Coiling simulations of medium-Mn sheet steels using dilatometry

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Abstract. The work presents the results of coiling simulations of two medium manganese steels containing 3 and 5% Mn. The steels were subjected to the heat treatment including an austenitization at 1000°C for 300s and next isothermal holding at temperatures of 750, 700, 650 and 500°C for duration of 5 hours. The results of dilatometric analysis showed that in case of the 3Mn steel the ferritic transformation occurred during the isothermal holding at 750 and 700°C. The amount of ferrite created during this step at 750°C was smaller compared to 700°C. Lowering the temperature to 650°C led to a transformation lack during the holding time. At 500°C a bainitic transformation occurred. Increasing the manganese content resulted in prolonging the incubation time before any transformations. For the 5Mn steel for all isothermal holding temperatures no transformation occurred within 5 hours. The conclusion was that manganese shifted significantly the ferritic and bainitic regions to longer times.

1. Introduction
Still growing demands for weight reduction and crashworthiness properties in automotive industry are the driving force for new steel grades and advanced heat-treatment cycles. Medium Mn steels, classified as the III generation of AHSS, are characterized by indirect properties of the two previous generations - high strength combined with very good ductility. Those features may be gained with relatively low cost due to reduced content of expensive alloying elements [1-3]. The main point in production process of medium manganese steel is the heat treatment [4]. During this stage performed in an intercritical region the redistribution of carbon and manganese in steel should occur. In the intercritical annealing two phases coexist – ferrite and austenite. Ferrite due to its low carbon solubility, displaces it, allowing austenite to enrich in this chemical element. Both carbon and manganese stabilize the austenite causing a decrease in its Mₐ temperature. When it is lower than room temperature, after cooling the material, a structure contains retained austenite. This phase exhibits a TRIP effect – during deformation metastable austenite grains transform to martensite causing very intense strain strengthening. This phenomenon in combination with a very fine grain provides great properties of medium manganese steels.

There are two different processing routes for the medium manganese steels. One performs the intercritical annealing which takes place after plastic forming (hot, warm or cold) from room-temperature microstructure (martensite in the majority of medium Mn steels). Recent researches have been mostly focused on this common route for obtaining considerable amount of retained austenite (20-40%) to realize better mechanical properties through the TRIP effect. On the other side, the different route of thermomechanical processing starting from hot rolling phase – austenite – can be applied from an economical viewpoint, since a conventional equipment in the steel industries can
be used [5,6]. After finishing the hot rolling process, material is cooled to coiling temperature. After this step coils of medium manganese sheet steel cool in the air. During first part of this stage material stays in the intercritical region allowing the chemical elements redistribution. From this viewpoint, the present study aims to clarify a microstructure evolution during physical simulation of coiling medium manganese steels with different content of Mn at various temperatures.

2. Materials and methods

Chemical compositions of the investigated 3 and 5% Mn steels given in Table 1 were designed from the viewpoint of maximization of retained austenite and obtaining carbide-free bainite by high-Al low-Si concept (susceptibility to galvanizing) [7,8]. The steels are characterized by high metallurgical purity connected to low concentration of phosphorus and sulphur (Table 1). Steel was melted in a vacuum furnace (Balzers VSG-50). Casting occurred in Ar atmosphere. Ingots with a mass of 25kg after austenitization at 1200°C within 3 hours were forged at a temperature range from 1200 to 900°C to a final width of 160 mm and a thickness of about 22 mm [9]. A last stage of preparing material to tests were cutting the dilatometric samples with dimensions ø4x10mm.

First investigation step was the austenitization at 1000°C for 300s. This stage was followed by cooling the samples to an intercritical temperature in the range 500-750 and holding them for 5 hours, which simulates a coiling process. The last step was cooling the material to room temperature at a cooling rate of 10°C/s. Investigations was performed using a dilatometer DIL805, which allows to determine time and temperatures of phase transformations during the simulation. Summarized heat treatment cycles simulating steel coiling are shown in Figure 1.

