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The Influence of Thermomechanical Treatment of TRIP Steel on its Final Microstructure

Bohuslav Mašek, Hana Staňková, Zbyšek Nový, Lothar W. Meyer, and Adam Kracík

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Higher demands are currently being made on material properties and their combinations, for example, high strength steel with good cold formability. With increasing strength, material formability generally worsens, but with some kinds of steels, for example, with TRIP steel, it is possible to obtain an excellent combination of strength and ductility. However, these materials are interesting not only for use as sheets but also for other applications. Semi-products with thin walls represent the best way of further extending TRIP steels into the bulk forming area. This trend supposes that suitable technological conditions will be found and the process for a chosen production procedure will be optimized. The model optimization of the process for TMT with incremental deformations was experimentally carried out on a thermomechanical simulating machine. Microstructures obtained by the model treatment were analyzed by means of optical and electron microscopy.

Keywords incremental forming, multiphase steel, thermomechanical treatment, TRIP steel

1. Introduction

Classical thermomechanical treatment (TMT) with isothermal deformation is very well known, and it is often used in standard practice for grain refinement to achieve the required mechanical properties. In various TMT strategies, the deformation can be applied before the phase transformation in the region of stable or metastable austenite, during the phase transformation whether pearlitic, bainitic, or martensitic, or even after the phase transformation.

The amount of deformation is often limited by the material behavior; the parameters of the technology in use including the kind, amount, and rate of deformation; and the possibilities of the forming machines such as the kinematics of the forming process, forming tool movement, and the rate and acceleration of forming tools. When applying TMT with incremental deformation, the deformation can be divided into several smaller deformation steps. As a consequence the forming forces decrease, allowing the use of less robust forming machines. Outstanding sets of mechanical properties can be achieved by combining contemporary progressive technologies with new material types. This can be illustrated, for instance, with TRIP steels (TRansformation Induced Plasticity steel).

TRIP steels are multiphase steels and their structure consists of ferrite, bainite, and a small amount of retained austenite (Ref 1). Because of their high capacity of energy absorption and good fatigue limit, they have recently been used in the automotive industry for constructing safety components. These include, for example, seat structures, cross-members, long post reinforcements, aprons, and fender reinforcements (Ref 2). They feature a good combination of strength and ductility ensured by the TRIP effect caused by the deformation-induced martensitic transformation. Other newly examined possibilities combining multiple technologies should be taken into consideration. These include TMT or just heat treatment in connection with incremental bulk cold forming. This research aims to explore the behavior of materials under specific conditions of selected unconventional TMT applications and to determine suitable technological parameters for their development.

2. Experiment

During the experiments, various conditions of model TMT were tested. The aim of this work was to obtain the required microstructures, which consist of ferrite, bainite, and retained austenite. The standard Mn-Si TRIP steel was used (Table 1). This steel is a low-cost steel with the main alloying elements playing an important role in the controlling of the transformation processes and in the stabilization of retained austenite.

A thermomechanical simulating machine was used for modeling and development of the thermomechanical process. The thermomechanically treated specimens were metallographically evaluated by means of light and electron microscopy. The volume fraction of retained austenite was detected by x-ray diffraction or it was determined together with the grain size and volume fraction of ferrite by image analysis after two-step etching. The two-step etching proceeded at room temperature. In the first step, the 2% HNO_3 was used for 10 s. The second

Bohuslav Mašek and **Hana Staňková**, Faculty of Mechanical Engineering, University of West Bohemia in Pilsen, Fortech, Univerzitní 22, CZ-306 14 Pilsen, Czech Republic; **Bohuslav Mašek, Hana Staňková** and **Lothar W. Meyer**, Faculty of Mechanical Engineering, Department of Materials and Impact Engineering, Chemnitz University of Technology, Erfenschlager Str. 73, D-09125 Chemnitz, Germany; **Zbyšek Nový**, COMTES FHT, s.r.o., Lobezská E-981 CZ-326 00 Pilsen, Czech Republic; and **Adam Kracík**, PILSEN STEEL s.r.o., Tylova 1/57, CZ-316 00 Pilsen, Czech Republic. Contact e-mail: h.stankova@seznam.cz.

step was carried out with the 10% water solution of $Na_2S_2O_5$ for 60 s.

