Study on the Influence of Thickness on Material Constant of Pipeline

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Abstract

Maintaining a high level of pipeline integrity and reliability is the primary task of ensuring the safe operation of the pipe network system. Mechanical damage is the main culprit in the frequent occurrence of pipeline accidents. The ductile safety criteria based on metal materials can be used to evaluate the safety of the pipeline. The material constant of the ductile fracture criterion has a large influence on the evaluation results. In this paper, the API X80 pipeline steel is taken as the research object, and the Oyane ductile fracture criterion is selected. The tensile test of the X80 pipe specimens with different thicknesses is carried out to investigate the variation of the material constant with thickness.

Keywords

Pipeline, ductile fracture criterion, material constant, tensile test.

1. Introduction

Since the 1960s, domestic and foreign scholars have conducted in-depth theoretical research and experimental research on the metal ductile fracture phenomenon from both macroscopic and microscopic aspects [1-3]. More than 10 semi-empirical toughness fracture criteria for suitable engineering applications have been proposed. Most of these criteria use threshold control methods, that is, the material is considered to initiate fracture before it exceeds the set threshold [4]. The following are widely used: energy criterion (Freudenthal model) [5], maximum tensile stress criterion (Cockcroft-Latham model) [6], Brozzo model [7], Oyane model [8]. In order to evaluate the applicability of different ductile fracture criteria, Huang applied these criteria to the fracture prediction of various experiments [9], and found that the Oyane fracture criterion has less deviation of the critical damage fracture value under tensile state. Some scholars use the Oyane toughness damage criterion to analyze dent defects, but the material constants are relatively lacking. Due to different materials and different conditions, the material constants are different; for the same material, the thickness and material constant will be different [10]. The effect of thickness on the material constant is neglected in existing studies, which leads to errors in the final evaluation results.

2. Theoretical basis

In the 1980s, Japanese scholar Oyane proposed that the hydrostatic pressure can suppress or accelerate the ductile failure, and proposed the Oyane ductile fracture criterion, which assumes that the fracture occurs when the ductile damage reaches a certain value [11]. M. Allouti uses the spherical indenter to apply dents to the pipeline. Based on the Oyane ductile fracture criterion, the results of finite element analysis of the influence of the dent depth on the damage degree of the pipeline are in good agreement with the experimental results [12].

$$\int_0^{\bar{\varepsilon}_f} \left| \frac{\sigma_m}{\bar{\sigma}} + C_1 \right| d\varepsilon = C_2 \tag{1}$$

Where $\bar{\varepsilon}_f$ is the equivalent strain at which fracture occurs, $\bar{\sigma}$ refers to the equivalent stress, σ_m refers to the hydrostatic pressure, and C_1、C_2 is material constant.

The material constant C_1、C_2 needs to be determined by at least two strains under strain conditions. The material constant is determined by the equivalent strain at which fracture occurs $\bar{\varepsilon}_f$. In order to obtain the integral value of the material at a certain load moment before the ductile fracture occurs, the two sides of the equation (1) can be simultaneously divided by a constant, then the value on the right side of equation (1) is equal to 1, that is, when the material undergoes ductile fracture, the integral value is equal to 1. Finally, the equivalent strain at which fracture occurs $\bar{\varepsilon}_f$ in equation (1) is replaced by the equivalent strain $\bar{\varepsilon}$, then equation (1) becomes:

$$\frac{1}{C_2}\int_0^{\bar{\varepsilon}}\left|\frac{\sigma_m}{\bar{\sigma}}+C_1\right|d\bar{\varepsilon}=I \tag{2}$$

If the parameters of the material at some point in the load history ($\bar{\varepsilon}$, $\bar{\sigma}$, σ_m) are known, the toughness damage value I of the material can be obtained by combining the formula (2). The value of $\bar{\varepsilon}$, $\bar{\sigma}$, σ_m can be calculated by finite element method. The toughness damage I on the right side of the formula can not only quantitatively represent the instantaneous damage state, but also reflect the degree of toughness damage of the material through the entire stress-strain history, and the material undergoes ductile fracture when the integral value is obtained [13].