Table 1. Chemical composition of the medium Mn steels used in the present study.

| Steel | C  | Mn | Al | Nb  | Mo | Si | M, °C |
|-------|----|----|----|-----|----|----|-------|
| 3Mn   | 0,17 | 3,1 | 1,6 | 0,04 | 0,22 | 0,22 | 384  |
| 5Mn   | 0,16 | 4,7 | 1,6 | -   | 0,20 | 0,20 | 320  |

For light optical microstructural investigations samples were grinded, polished and etched with 5% nital etchant. More detailed microstructural characterizations were carried out by scanning electron microscopy (SEM) on Zeiss SUPRA 35 microscope.
3. Results and discussion

3.1. 3Mn steel

Figure 2A shows the isothermal holding stage for 3Mn samples. In the case of samples tested at 650°C, the function is linear, which indicates the absence of phase transitions. This fact is confirmed by the fully martensitic structure shown in microscopic observations. At the initial endurance phase the 3Mn500 sample shows a significant increase in the relative length, indicating the start of phase transformation, as shown in Figure 2B. Microscopic observations (Figure 3) showed the presence of bainitic structures among the martensitic matrix. The decrease in length after this stage indicates that the precipitation processes in the material have started due to the long soaking time. Samples 3Mn700 and 3Mn750 (Figure 2C) show the slow start of transformation during the endurance step. A small proportion of the ferritic phase was obtained in both samples (Figure 4). The increase in elongation during this stage for the steel annealed at a lower temperature is twice as large, which indicates the more intense transformation kinetics, resulting in a larger ferrite content. In addition, it can be seen that at a lower temperature the transformation started immediately after reaching the isothermal temperature. Increasing the temperature by 50°C increased the incubation time needed to initiate the transformation. It is concluded that the transformation from austenite to ferrite is quite slow above $A_r$ temperature in the tested steel whereas bainitic transformation initiates quickly at temperatures lower than 600°C.

Figure 2. Dilatometric curves of 3Mn samples; A – holding stage for all samples; B – enlarged graph of holding stage for samples tested at 700 and 750°C; C – enlarged graph of holding stage for the sample tested at 500°C; D – final cooling stage.

Figure 2D shows the stage of final sample cooling. For samples annealed at different temperatures, there are slight differences in the temperature at the beginning of the phase transition, coinciding
with the results of the hardness measurement (Table 2). Lower Mₚ temperatures indicating some redistribution of alloying elements correlate well with the reduced hardness of the samples, which indicates the generation of non-martensite phases in the material.

Table 2. Dilatometry-determined Mₛ temperatures and hardness for 3Mn steel.

| Sample    | Mₛ, °C | Hardness, [HV] |
|-----------|--------|----------------|
| 3Mn500    | 393    | 438            |
| 3Mn650    | 392    | 421            |
| 3Mn700    | 374    | 379            |
| 3Mn750    | 385    | 348            |

Figure 3. Microscopic images for 3Mn500 sample; M – martensite; B – bainite.

Figure 4. Microscopic images for 3Mn samples; on the top 3Mn750 sample images; on the bottom 3Mn700 sample images; M – martensite; F – ferrite.
3.2. 5Mn steel

The linearity of the function during the isothermal holding stage (Figure 5A) for 5Mn steel samples indicates the absence of phase transformation. This in turn suggests that 5Mn steel is not susceptible to an applied method of heat treatment. Figure 5B shows the stage of final sample cooling. The dysfunction that indicates the start of the martensitic transformation occurs for all samples at a similar moment, which clearly indicates the lack of redistribution of alloying elements during the previous stage. Microscopic images (Figure 6) confirmed the assumptions about achieving a full martensitic structure.

It should be emphasized that ferrite transformation in conventional low-carbon steels containing 1.5-2 wt% Mn is commonly very quick. The increase of Mn content to 5 wt% significantly delayed the ferritic transformation of the tested steel. This fact has been proven in earlier studies [6,10].

4. Conclusions

Transformation kinetics and microstructure during coiling simulation of medium manganese steels have been investigated in two steels containing 3 and 5 wt% Mn using the dilatometry approach. The major results obtained are as follows:

- The occurrence of ferritic transformation in 3Mn steel led to a slight decrease in the $M_s$ temperature, which indicates the redistribution of carbon during the simulated coiling process.
In the case of 3Mn steel, lowering the holding temperature below 650° C leads to entering the area of bainitic transformation, during which the precipitation process prevents the enrichment of austenite in carbon.

The isothermal holding of 3Mn steel at temperatures of 700 and 750° C enabled the start of ferritic transformation, which is confirmed by dilatometric and microscopic tests and the results of hardness measurements. However, the time was too short to generate a sufficient part of ferrite to stabilize retained austenite by redistributing carbon and manganese.

Along with the increase in manganese content from 3 to 5%, the transformations occurring during the cooling of steel are significantly delayed, preventing their start even during several hours of annealing.

Samples of 5Mn steel annealed in the temperature range of 500-750° C do not show phase transformation of the austenite to ferrite/bainite. This is demonstrated by the full martensitic structure.

Under the experimental conditions used, the simulated coiling without a previous deformation can not be an alternative to intercritical heat treatment of medium-manganese steel. The further research will be focused on coiling process following plastic deformation. A positive effect can be brought by the use of plastic deformation before holding, which requires further research.

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