

Obtaining a TRIP microstructure by thermomechanical treatment without isothermal holding

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Abstract. The contemporary development of technological processes for the production of modern multiphase steels can be characterized by the need for precise control of their technological parameters. The design of modern technological processes that allow sophisticated microstructures to be obtained usually cannot be carried out on real production equipment for technical as well as economical reasons. Therefore, new processes and test devices are continuously being developed to make it possible to simulate and model thermomechanical treatments on small specimens with precise control and monitoring of process parameters. A simulator for experimental modelling of thermomechanical processes has been developed at the University of West Bohemia. In this paper, to demonstrate the feasibility of simulating thermomechanical treatments with this setup on a lab scale, we discuss the thermomechanical treatment of TRIP steels without isothermal holding – a processing route that is difficult to handle and thus poses several technological as well as economic problems. The realistic processing of wire rolling with different cooling strategies is tested on the TRIP CMnSiNb steel. Our results show that the processing route without isothermal holding allows to obtain multiphase microstructures with a tensile strength of up to 835 MPa and a ductility $A_{5mm} = 25\%$.

Key words: TRIP steel, thermomechanical treatment, isothermal holding, multiphase structure

1. Introduction

Rising prices of raw materials and energy, combined with the high workload of production devices, make it generally impossible to test or optimize new manufacturing processes and material treatments directly under production conditions. Material-technological modelling of microstructural evolution is a very efficient way of developing and optimizing new procedures. Material-technological modelling represents the establishment of such an environment that resembles the real time conditions for material processing as closely as possible. The process conditions in forming technologies, in thermomechanical treatments, and potentially in heat treatments can be characterized by a series of selected parameters. In material-technological modelling it is necessary to know the effects of these parameters and to adjust the model parameters accordingly. With properly selected parameters, a good agreement between the modelled and the real process can be expected [1-3].



For such a material-technological modelling approach, a thermomechanical simulator is available in the FORTECH Research Centre at the University of West Bohemia in Pilsen (Fig. 1). This custom-built simulator allows for the temperature and some selected deformation parameters to be controlled very carefully, so that they correspond closely to those of a real process – or those that can be expected in a real process in the case of the development of new technologies, materials or structures.

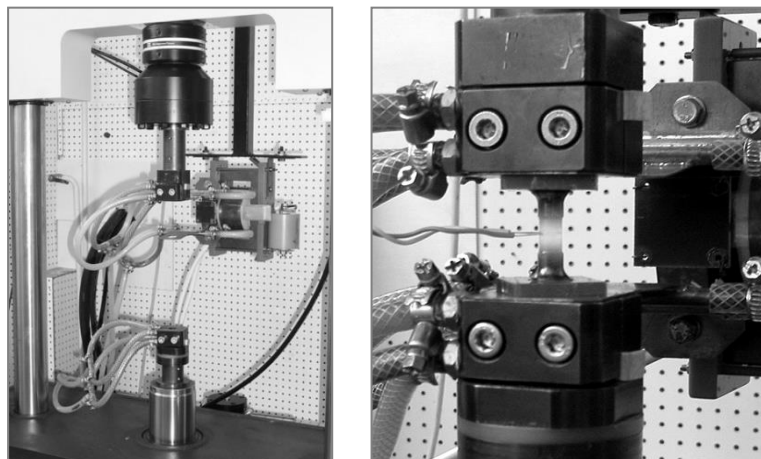


Figure 1. Thermomechanical simulator (overview: left; heated sample during a thermomechanical experiment: right).

This device also specifically allows rapid changes of both the temperature and the deformation parameters. Therefore even complex conditions associated with industrial/technological processes can be simulated accurately. For instance, the simulation of the deformation component can reach a speed of 3 m/s with the possibility of repeating several arbitrary, precisely driven deformation steps within a few seconds depending on the deformation regime. Concerning temperature behaviour, controlled changes of over 100 °C and 250 °C per second can be obtained both during heating and cooling of steel samples, respectively. Exact process monitoring is obviously guaranteed by the simulator's built-in high precision sensors and can further be improved and extended by attaching external monitoring devices to the control system. Examples of additional monitoring devices include an optical pyrometer with automatic emissivity correction or a high-speed camera capable of capturing fast deformation processes in detail, which may help to analyse, for instance, crack formation.

Material-technological modelling can be used not only for the development of new technologies but also for testing new materials such as multiphase steels. With these steels, it is possible to obtain very good mechanical properties, but the microstructural evolution must be carefully controlled during processing. Using the thermomechanical simulator presented here, it is possible to optimize the processing parameters [4, 5]. In this paper, we briefly discuss a challenging example for our experimental approach using the thermomechanical simulator: we study the thermo-mechanical treatment of a TRIP steel without isothermal holding.

