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Inherent strain calculation from inverse analysis of measured welding deformation based on python of ABAQUES CAE †

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KEY WORDS: (Inherent strain) (Inverse analysis) (Welding deformation) (Finite Element Analysis)

1. Introduction

To estimate the residual stress, a thermal elastic-plastic method could be used, but a large number of finite elements and a long calculation time is needed. Inherent strain generated in welded joints is considered as a source of welding residual stresses and deformation, which has been used for welding residual stress and deformation prediction [1-2]. Therefore, it is very important to develop the method to obtain the inherent strain. Prof. Ueda proposed a function method for describing and estimating the inherent strain distribution [3]. By using this method, the residual stress deformation could be calculated [4]. For large complex welding structure, it is difficult to calculate the inherent strain distribution.

In this paper, the "inverse analysis method" was used to calculate the inherent strain for a large complex structure, and an inverse analysis tool base on the FEA software ABAQUS CAE was developed to realize the inverse analysis of inherent strain. In the program, a plug-in technology of ABAQUS CAE and the user customized Python were used for coding. To calculate the inherent strain, the deformations of several numbers of points of the welded structure were measured. According to the measured results, the inherent strains were calculated by using the inverse analysis tool. The inherent strain and the induced deformation were calculated for the different welding structures. The comparison between the calculation and experiments shows that the inverse analysis tool is able to calculate the inherent strain and the accuracy is good enough for the requirement.

2. Principle of inverse analysis method for inherent strain

The principle flowchart of the developed method is shown in **Figure 1**. The measured displacement could be expressed as the product of elastic response matrix and the unknown coefficient vector of inherent strain. The elastic response matrix is related to the welding structure. If the unknown coefficient vector of the inherent strain is obtained, the inherent strain can be calculated by multiplying the coefficient vector and the distribution function vector. The distribution function of inherent strain is different for different welded joints.

3. Realization of the inverse analysis tool by ABAQUS CAE

The inverse analysis tool is realized based on the FEA software ABAQUS. A guide user interface was developed as a plug-in module in ABAQUS CAE. The plug-in GUI could ask the user to input the required information and values interactively. Then the program composed by Python calculates the required matrix, which is transformed to the ABAQUS kernel for Finite Element Analysis. The computer language Python was used to develop the ABAQUS plug-in and finish the matrix calculation of inherent strain.

As If the inverse analysis tool is installed, it can be selected under the plug-in menu, as showed in **Fig. 2**. From the user input interface shown in **Fig. 3**, the welding parameters can be input according to different welding structures.

In this inverse analysis tool, the measured deformation from experiments is used, which is saved in a txt file.

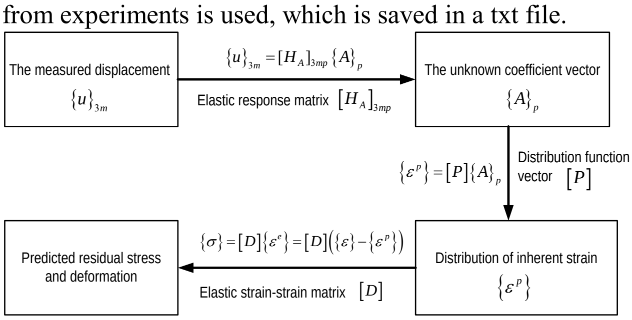

Fig. 1 The principle sketch of the inverse analysis method

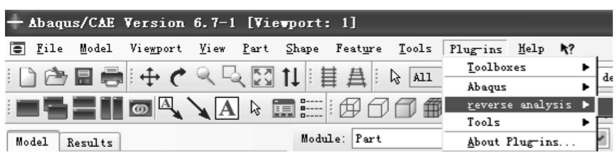

Fig. 2 The plug-in menu of the inverse analysis tool

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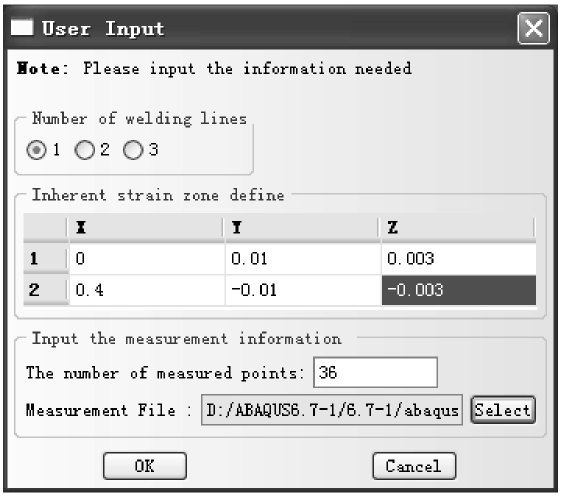


Fig. 3 The GUI of user input interface

Once the value for calculation is input by the developed GUI, the program can do the rest of the calculation work automatically, including several pre-calculations and the elastic response matrix calculation. From the matrix calculation, the unknown coefficient vector and the inherent strain distribution can be calculated. The tool can save the information of the inherent strain distribution to a readable file.

