1. Introduction

The motivation of microalloyed steels production have been reached high toughness, low impact transition temperature, high strength, similar hardness in various thicknesses and cost reduction.\textsuperscript{1,2} Properties in microalloyed cast steels depend on precipitation of carbonitride that forms with ferrous phase transformations during heat treatment.\textsuperscript{3}

Manganese is the main alloy element of microalloyed steels. It is cheap to buy and reduce the cost production, too.\textsuperscript{4} In these steels, Mn has the effective role on the activity of microalloying elements. In V-microalloyed steel, Mn increases the activity of V and decreases the activity of carbon concurrently. It will be caused by vanadium nitride, are more usable than vanadium carbide, form.\textsuperscript{5} Also Mn is important to provide a sufficient level of solid solution strengthening. In the microalloyed cast steels, further increase in Mn, in particular, is important to maximize the contribution of solid solution strengthening. Mn content is usually limited up to 2\% to avoid segregation problem.\textsuperscript{3,6}

Nitrogen is an important element in the microalloyed steels. Sufficient excess nitrogen is provided to react with microalloying elements, to form nitride. Taking these effects of nitrogen, the optimum content has been established at about 0.004\%. Nitrogen content should not exceed about 0.015\%, because it can cause the extensive precipitation of coarse nitride particles in the liquid prior to cast.\textsuperscript{6}

The microalloying elements are added to steels for only two purposes: to produce grain refinement and/or precipitation strengthening.\textsuperscript{21} Zirconium has been used as a microalloying element rarely and the beneficial influence of zirconium was observed on sulphide shape control in carbon killed steels.\textsuperscript{7,8} Thermochemical data indicate that Zr, similar to Ti, is a strong nitride as well as a strong oxide forming element.\textsuperscript{9} ZrN possesses solid state properties similar to those of TiN, such as 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.\textsuperscript{7,10} Work in Australia reported that Zr additions have also been found to result in grain refinement in the microalloyed cast steels, but few studies have been undertaken to assess the effectiveness of this element.\textsuperscript{8,21}

2. Procedure

To prepare the microalloyed cast steels, the plain steel scraps, low carbon ferro manganese and ferro silisium zirconium were used. Induction furnace was used for melting and casting was done in ductile iron mould. Heat treatments were carried out as follows,\textsuperscript{11}

- Homogenization at 1 000\°C for 6 h and air-cooling.
- Austenitization at 950\°C for 2 h and quenching.
- Tempering at 450\°C for 4 h and air-cooling.

Results were obtained by mechanical testing (hardness, charpy impact and tensile tests) and microstructure investigations (XRD, SEM).

3. Results and Discussion

3.1. Chemical Composition

The chemical compositions of Zr-microalloyed cast steels are given in Table 1. These steels are low carbon (0.06–0.07\% C) steels group and Mn is in suitable range for microalloyed cast steels.\textsuperscript{3} Also nitrogen contents of steels B and D are desirable to reach the aims in microalloyed steels.\textsuperscript{5}
3.2. Mechanical Properties

3.2.1. Hardness

Figure 1 shows the hardness of microalloyed steels with various heat treatments. It is obvious that the quenched and tempered treatment improves the hardness. As cast and homogenized Zr-microalloyed steels have similar hardness as that without Zr, while the quenched and tempered Zr steels have much higher hardness than those without Zr. The steel with 0.005% Zr has the largest hardness in each heat treatment process.

3.2.2. Impact Toughness

Results of charpy impact test on microalloyed tempered steels are given in Fig. 2. It is clear to improve the impact toughness by Zr addition. Figures 3 and 4 show the fractography of A and B tempered steels. In steel A the fracture is semi brittle but in steel B is fully ductile. It shows the improvement of toughness of steel by Zr addition. Increasing in Zr will cause much precipitation in base alloy. It will increase the solution period and the precipitations will not resolute in austenite completely. On the other hand, the volume of Zr-based precipitates during tempering can be effective. In the higher Zr steels, there are more Zr-based precipitates. It can be caused larger precipitates during tempering and decrease the impact toughness of steels.

In impact toughness, the steel C (0.01% Zr) has the best impact toughness. The instantaneous increasing of impact toughness of steel C may relate to lower Al content than other steels and to decreasing of Al nitride. Finally, the Zr between 0.005–0.01 percent has the best effect on hardness and impact toughness of steels.

