FORECASTING OF WELDING DISTORTIONS IN LARGE-SIZED STRUCTURES

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Abstract

The prevention of welding distortions is one of the most important and, at the same time, most difficult issues in welding engineering. The above-named distortions result from the combined effect of the shrinkage of solidifying weld metal and the shrinkage occurring in the partially melted zone (primarily in the HAZ). Welding distortions often preclude the obtainment of proper joints in large-sized elements and, could even lead to the disqualification of the final product failing to satisfy related standard requirements concerning maximum distortion values. In spite of extensive research focused on welding distortions, they remain the primary issue accompanying the making of steel structures. Various industrial sector organisations express their need for solutions making it possible to forecast the presence of welding distortions. The possibility of forecasting the probable structure imperfections during assembly and the prevention of such imperfections as early as at the design stage and when scheduling assembly make it possible to reduce costs and delays resulting from the removal of distortions. The use of appropriate methods can reduce welding distortions yet it does not ensure their entire elimination. Engineering practice relies on analytical methods involving calculations of total distortions present in elements of welded structures having one and two-sided longitudinal welds, transverse distortions generated during the butt welding of sheets as well as local distortions generated as a result of the loss of stability of thin-walled welded structures. Knowledge concerning possible welding distortions can also be obtained by performing FEM-based numerical analyses concerned with the welding of structures.

Keywords: Welding, welding distortions, hull section, shipbuilding industry, FEM

1. INTRODUCTION

The prevention of welding distortions is one of the most important and, at the same time, most difficult issues in welding engineering. The above-named distortions result from the combined effect of the shrinkage of solidifying weld metal and the shrinkage occurring in the partially melted zone (primarily in the HAZ), which, in turn, result from plastic strains and phase transformations. Welding distortions often preclude the obtainment of proper joints in large-sized elements and could even lead to the disqualification of the final product failing to satisfy related standard requirements concerning maximum distortion values [1,4].

Welding distortions occur along with stresses generated in the welded joint area as well as in areas located farther from the joint. Such stresses can be detrimental to the welded structure in terms of its load-carrying capacity as they may combine with externally-induced stresses. The above-named stresses could reduce the time of safe operation of the structure subjected to fatigue or trigger the formation of brittle cracks at the initial stage of structure operation. In spite of extensive research focused on welding distortions, they remain the primary issue accompanying the making of steel structures. Various industrial sector organizations express their need for solutions making it possible to forecast the presence of welding distortions in large-sized steel structures as well as enabling the determination of the effect of appropriate methods (e.g. fixing clamps, counter-distortions) aimed to limit the formation of distortions [3-6].

The possibility of forecasting the probable structure imperfections during assembly and the prevention of such imperfections as early as at the design stage and when scheduling assembly make it possible to reduce costs

and delays resulting from the removal of distortions. The use of appropriate methods can reduce welding distortions, yet it does not ensure their entire elimination. For this reason, the forecasting of distortion-triggered consequences is of great importance. Knowledge about possible structure defects when designing the process of assembling and that of welding can be utilized to prevent the occurrence of unwanted results through, among other things, providing allowances in elements being welded. Engineering practice relies on analytical methods involving calculations of total distortions present in elements of welded structures having one and two-sided longitudinal welds, transverse distortions generated during the butt welding of sheets/plates (and surfacing) as well as local distortions generated as a result of the loss of stability of thin-walled welded structures. Knowledge concerning possible welding distortions can also be obtained by performing FEM-based numerical analyses concerned with the welding of structures [5–9]. The issue of welding distortions is also present in the prefabrication of the hull structure, where the generation of distortions (if any) is additionally affected by the welding of stiffening elements (representing 1st and 2nd order) to flat sections. In addition, welding distortions could also result from the welding of complex sections composed of flats and/or trough sections such as deep tanks in the mid-ship, sections of superstructures as well as the double bottom of the bow and stern peak [10,11].

