용접부 물성을 고려한 유한요소해석모델 개발
Finite-element analysis of structural tests with weld line: Experimental and numerical analysis with FE code

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1. Introduction

Welding is a crucial manufacturing process of joining structural components together. It has been widely used in industry field. Meanwhile, a very large percentage of product failures occur at joints because they are usually located at the high stress points of an assembly [1]. Therefore, prediction of welding behavior is critical to improve the quality of welded structure. And a variety of methods have been developed to simulate this kind of behavior, especially by the finite-element methods [2]. During the welding process, the microstructures of the material around the weld line are changed due to the heat treatment. This part is the heat-affected zone (HAZ). And the inhomogeneous material properties should be taken into account in the FE analysis to get a more accurate result. A previous paper has described a method for determining the constitutive response of the HAZ in spot weld by fabricating the HAZ material in thermal condition independently [3].

In this paper, a simple methodology is described to determine the inhomogeneous properties instead of the fabrication of HAZ material. The simulated model is classified into various zones with different material properties depend on the distribution of the hardness test values over the specimen. And then, a series of mechanical tests with weld line and without weld line are carried out and the input data for implementation in the FE code are extracted from the experimental results. Finally, the quasi-static simulations of tensile tests under the same conditions with the experimental tests are defined by using the classical elastic-plastic material models (von Mises criterion) to determine the results of the methodology can be reached properly.

2. Classification of the specimen

The weld joint can be typically divided into three zones, the fusion zone (FZ) along the weld line, the HAZ and the original parent metal (PM). In order to specify these zones, hardness tests are carried out to determine the quantitative profiles of the material. In this work, the HRB scale of 1/16 ball of Rockwell Hardness test method is used due to its speed and simple process [4]. And a series of regularly distributed points were measured over the specimens. Fig.1 shows the distribution of average hardness and the typical classification of the specimen. The hardness of the parent metal is about HRB 78. As shown in the figure, there has a significant increase in hardness over the HAZ, range from 80 to 91 HRB. When performing the simulations, the HAZs can be divided into as many subzones with different material properties. In this work, the HAZ is kept as one zone only due to the width of the HAZ is very small compared to the dimensions of the specimen, about 6mm wide.

3. Material properties and FE modeling

Most of the finite-element code software allows the input of material property in the form of stress-strain points from the tensile test. This is due to the yielding criterion is commonly used. In this paper, the JIS SS400 steel is used as the parent metal, and the specimens are manufactured by CO2 welding method. The joint of the specimen is Single-V type, and the specimen has a gage length of 50mm and a width of 25mm, the thickness is 9mm. The tensile tests with weld line and without weld line are carried out on a universal testing machine.

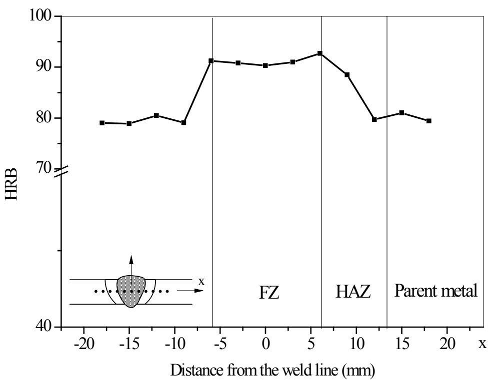

Fig.1 Hardness profiles of the weld joint

The engineering stress-strain points obtained from the tensile test cannot represent the true deformation of the material because it is based on the original section of the specimen. It must be converted into "true" value when large plastic strain is simulated. The stress and strain of this conversion are in the Cauchy and logarithmic forms respectively [5]. And this conversion suppose that the volume is constant during the plastic deformation, that is, the Poisson's ratio (u) is also a constant, and it is generally range from 0.25 to 0.3 for steel materials. Moreover, this conversion is true only in the case of no necking behavior of the specimen. Fig.2 shows the conversion method before the maximum load point.

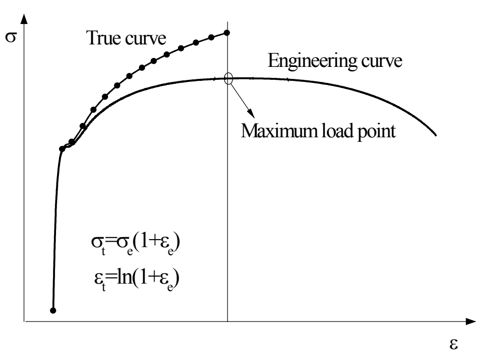

Fig.2 Conversion of the "true" value for an engineering stress-strain curve

Three specimens without weld line were tested for generating the material property of the parent metal SS400 and an intermediate curve was selected to extract the data points for inputting into calculation code. And about 15 points were used to describe the material behavior in the form of multi-linear isotropic hardening (MISO) or multi-linear kinematic hardening (MKIN). These points are all in true stress-strain format and there are no conversions beyond the maximum load point, as presented in Fig.2.

