

## Investigation of Hardness and Impact Toughness of Zr-Microalloyed Cast Steel

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### Abstract

Microalloyed cast steels are a group of microalloyed steels in which reliable mechanical properties could be achieved by heat treatment. In this work, the heat treatment processes were carried out on the cast specimens as the step samples by different thicknesses and Zr content.

The results show that after homogenization, variations in thickness have no effect on the hardness. Also, after heat treatment, Zr has more effects on properties. The optimum austenitization time was determined 2 hours in 950°C. Aging has no effect on hardness on Zr- microalloyed cast steels.

*Keywords:* Zr-microalloyed cast steel, Heat treatment, Hardness, Impact toughness

### Introduction

Nowadays after successful production of wrought microalloyed steels, a lot of research is being carried out to produce microalloyed cast steel. The reliable formability and strength has the most motive on the development of these steels. Microalloyed steels have reliable strength without adding high alloying elements<sup>1)</sup>. In these steels, the entire sequence of alloy design, melting, casting, processing and fabrication will be considered in developing and applying them. All of these considerations have a bearing on the cost, serviceability, use, reliability and even applicability of these steels<sup>2)</sup>.

The purpose of heat treatment is to adjust accurately the mechanical properties of the alloy. For low alloy cast steels, these heat treatments are generally performed in three stages: homogenization, austenitization followed by quenching or air-cooling, and final tempering. Initial homogenization is generally performed, particularly for heavy section castings, at temperatures ranging from 950-1100°C for times as long as seven hours. The primary effect of homogenization appears to improve the final toughness.

Homogenization does not appear to improve the properties of thin section castings, where segregation is not as severe. Austenitization of microalloyed steels is accompanied by a partial or complete re-solution of the microalloying carbonitride, depending on the austenitizing temperature chosen. During tempering, a microalloyed cast steel undergoes the standard tempering (softening) reaction of conventional steels, but also undergoes a simultaneous aging (precipitation strengthening) reaction<sup>3,4)</sup>.

The beneficial influence of Zirconium was observed on sulphide shape control in carbon steels. In the middle to late 1970s, Zr addition was considered a means of improving fracture toughness<sup>5-8)</sup>. Thermochemical data indicate that Zr, similar to Ti, is a strong nitride as well as a strong oxide forming element<sup>9)</sup>. ZrN possesses solid-state properties similar to those of TiN, such as a high melting point and a high hardness as well as the same rock salt crystal structure. Therefore, ZrN is expected to behave similarly to TiN in Nb-bearing steels<sup>10)</sup>. However, few studies have been undertaken to confirm this. In the present work, the effect of Zr addition as a microalloying element on low carbon steel melt, and the effect of heat treatment process on hardness and impact toughness were investigated.

### Experimental Procedure

To reach the steel, the plain steel scraps, low carbon Ferro Manganese and Ferro Silisium Zirconium were used. Induction furnace by frequency 3000 HZ and maximum power 75 kW was

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used for melting. The casting of specimens with different thicknesses (1-4 cm) were done in the ductile iron mould. Different thicknesses were used to investigate the effect of thickness and cycle of heat treatments on the mechanical properties.

Heat treatments were carried out in a muffle furnace by maximum power 4.5 kW. The cycles of heat treatments were designed as followed:

- Homogenization at 1000°C<sup>3, 4)</sup> for 6 and 7 hours following air-cooling.
- Austenitization at 950°C<sup>3, 4)</sup> for 1.5-2.5 hours.
- Tempering at 350-620°C for 4 hours and air-cooling for water-quenched specimens.
- Aging at 200-650°C for 30 mins and air-cooling for air-cooled specimens.

The results were achieved by using mechanical testing consisting of hardness and charpy impact tests. The hardness tests were carried out based on DIN 50133 by Vickers and 60 Kg forces. For charpy impact tests also DIN 50115 was used.

**Results and Discussion**

Table 1 shows the chemical compositions of steels A and B. These steels are in group of low carbon microalloyed cast steels.

Figure 1 shows the hardness of different thicknesses in As-cast microalloyed steels (A and B). It is clear that the hardness is very variable. It shows the segregations and heterogeneous structure. Therefore, the homogenization treatment will be necessary.

Table 1. Chemical compositions of Zr-microalloyed cast teel (wt. %).

Steel No. \ Elements	C	Mn	Si	S	P	Al	Zr	Fe
<b>A</b>	0.09	1.60	0.3	0.03	0.05	0.08	0.03	Rem.
<b>B</b>	0.1	2.3	0.1	0.03	0.04	0.1	0.06	Rem.

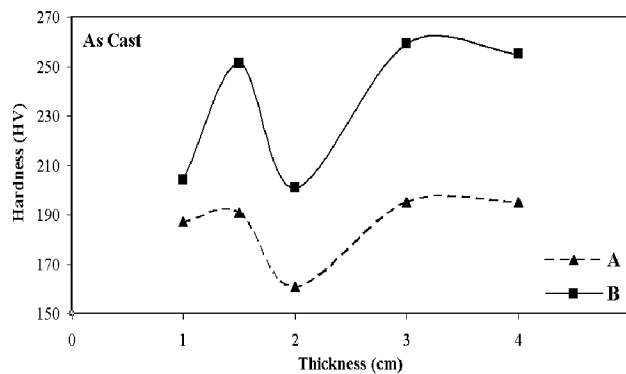


Fig. 1. The variation of hardness in different thicknesses of as-cast Zr-microalloyed steels.

