Experimental Investigation of Pull-out Load Bearing Capacity of Threaded End Pieces for Composite Pull Rods

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Abstract: The topic of this paper is an experimental research of pull-out load bearing capacity of a threaded end pieces for composite pull rods, which are made by a filament winding technology from a carbon/epoxy composite. The original pull rod design utilizes glued end pieces. The new design solution is based on an embeddable end pieces, which are integrated into the pull rod body directly during its production. A total of four variants of end pieces were tested. The optimal variant from the point of view of a maximal load bearing capacity and the optimal variant from the point of view of a composite production technology were found.

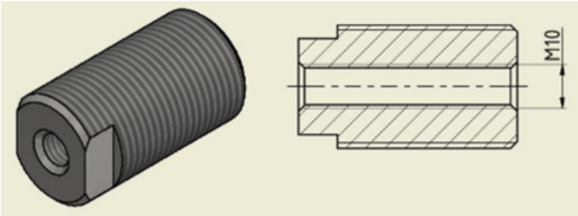
Keywords: pull rod; carbon composite; filament winding; glued joint; pull-out force.

1 Introduction

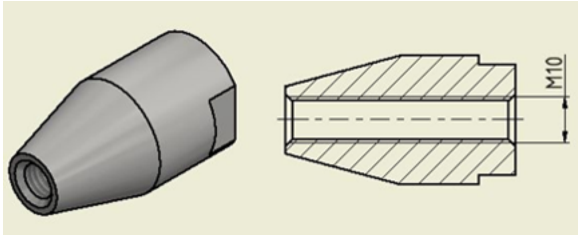
The paper is focused on an experimental development of end pieces for composite pull rods. For many industrial applications, it is still very effective to use a conventional mechanical force transmission. The advantages are simplicity, reliability, independence from a failure of a transmission path source (electricity, hydraulics, etc.), and a low implementation price. Power transmission by means of pull rods and levers is commonly applied in parts of aircraft structures (aircraft control systems or structural reinforcing rods) [1], in the automotive industry (suspension and steering mechanisms etc.), in systems of production machines (textile machines, manipulators, shifting and connecting mechanical drives, etc.). Pull rods are usually mounted on bearings and must primarily transmit tensile or compressive loads. The limiting factor is usually the buckling behavior under a compressive loading, or a natural frequency for dynamically excited systems. In a case of a traditional design of the composite pull rod, which consists of a composite tube and a glued end pieces, the weak point is the glued joint itself. The load bearing capacity of the glued joints is limited by the value of the achievable shear strength, which is approx. 20-30 MPa for the epoxy-based structural adhesive systems. However, the quality of the glued joint is strongly tied to the quality of the manufacturing technology [2]. In an addition, the subsequent inspection of the finished joint quality is difficult and often impossible. The solution is to develop an end piece, which is an integral part of the composite rod body itself. This would make it possible to achieve a composite pull rod design combining the advantage of a simpler production technology and a higher operational reliability.

2 Experimental configuration

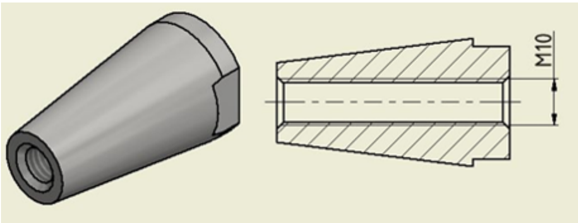
In this first phase of the experimental work, the load bearing capacity of the end pieces of four different types under the axial pulling force loading was evaluated. This first experimental test set contained a total of 14 specimens.



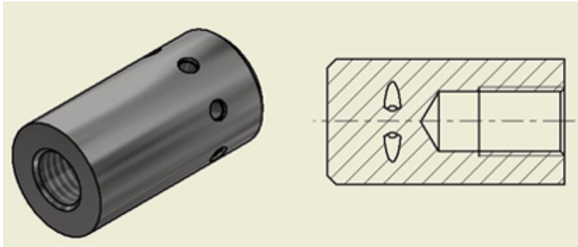
(a) A1



(b) B1



(c) B2



(d) C1

Fig. 1: Configuration of threaded end pieces.

2.1 Specimen description

Specimen bodies of a tubular shape were made of carbon/epoxy composite using the filament winding technology. One end of the specimen was fitted with an end piece and the other end was reinforced with a wound fiberglass reinforcement to prevent damage from the clamping grips of the testing machine. The end pieces were made of steel and provided with an internal thread. Four different types of end pieces were made (marked A1, B1, B2, C1), differing in their external shape, as can be seen in the Fig. 1. They were integrated into the composite structure of the pull rod during the winding process.

