# Research of the structure and properties of wear-resistant surfaces

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**Abstracts**. The share of horizontal wells has been significantly increasing as the drilling technologies used in Russia have improved over the past ten years. In this regard most of drilling contractors use hard-alloy surfacing - hardbanding - a wear-resistant metal coating, deposited in the form of belts on the outer surface of the joint, to protect the drill string.

## 1 Introduction

A large number of parts of machines and mechanisms fail during operation due to abrasion, impact loads, erosion, etc. Modern machinery has various methods of restoration and hardening of parts to increase their service life. At present, the question of choosing a method of effective protection of various products and parts between hardening the entire volume of the material and application of protective coatings on their working parts in most cases is unambiguously resolved in favor of the latter. This is explained by the fact that it is their surface that experiences the greatest degradation in the process of operation. The most promising methods of hardening and restoration, allowing to radically improve the properties of surfaces, is cladding.

Almost all the processes of wear, corrosion, growth of fatigue cracks (etc.) that lead to product failures begin with the surface and are determined by the properties of a relatively thin surface layer. Cladding is one of the main methods of creating coatings in order to obtain special properties on the surface of products, as well as to restore worn machine parts. It allows to solve one of the most important problems - providing an optimal ratio of surface properties and material volume. In this case there is no need to use volumetrically alloyed materials and there is an opportunity to solve to a certain extent the cardinal problem of mechanical engineering - increasing the reliability and durability of parts under operating conditions.

Wear resistance of surfaces at mechanical wear is determined by structural-phase composition. The surfacing process influences the course of structural-phase transformations in the surfaced metal. Changes in the chemical composition of the deposited layer depending on the percentage of base and filler materials, high heating temperature and a large range of cooling rates during surfacing lead to the formation of different structural-phase states in the surface layer, made by the same surfacing material.

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To increase the hardness, wear resistance, corrosion resistance and other properties of the surface layers of metals and alloys different types of cladding are used: plasma, laser, electron-beam and electric arc. Additionally, it is possible to increase the listed properties by introducing various alloying elements into the cladding layer. To date, traditional methods of improving the structure and properties of coatings have almost exhausted themselves, due to this fact, new techniques and technologies are addressed, which consist in solving the issues of nanostructurization of coatings.

Cladding coatings are characterized by the absence of pores, high values of elastic modulus and tensile strength. The bonding strength of these coatings to the substrate is commensurate with the strength of the part material.

With the arrival of foreign companies to the domestic drilling market, drilling technologies and techniques have changed. This has significantly changed the demands placed on the material and design of drill pipe. The most demanded today is high-strength steel drill pipe, which makes over 70 percent of the market. Extreme operating conditions of drill pipes lead to their destruction. The main reasons of drill pipe failure are cracks formed due to high stress of the pipe metal and surface wear and tear caused by corrosion and abrasive wear [1, 2, 4]. Taking into account the high cost of modern high-strength drill pipes, the losses of the companies from rejection make dozens of millions of rubles. Evaluating the statistical data, we can conclude that more than 60 % of the pipes are rejected because of wear of the outside diameter of the tool joint, while the other parameters of the pipes meet the admissible norms. Thus, one of the priority directions of drill pipe manufacture and overhaul has become the strengthening of outer surface of tool joints. Such methods of drill pipe tool tool joint hardening as surface and volumetric hardening, nitriding have one common disadvantage - wear of tool joint body. This subsequently leads to numerous restoration problems or to rejection. In the case of hardfacing, only the surfacing layer is subject to wear, which can be subsequently repaired without any problems. When selecting a surfacing material, it is necessary to take into account not only the lifetime of the drill pipe when working in the open hole, but also the service life of the casing, because when drilling in a cased borehole, mutual wear of the surfaces of the drilling tool and the casing will inevitably occur.

Drillpipes are subjected to abrasive wear as their outer surfaces rub against the borehole walls or casing. Worn drill pipes, in the best case, are relegated to a lower class, which does not allow using them when drilling directional wells in difficult geological conditions.

Drill pipe is a tool used when drilling wells, which provides torque transfer between the drive and the bit, as well as the circulation of drilling mud at the bottomhole. Drill pipe is connected to each other by tool joints, which can be either as separate items or as inseparable elements of the drill pipe. One of the most common drill pipe designs is a friction-welded joint made on special mills in the factory. The exterior view of such a drill pipe (after the restorative repair by cladding) is shown in Figure 1.

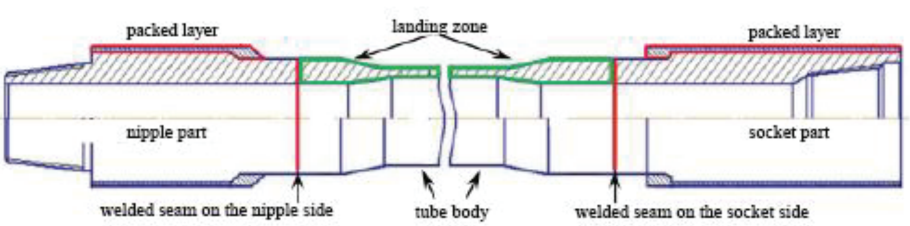


**Fig. 1.** Appearance of the drill pipe after cladding restoration.

The main structural elements of a drill pipe are the body and the lock, which are nipple and socket parts, welded together by friction in the landing zone of the drill pipe on opposite sides. Hereinafter in this paper the term "drill pipe" will be used only in the sense of a welded drill pipe body with tool joints (nipple and box) and the term "tool joint" in the sense of a drill pipe structural element (tool joint consisting of a nipple and a box joint of two drill pipes).