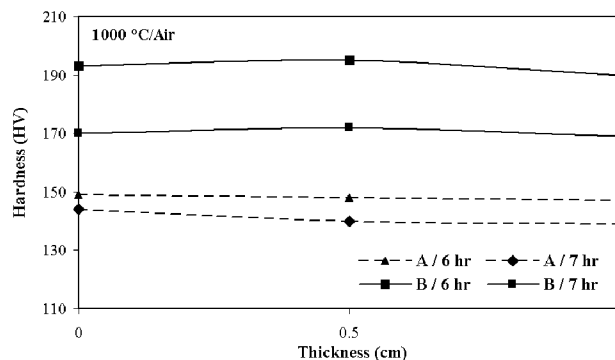


Fig. 2. The variation of hardness in different times and thicknesses of homogenized Zr-microalloyed steels.

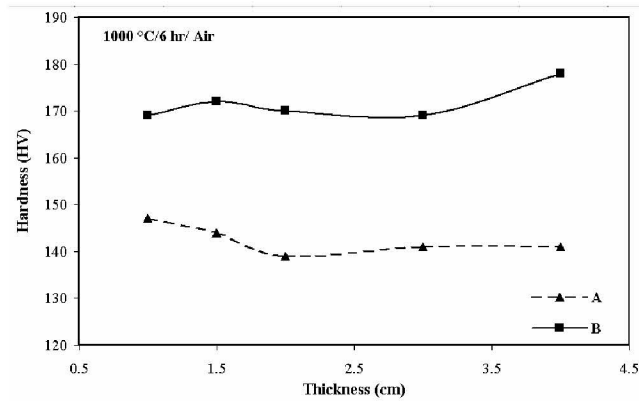


Fig. 3. The variation of hardness in different thicknesses of homogenized Zr-microalloyed steels.

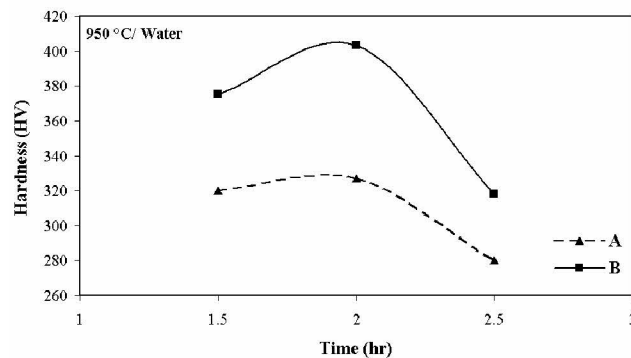


Fig. 4. The variation of hardness in different times of quenched Zr-microalloyed steels.

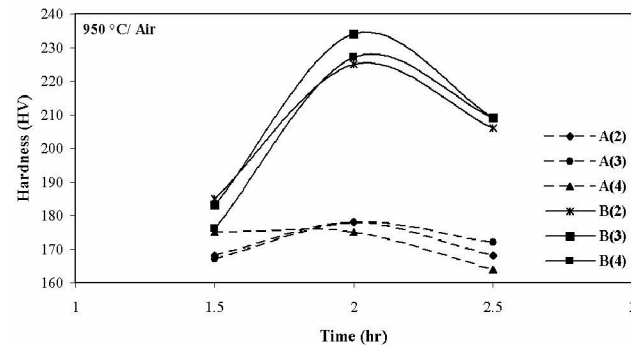


Fig. 5. The variation of hardness in different times of normalized Zr-microalloyed steels.

The homogenization treatment was carried out on steels to determine the suitable homogenizing treatment. Corresponding hardness of the homogenization treatment in various times (6 and 7 hours) results are shown in figure 2.

In both times, the hardness variations have disappeared and they are suitable times to remove structure segregation. Therefore, the reliable homogenization treatment was chosen at 1000 °C for 6 hours. The effect of determined homogenization treatment on hardness in different thicknesses is given in figure 3. The comparison between Figures 1

and 3 shows that the non-homogeneities of hardness disappear after homogenization. In addition, the variations in hardness are fewer in different thicknesses. This is one of the characteristics of microalloyed steels<sup>1)</sup>.

Figures 4 and 5 show the effect of austenitization time for quenched and normalized steels. The optimum time of the austenitization was chosen for 2 hours, because of this time, maximum hardness has been achieved. Similar to homogenization, Figure 6 shows that variations in hardness in different thicknesses are negligible.

