SIMPLIFIED METHOD FOR PREDICTING AND PREVENTING WELDING JOINTS INDUCED TRANSVERSE DEFORMATION IN PLATES

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Abstract The study deals with the problems that occur when welding flat parts with the pre-bending method. A simplified calculation method has been proposed to calculate the transverse deformation of 4 ... 10 mm thick non-alloy steel plates, for which the standard joints with the MAG method are welded. Experimentally transverse deformation for samples with similar sizes and welding technologies are determined. An analysis of the plate deflection in the heat affected zone and its parameters has been performed. It was determined, in which direction, in what place and to what extent the welded parts should be bent to obtain the required shape after welding and cooling. The developed methodology allows obtaining low-time and computational resources to obtain the information needed to minimize complex welds, if there is no increased requirement to ensure that the parts are flattened.

Keywords: MAG , pre-bending, transverse , steel, residual, stress.

Introduction

Problems how to foresee end prevent welding induced deformations are being solved using experimental methods [1], the method of fictional (equivalent) force [2] and the methods of thermo-analysis [3-5]. The presence of various changing in time and space factors, many kinds of materials and welding technologies, the change of qualities of materials, depending on temperature, load and time, make considerably more difficult the design of the universal method of calculation. Even more problems arise, if you have to secure the geometrical precision of the form of such a construction, the structure of which is asymmetrical or the asymmetry is being formed after the welding of some element, for example, rib or sheet. In order to prevent such deformations practically there are different methods used – the change of mutual position of welding parts, change of the seam – forming technology, thermal treatment of raw material, pressing of the part to the surface of a level table, deformation of the part before welding and others. One of the mostly used is deformation of raw material before welding. For successful performance of such an activity the welder should know: how big and where the deformation has to be made; where stress must be applied; where to measure the deformation; how the size of deformation changes depending on the dimensions of the part; the kind of welding, setting of welding, technologies, surrounding circumstances etc. There are many results of researches, in which there is defined the influence of various actors on the kind and size of deformation, depending on the welding technology, welding material properties, measures, etc. [2-5]. Researchers have created and widely employ the method of modeling temperature fields, using the final element method (FEM). The drawback of this method is very prolonged digital calculations, the purchase of programs, etc. In the literature [5] are given deformations, arising in the welding of T-joint seam. There is performed simplified research of welding deformation, using the 3D thermo elastic plastic deformation analysis and experimental research is carried out. There is proposed a new approach, modeling welding deformation and at the same time preserving the Strains how to Direct Boundary (SDB) mechanism. It has been clarified that in order to predict changes in huge constructions, a simplified analysis of welding deformation is the best solution and it should be performed in short time [4].

The hypothesis of work: by welding the plate seam, it is possible to use deformation of plate after cooling in free position as the basis to determine preliminary data for pre-bending.

The analysis of literature shows that effective usage of computing programs at the present time does not provide the possibility to calculate fast and precisely welding deformations and their methods of observation for all practically occurring variants because of lack of information. That is why at present practically, particularly in individual and experimental production, we have to employ simplified solutions, using conclusions of the theory of material resistance and methods of fictional forces [2; 6].

The aim of the research is to test the possibility of predicting deformations, which are created by welding on the pate a standard seam of given dimensions and to offer the method for prevention of deformations caused at welding using the pre-bending method. The tasks of the work include the theoretical and experimental determination of the size of the pre-bending deformation, the choice of the place of load application, determination of the area of the melting zone, assessment of altering parameters depending on the change of temperature, practically acceptable data calculation for the cases of welding, when the thickness of used for welding unalloyed steel plates with low carbon content is within the limits of 4 to 10 mm.

Materials and methods

To investigate the practical deformation of the seam in the zone of thermal influence there has been carried out an experimental research with steel S235JR plates with thickness of 4, 6, 8, and 10 mm, but the dimensions are 100 x 1000 mm. The seam is welded on the surface of the plate along the axis of symmetry in the length of 100 mm in one move. Welding is performed by a semi-automatic device in active protective gas CO_2 environment, with direct current DC/+ , corresponding to 135 process, with the company Fronius welding equipment TPS 320i. The diameter of the wire – 1 mm. Amperage for welding of 4 mm plate has been chosen – 120 ± 10 A, for welding of 6 mm plate – 150 ± 10 A, for welding of 8 mm plate – 180 ± 10 A and for welding of 10 mm plate – 210 ± 10 A. The voltage corresponds to 20 ± 1, 21 ± 1; 22 ± 1and 22 ± 1 V. The feeding speed of the wire –3; 4; 7; 11 ± 0.5 $m \cdot min^{-1}$; the medium speed of welding v_c corresponds to 240, 220; 200 and 180 $mm \cdot min^{-1}$. Welding was performed at the room temperature 20 ºC. Before welding the deflection of the plate from horizontal was determined. Raw material inclination for 500 mm length does not exceed 0.3 mm.

