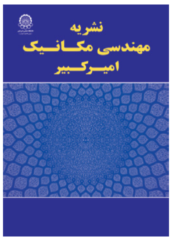

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Experimental and Numerical Investigation of Initial Notch Radius Effect on Charpy Fracture Energy in API X65 Steel

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ABSTRACT: Different factors such as initial notch angle, notch depth, notch root radius, notch, specimen size, hammer geometry, striker velocity, and initial notch creation method (i.e. broaching and machining), influence the experimental determination of Charpy impact energy. Thus, the study of the influence of these parameters on Charpy fracture energy is important. In the present research, Charpy impact experiments are conducted on test specimens made from API X65 steel (used for gas transportation pipelines). The tests samples have a standard size with different notch radius (within the range of 0.13 - 0.41 mm). By measurement of fracture energy, Charpy impact energy is determined as a function of variations of the initial crack radius. Through having geometrical dimensions of the initial notch and considering the stated standard tolerance the aforementioned function allows the determination of measurement error of API X65 steel Charpy impact energy. Then, the test samples are modeled as 3D in ABAQUS using Gurson damage theory. The comparison of test and simulation results for different notch radius are presented in compared.

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1. INTRODUCTION

Hashemi [1] measured the amount of Charpy fracture energy for different areas of pipe spiral API X70 of seam welder steel based on the ASTM E23 standard. The amount of fracture energy of this steel is reported 222 J for the area of the basic metal. Mosaddegh et al. [2] investigated the effect of radius and depth of notch on the fracture energy belonging to the three-point bending specimen with U-notched functionally graded copper-steel which is under the mode I loading. In this study, in order to evaluate the fracture force of specimens with finite element analysis, J integral standard was used. Comparison of results of the finite element analysis and the experimental test demonstrated that calculated fracture force by J integral standard has a difference of 17.84% with experimental results. Also, the linear relation between fracture energy and notch radius can be deduced by the resulting graph. Young et al. [3] considered the effect of geometric constraints (depth of notch) on the growth of soft notch in the API X100 steel. In this study, Gurson damage model is used for 2D simulation of the specimen under dynamic Charpy impact test and static tension test.

In the present study, the effect of radius change in the V-notched end on the fracture energy of impact belonging to Charpy experimental specimens is investigated in which specimens are made from API X65 steel. Hereby, a relation is obtained between fracture energy of the API X65 steel and radius of notch end to be used in the case of an error in the manufacturing of the specimen to calculate the standard amount of fracture energy. Also, 3D simulation of specimens is done in the ABAQUS software and the results of the numerical modeling and experimental tests are compared with each other.

2. EXPERIMENTAL STAGES

The experimental specimens with due attention to the ASTM 23 standard for the Charpy impact test [4] were prepared from API X65 tube with outer diameter of 1219 mm (48 inches) and thickness of 14.3 mm in the direction of circumferential (with a notch in the length of the tube). Twenty-four specimens with V-notched with variable end radius (eight radii, three specimens from each of one) were made with due attention to specified limits in the ASTM 23 standard.

Charpy impact test was carried out in the quality control laboratory of Ahvaz tubing factory in which a Zwick Roell system according to standard was used with the capacity of 750J in the environment temperature. The dimensions of the specimens are shown in Table 1.

Table 1: Dimensions of specimens with variable notch radius which are used in Charpy impact test

Number of specimens	Notch radius (mm)
1-3	0.13
4-6	0.17
7-9	0.21
10-12	0.25
13-15	0.29
16-18	0.33
19-21	0.37
22-24	0.41

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3. SIMULATION

In order to simulate the Charpy impact test, a 3D model is chosen. The simulation was done in ABAQUS 6.12 software. Fig. 1 shows an image of the Charpy impact test specimen accompanied by the striker and support in the environment of simulation software.

4. RESULTS

In Table 2, fracture energy is shown which is obtained from the impact test and numerical modeling.

Energy changes of the Charpy impact in terms of arc radius of V-notched are demonstrated in Fig. 2 (in two graphs, experimental and simulation results are shown). In this figure, the results of the standard specimen (259J) are obtained.

As shown in Fig. 2, by increasing the end radius of V-notched belonging to the standard specimen of the Charpy impact test, the amount of fracture energy increases linearly based on Eq. (1). Also, variation in the fracture energy based on V-notched arc from numerical modeling changes as follows:

$$E = 65.47R + 245.07 \quad (1)$$

Using the Eq. (1), the amount of impact energy for a standard specimen with R = 0.25 mm is 261J, which matches with experimental value (259J). The error resulting from interpolation of the Eq. (1) for calculation of the fracture energy of the standard specimen is just 0.77%. In Table 3, the results of the fracture energy of the standard specimen which are obtained from experimental equations and simulation, are compared with each other. According to the obtained results, errors are less than 1%, it can be deduced that the results of the simulation have a good fit (0.77%) with experimental results.

