Abrasive wear of Hilong BoTN hardfacings

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Abstract. The spread of steels, which are used to produce locks of steel drill pipes, adversely affects their wear resistance, which, in combination with low hardness of HV 2400 ... 2800 MPa as well as of the thread of screw, results in low wear resistance and the need for their reconstruction at the pipe control shop. An efficient way of improving the quality of drill pipe joints is to hard-face them by the outside diameter with wear-resistant materials (hardbanding). One of the companies engaged in the development of hardfacing materials and hardbanding is Hilong (China) with weld seams of the brand BoTn. According to the results of the studies the following conclusion can be made: hardfacing increases the durability of the hardware, contributing to an increase in wear resistance of locks of DP under the conditions of abrasive action of aggressive geological formations; the usage of DP without wear-resistant weld seams is impermissible, because their further operation, as part of the drill-stem, can lead to emergency consequences; application of the pipes with the hardfacing collars together with the collars without hardfacing, due to varying degree of wear of joints in the drill-stem, is also impermissible.

1. Introduction
One of the causes of low durability of drill pipes (DP) is an abrasive wear of joints[1]. More than 60 % of pipes are rejected due to the wear of outer joint diameter, while other parameters meet the acceptable norms. The main reason of drill pipe joint wear in an open wellbore is presence of hard layers in aggressive geological bodies. During drilling the lower part of drill stem consists of heavy-duty drill pipe (HDDP), heavyweight drill pipe (HWDP) and steel drill pipe (SDP). HDDP and HWDP are made of single structural alloy steel workpieces 40ХГМА (1.2311), 40ХН2МА (4340). The length of DP is 8,5...12,5 metres. During borehole drilling the lower part of drill stem is in direct contact with abrasive parts of rock-breaking layers. The intensity of wear of DP surface layers during abrasive wear hardly depends on original mechanical properties of joint material. The chemical composition of joint material [5] of steel pipes shows a significant dispersion of steels by carbon content (0,22...0,37), what, in combination with other alloying elements, matches steels 20XГНМ...40XГНМ. Hardness of the DP joint material is 28...36 HRC and is achieved by induction heat treatment. In order to increase the longevity of DP, hardfacings made of wear-resistant materials are welded to the outer diameter of the pipe. In most cases there are 3 of such hardfacings, each of them is 25,4 mm wide and overall width is 76,2±6,35 mm. Hardfacing are jam-welded in argon-shielded environment. Welded material stands above joint body up to 2,5 mm. Such way of increasing durability is widely used by foreign companies [2, 3, 6]. Thus, one of the priorities during production and full repair of drill pipes is reinforcing welding of wear-resistant materials (hardbanding) of outer joint surface[4, 5].
Hardbanding – wear-resistant metal coating, applied by way of electronic welding to the outer surface of drill pipe joint in order to increase the longevity of the joint and decrease the wear of casing pipe.

2. Research methodology

Further use of wear-resistant hardfacings for drill stems is impossible without determining their level of effectiveness. For this it is necessary to carry out a comparative test of different padding materials in relation to DP joints without hardfacings. Hilong hardfacings BoTn 1000, BoTn 3000, BoTn 5000 (table 1) are welded to joints by “Technomash” of Nevьansk.

Table 1. Parameters of the submitted samples

| Collar of drill pipe joint | SDP 89 in the strength group G105 |
|----------------------------|----------------------------------|
| External diameter of the lock, mm | 127 |
| Height of coating, mm | 2,38 (+0.8) |
| Width of coating, mm | 76.2±6.35 |
| Method of applying hardfacing | Standard |

For producing sample parts joints of SDP 89 were mechanically processed: turning to eliminate surface irregularities of hardfacings; inner diameter boring up to 105 mm; cutting a ring with a height of 20±0,1 mm. The ring was cut in segments 35 mm long. Each ring was cut in four segments, three of which were used for wear experiments, and one sample part for metallographic analysis.

