CZM Application to Failure Study of Brazed Joints: Parameters Determination

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Abstract: Failure of brazed joints is studied using the cohesive zone model (CZM) concept. The CZM provides a constitutive model by defining a relationship between traction and separation at the fracture process zone. The model is characterized by the two parameters of cohesive strength and separation energy. In this study, the CZM parameters of butt-brazed joints are determined in the normal mode of fracture. The tensile strength of the joints is obtained through uniaxial tensile test. To extract the separation energy, a four-point bend test is performed on butt-brazed rectangular beams. The bending test is numerically simulated, and the joint is modeled by employing the cohesive elements available in ABAQUS 6.7 software. The numerical load-displacement curve is fitted to that of the experiment to find the value of the second parameter. The results were verified by the optical measurement of the matching fracture surface heights on the corresponding 3-D profiles.

Keywords: cohesive zone model, brazed joints, parameters determination, finite element simulation.

1. Introduction

Brazing, as a type of welding process, is widely used in the joining industry to produce assembled products from two or more individual components. In the brazing process a filler metal, in the form of foil, wire, paste, plating, or powder, with a melting point of above 450° C and below the solidus of the base metal, is melted and distributed between the faying surfaces of the individual components to join them following solidification [1].

The key issue of the design of brazed joints is the consideration of mechanical reliability of the whole structure. As the joints are the most critical regions of an assembly, the failure study on them is of importance. Many researches have been conducted in order to experimentally study the brazed joint mechanical properties needed for the failure analysis. The joint strength variations have been evaluated under different brazing conditions, such as hold time and temperature, as well as type of filler metal and joint thickness [2]. Besides, as the joint ductility distribution has a significant effect on crack initiation locations, the brazing factors and working conditions incorporated in the joint embrittlement have been investigated [3]. The effect of brazing conditions and environmental factors on the fatigue life of the joints has also been of interest [4]. The numerical modeling of brazed joints was mostly limited to the prediction of residual stress effect on the joint strength [5]. To the best of author's knowledge there has been no study on modeling the brazed joint deformation and failure as an interface with independent material properties.

The cohesive zone method (CZM) is a numerical tool for interface failure analysis, which has been employed for modeling of adhesives [6], soldered [7] and welded joints [8]. The CZM concept provides an interfacial constitutive model by defining a relationship between traction, T, and separation, δ, at the fracture process zone [9]. This approach was first developed for modeling of crack initiation and growth [10]. Later, the application of the CZM was extended as a powerful method for failure analysis of interfaces and multi-layer structures [9].

The CZM is characterized by the two parameters of cohesive strength, T_{max}, and separation energy, Γ [8]. Determination of these parameters is the key issue in the modeling of interfaces. The techniques presented for determination of these parameters are generally categorized into direct and indirect approaches [10]. Direct approaches are those techniques in which all the CZM parameters are measured by experiments [11]. However, employment of a simulation tool for prediction of interface behavior in combination with experimental measurements is the concept of indirect approaches [12]. Testing technical problems and result interpretation are the challenging issues in parameter extraction. As these problems are more significantly involved in direct approaches, indirect methods have been of more interest [10].

For the fracture analysis of the brazed joints, the CZM approach is employed in this paper. An indirect method for determination of the CZM parameters is introduced and discussed. The tensile strength of the butt-brazed joint is obtained through uniaxial tensile test. To extract the separation energy, a four-point bend test is performed on butt-brazed rectangular beams. The bending test is numerically simulated using ABAQUS 6.7 software [13]. The numerical load-displacement curve is fitted to that of the experiment to find the value of the second CZM parameter.

2. Experiment

For evaluating the strength of butt-brazed joints, uniaxial tensile and four-point bend tests are recommended in AWS C3.2 standards [14]. In this study a tensile test is performed on butt-brazed joint specimens to obtain the cohesive strength.

The sample preparation procedure was done according to the AWS C3.2. First, the specimen blanks of AISI-1018 steel in the size of 35×14×38 mm were prepared, and the related faying surfaces were cleaned. Then, the filler metal in the shape of copper foil with the thickness of 75 µm was placed between the faying surfaces. The assembly was clamped and placed into a furnace with an Argon atmosphere and the hold time and temperature of 30 minutes and 1110° C, respectively. The rate of 18.5°C/min was considered for the air cooling segment of the brazing procedure. The flat dog-bone shape tensile specimens with a central joint were machined from the brazed block, as shown in Fig. 1.

