The Effect of V-notch Depth on Fracture Toughness and the Plastic Region of the Crack Tip Using Charpy Impact Test Data in API X65 Steel

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1. Introduction

Much of the steel pipeline used in Iran is made of API X65 steel, and 56-inch diameter outer pipes are currently made of this steel. Therefore, it is necessary to collect and study information about this type of pipes such as mechanical properties (fracture toughness, fracture energy, yield strength, and tensile strength), microstructure, and chemical composition.

In this paper, the K_{IC} values of the relationships between K_{IC} and Charpy impact energy are reported in studies for CVN impact test data. The CVN values were obtained from a previous research conducted by the authors. Charpy test specimens with standard dimensions (55×10×10 mm) and notch (notch arc radius 0.25 mm, 45-degree is notch angle and notch depth from 1.25 to 3 mm) were extracted in API X65 steel base metal.

2. Materials

The API standard describes the characteristics of high-strength steels such as chemical composition, yield strength, fracture strength, welding conditions, manufacturing processes, the way of performing mechanical tests and so on. Ranks denote all of these steels with one letter and one number. The number indicates (except ranks A and B) the minimum yield strength of these steels based on the English unit (ksi). By API standard, these ranks are A25, B, X42, X46, X52, X56, X60, X65, X70, X80, and X100. API products are expressed in two levels PSL1 and PSL2, which represent two different levels of standard of expertise required for these products.

3. Laboratory Experiments

To achieve the objectives of the study, 24 specimens were made in triple series with eight different notch depths industrial pipes made of API X65 micro-alloy steel with an outer diameter of 1219 mm and a wall thickness of 14.3 mm.

Dimensions (thickness, length, and width) of the specimens were measured in micrometers for verification. The notch dimensions of the specimens (depth and radius) were accurately measured with a macro lens camera and image-processing software with a precision of 0.001 mm following Figure 1. The specimens were then transferred to the Quality Control Laboratory (Ahvaz pipe industrial company) for Charpy Impact Testing.

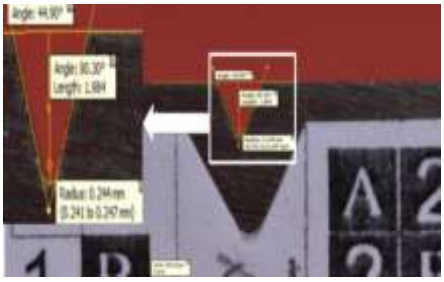

Figure 1. Measuring Specimens with Digimizer Software [1]

4. Results and Discussion

Because of the complicated, costly, and time-consuming fracture toughness test, more straightforward methods such as the Charpy Impact Test are attempted to calculate the K_{IC}. Since 1970, researchers have discovered that there is a relationship between fracture toughness and the fracture energy of a Charpy Impact Test (using a Charpy V-notch specimen). Table 1 lists some of the relationships that are applied to the API X65 steel pipe.

Table 1. Relations between KIC and Charpy Impact Energy

Number	Reference	Relation
1	WRC 265 [10]	$K_{IC}=8.47(CVN)^{0.63}$
2	Sailors and Corten [11]	$K_{IC}=14.6(CVN)^{0.50}$
3	Marandet and Sanz [15]	$K_{IC}=19(CVN)^{1/2}$
4	Robert and Newton [13]	$K_{IC}=8.47(CVN)^{0.63}$
5	Rolfe-Novak-Barsom [23,24]	$(K_{IC}/\sigma_{YS})^2=0.64((CVN/\sigma_{YS})-0.01)$
6	Ault et al. [25]	$(K_{IC}/\sigma_{YS})^2=1.37((CVN/\sigma_{YS})-0.045)$
7	Van der Sluys et al. [26] and Witt [27]	$(K_{IC}/\sigma_{YS})^2=0.893((CVN/\sigma_{YS})-0.0291)$
8	Kussmaul and Roos [28]	$(K_{IC}/\sigma_{YS})^2=1.23((CVN/\sigma_{YS})-0.0061)$

In the relations of Table 1, K_{IC} is the plane strain fracture toughness, σ_{YS} is yield stress, and CVN is fracture energy obtained from the Charpy Impact Test on the V-notch specimen, and the units of these values are MPa$\sqrt{m}$, MPa, and J, respectively.

Using the table relationships and fracture energy

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obtained from the Charpy Impact Test and also having σ_{YS}=505MPa, K_{IC} is first obtained in 8 states. Then, according to other researchers who obtained the standard K_{IC} for this steel , two well-matched relationships were selected and compared. Then, using the von Mises relationships of crack tip plastic zone and standard specimen simulation, the best fit is selected as the desired relation, and finally, the effect of notch depth on the crack tip plastic zone and K_{IC} for the tested steel is discussed.

