Effect of Thermo-Mechanical Treatment with Various Annealing Hold Conditions on Al Alloyed TRIP Steel

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Heat and thermo-mechanical treatment of TRIP (transformation induced plasticity) steels conventionally containes an annealing hold in the temperature region of bainitic transformation to obtain microstructure suitable for utilization of TRIP effect. The hold ensures stabilization of retained austenite and formation of sufficient amount of bainite.The conditions of this hold play an important role in obtaining good combination of high strength and total elongation of TRIP steel. This article deals with the effect of temperature and duration of a bainitic hold on the final microstructure and mechanical properties of TRIP steel processed by thermo-mechanical treatment. The holds in the interval of 350 – 500 °C were used with hold times of 25 – 1200 s. Tensile strengths of 815-976 MPa were obtained in combination with total elongations of 27-45%. The best combinations of tensile strengths around 850 MPa with total elongations above 40% were achieved for the holds at 450 °C.

Keywords: TRIP steel, aluminium alloying, retained austenite

1 Introduction

Increasing demands of an automotive industry on mechanical properties of used materials have been fuelling intensive work on new types of advanced high strength steels [1,2,3]. TRIP (transformation induced plasticity) steels belong to the first generation of modern AHSS (Advanced High Strength Steel). Chemical composition of original TRIP steels was based on a simple concept of 1-2% of silicon and manganese and 0.2-0.4% of carbon [1]. It was later demonstrated that higher silicon contents, which were used to prevent carbide precipitation during the processing, were responsible for low quality of surface of the steel causing problems during galvanizing [4, 5]. Silicon can be fully or partially replaced by aluminium, which also postpones precipitation of cementite and increases the strength by solid solution strengthening. Both of these effects are however lower than in the case of silicon for the same amounts of both elements [6, 7]. This is the reason why only partial substitution of silicon by aluminium is recommended to keep the strength relatively intact. Formation of carbides during the processing of TRIP steels is undesirable, as the carbon is needed for chemical stabilization of retained austenite. TRIP steels are typically produced by heat or thermo-mechanical treatments [1-7]. In both cases, an annealing hold at the temperatures where bainitic transformation occurs is applied as an important step of the processing. The risk of carbides precipitation is the highest during this hold at relatively high temperatures around 425 °C. The hold should be long enough to ensure that most of the remaining austenite will transform to bainite and the rest of the austenite will be properly stabilized against martensitic transformation during final cooling. On the other hand, the hold must not be too long to prevent precipitation of carbides, particularly cementite. Carbon in TRIP steels is needed for chemical stabilization of a sufficient amount of retained austenite and therefore carbide formation during the processing of the steel is undesirable. Stability of retained austenite is more important for the mechanical performance of the steel than the volume fraction of retained austenite itself [8-10]. The stability depends mainly on carbon content and morphology of a particular grain of retained austenite and also on the distribution in the multiphase microstructure. The effect of neighbouring phases on the behaviour of austenitic islands during plastic deformation was already observed by detailed EBSD analysis and in-situ experiments [9-11]. There is also a second reason why the effect of the conditions of this annealing hold on mechanical properties should be investigated. Large volumes of commercially produced TRIP steel sheet parts are undergoing hot dip galvanizing operation in the last state of their production, which is typically taking place at higher temperatures around 450 °C for relatively short times [4]. However, typical annealing temperatures of high strength low-alloyed steels are slightly lower, mainly in the region of 400 °C - 425°C. Therefore, it will be of a benefit for a particular TRIP steel grade, if the hold at higher temperatures around 450 °C would also yield good mechanical properties and could be used to combine bainite formation hold with galvanizing.

