Procedure for research of process strength of deposited high-speed steel used in cutting tools

E M Martynov¹, D A Barchukov² and E F Romanenko¹

¹ National Research Technological University «MISiS», 4, Leninsky Ave., Moscow, 119049, Russia
² Tver State Technical University, 21, Bobkova Str., Tver, 170024, Russia

Abstract. The article considers the existing research techniques applied to metal process strength. The author describes his own procedure for the research of process strength of deposited high-speed steel, taking full account of operating principal of trial plant. A quantitative criterion of the process strength of the deposited metal is proposed.

1. Introduction

Working efficiency is an object state wherein the parameter values characterizing the ability to perform specified functions meet the requirements of standards, regulations and specifications and (or) design (project) documentation. The efficiency of high-speed steel as a tool material is determined by its attribute level (mechanical, technological, operational) characterizing the ability to make a tool that meets the specified requirements.

Increasing the working efficiency and operability of tool making with the simultaneous reduction of high-speed steel consumption is a pressing problem. The solution of this problem is possible not least because of the improvement of the structural state of high-speed steels, i.e. the achievement of a duplex microstructure of tempered steel, the refinement of grains and carbides, the densification of carbon and alloying elements in a solid solution, and the martensitic hardening with high-dispersity carbides in the course of heat treatment. This solution is made possible with the introduction of deposited high-speed steel hardening into the tool manufacturing processes [1 – 4, 11-12].

However, the manufacture of deposited bimetallic tool can be associated with technological problems directly influencing its working efficiency. They results from the heat-affected zone (HAZ) occurring in a deposited bimetallic tool and the processes going on in base and deposited metals during and after metal deposition.

Strong changes in the structure and properties of a metal occur in a HAZ, which directly affects the working efficiency of a compound high-speed steel edge tool. The HAZ is extremely undesirable but, unfortunately, unrecoverable in high-speed steel deposition. However, the extent of the HAZ areas as well as their properties, including hardness can be influenced in a variety of ways [5 – 7, 13-14].

Process strength is an ability of a metal to withstand various kinds of impact without destroying in the course of its processing.

The ability to form seams without hot cracks, i.e. the ability to be in a state of elastic-plastic strain without destroying at high temperatures in the process of metal deposition or welding is called process strength of a deposited metal during the crystallization process. A quantitative assessment of
the process strength of deposited metal is basically a technique for determining the tendency of a deposited metal to form hot cracks during deposition.

There are many techniques to assess the process strength, which differ significantly in their effectiveness.

For the purpose intended, they are divided into two categories:

1. Techniques for assessing the resistance of alloys to the formation of hot cracks, regardless of the type and size of welded joints.
2. Techniques for assessing the resistance of a deposited metal to the formation of hot cracks for a given alloy composition and a deposition mode.

The classification of existing techniques for determining the process strength of welded joints is given in Table [8, 15-16].

Table 1. Techniques for assessing the resistance to the formation of hot cracks in the process of crystallization

| No | Technique | Criterion | Purpose |
|----|-----------|-----------|---------|
| 1. | Chemistry-based calculation of the tendency of an alloy to form hot cracks | Carbon equivalent Ceq, % | Approximate quantitative assessment of alloys |
|    |           | Amount δ-Fe, % for austenitic steels | Equilibrium eutecticum E,% |
|    |           | a. Presence of hot cracks in specimen deposition (a); semi-quantitative assessment |
|    |           | b. Hot crack frequency (b-d) of alloys; quantitative assessment (e) of alloys |
|    |           | c. Relative length of an hot crack |
|    |           | d. Critical speed of metal deposition |
|    |           | e. Critical size of a specimen |
| 2. | Deposition of laboratory technological specimens | Critical tensile speed | Quantitative assessment of alloys. |
|    |           | Critical tensile pace | Quantitative assessment of alloys and technological options of welding. |
|    |           | Critical strain | Not recommended. |
|    |           | Critical stress. | The same. |
| 3. | Deformation of the deposited metal during its crystallization when surfacing | Critical strain | Not recommended. |
|    |           | Critical stress. | The same. |
| 4. | Deposition of industry specimens | Allowable welding conditions, in which no hot crack is detected | Selection of welding technology |
|    |           | Determination of the metal resistance margin to hot crack formation in structural welding | Assessment of the construction and permissible indices of resistance to hot crack in welding |
|    |           | Resistance to hot crack for a under predetermined conditions specified design | |

Most of the existing techniques are based on the application of various external forces (stretching, bending, twisting, etc.) to the specimens both during and after the metal deposition process. The results of the tests are both quantitative (speed and magnitude of strain, etc.), and qualitative indicators of process strength (presence or absence of hot cracks, etc.). The simplest scheme of inner stresses comes out of the bead deposited on a plate. For a sufficiently light plate, these stresses have a
linear (uniaxial) nature; therefore their determination is reduced to the measurement of only one component of deformations [9, 17-18].