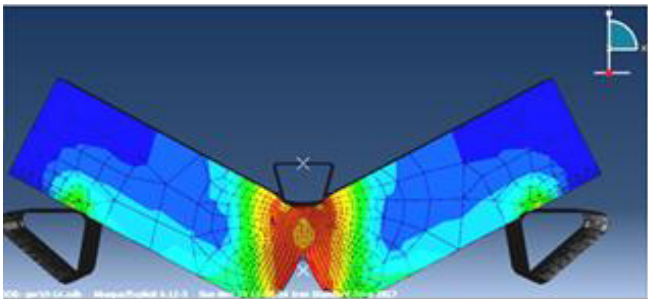

Fig. 1: The environment of ABAQUS software [15]

Table 2: Percentage error related to the results of experimental and simulation test

Radius (mm)	Fracture energy exp. (J)	Fracture energy sim. (J)	Error (%)
0.13	255	253	0.78
0.17	259	258	0.38
0.21	260	259	0.38
0.25	259	261	0.77
0.29	259	263	1.54
0.33	262	266	1.52
0.37	265	268	1.13
0.41	267	274	2.62

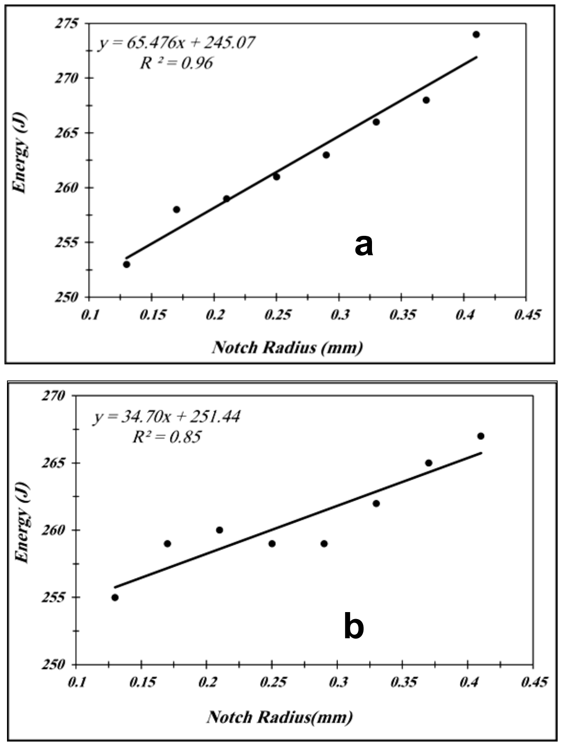

Fig. 2: Energy changes of the Charpy impact in terms of notch radius a) results of the simulation test b) results of the experiment

Table 3: Comparison of fracture energy of standard specimen using two simulation and experimental equations

parameter	Fracture energy (J)	Error (%)
Fracture energy resulting from the experimental test	259	-
Fracture energy resulting from the experimental equation.	260	0.38
Fracture energy resulting from the simulation equation.	261	0.77

5. CONCLUSION

In the present study, the effect of root radius variations in V-notched on the Charpy fracture energy of API X65 steel specimen was investigated. For this study, twenty-four specimens in seven specimen series (each series has three specimens.) with non-standard radius and a specimen series with standard dimensions were tested. The system used in this experiment was chosen with the capacity of 750J according to the ASTM E23 standard. Also, a 3D simulation of specimen took place in the ABAQUS software. The summary of the obtained results is as follows:

1- With increasing end radius of the notch, the Charpy fracture energy increases linearly based on this equation $E=34.70R+251.44$. By means of this equation, the exact amount of the Charpy fracture energy can be calculated even if there is an error in the manufacturing of the specimen for the tested steel (error in arc V-notched).

2- The amount of the impact energy obtained from the experimental equation for a standard specimen with R = 0.25 mm equals to 260J, which fits with the experimental value (259J). The error resulting from interpolation of the experimental equation for fracture energy calculation of the standard specimen is just 0.38%.

3- In order to validate the experimental results, the 3D simulation was used based on the Gurson damage modified model. Comparison of values obtained from experimental test and simulation results reveals that the amount of the impact energy obtained from Eq. (1) for a standard specimen with R = 0.25 mm equals to 261J, which fits with experimental value (259J). The error resulting from interpolation of the Eq. (1) for fracture energy calculation of the standard specimen is just 0.77%.

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