CORRELATION BETWEEN THERMAL TREATMENT, CHEMICAL COMPOSITION AND MECHANICAL PROPERTIES OF PM STEELS

A. KARELOVÁ[1], C. KREMPASZKY[1,2], E. WERNER[2],
T. HEBESBERGER[3], A. PICHLER[3]

Authors: ***A. Karelová[1], C. Krempaszky[1,2], E. Werner[2], T. Hebesberger[3], A. Pichler[3]***
Workplace: ***[1] Christian Doppler Laboratory of Material Mechanics of High Performance Alloys, Technical University of Munich;***
[2] Chair of Materials Science and Mechanics of Materials, Technical University of Munich;
[3] voestalpine Stahl Linz GmbH, B3E Research and Development;
Address: ***[1] Boltzmannstraße 15, 85747 Garching, Germany***
[2] Boltzmannstraße 15, 85747 Garching, Germany
[3] VOEST-ALPINE Straße 3, Postfach 3, Linz A-4031, Austria

Abstract

The impact of chemical composition and applied heat treatment on the evolution of the microstructure and the resulting mechanical properties of cold rolled partial-martensitic steels is investigated and discussed. Annealing cycles are applied to study the influence of the quenching and the overaging temperature. In addition to the characterization of the microstructure by means of light optical microscopy, the mechanical properties are determined and discussed.

Key words

PM steels, mechanical properties, microstructure, annealing parameters

INTRODUCTION

In the last years research work in the steel industry has concentrated on the improvement of the forming, solidity and processing properties of sheet materials. The progress in automotive engineering has led to reduced fuel consumption and decreased emissions. The range of the development extended from conventional mild steels to super high-strength martensite phase steels, see Fig. 1. The oil crises of the seventies led to the development of the dual-phase steels in an effort to reduce the weight of cars. DP steels are similar in composition to the conventional low alloyed steels, but are appropriately heat-treated to generate a dual-phase microstructure of ferrite and martensite. Despite the outstanding properties of this steel grade such as a superior combination of high strength and good ductility, continuous yielding and a high initial work hardening, there are difficulties associated with the dual-phase microstructure. DP steels do not exhibit sufficient stretch flangeability and may suffer from localized necking in the heat affected zone of welded parts. Attempts have therefore been made to create dual-phase steels in which bainite is introduced as a moderate hard phase. This mixed microstructure offers improved formability, due to the smaller contrast in hardness of bainite and martensite. The resulting microstructure is "mechanically" more homogenous thus exhibiting lower local stresses at the phases boundaries than the dual-phase microstructure under loading conditions typical for forming operations [1, 2].

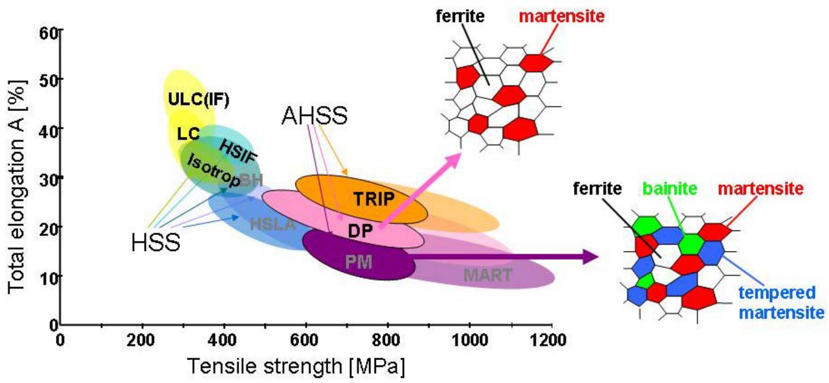


Figure 1. *Ductility–strength relationship of mild and high strength steels with schematic illustration of dual-phase and partial-martensitic microstructure*

The critical part in the manufacturing of sheet steels is related to the control of the processing conditions so that the desired microstructure and hence the strength-elongation balance can be optimized. In this work, the influence of the quenching and overaging temperature on the microstructure and mechanical properties of partial-martensitic steels is studied. Also, the influence of the alloying elements is taken into consideration and discussed.

