materials. Glass-fibre-reinforced plastic (GRP) profiles produced by pultrusion can be suitable for replacing metallic materials in many applications. However, one of the reasons for their limited distribution is the lack of well-established joining processes. The aim of the research is to test the tensile strength of the bolted connection of GRP sheet materials of different thickness according to an experimental design. Based on the experimental results, bolted joint recommendations can be provided for the examined GRP sections.

Keywords: *GRP, pultrusion, bolted joint, failure.*

1. Introduction

Pultrusion technology is a manufacturing process that produces composite profiles reinforced with longitudinal and continuous fibres. The reinforcing fibre material is most commonly glass or carbon fibre, although there are also natural fibre reinforcements available. The matrix material is usually a resin, typically polyester or epoxy. In the Pultrusion manufacturing process, the reinforcing fibres are first drawn into a resin bath. Then, the fibres and resin are pulled together through a heated mould designed to create the desired geometry. The matrix material gradually cross-links within the mould, and the resulting composite is cut to the appropriate length as it exits the mould. **Figure 1** illustrates the manufacturing process.

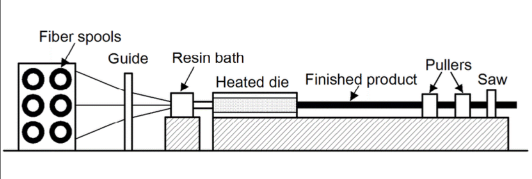

Fig. 1. *The pultrusion manufacturing process* **[1]**

The pultrusion process offers several advantages over other composite manufacturing processes, including the ability to produce profiles with consistent cross-sectional dimensions and properties, high strength-to-weight ratios, and tailored mechanical properties. Additionally, the process is highly automated and can be scaled up for high-volume production. However, there are also several challenges associated with pultrusion, such as the potential for voids or defects in the resulting composite and limitations on the complexity of the profiles that can be produced **[1]**.

Pultrusion technology allows for the cost-effective and precise manufacturing of profiles with unique cross-sections that are otherwise not possible or difficult to produce using conventional materials. The design of an efficient profile geometry and structure can be achieved by determining the fibre composition and orientation based on known load direction and type. The mechanical properties of fibre-reinforced composite sections are dependent on the percentage by volume of the reinforcing fibres. This technology has become increasingly popular in the construction industry; however, the lack of a mature bonding technology is the only obstacle to its rapid expansion. Two possible bonding technologies are the adhesive- and the bolted bonding. The moulding tool is treated with a mould release agent. From here, this material can be transferred to the profiles. This results in a low surface energy that is not favourable for adhesive joints, requiring surface treatment (cleaning) before bonding. The bolted bonding is more typical for GRP profiles than adhesive bonding [2, 3].

Due to the fibre reinforcement, the mechanical properties of glass fibre reinforced polymer profiles approach the load-bearing capacity of structural steels in the fibre direction, but the transverse load-bearing capacity can be an order of magnitude lower depending on the construction. The critical property of sections is, therefore, transverse strength. The holes required for bolting tear the fibres. The orientation of the fibres, their location, and the spacing of discontinuities must be considered when designing the bonding technology to ensure resistance to tensile and bending stresses. These factors fundamentally affect the mode of failure. Our research aims to investigate the quality and failure modes of twist bonding of GRP profiles of varying thicknesses [4, 5].

2. Failures of bolted joints in GRP profiles

Prior to the tests, based on a review of the literature, the possible failures occurring in the bolted connection of the GRP profiles were summarized. The possible failure modes are shown in Figure 2. During profile examination, several types of failure may occur, which are primarily influenced by hole placement.

Bearing type failure is a common type of failure that can occur at the edge of a bore, where the fastener comes into contact with the base material. It typically occurs when the bore position is chosen poorly and is characterized by failure of both the base material and the fastener (Figure 1). Net-tension failure, on the other hand, occurs when the bore diameter and the fastener are too large in relation to the width of the base material, resulting in cracking of the sheets in the transverse direction, with the base material tearing. Shear-out failure is caused by shear stresses and typically occurs in the main loading directions at the boundary of the hole caused by the fastener, when the fastener diameter is too small and is usually accompanied by damage to the fastener. Finally, cleavage failure occurs as an outgrowth failure and typically occurs in flat sections when the bore position tolerance is inadequate, leading to rupture and shear occurring together [6, 7].