3. Stretching test

The above ductile fracture criterion is applied to the evaluation of mechanical damage to determine the mechanical properties of the material itself and the material constants in the criteria. In this paper, the uniaxial tensile test and the plane strain tensile test are used to determine the material parameters, and the material parameters C_1 and C_2 in the Oyane criterion are solved by the Hill yield criterion suitable for anisotropic materials. The plane strain tensile test and the unidirectional strain tensile test were carried out in seven groups according to the thickness. According to the national standard "Metal Material Tensile Test" GB/T 228.1-2010 and the material's own mechanical properties, select 2mm as the minimum thickness of the tensile test. Each test material is increased by 1mm thickness on the basis of the previous set of thickness. A total of seven sets of tests were selected, and five identical test pieces were selected for each test to reduce the error. In this paper, X80 pipeline steel is selected as the research object, and the dimensions of the test piece are shown in Figure 1.

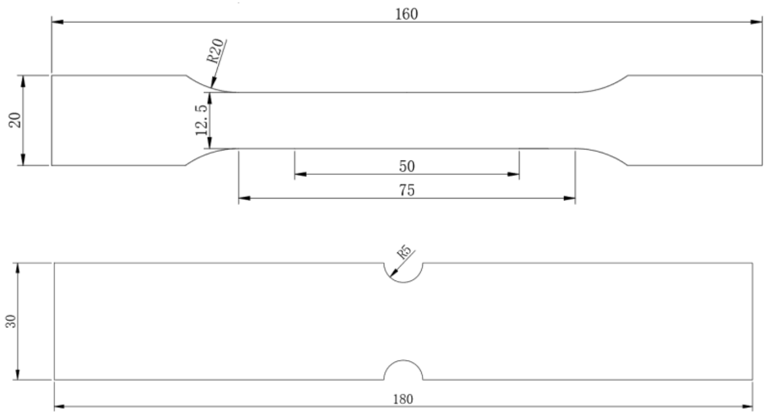

Figure 1 Dimensional tensile test specimen size

Figure 2 specimen fracture diagram

This test determines the reference specification "Metal material tensile test Part 1: Room temperature test method" GB/T 228.1-2010. The tensile test equipment is a microcomputer-controlled electro-hydraulic servo universal testing machine of Southwest Petroleum University. The uniaxial tensile test and the plane tensile test specimen were subjected to tensile fracture as shown in Fig. 2.

4. Data processing

After the tensile test of the test piece, the following stress-strain curve can be obtained. According to the Oyane fracture toughness criterion, the ratio of stress triaxiality and equivalent strain to uniaxially stretched first principal strain can be reduced to equations (3) and (4), respectively, without considering the difference in plane anisotropy. form.

Unidirectional stretching:

$$\frac{\sigma_m}{\bar{\sigma}}=\frac{1}{3}\sqrt{\frac{2(2+r)}{3(1+r)}};\ \frac{\bar{\varepsilon}}{\varepsilon_1}=\sqrt{\frac{2(2+r)}{3(1+r)}} \tag{3}$$

Plane stretching:

$$\frac{\sigma_m}{\bar{\sigma}}=\sqrt{\frac{2(2+r)(1+2r)}{3(1+r)}};\quad \frac{\bar{\varepsilon}}{\varepsilon_1}=\sqrt{\frac{2(2+r)(1+r)}{3(1+2r)}}\ \frac{\bar{\varepsilon}}{\varepsilon_1} \tag{4}$$

By comparing the five fracture data of each set of experiments, the data with large deviations were selected and deleted. After selecting the valid data, the material constants C_1 and C_2 were obtained according to the Oyane ductile fracture criterion. The material constant is the most direct manifestation of the performance of the pipe material. Obtaining effective experimental data is the premise of the entire law analysis. The final material constant is obtained as shown in Figure 4.

