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# Influence of Cooling Rate in High-Temperature Area on Hardening of Deposited High-Cutting Chrome-Tungsten Metal

N N Malushin<sup>1</sup>, D V Valuev<sup>2</sup>, A V Valueva<sup>3</sup>, A Serikbol<sup>4</sup>, I F Borovikov<sup>5</sup>

<sup>1</sup> 654007 Kemerovo region, Novokuznetsk, Kirova str. 42 Siberian State Industrial University,

<sup>2,3,4</sup> 652050, Kemerovo region, Yurga, Leningradskaya str.26 Yurga Technological Institute branch of Tomsk Polytechnic University

<sup>5</sup> The Moscow State Technical University of N.E. Bauman, Moscow, 5, 2nd Baumanskaya

E-mail: valuev@tpu.ru

**Abstract:** The authors study the influence of cooling rate in high-temperature area for thermal cycle of high-cutting chrome-tungsten metal weld deposit on the processes of carbide phase merging and austenite grain growth for the purpose of providing high hardness of deposited metal (HRC 64–66).

## Introduction

Hot-working steels like P18, P6M5, P9, P2M8, 3X2B8, 3X2B4Φ, X10B14, etc., which meet almost all requirements for deposited metal to harden metallurgical equipment parts, have as good service characteristics so unsatisfactory weldability. Usually to prevent cold cracks formation traditional technology of weld deposit uses preparatory and additional high-temperature heating (T. heat. = 400–700°C) and retarded piece cooling. During this process malleable austenite products of breakdown are formed and they have low hardness and enduring quality that causes difficult heat treating. During the process of bimetal piece heat treating it is not always possible to make use of all high-alloyed metal characteristics and to ensure its maximum hardness.

In developed weld deposit ways for hot-working steels with good hardness in order to prevent cold crack formation it is supposed to use a kinetic malleability effect (“extramalleability”). A special feature of proposed ways for weld deposit is application of preparatory and additional low-temperature heating (T. heat. = 230–280 °C).

We studied influence of a kinetic malleability effect on a formation character of temporary and retained stress when cooling patterns made of deposited metal of P18-type steel and 12X17-type steel in a hammered state with the help of the microscopy heat installation IMASH–5C–69. We made the patterns, which have the form of a two-sided “shovel” with a throat area in 9 mm<sup>2</sup> and a working section length in 46 mm, out of indicated steels in an annealed state. General view and a cutaway pattern scheme from deposited metal are presented in Figure 1.

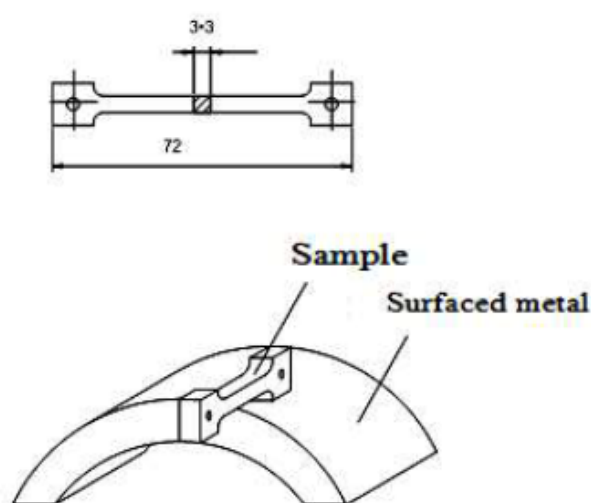
Kinetic malleability effect was evaluated according to temporary stresses decreasing when cooling steady patterns in the interval of martensitic transformation. Steadiness was ensured by electromechanical drive of a stressing installation system. Patterns were heated in vacuum 5·10<sup>–5</sup> mm Hg by means of heat, which came forth in the process of current flow. The temperature of heating was 800 °C, which was lower the point Ac<sub>1</sub>, and 1200 °C, which ensured high degree of carbide phase merging in austenite. After heating and holding the patterns were held rigidly for saving their lengths



on following cooling. Conditions of heating and cooling imitated a welding thermal cycle. Fixed length caused proper increase of pattern elastic plastic deformation under cooling. Strain-gauge indicator correct to  $\pm 1.5\%$  persistently transduced pattern stress in the process of cooling. Platinum took temperature: platinum-rhodium couple, welded to the center of pattern. Kinetics of temporary stress formation in fixed patterns depending on temperature was fixated on PDP-4-type two-dimensional potentiometer.

