Effect of heat treatment on toughness and strength properties of C-Mn steel
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Abstract

The strength and toughness of the heat-treated and tempered C-Mn are studied. Two type of heat-treatments have been carried out with the specimens in an argon gas. The variation in the fracture surfaces of the heat-treated and tempered specimens with impact test temperatures also is discussed.

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Introduction

C-Mn steel is the most common and economic material used in structural components such as bridges, building, ships, vehicles, boilers and pipelines. The steel has a medium resistance to sulphide stress corrosion, hydrogen induced cracking and stress corrosion cracking. It is not suitable to use under wet Cl and pitting. More recent steel making developments are introducing low carbon products manufactured using controlled rolling and cooling techniques. According to chemistry requirement, increasing of toughness can be achieved by lowering the carbon and sulphur levels with some additions of microalloying elements for grain refinement such as Nb and V, and sulphide shape control (Ca)\(^1,2\).

Charpy V-notch impact is used for comparing the influence of alloy studies and heat-treatment on toughness. It is used for quality control and material acceptance purpose. The notch toughness or tendency for brittle failure is determined by the transition temperature. The transition-temperature can help engineer to select a material which has a sufficient notch toughness when subjected to severe service conditions. The material with the lowest transition temperature is to be preferred because the lower this transition temperature, the greater the fracture toughness of the material. In mild steel, the change in transition temperature can be produced by changes in microstructure or the chemical composition such as C and Mn\(^3\). Grain size also has a strong effect on transition temperature.

The mechanical properties of a quenched and tempered steel may be altered by changing the tempering temperature. In the case of SAE 4340 steel, hardness and tensile properties are reduced with increasing of tempering temperature. The tensile properties of annealed and normalised steels are controlled
by the ferrite and the amount, shape and distribution of Cementite. The strength of ferrite depend on the amount of alloying element in solid solution and the ferrite grain size. The strength depends on the amount of cementite either as pearlite or as spherodite, in which the tensile strength of the spheroidized structure are difference compared with a pearlite structure.

The best combination of strength and ductility is obtained in steel which has been quenched to a fully martensite structure and then tempered. In this study, the works have been carried out to investigate the effect of heat-treatments on the toughness and strength properties of the carbon steel.

Material and Procedure

The chemical composition of the material used in this study is given in table 1.

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<th>Table 1</th>
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<td>element</td>
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<td>% weight</td>
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Two pieces of as-received steels has been homogenized at 1423K for 10h in argon gas environment. After being homogenized, two types of heat treatments were carried out with the specimens in an argon gas. They were type A; austenitized at 980°C for 2h and furnace cooling to room temperature, and heated to 760°C for 3h, water quenched. Type B, was austenitized at 980°C for 2h, furnace cooled to 760°C and maintain at 760°C for 3h, water quenched.

Both types of specimen were tempered at 200°C and 500°C for 1h. The Charpy V-notch impact test have been carried out on the specimens at several temperatures, ranging from -200°C to +150°C. These fracture surfaces were subsequently
examined by scanning electron microscope and the transition
temperature (ft-lb) was determined. The tensile tests were
carried out using a 10-T zwick Universal Testing machine.
The hardness was measured using a Vickers Microhardness Tester
with a load of 100g.

Results and discussion

(i) Microstructure and fractography

The optical micrographs of the as-received and heat-
treated specimens were shown in figure 1. The micro-
structure showing the presence of the ferrite-martens-
site mixed structures. The morphology features of the
structures observed by optical microscope were slightly
changed by the tempering.

Scanning micrographs of the fracture surface at different
temperature tests were shown in figures 2 and 3. In
figure 2A, the neat-treatment of type A shown dimpled
rupture at the temperatures of 50°C, 124°C and 191°C.
Some inclusions can be seen within dimples. The
inclusions have been identified as Mn S. The fracture
exhibits cleavage facets and dimples at the temperature
of - 15°C. The fracture mechanism was brittle cleavage
at temperature of - 116°C and - 167°C. In figure 2B,
the fractograph showed two mechanisms of fracture at
temperature of - 116°C.

