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Numerical Modeling of Fillet and Butt Welds in Steel Structural Elements with Verification using Experiment

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Abstract

The paper is focused on the numerical models of steel welded supporting elements and their verification using experiment. Currently, for the stress-strain analysis of the elements in supporting structures it is possible to use many commercial software systems, based on the finite element method - FEM. It is important to check and compare the results of FEM analysis with the results of physical verification test, in which the real behavior of the bearing element can be observed. The results of the comparison can be used for calibration of the computational model.
The article deals with the physical tests of steel supporting elements, whose main purpose is obtaining the material, geometry and strength characteristics of the fillet and butt welds. A welded joint consists of separate zones (such as the main material, the weld and the heat affected zone) with different mechanical properties, therefore it is mechanically heterogeneous. The main aim was at defining the tested samples of numerical models for using FEM analysis in commercial software ANSYS. The tension test was performed during the experiment, wherein the totals load value and the corresponding deformation of the specimens under the load was monitored. Obtained data were used for the calibration of numerical models of test samples and they are necessary for further strain analysis of steel supporting elements.

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Keywords: steel structure; welding joint; fillet weld; butt weld; numerical modelling; FEM; ANSYS; experimental test

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1. Introduction

Numerical modeling is increasingly promoting into design practice. Using powerful computers and efficient software systems can provide valuable results, which serve to increase the reliability of the proposed support systems and elements [1] as well as to a qualitatively higher level in the design of building structures [2-5]. An important tool for mathematical modeling is particularly the Finite Element Method – FEM (e.g. [6, 7]), whose principle is to discrete continuum to certain (finite) number of elements and the determination of calculated parameters in individual nodes. Numerical modeling finds its application in all sorts of areas of engineering and many high-quality papers and studies have already been published in this area of the research [8-12]. The results of numerical modeling have usually limited use without the experimental verification or without the load test [13, 14]. Test results may lead to calibration and validation of mathematical model, which should ensure compliance of the numerical model and the actual behavior of the investigated structure. Valuable results of mathematical modeling are also conditional on defining the material models, which are often associated with laboratory-obtained material properties [15, 16].

The stress analysis of welds has got also the considerable attention in the past. In [17] it was defined stress intensity factor of welded joint for typical structural details, among others for cruciform joint fillet weld. In [18] the authors discuss the derivation of the so called notch stress intensity factors for welded joints, using which can be accurately described stress distributions in the toe neighborhood of weld toes. An exact solution on the stress analysis of fillet welds was described e.g. in [19]. With the development of commercial computing systems there have been emerging works whose aim to describe the state of stress in the welds through FEM analysis. In [20] is described the approach for a determination of the notch stress intensity factor in welded joints using three-dimensional finite element models (SOLID 45) in software system ANSYS. Real behavior of welds in terms of stress analysis can be examined through physical tests. Publication [21] contains the results from twenty-four cruciform weld experiments and complementary finite element simulations to study the effect of the weld root notch on strength and ductility of fillet welds. Research of stresses in welds can also be performed e.g., using a digital camera, as in assessment of stress intensity factors for load-carrying fillet welded cruciform joints [22]. The publication [23] aims to investigate the stress–strain state in mechanically heterogeneous welded joints with a single-V butt weld by an analytical model along with a numerical simulation in ABAQUS finite element analysis software. From the above summary of publications aimed at mathematical modeling of structures, focusing on the problems of welded oriented problems is obvious that this is a very current topic.

The further interpretation is dedicated to problems of mathematical modeling of welded bearing elements in steel structures - fillet welded lap joint and double V butt welded joints. Some works focused on numerical modelling of welded joints based on experimental verification have been published [24-27].

2. Stress analysis of welding joints according to EC

The basic document for the design of steel structural joints subjected to predominantly static loadings is the standard EN 1993-1-8 (Eurocode 3: Design of steel structures - Part 1-8: Design of joints), where is possible to find among the other procedures specifications for designing and reliability assessment of welded joints, e.g. for fillet welds, fillet welds all round, butt welds, plug welds and flare groove welds. The material thickness should be at least 4 mm (special rules need to be applied for welding thin walled elements).

2.1. Fillet welds

For the calculation of design resistance of welds it is particularly necessary to define the length and the effective thickness of the welds and their design tensile and shear strength.

Hereafter, the paper is partly focused on the fillet welds, which may be used for connecting parts where the fusion faces form an angle of between 60º and 120º. The connected parts of the welded joints do not require further modification, such as preheating or bevel the edges of the edges. The effective throat thickness of a fillet weld should be taken as the height of the largest triangle (with equal or unequal legs) that can be inscribed within the fusion faces and the weld surface, measured perpendicular to the outer side of this triangle. The effective throat thickness of a fillet weld should not be less than 3 mm.