Improvement of mechanical properties of high strength low-alloyed steel
by unconventional heat treatment

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ABSTRACT

Modern steels processed using unconventional heat treatments can reach substantially better properties when compared to those processed using conventional treatments. This paper presents new possibilities of heat treatment for 42SiCr steel, which is a low-alloyed steel with a strength of 980 MPa and ductility of 30% in the basic state. Very high strength can be reached through conventional treatment, but ductility drops down to lower values. The aim of this experiment was to design and test an unconventional heat treatment procedure in order to reach a high strength of about 2000 MPa with ductility over 10%. For this purpose, the Q-P process was modified and optimized in several steps. The influence of the technological process parameters on the structure development was documented using metallography and the resulting mechanical properties were measured.

Key words: unconventional heat treatment, Q-P process, low-alloyed steel

1. INTRODUCTION

Conventional approaches such as quenching and tempering have long been used to achieve good mechanical properties, particularly toughness in the martensite structure. For newer types of materials, the majority of which are, for economic reasons sparingly alloyed, it is essential to use new treatments. For example, isothermic quenching has recently been used to attain excellent properties for bainite. These newer processes include intercritical annealing when treating TRIP steels or long-term annealing on bainite. To acquire even higher hardness values, isothermic quenching moved into the area in intervals between M_s and M_f. This is the quenching and partitioning process (Q-P Process). This experiment concentrates on the Q-P process, as it can be used to attain an attractive combination of hardness and ductility. Steels worked on using the Q-P process should be able to attain tensile strengths of up to 2000MPa and ductility higher than 10%.

2. Q – P PROCESS

This innovative heat treatment method differs from traditional quenching and tempering mainly in that during normal low temperature tempering, highly saturated tetragonal martensite is transformed to cubic martensite at the same time as the formation of iron carbide. This also occurs during Q-P, but the carbon diffusing from the martensite stabilizes untransformed austenite. The occurrence of carbon is suppressed by a suitable alloying strategy and heat treatment conditions. The carbon saturates the retained austenite which then remains stable even at room temperature and the resulting structure is formed of martensite and stabilized retained austenite (Fig.1). The quantity of retained austenite is influenced by more parameters which are closely related. They are mainly the lowest temperature reached during quenching, the temperature at which untransformed austenite is stabilized, the holding time at this temperature and the chemical composition of the material. After optimizing these parameters, the quantity of retained austenite in the resulting microstructure can be found with a high degree of accuracy, and also the resulting mechanical properties [1,2].

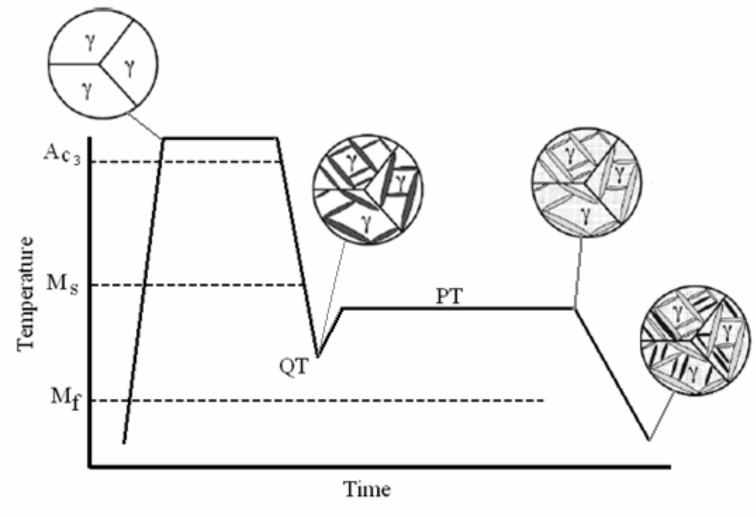

Fig. 1 Diagram of Q-P process showing microstructures [1]

3. EXPERIMENTAL PART

Obtaining excellent mechanical properties depends on setting the individual Q-P parameters correctly. In this experimental part of the study, several of these parameters were optimized. The aim of the experiment was to achieve a tensile strength higher than 2000MPa and ductility more than 10%.