2. TEST OBJECTS

The test objects included a flat section and stiffeners made of ship plate grade A in accordance with ASTM A131. The dimensions of the elements, the location of the stiffeners and the welding sequence are presented in **Figure 1**. In each case, the welding process was initiated on the same side of the plate. The section was placed on a 15 mm thick steel table. The welding linear energy amounted to 7.45 kJ/cm whereas the welding rate amounted to 45 cm/min. The welding process was performed using flux-cored wire ⌀1.2 mm grade Outershield 71M-H (Lincoln Electric).
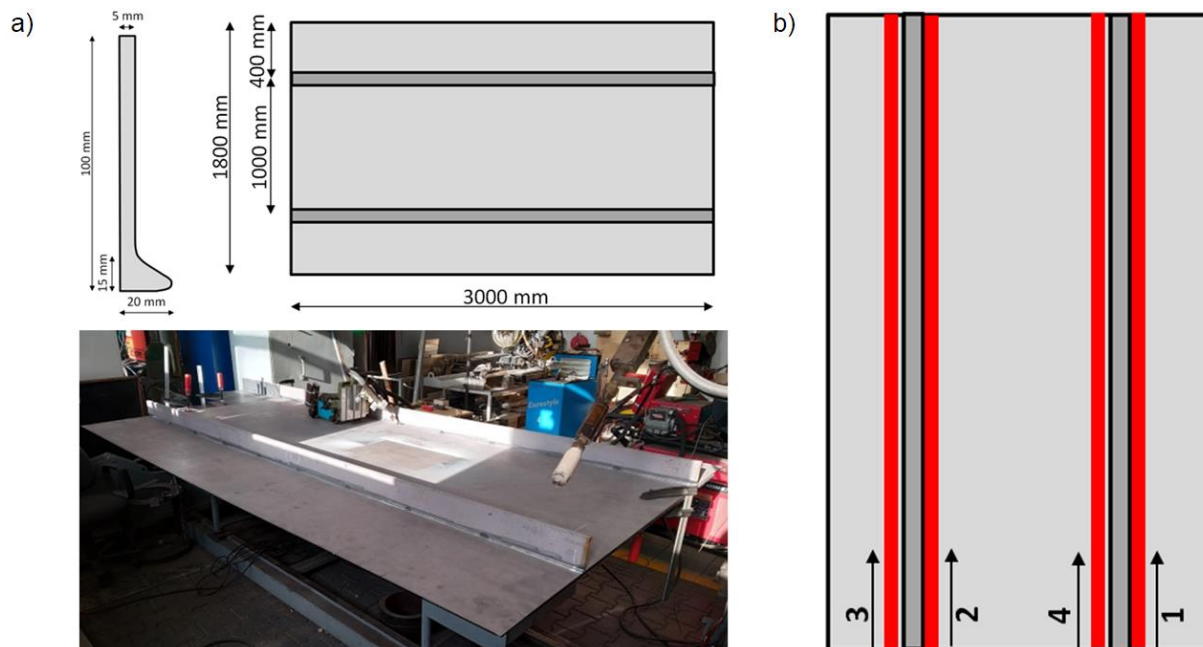

Figure 1 a) Dimensions of the flat section and the arrangement of the stiffeners of the first grade, b) welding sequence

Measurements of welding distortions, focused on a fragment of the element subjected to welding, were performed using a Dantec Dynamics Q-400 Multicamera Digital Image Correlation system and 3 cameras 5MPx (**Figure 2**). The first stage involved the measurement of the plate before welding. The second

measurement was carried out after the completion of the welding process and the cooling of the element. The difference between the measurement results obtained before and after welding constituted the value of displacements.

Figure 2 Fragment of the flat section and the stiffener used in the measurements of welding distortions and the Dantec Dynamics Q-400 Multicamera Digital Image Correlation system

The visual assessment and the measurements involving the use of the optical system revealed the corrugation of the flat section (**Figure 3**). The maximum value of displacement, amounting to 14.1 mm, was observed in the corner of the plate. The measurements focused on the analysis of the displacements in the direction perpendicular to the surface of the flat section. The reason for the aforesaid analytical approach resulted from the significant value of the above-named displacements in comparison with the values of the displacements in the remaining directions.
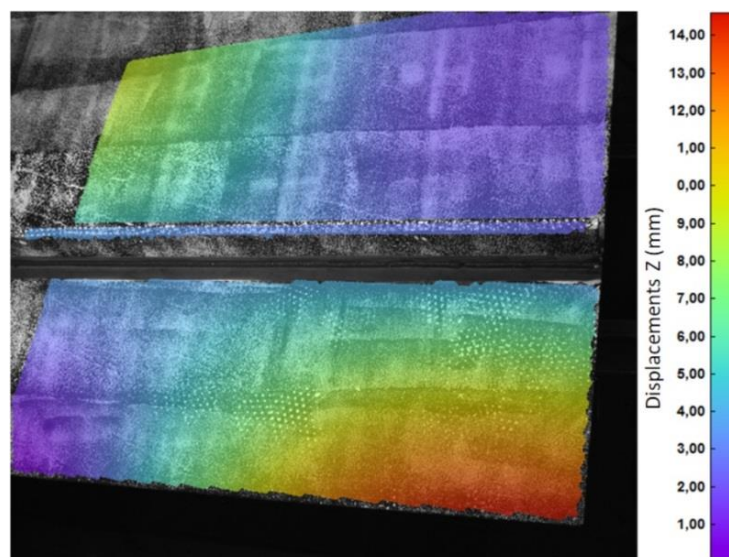