After welding of the seam the parts are cooled till the room temperature and there are measurements of horizontality carried out. The places of measurements are chosen 5, 10, 20, 30, 50, 100, 200, 300, 400, 500 mm from the axis line of the seam on three levels – along the axis of symmetry of the plate and 35 mm upwards and downwards from it. The unit value of the measuring device is 0.01 mm.

The average values of the results of measurements for the samples with thickness of 4, 6, 8 and 10 mm [1] are given in Table1.

Table 1

Average values of measurement results for 4, 6, 8 and 10 mm thick plates

Sample thickness, mm	Distance from seam axis, mm										
	5	10	15	20	30	50	100	200	300	400	500
4	0.0380	0.1000	0.1800	0.2200	0.3000	0.5200	1.0300	2.1100	3.2200	4.3000	5.4300
6	0.0310	0.0800	0.1365	0.1950	0.2650	0.4460	0.8800	1.9500	2.9200	3.8150	4.7800
8	0.0350	0.0880	0.1500	0.1870	0.2740	0.4500	0.8800	1.6000	2.4600	3.3200	4.3000
10	0.0270	0.0680	0.1200	0.1600	0.2200	0.3400	0.6800	1.3700	1.8700	2.5400	3.2400

Deviation of the plate from flatness is determined by the ratio of the deviation δ to the distance L. There have been calculated average deviations from the angular value α horizontally from 18 measurements in every place of the measurement and they are summarized in Table 2.

Table 2

Average deviations from the angular value α depending on the distance till seam axis

Sample thickness, mm	Distance from seam axis, mm										
	5	10	15	20	30	50	100	200	300	400	500
4	0.00760	0.01000	0.01200	0.01100	0.01000	0.00980	0.01010	0.01030	0.01070	0.01075	0.01086
6	0.00630	0.00800	0.01000	0.01100	0.01000	0.00940	0.00940	0.00975	0.00930	0.00950	0.00956
8	0.00600	0.00800	0.00900	0.00940	0.00910	0.00900	0.00880	0.00800	0.00800	0.00830	0.00800
10	0.00540	0.00680	0.00800	0.00800	0.00730	0.00680	0.00680	0.00685	0.00685	0.00635	0.00650

Fig. 1. shows that for plates with thickness within the limits of 4-10 mm the most essential deformations take place just near the seam in the area of 37 mm. Up to 20 mm angular values increase, reaching the maximum value and then decrease till about constant value. In the distance of about 50 mm from the axis of symmetry of the welded seam the influence of temperature on the form of the plate is not essential. With the preciseness corresponding to practical demands we can assume that in

the distance of 50 mm the plate surface is practically horizontal. Comparing with the deflection of deformed plates from horizontality in the distance of 500 mm from the seam axis of symmetry, it is seen that the deflection decreases with the increase of the plate thickness.

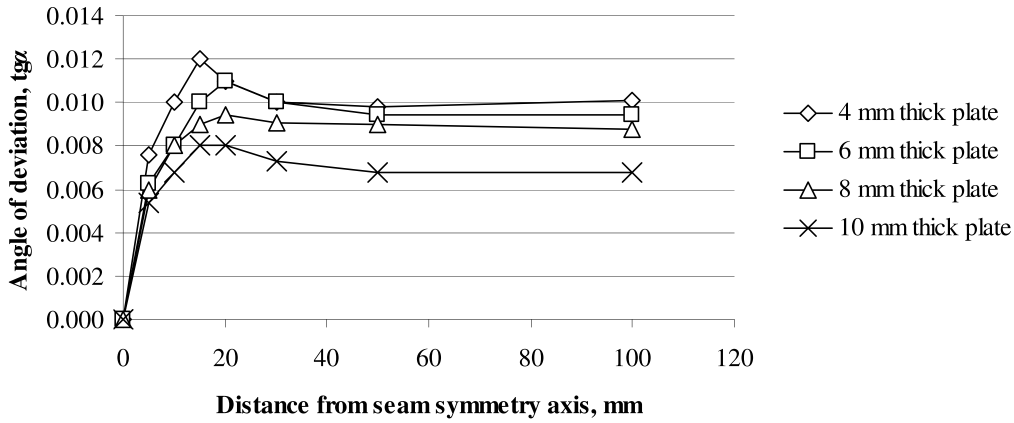

Fig.1. **Deviations of horizontality angle *α* changes depending on distance *L* of seam symmetry axis for plates with different thickness**

