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Procedia Engineering 40 (2012) 2 – 7

Procedia Engineering

www.elsevier.com/locate/procedia

Steel Structures and Bridges 2012

Size and distribution of welding stresses

M. Al Ali[a,]* and N. Daneshjo[b]

[a]*Technical University of Košice, Faculty of Civil Engineering, Vysokoškolská 4, Košice 042 00, Slovakia*
[b]*Technical University of Košice, Faculty of Aeronautics, Rampová 7, Košice 041 21, Slovakia*

Abstract

The high temperatures induced during welding process cause transient thermal stresses and plastic strains around the weld. The result of these strains are known as residual welding stresses. This paper deals with the analysis of welding stresses, and also with the determination of their size and distribution in the web and the flanges of welded I-cross-sections using some modified empirical formulae developed by the first author.
The paper also presents some results obtained by the application of modified formulae with their verification and comparison with experimental results of welded beams [1], [2].

Keywords: Welding stress; welding process; welding effect, residual stress.

1. Introduction

During the welding process the welded member undergoes high temperature fluctuations that melts the material around the weld. Uneven heating and cooling processes cause welding (or residual) stresses in the welded member. It is a complex physical and chemical process. Therefore, the determination of the size and distribution of the welding stresses is regarded as a complicated process, which depends on many factors, the so called welding process parameters.

In the case of welded members subjected to bending, the interaction between welding stresses and stresses caused by loading cause a premature plasticization in the most stressed cross-sections and areas of the beams, which results in the increasing of beams deflections. The paper presents a verification of modified empirical formulae developed by the first author [3], using experimental results and a research program oriented to the effects of welding stresses and beams deflections [1].

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* Tel.: +421 905 359 228; fax: +421 55 602 4293.
E-mail address: mohamad.alali@tuke.sk

doi:10.1016/j.proeng.2012.07.046

2. Formation and distribution of welding stresses

At present, some analytical methods based on the analysis of several welding parameters and their effects on the formation and distribution of welding stresses already exist [4]. Most of known analytical methods are developed for specific cases and their universal application is questionable. On the other hand, there are empirical formulae developed by a combination of experimental and theoretical analysis, which could be probably used. These formulae determine the welding stress in relative values of the yield stress of a welded material. Some sources [5], suggest that the following formulae for determining the welding stress in the web of welded I-cross-section should be used:

$$\sigma_1 = \xi f_y \tag{1}$$

$$\sigma_2 = \frac{2}{3} \xi f_y \tag{2}$$

ξ is a factor of <0 ~ 1>, depending on the welding technology and cross-sectional dimension.

The corresponding distribution of welding stresses in the web of a welded I-cross-section is illustrated in Figure 1.

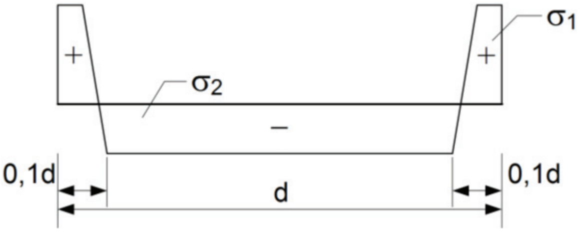

Fig. 1. Distribution of welding stresses in the web of welded I-cross-section according to [5]

Different empirical formulae used to determine the size of the welding stresses in the web and the flanges of a welded I-cross-section are given in [6]. These formulae have the following form:

$$\sigma_{zf} = \frac{f_y}{4}\left[8\left(\frac{x}{b}\right)^2 - 1\right] \tag{3}$$

$$\sigma_{zw} = \frac{f_y}{4}\left[1 - 8\left(\frac{y}{d}\right)^2\right] \tag{4}$$

σ_{zf} and σ_{zw} are the welding stresses in the flanges and the web, while x and y coordinates are located at their centres. The corresponding distribution of welding stresses in the welded I-cross-section is shown in Figure 2. Comparisons of Figures 1 and 2, and evaluation of relevant formulae, indicate apparent differences between the distribution and the size of the corresponding welding stresses. Analysis of the presented and other similar empirical formulae proved that these formulae do not have general application potential.

