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# The influence of pre – tempering on the mechanical properties of HS18-0-1 high speed steel

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## ABSTRACT

**Purpose:** Main objective of the research presented in this work was the evaluation of the influence of pre-tempering on the properties of HS18-0-1 steel after principal tempering.

**Design/methodology/approach:** Samples of test steel, previously hardened from the temperature of 1260°C have been pre-tempered at 20, 250, 450 and 520°C for 1,5 hour and subsequently cooled in air. After that principal tempering has been applied 3x580°C/1h. Due to high brittleness of test steel it was decided to test their strength with static bend test. The tests have been carried out on Φ5 samples using INSTRON testing machine. Evaluation of crack resistance of test steels has been made by means of linear elastic fracture mechanics method on the basis of the measurement of stress intensity factor KIc, in static bend test.

**Findings:** It has been stated that, in test steel in which remains a lot of retained austenite after hardening, the pre-tempering within the range of cementite precipitation and transformation of retained austenite, adversely affects the properties after principal tempering. Pre-tempering of the investigated steel at the temperature insignificantly higher than start temperature of precipitation of MC type alloy carbides results in decrease of strength properties by insignificant increase of $K_{Ic}$

**Research limitations/implications:** Description of the influence of pre – tempering on the mechanical properties of HS18-0-1 high speed steel

**Practical implications:** This results should be of interest to engineers concerned with design new technologies of steel tempering.

**Originality/value:** It was shown, that advance (by pre-tempering) of selected phase transformations during tempering may affect steel properties after principal tempering.

**Keywords: Tool materials; Pre-tempering; Mechanical properties; High-speed steel**

MATERIALS

## 1. Introduction

High speed steels owe its name to ability of fast machining and cutting of various materials among others the alloys with iron matrix. They are characterized by high content of carbon and other alloying elements, mainly carbide forming, such as W, Mo, V and Cr. Some types of high speed steels contain also Co [1÷3].

One of more important attributes of these steels are their cutting properties dependent on wear resistance, impact resistance and the resistance to heat tempering. Wear resistance depends on the type, content and form of primary carbides (MC, $M_6C$) and matrix hardness. Whereas the impact resistance is determined by the state of tempered matrix, grain size of former austenite, spatial arrangement and size distribution of primary carbides. Matrix of high speed steels consists of well tempered martensite and the carbides causing secondary hardness. [1,3]

Microstructure of correctly heat treated high speed steel should consist of a hard and homogeneous matrix with a high volume fraction of fine and uniformly distributed carbides both the undissolved during austenitizing and being formed during tempering.

Among numerous research conducted in recent years on high speed steels one may distinguish the research on modification of chemical composition [4÷9], phase transformations during tempering [10÷13] and the surface properties of tools made of high speed steels [14,15].

Main objective of the research presented in this work was the evaluation of the influence of pre-tempering on the properties of HS18-0-1 steel after principal tempering.

## 2. Test material

The research was conducted on HS18-0-1 high speed steel with chemical composition given in Table 1.

Table 1. Chemical composition of the investigated steel

| Grade | mass % | | | | | | |
|---|---|---|---|---|---|---|---|
| | C | Mn | Si | Cr | Mo | W | V |
| HS18-0-1 | 0,85 | 0,27 | 0,31 | 4,26 | 0,50 | 17,0 | 1,26 |

Prior to testing the samples of investigated steel were soft annealed at 840°C/4hours, and successively cooled at the rate of 6°C/hour to 600°C, and after that to the room temperature together with the furnace.

## 3. Experimental procedure

Samples of test steel, previously hardened from the temperature of 1260°C (austenitizing times were 5min for sample for testing of flexural strength, 7min for sample for crack resistance testing, quenched in oil), have been pre-tempered at 20, 250, 450 and 520°C for 1,5 hour and subsequently cooled in air. After that principal tempering has been applied 3x580°C/1h.

Due to high brittleness of test steel it was decided to test their strength with static bend test. The tests have been carried out on ϕ5 samples using INSTRON testing machine.