For theoretical calculations there are chosen plates of unalloyed steel plates S235JR with dimensions of plate in plane 100x1000 mm and thickness 4, 6, 8 and 10 mm. It is assumed that the seam is welded on the surface of the plate along the axis of symmetry in the length 100 mm, in one step. Theoretical calculations of deflection angle α are carried out using the three point bending expression:

$$\alpha = F \cdot l^2 / 16 \cdot E \cdot J \ [6],$$

where F – force, which acts on the plate perpendicularly to the axle of symmetry of the seam, N;
l – distance between supports, cm;
E – pattern of material flexibility, 2.10^7 N·cm^{-2};
J – moment of inertia of band profile.

$$J = h \cdot b^3/12, \text{ cm}^4,$$

where h – width of the slit plane, cm;
b – thickness of the plate, cm (Fig.2).

Force F is determined from the expression:

$$F = S \cdot R_t,$$

where S – area of melting, mm^2, which is determined from the assumption that area of melting equals to the area of the circle, the radius of which $r = d \cdot 0.5$ equals to the half of the plate thickness, $S = \pi \cdot r^2/2$.
R_t – denotes determined tensile limit of the tested material, which in the given work is determined from the expression $R_t = (R_m + R_e) \cdot 0.5$, N·mm^{-2}.
R_m – yield strength, N·mm^{-2};
R_e – limit of flexibility, N·mm^{-2}.

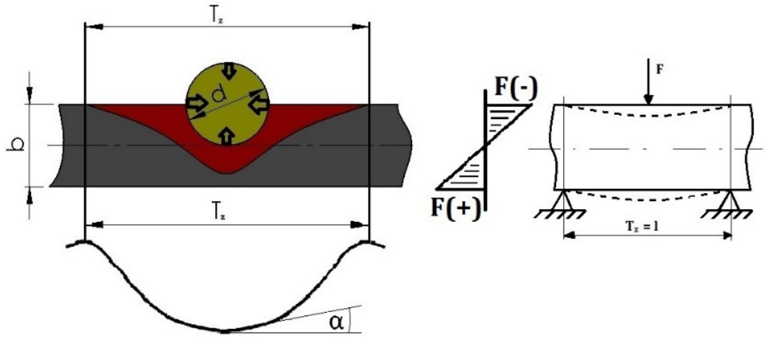

Fig. 2. **Distance between support *l* relationship with boundary of thermal zone width T_z**

Fig. 2: with d is denoted the diameter of the cross-sectional area of the melting zone; with b is denoted the plate thickness; T_z is the width of the thermal zone; F is the force analogous to the force of the shrinkage force; the curve shows the curvature of the plate in the heat impact zone.

For example, the curvature of 6 mm thick plate in the heat impact zone can be described by a third order polinomial. Angular value $\alpha(y)$ depending on the distance $dl(x)$ from the seam symmetrical axis $y = f(x)$ is shown in Fig.3.

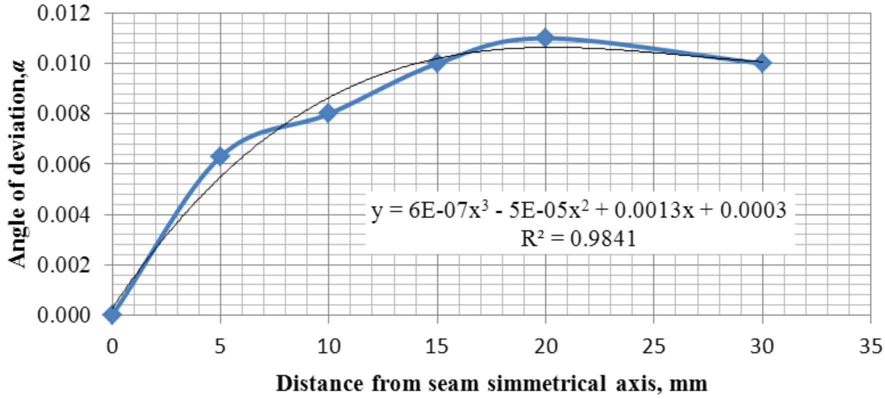

Fig. 3. **Curvature of 6 mm thick plate in heat impact zone**

It was observed that, at a distance of 15-20 mm from the joint seam axis, an excess of practically all thicknesses of the studied plates was formed. This size is assumed to be the distance between the supports using the three-point bending calculation methodology. Distance between the supports $l = T_z$ is calculated: $l = d + 30$, mm. Moving away from the heat impact zone, the curvature of the plate decreases and after approximately 50 mm the plate is practically flat.

Output data and results of theoretical calculations are summarised in Table 3.

