ISSN 1392 - 1207. MECHANIKA. 2008. Nr.3(71)

Influence of high temperature heat treatment on creep properties of high speed steel

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1. Introduction

Phases of hardened steel – martensite and retained austenite, are metastable satiate solid solutions and resolve into matrice with ferrite base and carbides during tempering. The character of structural transformations of carbon steel during tempering depends on tempering temperature, duration time and amount of carbon in solid solution of steel. Segregation of carbon atoms, i. e. formation of plane collections of carbon atoms (clusters) is already observable at ~ 100°C temperature [1]. Formation of clusters makes atoms of carbon to re-move. Lattice of martensite is deformed elastically. When temperature increases from 100 until 200°C, ε – carbide with hexagonal lattice (Fe_2C) forms, subsequently, η – carbide with rhombic lattice ($Fe_{2.5}C$) is observable. χ – carbide (Fe_5C) is dominant when high carbon steel is tempered at 250 - 300°C temperature. Eventually, at temperatures 300 - 400°C cementite Fe_3C forms – the most stable carbide phase [1]. Carbide coagulation and spheroidization proceed when temperature of tempering is increased until critical point A_{c1}. Enlarged transformation plasticity of steel and stress relaxation accompanies all these processes. Plastic deformation of the specimen of tested steel reaches suitably high magnitudes when bending stress is not higher than 0.4 σ_T [2, 3]. Singularities of this type of plasticity:

1. great and short-term increase of plasticity is related with the heating of tempered steel article until the tempering temperature is reached;
2. transformation plasticity is missing at repeatedly heating;
3. transformation plasticity increases with the increase of tempering temperature and amount of carbon in steel.

Alloying elements (Cr, Mo, W, V), that compose special carbides, strengthen interatomic bonds between solid solution and carbides, slow segregation and diffusion of carbon atoms. These alloying elements raise the temperature of carbon segregation from retained austenite from 200 - 300°C (for carbon steel) until 500 - 600°C (for high chromium and high-speed steel) [1].

Formation of carbide particles in grade X55Cr17 steel was investigated by electron microscopy [4]. Fragmentation of martensite begins after more than 10 seconds, but it is not fully acomplished after 10 minutes. Formed cementite has the same concentration of Cr and Mo as martensite phase in the steel with chromium and molibdenum after heating 40 hours at 350°C temperature. Considerable increase of the consentration of Cr and Mo atoms was observed in the interface of martensite-cementite after heating 187 hours at 450°C temperature [5]. This shows that the diffusion of chromium and molibdenum proceed already at 450°C temperature but very slowly. Increased short-term plasticity of hardened high chromium steel was obtained at temperature $T < 450°C$, when carbon separates from satiate solid solution; and great, long-lasting plasticity also existed during heating repeatedly was obtained at temperatures $T \geq 500°C$, when special carbides of chromium form [5-7].

High-speed steel has much special carbides of tungsten, molibdenum, vanadium and chromium. These steels (P6M5, P18, GOST or HS6-5-2, HS18-0-1, EN) also has increased plasticity at high temperatures. Its transformation plasticity at 560°C temperature is similar to the plasticity of grade X12M steel, GOST, (~X210Cr12, EN) at 520°C temperatures [8, 9]. Transformation plasticity of high speed steel was investigated during short-term tempering (15-60 minutes) at 560 – 600°C temperatures.

High-speed steel may be used as structural material at high temperatures for particular term because of its sufficient thermal durability. The aim of this work is to examine the variation of transformation plasticity of this steel due to the long-lasting thermal effect.

2. Testing procedures

Grade P6M3 steel, GOST (~HS6-5-2, EN) with such chemical composition (wt. %): C = 0.92; W = 6.10; Mo = 2.95; V = 1.52; Cr = 4.12; Si = 0.27 was used for the research. Specimens for bending with parameters 8 × 8 × 90 mm were made from rod of Ø14 mm diameter. For hardening, the specimens were pre-heated at 870°C temperature for 4 minutes in NaCl, then heated at 1240°C keeping 4 min in $BaCl_2$ + 5 % MgF_2, isothermally cooled at 400°C keeping 2 min in 50 %KNO_3 + 50 % NaOH, and later, in the soft air. Hardness of the specimens after hardening was HRC 64-65, quantity of retained austenite was 16-18 %.