The wearing scheme consist of a Sample 1 is fixed on the base of the pendulum arm 2 with lever 3 screwed in from the side. Weight is hanged from the right part of lever 3, which ensures constant pressure in the contact area of sample 1 and turning rubber roller 6. Abrasive material with grit of 16 mm is supplied through the distribution device 5 by the track pan 4 to the contact area of sample piece 1 and rubber roller 6. The duration of experiments, established by standards ASTM G65 and GOST 23.208-79, equaled 30 minutes for each sample piece.

Chemical analysis was carried out with laser atomic emission spectrometer «LAES». Cross-sections were made using stand methods with Stuers equipment. Etch processing was done in a 4% solution of nitric acid in ethanol. Etching welded hardfacings was done using the chemical agent Marble (20 g CuSO₄, 100 ml HCl, 100 ml ethanol).

Metallographic analysis was carried out using CarlZeiss Axio Observer D1 with zooming in from 200 to 1000 times. Microhardness was measured using a durometer DuraScan 70 with press of 100 grams.

3. Experiment results

Diameters of joint hardfacings for SDP were measured using a micrometer MC 125 with 0,01mm accuracy. Results of measurements of joints and hardfacings are presented in table 2.

Chemical analysis of sample pieces shows that joints were made of medium carbon – low alloyed steel 37ХГМА (4041). Alloying elements chrome, manganese, molybdenum, nickel significantly increases hardenability of steels. Hardening effect is amplified when steel is alloyed with several elements.

Table 2. Geometric parameters of the hardfacing collars

| The name of the lock | The outer diameter of the lock, mm | The outer diameter of the hardfacing collars, mm (1 plane) |
|----------------------|-----------------------------------|---------------------------------------------------------|
| Initial              | 127,14                            | 127,16  133,18  133,02  133,06  133,18  133,23  133,33  132,33 |
| BoTn 1000            | 127,23                            | 132,31  132,36  132,33 |
| BoTn 3000            | 127,21                            | 132,51  132,61  132,64 |
| BoTn 5000            | 127,19                            | 132,80  132,51  132,64 |
All alloying elements decrease critical hardening rate. Therefore, hardness of alloyed steels can be increased by cooling them at lower rates, than for carbon steels. Besides, hardening alloyed steels can be carried out using slower cooling agents, what can decrease the possibility of hardening defects, first of all hardening cracks. This is especially important for DP body and joint, that are assembled by friction welding.

Hardfacings were found to have carbon content up to 0,7% and carbide forming chemical elements: chrome – up to 8%, manganese – up to 0,8%, silicon – up to 0,4%, molybdenum – 0,13% (BoTn 5000). Main alloying elements increase ferrites hardness and durability. Silicon, manganese and nickel increase durability of ferrite the most. Chrome is known to improve mechanical properties of structural steel and special properties of steels, for example, resistance to aggressive environments, that are present during borehole drilling.

Molybdenum is a strong carbide that are forming element. It forms carbides and alloyed ferric carbide, promotes grain size reduction, increases durability and high temperature strength. At the same time, there was no molybdenum found in BoTn 1000 and BoTn 3000 hardfacings. Vanadium and titanium are also used to reduce grain size, but the content of these elements should be limited (up to 0,3…0,5%), as they can form carbides at grain boundaries, which can lead to brittle fracture. Among tested paddings titanium was only found in BoTn 5000, less than 1%. Nickel gives steels corrosion resistance, high durability and ductility, increases hardenability, impact toughness, decreases cold-shortness threshold, thus decreasing the potential of brittle fracture of welded metal. The largest content of nickel (up to 3%) was found in BoTn 3000 hardfacing. Niobium improves acid resistance and promotes the decrease of corrosion in welded constructions. Niobium in BoTn 3000 hardfacing is dispersed irregularly in the cross-section totaling 44 % in spectrum 2.

Microstructure of sample pieces is presented in fig. 1. Thickness of the hardfacing after mechanical processing equaled: about 2 mm for BoTn 1000 padding; up to 3,5 mm for BoTn 3000 and BoTn 5000 hardfacings.