Evaluation of crack resistance of test steels has been made by means of linear elastic fracture mechanics method on the basis of the measurement of stress intensity factor $K_{Ic}$, in static bend test. The samples with dimensions of 9×18×90 mm have been used for testing. The samples with a 2mm deep fatigue cracks on the bottom of mechanically cut notch have been three-point bent on INSTRON testing machine.

Hardness measurements have been made with Vickers method using HPO 250 apparatus.

Fractographic study has been performed on fractures of samples used for $K_{Ic}$ factor determination. The fracture surfaces have been observed using Hitachi 3500N type SEM analyzing microscope.

## 4. Research results and discussion

Fig. 1 presents the influence of pre-tempering on flexural strength and hardness of test steel after principal tempering. The temperatures and duration (1,5h) of principal tempering have been selected on the basis of previous research [10,11]. For test high speed steel a pre-tempering at the following temperatures has been selected: 250°C – i.e. slightly above the temperature of ε carbide precipitation end and start of cementite precipitation, 450°C – i.e. after the precipitation of cementite is finished and transformation of part of retained austenite 520°C – i.e. slightly above the temperature of precipitation start of independently nucleating carbides of MC type.

In test steel all variants of principal tempering caused a decrease of strength and hardness in relation to classic tempering 3x580°C/1h. In case of pre-tempering at 250°C this temperature has already been high enough for cementite precipitation start and lowering the stability of retained austenite prior to principal tempering. As a result the process of principal tempering (3x580°C/1h) had been facilitated. Therefore it is noticeable that pre-tempering at 250°C resulting in preliminary advance of cementite precipitation cases lowering of final (after principal tempering) hardness and strength. May be one should perform the pre-tempering of this steel at the temperature allowing to precipitate ε carbide only, i.e. not exceeding 200°C.

Pre-tempering at 450°C resulted in even further decrease, if compared to classic tempering 3x580°C/1h, of flexural strength with insignificantly smaller decrease of hardness. Most probably it is a resultant of full advance of cementite precipitation and transformation of part of retained austenite.

After pre-tempering at 520°C a significant part of retained austenite has transformed and also the process of precipitation of alloy carbides of MC type has been advanced. As a result the hardness after principal tempering has decreased significantly, while the decrease of strength has been stopped.

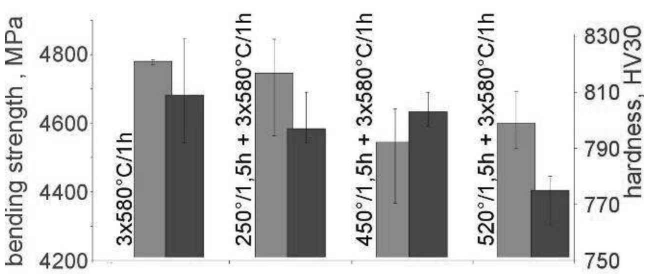



Fig. 1. Influence of pre-tempering on flexural strength and hardness of test steel

Fig. 2 presents the influence of pre-tempering on the fracture resistance expressed as stress intensity factor $K_{Ic}$ and on hardness of test steel. Pre-tempering has been conducted at the temperature above the range of cementite precipitation and partial transformation of retained austenite (450°C) and at the temperature slightly higher than start temperature of independently nucleating carbides of MC type (520°C). Compared to the results of hardness measurements performed on samples after bent test the results obtained are insignificantly higher what most probably is a result of a longer austenitizing time during hardening of the samples for $K_{Ic}$ test. Nevertheless the type of hardness changes is compatible for both tests. Pre-tempering at 450°C resulted in insignificant increase of $K_{Ic}$ by slight hardness decrease. At 450°C it is possible that significant part of retained austenite in this steel has already been transformed, resulting in facilitation of matrix tempering process, what is visualized by minimal increase of $K_{Ic}$. Insignificant hardness decrease after pre-tempering at 450° should be combined with advanced precipitation of cementite. As cementite has been inhibiting the precipitation of alloy carbides and thus the hardness of this steel does not decrease significantly. The increase of $K_{Ic}$ after pre-tempering at 520°C should be combined with start of independent carbides precipitation. Finally a higher fracture resistance has been achieved with lower hardness of the steel, though.

