BENDING STRAINS OF STEEL CONSTRUCTION IN PROCESS OF WELDING BY MAG TECHNOLOGY

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Abstract. Dimensional deformations of a steel beam after MAG welding ere analytically calculated as well as verified by experiment results. There are the key factors defined, which have an effect on the value of deformation as well as solutions offered for regulation of the value of deformation in dependence on the welding technology and by selection of the regime. Experimental studies have shown that in the researched plate by using of indirect bending in breaking jig on the calculated bending angle the deformation of the plate is reduced by 60 %; as a result the flatness after welding corresponds to the tolerance of ± 4mm.

Key words: welding, weld, bending deformations, breaking jig.

Introduction

In the process of welding, when the lap joints are formed by butt weld with prepared V-shaped edges and by welding of the ribs or the sheets from one side, the asymmetrically loaded structures are formed. Stress resulting from the welding process creates tension, compression, bending as well as torsion deformations, as the result the size and shape of the article change and often do not correspond with the parameters required.

Practitioners are interested in the possibility to evaluate lasting deformation and the size of the curvature in welded articles as well as activities for reducing of unwanted deformations. Knowing the size and type of deformation, it is probably more or less completely prevented by using a variety of technologic methods. One of the most effective methods for prevention of bending deformation is indirect bend of the parts before welding, it means bending in opposite direction, than will develop in the welded part after welding. In order to successfully be able to use this technique, it is necessary to know how to predict the types and sizes of deformations after welding. Longitudinal deformations, which occur in flat sheet from contraction of the metal of weld in plane, are identified with the practice satisfactory accuracy in the resource [1], by using of an analytical calculation method and welding practice results.

Bends, which formed a steel sheet with unilaterally welded overlay are calculated in the resource [2], by using of the Cosserat's theory of the moments. The size of deformation, resulting from the welding process, by using the finite element method is provided in publications [3-5]. The effectiveness of calculation methods are reduced due to the lack of reliable information, because the welding process affects a very large number of time-varying factors.

The size and shape of deformation in sheet welding depend on a number of factors, including the type of seam as well as the type of elements added at parts. This research focuses on the prediction of bending deformation in sheet of low-carbon steel, where tensions arise in the process of welding due to shrinkage of seam metal. For example: material has the plane, parallel to other planes and in each point there is one flexible symmetric plane, parallel to the middle plane; layer material has an isotropic structure and all layers deform in accordance with the Hooke's law; all layers are closely related, they are mutually deformed without slip and enforcement of the hypothesis of Kirhhoff about rigid normal. External forces do not work. Dimensional stress-state of the part due to shrinkage of the welded material arises after cooling. As a result, longitudinal and bending deformation appears. Bending deformation prediction is performed by the following algorithm: first determine the shrinkage force N; then calculate the moment M size; for the second order surface such as the cylinder (for example) the surface curvature is determined; knowing the surface of the form, the value and strength of reactive bending is chosen, as well as the place for force application. The value of the moment and curvature after welding is calculated by using methodology proposed in the resources [6; 7].

When low carbon steels are welded the shrinkage force increases, but rigidity of the construction decreases.

Materials and methods

For estimation of the shrinkage force P_{sh} coherence [1] was used:

$$P_{sh} = \frac{q}{v_c}, \tag{1}$$

where q – effective power of heat source, $J \cdot s^{-1}$, which for the welding processes can be expressed as $q = \eta \cdot I \cdot U$;
v_c – speed of welding, $cm \cdot s^{-1}$;
η – efficiency of welding equipment;
I – current intensity, A;
U – voltage, V.

The bending moment is determined: $M = P_{sh} \cdot e$, where: e – eccentricity, it is the distance from the plane of symmetry of the plate to the centre of the plastically deformed cross-sectional area.

Bending angle α is determined from the expression: $\alpha = M \cdot l / E \cdot I$, where: l – weld length, cm; E – module of elasticity of material; I – section moment of inertia.

The deviation from flatness of the plate is calculated from the expression: $\delta = \alpha \cdot L$, where: L – the distance, from the measuring base to the measuring point, cm.

Radius of bending R is determined: $R = L / \alpha = E \cdot I / M$.

In calculation, for example, 20 mm thick 700 mm wide and 3000 mm long steel sheet S355 according to LVS EN 10025:2001 was selected, on which one 20 mm thick, 570 mm wide and 700 mm long steel plate S355 is welded.