2.1 Optimization of Anisothermal Deformation

The initial regime of model TMT was taken from the classical TMT with isothermal deformation, which is used for sheet production. An austenitizing temperature of 1050 °C with 5 s hold time was selected. Such conditions represent a compromise between a technical and an economic point of view for a real process. An isothermal 8-step deformation was realized at 650 °C with a subsequent hold time of 600 s at 425 °C. With deformation at such a low temperature the pearlite formation was supported, but instead of a suitable structure for the TRIP effect, an unsuitable ferrite-pearlite microstructure was obtained (Fig. 1, Table 2).

The aim of the next step was, therefore, to suppress pearlite formation while promoting bainite formation. The temperature of incremental isothermal deformation was raised to 720 °C, while keeping other parameters identical. A ferrite-bainite microstructure with 9% retained austenite was achieved in this case (Fig. 1). However, the structure was composed of coarse bainite blocks as a result of such processing.

Isothermal deformation was replaced by an anisothermal route to refine the bainite morphology and to make model processing simpler and closer to real technology. A considerable amount of pearlite developed after deformation in the temperature range of 950 to 600 °C. Therefore, the temperature of the last deformation step was raised. Performing deformation in the range of 950 to 720 °C proved to be most suitable for achieving the required microstructure (Fig. 1). In this case, 14% retained austenite and 62% bainite were observed after such processing (Fig. 1).

Considerable grain refinement was achieved, with grain size of 3 to 4 μm. The tensile strength of about 1000 MPa verified the positive influence of the microstructure on the mechanical properties. Other parameters were not changed during this phase of experiments. The austenitization temperature remained at 1050 °C, with a 5 s austenitization hold time. The isothermal holding time for bainite formation was 600 s at 425 °C.

2.2 Influence of 20-Step Deformation in Various Deformation Intervals

At first, regimes with 8-step and 20-step deformation at the same austenitization temperature were compared (Table 3). The deformation interval spanned 900-720 °C. In the case of the 20-step deformation, the true logarithmic strain was triple that of the 8-step one.

The obtained structures showed similar microstructural features (Fig. 2, 3). In both regimes, a ferrite-bainite structure containing fine ferrite grains was observed. The ferrite volume fraction exceeded 50% with about 10% of retained austenite present. In the eight-step deformation regime, coarse bainitic

Table 1 Chemical composition of C-Mn-Si steel (%)

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

Table 2 Optimization of anisothermal deformation

Deformations		Retained austenite fraction, %	Bainite fraction, %	Tensile strength, MPa	Reduction of area, %
Temperature, °C	Number				
650	8	…	…	723	59.9
720	8	9	56.6	813	25.0
950-600	8	13	59.7	981	33.6
950-650	8	15	52.5	967	38.7
950-720	8	14	62.0	1000	32.3