If one considers a product of $K_{Ic}$ and hardness, any of the variants of pre-tempering applied brings a distinct advantage. Therefore one should consider different approach, by the same flexural strength and $K_{Ic}$ tend to increase of steel hardness. It seems that this goal is achievable by application of pre-tempering within the range of ε carbide precipitation (below 200°C for investigated steel) with subsequent principal tempering 3x580°C/1h applying fast heating (eg. in salts) to this temperature.

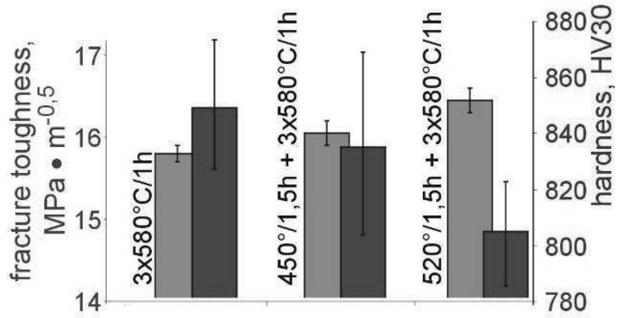



Fig. 2. Influence of pre-tempering on crack resistance expressed as stress intensity factor $K_{Ic}$ and on hardness of test steel

Fig. 3÷5 presents the fractures of test steel after crack resistance test. One may notice that the appearance of the fractures is similar. In all variants the significant influence on flexural strength and $K_{Ic}$ has had a content and distribution of undissolved carbides during hardening process.

a) b)

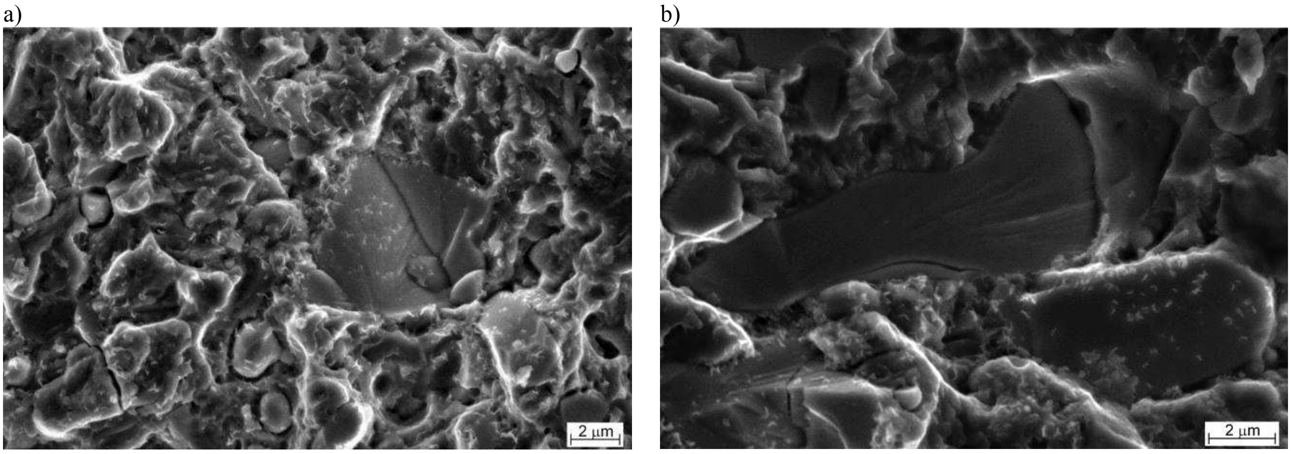



Fig. 3. Fractures of HS18-0-1steel samples after crack resistance test, tempered 3x580°C/1h

a) b)

