Testing experimental parts of metallurgical units for wear and impact in industrial conditions

A Z Issagulov, Sv S Kvon, V Yu Kulikov, D R Aubakirov, Ye P Chsherbakova and A M Dostayeva

Karaganda State Technical University, 56 N. Nazarbayev Ave., Karaganda, 100027, Republic of Kazakhstan

E-mail: mlpikm@mail.ru

Abstract. The paper presents the results of industrial testing parts made of experimental wear-resistant alloys. Cast iron was smelted with a high content of nickel and vanadium and steel with alloying elements, which vary widely over from 15% to thousandths. The prototypes wear resistance was increased by about 30-34%. The work was performed at Karaganda State Technical University. These studies were carried out as a part of the grant of the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan BR05236295 “Designing, Developing and Implementing Technologies of Producing and Machining New Generation Wear-Resistant Materials for Obtaining Parts of Metallurgical Units”.

1. Introduction

One of the existing trends in developing wear-resistant materials is improving the composition and properties of the alloy based on improved steels [1-4]. In previous studies, steel 30HN2MA deoxidized with ferrosilicon was considered as an analogue of the alloy with high wear-resistant properties [5-7]. The results of the experiments show that the composition and properties of 30HN2MA steel after deoxidation with ferrosilicon are close to the composition and properties of Hardox steel due to introducing micro amounts of boron.

Another analogue can be considered steel 30H3MF, which is used for manufacturing diesel parts, has wear-resistant properties and heat resistance up to 450 °C. Compared to Hardox steel, 30H3MF steel has a higher chromium content and does not contain boron. However, vanadium is present in the composition of 30H3MF steel, forming solid and resistant carbides of the MeC type; in addition, the presence of vanadium contributes to the grain grinding, which further strengthens the structure. Taking into account these features of the effect of vanadium, it can be assumed that the presence of vanadium in the composition compensates for the absence of boron.

The disadvantage of 30H3MF steel in this aspect is also a low content of nickel and manganese in the composition, which play an important role in the formation of alloy properties. Nickel does not form carbides and, therefore, does not affect hardness, but at the same time increases the matrix toughness and partially lowers the temperature threshold of cold brittleness. Manganese forms cementite-type carbides, thus hardening matrix. Thus, the presence of nickel and manganese in the composition of steel in the given amount (0.5-0.7% and 1.5-1.7%, respectively) is necessary, because these elements form the alloy matrix properties.
There are also carried out the studies [8-10], where it is proposed to use low- and medium-carbon steels that are microalloyed with strong carbide formers, such as vanadium and niobium, as wear-resistant materials. Microalloying with elements such as vanadium, titanium and niobium contributes to grain refinement, formation of stable carbides of the MeC type, and increasing hardness and wear resistance [11-15]. Introducing additives in micro quantities (the total content of vanadium, niobium and titanium does not exceed 0.1%) practically does not affect the cost of steel but significantly improves their properties.

2. Experimental studies
In the industrial conditions there was smelted an experimental alloy which composition is presented in table 1 [16-17].

| Experimental alloy | C    | Si   | Mn   | Cr   | Ni   | Mo   | V   |
|-------------------|------|------|------|------|------|------|-----|
| 2                 | 0.32 | 0.65 | 1.55 | 2.1  | 0.62 | 0.26 | 0.12|

The complexity of this task is caused by the “fine composition” of the alloys. The number of alloying elements varies over a wide range from 15% to thousandths. It should be borne in mind that alloying is carried out by the same ferroalloys, which must be taken into account when introducing and subsequent processing of alloys.

The total weight of the smelt, taking into account losses and waste, amounted to 418 kg. The smelt was poured into sandy clay molds. In total there were obtained 5 “jaw plate” castings, the weight of one casting was about 83 kg. One casting was obtained with an obvious casting defect, runout and was re-melted into a laboratory sample weighing 5.7 kg. The resulting samples (figure 1) were tested for wear and impact in industrial crushers.

![Figure 1. Jaw plate made of the experimental alloy.](image)

Cast iron with a high content of nickel and vanadium was also smelted [18–20]. During the melting process and after completing the melting, the chemical analysis of the alloy was controlled. The results of the final composition of the smelted alloy are shown in table 2.

| Sample No. | C     | Si    | Mn    | Cr    | Ni    | Ti    | Mo   | V         |
|------------|-------|-------|-------|-------|-------|-------|------|-----------|
| 1 preset   | 2.4-2.6 | 2.0-2.2 | 3.0-3.5 | 15-18 | 3.0-3.5 | 0.5-1.0 | -    | 0.1-0.15  |
| 2 smelted  | 2.5   | 2.2   | 3.4   | 16    | 3.4   | 0.9   | -    | 0.13      |
As it is seen from the data in table 2, the specified alloy composition (cast iron with a high content of nickel and vanadium) is achieved.

The smelt weight was 416 kg, taking into account losses and waste. The smelt was poured into sandy-clay molds for the grinding body “asterisk” (figure 2). There were obtained a total of 500 pieces, the weight of one casting was 0.8 kg. The losses during casting made 16 kg.

3. Discussion of the results
The grinding bodies melted of test alloy 1 in an ore-thermal furnace were loaded into the UZT 4/1 crusher in the conditions of the SPA Marganets LLP (Karaganda city) and poured into a sand-clay mold (figure 3). After complete cooling and heat treatment, the bodies were loaded into the UZT 4/1 crusher. For loading and unloading, the ZL 50C loader was used.

The bodies were loaded in batches of 100 pcs. and were used to crush manganese ore. The cycle of each test lasted within 18 hours. In total, 2 tests of grinding bodies were carried out, the total duration was 36 hours. The prototypes of each batch after testing were transferred to the customer for further studying.

