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ENHANCED COLD ROLL MATERIALS: ANSWER TO INCREASED ROLLING REQUIREMENTS OF MODERN STEEL GRADES[1]

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Abstract

Continuously increasing demands on hardness, depth of hardness, wear resistance and surface quality generate the need for cold rolls, consisting of improved or even new materials. The main developing efforts are made in order to enhance roll lifetime by optimising the metallurgical structure and increasing the depth of hardness. The development of ultra high strength steels leads to the requirement on higher wear resistance of cold rolls. In order to face this challenge, rolls of semi high speed steels (SHSS) and high speed steels (HSS) have been produced. A new primary hardening steel grade was developed. The alloy design was started by carrying out various numerical calculations attended by intensive experimental setups. The results are presented in this paper.
Key words: Cold roll material; HSS; Powder metallurgy; Compound roll; Alloy design.

MELHORIA DOS MATERIAIS LAMINADOS A FRIO: RESPOSTA ÀS EXIGÊNCIAS DE LAMINADO CRESCENTES PARA VARIANTES DE AÇO MODERNAS

Resumo

A procura crescente em termos de dureza, profundidade de dureza, resistência ao desgaste e qualidade de superfície geram a necessidade de desenvolver laminados a frio que consistem em materiais melhorados ou até novos. Os principais esforços de desenvolvimento têm como objetivo melhorar a durabilidade dos laminados através da optimização da estrutura metalúrgica e o aumento da profundidade da dureza. O desenvolvimento de aços de resistência ultra-elevada leva à necessidade de uma maior resistência ao desgaste dos laminados a frio. De modo a fazer face a este desafio, foram produzidos aços semi-superrápidos (SHSS) e aços superrápidos (HSS). Além disso, foi desenvolvido uma nova variante de aços de endurecimento primário. A concepção da liga começou com vários cálculos numéricos, acompanhados de amplas montagens experimentais. Os resultados constam deste documento.
Palavras-chave: Material laminado a frio; HSS; Metalurgia do pó; Laminado composto; Concepção da liga.

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1 INTRODUCTION AND STATE OF THE ART

Primary hardening steels (here referred to as "DHQ", deep hardening quality) represent the first and still strongly dominant class of cold roll materials (Figure 1). They are characterised by possessing their maximum hardness directly after quenching. Every tempering process leads to a decrease of that hardness.

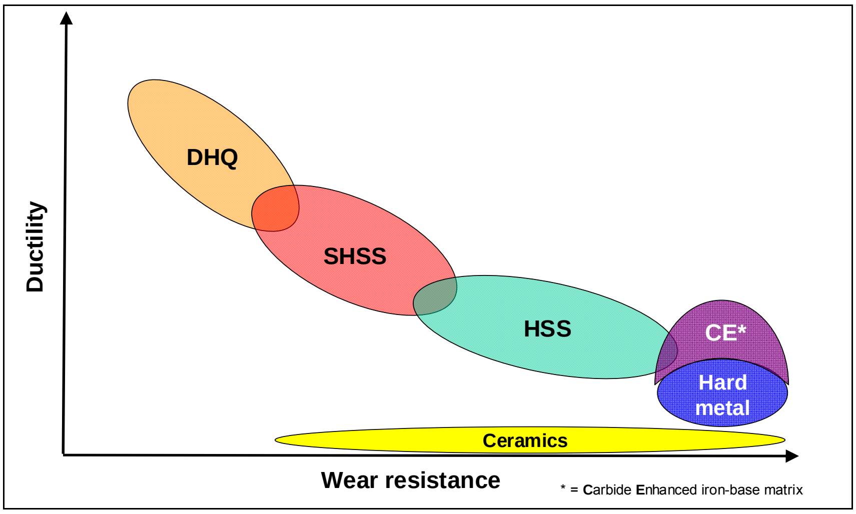

Figure 1. Classification of different types of cold roll steels and other materials.

