

EFFECT OF HEAT TREATMENT ON THE PROPERTIES OF THERMOMECHANICALLY TREATED STEEL

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Abstract: In order to determine the effect on the properties of precipitation processes conducted S700MC steel heat treatment consisting of annealed steel test temperatures: 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200 and 1300 °C. Sample obtained after the heat treatment process has been tested by Charpy V toughness, metallographic testing and measurement of Vickers hardness. In order to determine the strength and plastic properties of simulated heat affected zone S700MC steel material tensile test was carried out according to PN- EN 10002-1 for round samples. The study showed that the stability of bainitic structure is maintained to a temperature of 600 °C. In the temperature range 700 to 1000 °C, the test steel with ferritic-pearlitic structure with a small grain growth. The heat treatment above 1000 °C increases the amount of ferrite in the structure, and a strong growth of grain size. Tested steel retains its strength and hardness properties of the heat treatment does not exceed 600 °C. When this temperature is exceeded the tensile strength and hardness are significantly lower in comparison to the base material. Temperatures warm temperatures corresponding to the normalization cause loss of property obtained in the initial thermomechanical rolling process. It is impossible to return to the property upon cooling to ambient temperature, thus constantly this group should not be hot forming.

Keywords: S700MC STEEL, TMCP, HEAT TREATMENT, MECHANICAL PROPERTIES

1. Introduction

The modern, dynamically developing industry looking for new structural materials that meet certain criteria relating to the strength, weight, aesthetics and price. A major threat to the production of steel mills became the expansion of new materials with low density, based on aluminum, magnesium, titanium, as well as increasing market share of composite polymer materials. Steelmaking companies to meet the standards set by the market, they had to show in recent decades, a significant activity. The use of modern technology, metallurgical and steel manufacturing, as well as a new perspective on the importance and role of alloying elements used in steels, made it possible to produce a variety of steel groups with a wide range of mechanical and plastic properties. The first application of thermo-mechanically rolled steels were in the shipbuilding industry. The continuous search for new uses for steel TMCP in this area is dictated by the growing importance of security in maritime transport. In recent years, the exploitation of offshore oil and gas has moved into the northern regions of the North Sea and the Arctic Ocean. Offshore steel structures exposed to extremely low temperatures must show a yield strength of not less than 500 MPa. TMCP steels are also used in civil engineering. Have proven particularly useful in the preparation of the largest structure of suspension bridges, allowing the reduction of the main support and improve the welding efficiency. These steels are particularly suitable for making the construction of buildings located in seismic-prone areas. Due to the high strength, toughness and maintain these properties in chemically aggressive environments ever received in thermomechanical rolling process well suited for the construction of pipelines in hydropower or for the transport of crude oil from the bottom of the sea [1-11]. The automotive industry over the last 20 years especially strongly emphasized the need for sheet metal joining high strength properties and the arts. Answer steel industry to these needs from a number of international projects involving a number of companies including ULSAB-AVC (called Ultra Light Steel Auto Body - Advanced Vehicle Cocept) [12] or the TRAILTECH Arcelor Mittal, whose purpose is the development and production of components with high strength steel, which guarantees good formability. Such action is the ability to reduce the weight of vehicles, reducing fuel consumption. For example, using steel grades S500MC and S700MC, managed to build a chassis semi-trailer truck weighing about 39% less than the mass of the chassis of the standard [13]. Modern constantly produced by thermomechanical processing must satisfy not only the strength requirements placed on them, but also the environmental and social requirements [14-19].

2. Research

The aim of this study was to determine the effect of heat treatment on the properties and structure of thermo-treated S700MC steel with high yield, Figure 1, Table 1, 2.

Table 1. The chemical composition according to the regulation PN EN 10149-2 and mechanical properties of the S700MC steel subjected to thermomechanical treatment used for cold moulding.

Chemical composition [%]									
C	Si	Mn	P	S	Al	Nb*	V*	Ti*	C _e **
0,12	0,5	2,1	0,008	0,015	0,015	0,2	0,2	0,22	0,61
Mechanical properties									
Tensile strength R _m , MPa		Yield limit R _e , MPa		Elongation A ₅ , %		Impact strength, J/cm ² (-20°C)			
822		768		19		135			

* - total amount of Nb, V and Ti should be max. 0,22%.