3.2.3. Tensile Strength

Figures 5 and 6 show result of tensile test on steel C. The heat treatment has improved the tensile properties of steel. These confirm the hardness and impact toughness results else. Increasing in yield strength to 70% after tempering is noticeable, while this is negligible between homoge-

Table 1. Chemical composition of microalloyed cast steels.

<table>
<thead>
<tr>
<th>Steel No.</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>S</th>
<th>P</th>
<th>Al</th>
<th>Zr</th>
<th>N</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.06</td>
<td>1.60</td>
<td>0.14</td>
<td>0.07</td>
<td>0.03</td>
<td>0.05</td>
<td>-</td>
<td>-</td>
<td>Rem</td>
</tr>
<tr>
<td>B</td>
<td>0.06</td>
<td>1.80</td>
<td>0.14</td>
<td>0.08</td>
<td>0.03</td>
<td>0.05</td>
<td>0.005</td>
<td>0.0045</td>
<td>Rem</td>
</tr>
<tr>
<td>C</td>
<td>0.06</td>
<td>1.85</td>
<td>0.09</td>
<td>0.1</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>-</td>
<td>Rem</td>
</tr>
<tr>
<td>D</td>
<td>0.07</td>
<td>1.85</td>
<td>0.08</td>
<td>0.07</td>
<td>0.03</td>
<td>0.04</td>
<td>0.02</td>
<td>0.0048</td>
<td>Rem</td>
</tr>
<tr>
<td>E</td>
<td>0.07</td>
<td>1.90</td>
<td>0.08</td>
<td>0.09</td>
<td>0.01</td>
<td>0.03</td>
<td>0.1</td>
<td>-</td>
<td>Rem</td>
</tr>
</tbody>
</table>

Table 2. The hardness and impact toughness of Zr-microalloyed steels.

<table>
<thead>
<tr>
<th>Steel No.</th>
<th>Quenched Hardness (HV)</th>
<th>Tempered Hardness (HV)</th>
<th>Room Temperature Impact Toughness (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>382</td>
<td>300</td>
<td>79</td>
</tr>
<tr>
<td>C</td>
<td>330</td>
<td>261</td>
<td>117</td>
</tr>
<tr>
<td>D</td>
<td>328</td>
<td>273</td>
<td>70</td>
</tr>
<tr>
<td>E</td>
<td>329</td>
<td>263</td>
<td>66</td>
</tr>
</tbody>
</table>

Fig. 1. Effect of the heat treatments on the hardness of the Zr-microalloyed steels.

Fig. 2. The impact toughness of Zr-microalloyed tempered steels.
nized and quenched conditions. In addition, increases in tensile strength of 40%, elongation to 22% and area reduction of 19% are clearly shown after tempering. The improvements of tensile and formability properties could be achieved by formation and suitable distribution of precipitates inducing desirable precipitation hardening of steel by tempering.

3.3. Microstructure Investigations

3.3.1. XRD

XRD was carried out on steel C with various heat treatments. The precipitates are listed in Table 3. These results are conformed by the thermochemical characteristics of Zr carbide and nitride. It means that Zr carbide forms at high temperatures but Zr nitride does at low ones.

Because of non homogeneities of microstructure and high cooling rate, there are complex compositions of Zr carbonitride in as cast microalloyed steel. But only Zr nitride is homogeneously formed because of enough time being available to re-solute whole Zr carbide and transform to Zr nitride with the interface of (110)Fe|| (111)ZrN. On the other hand, high cooling rate in quenched steels, no precipitations have been detected.

3.3.2. SEM

SEM image of the tempered steel A and EDS analysis of a random point A are shown at Figs. 7 and 8. Only the peaks of main elements (Fe and Mn) have been detected. On the other hand, SEM image of tempered steel B and EDS analyses of A, B and C points are given in Figs. 9–12.
confirm the Zr precipitates. The points of A and B show the precipitates, while point C is matrix. These SEM observations and XRD results demonstrate the formation of Zr nitride after tempering.

Finally, precipitation of Zr nitride and beneficial heat treatment improve the mechanical properties of microalloyed cast steels.

4. Conclusion

(1) Zr-microalloyed tempered steels have the much higher hardness than without Zr steels. But these variations were not observed at as cast and homogenized conditions.

(2) Zr between 0.005–0.01 percent has the effect on increasing hardness and impact toughness of microalloyed cast steels.

(3) Tempering improved the tensile strength 70%, yield strength 40%, elongation 22% and area reduction 19% of Zr microalloyed cast steels.

(4) The Zr precipitates were contained in Zr microalloyed tempered steels.

Acknowledgment

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