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Characterization of fracture behavior of a Ti alloyed supermartensitic 12%Cr stainless steel using Charpy instrumented impact tests

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ABSTRACT

In this work, the toughness of a Ti-alloyed supermartensitic stainless steel with 12%Cr was evaluated by instrumented Charpy impact tests at − 46 °C. The material was heat treated by quenching and tempering at 500 °C or 650 °C. The temper embrittlement phenomena was detected in the specimen tempered at 500 °C, while the specimens as quenched and quenched and tempered at 650 °C presented a ductile fracture with high impact energy values. The predominance of cleavage fracture instead of intergranular cracks suggests that the temper embrittlement was caused by fine and disperse precipitation observed in the specimen tempered at 500 °C. The dynamic initiation fracture toughness (J_{Id}) was calculated from the force *versus* deflection curves using three different methods suggested in the literature to obtain the initiation energy.

1. Introduction

Supermartensitic stainless steels are a new class of high strength materials with higher toughness and corrosion resistance than conventional martensitic steels. The main chemical composition differences from usual martensitic stainless steels are the reduction of carbon contents to less than 0.03%, and the additions of nickel and molybdenum. Besides, small additions of Ti or Nb to the some 11–13%Cr steels are believed to improve overall properties. Several grades of 11–13% Cr SMSS were developed, and the main application till now is in the oil and gas industry, as oil country tubular goods (OCTG) [1]. However, the better weldability and the promising combination of mechanical properties of these materials make them good candidates to other applications.

According to Manahan and Siewert [2] the history of instrumented Charpy tests started in 1897 with the pioneer work of Dunn [3]. The measurement of load and deflection during the impact test became more accurate with piezoelectricity and oscillography, as described in the researches of Yamada [4] and Watanabe [5]. The technique was further improved with the introduction of strain-gages between 1930 and 1960 [6–7].

The primary result of the instrumented Charpy test is the load *versus* deflection curve, were the regions of crack initiation (1) and propagation (2) can be distinguished (Fig. 1). The energy for crack initiation is primarily defined as the area under the curve till the maximum load, and the energy for propagation corresponds to the area of region (2), *i.e.* from the maximum load to the end of the text. The yield load (P_y) and maximum load (P_m) can also be obtained from the curve.

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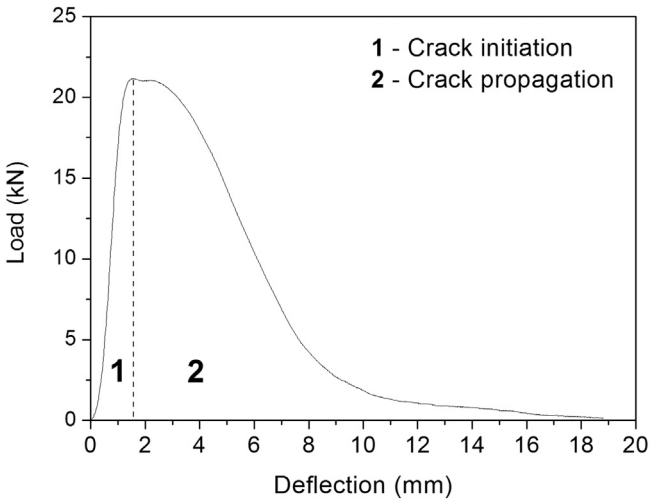

Fig. 1. Load *versus* deflection curve of specimen of SMSS quenched.

The interest on the instrumented Charpy further increased when some works were developed with the aim of obtaining fracture mechanics parameters of several materials [8–14]. Kobayashi et al. [9,10] and Angamuthu et al. [11] used the equation proposed by Rice [15] for the quasi-static fracture toughness (J_{Ic}) to determine, under dynamic load, the J_{Id} (dynamic initiation fracture toughness) value. After a further contribution of Tronskar et al. [12] and Jian et al. [13], the J_{Id} equation for a V-notched specimen could be written as follow:

$$J_{Id} = \frac{1.46 \cdot E_i}{[B \cdot (W - a)]} \quad (1)$$

where B is the thickness; W is the width and a is the notch depth; and E_i is the crack initiation energy.

As explained, the crack initiation energy (E_i) can be calculated from the area of the load x deflection curve till the maximum load (P_m). However, Kobayashi [11] proposed a correction to this value, due to the elastic deformation of the machine. After experimental measurements of the compliance (C) it was concluded that the initiation energy was approximately 80% (correction factor equal 0.8) of that calculated in the maximum load point, but Kobayashi [11] advised that this correction factor depends on the material. The method of E_i determination based on the compliance changing rate will be detailed in the next section (Experimental).

The instrumented Charpy test has never been used to supermartensitic steels. In this work, a Ti-alloyed 12%Cr SMSS (Table 1) was submitted to a study of low temperature (− 46 °C) toughness by means of instrumented Charpy tests. Three different heat treatments were performed, to produce specimens with different microstructures and mechanical properties.

2. Experimental

Table 1 shows the chemical composition of the SMSS used in this work. The chemical composition was verified by combustion method (C, S and N) and plasma spectroscopy (Cr, Ni, Mo, Mn, Si and Ti). The material was from a seamless tube with 200 mm of diameter and 10 mm of thickness. Charpy specimens were roughly machined and heat treated by quenching and tempering, according to the description of Table 2. After the heat treatment the specimens were machined to the final dimensions of subsize Charpy ($7.5 \times 10.0 \times 55.0\ mm^3$) with V notch.

Instrumented Charpy tests were performed in an Intron SI-1D3 machine with maximum capacity 400 J and precision ± 0.5 J. The tests were conducted at − 46 °C, and the pendulum velocity was 5.184 m/s. The main result of the instrumented Charpy test is the load *versus* deflection curve. From this curve the initiation and propagation energies were obtained, as well the J_{id} from Eq. (1). For the application of this equation, three methodologies were used to determine the crack initiation energy (E_i):

- Method 1: the value of E_i ($E_{i(1)}$) adopted was the energy calculated till the measured maximum load (P_m).
- Method 2: the value of E_i ($E_{i(2)}$) adopted was 80% of energy measured till the maximum load ($0.8 \cdot E_{i(1)}$), as adopted in [11].
- Method 3: the compliance changing rate method was used to determine the energy of crack initiation. The compliance (C) and the elastic compliance (C_{el}) are defined as follows:

Table 1
Chemical composition.

C	Cr	Ni	Mo	Mn	Ti	P	S	N
0.028	12.21	5.8	1.95	0.52	0.28	0.011	0.001	0.01