The axis of symmetry is 1750 mm from one end of the base plate. The plate is welded on with the MAG method over the whole perimeter of seam a5, in one stroke; the strength of current 220 A, voltage 27 V, welding speed of 0.40 $cm \cdot s^{-1}$; the depth of the melt 3 mm. It is assumed in the calculations that deflection of the part occurs due to shrinkage deformations of weld, as well as the stresses that occurred after plate welding.

Using the methodology proposed in the resource [1], we obtain:

$$P_{sh} = 1.7 \cdot \eta \cdot U \frac{I}{v_c} = 1.7 \cdot 0.85 \cdot \frac{230.28}{0.40} = 23264 \text{ kgf} .$$

Rate 1.7 takes into account the changes of mechanical and deformation characteristics of welded materials in the process of MAG welding in dependence on temperature [1].

$M = P_{sh} \cdot e = 23264 \cdot 2.85 = 19774$ kgf·cm;

$\alpha = M \cdot l / E \cdot I = 19774 \cdot 254 / 2 \cdot 10^6 \cdot (70 \cdot 43 / 12 + 220 \cdot 23 / 12) = 0.00477$;

$\delta_{long} = \alpha \cdot L_1 = 0.00477 \cdot 1750 = 8.35$ mm;

$\delta_{long} = \alpha \cdot L_2 = 0.00477 \cdot 1250 = 5.96$ mm;

$R = L / \alpha = 3 / 0.00477 = 629$ m.

By using of this methodology it is possible to calculate how the parameters change; deformation, if the weld parameters remain the same but the welded plate thickness changes, is described.

The results of the calculations are summarized in Table 1.

Table 1

Effect of plate thickness on the parameters of bending deformation

Plate thickness, mm	Angle of bending α	Flatness deviation δ_{long}, mm	Flatness deviation δ_{short}, mm	Radius of bending R, m
25	0.00244	4.27	3.05	1229
20	0.00477	8.35	5.96	629
15	0.0113	19.78	14.13	265
10	0.0381	66.75	47.63	78
5	0.305	533	381	9.8

The results of the calculation show that deformation leads to a surface with a very large radius of bending. Therefore, in order to simplify the calculations and technology, it is assumed that the shape of the parts describes two planes which are faced by the welded plate symmetry axis line. In relation to the ground plane, this plane is rotated on value as the bending angle α. By knowing this bend angle, before welding the workpiece bends with such account that the bend angle would be created in the opposite direction. Formation of deformation is shown in Fig. 1.

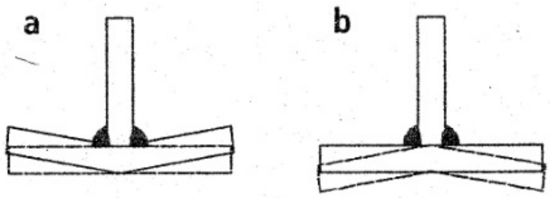

Fig. 1. **Scheme of formation of deformations:** a – welding without using of indirect bend; b – welding with using of indirect bend (the thick black line form the coupling parts after welding)

In order to determine the theoretical assumptions as well as to appreciate the accordance between the calculations and practical results, the experiment with a real plate was carried out, which is part of corpus workpiece. The part dimensions in the plane as well as the measurement scheme are given in Fig. 2. Thickness of the basic part and welded plate is 20 mm. The welded plate dimensions in the plan are 570x700 mm.