2. Experimental part

To carry out the study of the process strength of deposited high-speed steels, we used the procedure [10, 19-20] to determine the stresses in the deposited specimen in the event of hot cracks at temperatures close to the solidus curve.

When manufacturing a trial plant (Figure 1), we took into account that specimens are deposited directly during the research. Under these conditions, the values of thermal and welding strains are small, and the value of deposition strain pace does not reach values that can induce hot crack formation. So there appears a need to apply an external tensile load of an agreed value in the deposited metal brittle temperature range.

![Figure 1](image1.png)

The trial plant has movable (due to the screw pair rotation) jaw 2 and fixed jaw 10 and is fixed on deposition plant table 11. Two plates 5 and 9 are fixed on the trial plant. Plate 5 can move freely. Spring element 4 (flat spring) designed for fixing movements and load intensity of specimen 7 during deposition is connected rigidly with a movable plate and a movable jaw of the plant.

Dial indicator 3 (with the measuring accuracy of 0.001 mm) is directly mounted and screwed down on the spring element (Figure 2). The indicator shows the movements of a spring element $\Delta l_2$ and a specimen $\Delta l_1$ subjected to tensile loading. Specimens are fixed in clamps 6 and 8 mounted on the plates. Turning a screw pair with torque wrench 1 we can preload or load during deposition specimens with the given load intensity and monitor the value of a spring element movement with an indicator.

![Figure 2](image2.png)

A specimen form for the suggested testing of deposited metal is chosen according to the following criteria:

- A specimen must have minimum rigidity to enable testing of deposited metal at small values of tensile loading.
- Specimen dimensions must be selected so that to obtain the values of the deposited metal cooling rate not less than the critical rate of hardening.
- A specimen must provide strain concentration in the test cross-section when the specimen ends are loaded. These criteria are met for specimens of 5×25 mm bar (steel 30HGSA (30XГСА in Russian), σₕ=830 MPa, ГОСТ103-76) and 200 mm length (Figure 3).

1 mm deep grooves are milled at the ends to provide specimens with positive clamping in the rig. Two slots with 5 mm diameter are drilled in specimens to provide strain concentration in the test cross-section when the specimen is being deformed. The slot diameter is selected so that to form a quality weld bead and prevent deposited metal from leaking through slots during deposition.

1.5 mm slot is drilled in the specimen centre to fix a thermopair.

To obtain the value of tensile load the spring element is qualified which means that the dependence of spring element movement Δl₂ on the tensile load applied is determined.

The application of tensile load before and during deposition makes it possible to estimate the process strength margin of deposited metal at different temperatures in the test cross-section. The values of tensile load applied to specimens are increased consistently until hot cracks appear in deposited metal.

The criterion of the deposited metal process strength is maximal specimen strain in a brittle temperature range at the agreed value of tensile strength when hot cracks do not form in deposited metal.

The application of the same tensile load before and during deposition (in the area of elastic and plastic strain) causes various specimen deformations due to the change of base metal properties when its temperature increases.

The application of tensile load P in the area of elastic strain before deposition makes it possible to obtain the critical values of tensile stress in the test specimen cross-section which cause the formation of hot cracks in deposited metal. Indicator reading Δl, in this case, corresponds to spring element strain Δl₂.

The application of tensile load during deposition, when deposited metal temperatures in the test cross-section fit with a brittle temperature range, makes it possible to estimate the deposited metal resistance to hot crack formation with the measurement of critical specimen strain. Readings of indicator Δl correspond to the strain difference of spring element strain Δl₂ and plate Δl₁.

3. Conclusion
The prevention of crack formation is one of the main tasks in obtaining a deposited metal with alloying solid solution as hardened.

The deposition technology for manufacturing high-speed steel edge tools does not make it possible to apply fully the well-known destructive welding check, process strength testing in particular. Deposition, although being allied process to welding, is characterized by specific heat processes in base and deposited metals as well as their structural transformations.

Thus, to make deposited high-speed hardened steel with grain size 11 is a process task that can be solved successfully under a specified thermal cycle. Thereafter, the process strength criteria suggested in widely-known techniques are not appropriate in this case.
The present procedure uses the basic principles of the well-known technique determining strain rates in a deposited specimen when hot cracks form at the temperatures close to a solidus curve [10, 21] (loading diagram, the use of a spring element, tensile load during deposition, etc.).