The development of the DHQ grades was pushed by increasing the hardening depth, that means the distance below barrel surface, where ≥ 700 HV30 are reached, to avoid rehardening (i.e. if the roll hardness has been fallen under minimum level during lifetime, the roll had to be hardened again). The desired hardening depth results from enhancing the hardness of the matrix as well as modifying the transformation behaviour and carbide formation. In this context, chromium plays a dominant role as alloying element. Further major elements are manganese, silicon and molybdenum, which lead in combination with an adjusted thermal treatment to the needed material properties. Besides hardness, also a sufficient ductility is required, achieved by fine structured martensite in combination with numerous highly dispersed carbides. The newest development in this area is represented by steel grade DHQ 8, which will be explained later on in this text.
The increased exigencies on tempering and wear resistance induced the use of secondary hardening steels in cold rolls. These steel grades reach their maximum hardness not until tempering of about 500°C (Figure 2). Here, special carbides precipitate and improve the wear resistance and tempering stability. Partially higher temperature e.g. caused by strip slipping does not affect the microstructure and thus will not lead to local volume expansion and crack formation like primary hardening steels would do under equal conditions.

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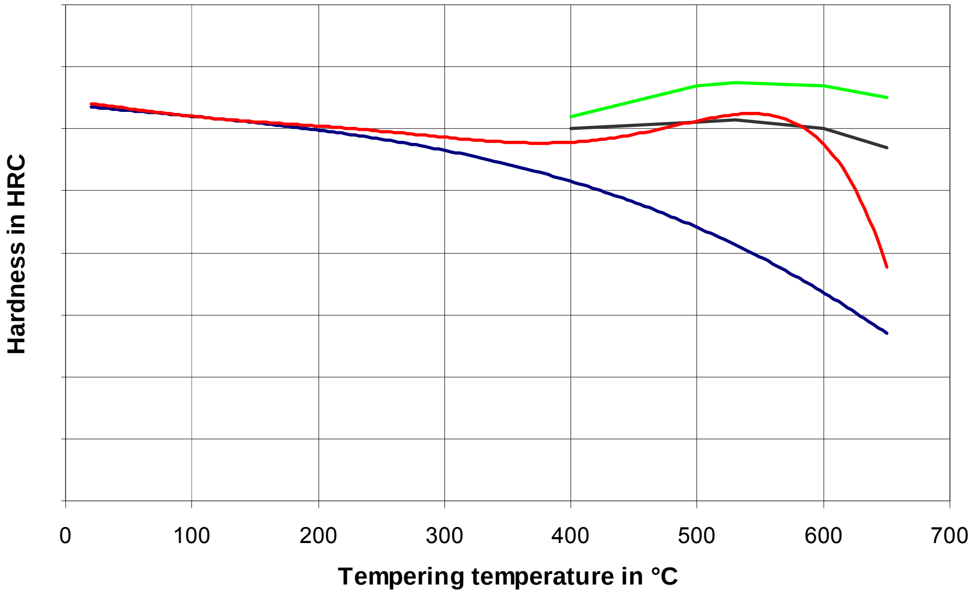

Figure 2. Reasons of secondary hardening behaviour: The primary martensitic hardness decreases constantly (blue line). Secondary hardening appears due to precipitation of special carbides (black) and transformation of retained austenite (green). The addition of these effects forms the typical tempering behaviour of secondary hardening steels (red line).

Depending on the contents of special carbide forming elements, secondary hardening steels are distinguished into SHSS (Semi High Speed Steel)[1] and classical HSS (High Speed Steel) grades (Figure 1). The intention for higher Cr-alloyed types is also the replacement for costly chromium coating.
As last step for now, the introduction of powder metallurgical materials can be regarded. Besides the possibility of introducing infusible materials, motivation was the prevention of segregations especially for higher alloyed steel grades. The development of new materials and the metallurgical treatment consider minimisation of segregations and inclusions. However, at higher concentrations of carbide forming elements, it is not possible to avoid segregations at all. Thus, blanks of PM material are produced by hot isostatic pressing (HIP), depending on the barrel diameter either as small single roll (monobloc), completely consisting of the PM alloy, or in a compound variant.[2] The latter consists of a cast and forged arbor of lower alloyed more ductile material and the usable zone of PM material. After HIP'ing both materials, the blank is hardened and tempered regularly according to its specification. This leads to a very wear resistant roll with an extreme homogenous microstructure.

2 METHODS USED FOR ALLOY DESIGN

The development of new steel grades nowadays relies not only on experimental trials but also on calculations of phase equilibria, solidification behaviour and microstructure formation. Base for this kind of calculation are the thermophysical data of all involved phases. The most popular software package in this area is Thermo-Calc®. It was used to deliver e.g. information on precipitation behaviour of carbides and non-metallic inclusions under local equilibrium conditions.