During investigation, the specimens were loaded by concentrated bending load for 1-3 h. The maximum normal bending stress was 200 and 300 MPa that made from 7 to 15 % of yield strength of the steel during bending at 560 - 650°C temperatures [10]. Furnace of experiments allowed keeping temperature with the accuracy of ± 2°C. Deflection of a specimen was measured with the accuracy of 0.01 mm at certain interval of time. For investigation of long-duration heat treatment influence on steel creep at high temperature, hardened specimens were tempered in the furnace, in the compound of cast-iron shaving, quartz sand and charcoal for the certain duration (1-74 h). After that, the specimens were investigated at bending equipment.

3. Results and discussion

During tempering of hardened steel, the deflection of specimens intensivelly grows during the first 10 minutes (Fig. 1) until the tempering temperature is reached. This moment of heating coincides with the segregation of carbon from martensite [4]. During further heating at 560°C temperature, deflection of bent specimens grows fractionally: about 8% keeping 60 minutes, and about 22% keeping 180 minutes (Fig. 2).

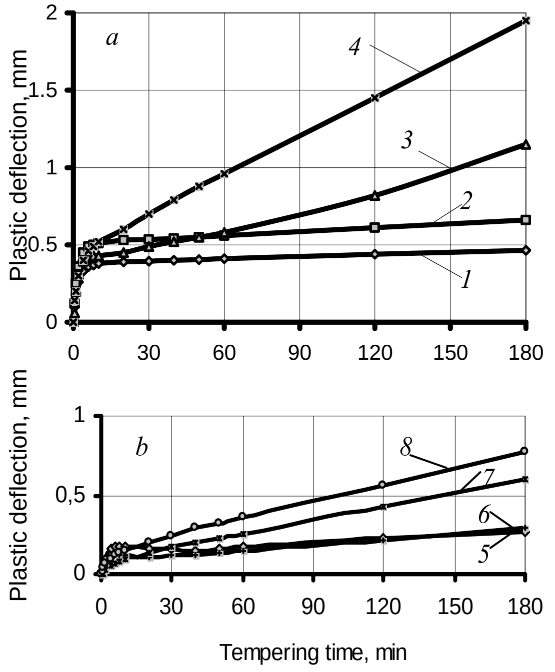

Fig. 1 Dependence of kinetics of plastic deflection on tempering temperature and structural state when $\sigma_l = 200$ MPa: *a* – tempering of hardened specimens at temperatures: *1* – 560°C; *2* – 580°C; *3* – 600°C; *4* – 625°C; *b* – tempering at 580°C after heat treatment: *5* – 560°C × 1 h × 3 times + 560°C × 54 h; *6* – 560°C × 1 h × 3 times + 560°C × 6 h; tempering at 600°C after heat treatment: *7* – 560°C × 1 h × 3 times + 560°C × 6 h; *8* – 560°C × 1 h × 3 times + +560°C × 54 h

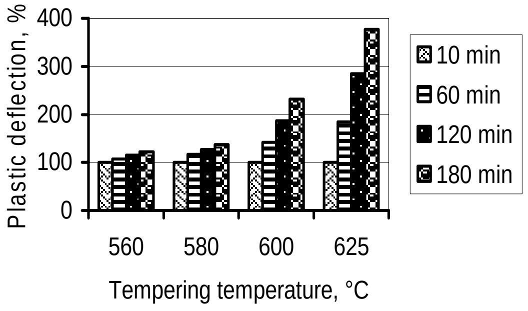

Fig. 2 Plastic deflection of specimens subjected to heating when $\sigma_l = 300$ MPa

Plastic deflection grows rapidly at higher temperatures keeping 60 and 80 min: accordingly from 17 until 37% at 580°C temperature, from 42 until 182% at 600°C, and from 86 until 278% at 625°C. Also, the character of deflection changes: deflection grows gradually when heating at the temperature of 625°C from 20 until 180 min. At lower temperatures deflection grows with rising intensity (Fig. 1, a).

After standard (three times by 1 hour) tempering at 560°C temperature, several specimens were tempered again keeping 6 hours (Fig. 1, b, curves *6*, *7*) or 54 hours (Fig. 1, b, curves *5*, *8*) at 560°C without load, then bent during heating at 580°C. These specimens bent quite unlikely (Fig. 1, b, curves *5*, *6*). Specimens treated by the same schedule and bent at 600°C for 180 minutes behaved differently, too. Deflection of the specimen heated 54 hours at 560°C (Fig. 1, b, curve *8*) was 28% higher than of the specimen heated 6 hours at 560°C (Fig. 1, b, curve *7*).

The results of Fig. 3 show, that kinetics of creep of steel P6M3 specimens at 600°C temperature is similar after one or three times 1 hour lasting tempering at 560°C. The value of deflection after 60 minutes of heating is close to the value of plastic deflection of hardened but not tempered specimen (Fig. 3, c).

