EFFECT OF QUENCHING AND TEMPERING PROCESS ON A MEDIUM C STEEL WITH LOW CHROMIUM AND MOLYBENUM ADDITION FOR FORGED COMPONENTS

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Abstract
In this paper the effect of quenching and tempering (Q&T) thermal treatment on mechanical properties of a C-Mn steel with 0.22% Cr for forged components is studied. Due to the lack of any micro-alloying elements (such as vanadium or niobium) such steel can just reach mechanical target allowed by its intrinsic hardenability. Aim of this work is to evaluate the mechanical properties dependence as a function of different quenching and tempering treatments. Results show that, after Q&T, steel can reach a yield strength of 330 MPa combined with a -20°C fracture appearance transition temperature (50% FATT) measured with a Charpy-V impact test making this steel suitable for low temperature application.

Keywords: Steel, heat treatment, mechanical properties

1 Introduction
Alloying elements such as chromium, molybdenum, tungsten, etc. are added in steel to improve properties such as hardness, strength and toughness. Different strengthening strategies can be chosen as a function of final product properties to be targeted. The standard methods used for strengthening steels are [1-2]:

- microstructure refinement
- solution hardening;
- dislocation strengthening;
- precipitation hardening;

It has been reported that microstructure refinement strongly affects the tensile properties increasing the yield strength up to three times [3-4] and that such method can allow the best strength/toughness combination [5-7]. Solution hardening can improve fatigue and high temperature behavior [8-10]. Anyway, such methods could be difficult or quite expensive (depending on the elements to be used for solution hardening). This paper will focus mainly on the quenching and tempering strategy adopted for steels for forgings [11-13]. Quenching and tempering (Q&T) is a one of the most common heat treatment processes after forging. Although forging could increase the product strength, in many cases achieved hardness values are still low. To obtain higher strength and hardness values, heat treatments are usually carried out after forging. By means of quenching and tempering the steel forgings become less brittle and more ductile without loosing hardness. It is the combination of these two processes that produces a

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harder, tougher part that's easier weldable and ductile than ordinary carbon steel. Unfortunately, however, producing forgings using the Q&T is inefficient and deleterious to the environment and alternative routes to high strength forgings have been studied for decades [14]. For flat C-Mn steel rolled product small addition of elements such as niobium or vanadium are usually adopted aimed to increase the strength [15-16]. When dealing with steels for forged components, if medium carbon steel is considered, vanadium is preferred over niobium because the dissolution of VCN particles occur at lower reheat temperature so niobium levels are very limited, while vanadium additions can be more substantial [17-20]. Thus, vanadium micro alloying is predominant in these steels, although growing importance is being placed on dual additions of vanadium with lower levels of niobium. Nitrogen additions are useful to enhance precipitation strengthening in the vanadium applications [21-22]. Moreover, increased yield strength can be achieved by improving hardenability and Mo or Cr are usually added with increasing material costs.

These micro alloying strategies are increasingly employed to increase strength and performance, or to reduce the number of heat-treating steps while maintaining adequate mechanical performance.

2 Experimental materials and methods

A steel with chemical composition 0.22% C – 0.95% Mn – 0.18% Cr – 0.25% Ni, measured by Quantitative Spectroscopy Analysis, is considered in the following. The steel was manufactured by electroslag remelting process resulting in high-quality ingots. From the ingot, specimens have been cut for continuous cooling temperature (CCT) curves determination. CCT curves were determined by means of dilatometry measurements carried out on 5 mm length 1 mm diameter specimens, with controlled cooling rate. After cooling all specimens were analyzed for hardness and microstructure by light microscopy (LM). Phase transformations has been studied and, following to it, quenching and tempering (Q&T) process have been performed starting from two different austenitization temperatures (980°C and 1050°C) followed by cooling at the cooling rate defined by CCT and tempering at different temperatures. Microstructure analysis and hardness of heat treated specimens have been carried out by means of light microscopy (LM) after 4% Nital etching and 2 Kg Vickers indenter (HV2). Room temperature tensile tests were carried out according to ISO 6892-1 specification. Charpy-V test have been performed on the most promising cases on 10 x 10 x 50 mm3 specimens machined on transversal section.

