

## INFLUENCE OF ALUMINIUM ON RETAINED AUSTENITE STABILIZATION DURING THERMOMECHANICAL TREATMENT OF LOW-ALLOYED TRIP STEEL

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## VLIV HLINÍKU NA STABILIZACI ZBYTKOVÉHO AUSTENITU BĚHEM TERMOMECHANICKÉHO ZPRACOVÁNÍ NÍZKOLEGOVANÉ TRIP OCELI

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### Abstract

TRIP steels are multiphase steels. At present, they find their use primarily in the automotive industry, where they are most frequently utilized for manufacturing body panels. The thin-walled hollow semi-products obtained by thermomechanical treatment could represent new possible applications. In standard TRIP steels cementite precipitation during bainitic transformation and retained austenite stabilization are carried out mainly through silicon alloying. Silicon at higher concentrations causes problems with surface quality in some applications. One of the alloying elements being taken into consideration for silicon replacement is aluminium, whose addition not only restricts carbide and pearlite formation during bainitic transformation, but also increases formation of acicular ferrite. A lower value of solid solution hardening and the increase of the  $M_s$  temperature represent the disadvantages of aluminium addition. Thermomechanical treatment with various parameters of bainitic transformation was investigated on the 0.26C-1.5Mn-1.3Al steel with the aim of determining how aluminium affects structure development, retained austenite stabilization and mechanical properties. Experimentally achieved structures were analyzed by means of light and confocal microscopy. The fraction of ferrite and retained austenite as well as the size of ferritic grains were determined via image analysis.

**Key words:** TRIP steel, aluminium addition, thermomechanical treatment, retained austenite

### Introduction

The amount of carbon and silicon in alloying strategies of low-alloyed TRIP steels are restricted by their negative effects on some properties, e.g. weldability and scaling. This is why some other alloying elements are used for further improvement of mechanical properties and technological behaviour.

One of the alloying elements coming into consideration for silicon replacement is aluminium. It is known that silicon can partly be replaced by aluminium assuming an increase of carbon content [1]. Complex alloying by silicon, aluminium and phosphor also come into account as another alternative (Fig.1).

Aluminium decreases the carbon activity in ferrite and increases its dissolubility. At the same time, aluminium increases the starting temperature of cementite formation and mainly accelerates the kinetics of bainitic transformation [2],[3].

The addition of aluminium not only significantly restricts the carbide and pearlite formation during bainitic transformation but it increases acicular ferrite building as well. It causes the content of bainite to increase and the retained austenite to decrease. Thus the concentration of carbon in retained austenite grows making the retained austenite more stable. [4],[5],[6]

Having lower efficiency compared to silicon aluminium contributes to the ferritic matrix hardening only very weakly. Complete replacement of silicon by aluminium worsens the ratio between strength and ductility [7]. In the case of aluminium alloying the transformation temperature of austenite to deformation induced martensite  $M_d$  rises, which leads to austenite destabilization and partial shift of the temperature interval  $M_s$ - $M_d$  above room temperature [3].

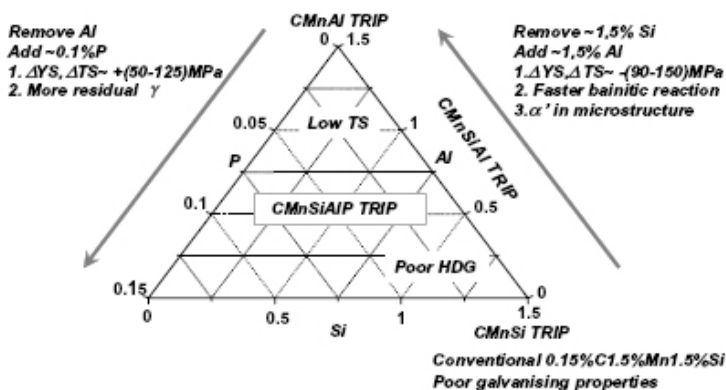


Fig.1 Influence of alloying elements on transformation process during cooling [3]

The aims of the experiment were to detect the effects of replacing silicon by aluminium and investigate its influence on the delay of cementite precipitation and thus on preserving retained austenite stability. The next step involved determining the impact of aluminium on solid solution hardening. The treatment we designed focused on investigating the behaviour of bainitic transformation at various temperatures, attempting primarily to obtain ferritic-bainitic structure with a sufficient fraction of retained austenite and fine ferritic grain.

The temperature and holding time in the region of bainite transformation represent an important part of the thermomechanical treatment design. Bainite transformation in TRIP steels generally takes place in the temperature interval between 400-450°C during an isothermal holding. This transformation is of a shear and diffusionless type and it develops in the so called "over ageing zone" [8]. It consists of two steps. Firstly, the ferrite laths are formed from the nontransformed austenite. Secondly, cementite precipitates on the interface of austenite and ferrite [9].