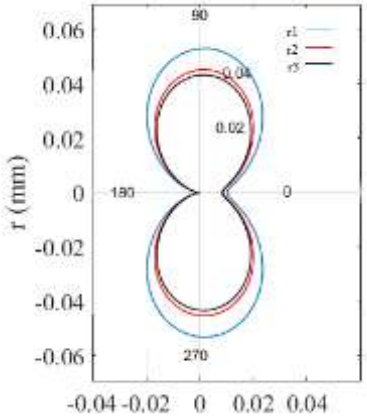

Figure 2. Crack tip plastic zone diagram for the standard specimen

In Figure 2, r3 is the result obtained from a previous research. By comparing the diagrams, the best fracture toughness can be reported as 295.3038 MPa√m. There is a difference of 3 to 4%, according to Figure 3, which shows the temperature diagram of API X65 steel due to temperature difference as an active factor in fracture toughness.

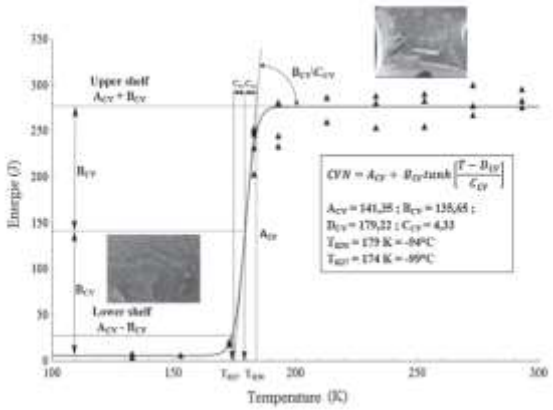

Figure 3. Energy-temperature diagram for API X65 Steel

Therefore, to obtain the K_{IC} of other specimens that vary the notch depth, the Marandet and Sanz relation was used. Figure 4 shows the effect of notch depth on the crack tip plastic zone on API X65 steel.

Figure 4 shows that as the notch depth increases, the crack tip plastic zones decreases.

Figures 5 and 6 show the crack tip plastic zone in the specimen with a notch and specimen without notch from the simulation.

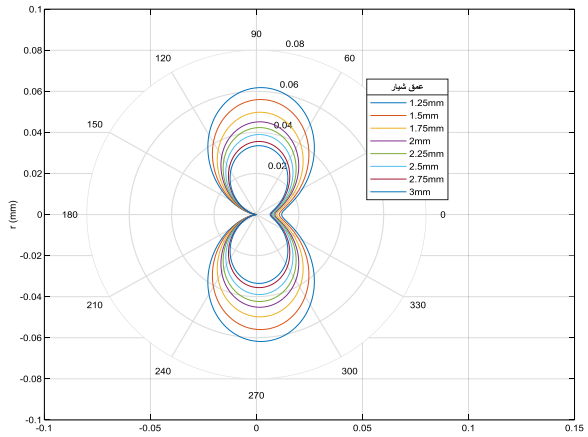

Figure 4. Effect of notch depth on the crack tip plastic zones

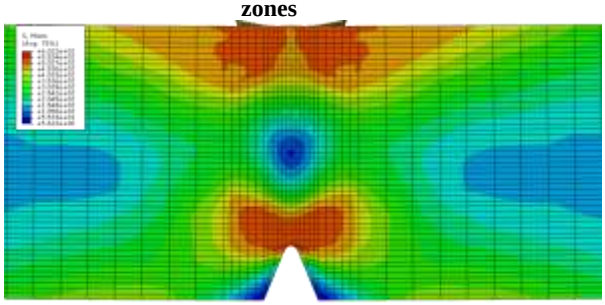

Figure 5. Crack tip plastic zone for Charpy standard specimen

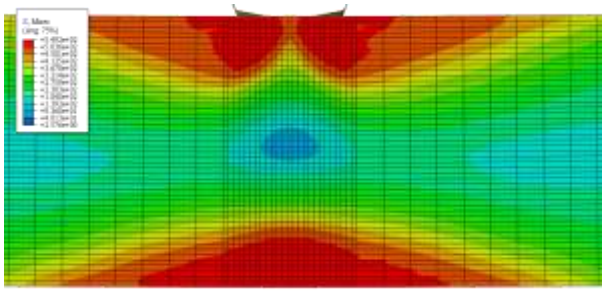

Figure 6. Crack tip plastic zone for Charpy non-standard specimen (specimen without a notch)

The comparison of the Crack tip plastic region in two samples with and without notch is seen in Figures 5 and 6. The plastic area in the non-notch sample is much larger than in the notch sample.

5. Conclusion

In the present study, the effect of V-notch depth on fracture toughness (K_{IC}) and crack tip plastic region was investigated using Charpy impact test in API X65 Steel.

1. As the notch depth increases, the fracture toughness decreases exponentially based on the $K_{IC} = 430.24e^{-0.181a}$ ratio.
2. The plastic zone of the crack tip was obtained using the von Mises table and the fracture toughness obtained from the relationship between the Marandet and Sanz. As the notch's depth increases, the Charpy fracture energy decreases exponentially based on the relation $E=503.44e^{-0.35a.}$