EXPERIMENTAL PROCEDURE

Production of the material

The chemical compositions of the investigated steel grades are shown in Table 1. The materials were hot rolled to the thickness of 3,8 mm. The finishing rolling temperature was between 850-920°C, steels were coiled between 680-720°C. The sheets were subsequently cold rolled to the thickness of 1 mm.

CHEMICAL COMPOSITIONS OF THE INVESTIGATED STEEL GRADES IN wt.%

Table 1

Alloy	C	Al	Si	Mn	Cr+Mo	P	S	Ti+Nb	B	Fe
A	0,05	0,06	0,17	~2,0	<0,25	<0,01	<0,005	0,039	0,002	bal.
B	0,13	0,04	0,16	~2,0	<0,25	<0,01	<0,005	0,036	0,002	bal.
C	0,16	0,20	0,42	~2,0	<0,20	<0,01	<0,005	0,032	0,000	bal.

Annealing simulation

The annealing simulations were conducted in the laboratory with the Multi-Purpose Annealing Simulator (MULTIPAS) at voestalpine Stahl GmbH using cold rolled material.

The annealing simulator enables the examination of the effects of various heat treatments on the steel properties in the laboratory, thus saving time and costs in the development of new grades as compared to the development in an operational plant [4].

To study the influence of the heat treatment and variations in the chemical composition on the resulting microstructure and the mechanical properties, specimens of steel grades denoted as A, B and C were annealed at T_{an} = 840°C for ~ 120s, then cooled to the different quenching temperatures T_Q with a moderate cooling rate of ~ 10K/s, subsequently quenched with the cooling rate of 50K/s and held at selected overaging temperature T_{OA} for 400s before cooling to the room temperature. The quenching temperature was varied between 600 and 750°C, the overaging temperature between 250 and 500°C, as schematically shown in Fig. 2.

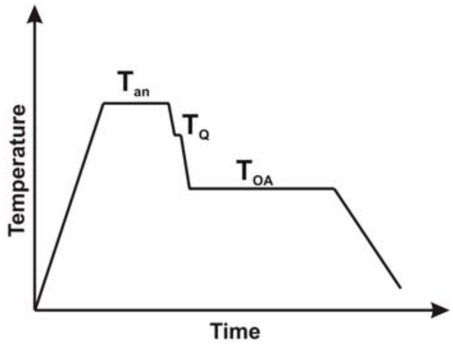


Figure 2. *Schematic representation of applied annealing cycles*

Characterization of the microstructure and testing of mechanical properties

Standard light optical microscopy was used to reveal the microstructure of the heat treated specimens. Specimens taken parallel to the rolling direction were conventionally prepared and etched with LePera´s etchant. Ferrite grains appear blue and/or light brown, bainite and tempered martensite dark brown to black, martensite and retained austenite remain white.

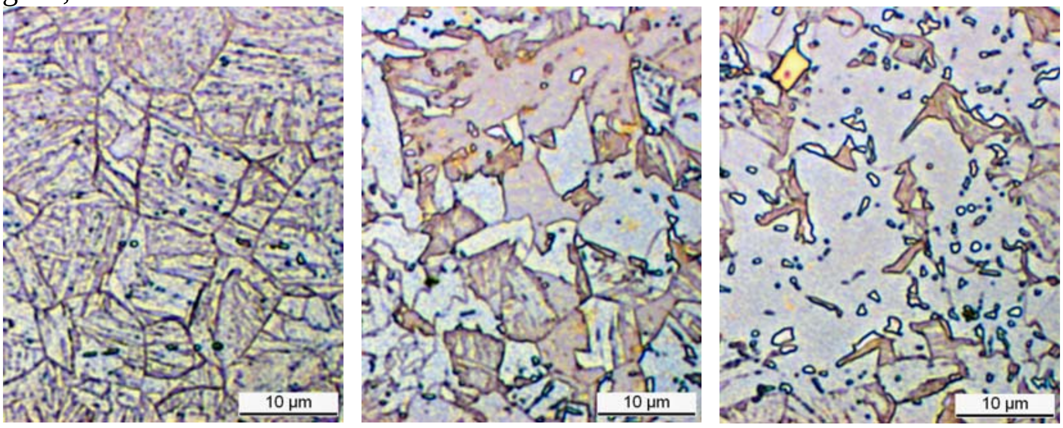
Selected large scale annealing simulations were conducted for the production of specimens for mechanical testing according to the EN10 002 standard. The mechanical properties were measured on a Roell-Korthaus RKM 250 testing machine. The tensile specimens were machined with their tensile axes parallel to the rolling direction and tested in the as-annealed condition.