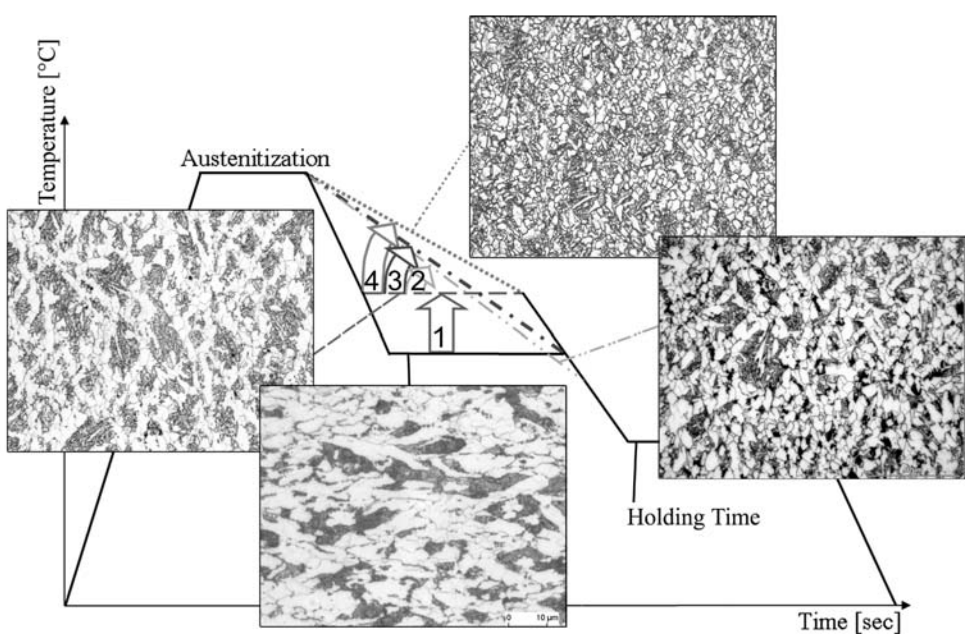

Fig. 1 TMT optimization diagram: step 1—raising the isoforming temperature, step 2—anisothermal straining at 950-600 °C, step 3—reduction of the temperature range for deformation 950-650 °C, step 4—optimized TMT with straining at 950-720 °C (Ref 3)

Table 3 Influence of deformation in various deformation intervals

Interval of deformation, °C	Number of def. steps	φ, −	Grain size of ferrite, μm	Ferrite, %	Ret. austenite, %
900-720	8	0.9	2.8 ± 1.2	52	9
900-720	20	2.8	2.3 ± 1.0	51	11
900-650	20	2.8	2.3 ± 1.2	64	4
900-600	20	2.8	2.6 ± 1.1	…	…
850-650	20	2.8	2.5 ± 1.2	…	…
850-600	20	2.8	2.2 ± 1.1	…	…
850-720	20	2.8	2.4 ± 1.2	52	10
800-600	20	2.8	2.5 ± 1.2	…	…

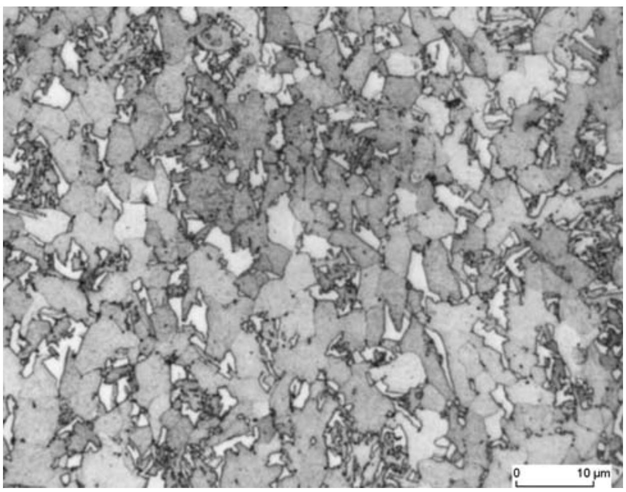

Fig. 2 Eight-step deformation: 900-720 °C, two-step etching

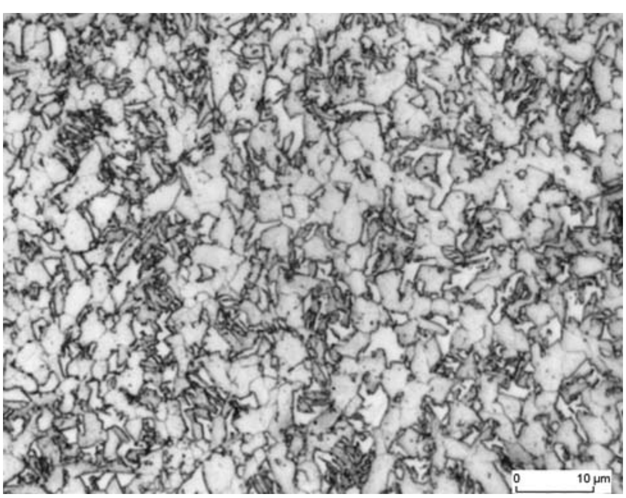

Fig. 3 Twenty-step deformation: 900-720 °C, two-step etching

blocks up to 15 μm occurred. These were refined to below 10 μm by applying the 20-step deformation processing sequence. Increasing the deformation intensity led to further refinement of ferrite grains.