2. Experimental program

For the experimental program, a low-alloyed CMnSiNb TRIP steel (see Tab. 1) was chosen. TRIP steels are multiphase steels and their microstructure consists of ferrite, bainite and small amounts of retained austenite [6]. Because of their high capacity for energy absorption and good fatigue behaviour they have recently been used in the automotive industry for safety components such as seat structures, cross-members, long post reinforcements, aprons and fender reinforcements [7].

The standard treatment of TRIP steels consists of isothermal holding in the bainitic temperature range. During this holding period, the formation of bainite is promoted and retained austenite is stabilized. The need to hold the material at constant temperature, however, is difficult to control and thus

causes several technological as well as economic problems. The material-technological modelling approach was used to examine a new technology without isothermal holding during cooling, and to compare it to a processing route with isothermal holding. The material was treated using a regime which simulates normal rolling mill processing, to determine whether or not this innovative and economically beneficial material is suitable for treatment in a specific rolling mill and what material properties can be expected in the final product.

Table 1. Chemical composition of the TRIP steel.

C	Mn	Si	P	S	Cr	Ni	Cu	Al	Nb	Mo	V	W
0.21	1.45	1.80	0.008	0.005	0.008	0.072	0.058	0.006	0.059	0.02	0.005	0.02

2.1 Thermomechanical treatment

For the experiment, a thermo-mechanical regime was applied that simulated a rolling strategy for a rolling track with heating to 1050 °C and passing through twenty rolling mills in 2.8 s (Fig. 2). The tensile and compressive deformations represent the individual passes. During the design of this deformation regime, time intervals between individual rolling mills were taken into account. The deformation took place during a temperature decrease within an interval from 1050 °C to 830 °C. During this deformation a true strain of 1.66 with various strain rates from 0.3 to 20 s⁻¹ was reached. In the final part of the simulated regime the influence of various cooling rates and isothermal holding times on the resulting microstructures was examined.

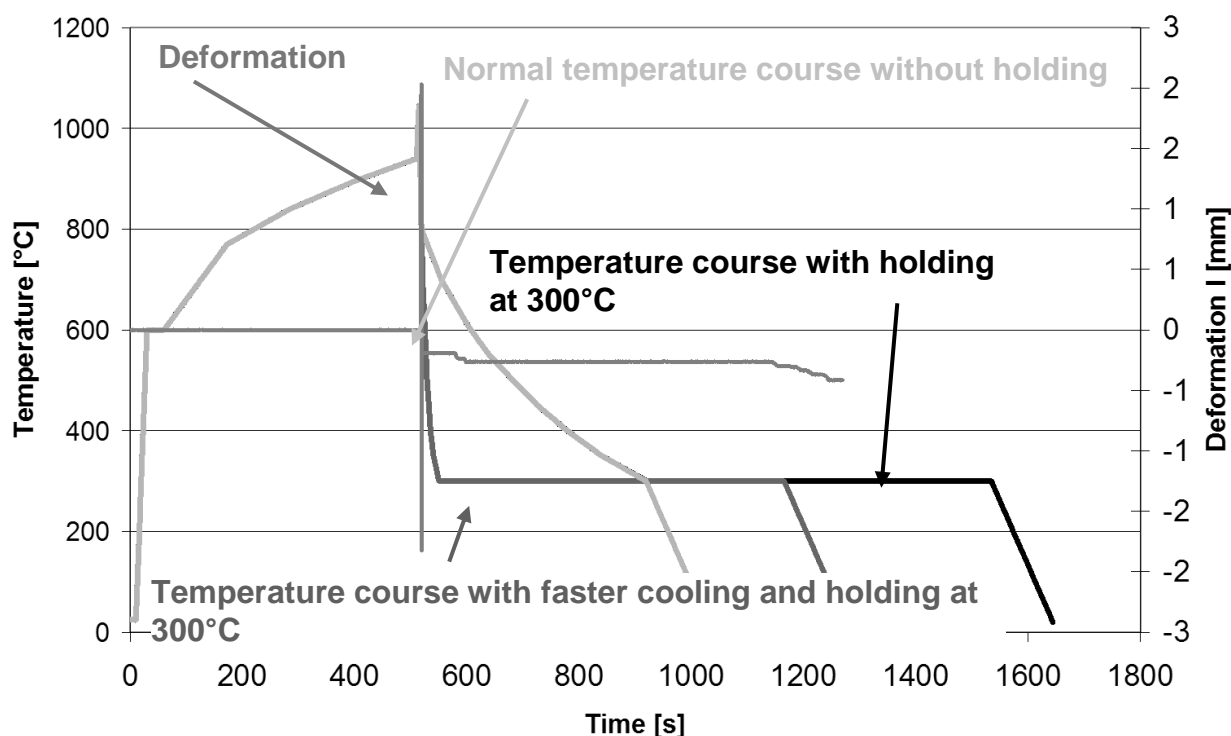


Figure 2. Temperature behaviour in regimes simulating the rolling mill process with various cooling strategies