Low-alloyed high strength steel 42SiCr was used. The main alloying ingredients are silica, which suppresses the formation of carbides during the decomposition of martensite, and manganese which stabilizes the austenite and limits pearlitization [3]. Another alloying ingredient is chrome which helps to harden the solid solution. The proportion of alloying constituents in this steel is very low, which keeps the cost down.

The structures obtained were evaluated using light and confocal microscopy, mechanical properties were determined using the mini-tensile test and the proportion of retained austenite was measured using x ray diffraction analysis.

In its basic state the structure is ferritic-pearlitic (Fig.2), tensile strength 980MPa, ductility higher than 30%. Hardness in this basic state is 290HV.

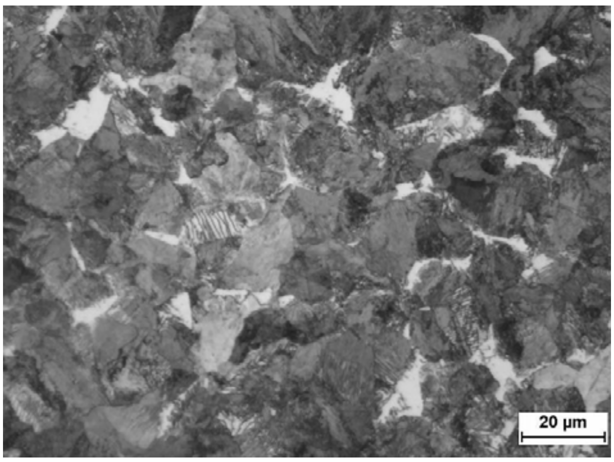

Fig. 2. Ferrite – pearlite structure in the basic state of the material

3. 1. Heat treatment strategy

During the design of the Q-P process, the influence of the holding time on the austenization temperature, the speed of cooling and the duration of isothermic holding in the salt bath were all examined. The holding time at austenization temperature was between 20-30 minutes and in the salt bath 5-20 minutes (Fig.3). Isothermic holding in the salt bath at temperature intervals between M_s a M_f helped diffusion of the carbon from the saturated martensite to the retained austenite. It is therefore important to find out how different holding times in the salt bath influence the stabilization of the retained austenite. To find the influence of the speed of cooling, one sample was cooled directly in the salt bath and two samples were first cooled for two seconds in water and then transferred to the salt bath at a temperature of 250°C. To enable comparison with conventional tempering, the experiment was supplemented by a regime of cooling directly in water or oil without isothermic holding. The samples used in the experiments were 55x18x25 mm. These small samples were used in order to obtain a homogenous structure throughout the sample.