** C_e – carbon equivalent (1).

Table 2: The real chemical composition of the original S700MC steel material.

Chemical composition, %									
C	Mn	Si	S	Al	Nb	Ti	V	N*	C _e
0,056	1,6	0,16	0,005	0,02	0,04	0,12	0,006	72	0,33

* - N: the amount given in ppm, the nitrogen was measured using the high temperature extraction method.

$$C_e = \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}, [\%] \quad (1)$$

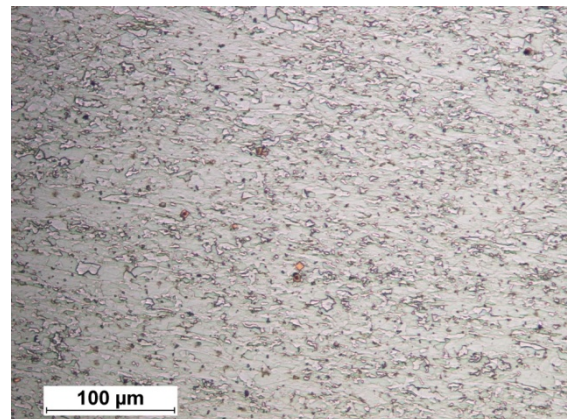


Figure 1. Structure of bainitic-ferritic steel S700MC with visible effects of plastic deformation.

Thermal Treatment

In order to determine the effect of temperature on the properties of S700MC steel, heat treatment was carried out whereby the investigated steel was annealing at temperatures between 100 °C to 1300 °C, with increments of 100 °C. Heat treatment was performed using 24-channel resistive heating setup WO6524 with a capacity of 65 kVA of LMS SC, equipped with P62 temperature controllers. Temperature measurement and control of the process was controlled by a thermocouple NiCr-Ni type K (measuring accuracy $\pm 0,5$ °C). Each sample was placed on a separate heating mat, insulated and has been treated with heat. Soaking time of the samples was 1 hour, and cooling was done in air.

The study

The resulting sample after the heat treatment process has been tested by Charpy V-notch impact test as metallurgical microscope and the Vickers hardness measured at a load of 9.81 N (HV1) on the device WILSON WOLPERT MICRO-VICKERS 401MVD in accordance with the requirements of BS EN ISO 9015-1. For each sample taken after 7 measurements. Then the two extreme values (minimum and maximum) was discarded and the remaining five measurements in the series of average values were calculated. In order to determine the mechanical properties of steel and plastic S700MC after heat treatment Static tensile test was carried out according to the standard EN 10002-1 for round specimens. The study was conducted on MTS Insight testing machine. This machine allows forcing the displacement of the transverse beam (cross beam), in which the force sensor at a constant speed. Force sensor, in which the machine is equipped with MTS Insight allows the measurement of the force of 10 kN to the nearest tenth of N. In order to meet the requirements for the static tensile test was adopted speed: 5 mm / min. Static tensile test was carried out at 24 °C with a relative humidity of 59%. In order to avoid deformation of the sample at the time of fastening the pneumatic grips of the testing machine, and the initial strength of the first generation devices. It is important to consider proper pre-load or set minimum pressure clamp bracket at which the specimen was mounted securely. The value of this pressure was 0,27 MPa. Repeatability alignment and depth of capture shapes was possible thanks to the prism holder. The depth of sample in the mounting brackets is equal to the length of the handle portion.

Results of studies on the influence of thermal treatment

Different thermal treatment levels were found to affect the S700MC steel, and in the case of heating in the temperature range from 100 to 600 °C the material is tempered in bainite structure, whereas from the temperature treatment of 500 °C would initiate the recrystallization process, formation of single grains and disappearance of strain hardening. When the temperature exceeds 800 °C, there is a process of recrystallization and the overall increase in the proportion of ferrite in the structure. A further increase in temperature above 1000 °C, resulting in a strong proliferation of grain (Figure 2). The research microscopy confirmed the high temperature stability of precipitates of Ti(C,N) and (Ti,Nb)(C,N), the size of tens of microns.

