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REFINEMENT OF TRIP STEEL MICROSTRUCTURE BY INCREMENTAL DEFORMATION

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Abstract: *TRIP steels represent a modern group of low alloyed steels offering a potential for excellent combination of strength and ductility. Unconventional forming methods employing the TRIP effect at final cold forming operation require not only very fine structure but also appropriate combination of phases in these steels. The microstructure development can be controlled by appropriate temperature interval and amount of incremental deformation. In this study, the influence of various temperature ranges and strain magnitudes in 20-step deformation schedule on grain refinement was investigated. Suitable parameters of the schedule led to ferrite-bainite microstructure with 15% retained austenite, ferrite grain size of about 2 um and elongation of about 30%.*
Key words: *multiphase steel, TRIP steel, incremental deformation, thermomechanical treatment*

1. INTRODUCTION

Low alloyed high strength steels represent new structural materials of recent decades. Upon appropriate heat or thermomechanical treatment, they can exhibit very good mechanical properties (Jirkova et al., 2009).

These materials include the group of TRIP steels. These are multiphase steels, whose microstructure consists of ferrite, bainite and a small amount of retained austenite (Bleck, 2002). They feature a good combination of strength and ductility provided by the TRIP effect based on the deformation induced martensitic transformation (Bleck, 2002). Thanks to their high capacity of energy absorption and good fatigue limit, they have recently been used in the automotive industry for making safety components (Li et al., 2011). These include, for example, seat structures, cross-members, long post reinforcements, aprons and fender reinforcements.

The aim of this research was to investigate the influence of the deformation temperature interval and of the strain intensity on grain refinement and the microstructure structure for the purpose of a novel application.

2. INFLUENCE OF DEFORMATION ON MICROSTRUCTURE DEVELOPMENT

The influence of deformation on TRIP steels covers several aspects. It does not concern only the grain refinement but also the distribution and the final morphology of individual phases.

The deformation in the intercritical region from 730 to 800°C increases the volume fraction of ferrite by accelerating nucleation. When undeformed austenite transforms to ferrite, the nucleation is only possible on the grain boundaries. However, in case of transformation of deformed austenite, ferrite forms within the austenite grains, as well as on their boundaries (Basuki et al., 1999; Godet, 2004). Plastic deformation in the intercritical region speeds up the bainitic nucleation as well, but slows down its growth at the same time. Consequently, the bainite regions are smaller and the volume fraction of bainite decreases (Basuki et al., 1999; Godet, 2004). At the same time, it decreases the volume fraction of needle-like retained austenite. For this reason, higher fraction of retained austenite is obtained in a globular form. The grains of retained austenite after deformation are smaller, and thus possess higher mechanical and chemical stability.

3. EXPERIMENTAL

For the experimental program, a low alloyed TRIP steel was chosen (Tab.1.). It is a low-cost steel, whose main alloying elements play an important role in controlling the transformation processes and stabilizing retained austenite.

The treatment schedule was simulated in a thermomechanical simulator with precise temperature and deformation control. The microstructures were examined using various metallographic methods. An appropriate etching method highlighting ferrite and retained austenite in the microstructure had to be devised. The microstructure was revealed by Nital etching, by two step etching using Nital + $Na_2S_2O_5$ water solution and by KLEMM etching colouring the retained austenite. The volume fraction of retained austenite was determined by X-ray diffraction.

The experimental program was divided into two parts. In the first part, the influence of 20-step deformation in various temperature intervals was investigated (Tab. 2). In the second, the influence of the cumulative amount of deformation on structure refinement was explored (Tab. 3).

3.1 Influence of 20 step deformation within various temperature intervals

At this stage, a suitable temperature window for deformation was sought. Austenitization at 900°C with the hold of 20s was followed by 20 step deformation with φ=2.8 across various temperature intervals. The temperature interval was chosen to cover both intercritical and lower temperature regions.

C	Mn	Si	P	S	Cr	Ni	Cu	Nb
0.19	1.45	1.9	0.02	0.07	0.07	0.03	0.04	0.003

Tab. 1. Chemical composition C-Mn-Si [wt. %]

Deformation interval [°C]	Number of def. steps /φ [-]	Size of ferrite grain [μm]	Ferrite [%]	RA [%]	HV10
900 – 720	20/2.8	2.3±1	51	15	241
900 – 650		2.3±1.2	64	5	256
900 – 600		2.6±1.1	-	-	256
850 – 650		2.5±1.2	-	-	259
850 – 600		2.2±1.1	-	-	263
850 – 720		2.4±1.2	52	-	247
800 – 600		2.5±1.2	-	-	266