## Experimental Program

Low alloyed C-Mn-Al TRIP steel was used for the experiment. In this steel silicon was almost completely replaced by aluminium (Table 1). The thermomechanical treatment was

carried out on a thermomechanical simulator, which allows precise controlling of the regime's temperature and deformation behaviour (Fig. 2). The precise control of the regime's behaviour makes physical modelling of real processes possible. Each deformation step consisted of tension and compression in order to obtain very high deformation intensity.



Fig.2 Thermomechanical simulator

The first regime applied to the thermomechanical simulator consisted of austenitization at 900°C with 20 s holding time, twenty step deformation in the temperature range of 900-720 °C and 600 s holding of bainitic transformation at 425 °C. Very fine structure with 9 % of retained austenite, 57 % of ferrite and with the ferritic grain of about 1.8 μm (Fig.3) was obtained.

Table 1 Chemical composition of TRIP steels [% wt.]

C	Mn	Si	P	S	Cr	Ni	Cu	Al	Nb	Mo	W
0.206	1.418	1.849	0.007	0.005	0.007	0.071	0.059	0.006	0.002	0.02	0.02
0.26	1.455	0.02	0.007	0.003	0.000	0.068	0.055	1.32	0.000	0.02	0.01

To compare the supportive impact of deformation on ferrite formation and grain refinement the regime with forty step deformation in the same temperature region was carried out (Fig. 4). No difference was observed between both structures. In other words, no effect of deformation on ferrite formation as well as further ferritic grain refinement was detected. The fraction of retained austenite was measured by means of image analysis after two step etching. X-ray diffraction analysis was used for validation of the retained austenite fraction. In order to eliminate effects of potential structure texture caused by deformation the measurement was carried out in three different tilt-angles of the specimen.

Regimes with various temperatures and holding times of bainitic transformation were used to investigate the influence of aluminium on the delay of cementite precipitation. The austenitization conditions, i.e. temperature and holding time, were identical for all these regimes. Based on previous experience three temperatures of bainitic transformation equal to 405, 425 and 450 °C and two various holding times of 100 and 600 s were chosen (Table 2).

The structures we obtained consisted of ferrite, bainite and retained austenite (Fig. 4, Fig. 5, Fig. 6). Only a very few islands of retained austenite contained the MA component. After each tested regime the volume fraction of ferrite between 57-59 %, average size of ferritic grain around 2 μm and volume fraction of retained austenite around 10 % were measured. Some coarser bainitic formations of approximately 15 μm appeared as well. Retained austenite

occurred in its granular as well as needle-like form. A higher amount of retained austenite was present between bainitic laths, which implies the presence of the needle-like form. This confirms the higher stability of the needle-like form compared to the granular type. No temperature of bainitic transformation or any holding time led to a significant decrease of the retained austenite volume fraction, which could further lead to worse mechanical properties. Even for very low temperatures of bainitic transformation just above the  $M_s$  temperature, no significant amount of temperature induced martensite was observed.

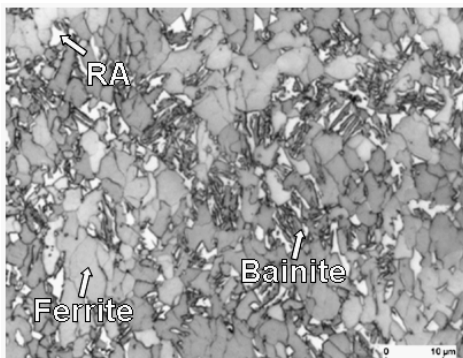


Fig.3 Twenty step deformation,  $T_B$ : 425°C/600s, two step etching

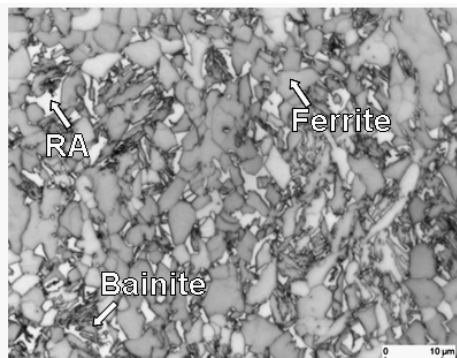


Fig.4 Forty step deformation,  $T_B$ : 425°C/600s, two step etching

Table 2 Influence of various intensities of true strain and the influence of various temperature and holding times of bainitic transformation on structure development:  $T_A$ - temperature of austenitization [°C],  $t_A$ - time of austenitization [s],  $T_B$ - temperature of bainitic transformation [°C],  $t_b$ - holding time at temperature of bainitic transformation [s],  $\phi$  - true logarithmic strain [-]

$T_A$ [°C]	$t_A$ [s]	$T_B$ [°C]	$t_b$ [s]	$\phi$ [-]	Structure	Fraction of ferrite [%]	RA – image analysis [%]	RA – X-ray diff. [%]	Size of ferritic grains [μm]
900	20	425	600	2.8	ferrite + bainite + retained austenite	57	9	14	$2 \pm 0.8$
			600			57	9	13	$2.1 \pm 1.1$
		450	100	10.4		58	11	13	$2.1 \pm 1.2$
			600			58	9	12	$2.4 \pm 1.3$
		405	100	59		10	13	$2 \pm 1.2$	
			600	60		-	11	$2.1 \pm 0.9$	