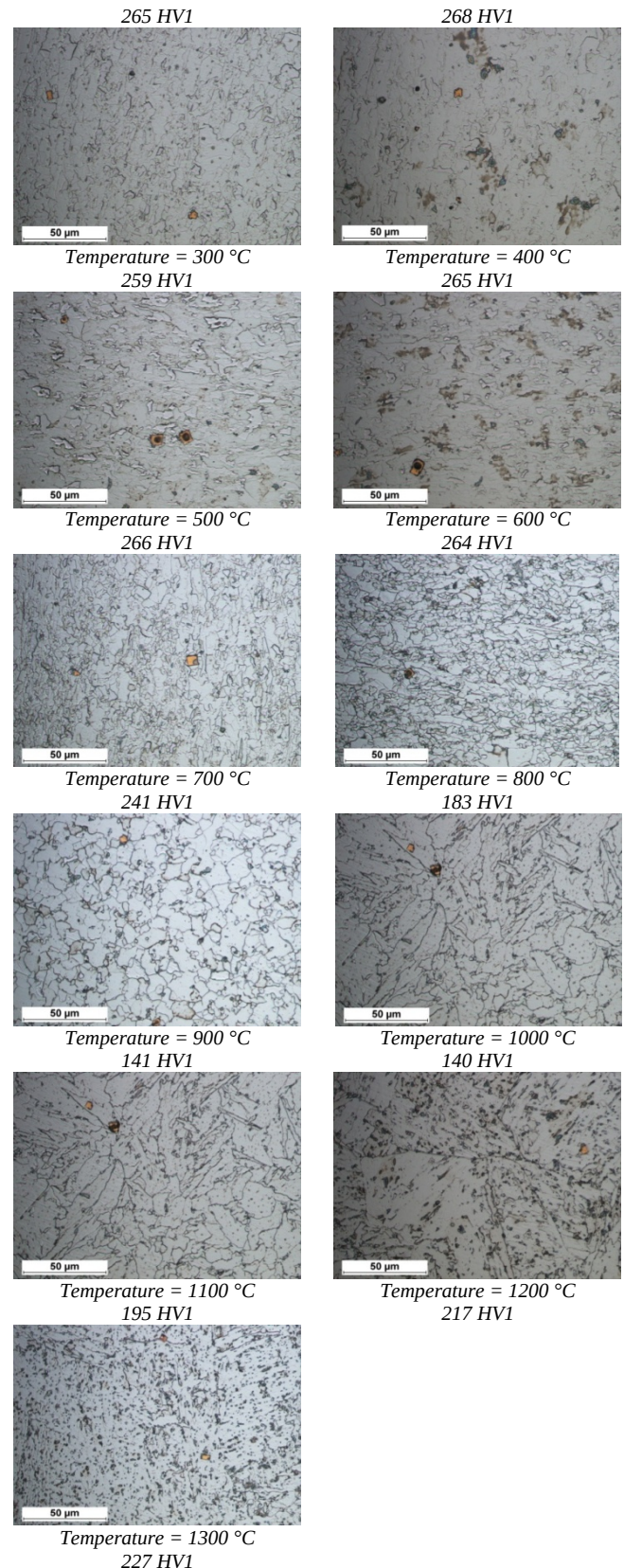
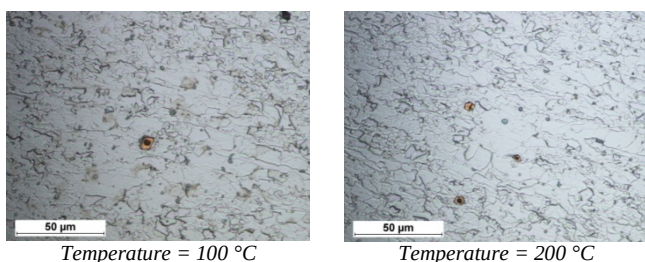


Figure 2. S700MC steel microstructure as a function of the heating temperature.

As a result of heating of S700MC steel in the temperature range from 100 to 600 °C, tempering process occurs bainite, a steel structure tends to thermodynamic equilibrium. Throughout the hardness of the tempering temperature is not changed (Figure 3) and is close to the hardness of the base metal. In the temperature range 700 - 1000 °C, the disappearance of the effect of strengthening of precipitation probably due to coagulation of the precipitates, which together with recrystallization leads to a decrease in hardness