2 Experimental program

Low carbon low alloyed steel with partial substitution of silicon by aluminium was designed for this experimental work, containing 0.2% of carbon, 0.6% of silicon, 1.5% of aluminium, 1.5% of manganese microalloyed by 0.06% of niobium. Content of alloying elements is given in weight percent. Micro-alloying by niobium should provide technological advantage of suppressing pearlite formation during slow cooling, as was demonstrated for low alloyed TRIP steel with similar chemical composition, but without aluminium [11, 12]. TTT (Time temperature transformation) diagram of this steel was calculated in JMatPro for a soaking temperature of 900°C. The diagram shows that pearlite nose of this steel is indeed shifted markedly to the longer transformation times in comparison to bainitic nose, enabling the production of bainite based microstructures. Calculated interval of bainitic transformation lies approximately between 350 °C – 540 °C.

The steel was vacuum cast and the 250 kg ingot was cut into four parts. Parts of the ingot were soaked at the temperature of 1150°C and forged into bars. The bars were finally annealed for two hours at 950 °C and air cooled to room temperature. Simple thermo-mechanical treatment was carried out using thermo-mechanical simulator to ensure repeatability of the processing parameters. Based on published results achieved on similar steel [13] and previous experiments [14], 100 s long soaking hold at 900 °C was carried out, with subsequent cooling by 30 °C/s to various annealing hold temperatures in the region of 350 °C -500°C. Two compressive deformations were applied during the cooling, the first one at the end of the soaking hold at 900 °C and the second one always at 720 °C. The holds of 300 s, 600 s, 900 s and 1200 s were tested for the temperatures of 350 °C, 400°C, and 450 °C. Shorter holds of 25 s, 300 s, 600 s and 900 s were used for the highest annealing hold temperature of 500 °C. Medium hold of 600 s was also utilized for annealing temperature of 425 °C to check the development between hold temperatures of 400 °C and 450 °C, where the most interesting combinations of mechanical properties were obtained. All samples were air cooled to the room temperature after the annealing hold.