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This kind of calculation does not deliver results of real thermal treatment to configure the performance characteristics of a roll, because the processes during the hardening take place far from thermodynamic equilibrium. Other software packages allow in principle the calculation of the hardening depth for certain types of steel grades, but especially for those steel grades, where dissolution of carbides at austenitisation temperature is a prominent factor for hardening, the real hardening depth still can only be determined experimentally.
A first step to understand the phase transformations during hardening is having a TTT-diagram for continuous cooling. But the definite result can be achieved not until testing the hardness of an existing roll. That means, a roll blank with so called "barrel extension" (the barrel of the blank is about 300 mm larger than necessary for the planned roll) is used. After hardening and tempering the complete barrel, the diameter of the overlaying part of the barrel is reduced stepwise to measure the hardness at each step directly (Figure 3). Additionally, also the fraction of retained austenite and the internal stress are determined to complete the available information. Hence, with this procedure of successive removal, the real depth of hardening can be determined and the optimisation of hardening parameters can be carried out on base of that information.


Figure 3. Experimental setup to determine the real hardening depth of a roll.

3 RESULTS AND DISCUSSION

Several alloys with different element concentrations are calculated with respect to possible phases and precipitations. As starting point, the well known steel grade DHQ 4 was chosen, one of the cold roll steels with best performance concerning hardening depth and reliability. Intention was the increase of secondary carbide fraction, the enhancement of matrix hardness, a better hardenability and the prevention of primary carbide formation.

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Table 1. Chemical composition (weight %) of DHQ 4 and DHQ 8

Alloy	C %	Si %	Cr %	Mo %	P %	S %
DHQ 4	0.80	0.75	3.0	0.55	≤0.025	≤0.015
DHQ 8	0.75	0.75	4.0	0.55	≤0.025	≤0.015

From the tested compositions, the one indicated as DHQ 8 in Table 1 was the most successful composition. As can be seen in Figure 4, the calculation according to Scheil module indicates, that DHQ 8 possesses a reduced vulnerability to precipitation of primary carbides. Even if it is assumed, that under experimental conditions primary carbides also will appear in DHQ 8, the fraction of it will be significantly smaller than at DHQ 4.

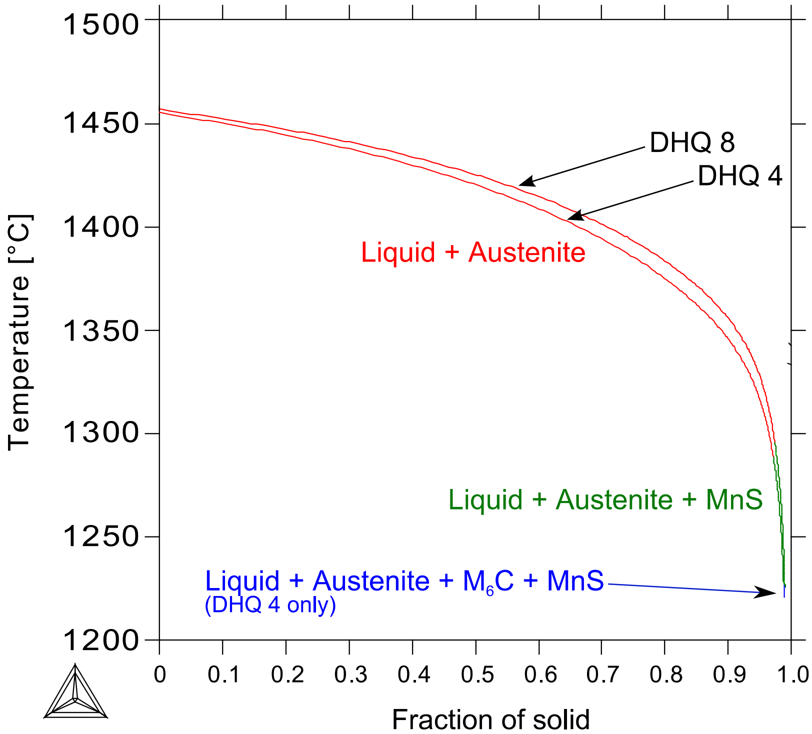

Figure 4. Results for DHQ 4 in comparison to new DHQ 8, concerning solidification behaviour, using Scheil module.

Also the phases, forming under local equilibrium conditions represent an optimisation. The part of M_7C_3 secondary carbides could be increased by 2% in the new composition, while M(C,N) and MC (according to Shipman) are reduced significantly (Figure 5).

