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Abnormal relationship between Ms temperature and prior austenite grain size in Al-alloyed steels

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ABSTRACT

It has been generally accepted in the literature that the decrease in prior austenite grain size leads to a decrease in Ms temperature in steels. However, in the present study, it is found that Ms temperature increases with the decrease of prior austenite grain size in steels with an addition of Al content higher than 1 wt%. It is revealed that the Al segregation at prior austenite grain boundaries may be the origin of this abnormal phenomenon.

The effect of prior austenite grain size (PAGS) on Ms temperature has been extensively studied in various steels with different chemical compositions [1–9]. The same conclusion has been reached from these studies that the decrease in prior austenite grain size leads to a decrease in Ms temperature. In addition, it was shown from the studies on Fe-Ni and Fe-Ni-C alloys that the effect of austenitization temperature on Ms temperature is only associated with the change of prior austenite grain size since martensitic transformation is independent of austenitization temperature with a constant austenite grain size [2,10].

The mechanism by which Ms temperature decreases with PAGS remains unclear and several hypotheses have been proposed. Some studies suggested that the Hall-Petch strengthening of the refined austenite grains can explain the shifting of Ms to lower temperature as the PAGS decreases [11–12]. By contrast, Cohen and Olson related this effect to a reduced probability of martensite nucleation as it decreases exponentially with grain refinement [13]. Based on the literature data, the Fisher model for the geometrical partitioning of austenite grains by plates of martensite [14] were further developed by Yang and Bhadeshia [4] to provide quantitative estimation of the dependence of the observed Ms on the PAGS.

The effects of different alloying elements such as C, Mn, Ni, Si, Cr and Mo on Ms have been well studied in the literature whereas the effect of Al on Ms has received much less attention. The objective of the present study is to investigate the evolution of Ms as a function of austenitization temperature and PAGS in steels with different Al additions.

Four steels with varied Al contents ranging from 0.021 to 1.54 wt% are selected for the present study. Their chemical compositions are listed in Table 1. The ingots were firstly hot rolled to 20 mm in thickness, then cut into blocks which were further homogenized at 1250 °C for 24 h to minimize micro-segregation of the alloying elements. Each block was wrapped in stainless steel foil and encased in a C-steel box during the homogenization to prevent excessive oxidation and decarburization. The blocks were finally hot rolled to 8 mm and machined into cylindrical dilatometric samples with a diameter of 4 mm and a length of 10 mm.

Dilatometry tests were performed using a Bähr 805 A/D dilatometer. Dilatometric samples were austenitized at different temperatures above Ac3 up to 1150 °C for 5 min followed by a rapid cooling at a rate of 70 °C/s to room temperature. By means of metallographic examinations, the cooling rate of 70 °C/s was confirmed to be high enough to avoid any ferrite and bainite transformations for all steels. The evolution of martensite fraction as a function of cooling temperature were determined from the dilatometric curves using the lever rule and assuming that the transformed volume fraction is directly proportional to the change in length. As it is always difficult to define the exact point for the very beginning of martensite transformation, the experimental values of $Ms_{,5\%}$ were determined from the martensite transformation kinetics curves, which corresponds to the temperature at which 5% martensite is formed. Prior austenite grain boundaries were revealed by means of Béchet-Beaujard etching, and then austenite grain size was measured from optical micrographs using Aphelion image analysis software. Fig.

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Table 1
Chemical compositions of the steels (in wt%).

Steel	C	Mn	Si	Al	P	S	N
0Al	0.25	2.07	0.098	0.021	0.023	<0.002	0.0033
0.5Al	0.247	2.07	0.083	0.53	0.025	0.0022	0.0038
1Al	0.256	2.07	0.085	1.01	0.026	0.002	0.0041
1.5Al	0.249	2.07	0.084	1.54	0.028	0.0021	0.0032

1a–b shows two examples of these micrographs and Fig. 1c gives the PAGS versus austenitization temperature for the four alloys. At a given austenitization temperature, only a very small variation in PAGS can be detected for the different steels. PAGS increases from around 30 to 170 μm when the austenitization temperature rises from 950 °C to 1150 °C.

By combining Fig. 1c and Fig. 2, one can find the evolution of $Ms_{,5\%}$ with austenitization temperature and PAGS for the different steels. They reveal that Ms temperature increases with the austenitization temperature and PAGS for the 0Al and 0.5Al steels, which is consistent with the literature data. With 1 wt% Al addition, there exists a small tendency for the Ms to decrease with the increase in austenitization temperature and PAGS. When the Al addition is increased up to 1.5 wt%, the Ms decreases significantly with the increase in austenitization temperature and PAGS, which is the opposite of what has been observed classically. As a result of the different evolution of Ms with austenitization temperature in steels with various Al additions, it appears that the effect of Al on Ms is dependent on the austenitization temperature. In addition, the relationship between Al content and Ms is non-linear and is more complicated than a simple description of +30 °C per 1% Al addition in the literature [15–16].

