Numerical simulation of impact toughness of welded joints for X80 pipeline steel†

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1. Introduction

Issues of impact dynamics exist in various engineering fields. As dynamic fracture problems were complex in many experiments, people began to simulate the whole process of impact dynamics and then analyze the dynamic response of materials under impact loads in a better way. Nowadays, nonlinear finite element method has been widely used in various fields.

With the application of dynamic analysis software ANSYS/LS-DYNA, a model of impact test specimen is established and a solid model for the simulation impact test is also set up in which the dynamic impact process for the impact test is simulated. The absorbed energy is calculated during the whole impact test and the difference in impact toughness caused by the notch located in the weld metal, HAZ and base metal is analyzed. Study proves that the numerical model can be used in prediction and evaluation of the toughness of welded joints.

2. Numerical modeling and meshing

For impact toughness test, finite element software LS-DYNA is used to carry out the dynamic numerical simulation of X80 pipeline steel welded joint. The actual impact test process is completely done according to Chinese standard GB/T229-1994. In the three-dimensional solid model, the supports are simulated as two fixed baffles. The dimension of the model is designed by the actual standard impact specimen. The shape and size of the impact rammer is modeled by the cutting edge shape of the actual pendulum. The total width of the HAZ is 3.5mm, among which the coarse grain zone is 1mm and the fine grain zone is 1.2mm.

The element meshes near the notch are dense while those far from the notch are sparse. When the notch is located in HAZ, weld metal or base metal, the heterogeneity of HAZ has great influence on the specimen impact result. The region near the notch is divided to simulate each area of the HAZ. The properties of material far away from the notch are set as those nearby. The impact toughness is simulated respectively when the notch is located at the three different regions. The impact model graph for the notch is located at weld metal is shown in **Fig.1**.

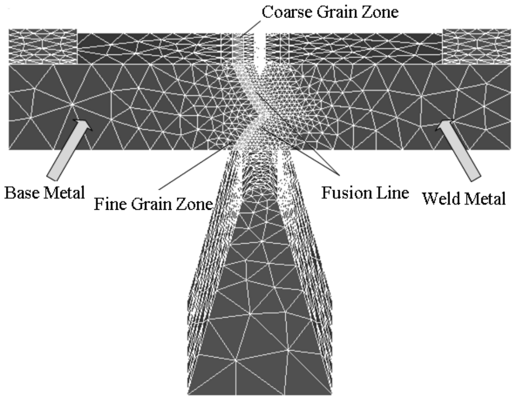

Fig. 1 Three-dimensional numerical model and FEM mesh for the impact testing

For welded joints, the density is 7820 kg·m^{-3}; elastic modulus and tangent modulus is 200GPa and 2.2GPa, respectively; Poisson ratio is 0.28; hardening exponent is 0.13; strain rate parameters are 40 and 5 separately.

Yield strength and failure strain have some effect to impact toughness. Therefore, the material properties of HAZ (including coarse grain zone and fine grain zone) are simulated by changing these two parameters. The properties of each region in the welded joint specimen are shown in **Table 1**. For the impact rammer, the elastic modulus and Poisson ratio is 400 GPa and 0.3, respectively. The density is 6.8×10^{6} kg·m^{-3}.

Table 1 Properties of welded joint at different parts

Region	Yield strength σ_s/MPa	Failure strain ε
Base metal	560	0.5
Coarse grain zone	545	0.45
Fine grain zone	550	0.47

3. Results and discussion

When the notch is located at weld metal, HAZ and base metal, the fracture situation of impact numerical model is shown in **Fig 2**.

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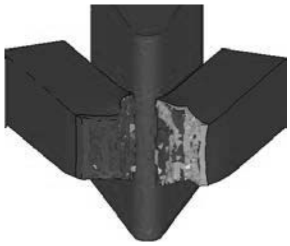
(a) The notch located at weld metal



(b) The notch located at HAZ

(c) The notch located at base metal

Fig. 2 Fracture model for different notch locations

When the notch is located at the weld metal, cracks initiate at the root of notch and weld metal, and then propagate through the coarse grain zone. When the notch is at the fusion line, the crack develops mainly through the coarse grain zone, which accounts for a large proportion of the fracture path. The specimen broke at the weld metal finally. When the notch is located in the HAZ, crack also grows through coarse grain zone. It can be seen that the boundary between coarse grain zone and fine grain zone on the fracture cross section obviously. When the notch is located at the base metal, the crack completely propagates through the base metal and the plastic deformation is large at impact fracture.

For analyzing the impact toughness of joint specimens, it is necessary to calculate the absorbed energy during the impact process. The impact toughness (absorbed energy) can be obtained from the force/displacement curve as shown in **Fig. 3**.

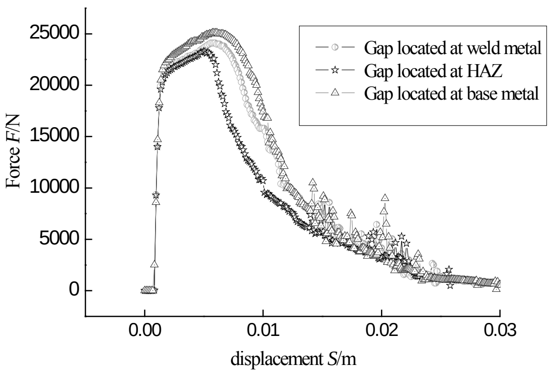


Fig. 3 Three force/displacement curves for notch located at different parts

Comparing the curves above it can be seen that the location of the notch has a great influence on the impact energy when the difference of material properties between HAZ and base metal is large. When the notch is at the base metal, the force/ displacement curve is the highest and the enclosed area is the biggest. This means the impact toughness there is the best. When the notch is at the weld metal, the toughness gets worse and becomes worst when the notch is in the HAZ. That is because the yield strength and fracture strain have a certain decline. Besides, softening phenomena in HAZ causes the impact toughness to reduce significantly.

According to the dynamic numerical simulation results and the force/displacement curves under various conditions, the impact absorbing energy, peak load and the initial cracking power are all counted as **Table 2** shows.

Table 2 Results statistics for notch located at different parts

	Weld metal	HAZ	Base metal
Peak force F/kN	24	23.3	25.1
Impact absorbed energy W/J	289	246	307
Initial crack energy W_1/J	96	83	107

From the table above, the load required for base metal fracture is the largest t. The impact absorbed energy of base metal is 307J, which is much higher than 246J for HAZ. That indicates HAZ properties have seriously declined. The toughness of weld metal near the HAZ has declined as well. It is the most difficult for base metal to initiate cracks so the required initial cracking power is the largest. Therefore, the toughness of base metal is the best and HAZ is the worst.

4. Conclusion

The LS/DYNA finite element software is used to simulate the impact testing with a reasonable FEM model. The numerical results show that the impact toughness is affected by yield strength and failure strain. The impact toughness is different when the notch is located at different regions. The impact toughness is the worst for a notch located at the HAZ and best in the base metal. It can be used to predict the impact toughness of welded joint and provides a new method to evaluate the properties of joint.

References

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