3 Results

CCT of the considered steel is reported in **Fig. 1**.

Based on results reported in **Fig. 1**, specimens were austenized at 980°C and 1050°C, cooled in air to avoid any bainite formation and to obtain a fully ferritic-pearlitic microstructure; specimens were tempered in the range 540°C – 660°C for 30 minutes holding. Microstructure obtained after cooling are reported in **Fig. 2**. Microstructure is fully ferritic and pearlitic, as expected following **Fig. 1**. Results of hardness measurements on quenched and tempered materials are shown in **Fig. 3**. Results show that hardness values do not significantly change in the range of the tempering temperature as expected in the case of microstructure mainly constituted by of ferrite and pearlite (**Fig. 4**). Results of tensile test and Chary impact test of Q&T materials after tempering at 640°C are reported in **Table 1** and **Fig. 5**.

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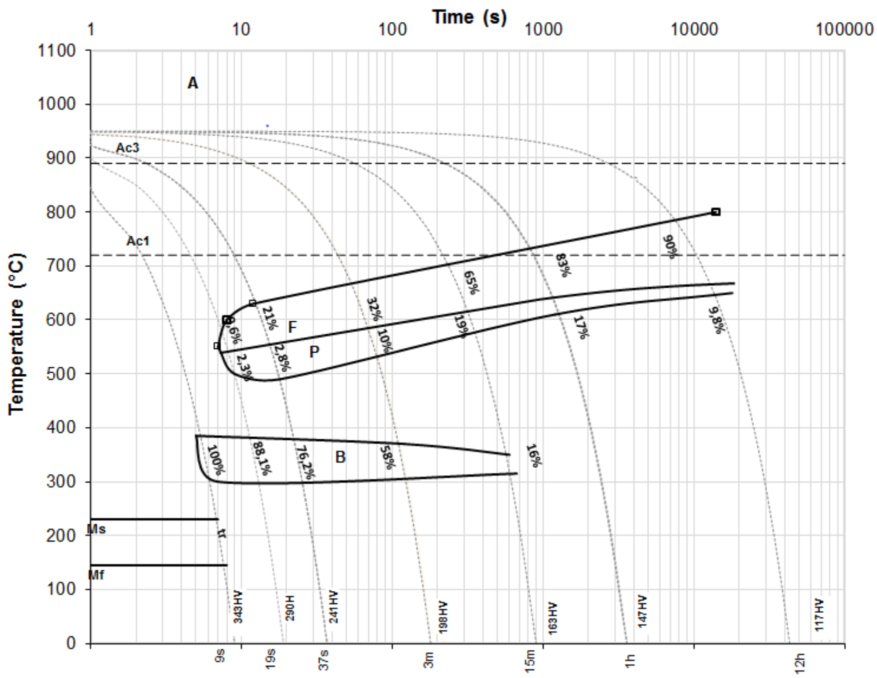
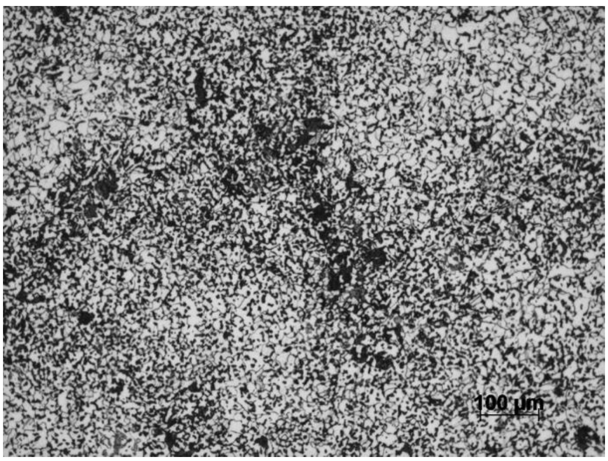