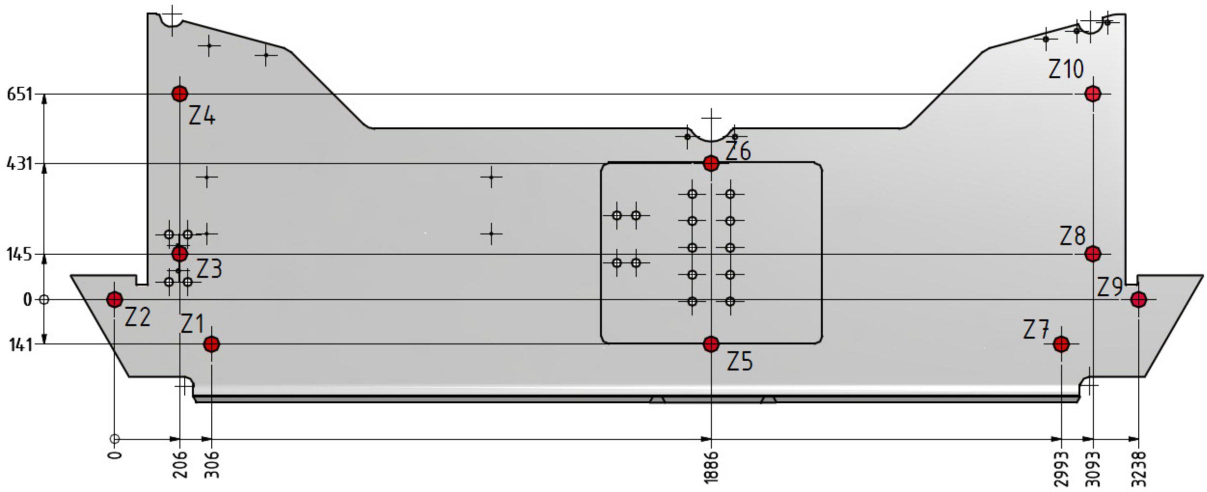

Fig. 2. **Part dimensions in plane and measurement scheme**

The experimental methodology includes the following steps: 1 – measurement of flatness before welding; 2 – measurement of flatness of welded parts without indirect bend using; 3 – measurement of flatness of welded parts with indirect bend using. The amount of the objects researched – 10 items.

Distribution of sizes before and after welding, without changing the sizes of parts, as well as welding regimes and seam preparation technology were defined. To determine the deformation of plates before and after welding, the laser measuring equipment "Status Pro" was used. It was measured in ten selected points. The measurement scheme and coordinates of the points are specified in Fig.2. To measure the flatness of the construction the laser measuring equipment "Status Pro" was used; it consists of the receiver "R310" and laser "T330". To mark off the coordinates of the points on the front beam the laser rangefinder "Leica DISTO D210" is used. The data of measurement are processed with the programme "ProLevel" which at the same time makes it possible to show the data visually. The negative value of the deviation is connected with the methodology of the measurement. Measurements of welded parts are easier if to upturn it with a welded plate to the bottom due to the measured surface being smooth, without bumps as well as the measurement base will be from the basic material. Welding was performed in accordance with the quality level B in accordance with the EN ISO 5817-2007 standards. Permissible dimensions of cathetus for corner weld a5 in the plan are 7.1 + 2.5 mm. Welding modes are given in Table 2.

Table 2

Welding modes

Join	Pad	Process	Wire diameter (mm)	Current, (A)	Voltage, (V)	The wire feed speed ($m \cdot min^{-1}$)	Welding speed ($mm \cdot s^{-1}$)	Heating input, ($kJ \cdot mm^{-1}$)
1	1	135	1.2	220-230	26-28	10-11	3.50-4.50	0.71-0.76

Weld profile Metallographic analysis (Fig. 3) revealed that the depth of the melt is 3 ± 0.5 mm.

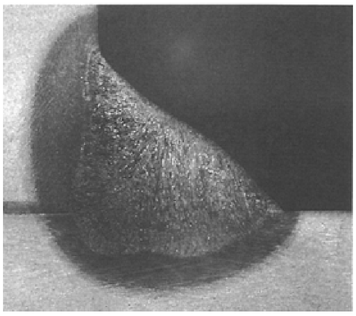

Fig. 3. **Weld profile a5, mag. 3 x**

Results and discussions

Deformation of the plate with the serial No.1 after welding is shown in Fig. 4. All results of the components of the measurement are summarized in Table 3.

