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ISSN 0543-5846
METABK 47(3) 187-190 (2008)
UDC – UDK 539.377:669-122.2:620.17=111

INFLUENCE OF REHEATING AND COOLING CONDITIONS ON STRUCTURE AND MECHANICAL PROPERTIES of C-Mn-Si STEEL

Received – Prispjelo: 2007-08-26
Accepted – Prihvaćeno: 2008-01-15
Original Scientific Paper – Izvorni znanstveni rad

The paper deals with structure and properties development of AHSS (advance high-strength steel) and UHSS (ultra high-strength steel) steel grades for various groups of automotive parts. C-Mn-Si type steel properties are evaluated based on the results of laboratory controlled rolling and cooling. The important influence on mechanical and plastic properties, amount of residual austenite (RA) and final structural type has, except for cooling rate, also starting temperature of intensive cooling (T_{IC}) which follows after hot plastic deformations. If T_{IC} is from interval of 620-760°C the final structure predominantly consists of ferrite with RA. Mostly acicular ferrite with RA, as well as bainite with RA was obtained when T_{IC} was kept in the range of 760-850°C.

Key words: controlled rolling and cooling, AHSS, UHSS, structure, mechanical projectie

Utjecaj uvjeta zagrijavanja i hlađenja na strukturu i mehanička svojstva C-Mn-Si čelika. Članak daje razvitak strukture i svojstava NVČČ (napredno visoko čvrstih čelika) i UVČČ (ultra visoko čvrsti čelici) za raznolike skupine dijelova automobila. Svojstva čelika C-Mn-Si su utvrđena na temelju laboratorijskog kontroliranog valjanja i hlađenja. Najveći utjecaj na mehanička i plastična svojstva uz zaostali austenit (ZA) i završni tip strukture, ima osim brzine hlađenja i početna temperatura intenzivnog hlađenja (Tpo) koja je nastavak vruće plastične deformacije. Ako je Tpo u intervalu 620-760°C, završna struktura se sastoji od ferita sa ZA. Pretežito acikularni ferit sa ZA, također bainit sa ZA je uočen kad je Tpo bila u intervalu 760-850°C.

Ključne riječi: kontrolirano valjanje i hlađenje, NVČČ, UVČČ, struktura, mehanička svojstva

INTRODUCTION

New trends in development of automotive industry can be formulated as follows: higher passengers safety, fuel consumption decrease and higher comfort with better furnishing. Since, at present, up to 62% of total car weight comes from weight of steel and cast iron parts it is obvious that the main focus of car designers is directed towards the weight reduction of vehicle body, chassis, engine etc.

The weight reduction results in decrease of fuel consumption and, consequently, in decrease of emissions. On the other hand – if together with cars weight reduction their safeness should be the same, or even higher, the new materials with better mechanical and plastic properties as well as with better weldability must be employed.

The attention of present research activities is devoted to the advanced high-strength (AHSS) and ultra high-strength steels (UHSS). The following steels are considered to belong to the AHSS steel category: dual-phase (DP) and complex-phase (CP) steels and steels with transformation induced plasticity (TRIP) containing residual austenite (RA). Mainly martensite containing steels belong to the UHSS category.

The above mentioned groups of steels have good cold formability and possess excellent combination of properties like strength, long period of service, fast and high energy absorption during dynamic load and good weldability. All these properties allow designers to realize their main goals: to decrease the weight of vehicles together with increase of safety in case of accidents [1, 2, 3, 4].

The DP, CP and TRIP steels are also called as multiphase steels, since they are consisting of at least two individual phases, e.g. relatively soft matrix phase (ferrite) that provides good cold formability and hard phase (bainite, martensite) that is needed to secure high strength.

Dual-phase steels [5] are characterized by small islands of martensite with total volume of 5-30 % that are located in the ferrite matrix. DP steels possess high value of strengthening coefficient (n) which allows better plastic deformation properties as well as more

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uniform elongation. DP steels are characterized by high level of uniform as well as total elongation, lower *Re/Rm* ratio and their coefficient of normal anisotropy (*r*) is close to 1.

Complex phase steels (CP) [6, 7] are characterized by fine distribution of ferrite, bainite and martensite.

TRIP steels [8, 9, 10] are mostly triple-phase steels with two major phases (ferrite+bainite) and residual austenite as a minor phase. Strengthening coefficient of TRIP steels - when they are deformed in region of 0-7% - is similar to that of HSS. However, at strains over 7%, their unique microstructure secures local stability of plastic deformation and increases their strength. TRIP steels possess good deep drawability.

Martensitic steels (M) consist of martensite of over 30 mas. %. As a consequence of martensite present in the structure the ratio *Re/Rm* is approaching one together with the decreasing elongation as the amount of martensite increases.