of 140 HV1 at a hardness of 260 HV1 parent material and the reduction of mechanical properties. A further increase in heat treatment temperature above 1000 °C results in partial dissolution of precipitates in the matrix. With the slow cooling process comes to re-strengthen the separation of phases, but this happens in an uncontrolled manner. Hardness begins to increase, reaching a value of 230 HV1. A very disturbing trend that could have a negative effect on the properties of welded joints were observed during treatment in the temperature range from 100 to 600 °C. Prolonged soaking at this temperature causes a sharp drop in impact toughness compared to the base material. Toughness drops to a value of several J/cm², the toughness of the base metal 50 J/cm² (Figure 4). No changes in hardness in the range of tempering temperatures and low impact values indicate that the properties of the test steel heat treated in the temperature range tempering mainly of austenite transformation is not determined, but probably of aging processes related to the diffusion of elements of low atomic diameter (nitrogen dioxide) at close range for testicular dislocation, resulting in their immobilization. The working temperature range of 700 to 1000 °C followed by an increase to the level of impact up to 250 J/cm², due to loss of strengthening (separation enhancing are coagulated) and recrystallization process. In the high temperature heat treatment (above 1000 °C) there is a partial dissolution of strengthening precipitates which are released during cooling in an uncontrolled manner or remain dissolved in the matrix, increasing its local hardenability. Additionally, in this temperature range, grain growth occurs which results in a rapid decrease in the impact strength values of several J/cm² (Figure 5). This test result indicates a high sensitivity to the effects of investigated steel thermal cycles.

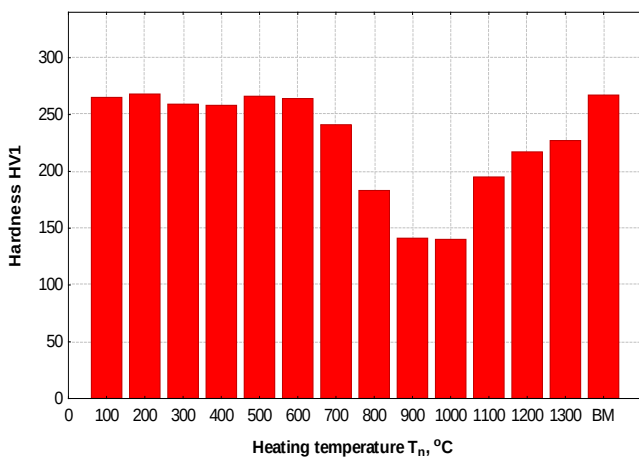


Figure 3. S700MC steel hardness after heat treatment.

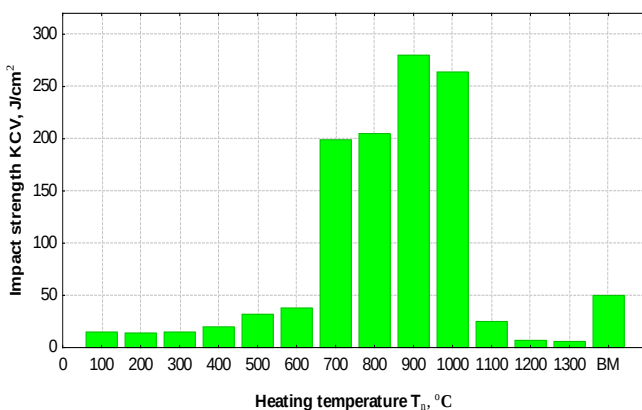


Figure 4. S700MC steel Charpy at -30 °C heat-treated.

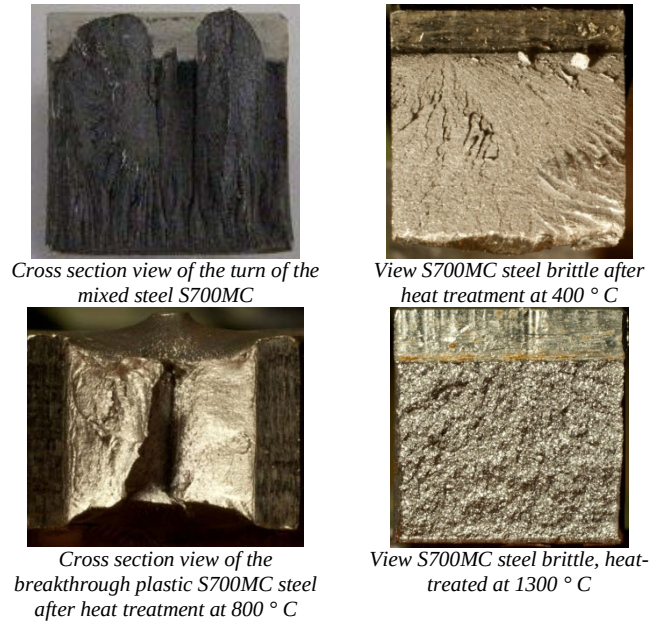


Figure 5. View of samples after fracture toughness tests.