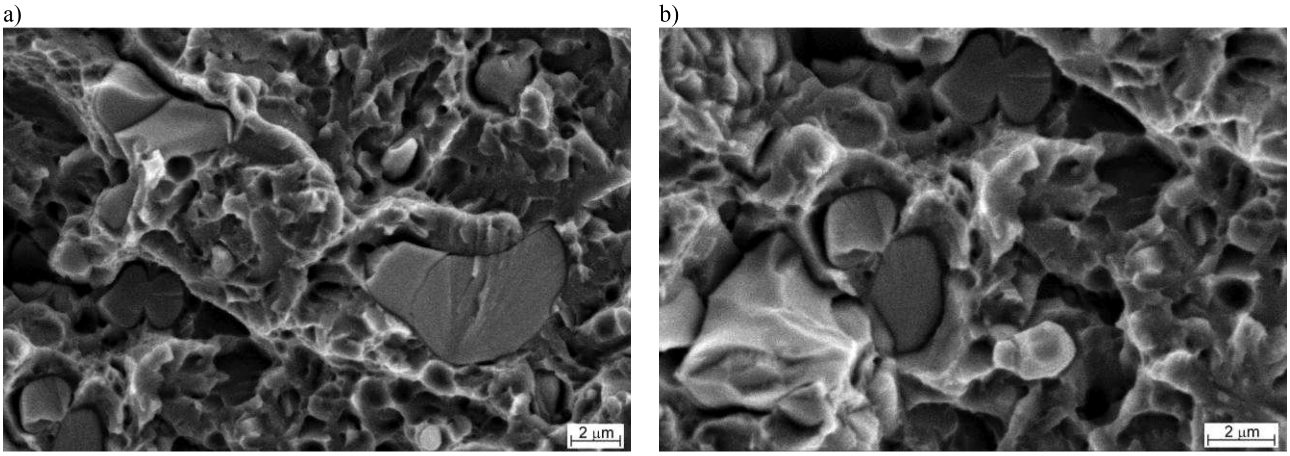
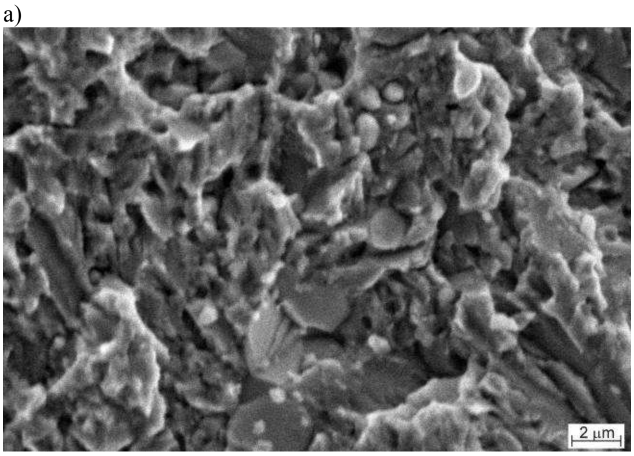



Fig. 4. Fractures of HS18-0-1steel samples after crack resistance test, tempered at 450°C/1,5 + 3x580°C/1h



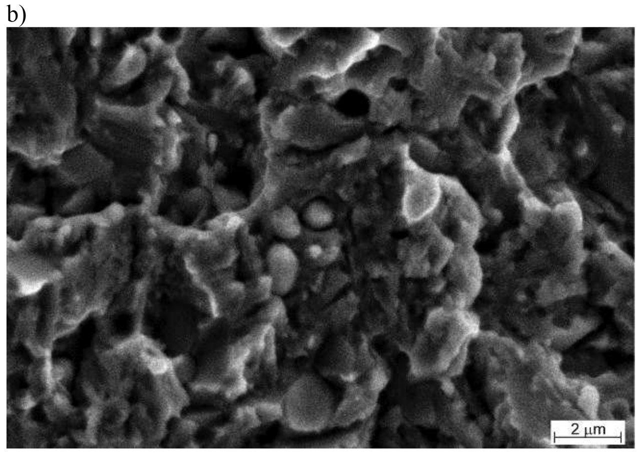




Fig. 5. Fractures of HS18-0-1steel samples after crack resistance test, tempered at 520°C/1,5 + 3x580°C/1h

## 5. Conclusions

Advance (by pre-tempering) of selected phase transformations during tempering may affect steel properties after principal tempering. It has been stated that, in test steel in which remains a lot of retained austenite after hardening (~27% [10]), the pre-tempering within the range of cementite precipitation and transformation of retained austenite, adversely affects the properties after principal tempering. Pre-tempering of the investigated steel at the temperature insignificantly higher than start temperature of precipitation of MC type alloy carbides results in decrease of strength properties by insignificant increase of $K_{Ic}$.

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