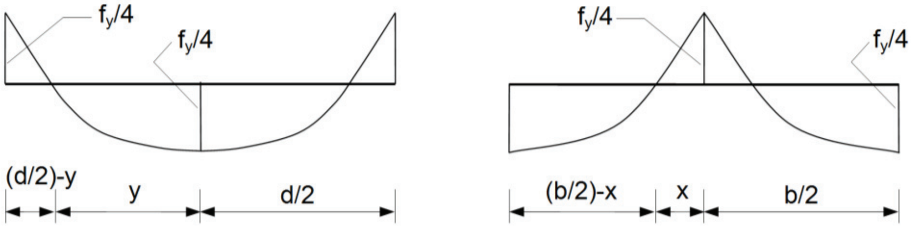

Fig. 2. Distribution of welding stresses in a welded I-cross-section according to [6]

3. Development of modified formulae

Experimental research [1], was used to verify the validity of the above mentioned empirical formulae. The experimental research was oriented to investigating elastic-plastic local stability of beams with welded I-cross-sections. Flanges and webs of all beams were made from one sheet plate. The beams were of equal height, but varied flanges widths to investigate their local stability in accordance with the research purpose. The experimental program consisted of 36 beams. According to the flanges slenderness β_f, beams were divided into groups A, B, C, D, E and F. Each group consisted of 6 beams. To find out the influence of welding stress, 3 beams of each group were annealed before testing. Boundary conditions, beam loading, location of strain gauges (1-8) and sensors for deflections measuring (I, III, VI and VIII) are shown in Figure 3.

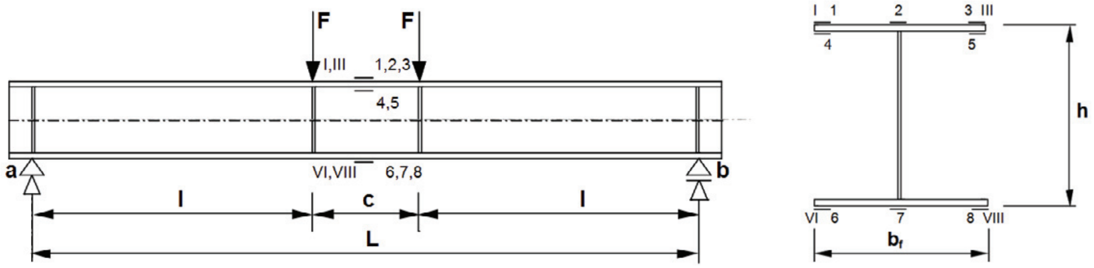

Fig. 3. Static scheme and layout of the tested beams

The results of all tested beams showed obvious differences between annealed and unannealed beams. Deflections of unannealed beams were larger at smaller loads, see Figure 4.

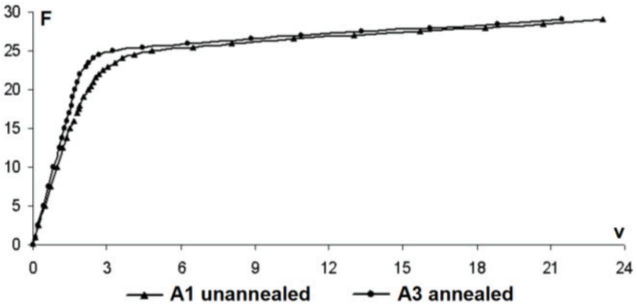

Fig. 4. Comparison of the deflections *v* according to the load *F*, beams of group A

Modified formulae assume that the absolute values of compressive and tensile stresses in the centre and at the edges are different. The maximum compressive stress has the value $f_y/4$, while the maximum tensile stress is adjusted to the value $3f_y/4$. Another modification is to shift the position of the beginning of y coordinates to the edge of the web, while the beginning position of x coordinates is placed at the centre of the flange. Points at which the stress passes from compressive to tensile values is defined as follows:

$$x_0 = \frac{b}{2\sqrt{2}} \;\; , \;\; y_0 = \frac{d}{2\sqrt{2}} \; . \tag{5}$$

In accordance with the above assumptions, the distribution of welding stresses in the web and the flanges of welded I-cross-section according to modified formulae acquired the following shape, Figure 5.

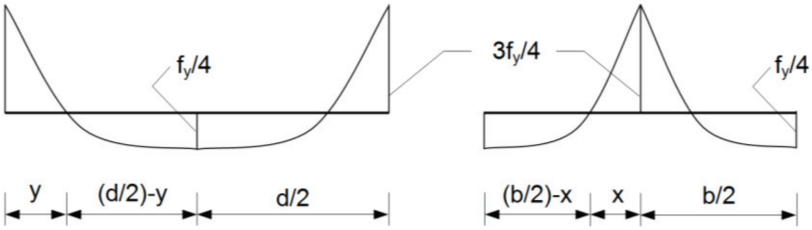

Fig. 5. Distribution of welding stresses in the web and the flanges of welded I-cross-section according to [3]

Taking into account the mentioned assumptions and the distribution of welding stresses from Figure 5, the modified formulae took on the following form:

- For the flanges

$$\sigma_{zf,m1} = \frac{3f_y}{4}\left[1-8\left(\frac{x}{b}\right)^2\right], \text{for } 0 \le \mathrm{x} \le \frac{b}{2\sqrt{2}}, \tag{6}$$

$$\sigma_{zf,m2} = \frac{f_y}{4}\left[1-8\left(\frac{x}{b}\right)^2\right], \text{for } \frac{b}{2\sqrt{2}} \le x \le \frac{b}{2}. \tag{7}$$