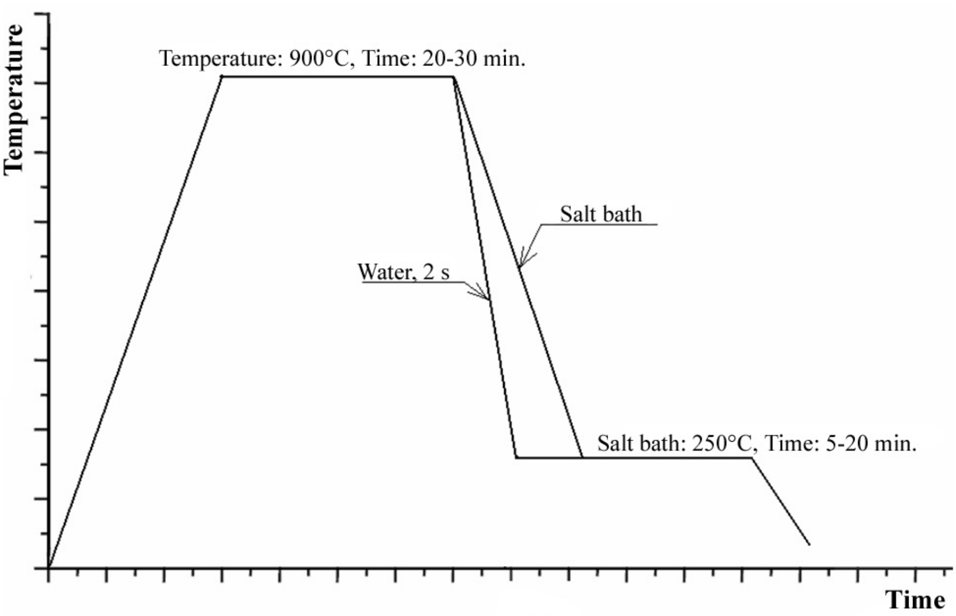

Fig . 3 Schematic representation of individual strategies

For all regimes, observations made after heat treatment revealed a martensitic structure without the development of ferritic islands. Neither was any pearlite detected. Therefore it can be said that just cooling in a salt bath was sufficiently rapid and the cooling did not run over ferritic or pearlitic nose.

The greatest difference is between the structure of the regimes of the Q-P process and direct thermal quenching. The martensite structures are much coarser in the sample subjected to direct quenching (Fig. 6) than those found in the Q-P sample (Fig. 5). A smaller difference was observed even between samples subjected to direct cooling in the salt bath and with the two second semi-cooling in the water bath (Fig. 7, 8).

Neither light nor confocal microscopy revealed the occurrence of retained austenite in the structure. This should probably form in thin films along the martensite needles. Because the proportion of retained austenite has a strong influence on mechanical properties, it was measured using X-ray diffraction analysis (Tab 2).

Results from XRD analysis showed that increasing the duration of isothermic holding increases the amount of stabilized austenite in the final structure. The highest fraction of retained austenite was obtained with an isothermic holding of 20 min. At shorter holding times of 5 and 10 min. similar amounts of retained austenite were obtained as for quenching directly in water or oil. Extending the holding time of the austenization temperature from 20 to 30 min. increased the fraction of retained austenite, as did the accelerated cooling before isothermic quenching, even during the short duration of isothermic quenching.

