Effect of thermomechanical treatment on wear resistance of Hadfield's steel

I I Mishin¹, V I Bolobov¹, T I Titova², D V Ratushev², K V Karpov¹

¹ Saint-Petersburg Mining University, 2, 21st Line, St Petersburg 199106, Russia
² OOO«TK «OMZ-Izhora», Izhorskiy zavod, Kolpino, St Petersburg 196650, Russia

E-mail: mishin-i-i@yandex.ru

Abstract. The technique of thermomechanical treatment of high manganese steel under high-temperature plastic deformation of cylindrical specimens with various degrees of reduction is presented. The experimental data on the wear of samples on granite and electrocorundum show that the use of the thermomechanical treatment method can significantly increase the abrasive wear resistance of high manganese steel by up to 50%, and the method itself can be recommended for the introduction into the technology of manufacturing wear parts of ore mining and processing equipment in order to increase their service life.

1. Introduction

Currently, a large part of the cost of mining and processing enterprises are accounted for the replacement of wearing elements of crushing and grinding equipment - beat, hammers, liners, etc. As in Russia and abroad, these elements are usually made by casting from austenitic manganese steel 110G13L (DIN 1.3401, BS BW10), known by the name of its inventor as Hadfield's steel, demonstrating an exceptionally high resistance to the impact of the rock, but clearly insufficient for a purely abrasive action.

2. Known patterns

It is generally accepted [1] that, with a purely abrasive action, Hadfield’s steel exhibits low resistance to wear, while under conditions of high specific loads and impacts, when the metal of the surface layer is subjected to severe hardening, the steel acquires an exceptionally high abrasive wear resistance. Although, as shown in [2-5], this statement is valid only for the wear of steel over relatively soft rocks (less than 1100 HV), whose hardness is inferior to the hardness of the steel in the cold-working state. In the case of wear of rocks of higher hardness, significant specific loads, as well as shock effects, contributing to the work hardening of the material, do not lead to an increase in wear resistance of Hadfield's steel, and this parameter does not differ from medium-carbon steel of type 45. (DIN C45, BS C45).

At the same time, it is known [6-19] that one of the best means of improving the strength properties of steels is their high-temperature thermomechanical treatment (HTTMT), available in the aggregate of plastic deformation in austenitic state with hardening. At the same time, along with the increase in hardness, yield strength and strength as a result of such treatment, the plasticity, viscosity and fatigue resistance of steel increase. With regard to the application of HTTMT to Hadfield’s steel in [20] it is reported, that its machinability pressure in the hot and cold state is satisfactory (since the hardening
Tests were carried out according to the modernized technique of [2, 3] on the installation, the scheme of which is shown in Fig. 1, at the spindle speed of the machine 11.4 s⁻¹. Test samples 2 (Fig. 1) in the form of cylinders with a diameter of 8 mm were made by free forging at a temperature of 1150 - 950°C from cylindrical castings of steel of large diameters to obtain a forging grade α = 1.56, 2.25 and 3.06, then subjected to hardening in water.

In an abrasive medium 1 electrocorundum 25A and granite Yelizovo fields were used as materials with aggregate hardness (~2500 and 2000 HV), obviously exceeding the hardness of Hadfield steel in cold-worked condition. At a constant static load (37N for electrocorundum, 76N for granite), the end surface of the sample was worn out for 3.5 min with measurement of their mass every 30 s (for granite for 50 min with measurement of mass every 10 min). The measurement of the mass of the sample before and after exposure of the rock to determine its loss Δm. For comparison, similar tests were carried out on cast steel samples of the same diameter.
4. Experimental result

As shown by the processing of the results in Table 1, all the experimental points dependency $\sum \Delta m = f(t)$ is satisfactorily extrapolated by straight lines, the tangents of the angle which represents the speed of the abrasive wear of the samples, and the inverse values - abrasive wear resistance $R_i$.

**Table 1.** The results of tests of samples with wear on electrocorundum

| № of sample | Processing method | Forging grade $\alpha$ | $\sum \Delta m$, mg per time $t$, min. | $K_i$, mg/min | $R_i, *10^{-3}$ min/mg |
|-------------|-------------------|------------------------|----------------------------------------|---------------|------------------------|
| 1           | Casting           | -                      | 180.3 378.7 617.7 816.3 1057.0 1286.7 | 443.73        | 2.25                   |
| 2           | HTTMT 2.25        |                        | 159.0 296.0 408.3 526.0 621.3 712.0  | 220.5         | 4.54                   |
| 3           | HTTMT 3.06        |                        | 144.0 296.7 437.3 568.7 687.7 788.7  | 258.7         | 3.87                   |

**Figure 2.** Dependence of the total mass loss of samples on the duration of wear on the electrocorundum.

Similar dependencies were obtained for granite (table 2, fig. 3).