For test material we selected rapid steel P18, harden on martensite, and chromous rust-resisting steel 12X17, referred to ferrite class. Constitution of studied steels is shown in Table 1.

The steel 12X17 does not experience  $\gamma \leftrightarrow \alpha$ -transformation in contrast to rapid steel, hardened even in the air. The data of Figure 2 shows that when cooling patterns made of the steel P18 from the temperature  $1200^\circ\text{C}$  one can see a kinetic malleability effect on a phase transformation, which is shown up in decrease of temporary stresses in the interval of martensitic temperatures.



**Figure 1.** General view of a pattern for high-temperature researches and its cutaway pattern scheme from deposited metal

Stress maximum on the curve of temporary stress formation in steel is about  $240^\circ\text{C}$ , which is quite close to the start point for martensitic transformation of the steel P18 on its hardening from the temperature  $T_{st} = 1200^\circ\text{C}$ , and minimum  $100^\circ\text{C}$  corresponds to such temperatures, laying higher than the temperature of martensitic transformation end ( $M_k^{\text{cond}} > M_k$ ), when transformation degree is quite high, and with the help of strong “frame” formation out of numerous martensitic crystals flow limit increases, and alloy malleability decreases.

Table 1. Constitution of the steels P18 and 12X17

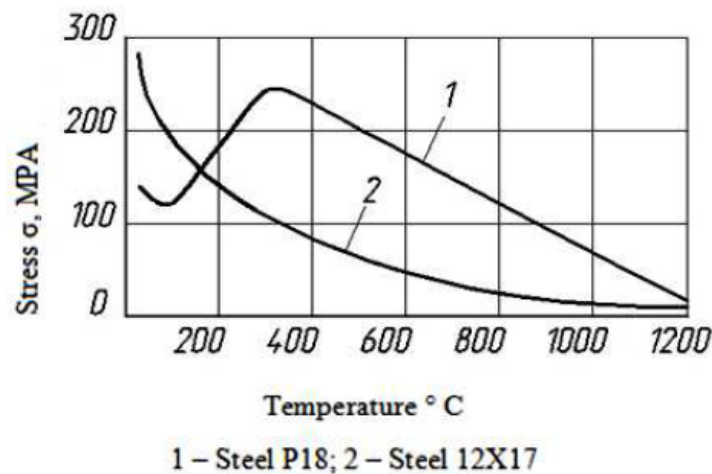
Steel class	Steel type	Constitution, in %					
		C	Si	Mn	Cr	W	V
M	P18	0.74	0.39	0.27	4.09	18.5	1.25
F	12X17	0.1	0.65	0.7	17.5		

The data of Figure 2 shows that in the interval of martensitic transformation temporary stresses have become a third-double fewer in comparison with stresses that are in austenite area.

During further cooling lower the temperature  $M_k^{\text{cond}}$  stresses increase till 120-180 MPa by means of certain increase of martensite quantity. A kinetic malleability effect is not shown up when cooling patterns made of the steel 12X17 because of lack of transformation phase.

Along with increasing temperature stresses persistently increase and reach the levels far exceed retained stress in the steel P18, which experienced martensitic transformation. When we heat patterns till  $800^\circ\text{C}$ , that is lower than  $A_{C1}$  temperature because of lack of a phase transformation both in ferrite and hardened metal of P18-type steel, and when we cool them a kinetic malleability effect is observed,

stresses persistently increase. Research results show that in high-cutting chrome-tungsten metal it is possible to observe an extra malleability effect at the moment of martenistic transformation.