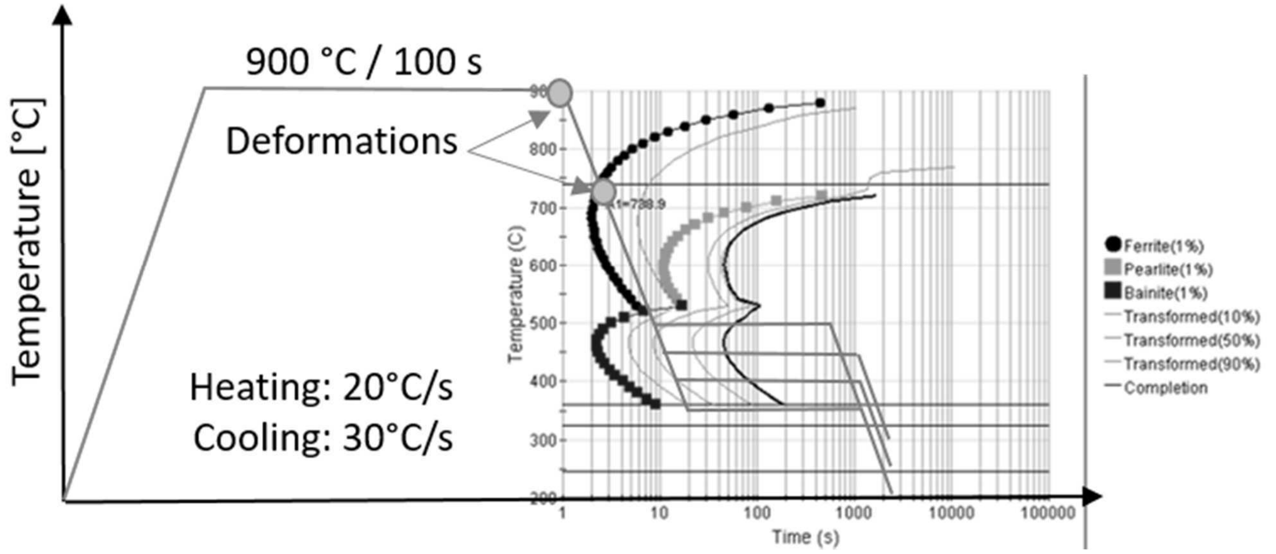
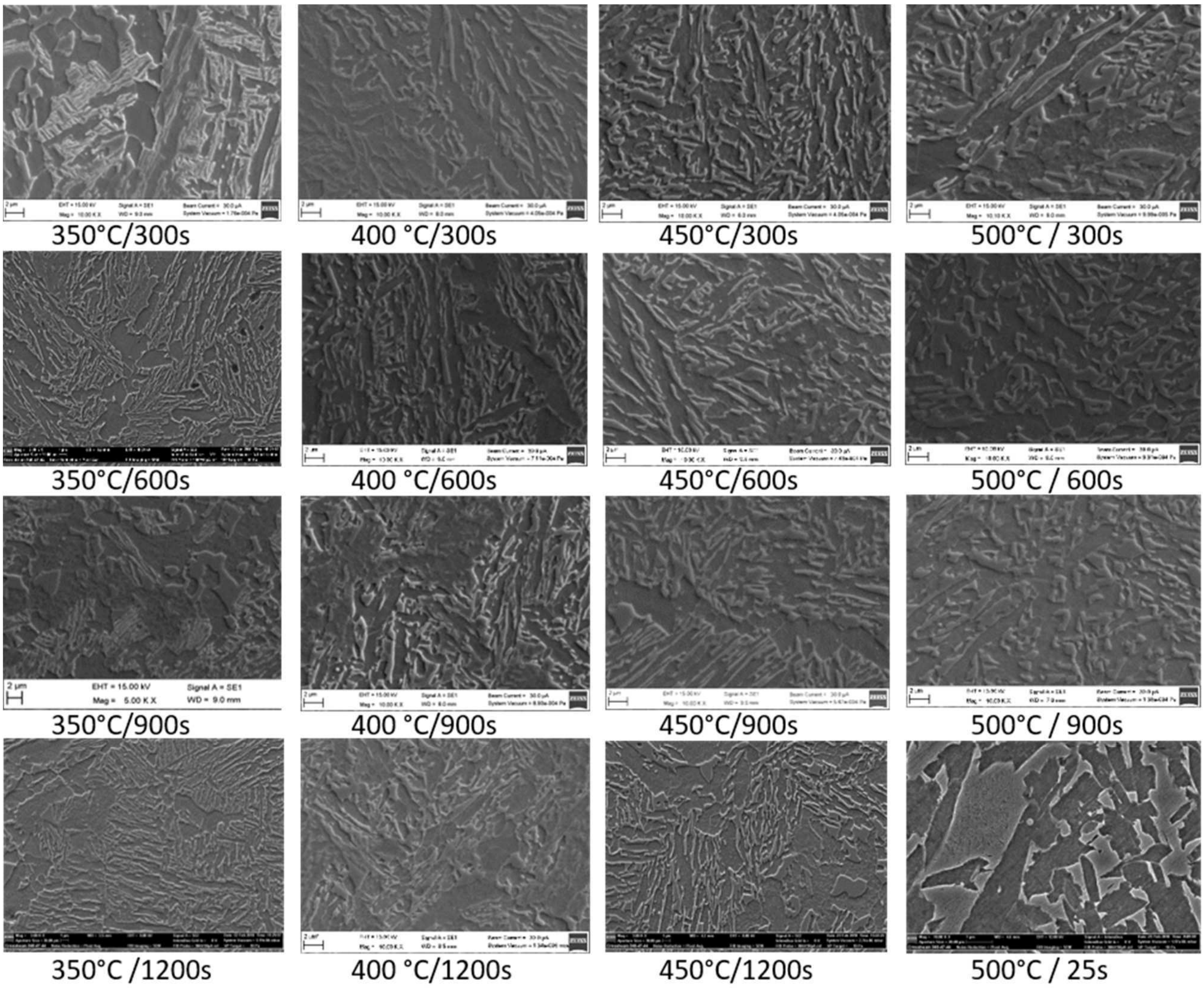


Fig. 1 *TTT diagram of experimental steel calculated in JMatPro software with the scheme of used thermo-mechanical treatment*

