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Residual stress generated by LBW on HT780†

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1. Introduction

For improving function and reducing the weight of steel structures, use of high strength steel has been tried frequently. As the joining method for the high strength steel, laser beam welding (LBW) is noted [1].

The characteristics of LBW such as heat input, bead width, welding speed and so on are largely different from those of existing arc welding.

In welding of high strength steel, martensitic transformation (phase transformation) occurs in the relatively low temperature region in the cooling process. It is known that the phase transformation largely affects the generation of distortion and residual stress [2].

It is unknown how residual stress is generated in welding of the high strength steel by laser beam.

In this paper, in order to elucidate how residual stress is generated by LBW on the high strength steel (HT780), an experiment is carried out and is simulated by a thermal elastic-plastic analysis with considering the phase transformation.

2. Experiment

One-pass bead-on-plate welding is performed on high strength steel by using a fiber laser. As the welding conditions, the laser power is 6kW and the welding speed is 0.6m/min.

The material is HT780 and the thickness is 12mm.

Table 1 shows the chemical compositions and the mechanical properties of the material.

Figure 1 shows the shape of the specimen and an example of the macrograph.

The width of the weld bead is around 5mm and the penetration depth is around 9mm.

After the welding, the residual stress is obtained by the stress relaxation method.

3. Idealization of Mechanical Properties with Considering Phase Transformation

In the welding of high strength steel, the phase transformation occurs in the relatively low temperature range in the cooling process. In that range, the mechanical properties cannot be specified because the transformation expansion and the transformation superplasticity (extraordinary ductility) occur.

It is necessary that the mechanical properties in the phase transformation range are idealized for simulating the welding of the high strength steel by FEM.

Table 1 Chemical compositions and mechanical properties.

Chemical compositions (mass%)				
C	Si	Mn	P	S
0.08	0.22	0.96	0.007	0.002
Mechanical properties				
Yield stress (MPa)		Tensile strength (MPa)		
813		840		

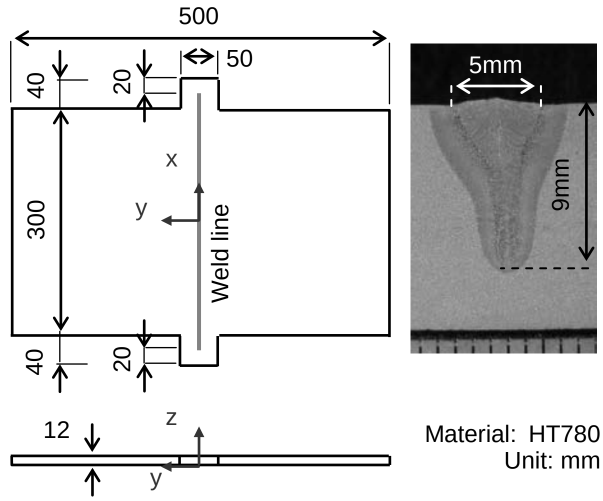

Fig. 1 Test specimen and macrograph.

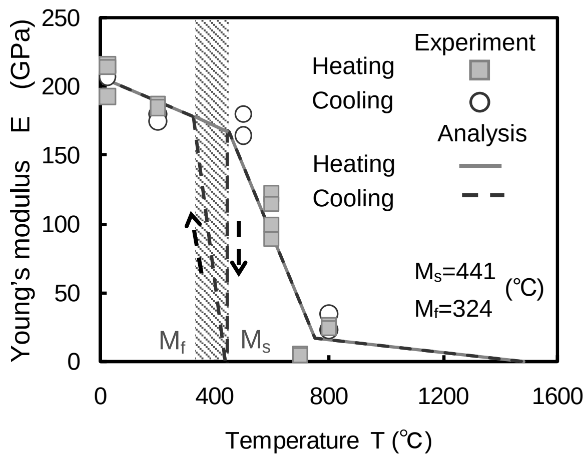

Fig. 2 Temperature dependency of Young's modulus.

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As an example, **Fig. 2** shows the idealized Young's modulus proposed by the author [3].

For simulating the extraordinary ductility due to the transformation superplasticity, Young's modulus; E at the start temperature of the phase transformation; M_s (=441℃) is lowered around zero and it is linearly recovered up to the finish temperature; M_f (=324℃) in the cooling process.

In the thermal elastic-plastic analysis described below, these mechanical properties are used in the cooling process in the elements where the temperature exceeds the A_1 transformation temperature (around 720 ℃) in the heating process, that is, the weld metal and HAZ. In the elements except them, the mechanical properties in the heating process are also used in the cooling process.

4. Thermal Elastic-plastic Analysis

The experiment is simulated by the thermal elastic-plastic analysis.