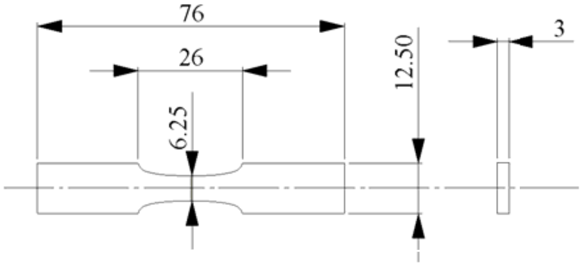

Fig.1. Butt-brazed joint tensile specimen (dimensions in mm)

Optical macrograph of the brazed joint region is shown in Fig. 2, in which the joint thickness was measured around 50 µm.

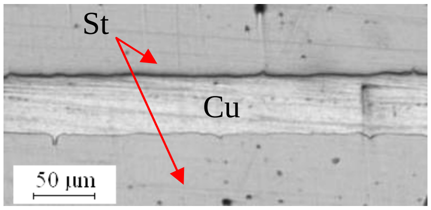

Fig.2. Brazed joint optical macrograph

The uniaxial tensile test on the butt-brazed joint specimens was performed under displacement control condition with the rate of 0.005 mm/s. The average tensile strength of 534 MPa was recorded, as shown in Fig. 3.

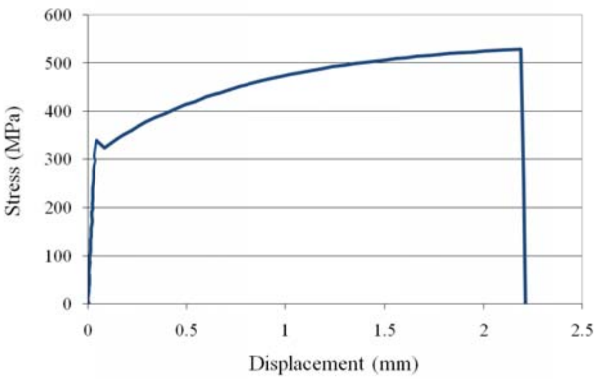

Fig.3. Stress-cross head displacement curve of the butt-joint tensile specimens

In order to obtain the second CZM parameter, i.e. the separation energy, a four-point bend test was performed on butt-brazed rectangular beams. The sample preparation procedure is the same as described for the tensile specimens. The beam specimens with a central joint were machined from the brazed block, Fig. 4.

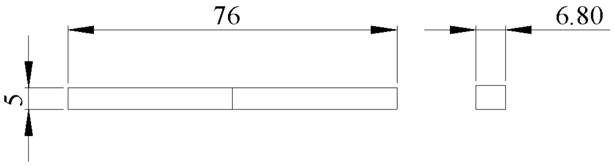

Fig.4. Butt-brazed rectangular beam specimen (dimensions in mm)

The test set up was prepared according to the standard AWS C3.2, which is shown in Fig. 5. The corresponding spans of upper and lower supports are 34mm and 68mm, respectively. The lower support moves upward with the rate of 0.005 mm/s, and the load-displacement data was recorded, as shown in Fig. 8.

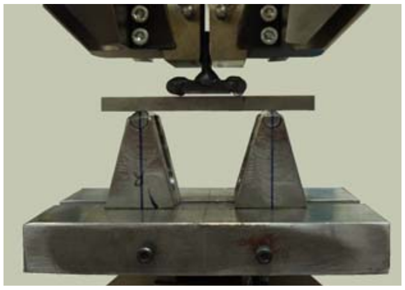

Fig.5. Four-point bend test set up

3. Numerical modeling

The four-point bend test is simulated using ABAQUS 6.7 software, in which the type of “cohesive element” is provided. The cohesive elements consist of two faces separated by a defined initial constitutive thickness, which is set equal to the joint thickness. Opening or closing of the interface they are placed is simply measured by the relative displacement of the opposite faces of these elements [13]. Constitutive response of the cohesive elements in the form of a traction-separation law is determined by the parameters of cohesive strength and separation energy. The relation between CZM parameters is described by Eq. (1), in which δ_f represents the separation at failure [15].

$$\Gamma = \frac{1}{2} T_{max} \delta_f \qquad \text{(Eq.1)}$$

The stiffness of the interface, K_C, is assumed to be defined by Eq. (2) [13].

$$K_C = \frac{T_{max}}{\delta_f} \quad \text{(Eq.2)}$$

The cohesive elements were tied to the surrounding bulk elements of the beam.