RESULTS AND DISCUSSION

Effect of the chemical composition and annealing parameters on the microstructure

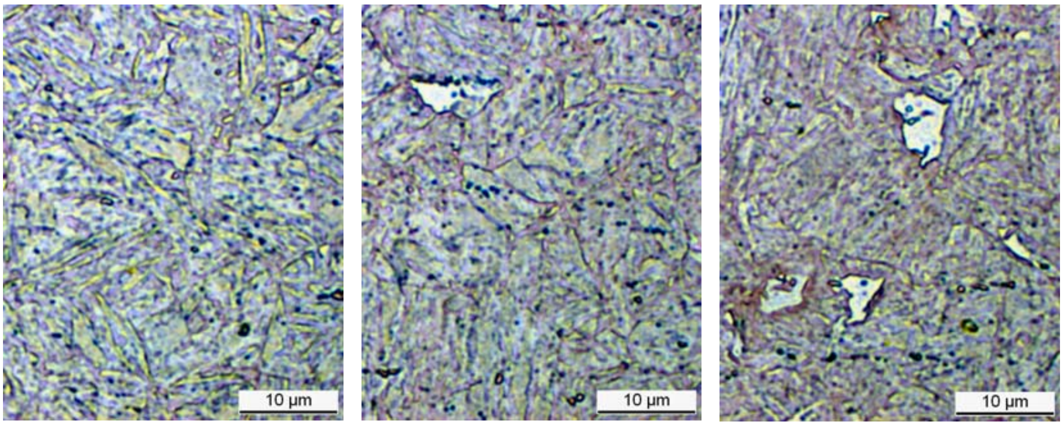
Micrographs of all investigated steel grades after application of defined annealing parameters are shown in Figs. 3-8a-c.

A negligible influence of the quenching temperature was observed in steel grade B. The microstructure remains martensitic, with a small amount of white phase, resembling retained austenite appearing at quenching temperatures below 650°C, Fig. 4a-c. This type of microstructure is offering very high tensile strength coupled, however, with poor elongation properties (cf. Fig. 9). Decreasing the quenching temperature down to 600°C, increasing therefore the time of moderate cooling and ferrite formation, results in the case of steels A and C in the formation of a dual-phase microstructure. During the moderate cooling from the annealing temperature to the quenching temperature, part of the austenite is transformed to ferrite by diffusion-controlled phase transformation, while the remaining austenite with a higher carbon content transforms to martensite and/or bainite during subsequent quenching. The formation of ferrite upon cooling affects the volume fraction of the second constituent formed. The longer the moderate cooling, the more austenite transforms to ferrite and the lower is the amount of austenite available to form martensite during subsequent quenching, see Figs. 3, 5b-c.