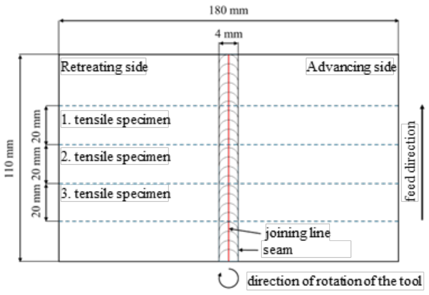

Fig. 2. *Failure modes: a) Plastic deformation b) Net-tension c) Shear-out d) Cleavage* [4]

3. Experimental conditions, measurements and results

In this chapter, the geometric design of the test specimens and the assembly required for the experiment are described. Additionally, the compiled experimental plan is presented.

3.1. The design of test specimens, experimental design

During the experiments, the overlapped GRP plates were fastened to each other with bolts. Figure 3 shows the geometric parameters of the GRP plates. During the series of experiments, the length (*L*) and width (*W*) of the specimens were not changed. Variable parameters were the thickness of the base material (*t*), the diameter of the fasteners and the hole (d_0), the distance between the holes (*b*) and the distance from the edge of the base material (*a*) [6, 8, 9].

During the tensile test, uniaxial tensile stress had to be provided so that the load force (F) exerted by the tensile machine was applied to the centre plane of the joint. In the case of overlap-

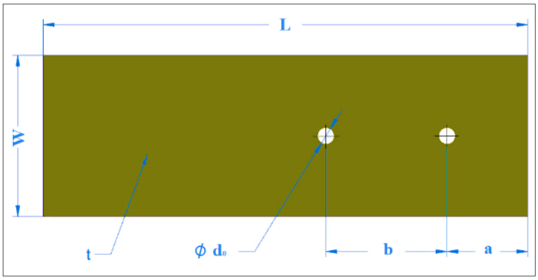

Fig. 3. *Geometry of GRP profiles.*

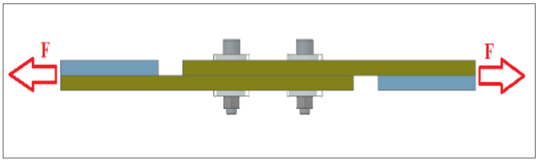

Fig. 4. *Assembly suitable for tensile testing.*

Table. 1. *Summary of the experimental design, determination of the experimental constants and variables.*

	Specimen dimensions				Hole dimensions			Bolt dimensions	
Experimental	**Thickness** ***t*** **(mm)**		**Width** ***W*** **(mm)**	**Length** ***L*** **(mm)**	**Front distance** ***a*** **(mm)**	**Middle distance** ***b*** **(mm)**	**Diameter** d_0 **(mm)**	**Bolt size**	**Tightening torque (Nm)**
1	t_1	4	50	500	25	37,5	4.1	M4	3
2	t_2	6							
3	t_3	10							
4	t_1	4	50	500	50	75	5,2	M5	6
5	t_2	6							
6	t_3	10							
7	t_1	4	50	500	100	150	6,4	M6	10
8	t_2	6							
9	t_3	10							

ping joints, this can be ensured by using a joint washer of the same thickness as the base material (**Figure 4**).