A Young’s modulus of 212 GPa and a Poisson’s ratio of 0.3 were defined as the base metal elastic properties. The real elasto-plastic behavior of the base metal is determined by a tensile test on its bulk specimen, Fig. 6, and implemented into the model.

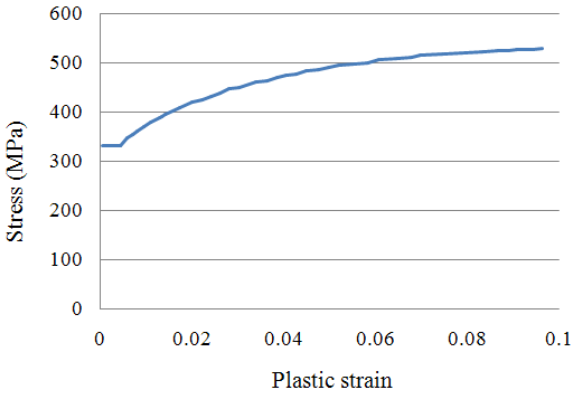

Fig.6. Stress-plastic strain of the base metal on tensile test

The model of the beam, meshing, and boundary conditions are shown in Fig. 7.

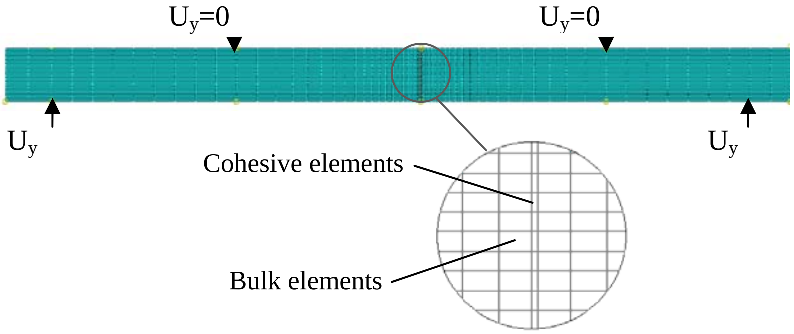

Fig.7. FE model and boundary conditions of the four-point bend test

The reaction force versus the lower support displacement is plotted and compared with that of the experiment, as shown in Fig. 8. Implementing the obtained value of the cohesive strength, the numerical results are plotted for different values of separation energy. The load-displacement curve with the separation energy of 1.5 kJ/m^2 best fits the experimental result.

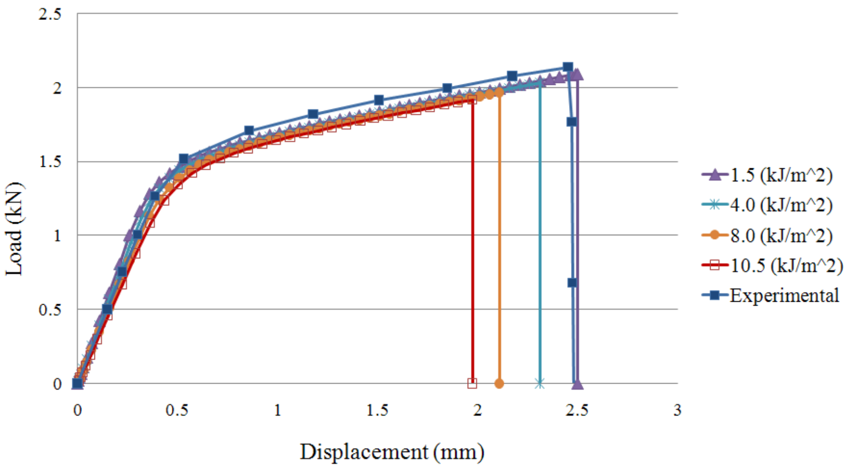

Fig.8. Experimental and numerical load-displacement curves of the four-point bend test for different values of the separation energy and the cohesive strength of 534 MPa

