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Effect of Charpy Impact Test on Microstructure Properties of AISI4140 Steel

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In this paper, the mechanical properties and microstructures of AISI4140 low alloy steel under different tempering conditions are investigated. The samples are quenched, tempered to a martensite structure and loaded to fracture by means of Charpy machine according to standard test. Fractography analysis showed that the morphology fracture surface was changed by increasing tempering temperature. The variation of energy of Charpy impact fracture as a function of tempering temperature exhibits minimum values at 300 °C, which suggests the occurrence of temper embrittlement.

Keywords: AISI4140, mechanical property, tempering temperature, Charpy imapact energy, temper embrittlement.

1. Introduction

42CrM04 or AISI4140, which is low-alloy steel, has been widely used in automotive driving elements such as crankshafts, front vehicle axles, axle journals, and steering components [1-3]. AISI4140 is usually preferred when high strength is required. It is characterized by excellent hardenability, high strength, good ductility and high resistance to corrosion.

On the other hand, the main concern of some literatures is improving the mechanical performance of the material using surface treatment [4-6], combining heat and corrosion protection treatment [7, 8], fatigue investigation [9-11] and wear behaviour [12-14].

However, considerable research efforts have been directed to determine the relationship between the microstructure and the mechanical properties in low-alloy steel as the result of heat treatment.

In general, quenching and tempering are well-established means to produce strengthening in steel which can be achieved mainly due to the precipitation of a fine dispersion of alloy carbides during tempering [15, 17].

The aim of the present paper is to study the correlation between the microstructure and the mechanical behaviour of AISI4140 steel. Further, the behaviour of tempered embrittlement, as well as, its formation mechanisms are also described.

2. Experimental methods

The AISI4140 sample was obtained from mixture elementary powders of Iron (Fe), Carbon (C), Chromium (Cr), Molybdenum (Mo), Manganese (Mn), Nickel (Ni), Silicon (Si), Phosphorus (P), Sulfur (S) and Aluminium (Al), according to a molar ratio given in Table 1.

Table 1 4140 chemical composition. The elements content is expressed in a weight basis (wt %)

Element	Fe	C	Cr	Mo	Mn	Ni	Si	P	S	Al
wt.%	96.8	0.424	1.07	0.185	0.763	0.162	0.201	0.0153	0.0735	0.0257

The heat treatment cycles were designed so as to produce significantly different microstructures. The as-received steel is firstly austenitised at 850 °C for 30 min, followed by oil cooling and tempering at different temperatures that range from 200 to 600 °C for 1 h.

After heat treatment, specimens were machined for impact testing. The toughness was characterized by measurement of the absorbed fracture energy of samples at room temperature. The size and geometry of the specimens as well as the testing procedure were in accordance with specifications of AFNOR A03-156.

Fracture surfaces of Charpy specimens were analyzed by scanning electron microscopy (SEM) to determine the fracture mechanism.

3. Results and discussion

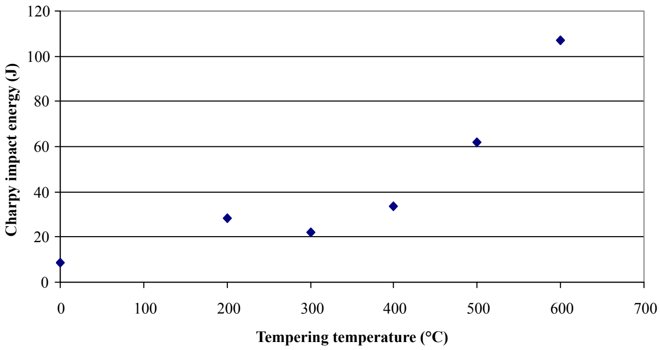

Figure 1 Variations of impact energy with tempering temperature

Figure 1 shows the effect of tempering temperature, on the impact energy variation, at room temperature. It was found that this last, decreases by 21% when the tempering temperature increases from 200 to 300°C as a consequence of the tempered martensite formation. This result is in accordance with several studies related to the same material [17-19]. In addition, the softening effect, due to tempering temperature rise, is well observed in various steels [20, 21].