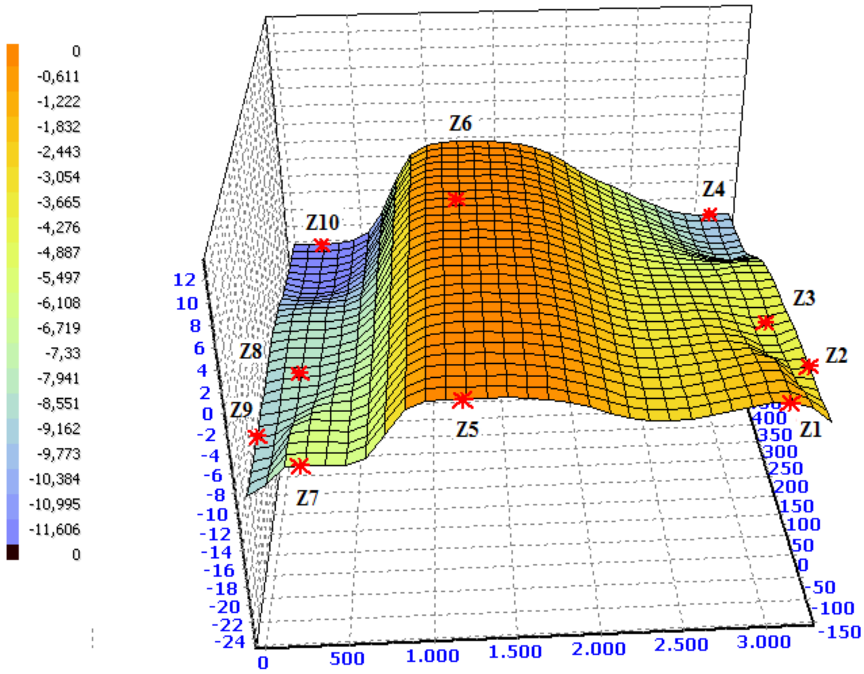

Fig. 4. **Bending strain of plate after welding**

According to the experimentally obtained results it can be concluded, that bending strains, arising during the welding process as well as the plate deviation from flatness after welding in the longest deal δ_{long} in the points Z_2 and Z_3 exceed 10 mm, but on average – 8.41 mm, which considerably exceeds the required tolerance of ± 4 mm.

In order to implement the welding process with using of indirect bend, the results of theoretical calculation of deformation as well as the experimental results of deformation welding without using of indirect bend are used. After analysing of the results the places for force application are selected as well as the value of indirect bend for deformation in the breaking jig.

Table 3

Experimentally obtained results of measurement of plates after welding, mm

No.	Z2	Z9	Z3	Z4	Z8	Z10	Z1	Z5	Z6	Z7
1	-9.041	-3.704	-8.448	-11.911	-4.549	-9.541	-6.014	0	0	-1.464
2	-7.523	-5.374	-7.995	-13.246	-3.569	-10.336	-7.008	0	0	-2.111
3	-9.249	-5.289	-9.623	-9.956	-5.261	-9.87	-6.285	0	0	-1.456
4	-8.995	-3.025	-10.028	-10.885	-4.332	-8.289	-8.096	0	0	-3.895
5	-6.022	-4.685	-6.590	-11.028	-7.589	-7.915	-5.120	0	0	-1.001
6	-10.235	-2.001	-8.003	-12.003	-5.117	-9.822	-7.896	0	0	-2.087
7	-5.689	-4.613	-9.147	-10.663	-6.258	-10.008	-6.844	0	0	-3.258
8	-9.016	-6.095	-10.209	-9.573	-4.856	-12.632	-7.596	0	0	-2.398
9	-7.877	-3.489	-8.001	-10.559	-3.665	-9.842	-6.589	0	0	-0.997
10	-9.283	-4.006	-7.289	-9.899	-5.008	-8.500	-7.001	0	0	-1.528

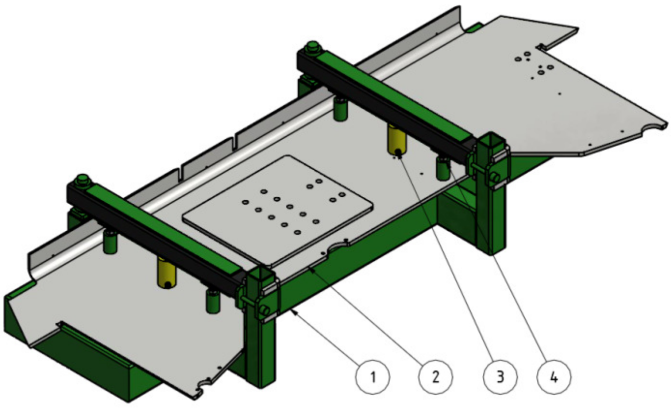

Fig. 5. **Overview of breaking jig:** 1 – breaking jig; 2 – plane; 3 – cylinder; 4 – tensioner

Hydraulic cylinders and tensioners are arranged symmetrically with respect to the basis points *Z*5, *Z*6 and the distance between them is 1500 mm. In order to ensure indirect bend at the bending angle 0.00477 at the distance 750 mm from the axis of symmetry of the part, the deformation on the vertical plane must be 5.78 mm. No.1 plate deformations after welding, by using of breaking jig, are shown in Fig. 6.