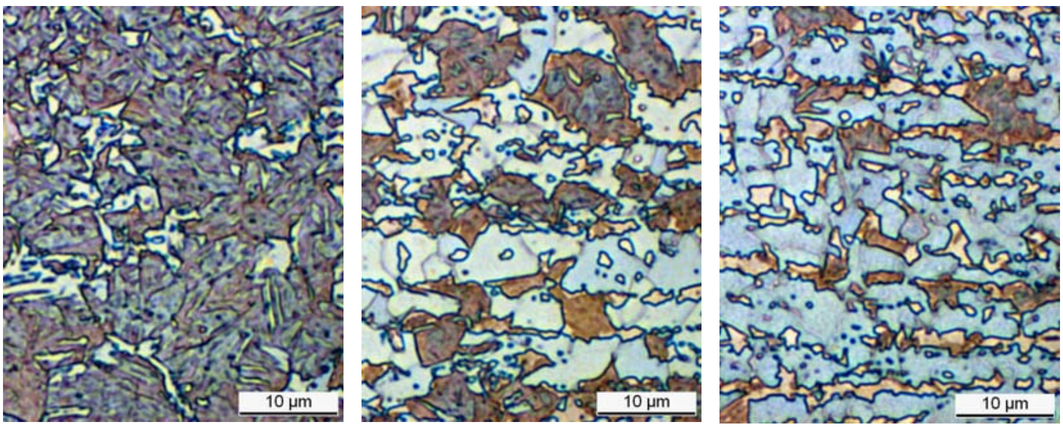
(a) T_Q= 725°C (b) T_Q= 650°C (c) T_Q= 600°C

Figure 3. *Influence of quenching temperature on the microstructure of steel A (T_{an} = 840°C/120s, T_{OA} = 300°C/400s)*



(a) T_Q= 725°C (b) T_Q= 650°C (c) T_Q= 600°C

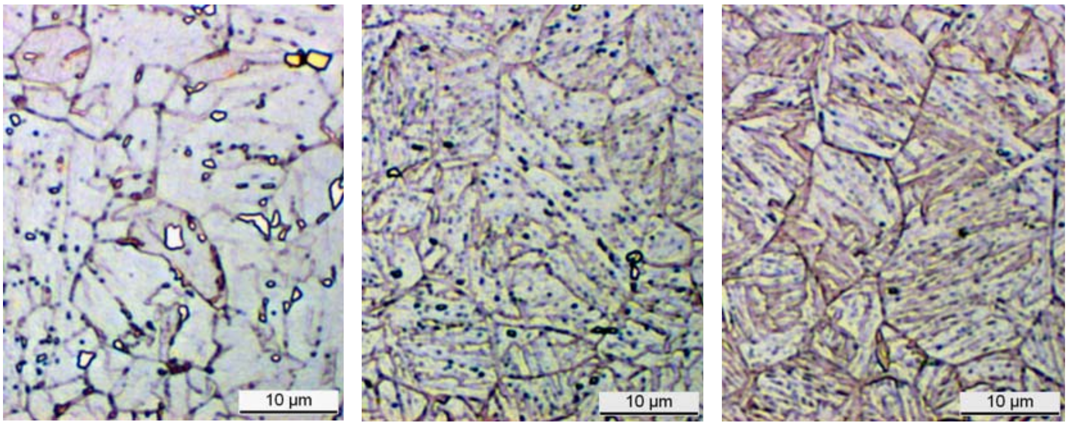
Figure 4. *Influence of quenching temperature on the microstructure of steel B (T_{an} = 840°C/120s, T_{OA} = 300°C/400s)*



(a) T_Q= 725°C (b) T_Q= 650°C (c) T_Q= 600°C

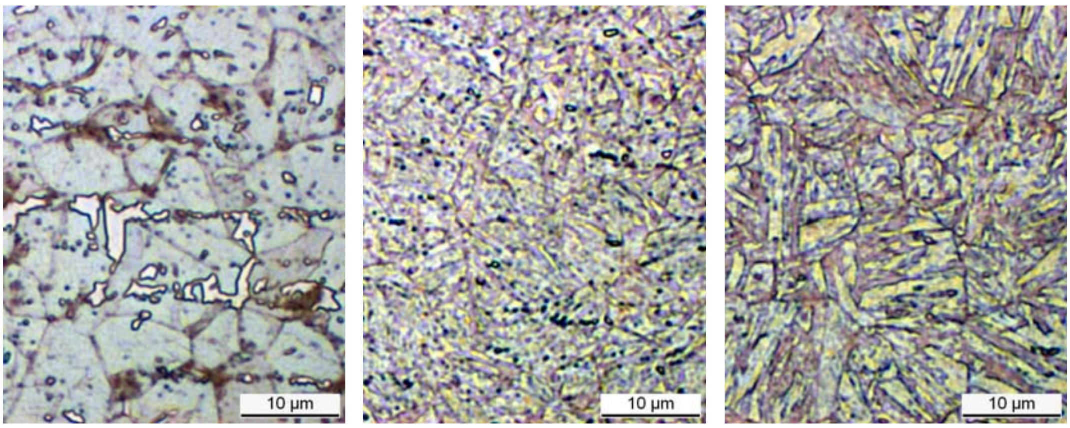
Figure 5. *Influence of quenching temperature on the microstructure of steel C (T_{an} = 840°C/120s, T_{OA} = 300°C/400s)*