**Table 2.** The results of tests of samples with wear on granite

| № of sample | Processing method | Forging grade $\alpha$ | $\sum \Delta m$, mg per time $t$, min. | $K_i$, mg/min | $R_i, *10^{-3}$ min/mg |
|-------------|-------------------|------------------------|----------------------------------------|---------------|------------------------|
| 1           | Casting           | -                      | 11.3 27.3 52.7 80.3 118.7 153.0 180.3 215.0 250.0 285.0 320.0 355.0 400.0 445.0 490.0 535.0 580.0 625.0 670.0 715.0 760.0 805.0 850.0 | 443.73        | 2.25                   |
| 2           | HTTMT 2.25        |                        | 32.7 63.3 79.0 102.0 121.0 153.0 185.0 217.0 249.0 281.0 313.0 345.0 377.0 409.0 441.0 473.0 505.0 537.0 569.0 601.0 633.0 665.0 697.0 729.0 761.0 793.0 | 2.212         | 452.1                   |
| 3           | HTTMT 3.06        |                        | 33.0 57.0 80.0 105.0 125.0 153.0 180.0 207.0 234.0 261.0 288.0 315.0 342.0 369.0 396.0 423.0 450.0 477.0 504.0 531.0 558.0 585.0 612.0 639.0 666.0 693.0 | 2.195         | 455.6                   |
As can be seen from the obtained data, the use of the high-temperature thermomechanical treatment method significantly (up to 20% for granite and up to 50% for electrocorundum) increases the abrasive wear resistance of Hadfield’s steel, which increases the intensity of plastic deformation (forging grade) of the metal during HTMT.

5. Conclusion
High temperature deformation of high-manganese steel before hardening contributes to the increase of its abrasive wear resistance, which can be used in the manufacture of wear-resistant elements of ore dressing equipment to improve their service life.

References
[1] Gulyaev A P 1986 Physical metallurgy (Moscow: Metallurgiya) p 544
[2] Bolobov V I 2014 Journal of Mining Institute 209 17-22.
[3] Bolobov V I, Bochkov V S, Syuj Cinyan 2012 Mining equipment and electromechanics 10 12-14.
[4] Hrushchov M M, Babichev M A 1960 Study of wear of metals (Moscow.: Publishing house of the Academy of Sciences of the USSR) 351
[5] Tenenbaum M M 1960 Wear resistance of parts and durability of mining machines (Moscow: Gosgortekhizdat) 238
[6] Smirnov M A, Pyshmincev I YU, Laev K A, Ahmedyanov A M 2012 Bulletin of the South Ural State University. Series “Metallurgy” 39(298) 85–88
[7] Guryanov D A, Tesker E I, Zamotaev B N, Rubezhanskaya I V 2009 Izvestia VSTU 3/11 134–137
[8] Zasyypkin A D, Dementev V B 2012 Tractors and farm machinery 4 37–39
[9] Shavrin O I, Dementev V B 2002 Metal science and heat treatment of metals 8 27–29
[10] Zamotaev B N, Eremin M P, Chechin S V, Kandaurov A S 2013 Izvestia VSTU 8/15 96–99
[11] Smirnov M A, Pyshmincev I YU, Laev K A, Hramkov E V 2015 Vestnik of Nosov Magnitogorsk State Technical University 3(51) 78–82
[12] Babuk V V, Yakovlev G N, Bemshitejn M L 1966 Vestnik mashinostroeniyta 7 67 – 69.
[13] Barroqueiro B, Dias-De-Oliveira J, Pinho-Da-Cruz J, Andrade-Campos A 2016 Multiscale analysis of heat treatments in steels: Theory and practice. Finite Elements in Analysis and
Design 114 39–56

[14] Krishna S C, Tharian K T, Chakravarthi K V, Jha A K, Pant B 2016 Metallography, Microstructure, and Analysis 5(2) 108–115

[15] Dobrzański L A, Czaja M, Borek W, Labisz K, Tański T 2015 International Journal of Materials and Product Technology 51(3) 264–280

[16] Bolobov V I, Chupin S A 2015 Nanoscale-Arranged Systems for Nanotechnology 112-115

[17] Karam-Abian M, Zarei-Hanzaki A, Abedi H R, Heshmati-Manesh S 2016 Materials Science and Engineering A 651 233-240

[18] Ivancivsky V V, Skeeba V Y, Bataev I A, Lobanov D V, Martyushev N V, Sakha O V, Khlebova I V 2016 The features of steel surface hardening with high energy heating by high frequency currents and shower cooling. IOP Conference Series: Materials Science and Engineering 156(1) 012025

[19] Plotnikova N V, Skeeba V Y, Martyushev N V, Miller R A, Rubtsova N S 2016 Formation of high-carbon abrasion-resistant surface layers when high-energy heating by high-frequency currents IOP Conference Series: Materials Science and Engineering 156(1) 012022

[20] Homberg W, Rostek T 2013 Thermo-mechanical hardening of ultra-high-strength steels. Key Engineering Materials 549 133-140

[21] Blyuher V V, Parfenov P I, Volchok I P 1970 Metal science and heat treatment of metals 12 32-34