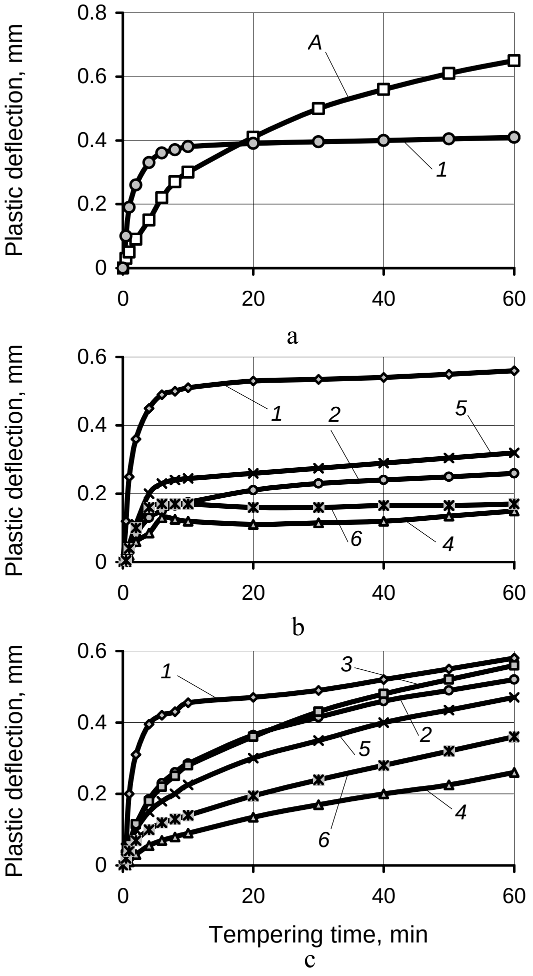

Fig. 3 Creep of steel during heating at 560°C (a), 580°C (b) and 600°C (c) temperatures ($\sigma_l = 200$ MPa) subjected to structural state: *A* – annealed; *1* – hardened; *2* – tempered at 560°C 1 h; *3* – tempered at 560°C 3 times for 1 h. Tempered at 560°C 3 times for 1 h and left for a long lasting heating for: *4* – 6; *5* – 24; *6* – 54 h

During investigation at 580°C temperature, the defection of specimens tempered once at 560°C is 50% lower than the deflection of hardened specimen (Fig. 3, b). The lowest plastic deflection was obtained for the specimen after standard tempering (3 times by 1 h) heated 6 hours at 560°C. The deflection grows minutely when the duration of heating is 24 hours. When the specimen is heated keeping 54 hours, its deflection decreases again but remains higher than after 6 hours lasting tempering.

Long-duration heating of hardened specimens at 625°C temperature has more observable influence on creep of the steel. Fig. 4 shows, that plastic deflection of the specimens tempered once or 4 times for 1 hour at 625°C temperature differs from the deflection of hardened specimens only at the first ten minutes. Creep grows particularly when heating duration at 625°C is prolonged until 23-73 hours. Creep of hardened and tempered specimens becomes similar to the creep of annealed specimens (Fig. 4), noticed already at 560°C temperature when bending load is 200 MPa (Fig. 3, a).

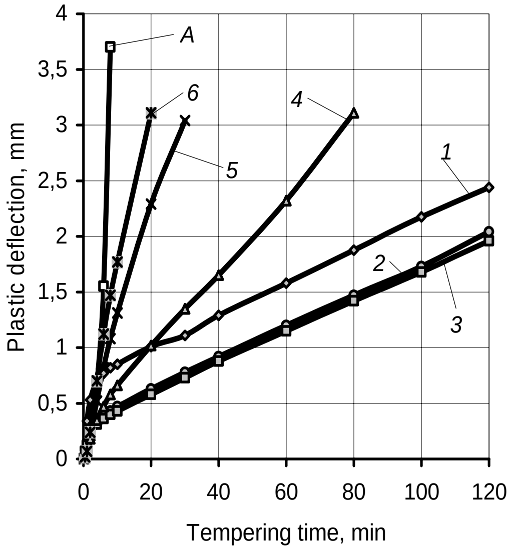

Fig. 4 Influence of long-duration heating on creep of grade P6M3 steel at 625°C when $\sigma_l = 300$ MPa: *A* – annealed; *1* – hardened; *2* – tempered at 625°C 1 h; *3* – tempered at 625°C 4 times for 1 h; *4* – tempered at 625°C 1 and 24 h; *5* – tempered at 625°C 1 and 44 h; *6* – tempered at 625°C 1 and 73 h

Great differences of creep of high speed steel subjected to the different heat treatment temperature, duration and cycling can be explained by complex transformation changes [1; 11].