The effect of various thermal-deformation and cooling regimes on the microstructure and properties of C-Mn-Si based TRIP steels is evaluated in this work.

EXPERIMENTAL PROCEDURE

Chemical composition of steels used in the below mentioned experiments is given in Table 1.

Table 1. Local chemical analysis of steel / mas.%

Element	Mn	C	Si	P	S	Cu	Cr	Ni
Content	1,47	0,18	1,8	0,015	0,007	0,06	0,06	0,04

The experiments were aimed at monitoring the influence of reheating temperature on austenite grain size, the influence of hot plastic deformations and different cooling regimes on final structures formation. Reheating of samples was carried out in supercantal furnace with subsequent fixation of primary structure, or more precisely heating was followed by a rolling process using rolling mill DUO 210 with the possibility to simulate various ways of cooling. Mechanical properties were examined (investigated) in accordance with STN 42 0321 (STN EN 10002 – 5) on circular sectioned short bars with diameter of 4 mm. Structure analysis was carried out by optical microscopy, whereby fraction of residual austenite was evaluated by X-ray analysis, REM analysis and metallographic analysis. Austenite grain size was evaluated in accordance with STN 42 0462. The results were processed by nonlinear statistical methods.

RESULTS AND DISCUSSION

a) Time and reheating temperature influence on austenite grain size

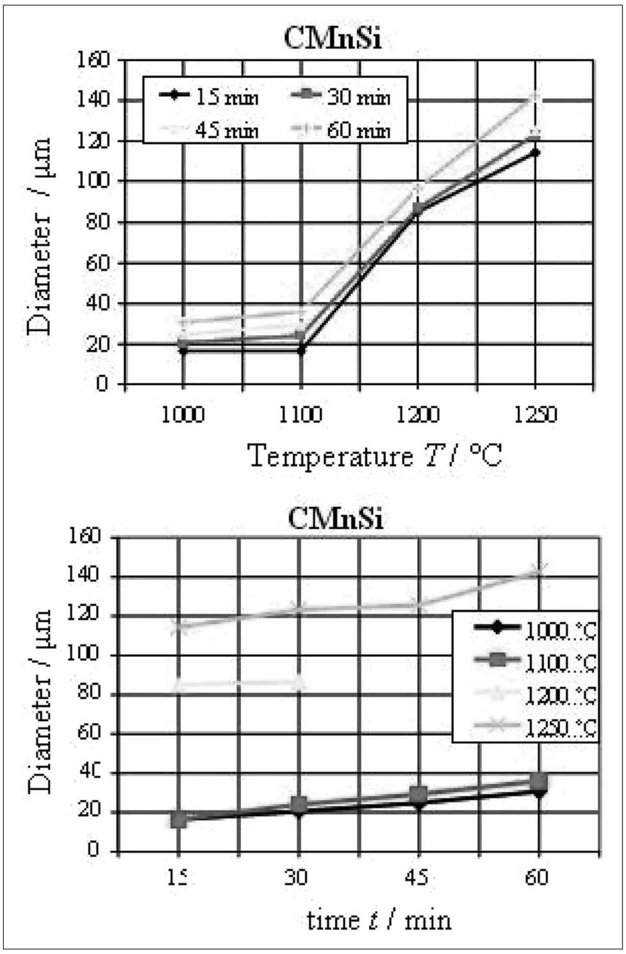

Figure 1. DAGS dependence on temperature and reheating time

Dependence of austenite grain size (DAGS) on reheating temperature and time is in Figure 1. The graphic dependences show that, reheating time has a small influence on change of DAGS, whereby reheating temperature has s dominant influence. Proportional grain coarsening appears at temperatures above 1100°C. Graphic dependences are characteristic for steels with no content of elements formating carbides, nitrides, or complex carbo-nitrides, which, with the increase of temperature, cause the blocade of high-angle grain boundaries migration.

b) Influence of cooling conditions on structures and mechanical properties formation

Next the laboratory hot rolling experiment with subsequent controlled slow cooling in furnace and quenching was performed on samples 25x30x72 mm cutted from the templets, as showed in Figure 2.

The structural analysis in samples cross section was made. The samples were etched in NITAL (2%) to evaluate the phase fractions in microstructure. Microstructure was observed by optical microscope OLYMPUS VANOX-T. The graphs and photographs of phase fractions dependences on furnace temperature and holding time in furnace are showed in Figure 3, Figure 4 and Figure 5.

