# Characterization of Bolted Joint: Measurement and Simulation

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**Abstract.** In this work, screw joints consisting of a metal screw and a polymer composite boss (PA6GF30) have been analysed. Both the change in the pretightening force and the deformation state on the surface of the composite boss have been measured in different operational phases and at various temperatures. Additionally they were analysed numerically by using an FE model taking into consideration the viscoelastic as well as the elastic-plastic behaviour of the polymer composite.

**Keywords:** bolted joint; PA6GF30 boss; stress relaxation measurement; finite-element analysis

## 1 Introduction

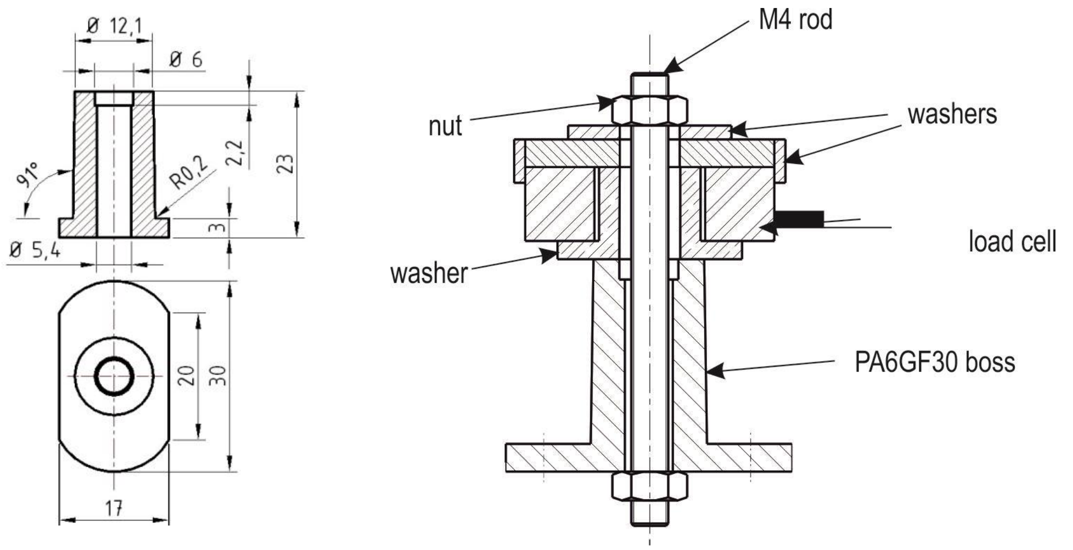
Nowadays plastic and composite materials are used not only as materials for covering but as materials for structural components as well due to a broad range of options for processing and utilization. Novel and economical joint types have been appeared making research thereon important. The economy of joints is increasingly coupled with recyclability as a high priority. Self-cutting screw joints are especially suitable in terms of both economy (only a hole needs to be made on the component) and recyclability as no further dismounting operations are required after removing the screw [1].

The applicability of this joint type is prejudiced by the fact that the pretightening force generated in the joint changes due to the time- and temperature-dependent material behavior of the plastic component and the differences in the thermal expansion of plastics and metals. Physical processes within the screw joint in the course of different operational states can be properly illustrated by simplified models. Nevertheless, constructors still fail to get a picture how a plastic component involved in a joint is deformed, and how its deformation affects the rate and way of changes in the pretightening force. The specialists involved in the production of self-cutting screws have an old need for a numerical model to follow both pretightening force relaxation and the stress and deformation states of the entire construction in the different phases of screw joint operation [2].

High-resolution cameras can be used for testing components without contact and destruction in dimensions ranging from a millimeter to several meters, at practically arbitrary loads. So in the case of self-cutting screw joints, for instance, not only the impact of the pretightening force can be tested by the methods available but the deformation state of the plastic component as well.