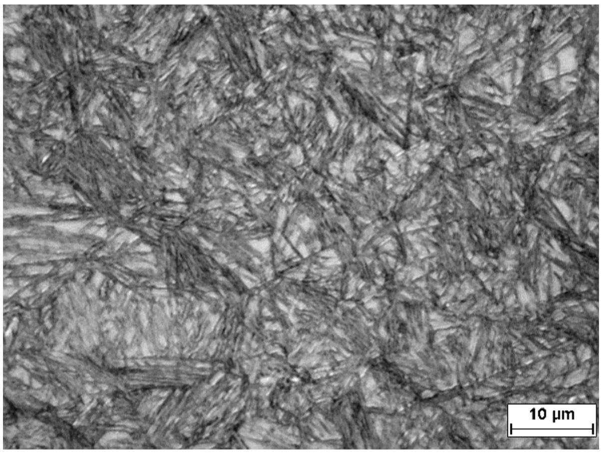

Fig. 5 Resulting structures - 900°C/20min – 250°C/10min

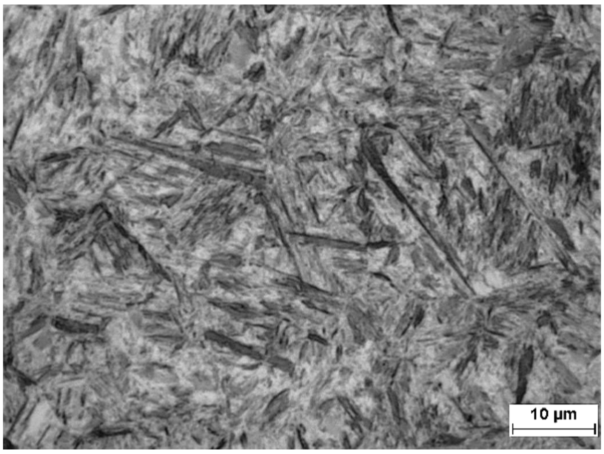

Fig. 6 Resulting structures – direct cooling in water

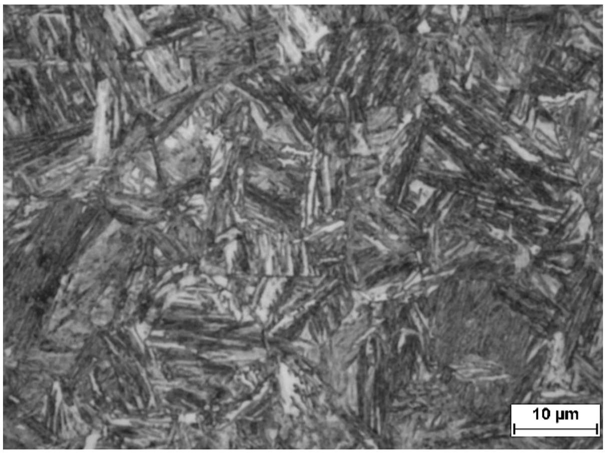

Fig. 7 Resulting structures – (900°C/30min – 250°C/10min)

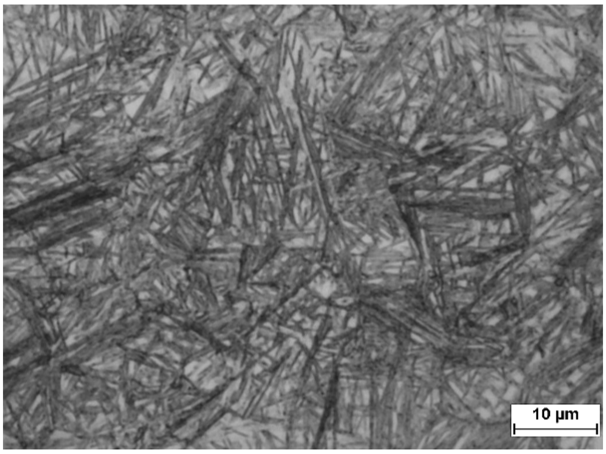

Fig. 8 Resulting structures – (900°C/30min – 2s water - 250°C/10min)

Strategy	**Proportion in individual phases**		**Hardness**	
	martensite [%]	**austenite [%]**	**HV30**	**HV10**
Quenching in water	95.8	4.2	700	699
Quenching in oil	95.3	4.7	632	641
900°C/25min – 250°C/5min	94.9	5.1	600	569
900°C/20min – 250°C/10min	95.9	4.1	621	592
900°C/20min – 250°C/20min	89.3	9.8	595	587
900°C/30min – 250°C/10min	93.1	6.9	570	559
900°C/20min – 2s water - 250°C/10min	92.9	7.1	613	619
900°C/30min – 2s water - 250°C/10min	92.5	7.5	629	641

Tab. 2 Proportions in individual phases and hardness measurements

Metallographic evaluation was supplemented by hardness measurements. Hardness is also dependent on the proportion of retained austenite. As the proportion of retained austenite increases, hardness decreases. Highest hardness values were obtained from direct cooling from austenization temperature into water. There was a marked decrease when quenched in oil. The hardness of the Q-P samples varied between 570-630 HV.

3. 2. Results of mechanical testing

Tensile testing was carried out on samples with an active part length of 5%mm (Tab.3, Fig. 9). Compared to the basic state, there was a great increase in tensile strength for all heat treatment strategies by a minimum of 1000MPa.

	$R_{p0.2}$ [MPa]	R_m [MPa]	A_{5mm} [%]
Basic state	592	981	31
900°C/25 min./quenching in water	1886	2255	2.5
900°C/25 min./quenching in oil	1780	2252	7.8
900°C/25min – 250°C/5min	1657	2157	14
900°C/20min – 250°C/10min	1714	2120	16
900°C/20min – 250°C/20min	1663	2038	18
900°C/30min – 250°C/10min	1728	2054	15
900°C/20min – 2s water - 250°C/10min	1765	2102	14
900°C/30min – 2s water - 250°C/10min	1852	2107	14