Tab. 2. Effect of 20-step deformation within various temperature intervals

Deformation interval [°C]	Number of def. steps /φ [-]	Size of ferrite grain [μm]	Ferrite [%]	RA [%]	HV10
900-720	20/2.8	2.3±1	51	15	241
	40/5.8	2.1±0.9	55	-	-
	40/10.4	2.1±0.9	60	10	245
	60/13.4	2.1±1.1	59	20	239
	60/15.8	Specimen destruction			

Tab. 3. Influence of different true strain amount on structure development

After deformation within the temperature interval between 900 and 720°C, fine ferrite-bainite structure with 15% of retained austenite was obtained (Fig. 1). The tensile strength reached 832 MPa with A_{5mm} ductility of over 32%. Expanding the temperature interval for deformation from 900°C down to 650 and 600°C caused pearlite to form in the structure. Pearlite is an undesirable phase in the TRIP steel microstructure, as it reduces the content of carbon in retained austenite, thus inhibiting its stabilization. The shift of the last deformation step down to 650°C led to stabilization of only 5% retained austenite (Tab. 2).

In other schedules, the temperature of the first reduction was decreased to 850°C in order to explore the influence of deformation applied in the intercritical region. Three temperature intervals of deformation were tested under these conditions (Tab. 2). When the last deformation step was shifted to 650°C or 600°C, pearlite formed, as in the previous cases. After the deformation interval of 850°C - 720°C, very fine ferrite-bainite structure with a high ferrite volume fraction and fine ferritic grain was obtained again.

In the last variant with deformation temperature from 800°C to 600°C, the impact of incremental deformation in the intercritical region and below was studied. A ferrite-pearlite structure with minimum volume fraction of bainite was obtained.

As evidenced by the experimental results, the temperature interval from 900 to 720°C appears to be the most suitable choice for deformation. Deformation applied in this temperature range promotes formation of the desirable volume fractions of ferrite and bainite and also prevents pearlite from forming.

3.2 Influence of accumulated deformation on microstructure development

The magnitude and intensity of deformation have substantial influence on resulting distribution and morphology of phases in TRIP steels. In this experiment, deformation was applied between 900 and 720°C. First, forty step deformation was applied with two different magnitudes of deformation steps (Fig. 1). Thus, two different true strain intensities of 5.8 and 10.4 were obtained. The same single-step amount of deformation was then used for the sixty step deformation (Tab. 3).

The schedule with 40 step deformation and smaller deformation steps with the final true strain of φ=5.8 produced very fine ferrite-bainite structure with 55% ferrite and 9% retained austenite. The ferrite grain size of 2.1±0.9 μm approaches the known physical limit of grain size achievable by thermomechanical treatment.

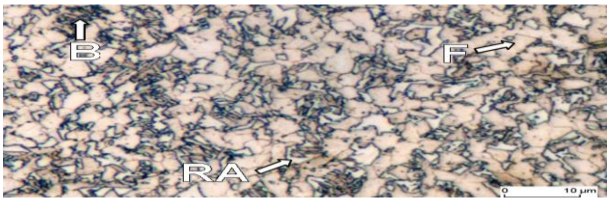

Fig. 1. 20-step deformation: 900-720°C, two step etching (Nital + 10% Na2S2O5 water solution)

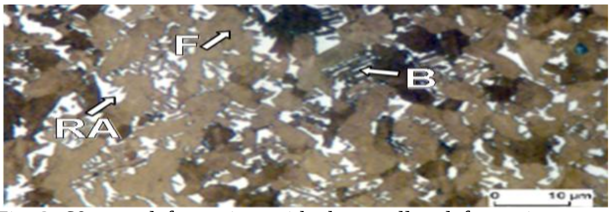

Fig. 2. 60-step deformation with the smaller deformation step: 900-720°C, KLEMM

Upon 40-step deformation with larger deformation steps and final true strain of 10.4, almost twice as high as the strain in the previous schedule, the ferrite fraction rose to 60% with the same ferrite grain size as above. The microstructure with high ferrite fraction and 10% retained austenite showed elongation of A_{5mm} = 34% and strength of 818 MPa. The fracture surface after tensile test was of ductile-type with dimple morphology. Further increase of true strain to 13.4 in sixty deformation steps brought no significant further refinement of microstructure and no further increase in ferrite volume fraction or grain refinement (Fig. 2). With another increase in true strain up to 15.8, the material exhausted its plastic capacity and the sample failed.

4. CONCLUSIONS

The effects of various deformation temperature intervals and deformation intensities were investigated on low alloyed high strength TRIP steel. It was found that if deformation finished at a temperature of 720°C or higher, very fine ferrite-bainite structure with retained austenite fraction between 10 to 15% was obtained. An increase in incremental deformation intensity refined ferrite grain to 2 μm and led to an increase in ferrite fraction up to 60%.

Future studies will focus on description of the effect of cooling rate on microstructure development.

5. ACKNOWLEDGEMENTS

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