The criterion of deposited metal process strength is a maximal specimen strain in a brittle temperature range at the agreed value of tensile strength when hot cracks do not form in deposited metal.

References
[1] Barchukov D A 2013 RU, Patent No. 2483120 Hardening method of deposited high-speed steels
[2] Barchukov D A 2012 Resource-saving technology for producing a tread cutter with a strengthened cutting part Nauchnoye Obozrenie (Science Review) 5 404-407
[3] Gadalov V N, Kolmykov D V, Korenevskii N A, Chernysheva E V and Ziborova T 2010 Low-temperature nitrocarburization to improve the life of resurfaced tractor crankshafts Russian Engineering Research 30 1090-1091
[4] Grigoriev S B, Efimenko L A, Salnikov V G and Gadalov V N 2013 Evaluation of hard-facing process and its application on drill pipe tool joints Chemical and Petroleum Engineering 48 642-645
[5] Lavrentiev A Yu, Dozhdelev A M and Barchukov D A 2014 Change of structure and properties of the zone of thermal influence at production of the welding tool from high speed steels Proceedings of the Southwest State University 5 (56) 14-20
[6] Lavrentiev A Y, Dozhdelev A M, Romanenko D N and Filonovich A V 2017 Research of structural phase transformations in the fusion area of bimetallic punching tools Journal of Chemical Technology and Metallurgy 52 707-710
[7] Romanenko D N, Artemenko Yu A, Emelyushin A N, Dema R R, Nefed’ev S P and Zhiravlev G M 2017 Physical modeling of the mechanism of modification with wear-resistant surfacing Chemical and Petroleum Engineering 52 769-773
[8] Vinikurov V A 1979 Welding in machine building (Moscow: Machine Building)
[9] Nikolayev G A and Vinokurov V A 1990 Welded Structures. Calculations and design (Moscow: Higher School)
[10] Prokhorov N N Hot Cracks in Welding (Moscow: Mashgiz)
[11] Romanenko D N, Markelov E A and Nikolaenko A V 2013 Attachments for diamond smoothing Russian Engineering Research 33 379-380
[12] Gorozhankin V V and Kolmykov V I 2013 Reinforcement of button roller bits by thermochemical processing Gorny Zhurnal 10 98-100
[13] Gadalov V N, Abakumov A V and Turaeva O A 2014 Effect of carbide content in carburized layers on drilling tool self-sharpening capacity Chemical and Petroleum Engineering 50 547-549
[14] Kolmykov V I, Abyshev K I and Nasteka V V 2015 Effect of structural characteristics on abrasive wear resistance and impact strength of facing and carbonitrided coatings Chemical and Petroleum Engineering 50 610-613
[15] Kolmykov V I, Abyshev K I, Kolmykov D V and Bedin V V 2015 Efficiency of surface hardening by carburizing steel objects operating under abrasive wear conditions Chemical and Petroleum Engineering 51 58-61
[16] Shcherenkov A S, Shkatov V V and Gadalov V N 2015 Study of electrolytic chromium coatings with ultradisperse superhard fillers Chemical and Petroleum Engineering 51 277-282
[17] Gadalov V N, Gvozdev A E, Vornacheva I V and Kovalev S V 2016 Burnishing with wear-resistant mineral–ceramic and hard-alloy indenters Russian Engineering Research 36 731-734
[18] Shkatov V V, Pogodaev A K and Mazur I P 2017 The influence of nanoscale precipitation of aluminum nitride on the formation of recrystallization texture in aluminum deoxidized low-carbon steels Journal of Chemical Technology and Metallurgy 52 617-620
[19] Romanenko D N, Kolmykov V I, Ermolaev D V and Mazur I P 2017 Increasing of fatigue limit and efficiency of constructional steels through additional chemical and thermal treating using nitrogenous carbonaceous carburizers *Journal of Chemical Technology and Metallurgy* **52** 990-995

[20] Gubanov O M, Shkatov V V and Kozhukhov A A 2017 Formation of non-uniform grain structure of steel in the process of heat treatment and method of evaluation of microstructure with significantly non-uniform grain *Journal of Chemical Technology and Metallurgy* **52** 996-1001

[21] Gadalov V N, Boldyreva O N and Kovalev S V 2018 Decreasing technological risk through optimization of maintenance of the equipment of an oil and gas complex *Chemical and Petroleum Engineering* **53** 610-613