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EVALUATION OF PHYSICO-MECHANICAL PROPERTIES OF HIGH-CHROMIUM TOOL STEELS MODIFIED WITH HARRINGTON METHOD

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Abstract. The qualimetric evaluation of high-chromium tool steels with application of modified desirability function was performed. It was shown that high qualitative performance was demonstrated by low carbon steels additionally alloyed with rare-earth metals, as well as optimally heat-treated steels. The methodologies for assessing the economic characteristics of high-chromium tool steels were proposed. The first technique is an assessment of the production cost of high-chromium tool steels in its early stages. The second technique is a value analysis of technological equipment, whose manufacturing needs high-chromium tool steels.

1. Introduction

The most important issues related to the development of cold stamping processes are the tools, technological equipment and the materials from which they are made, whereas they form the basis, which provides quality at the initial stages of manufacturing of any product. Therefore the most important role in mechanical engineering plays tooling, equipment and their functionality. Especially important task is increasing the tool durability while processing new and difficult deformable materials. Increased tool durability reduces the downtime of the equipment and the time for necessary adjustments as well as costs for production and repair. Also it reduces product costs and improves the quality of the produced parts.

The research is based on high chromium instrumental steel type Cr-12, obtained through optimization of alloying and heat treatment [1]. The quality of these steels was evaluated by specially modified desirability function method.

2. The economic evaluation of high-chromium tool steels

The usage of high chromium tool steel in the enterprise should be justified not only by the strength, technical and operational properties of steel, but also must be economically justified.

The cost of production of the alloy steel depends on the chemical composition of steel, the type of semi-finished product and its size. To a first approximation, the comparative cost of production of the alloy steel {L1X1, L2X2, … , LnXn} can be estimated, based on data of A.P. Gulyaev [2]. The comparative production costs are proposed to estimate by the formula:

$$C_{st} = 0{,}01[C_{Fe}(1-\sum X_i) + \sum C_i X_i], \tag{1}$$

where C_{Fe} = 0.01 is the price of iron; X_i is the content i-th alloying element, %; C_i is the relative cost of i-th alloying element.

The comparative cost of production of the steels 60Cr9Mo2WVZr, 70Cr12VNbZr, 110Cr12VNbZr, and Cr12V1 are:

$C_{60Cr9Mo2WVZr}$ = 11.99;
$C_{70Cr12VNbZr}$ = 10.64;
$C_{110Cr12VNbZr}$ = 10.73;
C_{Cr12V1} = 10.1.

The economic expedience of the usage of a specific steel grade in each case Y.M. Lakhtin [3] proposes to evaluate with the economic expedience indicator K_e:

$$K_e = \frac{C2/C1}{CB2/CB1}, \quad (2)$$

where C2/C1 is the relative change in production costs of steel 1 and steel 2; CB2/CB1 is the relative change in the analyzed property of steels 1 and 2.

The comparative analysis can be carried out with regard of the physical and mechanical properties of steels and their combinations. The choice of the analyzed property depends on the particular usage of the steel. When $K_e > 1$ regarding some property of the steel it means that transition from steel 1 to steel 2 is economically justified. If $K_e < 1$ it means that the transition to another steel grade is no sense from the economic viewpoint.

Within this work there were selected physical and mechanical properties of hardness, tool durability, bending strength and toughness of steels 60Cr9Mo2WVZr, 70Cr12VNbZr, 110Cr12VNbZr and Cr12V1. The results of the estimated economic expedience are given in Table 1.

Table 1. The economic feasibility of high-chromium tool steels.

Steel grade	Hardness	Tool durability	Bending strength	Toughness	Carbide grade
70Cr12VNbZr	0.98	2.37	1.32	1.86	3.8
110Cr12VNbZr	0.97	2.85	1.19	1.6	1.9
60Cr9Mo2WVZr	0.82	3.83	1.05	1.56	3.4
Cr12V1	1	1	1	1	1

Conclusion: the calculations show that transition from the standard steel grade Cr12V1 to steel grades 60Cr9Mo2WVZr, 70Cr12VNbZr and 110Cr12VNbZr is economically justified in all the properties but hardness. The transition makes sense also if the physical and mechanical properties are considered aggregately.

3. The Harrington method (the desirability function) modified with economic expedience

In order to build the desirability function [4] some performance characteristics were selected as the material desirability indicators. These characteristics are hardness, tool durability and carbide grade of steel. The indicators that are linking dimensional values with non-dimensional ones were determined through solving the systems of equations for the characteristics: hardness, tool durability and carbide grade of steel.

The obtained data of the desirability function are given in Table 2.

Table 3 contains single and complex indicators of desirability for the researched grades of steel.

For the purposes of comparison the hardness values for the ordinarily obtained steels of grade Cr12 were taken as the basic ones. The same concerns the values of tool durability and mechanical properties empirically obtained with steel Cr12.

Table 2. Indicators of desirability and non-dimensional auxiliary indicators.