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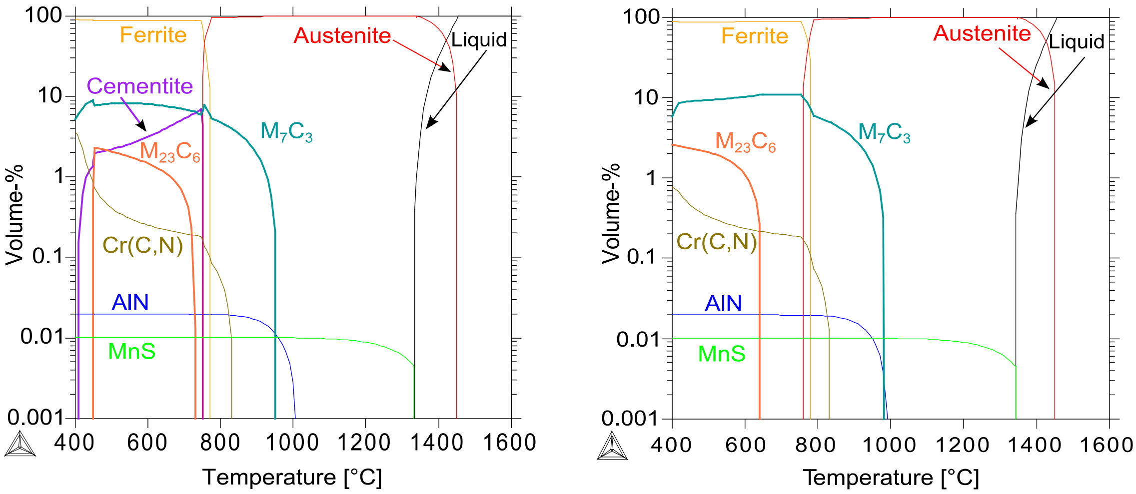

Figure 5. Results of Thermo-Calc® calculation for DHQ 4 (left) in comparison to new DHQ 8 (right), phase formation, assuming local equilibrium.

In addition, the calculation delivered the information that the increased content of some of the alloying elements would have lowered the solidus temperature to regions, where the forging of the blank could run into problems due to a partially melting of the block.

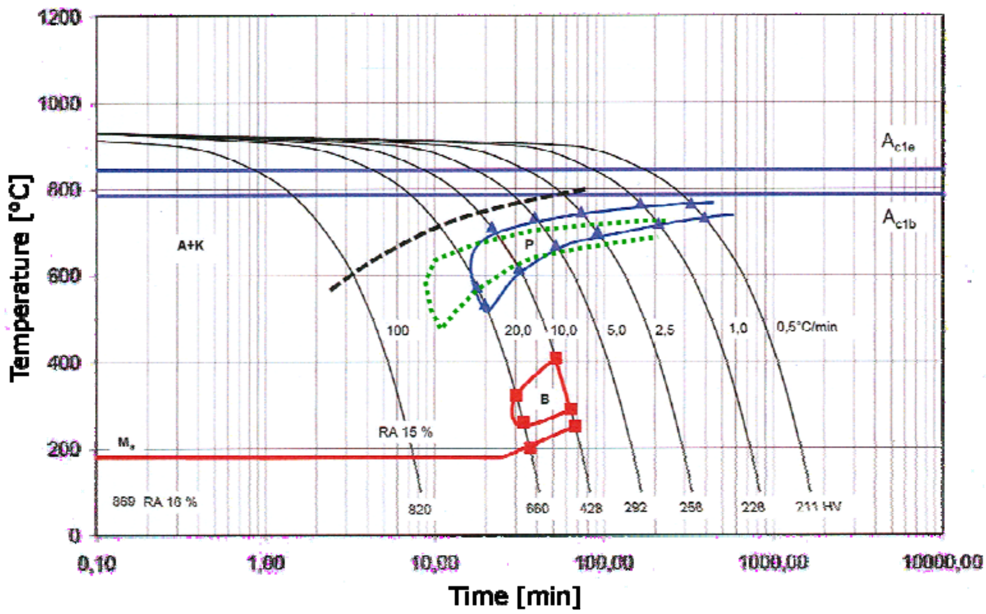

Figure 6. CCT- (continuous cooling transformation) diagram for DHQ 8, determined by experimental dilatometer tests. The green dotted line denotes the position of the pearlitic zone of DHQ 8's predecessor DHQ 4.

