Bolted Connections for the Transparent Thermoplastic PMMA

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Summary

Connection methods are very important in the use of thermoplastic materials in architecture. In cooperation with industry partner Evonik Röhm GmbH, the Technical University of Darmstadt analysed bolted connections to create lightweight structures made of combinations of timber or steel and PMMA.

Keywords: PMMA, bearing stress, Plexiglas, palace moat bridge Darmstadt, transparency, composite girder, bolted connection

Light, filigree structures are becoming increasingly more significant in architecture. By utilising transparent materials the feeling of lightness can be conveyed. In research work at the Technical University of Darmstadt in cooperation with plastics manufacturer Evonik Röhm GmbH bolted connections using PMMA were investigated and used in a prototype structure. The prototype is a foot and cycle bridge that spans the palace moat in Darmstadt (see [4]). In this project a new type of composite girder made of PMMA and wood was used; the tensile and compressive forces are transmitted to the wood and the PMMA forms a shear connection. The material characteristics of PMMA are dependent on the production method, ambient temperature, weathering conditions and loading duration. The Young's Modulus is over 2900 MPa and the tensile strength is over 60 MPa for extruded material and standard climate conditions. The thermal expansion coefficient is 7×10^{-5} K^{-1}.

It is the task of the engineer to design a structure in a way that the residual risk is small enough. As a consequence an approach was defined in civil engineering which considers the probability of failure and the damage with two different measures. The first one is taken into account when defining safety factors considering the scattering of action and resistance. The latter one is usually used when declaring requirements for structural elements und construction hints.

Especially when dealing with brittle materials both of these aspects and the respective requirements have to be adjusted. In general thermoplastics used as structural materials have to be classified as brittle materials as they exhibit, at least at normal temperatures and short term loading, a linear stress-strain relationship until failure. With respect to the practical work one has to distinguish between different related aspects: design procedure based on calculation, verification/confirmation of material resistance and substitution of calculation by experiments. The first aspect is very well known and common practice. The standards and regulations offer the necessary tools and information for design, especially safety factors. However problems arise when trying to confirm resistance parameters or when substituting calculative methods by experiments.

While the method can be used without special problems when defining a design relevant value, the same procedure leads to complications if used for the purpose of verification/confirmation tests.

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The small number usually chosen for verification leads to very small values if one applies the method consequently. To resolve this situation a procedure was derived which leads to a method that satisfies the aspects of safety as well as the aspects of limited number of verification tests. The basic idea lies in the fact that all materials to be used in engineering structures have a certain minimum strength. This basic fact is not considered in the probabilistic approach using distribution functions with low values and low probabilities. Reality shows however that all materials have a certain minimum resistance. Using this observation as a fact, the method can easily be described: Instead of proving the characteristic value by probabilistic means, the minimum value is chosen for the verification. The respective concept is named "Minimum Value Concept (MVC)".

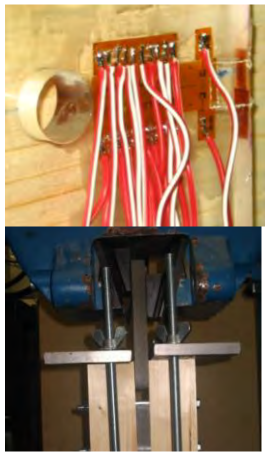

Fig. 1: Test setup: wood-PMMA bearing stress tests, strain gauges

The proper mechanical processing of PMMA is very significant for its use in structures, as mistakes made here can lead to a reduced load-bearing capacity. When processing the most important thing to ensure is that the tools are well-sharpened and have sufficient cooling. The load-bearing capacity of the bore holes for the bolted connections is highly dependent on the quality of the bore hole. The quality of the bore holes can be divided into different categories (see table 2 in full paper). Since PMMA is relatively brittle, the familiar calculation methods used in steel construction cannot be applied. The transfer of the bolt force leads to high localised stress peaks. PMMA is not in sufficient measure able to transfer these by plasticization and breaks without warning when overstrained. Thus an analytic model was developed, which was checked by carrying out numerous tests (see Fig. 1) and FE calculations. The goal was to find a calculation model that takes into consideration various bolt and sheet geometries, which would be as easy to use in practice as possible.

The stresses in a PMMA panel can be approximately defined by superposing the state of the bearing stress in an infinite panel and a state of auxiliary stress in a panel of finite width with a circular hole (see Fig. 2 and [1]). Girkmann in [2] presents a solution method for the first state of stress. In practice the usual dimensions of components are finite so that an expansion of the solution is made with a state of auxiliary stress for a panel of finite dimension with a circular hole. When the solution is applied to a finite panel width b_w, the stresses on the perimeter of the hole are only minimally influenced. In this way the actual panel geometry can be taken into consideration. Analysis leads to a minimum distance to the edge of the sheet of $2 \cdot r_0$.

By superposing both states of stress, the stresses can now be analytically calculated based on the equations presented in the full paper. Tests show that the stresses actually measured are marginally below the results of the numeric and analytic calculations. Usually a side wall failure occurs that is triggered by the maximum tangential stress directly on the perimeter of the bore hole. The load-bearing capacity of bolted connection can be specified as follows:

$$P_{\vartheta,R,k} = \frac{\sigma_{R,k}}{\dfrac{4}{t \cdot r_0 \cdot \pi^2} + \dfrac{3}{2 \cdot t \cdot b_W}}$$

In doing so $\sigma_{R,k}$ is identified as the characteristic resistance for the ideal bearing stress. This was determined from a large number of bearing stress tests for various levels of bore hole quality and can be found in Table 2 (full paper). When carrying out a connection between PMMA and wood, the solution method presented can also be referred to. For this Johansen's theory (see [3]) can be applied.

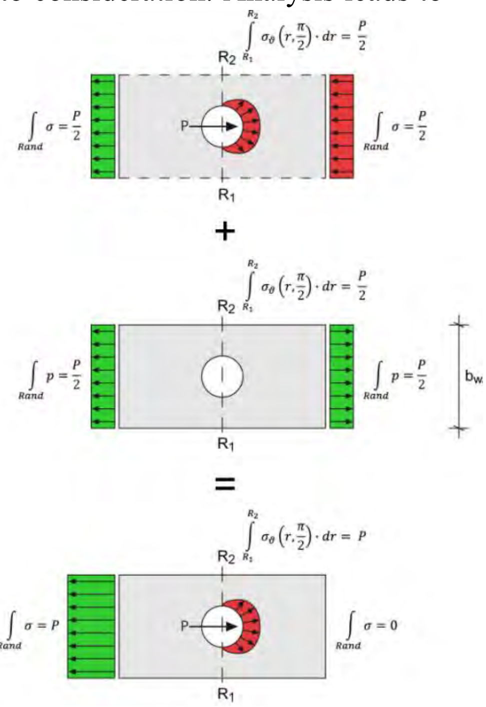

Fig. 2: Superposition of state of the bearing stress with a state of auxiliary stress