However, the increase of impact energy, as a function of the increase of tempering temperature, beyond the temperature of 300 °C, is often related to the formation of carbide films [21-23].

In our case, the fracture properties improvement is primarily explained by the formation of fine carbides and secondarily by the formation of particles of hexagonal Molybdenum Carbide (Mo_2C), which takes place between 400 °C and 600 °C. The presence of manganese Sulfide clusters (MnS) is also important. These clusters should have a certain inclusion density to be potentially critical, which may explain the active role of sulphide manganese inclusions.

The fractography results of Charpy impact are shown in Figures 2 and 3. The size of the dimples increased with the increase of tempering temperature from 300 °C to 600 °C. The origin of these dimples can be from the carbides produced in the tempering of martensite during the tempering treatment [24].

These findings suggest a phenomenon linked to temper embrittlement, although the general appearance of cracks in specimens does not show a brittle fracture. Many authors [24-26], have reported a link between the phenomena of temper embrittlement and possible embrittling segregation of elements such as S, P, Sb, Sn at the grain boundary of austenite.

For the steel studied, tempering embrittlement occurs at a temperature of 300°C associated with a decrease of the impact fracture energy. This temperature corresponds to an area where carbon precipitates in the form of carbide type Fe_3C [27, 28]. Carbides exhibit obstruction to dislocation motion resulting in a structure with less resistance.

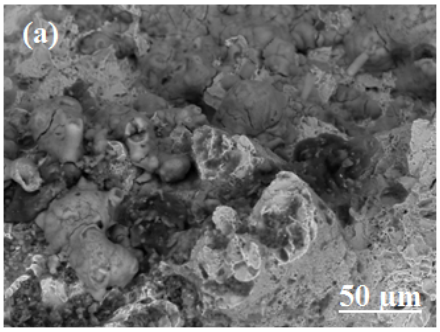

Figure 2 SEM fractography of Charpy specimens austenitized at 850°C for 30 min and then tempered at: a) 200°C

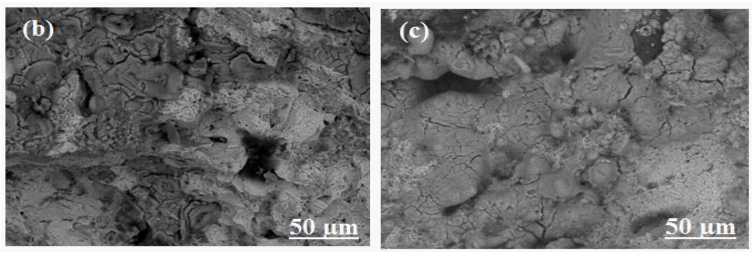

Figure 3 SEM fractography of Charpy specimens austenitized at 850°C for 30 min and then tempered at: (b) 400, (c) 600°C

Figure 4 Fracture appearance of a specimen quenched in oil (850°C/30 min) and tempered at 600°C for 1 h

The observation with the naked eye or through a magnifying glass reveals a fracture which is flat at the center of the section and inclined at the periphery, characteristic of ductile lips (Figure 4). Failure was in all cases (tempering treatment) typically ductile. This kind of fracture is generally associated with the existence of inclusions and large precipitates causing decohesion of material.

4. Conclusions

The fracture properties and microstructure evolution of AISI 4140 steel under different tempering conditions have been studied. The results obtained can be summarized as follows:

1. The impact energy is found to decrease by 21% when the tempering temperature increases from 200 to 300°C as a consequence of the tempered martensite formation.

1. The variation of impact fracture energy as a function of tempering temperature exhibits a minimum at 300°C, which suggests the occurrence of temper embrittlement (TE).

1. Fractography of the Charpy impact samples indicate a ductile fracture mechanism for all tempering temperatures. However, at 300°C, the studied material failed in the brittle manner due to the occurrence of tempered embrittlement.

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