Overaging at a temperature of 500°C for 400s after quenching from 750°C results in all grades in a microstructure consisting of ferrite (blue colored), some white grains (resembling martensite and/or retained austenite) and a third, brown colored phase (bainite/tempered martensite) located on the ferrite grain boundaries. The amount of the third phase is significantly higher in grades B and C due to the higher carbon content. The microstructure of steel grade C is due to the addition of Nb exhibiting smaller grains as compared to the other grades. Decreasing the overaging temperature, the microstructure appears coarser and more structured. The amount of formed martensite is increasing and the final microstructure after overaging at 250°C can be denoted as partial-martensitic, consisting of a mixture of martensite, tempered martensite (hardly distinguishable from bainite) and ferrite. The formation of carbides inside martensite during overaging at temperatures below 350°C, Figs. 6, 7b, also contributes to a decrease of the elongation values. The ductility increases with an increase of the volume fraction of ferrite and a decrease in the amount of martensite (cf. Fig. 10) [3-7].



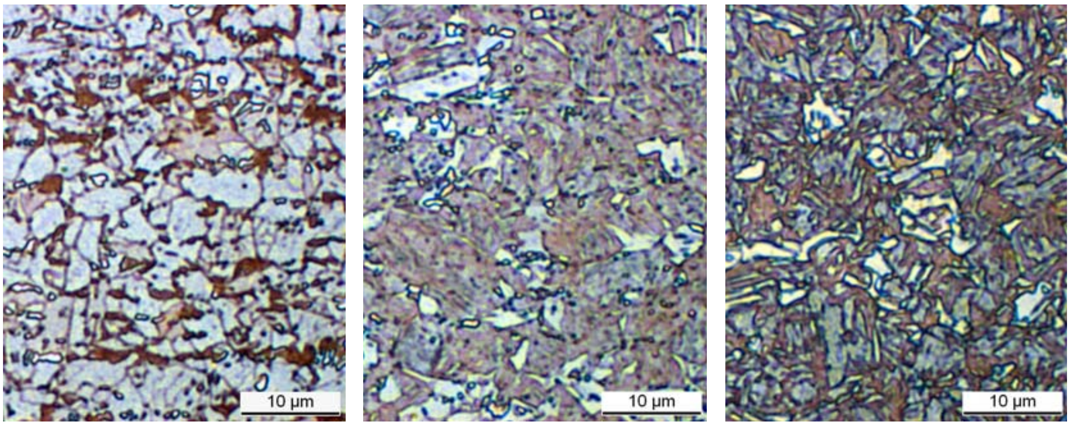
(a) T_{OA}= 500°C/400s (b) T_{OA}= 350°C/400s (c) T_{OA}= 250°C/400s

Figure 6. *Influence of overaging temperature on the microstructure of steel A (T_{an} = 840°C/120s, T_Q = 750°C)*



(a) T_{OA}= 500°C/400s (b) T_{OA}= 350°C/400s (c) T_{OA}= 250°C/400s

Figure 7. *Influence of overaging temperature on the microstructure of steel B (T_{an} = 840°C/120s, T_Q = 750°C)*