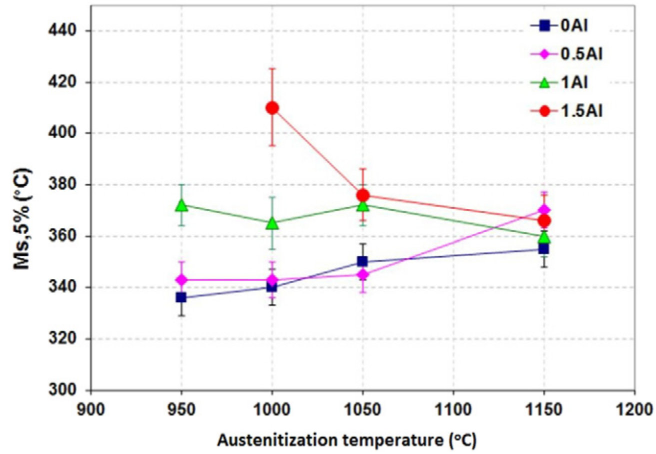

Fig. 2. $M_{s,5\%}$ temperature as a function of austenitization temperature for the different steels.

It is known that the change of austenitization temperature induces not only the variation in austenite grain size, but also the modification

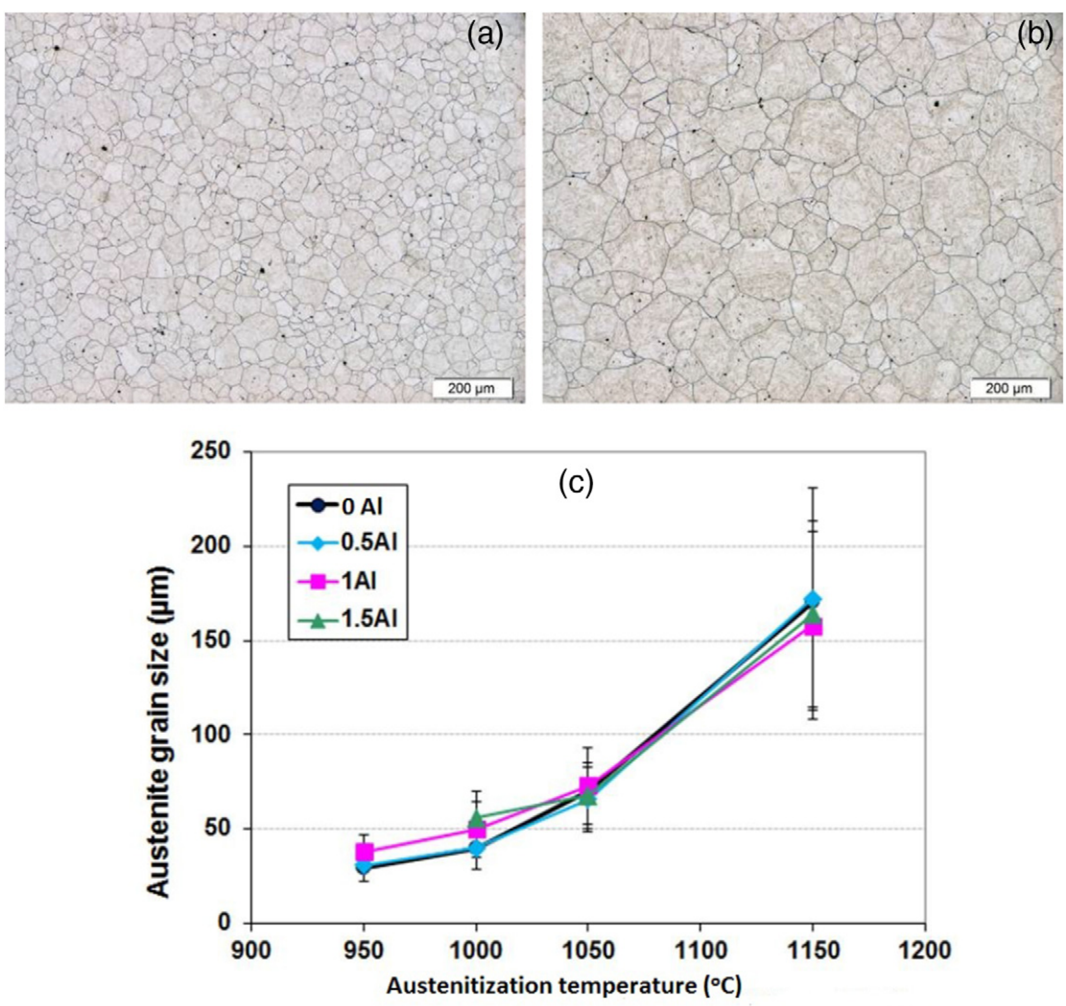

Fig. 1. Optical micrographs with Bechet-Beaujard etching for 1Al steel after an austenitization at (a) 950 °C, PAGS = 38 ± 10 μm and (b) 1050 °C, PAGS = 73 ± 21 μm. (c) Evolution of PAGS as a function of austenitizing temperature for the four steels.