In the heat-treatment of type B as shown in figure 3A,
two mechanism of fracture occurred at the temperature of -
129°C, meanwhile in figure 3B, the two mechanisms of
fracture occurred at the temperature of - 133°C.

(ii) Hardness and strength

Heat-treated samples A and B have a higher hardness;
93.0VHN and 83.2 VHN, respectively. After tempering at
500°C and 200°C, 1h; the hardness of the sample B was reduced to 67.6 VHN and 60.6 VHN respectively. Meanwhile, the hardness of the sample A was reduced to 61.5 and 62.8 VHN, respectively. The as-received sample has a hardness of 64.6 VHN.

Graph 1 has shown the effect of heat-treatments on the stress-strain curves. The tensile strengths of the heat-treated specimens A and B were 598.98 and 592.03 Nmm⁻² respectively. The tensile strength of A was reduced to 388.83 and 365.28 Nmm⁻² after tempering at temperatures of 200°C and 500°C for 1h, respectively. Meanwhile, the tensile strength of B was reduced to 372.56 and 363.17 Nmm⁻² after tempering at temperatures of 200°C and 500°C, for 1h, respectively. The strain was higher at tempering temperature of 500°C, 1h compared with tempering temperature of 200 1h for both samples of A and B. The strain values of sample A and B as a result of tempering at 500°C, 1h was 45.64% and 43.55%, respectively.

The strain values of sample A and B before tempering were 13.97 and 12.78%, respectively. The strength and ductility of A was better than that of B.

(iii) The transition temperature

The effect of heat-treatments on the energy-transition temperature was shown in graph 2. The tempered samples A and B at 200°C, 1h has a transition temperatures of -57°C and -121°C, respectively. The tempered samples A and B at 500°C, 1h had a transition temperature of -148 and -152°C, respectively. The transition temperature of B was slightly lower than that of A.

Conclusion

Heat-treatment and tempering of C-Mn steel can effect to the toughness and strength. After the heat treatments and
tempering the microstructure consists of a Ferrite matrix and cementite changed their size and distribution. Combination of good strength and toughness had be obtained in the C-Mn steel after heat-treatment A and tempering at temperature of 500°C, 1h.

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References

1. C.L. Jones : in 'Manufacturing, fabrication, and operation of pipelines', 2; 1982, Glasgow, Scottish Association of metals.


Fig. 1: (a) as-received Sample.
(b) Heat treatment A.
(c) HT A + tempering at 200°C, 1h.
(d) HT A + tempering at 500°C, 1h.
(e) HT B.
(f) HT B + tempering at 200°C, 1h.
(g) HT B + tempering at 500°C, 1h.
Fig. 2A: SEM fractographs of HT(A) and tempered 200°C, 1h specimens tested at temperatures of:
   (a) 191°C; (b) 124°C; (c) 50°C
   (d) -15°C; (e) -116°C and (f) -167°C
Fig. 2B: SEM fractographs of HT (a) plus tempered at 500°C, 1h specimens tested at temperatures of:
(a) 156°C (b) 52°C (c) -116°C
(d) -152°C and (e) -182°C
Fig. 3A: SEM fractographs of HT (b) plus tempered at 200°C, 1h.

Specimens tested at temperatures of:

(a) 124°C (b) 52°C (c) -114°C (d) -127°C

and (e) -170°C.
Fig. 3B: SEM fractographs of HT (H) plus tempered at 500°C, 1h, specimens tested at temperatures of:
(a) 51°C (b) 124°C (c) -109°C
(d) -166°C and (e) -192°C
Graph 1: Stress-strain curve of heat-treated and tempered C-Mn steel

- Solution-treated at 980°C, 2h, FC, to 760°C, maintained at 760°C, 3h, WQ (B)
- Solution-treated at 980°C, 2h, FC, to room temperature, Heated at 760°C, 3h, WQ (A)
- Temper at 200°C, 1h, WQ
- Temper at 200°C, 1h, WQ
- Temper at 500°C, 1h, WQ
- Temper at 500°C, 1h, WQ

Graph 2: Effect of heat treatment on the energy-transition-temperature curves for Mn-C steel