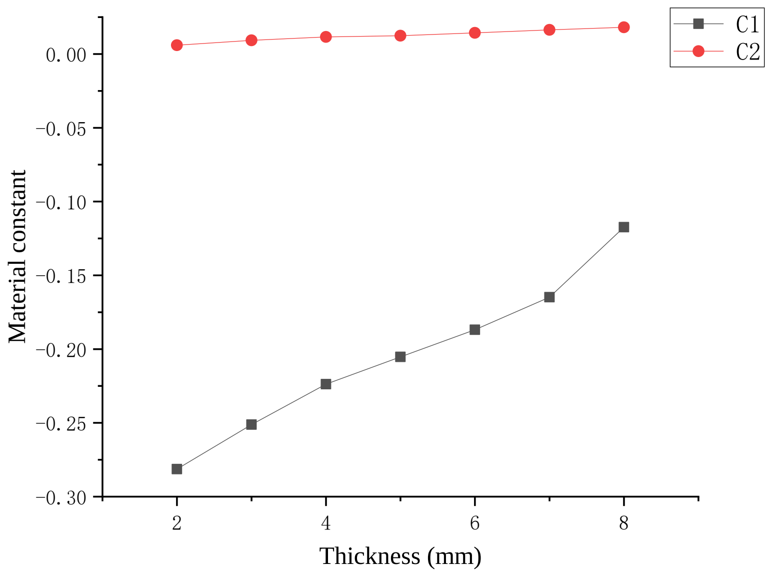

Figure 4 Material constant versus thickness

It can be seen from the experimental results that the material constant C1 shows an increasing trend with the increase of the thickness of the test piece, and the material constant C2 does not change substantially with the increase of the thickness of the test piece.

5. Conclusion

1. It is verified by the uniaxial tensile test and the plane tensile test that the material constants C_1 and C_2 will be different for the same material and different thicknesses. And the material constant will change linearly with the thickness, C_1 will increase with the increase of thickness, and the material constant C_2 will not be affected by the thickness variation of the test piece.

2. The I is the integral value in the Oyane ductile fracture criterion. When I is greater than a certain critical value, the material ruptures. In the case of a thickness change, the material constant C_1 will increase while C_2 remains unchanged, which will cause the integral value I to be too large, which will cause a deviation in the final evaluation result of the pipe recess.

References

[1] Ozturk F, Lee D. Analysis of Forming Limits Using Ductile Fracture Criterial [J]. Journal of Materials Processing Technology, 2004 , 147(3):397-404.
[2] Bao Yingbin, Wierzbicki, Comparative Study on Various Ductile Crack Formation Criteria[J]. Journal of Engineering Materials and Technology ,2004, 126(3):314-324.
[3] Venugopal, Ramakrishnan, Krishna K R. A Comparative Evaluation of the Theoretical Failure Criteria for Workability in Cold Forging [J]. Journal of Materials Processing Techno log y , 2003 , 142(1):29-42.
[4] Pu Sihong, Wen Wei, Wu Wei. Theoretical and Experimental Study on the Selection of Ductile Fracture Criterion and Threshold[J]. Hot Working Technology, 2009, 38(03):18-21.
[5] Freudenthal. The Inelastic Behavior of Engineering Materials and Structures[J]. Journal of the Royal Aeronautical Society,1951,55(490).
[6] Cockroft M, Latham D. Ductility and workability of metals[J]. Journal Institute of Metals, 1968,96:33-39.
[7] Brozzo P, Deluca B. A new method for the prediction of formability limits in metal sheets[J]. Proceeding of the 7th Biennial Conference of the International Deep Drawing Research, 1972.
[8] Oyane. Criteria for ductile fracture and their applications[J]. Journal of Mechanical Working Technology, 1980, 4:66-81.
[9] Huang Jianke, Meso-damage mechanics model and ductile fracture criterion in metal forming process [D], Shanghai Jiaotong University, 2009.
[10] Zhang Jing.Study on the spinning process of 304 stainless steel tube [D]. Shenyang Institute of Technology, 2014.
[11] MoriyaOyane. Criteria for ductile fracture and their applications [J]. Journal of Mechanical Working Technology, 1980, 4: 65-81.
[12] M.Alloutia, C.Schmitta, G.Pluvinagea, J.Gilgerta, S.Haririb. Study of the influence of dent depth on the critical pressure of pipeline [J]. Engineering Failure Analysis, 2012, 40-51.
[13] Qiu Orange. Study on damage degree of oil and gas pipelines with simple dent defects [D]. Southwest Petroleum University, 2014.