Various grades of structural alloy steels may be used for manufacturing drill pipe and tool joints (if the tool joint is a welded joint). According to the requirements of domestic and foreign standards (GOST, API) in the vast majority of cases the steel grade is not regulated by a normative document and is set by the manufacturer on the condition of providing the requirements of the corresponding standard for mechanical properties of the given strength group, as well as limiting the harmful impurities of sulfur (S) and phosphorus (P).

Nowadays in order to increase the operational life of drill pipe such methods are used as protective or strengthening coating on the surface of the tool joint (in particular hardfacing), wear-resistant spraying, metal strengthening with the use of special technology.

Hardbanding is a coating applied by welding to a drilling tool in the form of belts. These bands are harder than the pipe metal and have a special microstructure. The main purpose of hardbanding is to protect drill pipe and casing from friction wear and thereby increase their service life [6].

The technology of hardbanding is a welding process in an inert gas with a special flux-cored wire [3].

In the process of work both in open and cased wellbore the drilling tool performs translational and rotational motion, to a greater extent coming into contact with the open or cased wellbore by its interlocking joints. For this reason, it is more likely to wear at the interlocking joints, reducing in diameter.

Carbide hardfacing applied to the tool joints takes the abrasion load during the drilling process, thereby sacrificing itself and saving expensive equipment. Carbide cladding withstands abrasion much more effectively, and due to the lower coefficient of friction, it also reduces drilling torque. In addition, the microstructure of the clad metal has less abrasion effects on the casing [8,9].

Hardbanding is applied to steel drill pipe (SDP) interlocks, thick-wall drill pipe (DWP) interlocks and center discharges, and weighted drill pipe (DWP) by cladding. Typically three 25-mm wide belts are used for a drill pipe, which are cladded onto the socket of the tool joint at a slight offset from the 18-degree (or 90-degree) shoulder, without affecting the socket section of the pipe wrench. Subsequently, during the drilling process, it is this hardbanding (75 mm wide and 2.4 to 3.2 mm high) that protrudes over the drill collar surface and contacts the casing and rock in the uncased borehole, thereby protecting the tool joint from wear. In addition, hardbanding can be applied to the nipple end of the interlock to protect it from wear. [13,14]

The chemical composition of modern hardbanding materials provides a reduced coefficient of friction with the casing as it rotates inside it, and consequently, a low casing wear factor.

The reduction of friction between the drill string and casing in the borehole and the reduction of the contact area between the drill string and uncased borehole result in a reduction of torsional and axial loads on the string, which contributes to improved drilling efficiency and an increase in the mechanical rate of penetration.

Cladding does not damage the casing, and application is possible both on new equipment and tools after storage, as well as recladding and restoration of most existing worn-out carbide cladding.

The wear rate of drill pipe (DP) depends on many factors, such as hardness of material, friction path the pipe passes during operation, hardness and abrasiveness of rocks, size of forces pressing the DP against the wellbore walls or casing, lubricating properties of flushing fluids, etc. At the same time the wear is unevenly distributed along the length and perimeter of CT. The biggest wear is on interlocks and the middle part of CT body, and the wear is eccentric.

Nowadays different methods of drill pipe elements protection, both inner (less spread) and outer surface, are used.

It has become a common practice to send discarded tool joints to a reclamation procedure, which involves surfacing of an additional outer layer to bring the geometry of the tool joints to the nominal value along the outside diameter. It is 2 to 3 times cheaper to restore drill pipe than to buy a new one, but not all companies allow to use restored drill pipe. As a result of searching for solutions to this problem the following ways of increasing durability of drill pipe tool joints have been developed:

- protecting the outside diameter of the lock with hardfacing;
- protection of the outside diameter of the lock with wear-resistant spraying;
- surface hardening of the lock joint material.

## 2 Wear resistance of drill pipe tool joints

Wear resistance depends on composition and structure of processed material, initial hardness, roughness and technology of detail processing, state of reciprocating part.

As a result of the analysis, in terms of ensuring wear resistance of drill pipe tool joints and a specified durability of their operation, there are two directions that do not require much time and resources for their realization:

1. hardening of the part due to the modification of its surface by technological methods (changing the structure or changing the chemical composition of the surface layer);
2. application of protective or hardening coatings

## 3 Working conditions, operating characteristics and types of drill pipe wear

Together with the rest of the process elements, the drillpipe and the drillstring form a drill string. The drillstring operates under extremely harsh conditions and its condition largely determines the efficiency of working time during each run. The length of the drillstring life depends on a wide variety of factors, the most important of which are the following:

- The magnitude and nature of the loads acting;
- The presence of stress concentrations, such as threaded joints and drillstring joints of varying stiffness;
- Corrosive effects of the environment in which the drill string is located;
- abrasion of the drill string by the borehole walls and solid particles in the circulating drilling mud;
- The occurrence of oscillatory processes, resonance phenomena and reactive moments in the drill string.