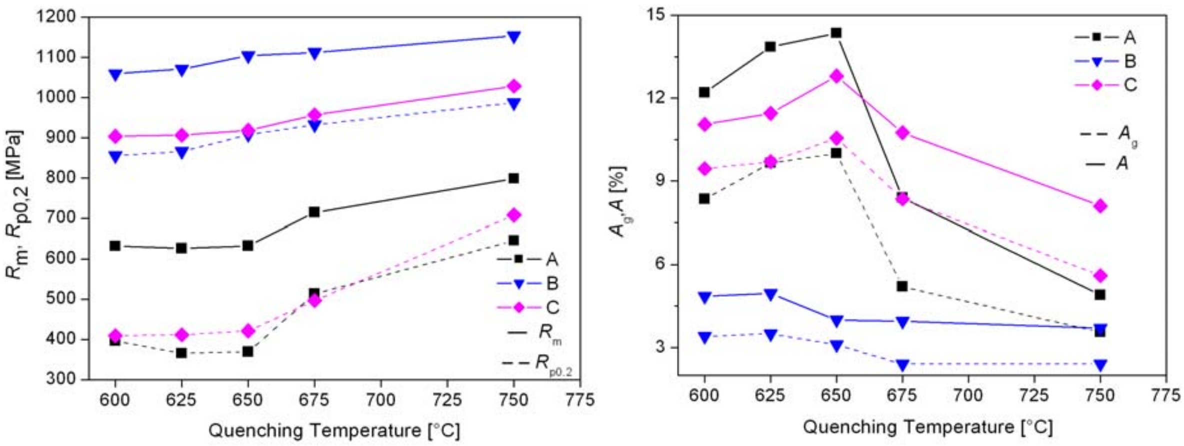


(a) T_{OA}= 500°C/400s (b) T_{OA}= 350°C/400s (c) T_{OA}= 250°C/400s

Figure 8. *Influence of overaging temperature on the microstructure of steel C (T_{an} = 840°C/120s, T_Q = 750°C)*

Effect of the chemical composition and annealing parameters on the mechanical properties

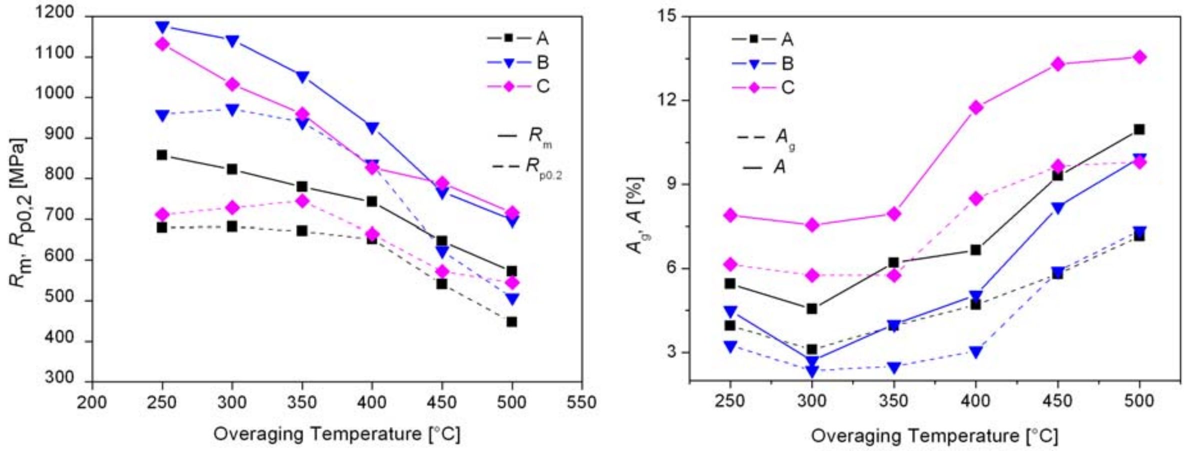
The mechanical properties of the materials as influenced by the quenching temperature are show in Fig. 9. Both yield and tensile strength decrease with decreasing quenching temperature. The level of the tensile strength of grades B and C is significantly higher due to the increased carbon content in comparison to grade A.