The A1, B1 and B2 types rely on a simple shape connection between the end piece and the composite rod body, without additional fixing elements. The C1 type is equipped with pins inserted into radially oriented holes. This is advantageous in terms of the load bearing capacity, because the carbon composite tows can be wrapped around these pins. Of course, this is a demanding solution from the point of view of assembly and the following operational life, because each of the pins needs to be reliably secured against movement.

2.2 Testing method

Heckert UFP 400 hydraulic testing machine with a maximum loading force of 400 kN was used for an experimental evaluation of a pull-out force in an axial direction. Specimens were loaded quasi-statically in a displacement loading mode until the damage occurs. Specimen loading rate was 1 mm/min. The specimen and loading configurations are shown in the Fig. 2.

3 Results and discussion

The results for each type of end piece are plotted in the graphs in the Fig. 3. It can be seen that C1 specimens have sligthly lower stiffness response, compared to A1, B1 and B2 type specimens. This is due to the smaller amount of a load-bearing carbon fibres in the end piece area. The measured pull-out forces were compared on a relative scale, where 100 % is the highest determined force of all specimens. In this experimental set, maximum measured force was indicated for the C1 type end piece specimen C1-1-1. The average load bearing capacity of the A1 type reaches about 69.3 % of the maximal determined force. In the case of the end piece types B1, B2, and C1 it is 78.4 %, 85.9 % and 86.4 % respectively. Although the tested set is still relatively small, it is possible to evaluate the B2 end piece type as a good compromise between the pull-out load bearing capacity and the requirements for the simplest possible production technology. If we try to compare the current concept of glued end piece (cylinder glued inside the tube) with the integrated end piece solution, we come to the following.

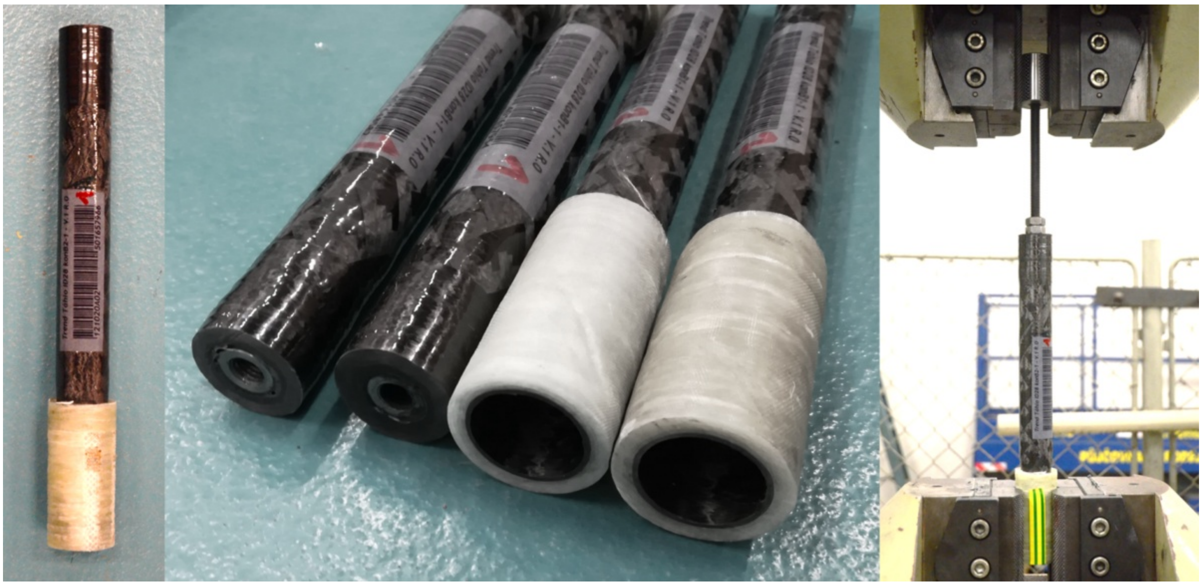


Fig. 2: Composite pull rod specimen configuration; experimental configuration (right).