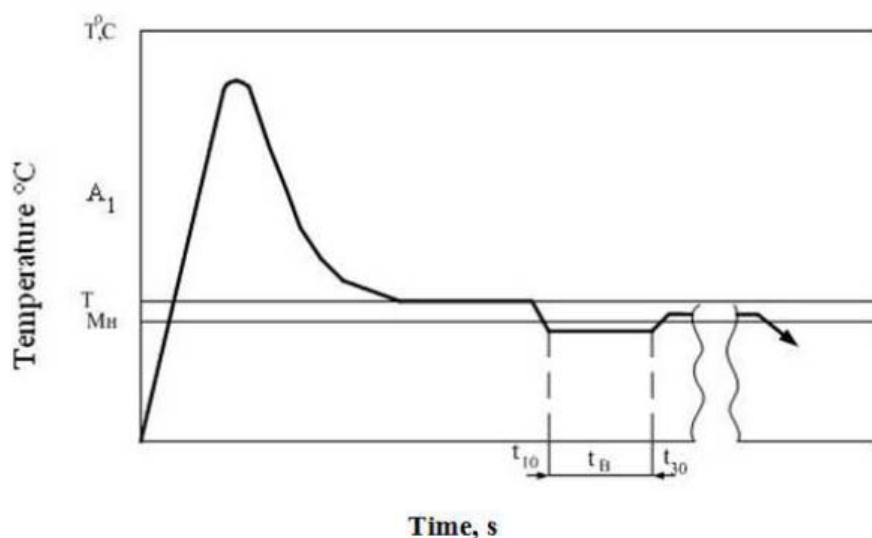
**Figure 2.** Temporary stress formation in patterns made of the steel P18 and 12X17

To get deposited steel almost without a tendency to crack formation one should level temporary stresses during a deposit process with the help of their partial relaxation by means of kinetic malleability effect activity at the moment of martenistic or bainitic transformation. Special feature of a proposed thermal deposit cycle is in its three stages. The first one ensures heat time limit and cooling rate increase in the areas with high temperatures, prevents from grain growth and austenite decay with break-even low-strength structure formation. It could be realized by means of high-concentrated heating source application (for example, plasma deposit) and accompanied by cooling. The second stage of a thermal cycle allows deposited metal to be in an austenite state during making all the layers in a deposit process. It is achieved by heating with  $T_{\text{heat}} = M_{\text{st}} + (50 - 100) ^\circ\text{C}$ . To get deposited metal almost without a tendency to crack formation temporary stress level should be compensated in a deposited process during the third stage of a thermal cycle by means of temporary  $T_{\text{heat}}$  decreasing lower than  $M_{\text{st}}$  temperature. Here temporary stresses decrease with the help of partial relaxation at the moment of martenistic or bainitic transformation. It allows getting deposited metal in a hardened state with a low level of retained stresses [1].

The basis of multilayer plasma deposit method is abidance by a certain thermal cycle [2]. In the context of forming roll plasma deposit with the help of hot-working rapid steels a thermal deposit cycle should have the following characteristics:

- heating rate should be at its maximum in the interval of the temperatures  $750 ^\circ\text{C} - T_{\text{heat}}$ ;
- the duration of stay under temperatures higher the point  $A_1$  should be as small as possible and for rapid P18-type steel it should not exceed 60 sec;
- cooling rate in the interval  $T_{\text{heat}} - M_{\text{st}} + (50 - 100) ^\circ\text{C}$  should be higher than critical, that is  $3 ^\circ\text{C}/\text{sec}$ , what allows stopping a decay process of high-alloyed austenite;
- heating temperature during a deposit process should not be lower than  $M_{\text{st}} + (50 - 100) ^\circ\text{C}$ , that is  $230 - 280 ^\circ\text{C}$  for P18 steel.

