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Development of Eurocode-based design rules for adhesive bonded joints

Hartmut Pasternak, Yvonne Ciupack*

Brandenburg University of Technology, Chair of Steel and Timber Structures, Cottbus, Germany

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ABSTRACT

Despite many advantages, adhesive bonding technology has not been able to establish in construction and specifically steel construction. The reasons for this are doubts by engineers, architects and contractors regarding the verifiability, durability and load bearing capacity of bonded steel constructions. In order to facilitate the use of the innovative bonding technique in construction too, it is necessary to process bonded joints close to standardisation. The general interest of automotive manufacturing, construction, chemistry and other industries and research is highlighted by numerous experimental and analytical studies. The aspect of standardisation is of particular importance to construction engineering. While various guidelines for adhesive bonds exist, these are either not applicable to steel construction or are based on an obsolete concept. Practically relevant design concepts are based on the semi-probabilistic method of the Eurocode. In order to develop such a concept, it is necessary to calibrate analytical models by experimentation. The statistical method aims to determine partial safety and conversion factors. Therefore, a comparison of experimental results with analytical solutions is necessary. In the article, analytical models, experimental studies and statistical calibration methods are introduced.

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1. Introduction

Many studies have shown that adhesive bonding technology can be successfully utilized in lightweight steel construction. The classic joining techniques in steel construction have undergone advancements, but fundamental problems and limits still remain. The use of adhesive bonding can remedy the situation. Therefore, it is necessary to continuously work on establishing innovative joining processes in the steel construction.

Civil engineering, especially steel construction is cautious of this joining technology, justified by doubts about durability and above all by the lack of design rules. Nevertheless, there is a long tradition of application of adhesive technology in civil engineering. Mortar, which is used for masonry and for installing ceramic tiles, is an adhesive. Similarly, the material concrete should be mentioned here, which can be understood as a composite of aggregates and reinforcement.

The fixing of glazing and curtain walling panels to the façade support structure with elastic silicones is known as “Structural Silicone Glazing”. By this method, visually attractive structures completely encased in glass can be built. One of the most important buildings to demonstrate the functionality of structural adhesive joints is the Sacred Heart Church in Munich (Fig. 1). The essence of the impressive façade is defined by horizontal and vertical glass fins. For the transfer of loads in the rigid steel frame, the glass fins are bonded with silicone adhesives into U-shaped stainless steel profiles (Fig. 1, right). This innovative system has optical, structural and economic advantages.

Also, in steel construction there are few examples of bonding technology. In the years 1955 to 1956 the first bonded pipe and pedestrian bridge was built near Marl with a span of 56 m [2]. The basic idea was the replacement or improvement of sliding resistance of pre-stressed screws.

With recent developments in adhesive technology, material and structural lightweight construction and the growing demand for aesthetics and weight reduction, the interest in adhesive bonding noticeably increased. As an alternative to conventional welded orthotropic plates, Feldmann et al. [3] provide bonded plate elements. Meinz impressively shows in [4] a simple calculation for bonded connections of trapezoidal sheets and bonded reinforcement of hollow profiles. In Ref. [5] van Straalen shows a general procedure for the determination of design rules for overlap joints and sandwich panels. For the verification of bonded joints different design concepts can be found. An example from civil engineering is the guideline for European technical approval for structural sealant glazing systems (ETAG) [6], which provides principles and requirements for the design of bonded joints in glass structures. The proof is performed using the concept of

* Corresponding author. Tel.: +49 355 69 22 55; fax: +49 355 69 21 44.
E-mail address: yvonne.ciupack@tu-cottbus.de (Y. Ciupack).

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permissible stresses. The permissible stresses in the bondline are to be determined based on established test methods and for defined adherend surfaces [18].

From the perspective of design concepts the approach of ETAG is out of date and in need of revision. Current design concepts are based on the partial safety factor concept of Eurocode [7]. In this concept, design values of the effect of actions (E_d) are compared with design values of the associated component or material resistance (R_d). The partial safety factors are to be determined by a suitable calibration of the analytical model or simplified estimate based on Eurocode [7] Section 4.2 (10) P, where the following information can be found: “Where a partial factor for materials or products is needed, a conservative value shall be used, unless suitable statistical information exists to assess the reliability of the value chosen”. Examples of Eurocode-based design concepts are the Eurocomp design code for the design of polymer composite structures [8] and the Standard for the design of aluminium structures [9]. The Eurocomp Design Code [8] deals with the design of polymeric materials and includes the calculation of adhesive bonding of plastics. Maximum shear and tensile stresses are defined as design relevant conditions. Only cohesive failure of the adhesive layers can be taken into account. The general design principle is based on analytical models for the adhesion between components, wherein a perfect bond between the bondline and the adherend is assumed. The mechanical properties can be taken from data sheets or experiments which are described in the corresponding manual. The Eurocomp Design Code is of particular interest because specific characteristics influence the design results, such as the source of the adhesive characteristics, the method of application and environmental conditions. This is done by forming the partial safety factor γ_M.