To describe the transformation properties of the new material, a continuous cooling transformation (CCT) diagram was compiled (Figure 6). Base of the diagram are results of several dilatometer tests, performed with different cooling rates. In combination with metallographic determined microstructure at room temperature, the information can be

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made visible. In comparison to DHQ 4 (green), die pearlitic field of DHQ 8 was shifted of about 10 minutes backwards, i.e. pearlitic phase fraction in the hardened microstructure could be found only at larger distances form the barrel surface in DHQ 8.

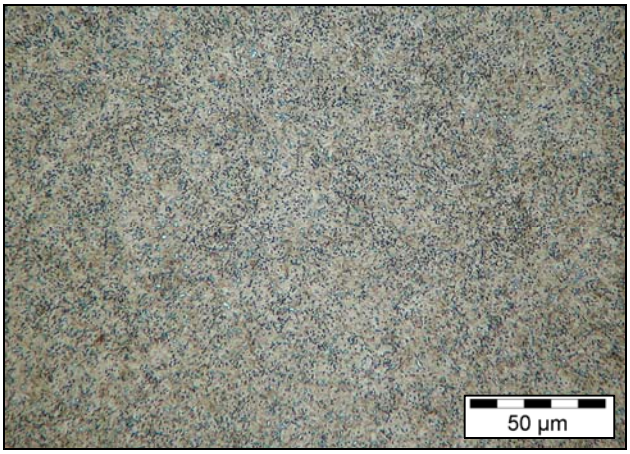

Figure 7. Microstructure of the barrel surface in hardened state, steel grade DHQ 8.

The first rolls out of DHQ 8 were already hardened. The metallographic examination of the barrels surfaces shows a very fine martensitic microstructure with small embedded dispersed carbides (Figure 7). While completing the article, the test on hardening depth are going on, to find the optimal parameters for the hardening procedure. Even though the tests are not completed, the preliminary results promise, that the aspired hardening depth will be achieved (Figure 8).

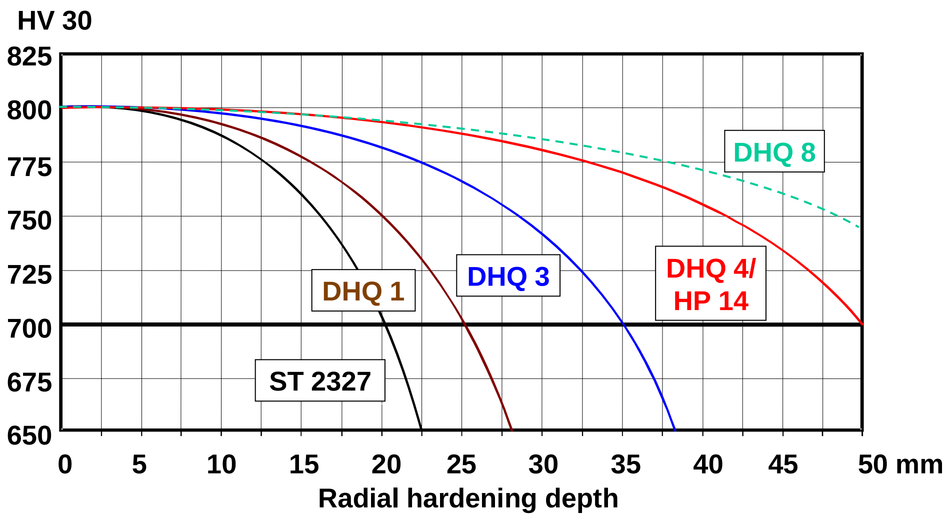

Figure 8. Estimated hardening depth of DHQ 8 in comparison to conventional cold roll steel grades.

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4 CONCLUSIONS

The development of cold roll steel grades still allows significant advances in technological properties of cold rolls. It was shown, that the support of numerical calculations and well proved experimental setups permit to shorten the innovation cycles also in applied material sciences. This enables the customer to benefit fast and directly from the innovations in this industry.

Acknowledgements

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REFERENCES

1 Ernst, C.: "*New cold work steels for sheet metal processing and cold massive forming*", The Heat Treatment Market (2005), No. 2, P. 5 – 8

2 Hofer, B.: "*Werkstoffverbund mittels heissisotatischem Pressen*" (*Materialscompound by hot isostatic pressing)*, Technische Rundschau/ Swizerland (2000) No. 4 (in german)