EFFECT OF MICRO-ALLOYING ON QUENCHING BEHAVIOUR OF STEELS FOR BACK-UP ROLLS

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Abstract

The use of micro-alloyed steels for back-up rolls manufacturing gives the possibility to obtain advantages associated with the benefit of the application of micro-alloying elements and thermo-mechanical treatments. In this paper the effect of alloying elements has been evaluated aimed to improve steel hardenability and at the same time to reduce the fabrication cost. 3% Cr and 5% Cr steels are considered with a reduced Mo content. Analysis of alloying on hardenability is performed by means of metallurgical models and on laboratory scale. Results show a higher hardenability in the case of 5% Cr steels. Moreover, such family of steels also show a dependence on prior austenitic grain size. In both the steel families no warnings are detected in terms of residual austenite presence after quenching.

Keywords: Micro-alloyed steels; mechanical properties; quenching; tempering

1 Introduction

Today, there are essentially three methods for manufacturing high strength steels, i.e., steels with yield strength in excess of about 415 MPa and UTS levels above about 515 MPa [1].
These methods are;

- Innovative heat treatments on low alloyed steels [2-5]
- Micro-alloying medium carbon steels [6-8]
- Adopting micro-alloyed multi-phase steels [9-11]

This paper will focus on the second group because micro-alloyed forging steels can be processed by conventional forging practices with a minimum of process adjustments and offer the forge shop opportunities to produce steel with specific properties, which may be optimized for a specific application. Increased yield strength can be achieved by precipitation mechanisms or by improving hardenability. Concerning the hardenability increase, Cr is usually added. Boron is sometimes added to steels in small concentrations to increase hardenability [12], especially in the case of high thickness components.

Back-up rolls are usually manufactured by 0.40% carbon steels with 3% or 5% Cr content and about 1.00 % Mo. The effect of steel chemical composition on steel hardenability, aimed to reduce the Mo content (hence to reduce cost) is reported in this paper. In particular, the effect of Mn is reported as effective in hardenability [13].

In order to recover the original hardness for steels devoted to this application, precipitation strengthening has also been exploited. In this case, the use of V is normally preferred over Nb

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because of the high solubility of V in austenite which permits the dissolution of VC particles at lower temperatures [14] further favouring grain size refinement [15]. Even higher strengths can be achieved by adding higher N levels in the range of 150-200 ppm [2]. Moreover, V can be fully dissolved in the austenite during normal reheating and precipitates as fine V particles in ferrite as well as in ferrite lamellae of pearlite on cooling after hot forging, which provides a significant increase in strength regardless of carbon content [16-17].

In addition, the high solubility of V in the austenite requires lower billet re-heating temperatures with the consequence of lower production costs on the shop floor, more uniform properties and lower straightening costs because microstructure and mechanical properties of vanadium micro-alloyed steels don't vary much with changes in reheating temperature.

The use of V as micro-alloying element is quite common in the case of flat product (plate or coils); anyway it is not so common in the case of forgings. This is particularly true in the case of high thickness forged components, where ferrite-pearlite microstructure is normally created.

The main novelty of this paper is to show the evidence of the possibility to achieve high strength levels in ferrite-pearlite microstructures based on heat treatment [18] and precipitation contribution [19] on forged components [20].

2 Experimental

Steel chemical composition of the considered steels is reported in **Tab. 1**.

Table 1 Steel chemical composition of the considered steels (mass, %)

	C	Cr	Ni	Mo	Mn	V
Steel 3-A	0.40	2.80	-	0.85	0.70	0.10
Steel 3-B	0.40	3.30	0.15	0.65	0.70	0.10
Steel 5-A	0.40	5.00	1.00	0.90	0.70	0.30
Steel 5-B	0.40	4.50	0.10	0.40	0.70	0.10
Steel 5-C	0.40	5.50	0.60	0.50	0.70	0.15

Steels 3-A and 5-A are taken as a reference for the two classes of 3%Cr and 5% Cr respectively. Starting from such reference compositions, the modification in steel hardenability are evaluated in steels 3-B, 5-B and 5-C based on metallurgical modelling [18] and laboratory scale materials production. In particular, such steels were cast by Vacuum Induction Melting (VIM) plant, and subsequently hot rolled and quenched at different cooling rates (CR). The quenched specimens were analysed by Light Microscopy (LM) after 4% Nital Etching. Electron Back Scattered Diffraction (EBSD) was used to evaluate of any residual austenite was present after quenching.

