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Effect of tempering conditions on the mechanical properties of ductile cast iron with dual matrix structure (DMS)

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Abstract

In this work, the effects of tempering time and temperature on the mechanical properties of a new class of ductile cast iron is investigated. The results show that for a tempering temperature range of 450–500°C, there is a sudden rise in the impact strength and ductility. By increasing the tempering temperature, the ultimate tensile strength drops initially, and within the range of 400–500°C, remains almost constant and is then followed by a decrease. With increasing the tempering time, the ultimate tensile strength and yield stress decrease for tempering periods up to 120 min, the impact strength increases for periods up to 90 min and ductility increases for periods up to 120 min. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Tempering conditions; Ductile cast iron; Dual matrix structure (DMS)

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1. Introduction

Tempering is one of the most important heat treatment processes that is applied to quenched steel and cast iron. The objectives of this process include reducing the brittleness of materials, improvement of toughness and ductility, and also, reducing the probability of cracking. Review of the relevant literature shows that the effect of tempering conditions (i.e. time and temperature) on the mechanical properties of most steel and cast iron has already been studied [1,2]. However, there is no available report on the effect of tempering variables on mechanical properties of dual matrix structure (DMS) ductile cast iron. The only considerable report belongs to Okabayashi et al. [3] whose results indicate that impact strength of the samples, tempered at 600°C for 20 min, is better than those tempered at 200°C for 1 h. The lack of published information on this subject can be due to the fact that this material has only recently been introduced. DMS ductile cast iron is a new class of materials that in the early 80s was first introduced as Soft Eye and Hard Eye [3,4]. Matrix structure of this type of ductile cast iron consists of a soft phase (i.e. ferrite) and a hard phase (i.e. martensite or bainite) that are formed by a special heat treatment process. According to Kobayashi and Yamoto [5], the combined strength-elongation percentage of DMS ductile cast iron with ferrite–bainite matrix that is often referred to as Developed-ADI, is better than the conventional austempered ductile cast iron. The results of the work carried out by Wade et al. [4]

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Table 1
Chemical composition of the employed ductile cast iron (wt.%)

S	P	Si	Mo	Ni	Mn	C
0.012	0.017	1.94	0.29	1.33	0.28	3.56

indicated that the mechanical properties of DMS ductile cast iron with a ferrite–bainite matrix are improved, more than those of the same DMS cast iron with a ferrite–martensite matrix. One of the authors' recent work [6] shows that there is no apparent disparity between ferrite–bainite DMS ductile cast iron and ferrite–martensite that is treated by the process of partial austenitization.

We speculate here that the disagreement between the two results in Refs. [4,6] could be due to difference in the tempering conditions on ferrite–martensite. Hence, in order to determine to what extent tempering conditions are responsible for this discrepancy, the effect of tempering conditions on the mechanical properties of DMS ductile cast iron with Ni–Mo low alloyed is investigated. This paper presents the results of such investigation.

2. Experimental procedure

The raw material for the considered ductile cast iron was melted in an induction furnace. Magnesium was added, by the Sandwich method [7], with a magnesium ferro-silicon alloy, containing 5% Mg. The melt was first inoculated by the addition of ferro-silicon (75 wt.% Si) and then poured into a Y-block mould with dimensions of 25 × 75 × 175 mm, using the CO_2 method. The chemical composition of ductile cast iron is given in Table 1. The tension and notched Charpy impact test pieces were rough machined and prepared oversized relative to the Y-blocks. In order to obtain a complete ferrite structure, these samples were first heated at 950°C for 2 h, cooled down to 760°C and were held at this temperature for 5 h and then cooled down in the furnace. Finally, the samples were partially austenitized at 900°C for 480 s and then quenched in warm water. Apart from the two tension test pieces and three impact ones, the rest were tempered at 300°C, 400°C, 450°C, 500°C and 600°C for 1 h and also at 500°C for 30, 90, 120, 150 and 180 min. Finally, the