The material properties of the HAZ and FZ zones cannot be obtained from the tensile test directly. Assume that these zones have the same Young's modulus (E) and tangent modulus (E_t) with the parent metal SS400, and the bilinear isotropic hardening (BISO) material model is used for these zones. The yield points can be calculated by using the correlation of yield strength (YS) and tensile strength with hardness [6]:

$$YS = -90.7 + 2.876HV \quad (1)$$

where YS has the units of MPa and HV is diamond pyramid hardness. HV can be converted from the previous HRB hardness value according to the ASTM standard [7].

When modeling the tensile test in ANSYS code, the model should be created in a simple way that cost less computational resource. And if the material suffers necking behavior in the simulation, the stiffness of the structure could change abruptly and un-convergence may occur, these will cause instability of observing the necking behavior. In this paper, shell element has been used in the simulation to reproduce the behavior of the materials. Fig.3 shows the classification of the CAD geometry and the material properties are presented in Table 1.

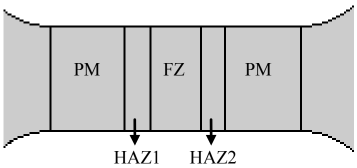

Fig.3 CAD geometry and classification of the specimen

Table 1 Material property of the classified zones

Zone	E(GPa)	YS(MPa)	E_t(MPa)	HRB
PM	143.75	331.4	1150.55	78
HAZ1	143.75	340.7	1150.55	80
FZ	143.75	455.7	1150.55	91
HAZ2	143.75	366.6	1150.55	83

4. Comparison between the experimental and simulation results

The experimental and simulation results are displayed in Fig.4 and Fig.5 respectively, and the curves are compared in Fig.6. The necking behavior can be observed in Fig.5. In Fig.6, all the values are in true stress-strain format. The result obtained from the simulation contains the plastic behavior after the necking effect, and this part of value is meaningless. It can be seen that the correlation level of the simulation can be reached properly. Due to the discontinuous material properties, the result of the stress may not continuous, and this will be considered in the future work.

Fig.4 The specimen after tensile test

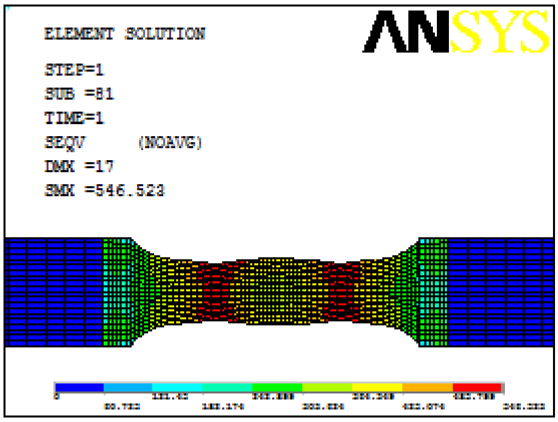

Fig. 5 Simulation of the necking effect of the specimen

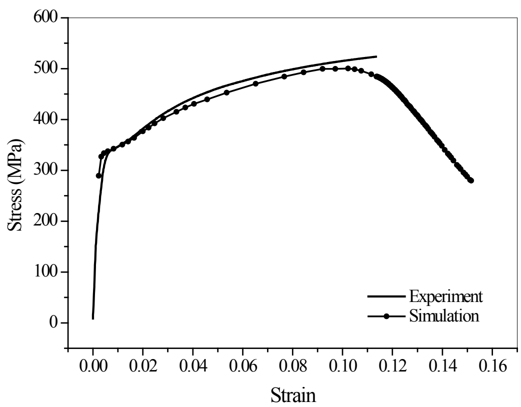

Fig.6 Comparison between the experimental and simulation results

5. Conclusions

In this work, the simulated model has been divided into three zones with different material properties, and the quasi-static simulation has been carried out. From the results obtained, it can be seen that the simulation result can match the experimental result properly. And in the future work, the influences of different variables will be covered, such as element type, mesh quality and various numbers of the classified zones.

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