The influence of the solid state phase transformation on welding deformation of low alloy high strength steel†

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KEY WORDS: (welding deformation) (phase transformation) (measurement) (prediction) (FEA)

1. Introduction

As low alloy high strength steel is widely used in many fields such as in shipbuilding and so on, the influence of phase transformation on welding deformation has attracted researchers' attention all over the world. In this paper, we did some welding experiments with low alloy high strength steel AH3201, which is popular with shipbuilding. During the welding, we measured the deformation in three positions dynamically with a program based on LabVIEW. Then we calculated the deformation in the same condition as that in the experiment on ABAQUS, taking account of phase transformation, which could be in contrast with the experiment.

2. Measurement

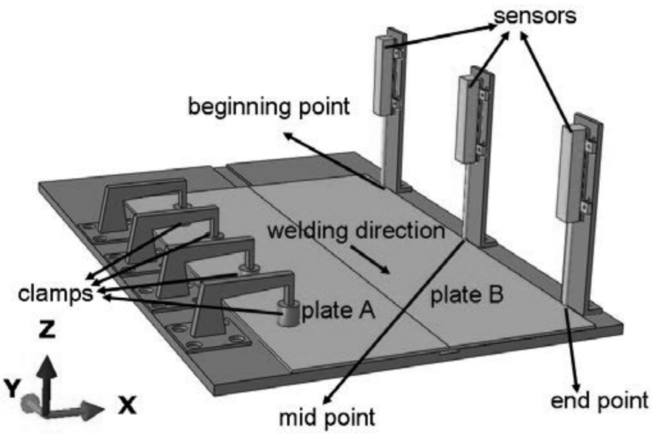

Fig. 1 Assembly chart

Figure 1 shows the assembly chart in this experiment[1]. Two 500mm*150mm*3mm plates placed on a large plate are to be welded. The plate A is fixed by four clamps so that it can not move in any direction. The plate B is not fixed by clamps but by spot welding at the beginning and the end of the gap, which means that it can deform much more freely. Three resistance displacement sensors are placed next to plate B to get the displacement in the Z-direction at three points along the edge of the plate. We didn't measure the displacement in the other two directions because the plate was too thin to be attached to the sensors. The welding method is CO_2-GMAW. The welding parameters are shown in **Table1**.

Table1 Welding parameters

Current	Voltage	Speed	Gas flow	Wire dia.
170A	29V	50cm/min	8L/min	1.2mm

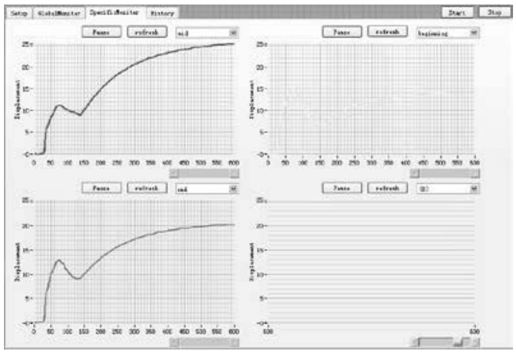

Fig. 2 Result got in LabVIEW program

Figure 2 shows the displacement in the Z-direction at three points. We can see the maximum displacement after cooling for nine minutes occurs in the middie, which is about 25mm.

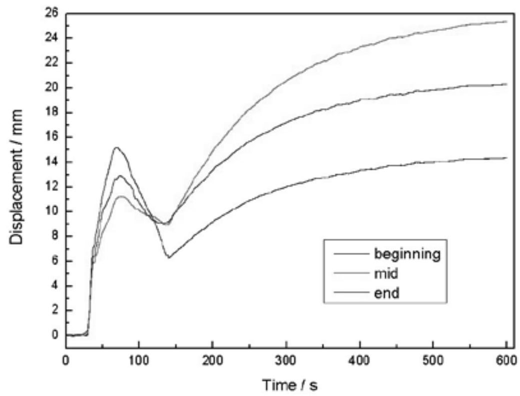

Fig. 3 Measured displacement at three points

We compound these three plots together, as shown in **Fig. 3**. In the experiment, the period for arc heating is from 0 to 67th second, and from 67th second to 600th second for cooling, when we found the displacement didn't change a lot any more. Fig.3 takes on three characteristics.

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1) The maximum displacement occurs in different positions at different time- at the beginning after heating and in the mid after cooling. Transferred into angle, the maximum angle deformation is about 10 degrees. Notice that the displacement on plate B was measured in the condition that the plate A was fixed and didn't deform a lot.

2） The plots can be divided into four sections. In the first section, the displacement didn't increase possibly because the beginning and the end of two plates were not well jointed by spot welding. Then the displacement at three points increased drastically till heating finished. The first inflexion appeared at about the 72th second, after which the displacement decreased at different speeds. The second inflexion appeared at about the 135th second, after which the displacement increased again and reached the steady state at last.