4. An example of inverse analysis method

To verify the inverse analysis tool, experiments were done for different welding structures such as bead-on-plate welding, butt welding and T-joint welding. The welding deformation was measured by using the 3-dimensional coordinate measurement system. **Figure 4** shows the deformation of butt welding by experiments. From the figure we can see the obviously angular distortion and bending deformation, the deformed structure is like a horse back.

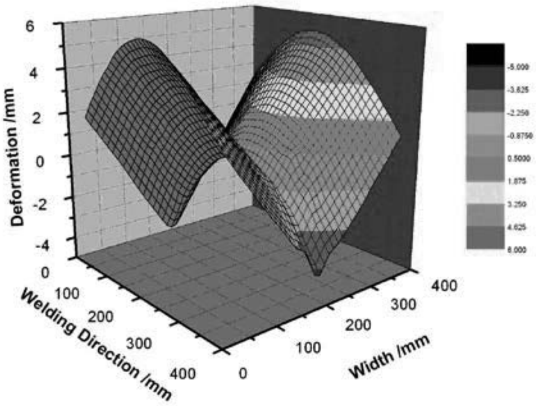
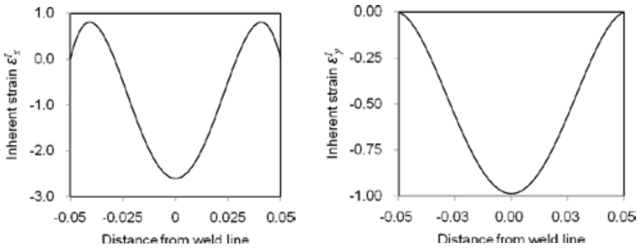


Fig. 4 Experimental results of butt welding deformation

From the measured welding deformation, the inherent strain distribution of the butt welded joint is calculated by using the inverse analysis tool. **Figure 5** shows the inherent strain distribution of the cross section perpendicular to the welding line.

Because the inherent strain is calculated from "inverse analysis" of measured welding deformation, the different inherent strain distributions (e.g., from different distribution functions) can have the same welding deformation. Therefore, the selection of proper distribution function is very important.



(a) (b)

Fig. 5 Distribution of inherent strain: (a) ε_x^I , (b) ε_y^I

By using the calculated inherent strain, the corresponding deformation of the structure can be calculated by FEA. **Figure 6** shows the calculated deformation of butt welded joint by the inherent strain from the developed tool. The comparison between the calculation and experiments shows that the inverse analysis tool is able to calculate the inherent strain and the accuracy is good enough for the requirement. **Figure 7** shows the influence of the number of measured points on the accuracy of angular distortion. It was found that the calculated error is reduced with an increasing number of measured points. The error is small enough when the measured points over 50 in this case.

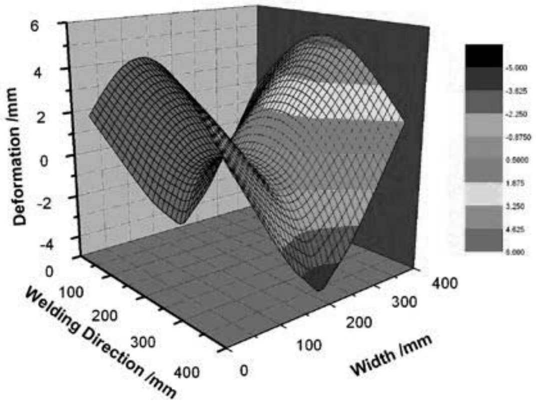


Fig. 6 Calculated results of butt welding deformation by using the inherent strain from the developed tool

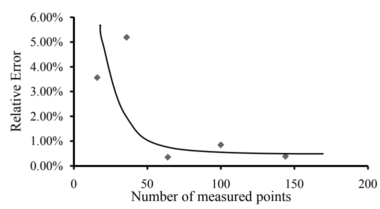


Fig. 7 The influence of the number of measured points on the calculated welding deformation

5. Conclusions

(1) The inverse analysis tool of inherent strain from the measured deformation was developed based on Python of ABAQUS CAE.

(2) The developed inverse analysis tool is able to calculate the inherent strain with acceptable error, and the calculated accuracy is increased by increasing the measurement points

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