3 Results and discussion

Hardenability behaviours of the considered steels were compared based on [18]. Results reported in **Fig. 1** show that:

1. 5% Cr steels are characterized by higher steel hardenability
2. Steel 3-B shows a higher hardenability with respect to the reference 3% Cr steel (steel 3-A). In this case, in fact, the reduction of Mo content (from 0.85% down to 0.65 %) is balanced by the increase in Cr content (from 3.0% to 3.3%). In the case of Steel 5-B, on the other hand, the simultaneous reduction of both Mo and Cr content leads to a reduction in terms of hardenability with respect to Steel 5-A.

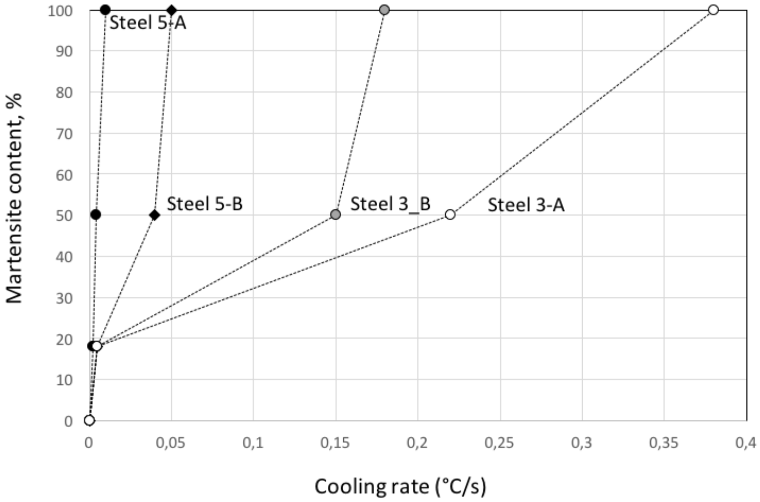
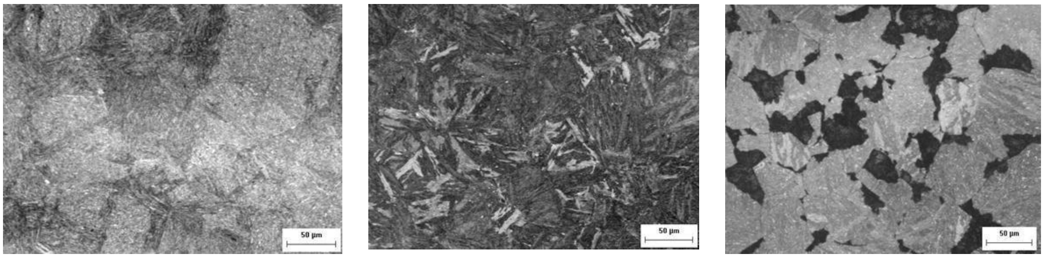


Fig. 1 Comparison of steels hardenability (calculated)

In order to validate the model, quenching treatments have been performed on the considered steels at the following cooling rates and microstructures were analysed:

- 0.860 °C/s,
- 0.140 °C/s,
- 0.012°C/s.

Just as an example the microstructure variations with cooling rates is reported for Steel 3-A in **Fig. 2**. The cooling rate variation leads to a passage from a fully martensitic to a ferrite-pearlite microstructure.



CR=0.86 °C/s CR=0.14 °C/s CR=0.012 °C/s

Fig. 2 Effect of cooling rate on microstructure in Steel 3-A

The effect of cooling rate on steel hardness for the different considered steels is reported in **Fig. 3**. If CR=0.14 °C/s is considered, experimental results reported in **Fig. 3** confirm previsions by modelling (**Fig. 1**) in terms of hardenability ranking. Moreover, it is interesting to note the strong hardness decrease in the case of Steel 5-B if very low cooling rates are considered (CR=0.012 °C/s). If CR>0.86 °C/s are considered, steels show very similar hardness values, following a fully martensitic microstructure in all cases.