Three different cooling strategies were tested (Tab. 2). In the first simulated regime, the deformation was followed by cooling at a rate of 1 K/s to room temperature. This slow cooling represents one of the realistic processing alternatives. In the next strategy, cooling was interrupted at 300 °C (with a

holding time of 600 s). This isothermal holding time is characteristic for TRIP steels and it serves to stabilize the retained austenite. Stabilized austenite contributes to a good combination of strength and ductility during a subsequent cold deformation. To avoid pearlite formation, the cooling rate in the third strategy was increased up to 16 K/s.

The obtained microstructures were investigated by optical, laser confocal and scanning electron microscopy. The fraction of retained austenite was measured by X-ray diffraction analysis and the mechanical properties were documented by performing tensile tests on mini tensile test specimens with a gauge length of 5 mm.

Table 2. Parameters and results (volume fraction of retained austenite: R_A ; ultimate tensile strength: R_m ; fracture strain: A_{5mm}) of material–technological modelling of a rolling mill process with different cooling strategies.

Cooling time after deformation	T_B [°C]	t_B [s]	R_A [%]	R_m [MPa]	A_{5mm} [%]
830-200°C / 1 K/s	without bainitic holding		15	835	25
830-300°C / 1 K/s	300	600	16	835	26
830-300°C / 16 K/s	300	600	12	1043	29

3. Results and discussion

After the first simulated regime with a cooling rate of 1 K/s and without isothermal holding, the microstructure consisted of ferrite, bainite and M-A constituent with a small amount of pearlite (Fig. 3a). The presence of pearlite and the transformation of retained austenite to martensite in the M-A constituent could be confirmed by scanning electron microscopy (Fig. 3b). Pearlite is undesirable in TRIP microstructures because it decreases the carbon content in the retained austenite and therefore reduces its chemical stability. The ferrite volume fraction was 59 % and the volume fraction of retained austenite measured via X-ray diffraction analysis reached 15 %. The ferritic grain size was determined to be approximately 3.5 μm .

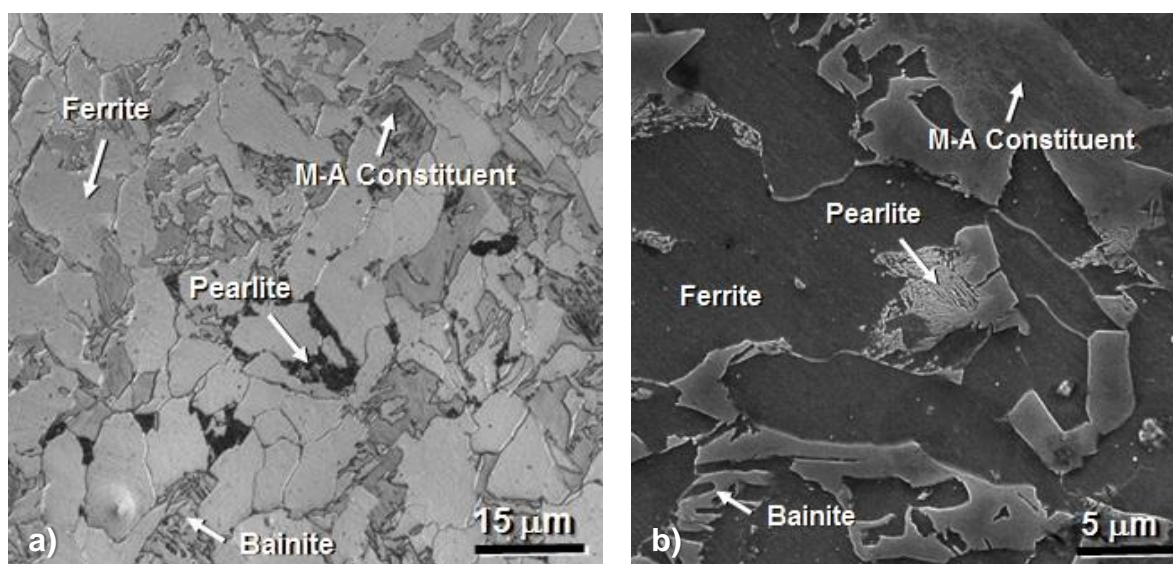


Figure 3. Microstructures obtained following a regime with usual behaviour for rolling mill. a) laser confocal microscope, b) scanning electron microscope – detail of pearlite islands and M-A constituent.