Recommended thermal cycle for plasma deposit of forming rolls is done in Figure 3 [2, 3]. This thermal cycle prevents from crack formation and ensures high hardness of deposited metal along with not difficult deposit technology. Higher cooling rate in the areas with high temperatures prevents from grain growth and austenite decay with break-even low-strength structure formation. Higher cooling rate influences almost only those characteristics of hardened and tempered deposited chrome-tungsten metal that are connected with carbide merging increase and increase of austenite grain, what in its turn influences hardness of deposited metal.



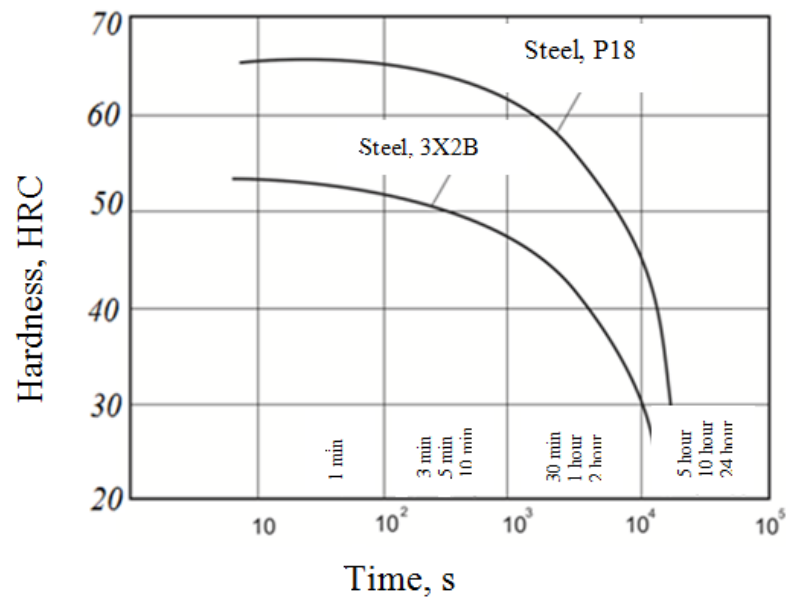
**Figure 3.** Recommended thermal cycle for plasma deposit of forming rolls

Research objective is to study cooling rate influence in areas with high temperatures of thermal cycle for high-cutting chrome-tungsten metal deposit on carbide phase merging processes and austenite grain growth to ensure high hardness of deposited metal.

In the proposed method of multilayer deposit we recommend to apply higher cooling rate in a high temperature area of a thermal cycle because it is aimed at high-alloyed austenite preservation during layer deposit process. Higher cooling rate application should prevent from carbide precipitation in temperatures of minimum austenite stability and from unstable pearlite formation. Austenite stability in chrome-tungsten steels is quite high. It is especially high in rapid steels, where diffusion transformation in the point higher than  $M_{st}$  usually is not observed. Less alloyed die steels (of 3X2B8-type steel) have less austenite stability in 750–550 °C temperature areas. To define allowable cooling rate when quite alloyed austenite is preserved we studied cooling rate influence in a high temperature area (higher than the temperature of 550 °C) on chrome-tungsten metal hardening [1]. We heated patterns made of P18 and 3X2B8 steel in a vacuum vessel of a microscopy heat installation “ALA-TOO” till the temperature of 1200 °C, which allows obtaining quite alloyed austenite. After 10 min holding we cooled the patterns at different rate. To consider cooling rate influence on metal hardening we measured pattern hardness at room temperature.