Static tensile test on specimens taken from a circular steel heat treated confirmed the results of metallographic microscope, impact tests and hardness measurements. The test steel heat treated in temperature between 700 and 1000 °C is characterized by the lowest values of tensile strength - drop compared to the strength of the material in the initial state of about 25% (Figure 6) and the properties of the plastic top at the same time - the elongation at A₃ in material elongation the initial state (Figure 7).

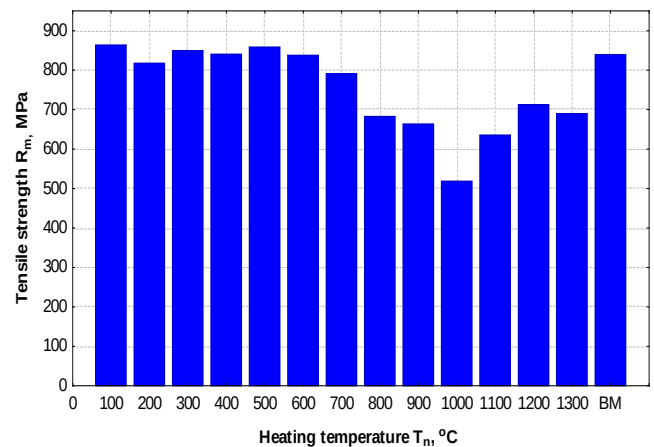


Figure 6. Tensile strength of steel after heat treatment S700MC.

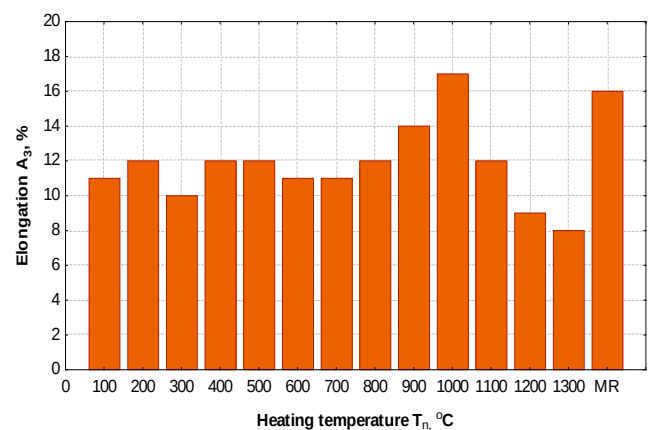


Figure 7. Relative elongation of S700MC steel after heat treatment.

4. SUMMARY

Investigation of the effect of heat treatment on the properties of the steel S700MC confirmed the thesis of the high sensitivity of steel S700MC the impact of thermal cycles. Low temperature heat (up to 600 °C), in which there is a process of tempering bainitic structure, do not change the hardness. No change in hardness with increasing tempering temperature is associated with low levels of the elements that increase the hardenability, especially coal. The calculated carbon content in the unbound carbides and nitrides is about 0,03%. A dominant influence on the properties of the steel in the temperature range of heat treatment processes have of aging character, which is confirmed by the results of the impact test. With increasing tempering temperature of 100 °C, toughness increases from 15 to 38 J/cm² at 600 °C, but it is lower than the toughness of the material at ambient temperature (50 J/cm²). In the temperature range 700-1000 °C, the disappearance of the effect of strengthening precipitates by coagulation, loss of coherence and a decrease in internal stress. In addition, recrystallization processes occur which reduce the hardness and the large increase in impact strength, even to 280 J/cm². Further increase in heat treatment temperature results in partial dissolution of precipitates in the matrix, and with slow cooling process following the re-release of microalloying strengthening, but in an uncontrolled manner, resulting in a decrease in toughness to the level of a few J/cm².

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ACKNOWLEDGMENTS

This work was funded through the following research grant: „Control properties and structure of steel joints for thermomechanically processed high yield”, No. N N507 321040, Silesian University of Technology in Gliwice, Poland.