Fig. 1 CCT of the considered steel

Based on results reported in **Fig. 1**, specimens were austenized at 980°C and 1050°C, cooled in air to avoid any bainite formation and to obtain a fully ferritic-pearlitic microstructure; specimens were tempered in the range 540°C – 660°C for 30 minutes holding. Microstructure obtained after cooling are reported in **Fig. 2**. Microstructure is fully ferritic and pearlitic, as expected following **Fig. 1**. Results of hardness measurements on quenched and tempered materials are shown in **Fig. 3**. Results show that hardness values do not significantly change in the range of the tempering temperature as expected in the case of microstructure mainly constituted by of ferrite and pearlite (**Fig. 4**). Results of tensile test and Chary impact test of Q&T materials after tempering at 640°C are reported in **Table 1** and **Fig. 5**.



a)

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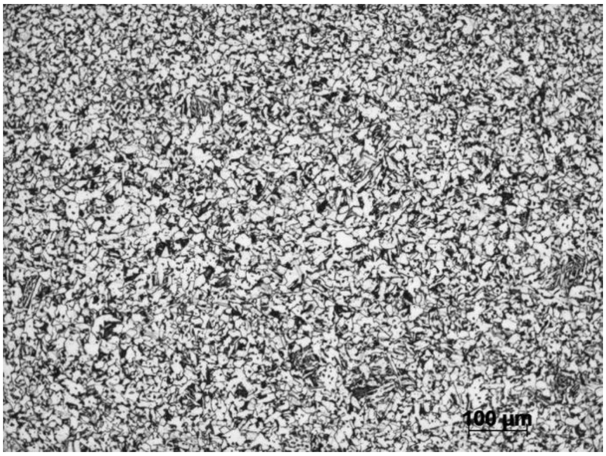

b)

Fig. 2 Microstructure after austenitization and cooling: (a) austenitization temperature = 980°C and (b) austenitization temperature = 1050°C

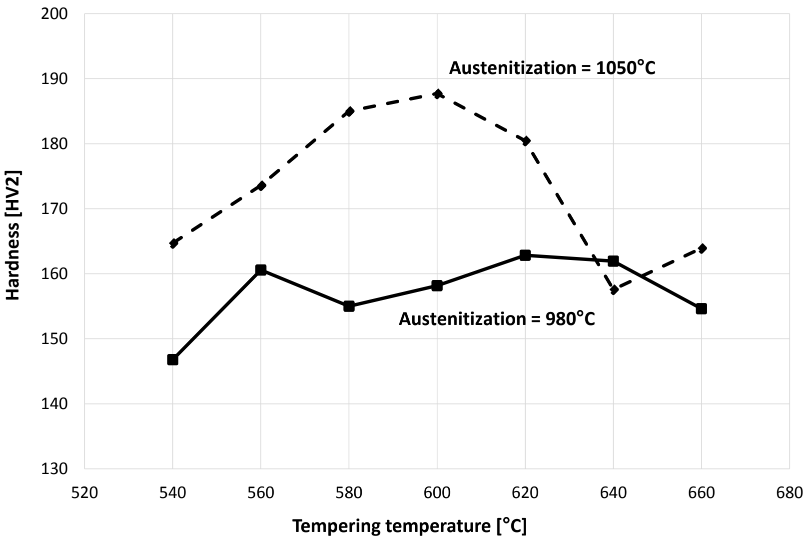

Fig. 3 Effect of tempering on hardness. Austenitization time: 30 min, tempering time: 30 min

Charpy impact test was performed in the temperature range of -80°C to 80°C and the results indicate that the 50% FATT (fraction appearance transition temperature) temperature is equal to -20°C.

Table 1 Tensile properties of material austenitized at 980°C and tempered at T=640°C

Austenitization temperature (°C)	Tempering Temperature (°C)	$R_{p0.2}$ (MPa)	Tensile strength (MPa)
980	640	331.4	534.4