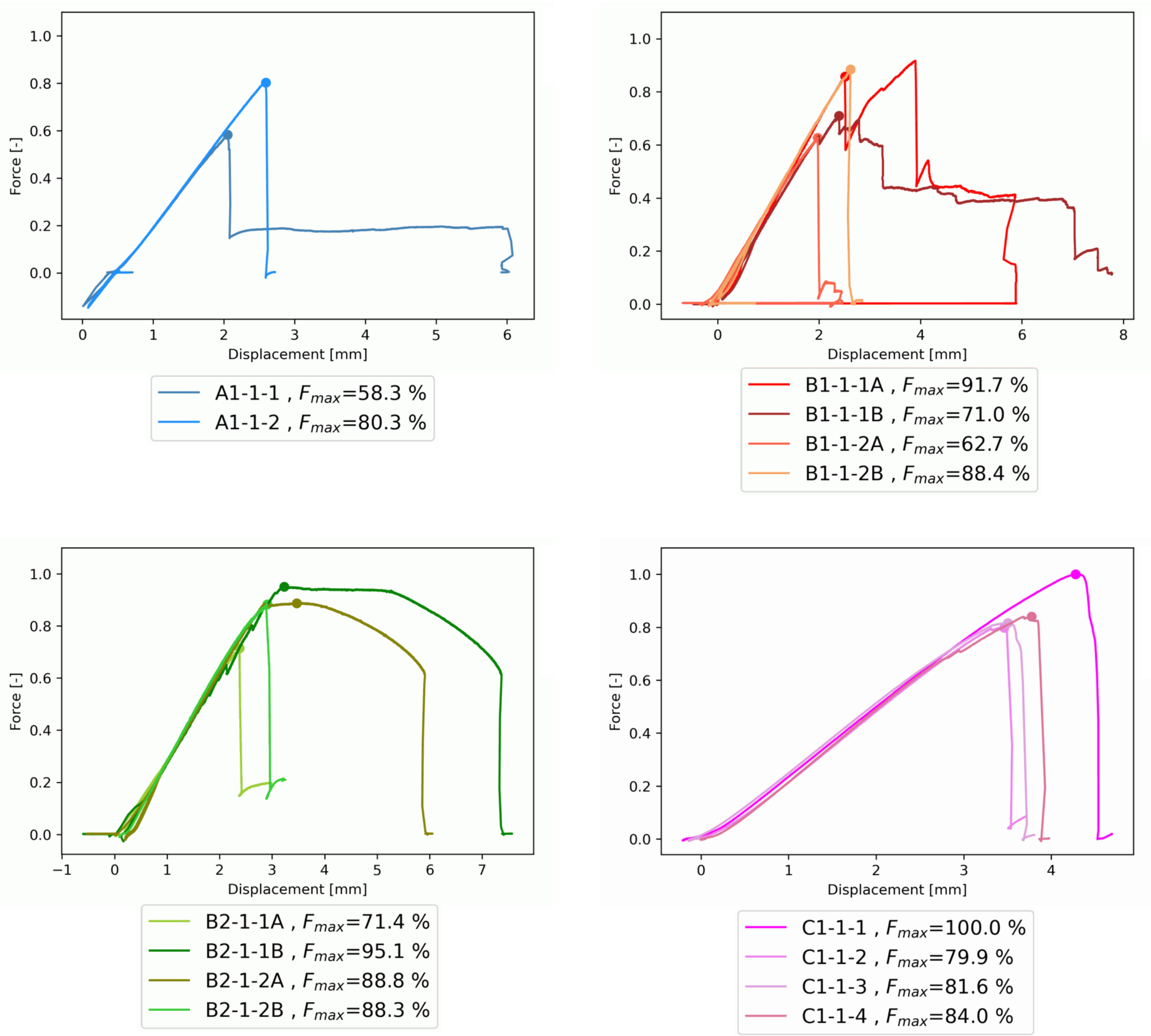


Fig. 3: Summary of experimentally determined pull-out forces.

While maintaining the size of the glued surface (or a functional length and a diameter of the end piece), if we needed to transfer the pull-out load corresponding to the individual types of integrated end pieces, the shear stress in the glued joint would reach 19, 21, 23 and 24 MPa for the average maximum pull-out force of the A1, B1, B2 and C1 end piece type respectively. Due to the quasi-static nature of the load, these values are quite high and would not provide sufficient safety margin for a normal operation of the pull rod, where the end pieces are also loaded dynamically.

4 Conclusion

Specimens with four different types of integrated end pieces were tested. The aim was to identify the shape of the end piece with the greatest pull-out load bearing capacity. Due to the small number of specimens so far, the results are preliminary. However, it can be seen that from the point of view of the application oriented to the maximum load bearing capacity, the C1 type is the best. From the point of view of the effectivity of the manufacturing technology in combination with sufficient load bearing capacity, the B2 type is the best choice. At the same time, it was confirmed that the integrated types of the end pieces will safely transmit a greater pull-out force than the glued end piece type with the similar dimensions, for which the upper limit of shear strength of the adhesives used would be reached.

Acknowledgement

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