Such cooling rates can bee considered as typical of industrial quenching process, in the case of back up rolls. In such cases, toughness needs to be ensured by the presence of residual austenite

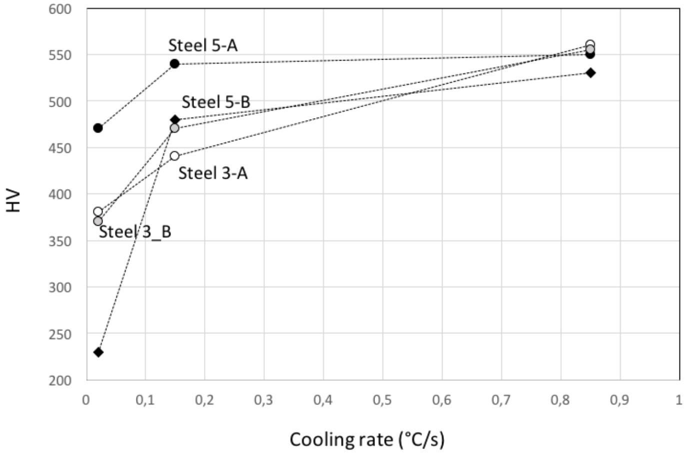
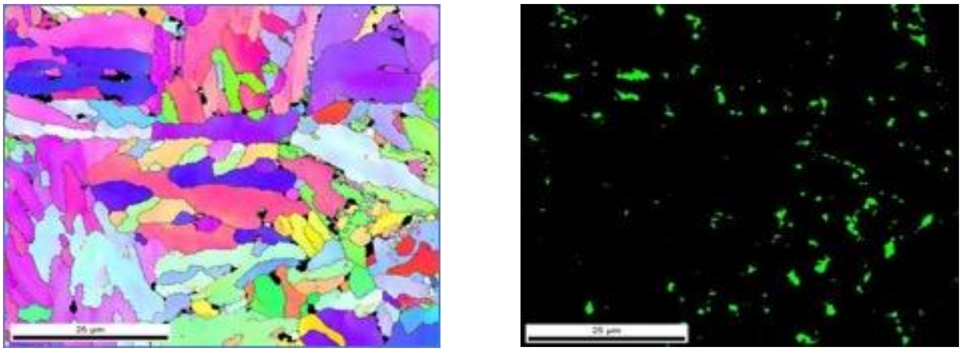
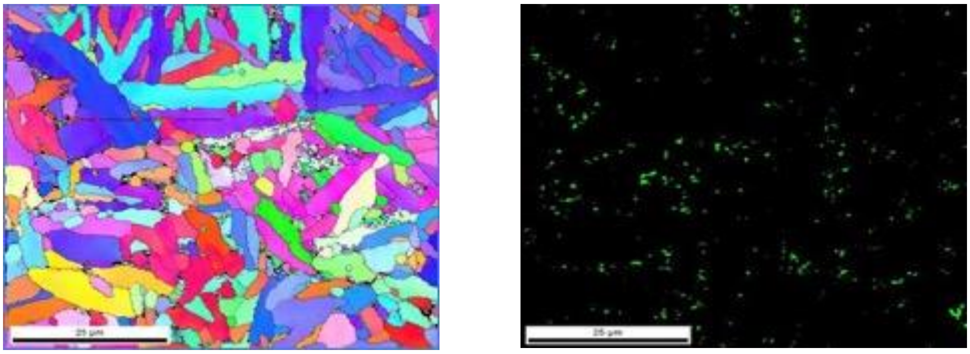


Fig. 3 Hardenability comparison (experimental)

in the martensitic matrix on contents lower than 3%. Therefore, the chosen steel for such kind of application needs to be able to maintain some untransformed austenite after quenching. In order to verify is such conditions is satisfied in Steel 3-B and Steel 5-B, residual austenite content was measured by EBSD technique. Results, reported in **Fig. 4**, show that in both cases residual austenite content was lower than 3%.