Welded metal has dendrite structure. In contact are of hardfacing and base material dendrite axes are structured perpendicularly to the plate surface. This is especially distinct for BoTn 5000 hardfacing. Hardfacing has an area of thermal influence with changed structure close to it – large-needled martensite near the hardfacing, small-needled martensite further. Structure of the main metal – secondary sorbite. Segregation banding can be visible in the main metal, which is typical for hot forming.

Dispersion of microhardness in welded layers on sample pieces is given in figure 3. Hardfacing hardness decreases with distance from the surface due to dendrite structure enlargement and is within the range: HV7300…8000 MPa for BoTn 1000, HV 8100…9600 MPa for BoTn 3000 и HV 9400…11200 MPa for BoTn 5000.

![Figure 1. Fragments of the microstructure of the hardfacing samples, x50: a – BoTn 1000; b – BoTn 3000; c – BoTn 5000](image-url)
**Results of wear test for sample pieces (figure 6) are given in figure 5.** Tests of welded materials in relation to joint material used in batch production tell about the effectiveness of each tested sample piece. BoTn 5000 hardfacing provide the best wear resistance. Overall, there is a correspondence between hardfacing hardness and wear resistance.

In order to determine the effectiveness of wear resistant hardfacings for SDP 86, metrological test were carried out on the premises of «BIS-Service» in Nizhnevartovsk, Russia. SDP 86 were supplied for repair due to them having been rejected because of inner and outer joint threads. Measurements of outer joint diameter were carried out using a beam trammel BT 250 with 0,05 mm precision. It was found out that one drill stem contained both SDP 86 with outer welded hardfacings (BoTn 3000), and joints without hardfacing.

The outer diameter of joint without paddings equaled 103,5…104,8 mm, while for joints with paddings – 108±0,1 mm. Measurements of outer diameter for areas with paddings for SDP 86 show a
minor wear of welded material (diameter 110, 8…112,0 mm) and no joint wear. There was also no roughening and detachment of material.

According to metrological analysis of SDP 86, supplied for repair, following conclusions can be made:
- hardfacings increase durability of drill pipe parts, promoting increased abrasive wear resistance for DP joints in the aggressive geological environments;
- using drill pipes without hardfacings is unacceptable, as their further use as parts of drill stems may lead to emergencies;
- application of the pipes with the hardfacing collars together with the collars without hardfacing, due to varying degree of wear of locks in the drill-stem, is also impermissible.

4. General conclusions and recommendations
1. Dispersion of types of steels, used to make drill pipe joints, has a negative effect on their durability, what in combination with low hardness HV 2400…2800 MPa and strength of thread turns leads to low durability and having to repair them at pipe control shops.
2. Effective way of improving the quality of drill pipe joints is welding wear-resistant hardfacings to them (hardbanding). One of the companies developing hardfacing materials and providing hardbanding services is Hilong (China) with BoTn hardfacings.
3. Chemical composition of hardfacing materials BoTn shows the presence of carbide forming elements (Cr, Ti, Mo, Mn), irregularly dispersed along the welded padding, that increase hardness and form simple and complex carbides, that possess high hardness along with decent viscosity (due to the presence of Ni, Nb).
4. Results of wear test of welded materials, in relation to joint made in batch production (test ASTM G65 degree of resistance to abrasive wear), shows the effectiveness of all the parts made by «Technomash» using the technology from Hilong (China). BoTn 5000 has the best wear resistance and, overall, there is a correlation between hardness of the material and wear resistance.
5. Results of metrological analysis of drill pipes repaired by «BIS-Service» from Nizhnevartovsk by recutting threads of nipple and collar parts, show no wear of the joint body with BoTn 3000 hardfacing. Pipes without hardfacing have outer wear that equals 103,5…104,8 mm and they are subject to demotion to lower quality grade, while their further use as parts of drill stems may lead to emergencies.
6. Due to different wear resistance of original joint materials and welded materials it is highly recommended that the same type of BoTn hardfacing are used as parts of a single drill stem.

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