3） The inflexions at three points are almost at the same time. Considering that the temperature history for these points in distance of 200mm should have an interval much more than six seconds, we infer that the occurrence of each inflexion doesn't result from something such as phase transformation in the region near the very point only, but from the temperature field and phase distribution of the whole model.

3. Calculation

We did a sequential coupled analysis on the same model based on ABAQUS, taking account of the factor of phase transformation. During the welding, diffusion and no diffusion phase transformation happens in the region near the weld at different cooling speeds[2]. The diffusion phase transformation can be described by the following Kamamoto model[3]:

$$X = 1 - \exp[-k(\frac{T_s - T}{T_s - T_f})^n] \qquad (1)$$

X represents the volume percentage of the new phase. T_s and T_f represent the moment phase transformation starts and finishes, which are determined by the cooling speed and continuous cooling transformation chart as shown in **Fig. 4**. The parameters k and n come from previous experiment result.

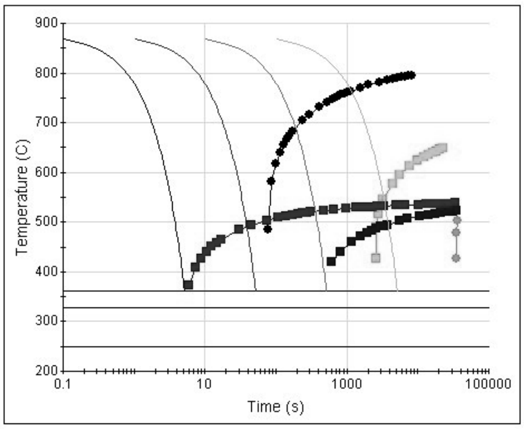

Fig. 4 The CCT chart of AH3201

The no diffusion-phase transformation can be described by K-M formula:

$$X = 1 - \exp[-c(M_s - T)] \qquad (2)$$

The parameter c is supposed to be a constant 0.01.

The expansion coefficient of each phase is different in the form:

austenite > ferrite > pearlite > bainite > martensite

So it has an influence on welding deformation. The average expansion coefficient is:

$$\alpha = \alpha_1 X + \alpha_2 (1 - X) \qquad (3)$$

On the other hand, an linear expansion about 1.6% occurs when austenite transfers to other phases in a lower temperature because of the difference in specific volume[4]. The corresponding incremental strain is about:

$$\Delta\varepsilon_{sv} = 0.016X \qquad (4)$$

So the total incremental strain caused by phase transformation at each increment is:

$$\Delta\varepsilon = 0.016(X - X_{pre}) + \frac{1}{2}(\alpha + \alpha_{pre})(T - T_{pre}) \qquad (5)$$

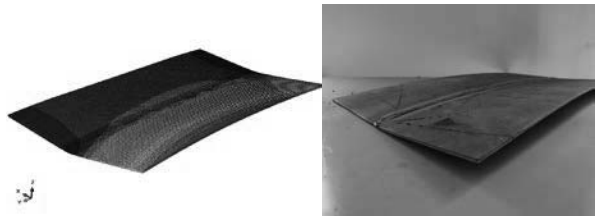

Fig. 5 Comparison of calculation and experiment

Figure 5 shows the calculated result compared with the experiment result. **Figure 6** shows the calculated displacement in the mid point compared with the experiment, with another plot not taking account of phase transformation. We can see the trend of deformation conforms to the experiment, but the values differ a lot. The displacement taking account of phase transformation is smaller than that of not taking account of phase transformation.

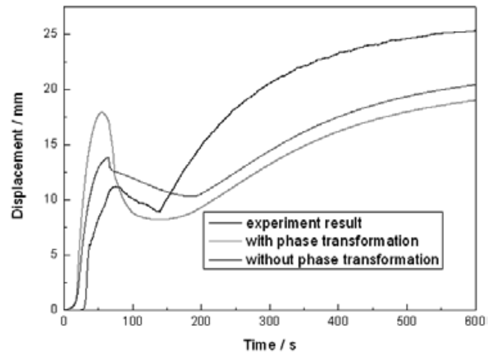

Fig. 6 Calculated displacement at the mid point

4. Conclusions

The conclusions of this study are summarized as follows.

(1) In one-side fixed welding of thin plate, the unfixed side warps a lot, especially at the position in the middie.

(2) The deformation appears to be an increase-decrease-increase process, either in the experiment or in the

calculation, no matter if we take account of phase transformation.

(3) Phase transformation from austenite to phases at a lower temperature decrease the welding transformation.

Acknowledgement

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