Table 3

Output data and results of theoretical calculations

Parameters	**Symbols, unit of measure**	**Welding plate thickness, mm**			
		4	6	8	10
Melting area	S, mm^2	6.28	14.13	25.12	39.25
Determined tensile strength	R_t, N·mm^{-2}	290	290	290	290
Shrinkage strength	F, N	1821.2	4097.7	7284.8	11382.5
Distance between supports	l, cm	3.4	3.6	3.8	4.0
Inertia moment of plate profile	J, cm^4	0.00533	0.018	0.0427	0.0833
Deviation from horizontality angle	α	0.0123	0.0092	0.0077	0.00683
Angle of deviation	tgα	37′	30′	26′	24′
Deviation from horizontality	δ, mm, if L = 500 mm	6.15	4.60	3.85	3.416

The summary of theoretical and experimental results at deviation s = 500 mm is given in Table 4.

Table 4

Summary of theoretical and experimental results at deviation L = 500 mm

Obtained parameters	**Method**	**4 mm**	**6 mm**	**8 mm**	**10 mm**
Deviation, if L = 500 mm	Theoretical calculations	6.15	4.60	3.85	3.415
	Experimentally determined	5.43	4.78	4.30	3.24
Difference if, %		+13.26	-3.77	-10.47	+5.40

Results and discussion

Summarizing the theoretically and experimentally obtained results we can conclude that the theoretically calculated data quite substantially differ from those of the experiment. It is caused by the fact that during welding it was not possible to form such a profile of the seam, which is accepted in theoretical calculations. If the area of the cross-section of the seam turned out to be greater than that accepted in calculations, there was an increase of the shrinkage power. With the decrease of the seam cross-section area, the deflection decreases.

In order to test the proposed hypotheses that creating before the welding such a great deflection of the plate from horizontality, how it was obtained in calculations and experimentally, after welding and cooling till ambient temperature and after taking off the load, deflection of the plate from horizontality will be minimal. At testing of the hypotheses experimentally, there were used analogue samples and the welding technology, only before welding under the place of the seam there were put 37 ± 3 mm wide and 100 mm long plates, the thickness of which depends on the maximal deflection from horizontality in the distance of 500 mm from the axis of symmetry of the welding seam. Correspondingly, for 4 and 6 mm thick samples the thickness of the plate was 5 mm, but for 8 mm thick samples – 4.5 mm and for 10 mm thick samples – 3.5 mm. The samples were loaded in the distance of 150 mm from the axis of the seam, so that both ends of the samples should contact the surface of the table. The settings of the welding were analogue to welding without preloading. After welding of the seam and cooling the sample till ambient temperature the load is taken off. Performing measurements of horizontality, it was stated that the plates welded by such technology have preserved practically their horizontality. The maximum deflection from horizontality for the length of 1000 mm did not exceed 0.53 mm.

The obtained results enable us with preciseness suitable for practical usage to determine the magnitude of previous deformation, which must be secured for the part depending on its thickness and distance from the seam perpendicularly to the direction of the seam, if after welding of the seam there is formed asymmetrical condition of strain and there could bending of the part be expected. The magnitude of the previous deformation δ is determined, magnifying the medium deflection from the horizontality α by the distance L till the place of welding. With the increase of the length of the plate we have to take in consideration the very weight of the plate. Besides, in the course of experiments it has been observed that in the course of time the magnitude of transversal deformation slightly decreases, which shows the relaxation of the strain.

Table 5

Magnitude of previous deformation of plates δ in mm

Plane thickness in mm	Distance L from seam till measuring place in mm					
	200	400	600	800	1000	1500
4	2	4	6	8	10	15
6	1.9	3.8	5.7	7.6	9.5	14.25
8	1.6	3.2	4.8	6.4	8.0	12.0
10	1.36	2.72	4.08	5.44	6.80	10.2

Conclusions

1. Experimentally deformations of 4, 6, 8 and 10 mm unalloyed steel plates with low carbon content, caused by welded upon them a standard seam, are determined.
2. Using the theory of material resistance and the method of fictitious forces there has been calculated deformation of plate materials with asymmetrical loading in transversal direction.
3. Curvature of 4-10 mm thick plates in the heat impact zone can be described by a third order polinomial. Moving away from the heat impact zone, the curvature of the plate decreases and after approximately 50 mm the plate is practically flat.
4. There has been offered a plate bending calculation method, which enables us to determine quickly and with practically applicable preciseness for practical usage the magnitude of previous deformation, which must be secured for the part depending on its thickness and measurements from the seam in transversal direction, if after the seam welding there is created asymmetrical strain condition and there is a possibility of bending of the part.

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