4. Discussion

The failure of St/Cu/St butt-brazed joints was studied using the CZM concept. The CZM parameters of cohesive strength and separation energy were determined in the normal mode of fracture. The cohesive strength was measured by a uniaxial tensile test on butt-brazed joint specimens, and the average value of 534 MPa was recorded. The separation energy was indirectly determined by performing a four-point bending test on butt-brazed rectangular beams. The bending test was numerically modeled using ABAQUS 6.7, and the load-displacement curves are plotted for different values of the second CZM parameter. The separation energy of 1.5 kJ/m^2 best fitted the numerical results to the experimental curve. Replacing the obtained values of the cohesive strength and separation energy in Eq. (1), the separation at failure, δ_f, is calculated 5.6 µm.

3-D profiles of the butt-brazed joint matching fracture surfaces, taken by WYKO NT1100 Optical Profiler, are illustrated in Fig. 9. The contours of the fracture surface height are shown on these images. Average of total fracture surface heights of the two corresponding surfaces relative to the St/Cu interface was measured 55.8 µm on the profiles. Considering the initial thickness of the joint (50 µm), the separation at failure, δ_f, is calculated 5.8 µm which has a good agreement with the obtained value through the approach presented in this paper.

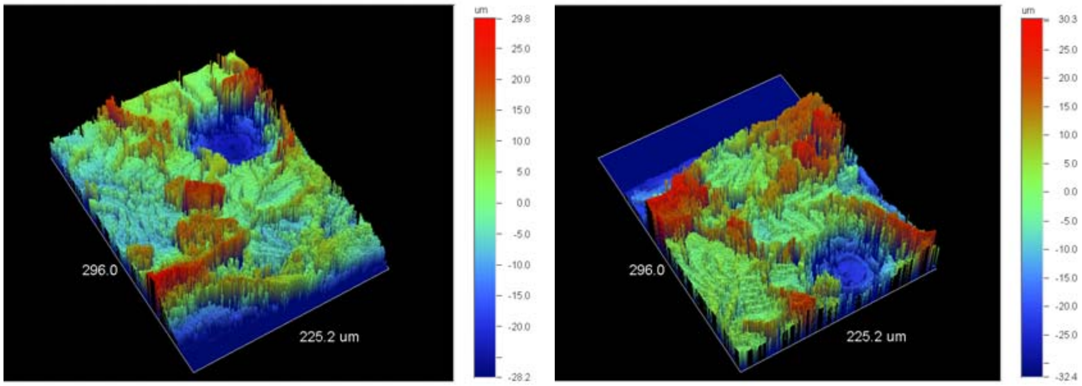

Fig.9. 3-D profiles of the butt-brazed joint matching fracture surfaces

The separation energy of the joint is a good measure of its rigidity. In the numerical simulation the response of the joint indicates that when the separation energy increases, the deformation of the beam decreases as shown in Fig. 8. Owning to the fact that the brazed joint behaves as a constraint on the base metal, the joint with a higher separation energy apply a less rigidity on the whole of the structure. Therefore, the predicted strain energy of the beam specimens is reduced by increasing this parameter, as shown in Fig. 10.

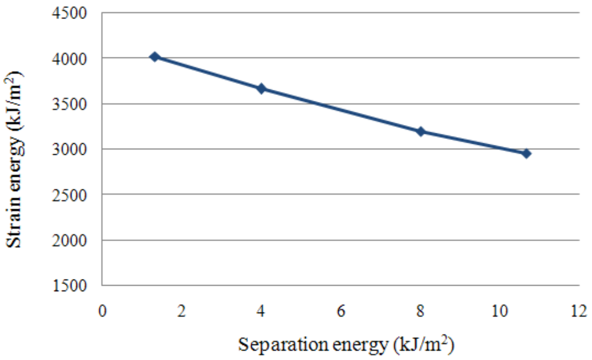

Fig.10. Strain energy of the beam versus the joint separation energy

The approach presented in this paper could determine the parameters used in the cohesive zone modeling as a powerful tool for prediction of strength, deformation and failure of jointed structures.

5. Acknowledgements

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6. References

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