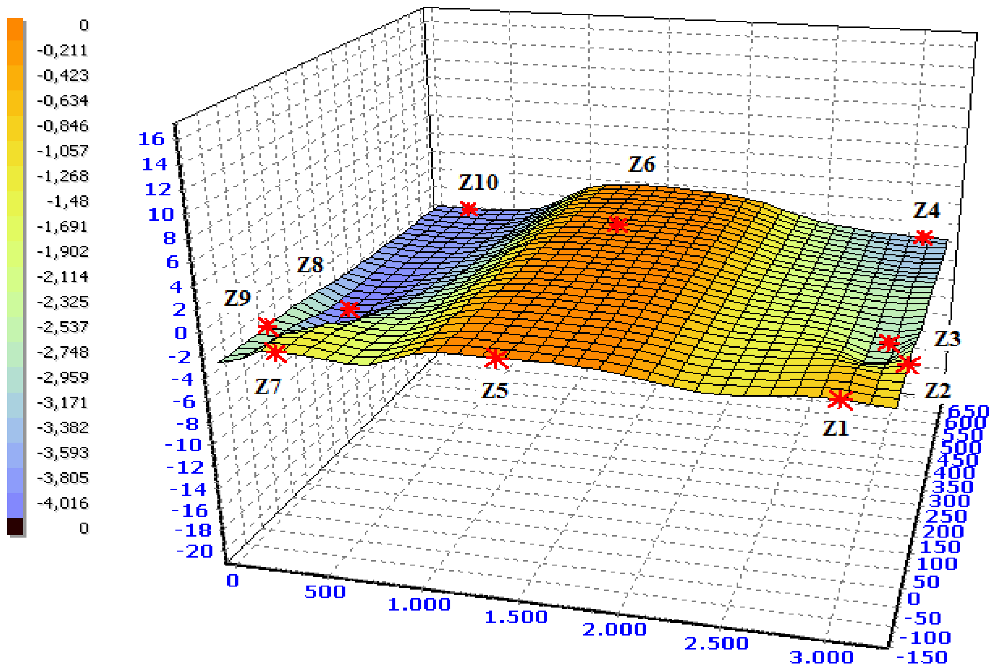

Fig. 6. **Deformations of plate after welding, by using of breaking jig**

In Fig. 7. average values of deflection in points *Z*8, *Z*5 and *Z*3, obtained in measurements of all parts, welded with or without using of indirect bend, are summarized.

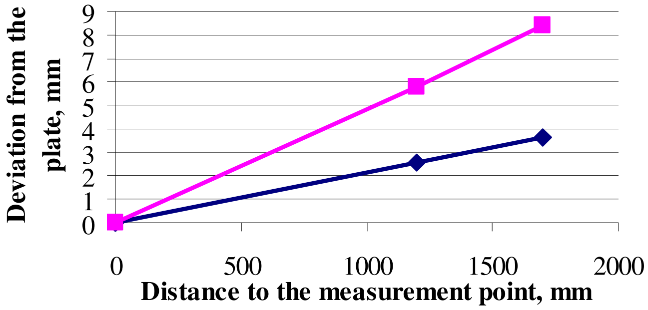

Fig. 7. **Bending deformations of plates after welding:** without using of indirect bends (upper curve); with using of indirect bends (bottom curve)

The experimental results show that by welding on to the base plate the addition plate with indirect bend method deviation from flatness has fallen on average more than twice. However, the deviation is not yet fully resolved and it still has the same sign. It is possible that in the calculation of value of indirect bend it is necessary to evaluate the factor that during the welding process without using of indirect bend the weight of the same part partially replaces indirect bend. Therefore, the experimentally obtained deformations are likely lower than it would be in case, if the dead weight effect would be avoided welded without using of indirect bends.

Conclusions

1. A simplified methodology is offered for calculation of bending of oversized flat plates from low carbon steels in cases with MAG welding and resulting with formation of asymmetrical load.
2. It is estimated that the main factors affecting the value of bending deformation are: molten weld depth, shape, volume, location, welding mode, mechanical properties of welded material and geometrical dimensions.
3. The experiments revealed that in the considered size range the bending angle of the plate is small and in the second-order equations that describe the bent plate shape, when calculations are made, it can be replaced with a plane.
4. Theoretical and experimental analysis of the results shows that the methodology used to calculate the deformation of the practice acceptable accuracy enables you to calculate the plate bending in result of formation of asymmetric loads.
5. Experimental studies have shown that in the researched plate by using of indirect bending in breaking jig on the calculated bending angle, the deformation of the plate is reduced by 60 %; as a result the flatness after welding corresponds to the tolerance of ± 4mm.

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