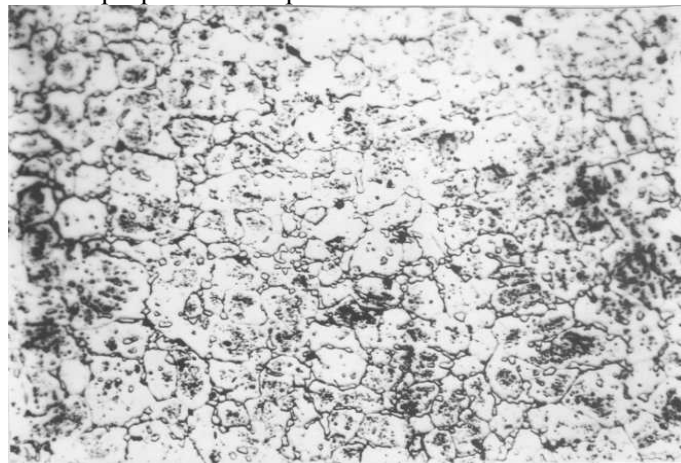
Obtained data is presented in Figure 4: cooling rate of rapid steels, when quite alloyed austenite is preserved as well as high hardness, is much lower than analogical critical rate for 3X2B8 die steel. HRC 64–66 hardness is preserved by P18 steel at cooling rate more than 6°C/sec, and 3X2B8 steel has critical cooling rate at 60°C/sec. Consequently to harden metal during deposit process it is necessary to cool it at a rate that is higher than critical one. Therefore more alloyed steels with stable austenite are more preferable for multilayer deposit because of their low critical hardening rate.



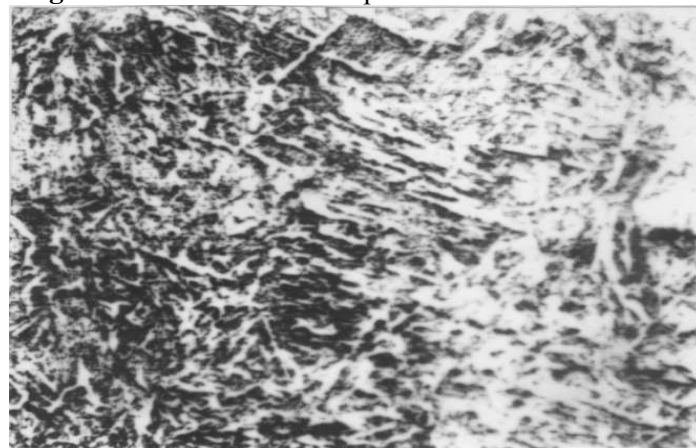


**Figure 4.** Cooling rate influence in high a temperature area on hardness of hardened steels

Application of P18-type rapid steel alloyed by aluminium and nitrogen as deposited metal favorably affects preservation of smaller austenite grains, preparation quite alloyed mixed crystals, which provide high mechanical properties of deposited metal.



**Figure 5.** Structure of the deposited metal P18UN  $\times 340$



**Figure 6.** Structure of the deposited metal 3X2B8  $\times 340$

To provide such properties it is unnecessary to hold deposited chrome-tungsten metal in high-temperature area for more than 60 sec and cool it in this area at rate that is lower than critical one. P18IOH and 3X2B8 metal structures are shown in Figures 5 and 6.

Our research devoted to influence of a thermal deposit cycle on hardening of chrome-tungsten deposited metal absolutely confirms basic process principles of tool steel hardening, which are given in the works [4-10]. Central tenets of the theory about tool chrome-tungsten steel thermal processing are acceptable for analysis of deposited metal hardening processes.

Therefore the work demonstrates that the first stage of a proposed deposit thermal cycle for chrome-tungsten metal provides heating time limit and higher cooling rate in high temperatures areas, prevents from grain growth and austenite decay with break-even low-strength structure formation. It could be realized by means of high-concentrated heating source application (for example, plasma deposit) and accompanied by cooling.

### Conclusion

It is found that increased cooling rate in high temperature areas and holding time under this temperature influence greatly the processes of carbide phase coagulation and merging, austenite alloy degree and its grain size in chrome-tungsten deposited metal of high hardness. To provide maximum hardness of chrome-tungsten deposited metal it is necessary to limit heating time and ensure increased cooling rate in high temperature areas. For these purposes it is proposed to use high-concentrated heating sources (plasma deposit) and accompanied cooling of a deposited detail.

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