Steel grade, thermal treating mode	Hardness HRC		Average tool durability T, min.		Carbide grade of steel	
	y	Q	y	Q	y	Q
According to the experimental data						
70Cr12VNbZr	4.5	0.80	2.453	0.67	4.5	0.80
110Cr12VNbZr	4.5	0.80	3.029	0.72	3.33	0.74
60Cr9Mo2WVZr	1	0.37	4.5	0.8	4.5	0.80
According to the regulatory specifications						
Cr12V1	2.75	0.70	1	0.37	1	0.37

The modification of the method. The formula for the calculation of complex desirability has been modified by the introduction of economic expedience coefficients of the researched material. The formula of complex desirability is as follows:

$$\mathbf{Q} = \sqrt[n]{\prod_{i}^{n} q_i k_i},$$

where n – the number of single desirabilities; q – the indicator of single desirability; k_i – the coefficient of economic expedience of the property of the material.

Taking the mechanical properties of high-chromium tool steels (tool durability, hardness, carbide grade) and related factors of economic expedience of these properties as an example, the following results were obtained:

$$\mathbf{Q}_{70Cr12VNbZr} = \sqrt[3]{0,67 \cdot 2,37 \cdot 0,80 \cdot 0,98 \cdot 0.80 \cdot 3,8} = 1,55;$$

$$\mathbf{Q}_{110Cr12VNbZr} = \sqrt[3]{0,72 \cdot 2,85 \cdot 0,80 \cdot 0,97 \cdot 0,74 \cdot 1,9} = 1,3;$$

$$\mathbf{Q}_{60Cr9Mo2WZr} = \sqrt[3]{0,80 \cdot 3,83 \cdot 0,37 \cdot 0,82 \cdot 0,80 \cdot 3,4} = 1,36;$$

$$\mathbf{Q}_{Cr12V1} = \sqrt[3]{0,37 \cdot 1,0 \cdot 0,70 \cdot 1,0 \cdot 0,37 \cdot 1,0} = 0,46.$$

Table 3. Single and complex indicators of desirability of the researched steels.

Steel grade, thermal treating mode	Single desirability indicators of various properties			Complex desirability index
	Average tool	Hardness HRC	Carbide grade	
70Cr12VNbZr	0.67 (good)	0.80 (excellent)	0.80 (excellent)	1.55
110Cr12VNbZr	0.72 (good)	0.80 (excellent)	0.74 (good)	1.3
60Cr9Mo2WVZr	0.80 (excellent)	0.37 (satisf.)	0.80 (excellent)	1.36
Cr12V1	0.37 (satisf.)	0.70 (good)	0.37 (satisf.)	0.46

The analysis of the desirability indicators shows that the highest indicator of hardness was obtained with the steels 70Cr12VNbZr and 110Cr12VNbZr. The steel Cr12V1 shows good performance whereas the steel 60Cr9Mo2WZr performs only satisfactory. But when such mechanical property as tool durability is analyzed the steel 60Cr9Mo2WVZr performs somewhere between “excellent” and “superior”. The steels 70Cr12VNbZr and 110Cr12VNbZr demonstrated also excellent performance, while the steel Cr12V1 performed poorly with grade “satisfactory”. While analyzing the carbide grade the steels

60Cr9Mo2WVZr and 70Cr12VNbZr show excellent performance. The same result with the steel 110Cr12VNbZr, while the steel Cr12V1 performed poorly with grade "satisfactory". The modified complex desirability index shows that the best combination of properties demonstrate the steels 70Cr12VNbZr and 110Cr12VNbZr, where the complex desirability function has its maximum values of 1.55 and 1.3. The steel 60Cr9Mo2WZr has the value of 1.36, which is a good combination of properties. The steel Cr12V1 shows substantially worse results with complex desirability index of 0.46.

4. The economic evaluation of the properties of the tools and equipment made of high chromium tool steels

The evaluation of the economic properties of tooling and equipment made of high-chromium tool steels along with the physical and mechanical properties of steels is the most important stage of analysis of high-chromium instrumental steels. The evaluation of economic properties of tooling and equipment made of high-chromium tool steels includes 2 methodical approaches: (A) The evaluation of production cost of tooling and equipment made of high-chromium tool steels on the early stages, which is actually forecasting of production cost of high-chromium tool steels. (B) The economic evaluation of tools and equipment that are produced with high chromium tool steels is normally carried out with value analysis [5].

5. Conclusion

On the basis of the performed research we can conclude that the modification in the calculations of the composite desirability indicator has substantially improved the objectivity and sufficiency of the qualimetric evaluations of high-chromium tool steels. The qualimetric evaluation has shown the advantages of new high-chromium tool steels 70Cr12VNbZr, 60Cr9Mo2WVZr and 110Cr12VNbZr over the steel Cr12V1 not only in mechanical properties, but also in economic expedience of usage of these steels. The modification of the integrated desirability index is one of the aspects of improvements of the high chromium steels evaluation technology.

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