Tab.3 Results of mechanical testing

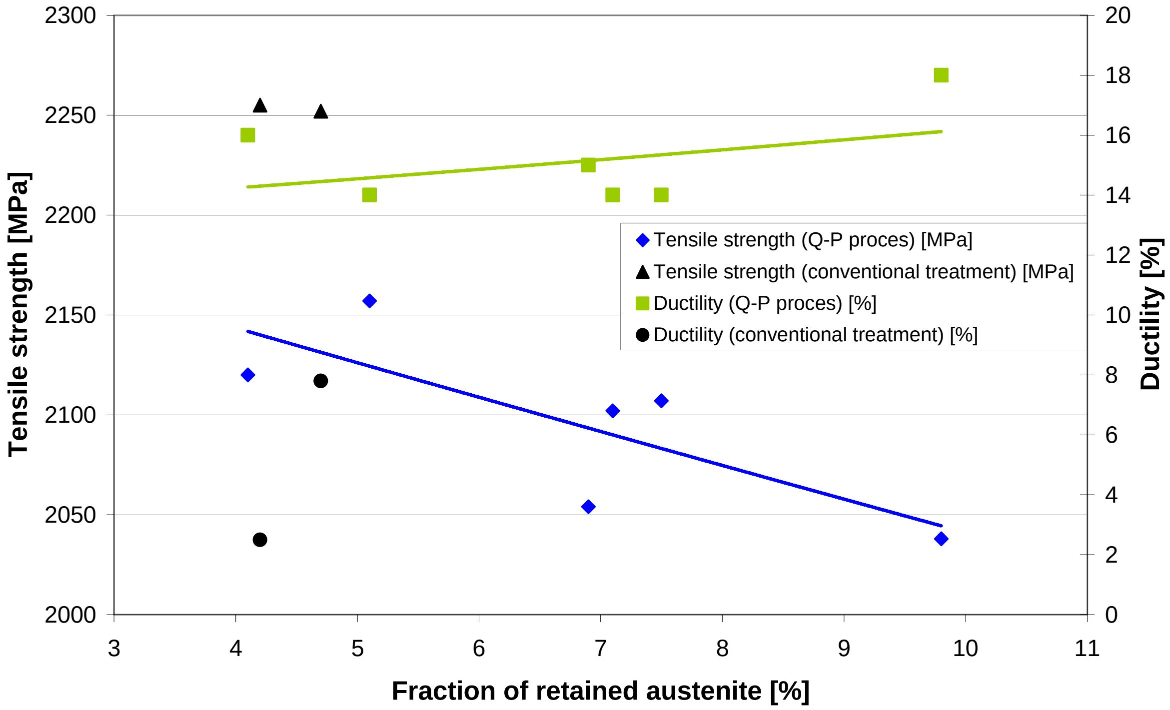

Fig. 9. The dependency of ductility A_{5mm} and tensile strength R_m in relation to the fraction of retained austenite

The highest increase was observed in the samples subjected to direct quenching, but this strength was achieved at the expense of ductility. The ductility of the sample quenched in oil did not exceed A_{5mm} 8%, and the sample quenched in water did not even reach 3%. Ductility values increased significantly with the application of isothermic quenching below temperature M_s. For all regimes, ductility A_{5mm} was higher than 14% with a slight lowering of tensile strength when compared with the samples exposed only to quenching. The highest ductility values were obtained from samples which contained the highest proportions of retained austenite.

4. CONCLUSION

The aim of this experiment was to design and test selected parameters of the Q-P process on low-alloyed steel 42SiCr. A variety of holding times at the austenisation temperature were tested and various speeds of cooling at the temperature of isothermic holding and various durations of holding at this temperature. Direct quenching in water and oil was also tested to compare the mechanical properties of conventionally processed materials.

The results obtained so far show that application of the Q-P process achieves outstanding results. For all samples subjected to this treatment tensile strengths exceeding 2000MPa were achieved whilst retaining excellent ductility. It was shown that excessively long holding times in the salt bath results in increased amounts of stabilized austenite which, despite resulting in higher ductility values, lowers the strength.

It was also found that cooling in water before transferring to the salt bath does not significantly affect mechanical properties when compared to the regimes of direct cooling in the salt bath.

Further steps will be taken to test other variants of isothermic quenching and the influence on the structure and mechanical properties.

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