Metallographic cross sections were prepared in longitudinal direction (i. e. along the axes of the bars) and etched in 3% Nital. The microstructures were characterized by light and scanning electron microscopy, using an Olympus BX 61 and an EVO 25 Zeiss microscopes respectively. Mechanical properties were tested on sub-size flat samples with the gauge length of 5 mm. Average values of tensile strength and total elongation were calculated from two samples tested for each annealing condition. The volume fraction of the retained austenite was determined by X-ray diffraction phase analysis using an AXS Bruker D8 Discover automatic powder diffractometer with a HI-STAR detector and Co lamp (λKα = 0.1790307 nm). A focusing polycapillary lens was used to achieve an X-ray spot with 0.5 mm diameter. The measurement was carried out in the central part of the samples and spectra were taken in the range of 2 ϑ from 25° to 110°. The integrated intensities of (200) ferrite peak and (111), (002) and (022) austenite peaks were used for evaluation.

3 Results and discussion

According to the JMatPro calculation (Fig. 1), bainitic transformation should be finished at all tested hold temperatures within the first 100 s of every hold and therefore carbide precipitation could be expected to occure during the longest holds of 1200 s. The only hold which should finish before completition of bainite transformation is 25 s hold at 500 °C. In the microstructure prepared by this treatment, larger amounts of martensite could be produced during the cooling. Samples with annealing hold at 350 °C (Fig. 2, Fig. 3) obtained tensile strengths around 900 MPa with total elongation around 29% (Fig. 4). High strength was accompanied by high hardness of 297 HV 10. Relatively low amount of retained austenite around 10% was detected, which might explain lower total elongations. The microstructure consisted of bainitic matrix with the chains of fine polygonal ferrite grains lining the boundaries of prior austenite grains (PAG). This ferrite formed during the cooling from a soaking temperature and was present in all the microstructures, regardless of the annealing temperature or hold duration. Bainite was predominantly of the lath type with dense and long laths of bainitic ferrite. Larger islands of M-A constituent (islands of austenite which partially transformed to martensite during cooling) were found at the edges of bainitic blocks, particularly in the microstructure prepared by the shortest hold of 300 s. Longer holds at 350 °C resulted in a slight increase of elongation and retained austenite volume fraction and decrease in tensile strengths (Fig. 4).


350°C/300s
400 °C/300s
450°C/300s
500°C / 300s
350°C/600s
400 °C/600s
450°C/600s
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350°C/900s
400 °C/900s
450°C/900s
500°C / 900s
350°C /1200s
400 °C/1200s
450°C/1200s
500°C / 25s

Fig. 2 *Microstructure overview for various annealing hold conditions.*

Higher annealing hold temperature of 400 °C generally resulted in finer bainitic matrix, with shorter laths of bainitic ferrite and more homogenous distribution of bainite (Fig. 2). There was no visible difference in the microstructures obtained by processing with various hold times. Tensile strengths around 820 MPa and total elongation around 38% were achieved, due to the increasing amount of retained austenite (13%) (Fig. 4). There wasn´t any trend in development of mechanical properties with changing hold time, the small differences can be attributed rather to the scatter of measured values.