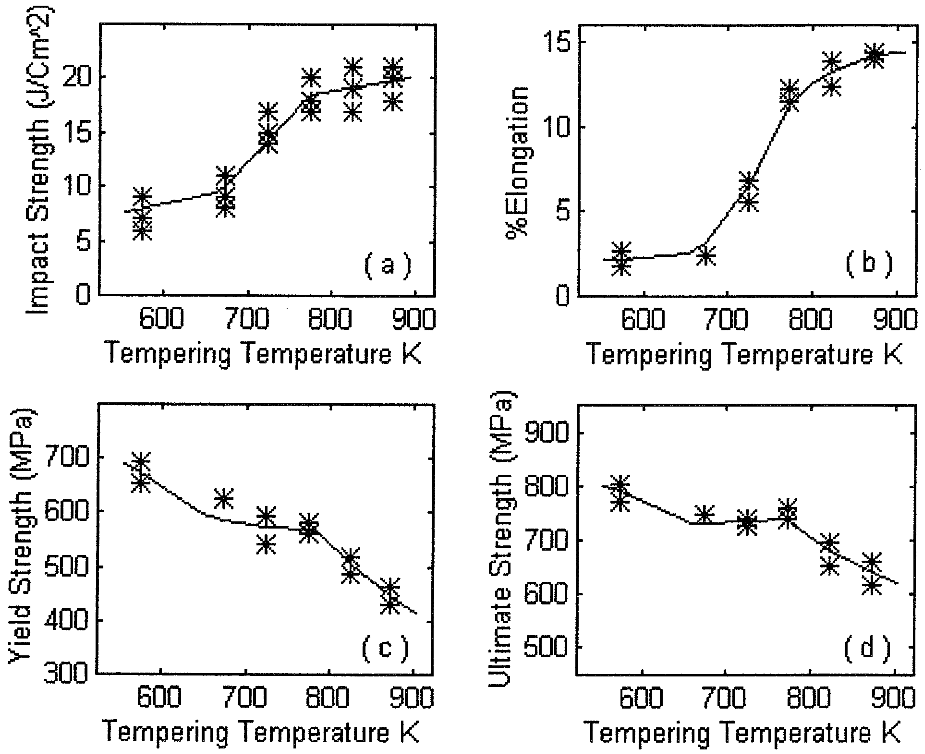

Fig. 1. Effect of tempering temperature on: (a) elongation %, (b) impact strength, (c) yield strength, and (d) tensile strength.

samples were machined down to the standard dimensions and then tension and impact experiments were carried out.

3. Results

The effects of tempering temperature on the yield stress, ultimate tensile strength, impact strength and elongation percentage are demonstrated in Fig. 1, and the effect of tempering time when the temperature is 500°C is shown in Fig. 2.

4. Discussion

As Fig. 1a and b demonstrate, by increasing the tempering temperature, there is a rise in impact strength and elongation percentage, prior to a sudden jump that occurs within the range of 400–500°C, followed by a slow and gradual increase. Therefore, if the aim is to achieve high toughness and ductility, the dual phase ductile cast iron with ferrite–martinsite matrix structure should be tempered at temperatures higher than 500°C.

Fig. 1c and d demonstrate that by increasing the tempering temperature, the yield strength and ultimate tensile strength initially decrease, then, within the range of 400–500°C, remain roughly constant and then drop. The presented plots of variation in strength and yield stress vs. tempering temperature for ductile cast iron [2,8] indicate that by increasing tempering temperature, yield strength and ultimate tensile strength decrease. However, similar behaviour to those of Fig. 1c and d for some steel alloys are reported [1,9]. This phenomenon (strength remaining constant or re-increasing with a rise in tempering temperature) is commonly known as secondary hardening, which is due to the precipitation of fine dispersed complex carbides and the martensite being formed from the retained austenite [9,10].

Experimental results related to the effect of tempering period (see Fig. 2a and b) show that there is a

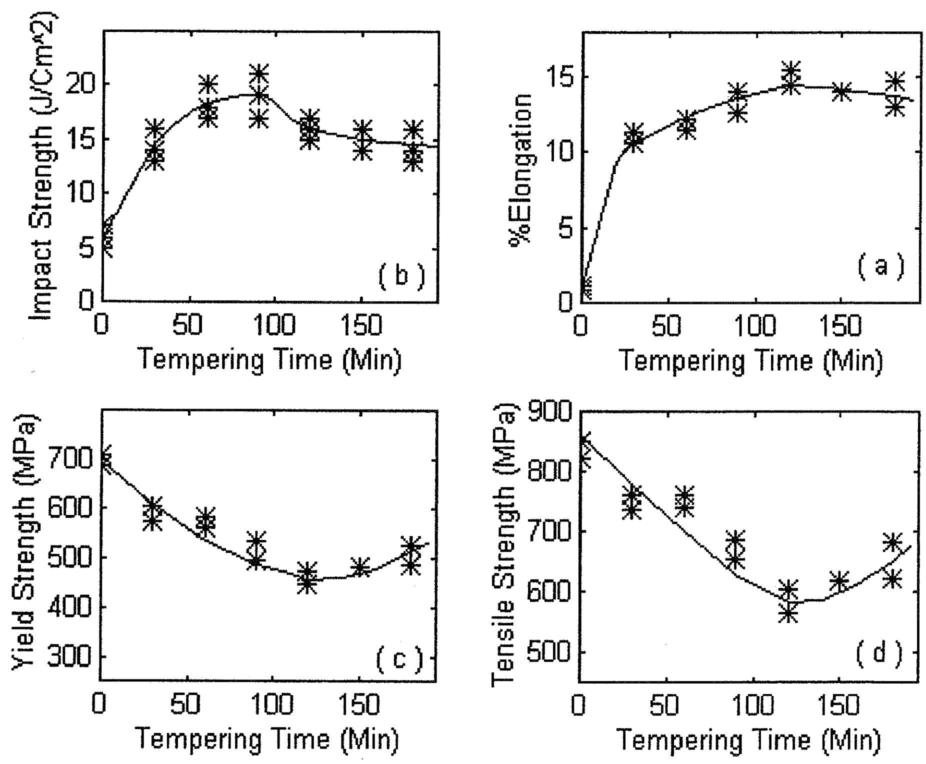

Fig. 2. Effect of tempering time on: (a) elongation %, (b) impact strength, (c) yield strength, and (d) tensile strength.