Figure 3 Z-displacement (perpendicular to the flat section) field of the fragment of the welded elements

3.   FEM NUMERICAL ANALYSIS

The approach used for the modelling of the welding process and applied in the FEM model was based on the "Imposed Thermal Cycle" method implemented in the SYSWELD software. In the aforesaid method, a specific fragment of the welded joint is subjected to the effect of the welding thermal cycle. In the above-named FEM model, the weld is divided into segments subjected sequentially to the thermal cycle determined using the model with the moving Goldak heat source [12]. The modelling of the geometry of the element subjected to welding involved the use of shell elements based on midsurfaces. The flat section and the stiffeners of the first order were modelled using shell elements based on midsurfaces. In turn, the welding process was modelled

using the "Imposed Thermal Cycle" method by dividing the weld into segments sequentially subjected to welding thermal cycles; the weld was modelled using shell elements. Preseted boundary conditions aimed to model the section restraint conditions during the actual welding process. The flat section was restrained using a welding clamp and placed on a steel plate. The model involved the application of the boundary conditions of symmetry and restrains in all directions representing the effect of the welding clamp on the system (**Figure 4**). The effect of the table on the element during welding was modelled by means of the "stop" boundary condition, preventing the displacement of the nodes in the y-direction (normal in relation to the section). The model also involved taking into consideration the effect of gravity force.
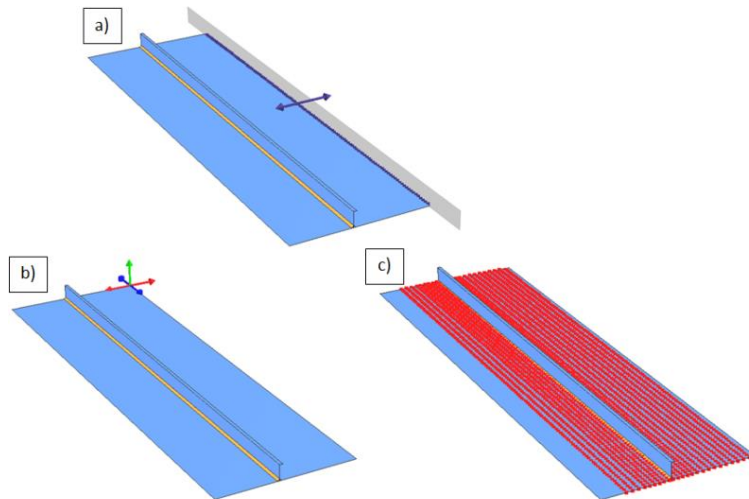

Figure 4 Preset boundary conditions a) of symmetry, b) restraint in all directions and c) "stop" boundary condition
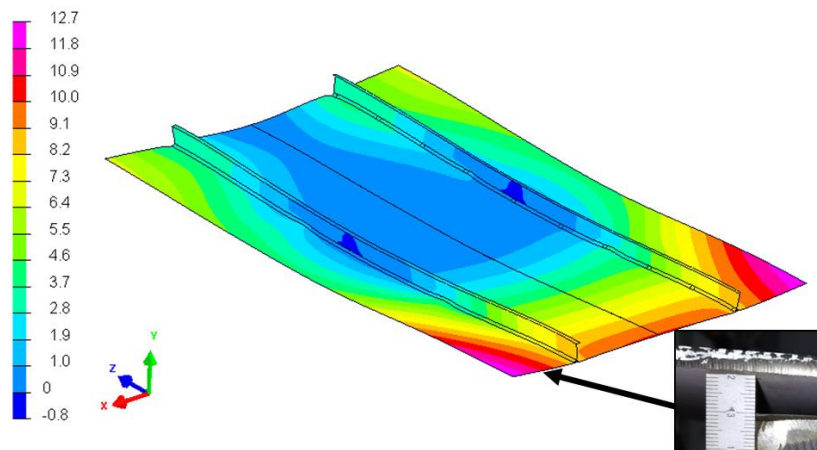

Figure 5 Field of displacements in the normal direction in relation to the section surface, mm