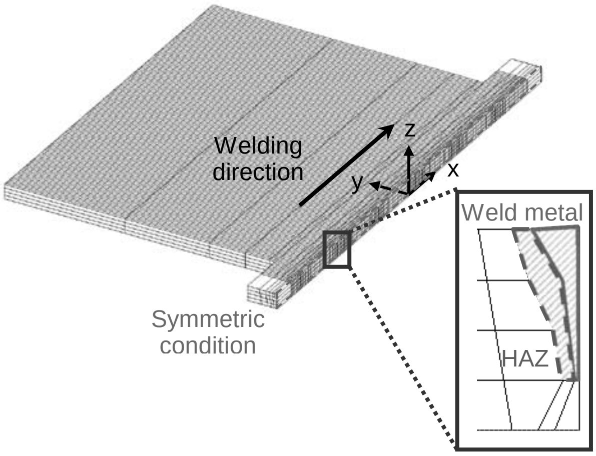


Fig. 3 Model for thermal elastic-plastic analysis.

Figure 3 shows the analysis model.

The isoparametric solid elements with 8 nodes are used.

The half model is adopted. The heat input (the weld metal) elements are decided by referring to the macrograph (Fig. 1).

The model with considering the phase transformation by using the above idealized mechanical properties is defined as 'with PT' model.

On the other hand, the model without considering the phase transformation, i.e., the same mechanical properties in the heating process are also used in the cooling process, is defined as 'without PT' model.

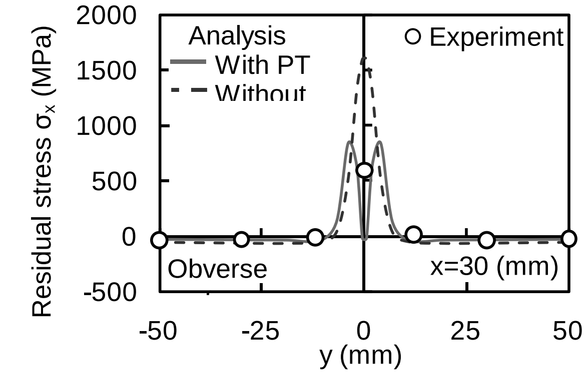
The analysis results of these two models are compared to investigate the effect of the phase transformation on the residual stress.

5. Results of Experiment and Analysis

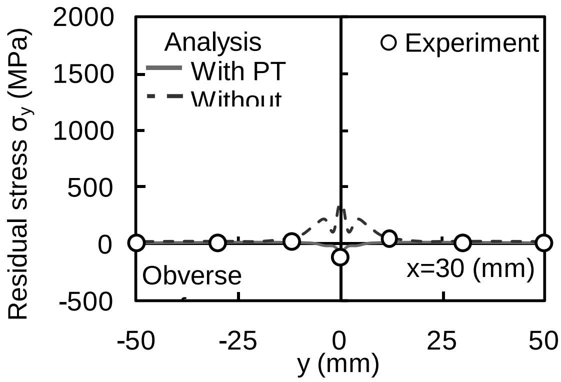
Figure 4 shows the residual stress distribution obtained by the experiment and the analysis.

The stress at the center of the welding direction (x=30(mm)) on the obverse surface is shown in the figure.

The stress component in the welding direction; σ_x (Fig. 4(a)) is noted.



(a) Stress component in welding direction; σ_x



(b) Stress component in transverse direction; σ_y

Fig. 4 Residual stress distribution

In the case of without PT model, σ_x is over the yield stress. However, it is confirmed that the equivalent stress agrees with the yield stress. On the other hand, σ_x varies from the yield stress to zero in the case of with PT model. The experimental result is within the result obtained by the analysis of with PT model. Considering the accuracy of the stress relaxation method, the experimental result is substantially simulated by the analysis of with PT model.

The stress component in the transverse direction; σ_y (Fig. 4(b)) is noted.

In the case of without PT model, σ_y is tension and the value is around 300MPa. It does not agree with the experimental result which is small compression. On the contrary, the result obtained by the analysis of with PT model accurately agrees with the experimental result.

From these results, the validity of the treatment in mechanics of with PT model idealizing the mechanical properties with considering the transformation expansion and transformation superplasticity is verified.

The residual stress generated in the weld metal is largely affected by the phase transformation in the cooling process although the bead width of LBW (around 5mm) is extremely narrow. The tensile residual stress generated in the weld metal is largely released by the phase transformation.

6. Conclusions

In order to elucidate how residual stress was generated by LBW on the high strength steel, one-pass bead-on-plate welding of HT780 by laser beam was simulated by the thermal elastic-plastic analysis with using the idealized mechanical properties considering the phase transformation.

(1) The residual stress obtained by the experiment could be simulated by the analysis with high accuracy. The validity of the treatment of the mechanical properties in the phase transformation range was verified.

(2) It was known that the residual stress generated in the weld metal was largely affected by the phase transformation in the cooling process although the bead width of LBW (around 5mm) was extremely narrow compared with that of existing arc welding.

(3) The tensile residual stress generated in the weld metal was largely released by the phase transformation.

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