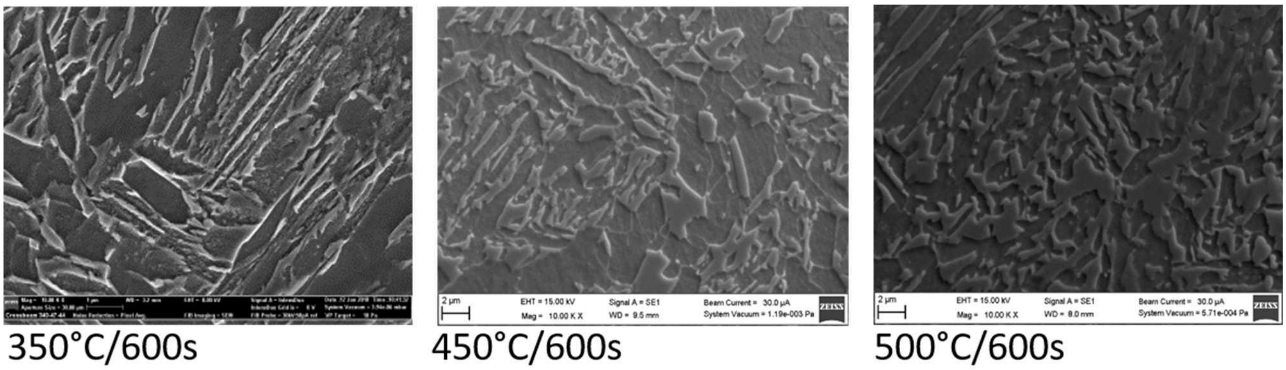
350°C/600s
450°C/600s
500°C/600s

Fig. 3 *Comparison of microstructures obtained for 600s annealing holds*

The best total elongations around 43% were achieved by thermo-mechanical treatments with annealing holds at 450 °C, with good tensile strengths around 850 MPa (Fig. 4). This excellent combination of mechanical properties corresponded to the highest volume fraction of austenite retained in these microstructures (around 17%). In comparison to microstructures provided by treatments with lower annealing holds, bainitic matrix was in these cases formed by a mixture of fine lath bainite and increasing amount of granular bainite with larger islands of retained austenite (Fig. 2, Fig. 3). There was again no visible difference between microstructures provided by treatments with various holding times and also their mechanical properties did not differ significantly and carbide precipitation was not observed for any sample.