## 2 Experiments

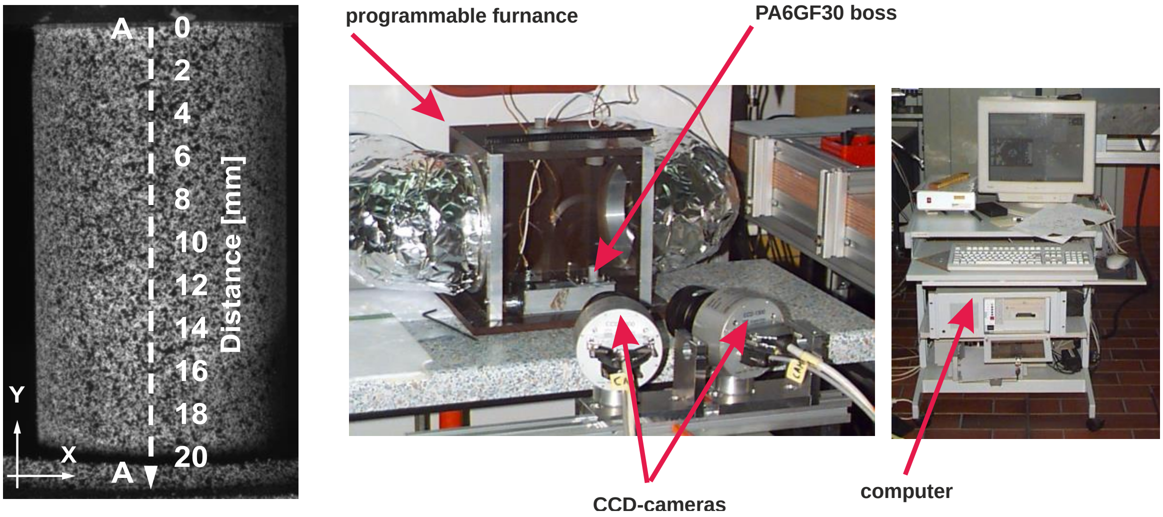
### 2.1 The test rig




(a) (b)

**Fig. 1.** The composite boss (a) and the test rig (b)

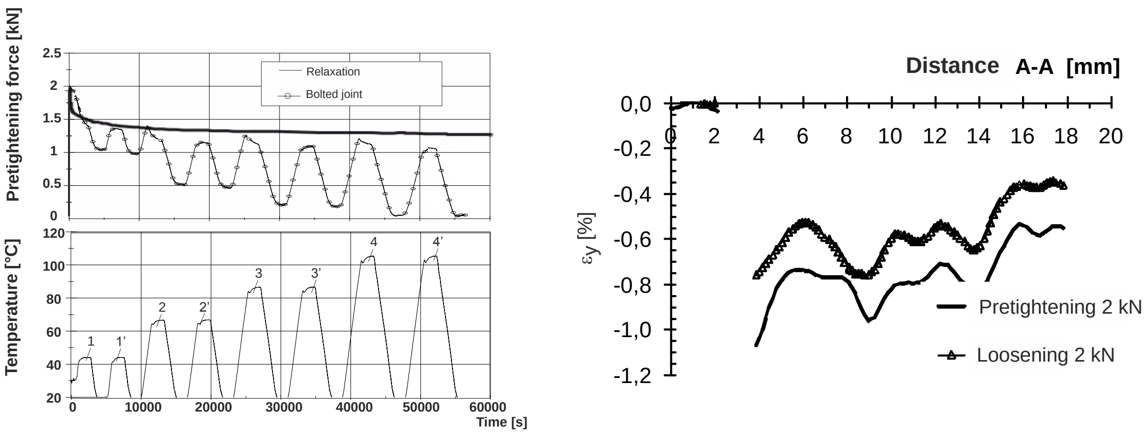
The stress and deformation state developed in a poymer boss (see Fig. 1a) as well as changes in the pretightening force as a function of time and temperature can be studied both experimentally and numerically. Processes such as pretightening, heat-up, holding at constant temperature, cool-down, and loosening can be studied separatelly. However it is somewhat more difficult to analyze these processes and other parameters affecting joint operation experimentally. In the course of my work, I traced both the pretightening force changes in the joint and the deformation states on the surface of the plastic boss in different operational phases (screw-in, pretightening, heat-up, holding at constant temperature, cool-down, loosening, and screw-out) and at various temperatures. The former was performed by a load-cell (see Fig. 1b) while the latter by a type of optical deformation analysis, namely the optical grating method. A short review of the optical grating technique can be found in [3]. The encoded boss and the measurement assembly can be seen in Fig. 2.