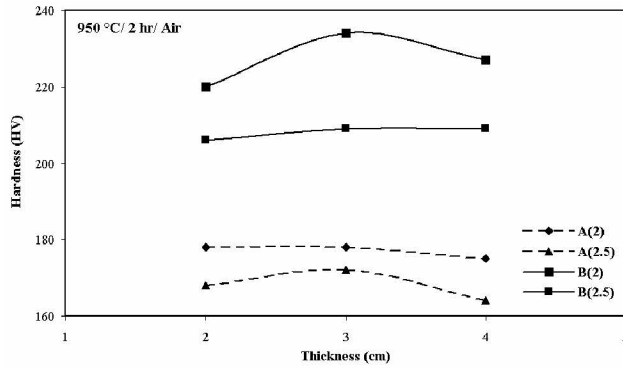


Fig. 6. The variation of hardness in different thicknesses of normalized Zr-microalloyed steels.

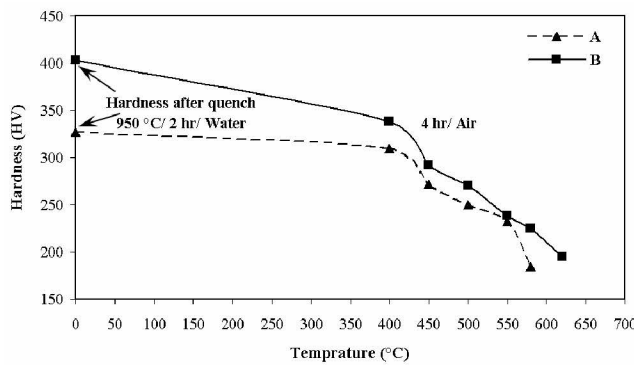


Fig. 7. The variation of hardness in different temperatures of tempered Zr-microalloyed steels.

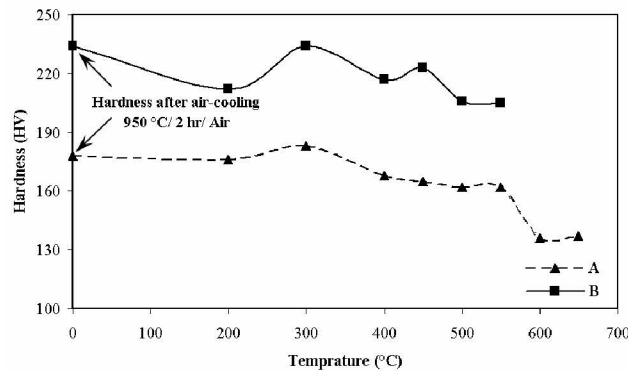


Fig. 8. The variation of hardness in different temperatures of aged Zr-microalloyed steels ( $t = 30$  mins).

The conditions of tempering of Vanadium and Niobium microalloyed cast steels have been reported at the range of 580-620°C for 4 hours<sup>3,4)</sup>, but this temperature reduced the hardness of Zr-microalloyed steels strongly. Therefore, this treatment was repeated at lower temperatures.

Figure 7 shows that in 4 hours the suitable temperature of tempering can be selected at 450 °C. This reduction of temperature is related to the characteristics of Zr precipitate formation that is formed in lower temperatures compared to V and Nb precipitates<sup>9)</sup>.

Figure 8 shows the result of aging treatment on hardness of normalized Zr-microalloyed cast steels. The temperature in the range of 300-350 °C was chosen for aging of these steels, but the variations are not remarkable. Therefore, aging cannot be a suitable process to improve the hardness of these steels. It can be related to the thermochemical characteristics of Zr precipitate formations.

The variations of hardness of A and B alloys in each process of heat treatment have been shown in Table 2. It is clear that Zr addition causes the

Table 2. The Vickers hardness of steels in various heat treatment stages.

Steel No.	1000°C/6 h/Air	950°C/2h/Water	450°C/4 h/Air
<b>A</b>	140	327	268
<b>B</b>	167	403	293

Table 3. The impact toughness of steels in various heat treatment stages (J).

Steel No.	1000°C/6 h/Air	950°C/2h/Water	450°C/4 h/Air
<b>A</b>	44.6	16.8	25
<b>B</b>	42.2	20.2	26.8

hardness to improve. It results from formation of Zr precipitation contents<sup>11)</sup>.

The impact toughness of A and B alloys is given in Table 3. Zr has no effect on the decrease in impact toughness of these steels. This result can be derived from fine and distributed Zr precipitates that do not have a considerable effect on the reduction of impact toughness<sup>11)</sup>. Finally, Adding Zirconium to steel improves the hardness without decreasing the impact toughness considerably.

### Conclusions

- 1- The homogenization treatment is necessary in these microalloyed steels to remove the non-homogeneities of microstructure. Therefore, the time of homogenization was determined for 6 hours at 1000°C.
- 2- The time of austenitization was determined for 2 hours at 950°C.
- 3- The suitable temperature of tempering treatment of Zr-microalloyed steels was chosen at 450 °C for 4 hours.
- 4- The aging treatment has no effect on the hardness of Zr-microalloyed steels.
- 5- Zr addition improves the hardness and impact toughness of the microalloyed cast steels.
- 6- Zr addition, from 0.03 to 0.06 percent, increases the hardness of the microalloyed tempered steels from 269 to 293 without any decrease in impact toughness.

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