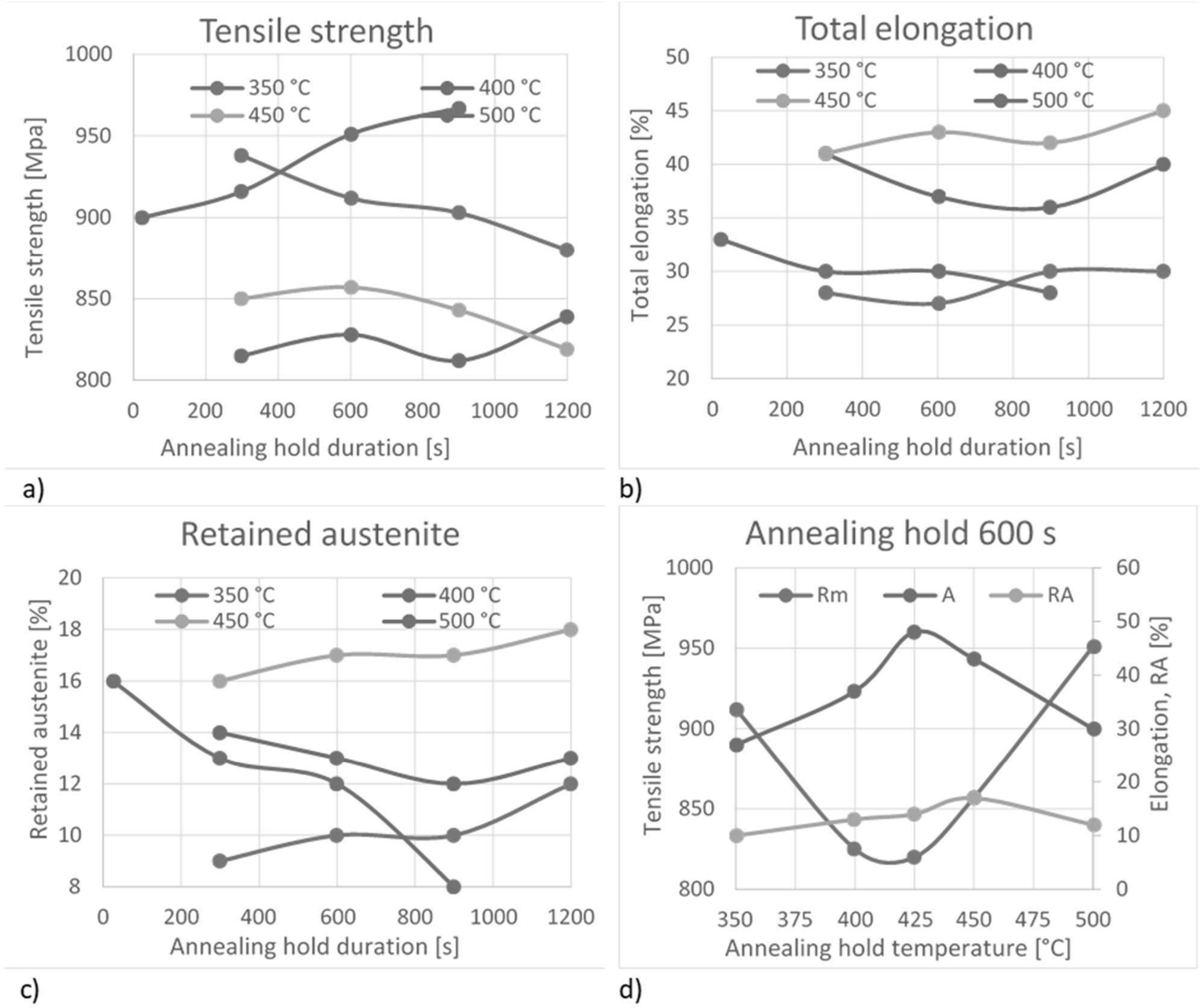

Fig. 4 *Development of mechanical properties and retained austenite volume (RA) for various annealing hold conditions: a) tensile strength, b)ttotal elongation, c) retained austenite d) Comparison of tensile strength, total elongation and retained austenite volume fraction for samples with annealing hold 600s.*

Finally, the highest annealing hold of 500 °C resulted in the biggest increase of strength to 930 MPa, while total elongation dropped to 30% and retained austenite volume fraction to 10% (Fig. 4). The microstructures consisted again of the mixture of lath and granular bainite and larger islands of M-A constituent with large fractions of martensite (Fig. 2, Fig. 3). Individual larger areas of martensite were particularly observed in sample processed by the shortest annealing hold of 25s, confirming that this hold was too short to complete bainitic transformation. On the ohter hand, lower bainite formed during the cooling from the annealing hold temperature to the martensite start temperature was probably responsible for relatively low strenght of 900 MPa obtained by this mixed microstructure. With longer holds at 500 °C, the elongation slightly decreased (together with retained austenite amount), while tensile strength gradually increased from 900 MPa for 25s hold to 976 MPa for 900 s hold. This increase of the strenght might have been caused by the early stages of carbides precipitation, which could not yet be detected in the micrographs, but which were already able to atribute to precipitation strenghtening. It should be noted that in the case of various holds at 500 °C, mechanical properties did follow a trend.

The highest tensile strength vas obtained for samples with longer holds at the temperature of 500 °C. However, elongation values of these samples showed gradual decrease with increasing hold duration with the best combination of tensile strength of 950 MPa and total elongation of 30% for 600s hold. Generally, 600 s holds seems to be the most convenient for achieving good mechanical properties for all tested temperatures (Fig. 4).

The development of the retained austenite volume fraction corresponded closely to the trends of development of total elongation (Fig. 4b,c).

4 Conclusions

A set of annealing holds at the temperatures of 350 °C -500 °C with the durations of 25s -1200 s was tested within thermo-mechanical treatment of low alloyed TRIP steel with partial substitution of silicon by aluminium. Resulting mechanical properties suggested that the most convenient temperature for the processing should be chosen around 450 °C. Annealing at this temperatures resulted in an interesting combinations of tensile strengths around 850 MPa with high total elongations above 40%. It can be stated that the duration of the annealing hold at this temperature can be varied between 300 s and 900 s without significant changes in obtained elongation and tensile strength. This relatively high annealing temperature has a good practical potential also with respect to the finishing hot dip galvanizing treatment of processed TRIP steel sheets, which is typically taking place around the temperature of 445 °C.

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