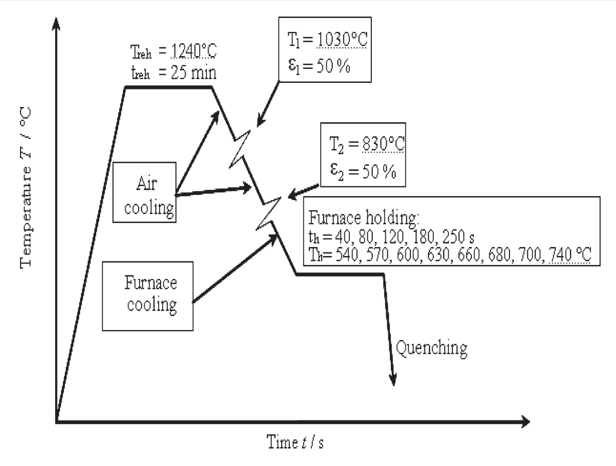

Figure 2. Experimental schedule of laboratory rolling and cooling

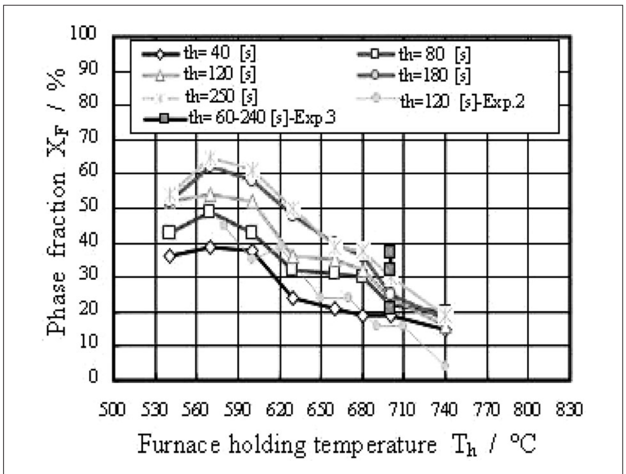

Figure 3. Dependence of ferrite formation on cooling conditions

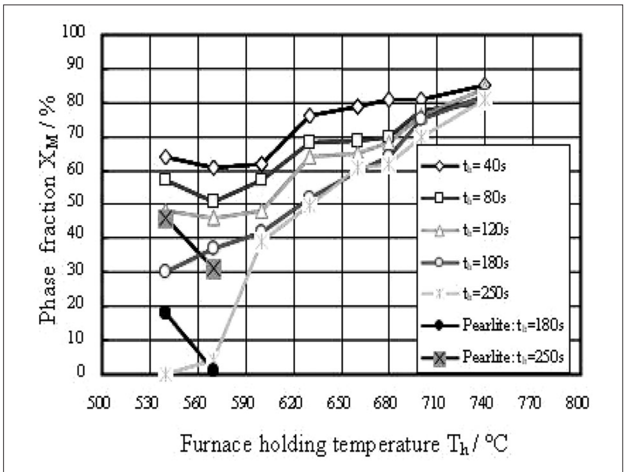

Figure 4. Dependence of pearlite and martensite formation on cooling conditions

For C-Mn-Si steel conception a significant shift of ferrite generation area towards lower temperatures can be seen, the biggest ferrite fraction X_F=65% was reached at T_h=570 °C and at the longest holding time t_h=250s but pearlite formation was observed. Temperature T_h=740 °C for all holding times t_h=40-250s enables the ferrite generation in the amount range of X_F from 5 to 20% and the effect of the holding time is negligible. The holding time effect on the ferrite formation can be seen for lowering the temperature; the longer time at lowered isothermal temperatures cause the ferrite portion increase. Decreasing T_h temperature generate an extensive driving force for austenite transformation to ferrite, the longer time allows the carbon diffusion from ferrite to austenite, what leads to austenite stabilization, which is a good condition for residual austenite (RA) formation.

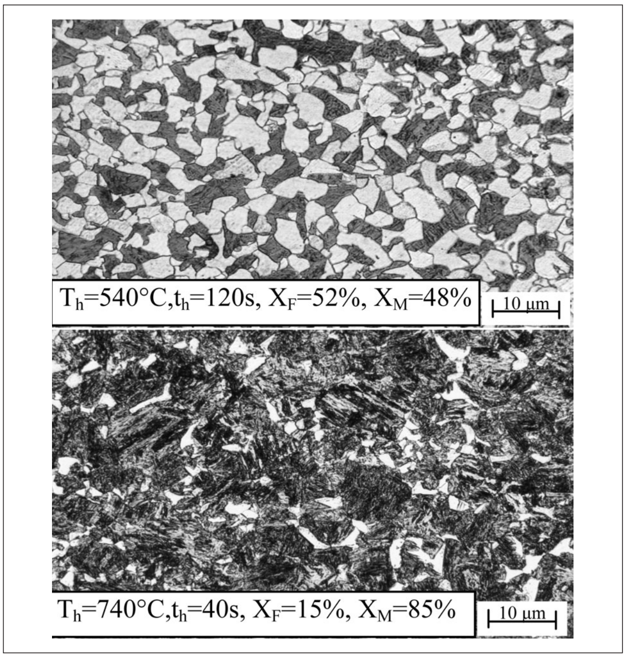

Figure 5. Phase fractions formation on cooling conditions

Martensite is a supplement to ferrite in quenched structures, while at the temperature $T_h \leq 570$ °C and time t_h = 180s pearlite begins to form in the structure. Long times and low temperatures caused that pearlite