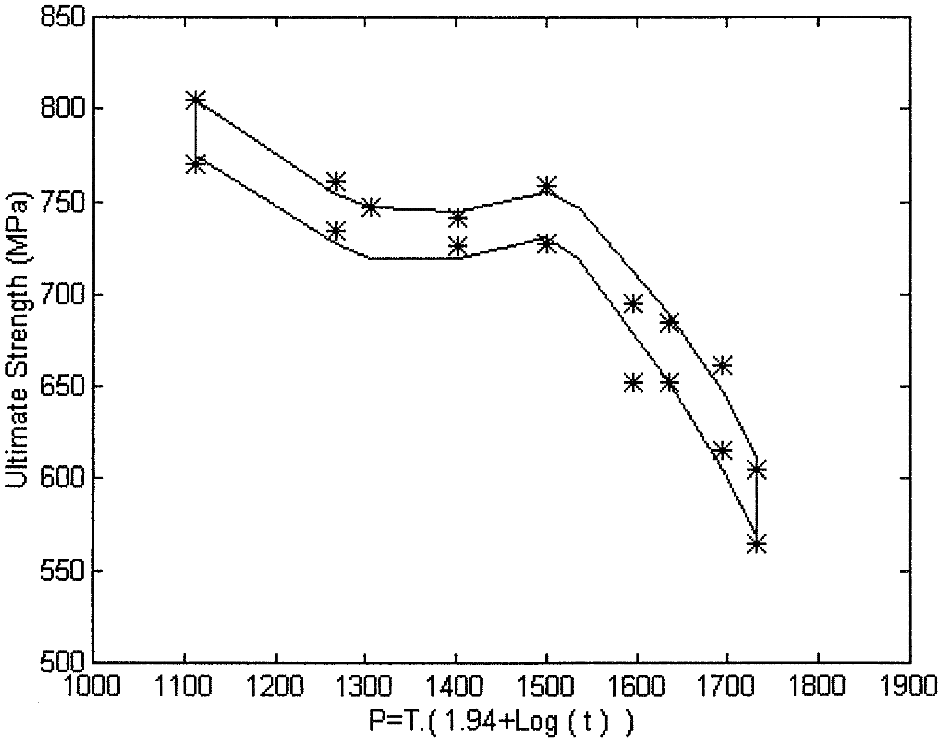

Fig. 3. The master curve for variation of tensile strength with tempering time and temperature.

rise in impact strength for tempering periods of up to 90 min before it decreases, while this time duration for elongation percentage is 120 min before its final drop. The reason for the reduction in impact strength is likely to be due to a phenomenon called temper embrittlement, where for steel, this occurs within the temperature range of 375–575°C [9]. As can be seen in Fig. 2c and d, ultimate strength and yield stress is decreased with the tempering period of 120 min, and then increase. Close examination of the hardness-tempering period curves that are plotted for various tempering periods [10,11] reveals similar behaviour in steel. For studying the simultaneous effect of temperature and tempering period, the method described by Hollomon and Jaffe [12] can be employed to plot the master-curve of hardness vs. the tempering parameter $P = T(K + \log(t)$, which can then be used to estimate the effect of every time and temperature. The obtained tempering parameter (P) for the results of this work is:

$$P = T[1.94 + \log(t)] \qquad (1)$$

where T is the tempering temperature in Kelvin and 't' is the tempering period in hours. In Fig. 2, the ultimate tensile strength variation with respect to tempering parameters is plotted. As can be seen, the only result that does not follow the general trend of the curve is that of tempering at 500°C for 180 min. Therefore, for tempering periods of up to 120 min, the ultimate tensile strength of the tempered dual phase ductile cast iron with ferrite–martensite matrix structure can satisfactorily be estimated from the plotted hardness tempering parameter master-curve in Fig. 3.

5. Conclusions

1. Within the temperature range of 400–500°C, there is a sudden increase in impact strength and elongation percentage, whereas within the same temperature range, the ultimate tensile strength and yield stress remain almost unchanged.

2. By increasing the tempering temperature, except for the temperature range of 400–500°C, both strength and yield stress decrease.
3. Increasing the tempering period at 500°C causes a rise in impact strength for tempering periods up to 90 min, and then it decreases again.
4. Longer duration of tempering period at 500°C increases the elongation percentage for tempering periods up to 120 min followed by a gradual decrease.
5. Increasing the tempering period for up to 120 min reduces strength and yield stress, and thereafter, they both go up again.
6. For any combination of temperature and tempering period and for tempering periods of up to 120 min, the amount of ultimate tensile strength can satisfactorily be obtained from the master-curve's strength-tempering parameter.

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