1. Segregation of carbon atoms from satiate solid solution – martensite and austenite, their diffusion and formation of alloyed cementite Me_3C at temperatures $T \leq 450°C$.
2. Formation of dispersive carbides Me_2C at temperature $T < 600°C$ in the defects of structural state, blocking of dislocations and increase of hardness and creep resistance.
3. When intensive processes of diffusion occur at temperatures $T \geq 600°C$, the concentration of alloying elements (W, Mo, Cr, V) increases in carbides. Such carbides form: $M_2C \rightarrow Me_{23}C_6 \rightarrow Me_6C$.
4. Coagulation of carbides proceeds during last-holding heating at temperature $T > 600°C$: dispersive carbides dissolve, atoms of carbon and metals migrate through the solid solution and precipitate on larger growing carbides. Blocked dislocations release, it becomes more mobile.
5. During segregation of carbon atoms from the satiate solid solution and diffusion of atoms of alloying elements, the strength of interatomic bonds and local microstress of lattice change. This relieves the mobility of dislocations that determines creep of the steel.
6. Alloying elements (W, Mo, Cr and V) slows significantly diffusion of carbon atoms. Therefore, changes of structure and mechanical properties are long lasting and require high temperatures.

4. Conclusions

1. Increased plasticity of hardened high speed steel during the first tempering is relative to the segregation of carbon atoms from satiate solid solution.

2. Specimens of investigated steel have the lowest creep at 580 - 600°C temperatures after standard tempering.

3. Steel loose its creep resistance during heating at 625°C temperature already after few hours.

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ILGALAIKIO TEMPERATŪRINIO POVEIKIO ĮTAKA GREITAPJOVIO PLIENO VALKŠNUMUI

Reziumė

Ankstesniuose darbuose buvo eksperimentiškai tiriama virsminio plastiškumo kinetika atleidžiant grūdintą anglinį ir legiruotąjį įvairaus anglingumo plieną. Nustatytas didelis virsminis plastiškumas pirmą kartą kaitinant iki 450°C temperatūros, kai iš persotinto kietojo tirpalo išsiskiria anglis ir susidaro dispersiški karbidai. Atleidžiant daugiachromį plieną, didelis virsminis plastiškumas pasireiškia kaitinant ilgą laiką bei pakartotinai kaitinant aukštesnėse nei 450°C temperatūrose.

Šiame darbe, naudojant lenkimo bandinius, tiriama greitapjovio plieno virsminio plastiškumo kinetika 560 - 650°C temperatūrose. Tyrimų rezultatai gali būti naudojami lyginant grūdinimo metu deformuotus gaminius.

J. Žvinys, R. Kandrotaitė Janutienė

INFLUENCE OF HIGH TEMPERATURE HEAT TREATMENT ON CREEP PROPERTIES OF HIGH SPEED STEEL

Summary

In earlier works were presented the investigation on transformation plasticity of hardened steel with various amount of carbon and alloying elements. High transformation plasticity was obtained during the first tempering at 450°C temperature when carbon segregates from solid solution and dispersive carbides form. During tempering of high chromium steel, high transformation plasticity is observable during long-lasting heating and during heating repeatedly at higher than 450°C temperatures.

The aim of this work is to investigate the kinetics of transformation plasticity of high-speed steel at 560 - 650°C temperatures using bending specimens. Results of the investigation can be used for smoothing of the deformed articles during hardening.

Ю. Жвинис, Р. Кандротайте Янутене

ВЛИЯНИЕ ДЛИТЕЛЬНОЙ ТЕРМИЧЕСКОЙ ОБРАБОТКИ НА ПОЛЗУЧЕСТЬ БЫСТРОРЕЖУЩЕЙ СТАЛИ

Резюме

Кинетика пластичности превращения при отпуске закаленной углеродистой и легированной стали с различным содержанием углерода исследовалось экспериментально в предыдущих трудах. Установлена существенная пластичность превращения при первом нагреве на отпуск до температуры 450°C, когда из пересыщенного твердого раствора выделяется углерод и образуются дисперсные карбиды. При отпуске высокохромистой стали существенные превращения пластичности наблюдаются при длительной выдержке и повторном нагреве в температурах выше 450°C

В данной работе исследуется кинетика превращения пластичности быстрорежущей стали при температурах 560 - 650°C на изгибаемых образцах. Результаты исследования могут быть использованы для правки изделий, покоробленных при закалке.

Received March 14, 2008

DOI: 10.5755/j02.mech.15091