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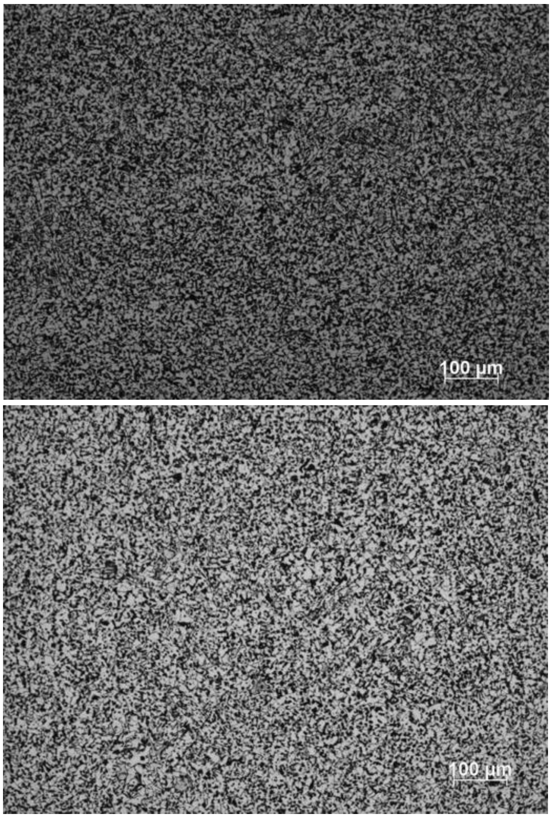

Fig. 4 Microstructure after Q&T (austenitisation temperature = 980°C): (a) tempering temperature = 660°C , (b) tempering temperature = 540°C

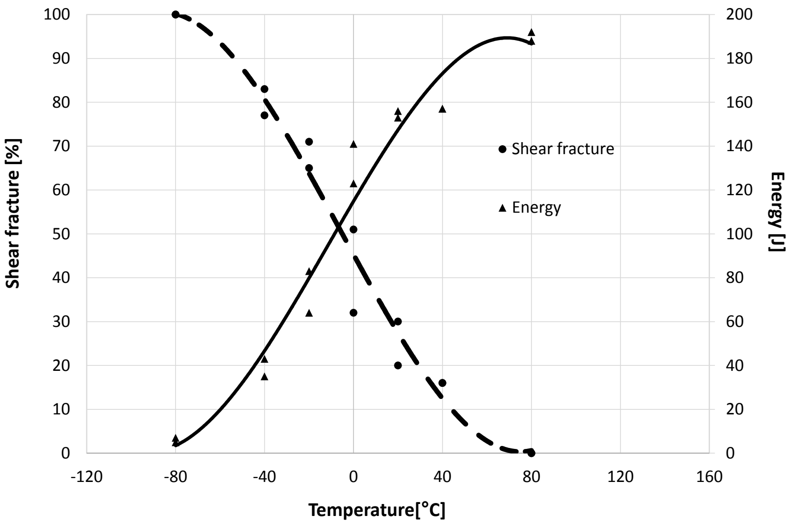

Fig. 5 Plot of percentage of shear fracture versus temperature of 0.22% C - 0.95% Mn – 0.22% Cr – 0.25% Ni

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4 Discussion

One of main critical points concerning forge steel components is in the high transition temperature (50% FATT) as measured by Chapy-V tests. In particular, in the case of V micro-alloyed steels a 50% FATT higher than room temperature is quite often found, thus limiting possible applications fields (or geographical regions for applications of the products). This is mainly due to the presence of fine precipitates which interact with dislocation increasing tensile properties but also act as possible cracks initiation sites. In the case of the 0.22% C – 0.95% Mn – 0.18% Cr – 0.25% Ni considered steel, the absence of micro-alloying elements coupled with the presence of Ni allows to obtain suitable mechanical properties together with low temperature impact toughness behaviour. Moreover, it has to be noted that thanks to the generation of ferrite-pearlite microstructure, obtained following to the low cooling rate simulating the large forged components heat treatment, the material mechanical properties appear to be quite quite stable during the tempering process, thus making such process step lower critical with respect to the use of V micro-alloyed steels. In fact, in such last case a □YS/□□tempering= 10 MPa/°C [23] is reported as a critical point.

5 Conclusion

In this work the effect of quenching and tempering (Q&T) thermal treatments on mechanical properties of a C-Mn steel (0.22% Cr) for forged components has been exploited on a laboratory scale. Results show that the microstructure obtained after Q&T treatments is almost totally ferritic and perlitic and the hardness of Q&T samples does not change in the range of 540°C to 660°C of tempering temperature. The obtained $R_{p0.2}$ value, for a sample austenitized at 980°C cooled in air and tempered at 640°C, are in accordance to a typical 0.20% C -1.00% Mn steel and the 50% FATT temperature of the steel is about -20°C.

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