Another optimization task was to study the impact of deformation in the intercritical region and to determine a convenient temperature interval for forming. The process with the 20-step deformation was chosen to compare various temperature regimes.

The possibility of extending the temperature interval of deformation from 900 °C down to 650 and 600 °C was also examined. In both cases, a fine ferrite-bainite structure with a significant volume fraction of pearlite was obtained. Pearlite is an undesirable phase in the TRIP steel microstructure because it reduces the content of carbon in retained austenite, thus also decreasing its stabilization. In the regime with the temperature interval of deformation spanning 900-650 °C, a 7% reduction of retained austenite was observed in comparison to the specimen whose deformation was stopped at 720 °C.

In the other regimes, the temperature of the first deformation reduction was decreased to 850 °C to document the influence of deformation directly in the intercritical region. Three temperature intervals of deformation were tested under these conditions (Table 3). When finishing the last deformation step at 650 or 600 °C, pearlite was present in the resulting structure as well as in the previous cases. In the case of deformation interval from 850 through 720 °C, a very fine ferrite-bainite structure with a high ferrite volume fraction and fine ferrite grain was obtained again. Coarser bainitic formations were observed in the structure in comparison to deformation beginning at 900 °C.

In the last modification with deformation temperature from 800 through 600 °C, the impact of the deformation interval in the intercritical and subintercritical region was studied. A ferrite-pearlite structure with minimum volume fraction of the bainite phase was obtained.

According to the experimental results, the temperature interval from 900 through 720 °C appears to be the most suitable choice for deformation. Deformation in this temperature range supports formation of the desirable volume fractions of ferrite and bainite. It also prevents pearlite from forming, thus ensuring sufficient content of carbon in the solid solution for stabilization of the necessary volume fraction of retained austenite. The experiment further shows the importance of finishing the deformation above 720 °C. The upper limit plays a minor role with such a low temperature of austenitization.

2.3 The Influence of Temperature and Holding Time on Bainite Transformation

The temperature and holding time in the region of bainite transformation represent an important part of the TMT design. Bainite transformation in TRIP steels generally takes place in the temperature interval between 400 and 450 °C during an isothermal hold. This transformation is a shear-diffusionless one and it develops in the so-called over aging zone (Ref 4, 5). It consists of two steps. First, the ferrite laths are formed from the nontransformed austenite. Second, cementite precipitates on the interface of the austenite and ferrite (Ref 6).

Carbon is the most important element for austenite stabilization. Therefore, it is necessary to avoid the precipitation of cementite, which strongly reduces the content of carbon in austenite. Cementite precipitation usually occurs during the formation of bainitic ferrite. For this reason, it is essential to delay this precipitation adequately during the bainite transformation. The addition of silicon inhibits cementite precipitation significantly, because silicon shows low solubility in cementite, thus causing extremely slow growth of cementite. Other important elements include Al, Cu, and P (Ref 5).

Table 4 The influence of temperature and holding time on bainite transformation

T_A, °C	t_A, s	T_B, °C	t_B, s	φ, −	Structure	Grain size of ferrite, μm
900	20	405	600	10.4	Ferrite	2.9 ± 1.5
			300		+ Bainite	3.2 ± 1.6
		450	600		+ Retained austenite	2.9 ± 1.6
			300			2.8 ± 1.4
			100			3.1 ± 1.4

T_A—temperature of austenitization (°C), t_A—time of austenitization (s), T_B—temperature of bainite holding (°C), t_B—holding time at T_B (s)

The temperature of the bainite hold and the silicon content affect the bainite transformation kinetics in TRIP steels. The length of the bainite holding time influences the carbon content in retained austenite. With silicon content of about 1.5%, the typical behavior, called incomplete reaction, was observed, which corresponds to the maximum enrichment of austenite with carbon. The bainite transformation finishes before the complete depletion of intercritical austenite. Enrichment of retained austenite with carbon up to the maximum level accompanies this transformation (Ref 7).