4. TEST RESULTS

The tests focused on the analysis of the displacements in the direction perpendicular to the surface of the flat section. The reason for such an approach resulted from the significant values of the above-named displacements in comparison with the values of the displacements in the remaining directions. **Figure 5** presents the field of displacement in the normal direction in relation to the section subjected to welding. The maximum value of displacement amounted to 12.7 mm. It was possible to observe the characteristic corrugation of the plate, similar to that presented in **Figure 3**. The FEM calculation results were compared with

the values measured using the optical system (**Figure 6**) and a gap gauge (**Table 1**). The difference between the calculated displacement and the displacement measured using the optical system in points nos. 1 and 2 amounted to 11%.
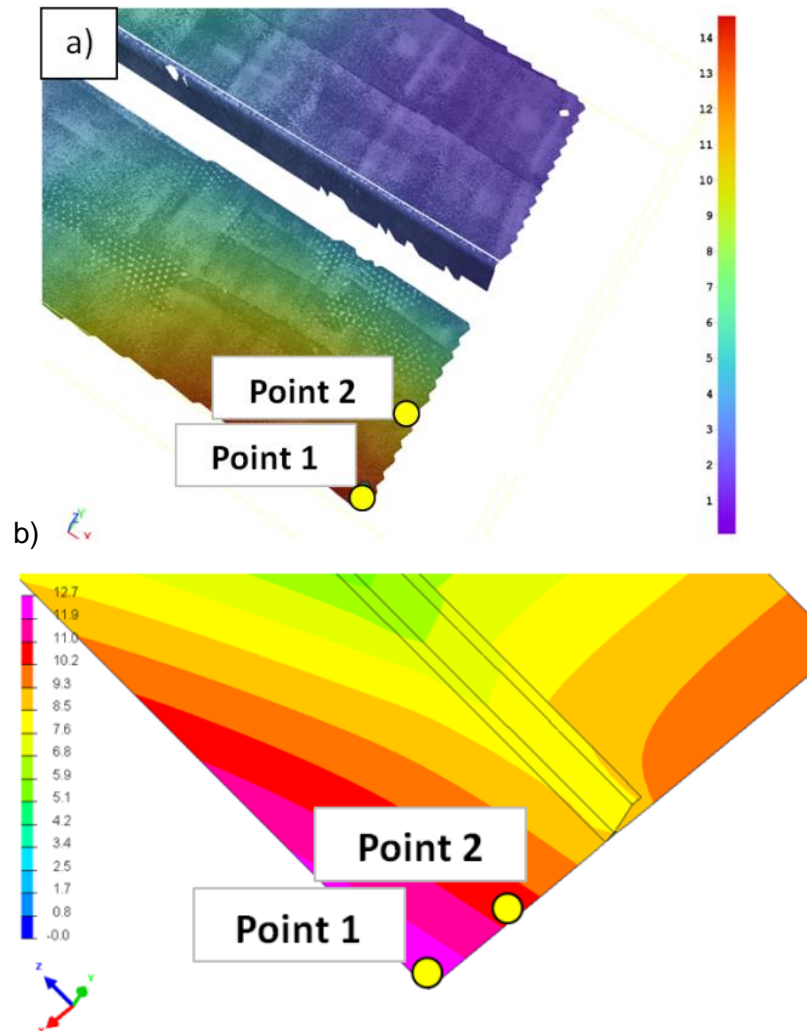

Figure 6 Displacement in the normal direction in relation to the section surface a) measurements of the actual element (performed using the optical system) and b) FEM calculation results

Table 1 Results of displacements in the normal direction in relation to the section surface in points 1 and 2 in accordance with **Figure 6**

Point	Optical system-based measurement results (mm)	FEM calculation results (mm)
1	14.1	12.7
2	9.1	10.1

5. CONCLUSIONS

Because of their low rigidity, spatial-flat elements are particularly susceptible to welding distortions. In cases of large welded sheets/plates with stiffeners it is often necessary to make long welds, frequently resulting in shrinkage and, consequently, in the corrugation of a given element.

The above-presented procedure used for the modelling of large-sized elements enables the obtainment of computational results consistent with those obtained in actual conditions. In comparison with the method based on the moving heat source, the application of the "Imposed Thermal Cycles" method (implemented in the SYSWELD software) in the FEM numerical model reduces time necessary to calculate welding distortions consistent with those observed in the actual welding process. The time of calculations can be additionally reduced (without compromising the correctness of calculation results) by applying thin (i.e. shell) elements in the FEM numerical model.

The method discussed in the article can be successfully applied in the forecasting of welding distortions in large-sized welded structures.

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