(a) Yield and tensile strength (b) Uniform and total elongation

Figure 9. *Influence of the quenching temperature on the mechanical properties (T_{an} = 840°C/120s, T_{OA} = 300°C/400s)*

Grade B shows a significantly higher yield strength as compared to the other two grades. The addition of alloying elements such as Al, Si and Nb in grade C, obviously influences the yield strength, that is much lower than that of grade B, possessing a comparable carbon content. The uniform and total elongations of grades A and C increase for quenching temperatures between 650°C – 750°C. Quenching from temperatures below 650°C results in a decrease of the elongation. Grade B shows a constant moderate increase of the uniform and the total elongation with decreasing quenching temperature. Higher yield and tensile strength values are associated with lower uniform and total elongation. This is more pronounced for grades A and C than for grade B, which shows a moderate sensitivity of both elongation and strength to a variation of the quenching temperature.



(a) Yield and tensile strength (b) Uniform and total elongation

Figure 10. *Influence of the overaging temperature on the mechanical properties (T_{an} = 840°C/120s, T_Q = 750°C)*

The influence of the overaging temperature on the mechanical properties is shown in Fig. 10. Tensile strength increases monotonically with decreasing overaging temperature for all grades. Yield strength significantly increases with decreasing overaging temperature down to 350°C. Overaging at temperatures below 350°C causes a moderate increase of the yield strength for steel A and a decrease for steels B and C. Both uniform and total elongation become smaller by lowering the overaging temperatures to 300°C for steels A, B and to 350°C for steel C, for which the maximum in elongation coincides with the minimum of the strength values.

SUMMARY

A laboratory study was conducted in order to investigate the effects of heat treatment and chemical composition on the development of the microstructure and the mechanical properties of thin sheet steel grades. Different annealing cycles were applied on a laboratory annealing simulator to investigate the influence of varied quenching and overaging temperatures. Lowering the quenching temperature down to 600°C decreases the tensile and yield strength. A similar trend for the uniform and the total elongation is however detected. Decreasing the overaging temperature deteriorates strength and improves ductility for all steel grades. The development of the microstructure was studied by means of light optical microscopy. The microstructure is markedly influenced by the applied annealing conditions as well as by the differences in the chemical composition. Fully martensitic microstructures were observed, offering high levels of strength coupled with low ductility. Microstructures consisting of a mixture of ferrite, martensite, bainite and/or tempered martensite show improved elongation properties due to the more homogenous microstructure. Combining the wide knowledge in this field with the results obtained in this work may help to adjust industrially applied annealing cycles in order to produce those microstructures exhibiting the desired mechanical properties.

References

[1] BACH, F., W., ROßBERG, A., SCHÄPPERKÖTTER, M., SCHAPER, M. WALDEN, L. WEBER J. *Today's sheet metal materials and their forming properties.* Mat.-wiss. u. Werkstofftech. No. 7, 2004.

[2] ZRNÍK, J., MAMUZIC, I., DOBATKIN, S.,V. Recent progress in high strength low carbon steels. In *METALURGIJA*, 45 (2006) 323-331.

[3] P. STIASZNY, E. TRAGL, A. PICHLER, R. ANGERER, M. HACKL. Development and application of a modern effective annealing simulation equipment for process and material development. In *proc. of THERMEC 2000*, Las Vegas, December 4- 8, 2000.

[4] ROCHA, R.,O., MELO, T.,M.,F., PERELOM, E.,V. SANTOS, D.,B. Microstructural evolution at the initial stages of continuous annealing of cold rolled dual-phase steel. In *Materials Science and Engineering A* ,391 (2005) 296–304.

[5] LIS, J., LIS, A.,K., KOLAN, C. Processing and properties of C–Mn steel with dual-phase microstructure. In J*ournal of Materials Processing Technology*, 162–163 (2005) 350–354.

[6] PICHLER, A., TRAINT, S., BLAIMSCHEIN, M., SPERL, J. ,STIASZNY, P. WERNER, E. Correlation between thermal treatment, retained austenite stability and mechanical properties of low-alloyed TRIP steels. In *proc. of Int. Conf, On TRIP-aided high strength ferrous alloys*, Gent, 2002.

[7] POTTORE,N. GUPTA,I. PRADHAN. R. Effect of composition & processing in cold-rolled dual-phase steels for automotive applications. In *proc. of MS&T2006*, Conf., Detroit, 2006.