Based on these facts, an experiment was designed in which the examined deformation schedules were complemented with various temperatures and holding times in the region of bainite transformation (Table 4). The aim of this part of the experiment was not only to obtain the optimal structure but also to find the interval of technological parameters suitable for the planned technologies.

Because of the austenite stabilization during the bainite transformation, the TMT-processed structures must not contain phases like martensite or pearlite. The presence of these structural phases would not only cause a decrease in the stability of retained austenite but it also lead to the deterioration of the mechanical properties, especially ductility. The temperature interval of bainite transformation hold from 405 through 450 °C was selected. The original standard temperature used for bainite transformation was 425 °C. The bainite holding time varied from 100 to 600 s.

After the reduction of the bainite transformation temperature to 405 °C, which is just above the martensite transformation limit, a fine ferrite-bainite structure with a ferrite grain size of about 3 μm formed with the holding times of 600 and 300 s. However, thorough observation using the electron microscope revealed the presence of (most probably) temperature-induced martensite inside the retained austenite islands (Fig. 4, 5).

Raising the temperature of the isothermal bainite transformation to 450 °C at hold times of 600, 300, and 100 s led to the formation of a ferrite-bainite structure, which was the same in each case. The size of the ferrite grain was about 3 μm. However, structural analysis via electron microscopy showed small pearlite islands, which are undesirable in a TRIP steel structure.

3. Conclusion

During the experiment, optimization of different parts of TMT was carried out. The results showed it was possible to apply anisothermal deformation in the temperature interval of 900-720 °C during cooling to the bainite transformation temperature. The temperature must not drop below 720 °C, since pearlite would form in the structure in this type of steel. During the examination of the influence of temperature and length of hold time on the bainite transformation, it was found that temperature-induced martensite begins to occur inside the retained austenite islands at the bainite transformation temperature of 405 °C. After an increase in bainite transformation temperature to 450 °C, pearlite formed in the structure during cooling. The temperature leading to optimal carbon content in the retained austenite was 425 °C.

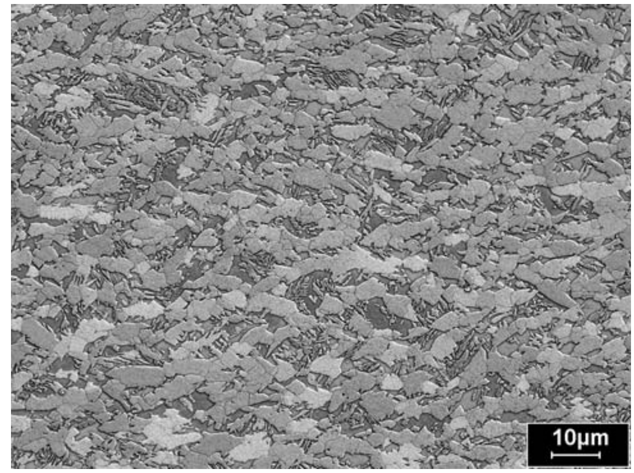

Fig. 4 Bainite tran.: 405 °C, 300 s, Nital

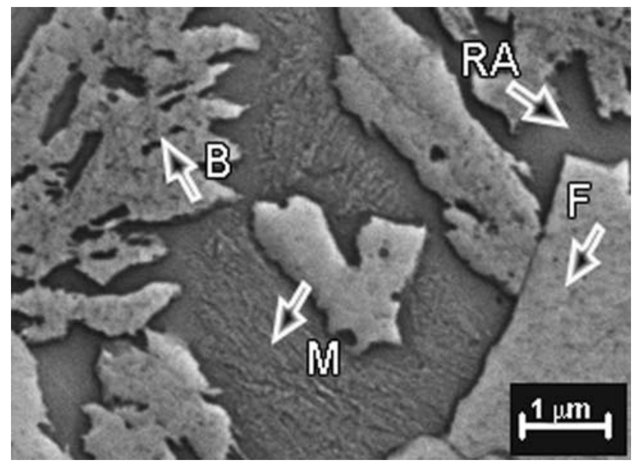

Fig. 5 Details of martensite needle in the retained austenite, Nital, RA—retained austenite, B—bainite, F—ferrite, M—martensite

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