Steel 3-A



Steel 5-A

Fig. 4 Inverse pole figure maps. Residual austenite is the black phase in on the images on the left and green phase on the images on the right

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The effect of austenite grain size on hardenability is reported in **Fig. 5**.

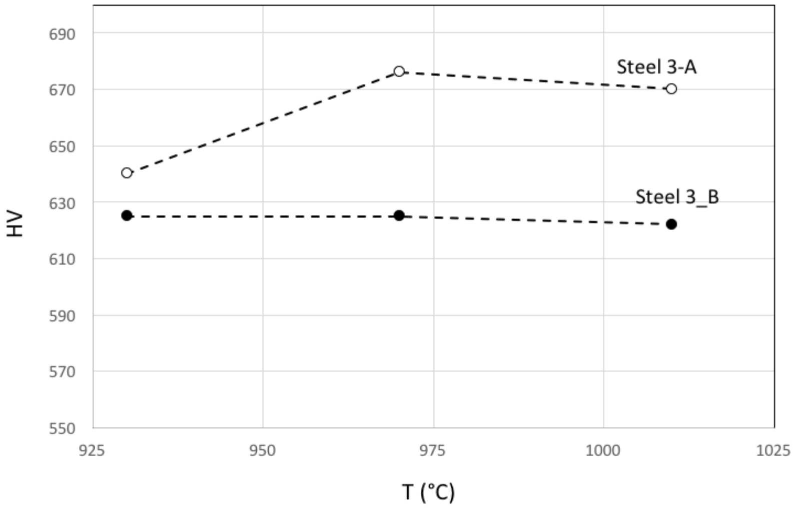

Fig. 5 a. Austenitisation temperature effect in steel hardenability (3% Cr steels)

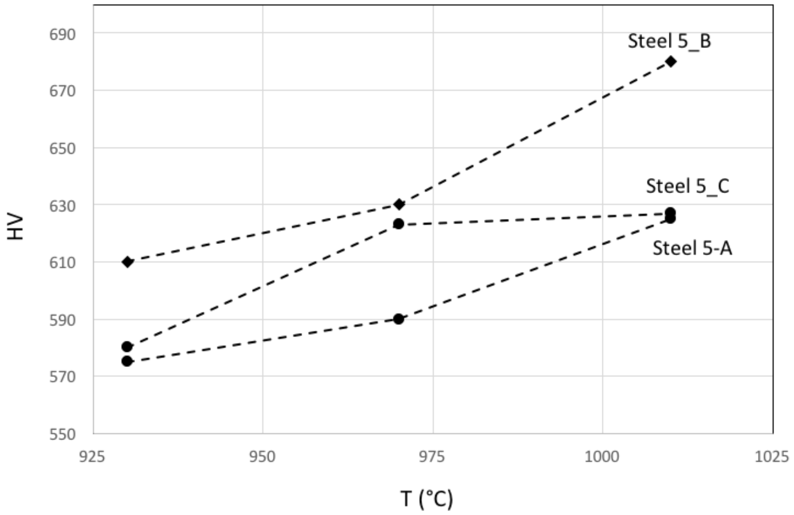

Fig. 5 b. Austenitisation temperature effect in steel hardenability (5% Cr steels)

Results show a poor effect of austenitisation temperature (hence of austenite grain size) on hardness after quenching in the case of 3% Cr steels. On the contrary, an effect is detected in the case of 5% Cr steels. Such result has a direct industrial implication in the definition of austenitisation temperature in the case of 5% Cr steels at the industrial level.

4 Conclusions

The hardenability behaviour of 3% Cr and 5% Cr steels has been studied by modelling and experiments. Results show a higher hardenability u the case of 5% Cr steels. Moreover, such family of steels also show a dependence on prior austenitic grain size. In both the steel families no warnings are detected in terms of residual austenite presence after quenching.

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