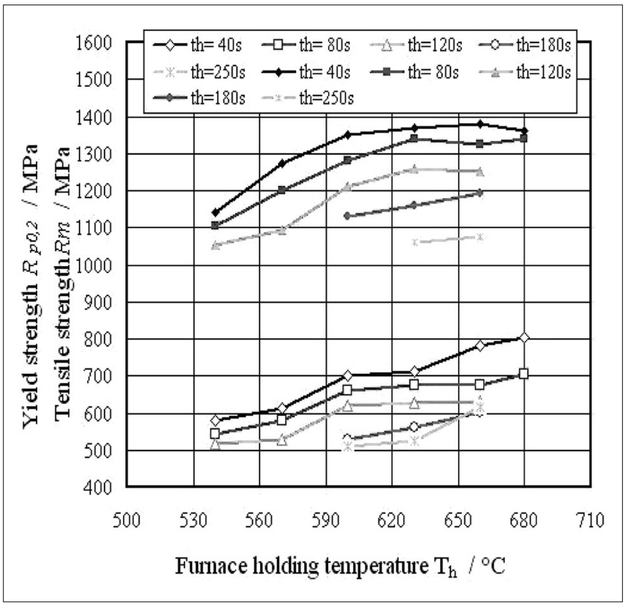

Figure 6. Dependence of yield and tensile strength formation on cooling conditions

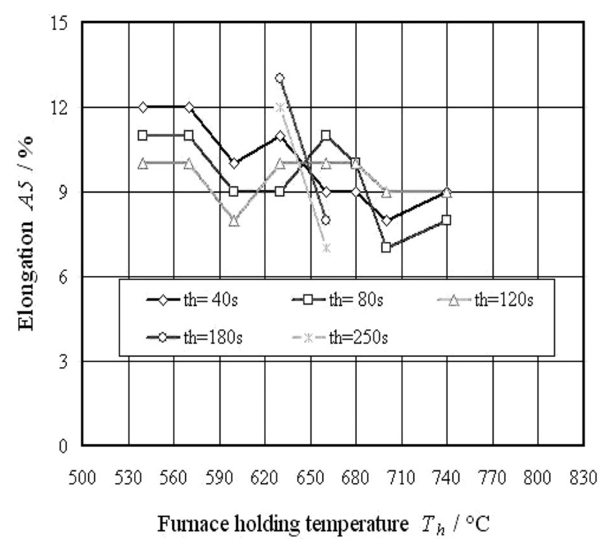

Figure 7. Dependence of elongation formation on cooling conditions

formed from austenite stabilized by carbon and consequently the carbon content in austenite decreased. This state can be already considered as not suitable for RA formation.

The dependences of mechanical and plastic properties of dual phase structures on furnace temperature and holding time in furnace are showed in Figure 6 and Figure 7.

Yield and tensile strength have increasing trend when furnace´s hold temperature is growing. This increasing trend of mechanical properties is depending on growing of matrix martenzite fraction. On the other side elongation is decreasing with growing furnace´s hold temperature because of ferrite fraction as plastic phase is reduced.

SUMMARY

Based on studies of relevant literature and experimental results the following conclusions can be summarized:

Conception of C-Mn-Si steel is characterized by shift of ferrite formation to lower temperatures.

The highest ferrite fraction X_F=65% was reached at the temperature T_h=570 °C and the longest holding time t_h=250s.

Temperature T_h=740 °C for all holding times t_h=40-250s enables the ferrite formation in the range of X_F from 5 to 20%; time factor is negligible.

Thermodynamic instability of austenite was recorded at 740°C.

Decreasing T_h temperature forms a substantial driving force for austenite transformation to ferrite, while the extending t_h time enables carbon diffusion from ferrite to austenite and austenite stabilization.

Long times and low temperatures cause that pearlite formation in austenite stabilized by carbon and consequently the carbon content in austenite decreases.

Yield and tensile strength have increasing trend when martenzite fraction in dual phase structure is growing up.

Elongation is decreasing when ferrite faction is reduced in dual phase structure.

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***Acknowledgements* -** The research was supported by Slovak Grant Agency for Science -VEGA project No. 1/4136/07.

Note: Author T. Kvačkaj is responsible as the lecturer for English language.