Engineering Failure Analysis 37 (2014) 110–119

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

On the use of Charpy transition temperature as reference temperature for the choice of a pipe steel

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ARTICLE INFO

Article history:
Received 1 August 2013
Received in revised form 11 November 2013
Accepted 19 November 2013
Available online 10 December 2013

Keywords:
Transition temperature
Constraint
Effective *T* stress
Reference temperature

ABSTRACT

Transition temperature is not intrinsic to material but depends on specimens and mode of loading used for tests. Here, the linear dependence of transition temperature with constraint is shown. Constraint is evaluated by the effective *T* stress which is the value of the stress difference distribution for the effective distance provided by the Volumetric method.

Application of this approach gives the best choice of the reference transition temperature by reducing conservatism when comparing with intrinsic transition temperature of the studied structure.

1. Introduction

The concept of brittle–ductile transition temperature was developed during the Second World War, because of the rupture of liberty ships at sea. The ductile–brittle transition temperature (DBTT), nil ductility temperature (NDT), or nil ductility transition temperature (NDTT) of a metal represents the point at which the fracture energy passes below a pre-determined value.

Design against brittle fracture considers that the material exhibits at service temperature, a sufficient ductility to prevent cleavage initiation and sudden fracture with an important elastic energy release. Concretely, this means that service temperature T_s is higher than transition temperature T_t:

$$T_s \geqslant T_t \quad (1)$$

Service temperature is conventionally defined by codes or laws according to the country where the structure or the component is built or installed. For examples, in France, a law published in July 1974 indicates that service temperature in France is −20 °C.

However, despite the introduction during the 1960s of Fracture Mechanics tests to measure fracture resistance of materials, the practice of the Charpy impact test remains. It always gives a simple and inexpensive method to classify materials by their resistance to brittle fracture. The current trend is also to use these tests to measure fracture toughness and ductile tearing strength. The comparison of the two methods requires taking into account two major differences:

- Charpy test uses a notched sample, and fracture mechanics tests use a pre-cracked specimen (but a pre-cracked Charpy specimens may also be used).
- Charpy tests are dynamic tests, although the conventional fracture mechanics tests are static ones.

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http://dx.doi.org/10.1016/j.engfailanal.2013.11.001

Different Charpy specimens are used in standard. The most widely used is Charpy V specimens (V notch, notch radius ρ = 0.25 mm, notch depth a = 2 mm). Other specimens like Charpy U (U notch, notch radius ρ = 1 mm, notch depth a = 5 mm) are also used in standards [1].

Increase of notch acuity of Charpy specimen shift transition temperature to higher value and increase scatter in transition temperature [2,3].

Several definition of transition temperature are used in Charpy test:

- temperature at a conventional level of Charpy energy (generally 27 J) and called T_{K27},
- temperature corresponding to half also at half the jump between brittle and ductile plateau ($T_{K1/2}$),
- temperature corresponding to 50% of fracture cristallinity T_{K50}.

A Fracture Mechanics based design ensures that design stress intensity factor is lower than admissible fracture toughness and fracture toughness is greater than 100 MPam (i.e. the reglementary service temperature defined is above the reference temperature). This additional criterion introduces the concept of reference temperature RT and is expressed by:

$$T_s \geqslant RT_t + \Delta T \tag{2}$$

where ΔT is the uncertainty on reference temperature (8 °C for ASME API 579 code) [4]. This reference temperature RT_i varies according to codes (RT_{NDT}: Nil ductility transition reference tempeature or RT_{T0}: reference temperature for a conventional value of 100 MPam):

$$RT_{NDT} = T_{NDT}$$

$$RT_{T0} = T_0 + 19.4\,^{\circ}\mathrm{C} \tag{3}$$

Generally, in codes the choice of the reference temperature is under the responsibility of the designer). Due to the fact that different fracture tests give different transition temperatures, the choice of the most adequate test to provide a value close to the "structure or component" transition temperature T_{struct} is an open question. Thus, it is necessary to know the degree of conservatism of the designer approach.

It has been seen that transition temperature is sensitive to constraint [5]. Transition temperature decreases when effective T stress decreases. Therefore, the choice of the reference temperature can be made on the basis of a specimen providing a constraint value close to the structureone to minimise conservatism or to increase safety factor. One notes that choosing a specimen providing high constraint like Charpy V test is conservative.

In this paper, a selected pipeline steel API 5L X65 is controlled by 3 different instrumented Charpy impact using three types of specimens (Charpy V, Charpy U and a modified Charpy U). Then transition temperatures are expressed versus effective T stress computed by finite element method. A discussion on effect of loading rate and comparison with T_0 transition temperature is proposed. Microstructure consists of ferrite and perlite (see Fig. 1).

2. Material

The investigated material is a pipeline steel API 5L X65 grade supplied as seamless tube with wall thickness equal to 19 mm and external diameter of 355 mm. The typical chemical composition is given in Table 1, mechanical properties at room temperature are given in Table 2, and microstructure in Fig. 2.

Tensile tests at very low temperature exhibits brittle fracture and ductile failure at high temperature. At very low temperature, fracture always occurs at yield stress. This phenomenon was proven by compressive tests where no failure occurs, but yield stress is easily determined. When test temperature reaches transition temperature, failure occurs with plasticity at

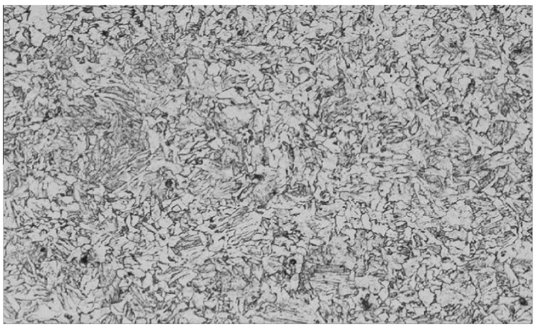

Fig. 1. Microstructure of pipeline steel API 5L X65 (x100, nital etching).