The experimental variables required for the experiment were determined based on a review of the current international literature on the research topic. A summary of the experiments is shown in **Table 1. [6, 10]**. Three tensile tests were performed. The bolts used for the tests were in accordance with the MSZ EN ISO 4014 standard and had a strength class of 8.8. The bolt nuts were standard MSZ EN ISO 4034 and had a strength class of 8. Washers made of stainless-steel flat washers according to MSZ EN ISO 7094 were used. This was necessary to distribute the load on the surface of the GRP profiles as effectively as possible. The tightening torque of the bolts was based on a review of the literature. G. J. Turvey observed in his research that the quality of the joint is influenced by the tightening torque of the bolts. Therefore, the tests were carried out in a finger-tight state, the values are listed in **Table 1 [4, 6, 7]**

3.2. Mechanical testing of the raw material

The bond strength of the specimens was tested on an INSTRON 5800R 4482 universal material testing machine in accordance with the relevant standards. As a reference measurement, the tensile strength of the base material was also measured. During the tensile test of the base material, the following results were measured: the 4 mm thick GRP sheet ruptured at 50 kN, the 6 mm thick sheet at 75 kN and the 10 mm thick sheet at 95 kN.

3.3. Mechanical testing of the test specimens

Based on the experimental design, three tensile tests per series of experiments were performed. The experiments resulted mainly in bearing type failures. At 6 mm and 10 mm thickness, the bolts were found to be weak, as nearly identical values were measured during the experiments. The failure modes were also the same, in all cases the fasteners were trimmed. At 10 mm plate thickness, the hole was only damaged when using an M6 bolt, but this was barely noticeable. At 6 mm plate thickness, the use of an M6 bolt resulted in noticeable hole deformation, i.e. bearing-shaped failure, but the tensile force amplified the shear of the bolt. When using M5 and M4 bolts, the shear of the bolts was clearly measured.

Different results were obtained for a plate thickness of 4 mm. **Table 1** shows the number of experiments as 1, 4 and 7. In each of these series of experiments, three were measured and the results are shown in **Figure 5**. The figure shows that, compared to the M4 bolt, the M5 can withstand 218% more load and the M6 260% more load. Compared to the M5 bolt, the M6 could withstand 119% more load. This result is consistent with the literature finding that the highest bond strength is associated with bearing type failure. For the 4 mm GRP plate, the M4 bolts suffered shear fail-

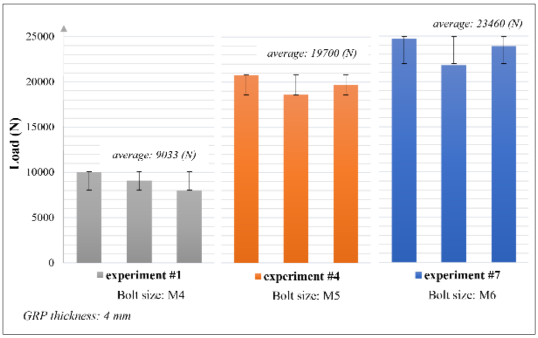

Fig. 5. *Tensile test results for GRP plates.*

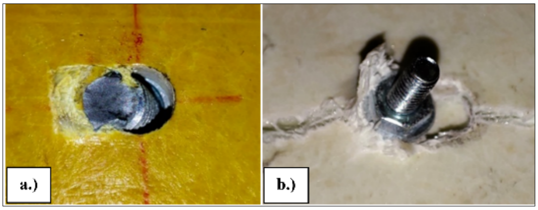

Fig. 6. *a) Bearing type failure with sheared fastener (t=6, M6 bolt)*
b) Shear type failure (t= 4 mm, M5 bolt).

ures, while the M5 and M6 bolts suffered mixed, but increasingly bearing-like failures. By increasing the diameter of the bolts, increasingly higher bond strength was achieved, but there is an upper limit to this when the hole required for the bond diameter breaks too much glass fibre, and the failure mode is Shear-out or Cleavage as shown in Figure 2 (c and d). The bond strength would then show a downward trend again..

During the series of experiments, we observed two typical failures (Figure 6). More common is the bearing type (Figure 6.a), which in all cases was connected with a sheared fastener, but the raw material was damaged to varying degrees. The other is shear failure, which only occurred with a plate thickness of 4 mm (Figure 6.b). During this failure, the fastener was torn from the base material (without significant damage to the fastener).