The values and character of loads acting on the drill string depend on the drilling method, trajectory and condition of the well, applied drilling modes, technical condition of the surface equipment, its equipment with mechanization, automation and control means, as well as on qualification of the drilling personnel [9].

During the operation of drill pipes the uniform and non-uniform wear is observed, as well as the formation of risks and burrs on the working surfaces of the parts. As the pipe is subjected to loads of variable magnitude and sign, the most widespread is irregular wear. [15] Drill joints are subject to especially fast wear, first of all, because of abrasion against a wellbore wall, as well as fatigue from cyclic loads and thread wear by flushing fluid jet in case of underpulling [10]. The pipe body, in this case has a rather low operating time and could be involved in further well construction. The analysis of statistical data from tube bases, as well as long-term experience of well operation allow us to state that the most frequent reason of drill pipe failure today is exactly the abrasive-erosive wear of tool joint body, that is why the drill pipe repair in the part of overlaying forming tool joints with thread rethreading is a very actual and demanded practice.

## 4 Reapplying of hardbanding

Premium hardfacing materials are a hard steel matrix with carbide inclusion and provide maximum abrasion resistance and a low casing impact factor. Over time, drilling operations lead to wear of the protective hardbanding. The rate of wear is determined by the profile of the wellbore, the characteristics of the rocks being drilled, the drilling techniques used and other factors. If inspection reveals that the build-up height has decreased to 0.8 mm or less, the hardbanding should be reapplied. Wear rates for different surfacing materials will differ, even if the operating conditions are the same [7].

Depending on what material the worn hardbanding was made with, reapplying the hardbanding can be either quite easy or very difficult. In the surfacing process, the hardbanding material is fused and blended with the base metal of the drill collar. When hardbanding is first used on a new lock, the final formed protective coating is partially diluted with the base metal of the lock joint. That is, the hardbanding layer includes both hard and softer alloys in a certain proportion. When reapplied, the wear material is applied on top of the previously partially diluted hardbanding material, and the resulting percentage of hard alloy increases.

Dilution is an important factor to consider because the chemical composition of the various hardbandings varies considerably. [11] Both the base matrix and the carbides that provide wear resistance are unique in each particular hardbanding material. The material composition includes such carbide-forming elements as niobium, titanium, boron, and chromium, and the proportion of each of these in the total chemical composition of specific materials varies significantly.

It is possible to classify claddings according to the presence of one or the other carbide. [12] Although some materials are compatible with each other, care must be taken when applying one over the other: incompatible chemical compositions can lead to cracks in the carbide cladding and the failure of the protective coating.

If the material is properly selected, there is virtually no limit to the possibility of reapplying hardbanding to the same lock joint without appearing defective. With regular inspections and repeated hardbanding, tool joint wear and tear never becomes a reason to downgrade or retire a drill pipe. According to a survey of Russian drilling contractors conducted by Hardbanding Solutions, it turned out that in 67 percent of the cases significant wear and tear of unprotected tool joints on the outside diameter was the reason for downgrading drill pipe to a lower strength group or for putting it out of service. Reinstating the hardbanding on drill pipe before it wears to zero and keeping it in service will keep drillpipe OD locks from deteriorating and provide significant savings by extending the effective life of the drill tool.

Modern drilling techniques have markedly reduced the operating life of drill strings with unprotected tool joints.

## 5 Improvement of drill string operational reliability

When drilling directional and horizontal wells, it is recommended to use drillpipe with hardbanded surface hardening of locking parts ("hardbanding") to protect both casing and locks from wear. Wells with trajectories that have large deviations from the vertical are characterized by increased torque and resistance of the borehole walls. Such drilling trajectories create conditions of severe wear and tear of both the casing and the drill pipe (primarily the lock), which greatly affects drilling efficiency. The application of tungsten carbide surface hardening on tool joints is especially effective for rotary drilling in open boreholes, with aggressive geological formations. The use of tungsten carbide shot peening will increase the service life of tool joints and consequently of drill pipes.

The main advantages of using surface hardfacing are:

- reduction of lock wear during drilling in open and cased borehole, which positively affects the strength characteristics of the locks;
- prevention of thermal cracks in tool joints, caused by friction against the borehole wall during steep curvature stages;
- use of drill pipes with welded-on tool joints of smaller outside diameter;
- reduction of casing wear as a result of locks friction while rotating and tripping in the casing.

The surface hardfacing may be applied to used drill pipe after the tool joints have been cleaned and repaired in accordance with the approved technology. The only limiting condition for using wear-resistant surfacing is the sufficient length of the keyway on the drill pipe tool joint to be repaired. When repairing a worn coating applied by other manufacturers, it is recommended to check for compatibility of the new cladding with the previously applied wear-resistant coating.

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