In the next strategy with a holding time at 300 °C a ferrite-bainite microstructure with 58 % of ferrite and 16 % of retained austenite was achieved. The grain size remained unchanged. In comparison to the strategy without holding, no pearlite was detected (Fig. 4a).

Further, the cooling rate between the last deformation step and holding at 300°C was increased up to 16 K/s. This treatment resulted in a ferrite-bainite microstructure with large bainitic blocks (Fig. 4a) laser confocal microscope, 4b). Only laths of bainitic ferrite were observed and no polyhedral ferritic grains were detected. The structure contained 12% of retained austenite. The retained austenite typically occurred between the laths of bainitic ferrite.

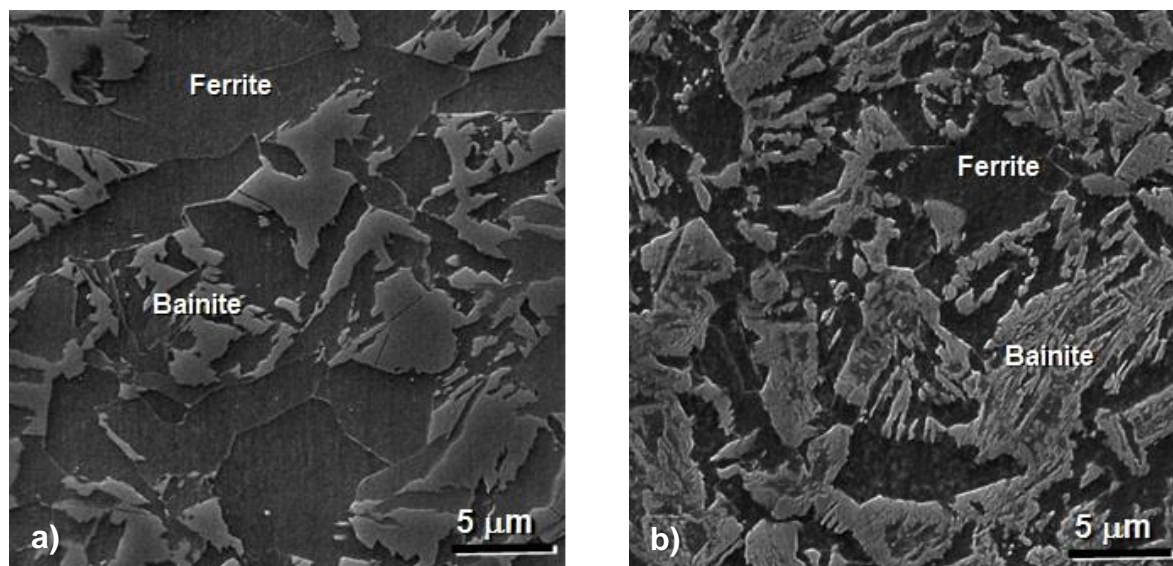


Figure 4. Microstructures produced from regimes with holding time at 300 °C.
 a) Cooling rate of 1 K/s, b) cooling rate of 16 K/s.

The results of the mechanical tests performed on the different samples are summarized in Table 2. Because of the relatively small amount of thermo-mechanically treated material, mini-tensile samples were used for testing. The mechanical data in Tab. 2 shows that the best results were achieved for the regime with fast cooling and with holding at 300 °C. With this regime, the tensile strength was determined to be 1043 MPa and ductility is characterized by a fracture strain of $A_{5mm} = 29\%$. Both strategies with longer cooling times gave rise to lower tensile strength (by approximately 170 MPa lower), but at a similar ductility.

4. Summary and conclusions

The behaviour of low-alloyed CMnSiNb steel under various treatment strategies was studied with the help of material-technological modelling on a custom-built TMB simulator. The thermomechanical process consisted of thermal and deformation phases. The deformation regime ran at a high strain rate, which corresponds to the real conditions in a rolling mill. The first results discussed here very briefly demonstrate the high sensitivity of microstructural development to changes of processing simulation parameters. The required microstructures were achieved through material-technological modelling on real material specimens, which allowed material and mechanical properties to be measured. The verified parameters of the thermomechanical process can be used for accelerated application of the innovative treatment of CMnSiNb steels with a tensile strength of over 1000 MPa and ductility $A_{5mm} = 29\%$. Finally, it was found that even when isothermal holding is removed, the required microstructures with very small fractions of pearlite, and with reasonably good mechanical properties, can be achieved. This may well provide the basis for a wider application of this type of steels.

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