4. Conclusion

During the experiments, two typical failure types were observed. Based on research in the literature, bearing failure ensures the greatest power transmission. In the case of the 10 mm thick GRP plates, the fasteners used proved to be inadequate, as the failure of the test specimen was always caused by the shearing of the fasteners. Therefore, further research is needed here.

For the 6 mm thick plates, the M4 and M5 bolts were also cut, and the hole was not significantly damaged. For the M6 screw, the hole shown in Figure 6.a showed slight deformation, but the measurement results show clear shearing of the fastener. These results suggest that even with a plate thickness of 6 mm, further tests will be needed with M6 and larger fasteners.

Different results were obtained when testing 4 mm GRP sheets. The use of the M4 fastener resulted in the lowest bond strength with shear-out failure alone (Figure 6.b). The fastener remained almost intact and was torn from the material. The M5 and M6 bolts showed a mixed shear-out and bearing failure pattern, but the fastener was not significantly damaged. Based on the results (Figure 5), it is not recommended to use M4 or smaller bolts for a 4 mm thick GRP plate. When M5 bolts were used, a 218% increase in bond strength was measured compared to M4 bolts. It can be seen that a larger screw diameter results in a more favourable bond strength, but there is an upper limit to this. Too many fibre breaks result in lower bond strength.

Overall, it can be stated that our results can be used as basic data for future research. It would be advisable to carry out a new series of experiments for each plate thickness, using fasteners with a larger diameter. In this way, a technological recommendation could be developed for every material thickness.

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References

[1] Barkanov E., Akishin P., Emmerich R., Graf. M.: *Numerical simulation of advanced pultrusion processes with microwave heating*. In Proceedings of the VII European Congress on Computational Methods in Applied Sciences and Engineering. 2016, vol. 4. 7720–7738). https://doi.org/10.7712/100016.2368.5953

[2] Gallegos C., Marco F.: *Theoretical and Experimental Performance Analysis of a Cellular GFRP Vehicular Bridge Deck*. 2016. https://doi.org/10.13140/RG.2.1.1737.6887

[3] Coelho A. M. G., Mottram J. T.: *A review of the behaviour and analysis of bolted connections and joints in pultruded fibre reinforced polymers*. Ma-

terials & Design, 74. (2015) 86–107.
https://doi.org/10.1016/j.matdes.2015.02.011

[4] Bank L. C.: *Composites for construction: structural design with FRP materials*. John Wiley & Sons, 2006. ISBN-13: 978-0471-68126-7

[5] Ramful R.: F*ailure Analysis of Bamboo Bolt Connection in Uniaxial Tension by FEM by Considering Fiber Direction.* Forest Products Journal, 71/1. (2021) 58–64.
https://doi.org/10.13073/FPJ-D-20-00066

[6] Turvey G. J.: *Single-bolt tension joint tests on pultruded GRP plate – effects of tension direction relative to pultrusion direction*. Composite structures, 42/4. (1998) 341–351.
https://doi.org/10.1016/S0263-8223(98)00079-8

[7] Turvey G. J., Sana A.: *Pultruded GFRP double-lap single-bolt tension joints – temperature effects on mean and characteristic failure stresses and knock-down factors.* Composite Structures 153. (2016) 624–631.
https://doi.org/10.1016/j.compstruct.2016.06.016

[8] Tajeuna T. A., Légeron F., Langlois S., Labossiere P., Demers M.: *Effect of geometric parameters on the behavior of bolted GFRP pultruded plates.* Journal of Composite Materials, 50/26. (2016) 3731–3749.
https://doi.org/10.1177/0021998315625101

[9] Wang Y.: *Bearing behavior of joints in pultruded composites*. Journal of composite materials, 36/18. (2002) 2199–2216.
https://doi.org/10.1177/0021998302036018535

[10] Mottram J. T., Zheng Y.: *State-of-the-art review on the design of beam-to-column connections for pultruded frames.* Composite structures, 35/4. (1996) 387–401.
https://doi.org/10.1016/S0263-8223(96)00052-9