Due to a lack of standards for verification of bonded joints in steel construction, functional and practical applications of this joining technique are still not verifiable without considerable effort. Planning and realization of bonded constructions thus always require an “individual approval” or a “general technical

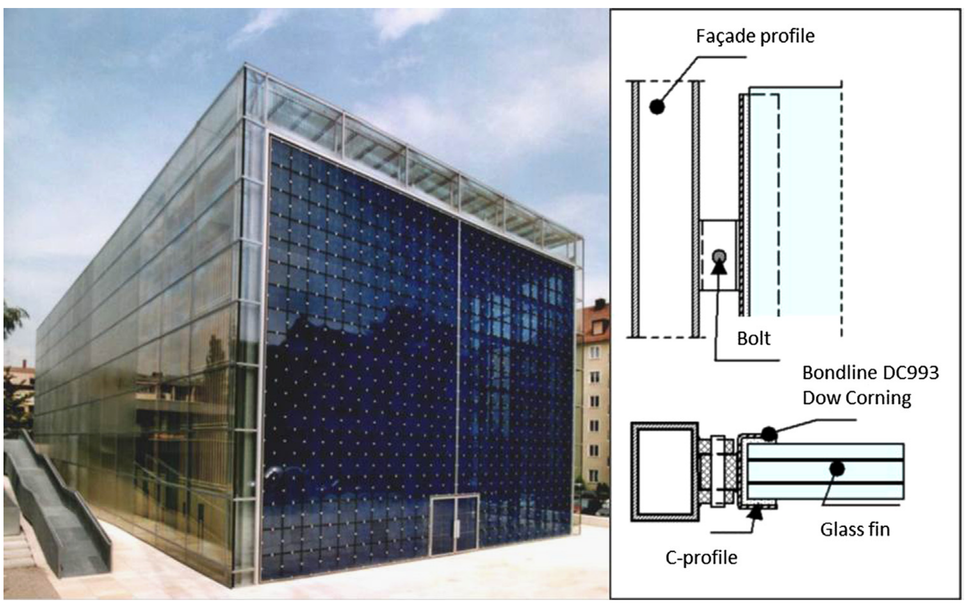

Fig. 1. Left: view Herz Jesu Church; right: detail connection vertical glass fin; [1].

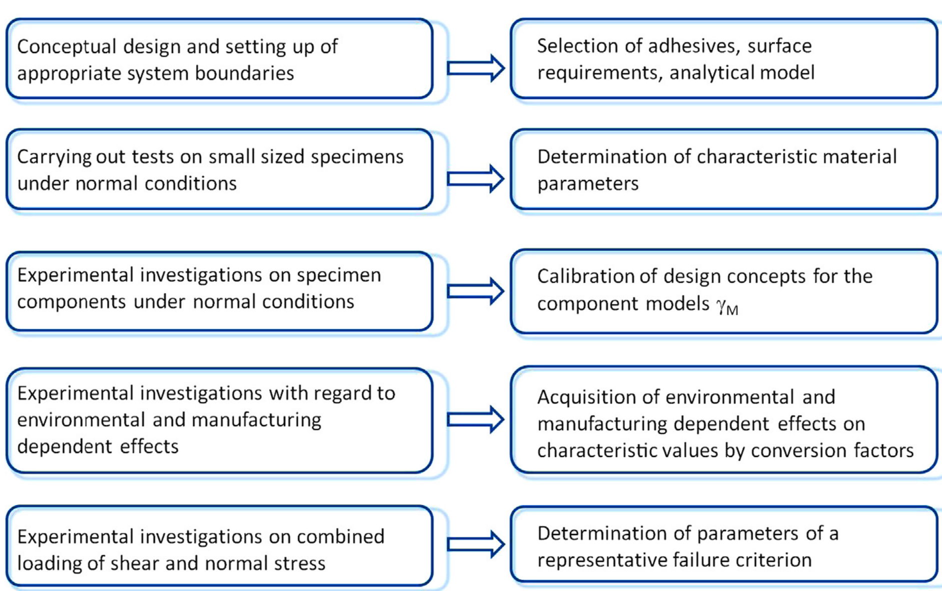

Fig. 2. Overview of the required operations.

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