(a) (b)

**Fig. 2.** The encoded boss (a) and the measurement assembly (b)

## *2.1.1 Experimental results*




(a) (b)

**Fig. 3.** Changes in the temperature profile applied and the pretightening force as a function of time as well as the result of a relaxation test at room temperature (a) and the axial strains along the line A-A on the boss surface (b)

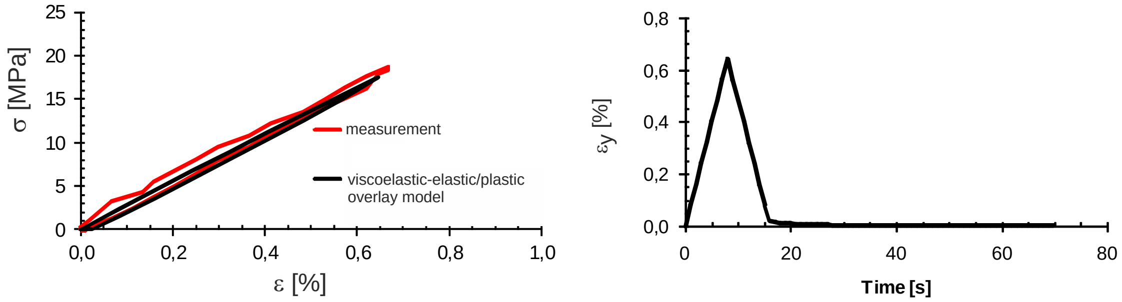
The main aim of the measurements under cyclic thermal load was to analyse the mechanical behaviour of the plastic tube. The whole test rig was placed in an owen and after the pretightening process (F=2 kN) the inside temperature was changed according to the profile seen in Fig. 3a. The change in the pretightening force as a function of temperature is represented in Fig. 3a. The most important result of the measurement is that at the end of the prescribed temperature profile the pretigthening force has a value of 0.1 kN. After the pretightening process a quick relaxation can observed. This relaxation process is slowed down by the thermal expansion of the polymer tube at 40°C (The thermal expansion of the polymer tube is grater than that of the steel screw: $\alpha_{PA6GF30} = 3.2 \;\; 10^{\;5}\, 1/{}^{\circ}C, \quad \alpha_{steel} = 1.17 \;\; 10^{\;5}\, 1/{}^{\circ}C$). The intensive relaxation of the PA6GF30 boss can also be seen on the relaxation curve (pretightening force vs. time curve at room temperature) of Fig. 3a. When bolted joint is subjected to a higher temperature than in the former step (see cycles 1, 2, 3 and 4 in Fig. 3a) the pretightening force changes significantly. It is important to note that, the repeated heating to the same temperature practically has no influence on the decrease in the pretightening force (see cycles 1', 2', 3' and 4' in Fig. 3a). The complex thermo-mechanical processes are affected by the viscous property of the polymer tube, the temperature dependent E-modul and the temperature dependent thermal expansion. Based on the results measured by using the optical grating method it can be concluded that the change in the axial strain during the first temperature cycle is irreversible (see Fig. 3b).

# 3 Finite element simulation

## 3.1 The FE model

In order to facilitate numerical simulations, the composite material properties have been determined experimentally. As the boss is predominantly compressed in the joint, material properties were determined by compression tests. It should be mentioned here that measurements at various temperatures were performed on real plastic bosses. The axisymmetric model developed takes into consideration both the viscoelastic and the elastic-plastic behavior of the composite boss. A 40-term generalized Maxwell model was used for modeling viscoelastic behavior while the elastic-plastic behavior was modeled by the "overlay" technique [4]. The detailed description of the parameter identification can be found in [4].

## 3.2 Numerical results




(a) (b)

**Fig. 4.** Computed and measured stress-strain curve (a) and strain history of the viscoplastic overlay model (b) in case of compression loading-unloading test (T=25°C, conditioned PA6GF30, $\sigma_y$=20 MPa, linearly elastic-perfectly plastic ($E_T$=0 MPa) „elastic-plastic" spring)

The correlation between the experimental and the numerical results can be seen in Fig. 4a. The strain history of the viscoplastic overlay model is shown in Fig. 4b.

# 4 Conclusions

The combination of the optical grating method and the FE technique allows us to study the complex thermo-mechanical behavior of the polymer composite boss in depth. The first FE results are realistic and prove clearly the applicability of the FE technique. In order to obtain a good agreement between measurement and simulation, however, the FE models presented here should be improved in the near future.

## References

[1] Ehrenstein, G.W.: Mit Kunststoffen konstruieren, Carl Hanser Verlag, München (2007)

[2] M. J. Troughton (ed.): „Handbook of plastics joining: a practical guide", William Andrew Inc. (2008)

[3] Aramis 4.6.5 - Deformation measurement using the grating method, Gesellschaft für Optische Messtechnik mbH, Braunschweig, (2000)

[4] Soós, E., Goda, T.: Mechanical behavior of glass fiber-reinforced bosses: experiments and FE simulations, Periodica Polytechnica 55/1, pp:1-12 (2011) ISSN 1587-379X