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Advanced residual stress assessment of plate girders through welding simulation

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Abstract

This article provides an impression on potentials in applying nowadays welding simulation tools in construction design. This is carried out exemplary on plate girders from two structural steel grades. The calculated residual stresses are compared with measurements by sectioning method. It has been repeatedly stated that present Eurocode models fail to approximate the residual stresses. Especially for high strength steel (HSS) only limited information is available on realistic occurring residual stresses in typical I-girders. The investigations are aimed to give further guidance on these values. A few proposals on advanced models are discussed.

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Keywords: Residual stresses; Plate girders; I-shape sections; High-strength steel; Welding simulation; Advanced models.

1. Introduction

Welded I-girders are used in many applications in steel construction, especially a tailored mixture of different plate thicknesses is difficult to manufacture by rolling. The ultimate limit state of plate girders under compression or bending is significantly influenced by the present imperfections. Load influencing imperfections are mainly geometric deviations from the ideal shape and residual stresses (both due to assembly or weld manufacturing). The following sections are referred to the influence of residual stresses only. The general influence of residual stresses on structural

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members is to cause premature yielding leading to a loss of stiffness and a reduction in load-carrying capacity [**1**]. Typical yield zone patterns of an I-shape section at ultimate limit state (ULS) are presented exemplary for pure compression and 3-point bending in Figure 1. Both cases show broadly comparable yielding over wide areas of the corresponding side of the chords in compression. Hence, the residual stress amplitudes near the chord edges are of importance. Previous studies have shown that the reduction in load-carrying capacity is particularly noteworthy in the lower and medium slenderness range [**1**]. For the residual stresses, the recommendation from Eurocode only reads that a typical residual stress pattern (reflecting the “mean” expected values) must be included. This recommendation is independent of the type of loading and does not suggest any specific residual stress pattern. The decision on the type of pattern which fits best (and safe-sided) for a particular problem must be taken by the designer.

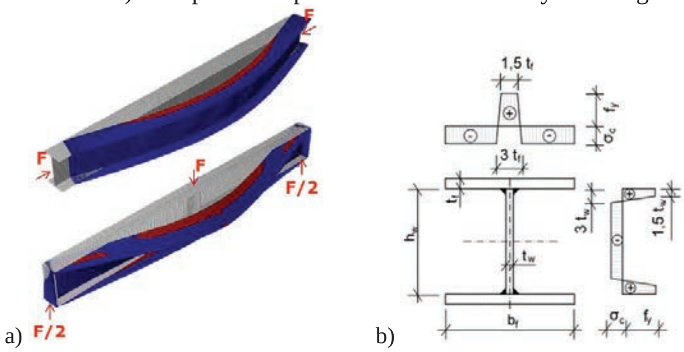

Fig. 1. a) Typical yield zone patterns at ULS for pure compression and 3-point bending; b) Typical distribution of residual stresses for design purposes [**2**].

The formation of residual stresses in steel girders occurs primarily during the section production process, e.g. due to cutting (especially thermal cutting processes involve intense local heating and rapid cooling) and all types of welding. In this paper, the latter is investigated. Tensile and compressive longitudinal stresses are observed in all welded girders in a quite regular fashion. Models can be found e.g. in the Swedish provisions for the design of bridges [**2**] and in several works of the ECCS [**3,4**]. The residual stress pattern is characterized by longitudinal stresses acting symmetrically on the cross-sectional area of the plate girder, whereas boundaries are often determined by geometrical parameters. A general recommendation which model should be used is not possible, because no information on the validity range is available (except for the maximum plate thickness in [**2**]). Hence, their match is random for the most part.

The amplitudes in compression (referred to the yield stress) and especially the distribution near the edges are the main influencing factors on the load-bearing capacity. For narrow chords the distribution is simplified as a constant. Thus, the values can be calculated from equilibrium if the sum of tensile residual stresses is known. Those must be referred in some way to the material grade, the plate thickness and the weld heat input (or an equivalent parameter) [**1**]. The attempt to establish a correlation only with the profile shape or the dimensions (such as originally by [**3**]) seems connected with the fact that this procedure applies to rolled sections, and is therefore probably developed historically. For rolled sections the temperature field is initially homogeneous. The subsequent zonal change in temperatures causes residual stresses. However, these relations cannot be used for welding (locally concentrated heat).

It should be added also that present models are based on (very few) specimens from mild structural steel [**5**]. For such steel the residual stresses close to the weld are typically assumed to meet the nominal yield stress in tension. For high-strength steel (HSS) less information is available. Clarin [**6**] noticed that, when considering the steel grades with higher grades, the tensile residual stresses seem to be lower in comparison to the yield stress. Nevertheless, no firm conclusion has been drawn yet. As a temporary recommendation it is suggested to use 500 MPa as an upper limit even if the actual yield stress is higher [**7**]. Ban [**8**] suggests tensile residual stresses at 75 % of the nominal yield stress for S460. This also implies that the residual stress effects would be less severe on the structure response for HSS. However, more experimental data are in need to conform the research conclusions. Apart from that no data are reported.