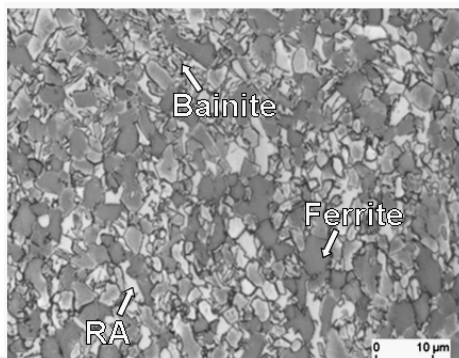


Fig.5 Forty step deformation,  $T_B$ : 425°C/100s, two step etching

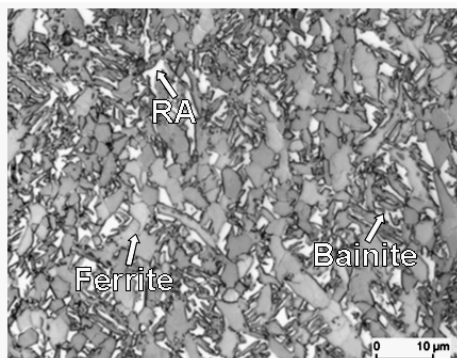


Fig.6 Forty step deformation,  $T_B$ : 450°C/600s, two step etching

## Mechanical Tests

Mechanical properties were evaluated by tensile test as well as Charpy impact test. Both tests were carried out on mini-specimens, which had been cut from the central part of thermomechanically treated specimens (Fig. 7).

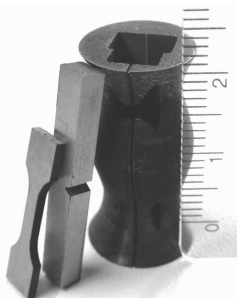


Fig.7 Specimens for mechanical tests

Applying the regimes with the temperature of bainitic transformation equal to 450 °C, a tensile strength of about 640 MPa and  $A_{3,2}$  ductility of around 30 % was measured for both the 100 and 600 s holding times.

With the temperature of bainitic transformation being 425 °C, great differences were observed between the two holding times of 100 and 600 s. For the 600 s holding time, a tensile strength of 649 MPa and 26 % ductility were measured, which does not significantly differ from the results obtained at the higher temperature of bainitic transformation. The shorter holding time of 100 s led to a strong increase of tensile strength up to 740 MPa and high ductility of 36 %. At the lowest temperature of bainitic transformation of 405 °C and 600 s holding time, the lowest tensile strength of 601 MPa and ductility of only 23 % was obtained. These worse mechanical properties may have been caused by the influence of aluminium on the shift of the  $M_s$  temperature to higher values. The austenite in the structure was presumably not stable enough to significantly influence mechanical properties.

These results imply that specimens with 100 s bainitic holding at 425 °C featured the highest stability of retained austenite during subsequent cold forming. Lower tensile strength compared to the standard alloyed C-Mn-Si TRIP steel in general is caused by a lower ability of aluminium to harden the solid solution.

Table 3 Mechanical properties of tested structures

$T_A$ [°C]	$t_A$ [s]	$T_B$ [°C]	$t_B$ [s]	$R_{p0,2}$ [MPa]	$R_m$ [MPa]	$A_{3,2}$ [%]	Z [%]	KCV [J.cm <sup>-2</sup> ]
900	20	425	600	500	649	26	64	60
			100	487	741	36	67	62
		450	600	473	647	31	45	62
			100	444	641	28	64	50
		405	600	455	601	23	65	59

The results of the Charpy impact test on specimens with 4x3 mm cross-section and a 1 mm deep V-notch showed no significant differences for the tested regimes. Notch toughness fell into the interval from 59 to 62 J.cm<sup>-2</sup> in all the cases except for the regime with a temperature of bainitic transformation at 450 °C and 100 s holding time, where the value decreased by 10 J.cm<sup>-2</sup>. The instrumented Charpy impact test implies that all the fractures show the characteristics of ductility failure.

## Conclusion

The experiment compared the influence of bainitic transformation temperature and holding time on the structure development during thermomechanical treatment. The metallographic evaluation did not discover any significant difference between individual structures. Besides bainite the structure contained 57-59 % of ferrite and 9-11 % of retained austenite, with the average size of ferritic grain being approximately 2  $\mu\text{m}$ .

The best mechanical properties were reached with the bainitic transformation at 425 °C and 100 s holding time. Under these conditions of thermomechanical treatment, the nominal yield strength of 487 MPa, tensile strength of 741 MPa and ductility of 36 % were achieved. Notch toughness of 62 J.cm<sup>-2</sup> was measured on the mini-specimens.

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