- For the web

$$\sigma_{zw,m1} = \frac{3f_y}{4}\left[1-8\left(\frac{y}{d}\right)^2\right], \text{for } 0 \le \mathrm{y} \le \frac{d}{2\sqrt{2}}, \tag{8}$$

$$\sigma_{zw,m2} = \frac{f_y}{4}\left[1-8\left(\frac{y}{d}\right)^2\right], \text{for } \frac{d}{2\sqrt{2}} \le y \le \frac{d}{2}. \tag{9}$$

In order to simplify the calculation and for practical application, it is necessary to idealize the shape of the stress pattern from Figure 5, provided that the “pass point” from compressive to tensile zone is invariable.

The task was to idealize the formulae and achieve a stress balance. Idealized formulae took on the form:

$$\sigma_{1,m} = \xi f_y, \tag{10}$$

$$\sigma_{2,m} = 0{,}414\xi f_y. \tag{11}$$

The stress balance was achieved with a value $\xi = 0{,}4$. The distribution of welding stresses in the web and flanges of welded I-cross-section, according to idealized stress pattern is given by Figure 6.

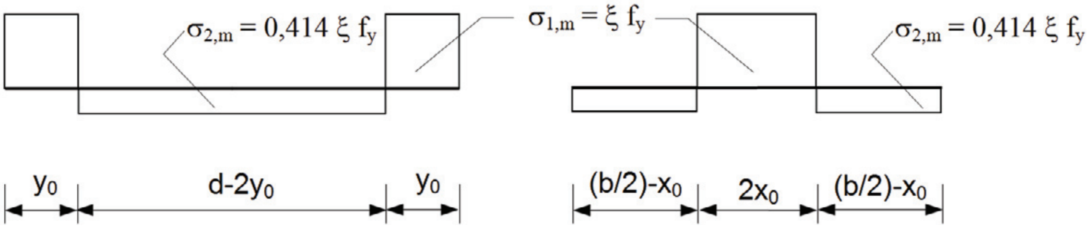

Fig. 6. Idealized pattern of welding stresses in the web and flanges of welded I-cross-section

3.1. Application of modified formulae

The application of the above mentioned modified empirical formulae was realised as following:

1. Theoretical elastic limit loads $F_{t,el}$ and theoretical elastic deflections $v_{t,el}$ for all beams of group A - F were calculated, without considering the influence of welding stresses.
2. The values of welding stresses for individual beams were calculated using the idealized modified formulae.
3. The obtained values of welding stresses were subtracted from the actual material yield stress f_y, otherwise: $\sigma_{max}^{-} = f_y - \sigma_{1,m}$, and $\sigma_{max}^{+} = f_y - \sigma_{2,m}$.
4. Stress σ_{max}^{+}, obtained from step 3 was considered as the limit elastic stress. With this consideration, new limit loads $F_{max,el}$ and deflections $v_{max,el}$ were calculated for all beams.
5. This analysis assumes that the difference between $F_{t,el}$ and $F_{max,el}$ is a result of welding stresses. The analysis also assumes that $F_{max,el}$ should be close to the experimental limit load $F_{exp,el}$ for unannealed beams.

Some results from the analysis and the calculation of limit loads for unannealed beams are given by Table 1. The greater differences in the case of groups E and F are due to the influence of local stability problems.

Table 1. Elastic and experimental limit loads of unannealed beams and their comparison

Beams group	$F_{t,el}$ [kN]	$F_{exp,el}$ [kN]	$F_{max,el}$ [kN]	$F_{exp,el}$ / $F_{max,el}$
A	19,68	16,848	16,404	1,027
B	22,293	19,018	18,585	1,023
C	24,81	21,118	20,684	1,020
D	27,597	23,426	23,008	1,018
E	30,185	23,896	25,165	0,949
F	32,826	25,467	27,367	0,930

4. Conclusion

The experimental results of annealed and unannealed beams demonstrate a clear effect of welding stresses, as illustrated in Figure 4.

Performed analysis and limit loads presented in Table 3, reflect an agreement between experimental results and the results obtained by modified formulae. In the case of unannealed beams of groups A, B, C and D the difference does not exceed 2.7%. In the case of groups E and F the difference was 5-7%, it appeared because the beams of these groups had slender flanges and the influence of local stability is manifested here, which is in accordance with the research goals.

Generally, it can be concluded that the modified formulae provide reasonable results for the preliminary determination of the size and distribution of welding stresses.

Acknowledgements

This paper has been supported by the project NFP26220120037: Centre of excellent research of the progressive building structures, materials and technologies, supported by the European Union Structural funds.

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