Figure 2. The grinding body (asterisk): a – after testing; b – in the course of testing.

Figure 3. UZT 4/1 crusher for testing grinding bodies.
The testing results are given in table 3.

### Table 3. Results of testing grinding bodies made of the experimental alloy 1 in semi-industrial conditions.

| No. | Sample                           | Number of splits, pcs. | Number of cleavages, pcs. | Surface wear over 15%, pcs. |
|-----|----------------------------------|------------------------|---------------------------|-----------------------------|
| 1   | IHCh28N2 (reference)             | 14                     | 43                        | 22                          |
| 2   | Experimental alloy 2             | 8                      | 29                        | 21                          |

In the UZT 4/2 crusher (figure 4), two jaw plates (a crusher part operating under conditions of increased wear and impact) smelted of experimental alloy 2 were delivered for each cycle.

Smelting alloy 2 was also carried out under the conditions of the SPA Marganets LLP in an ore-thermal furnace. Pouring was carried out in sand and clay molds. The obtained prototypes were placed in the crushers and tested within 18 hours of each cycle. A total of 2 cycles were carried out, the total duration of the work was 36 hours. Loading, unloading and transporting from the smelter to the crusher was carried out by a ZL 50C loader.

The prototypes from each batch after testing were transferred to the customer for further studies.

The remaining part of the batch of prototypes (grinding bodies and plates), according to the transfer act, was left to the contractor as working parts in his ownership, subject to the provision of an act on the experimental parts condition after starting the operation. The customer has no further complaints on this issue.

![UZT 4/2 crusher for testing the plate.](image)

**Figure 4.** UZT 4/2 crusher for testing the plate.

The results of testing in semi-industrial conditions are presented in Table 4. Wear was determined by means of changing the sample mass after testing according to the formula:

\[ L = \frac{m_1 - m_2}{m_1} \times 100\% , \]

where \( m_1 \) is the initial mass, kg;
\( m_2 \) is the mass after testing, kg.
Table 4. Results of testing samples made of experimental alloy 2 in semi-industrial conditions.

| No. | Sample                      | Initial mass, kg | Mass after testing, kg | Wear, % |
|-----|-----------------------------|------------------|------------------------|---------|
| 1   | Operating at present (reference) | 83.0             | 74.2                   | 10.6    |
| 2   | Experimental alloy          | 83.2             | 77.1                   | 7.3     |
| 3   | Experimental alloy, Upper plate series 1 | 83.1             | 78.1                   | 6.1     |
| 4   | Experimental alloy, Lower plate series 1 | 83.0             | 76.9                   | 7.3     |
| 5   | Experimental alloy, Upper plate series 2 | 83.1             | 77.1                   | 7.2     |

The grinding bodies made of cast iron with a high nickel content and additionally microalloyed with vanadium showed high wear resistance with good impact strength. The prime yield (the number of intact parts without splits and cleavages) after 36 hours of testing increased by 33%. The jaw plates wear resistance under the same test conditions increased by about 34% compared to the reference.

4. Conclusion

Thus, the semi-industrial tests showed the possibility of smelting experimental alloys of a preset composition on existing production equipment and using traditional charge materials. The prototypes wear resistance increases by about 30-34%. However, it should be noted that this characteristic is “floating” and depends on the properties of the mineral raw materials being treated.

References

[1] Zou Xiaodong, Sun Jincheng and Matsuura Hiroyuki 2018 Metallurgical and Materials Transactions B: Process Metallurgy and Materials Processing Science 5(49) 2168–73
[2] Li Hui-rong, Sun Li-gen and Zhu Li-guang 2018 Metals 8(8)
[3] Wang Yan, Zhu Liguang and Zhang Qingjun 2018 Metals 8(8)
[4] Zou Xiao-dong, Sun Jin-cheng and Zhao Da-peng 2018 Journal of Iron and Steel Research International 2(25) 164–172
[5] Mascaraque-Ramírez C, Franco P 2018 Ships and Offshore Structures 7(13) 750–758
[6] Chaudhari V, Kulkarni D M and Rathi S 2017 ASME International Mechanical Engineering Congress and Exposition (Tampa, FL) vol 9
[7] Sekban D M, Akterer S M and Saray O 2018 Journal of Materials Science & Technology 1(34) 237–244
[8] Nuesse G 2017 Stahlbau 9(86)
[9] Mert T and Ekinci S 2017 Acta Physica Polonica A 3(13) 495–499
[10] Yu Yan-chong, Li Hao and Wang She-bin 2017 Metallurgical Research & Technology 4(114)
[11] Filippov M A, Gervasyev M A et al 2017 Diagnostics, Resource and Mechanics of Materials and Structures 1 43–54
[12] Orlov V V, Malyshevsky V A et al 2014 Steel 9 79–88
[13] Issagulov A Z, Kim V A et al 2014 Metalurgija 53(4) 685–688
[14] Dub A V, Barulenkova N V et al 2004 Metalurgija 4 67–73
[15] Kulikov V Yu, Issagulov A Z et al 2017 Metalurgija 56(3–4) 409–411
[16] Arinova S K, Issagulov A Z et al 2017 Proc. of the XX Int. Sci. Pract. Conf. In Metallurgy: Technologies, Innovations, Quality 222–227
[17] Kvon S V, Kulikov V Y et al 2016 Metalurgija 55(2) 206–208
[18] Issagulov A Z, Kulikov V Y et al 2016 Metalurgija 55(3) 426–428
[19] Kvon S S, Kulikov V Y et al 2019 Metalurgija 58(3–4) 315–318
[20] Kovalev P, Riaboshuk S et al 2019 Metals 9(2) 203–208