Tribological characterization of the drill collars and casing friction couples

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Abstract: Drill collars are special pipes used in the drilling of wells for weighting the drill bit, enabling it to drill through the rock. In the drilling process, the drill collars are exposed to an intensive wear due to friction on inner surface of casing wall. In order to evaluate the tribological behaviour of this friction couple, paper presents the drill collars parent material, reconditioned and casing pipe chemical composition, microstructures, hardness and friction tests. For friction tests were prepared samples extracted from new and reconditioned drill collars and from casing pipes and tested on a universal tribometer. Were used plane-on-disk surface friction couples and tests were conducted at two sliding speeds and three normal loads for each materials couple. Plane static partner samples were extracted from casing pipes and disks samples were extracted from new and reconditioned drill collars. Were obtained friction coefficients values and also the temperatures increasing values due to friction working tests parameters. The temperature increasing values were obtained by measuring it with an infrared thermographic camera.

Keywords: drill collar, casing, friction coefficients, temperature.

1. Introduction

Drill collars used in petroleum industry works in heavy conditions. A drill collar is a device used in the drilling of oil wells for weighting the drill bit, enabling it to drill through rock. The drill collars it is manufactured from a bar made of non-magnetic steel alloy, drilled on entire length to permit the flow of drilling fluids. The drill collars are the most expensive elements of the drill string and their durability is essential for the economical drill work efficiency. These devices are typically about 9450 mm long and threaded at both ends (pin and box) to allow multiple drill collars to be joined above the bit assembly. The outside diameter of the drill collars may vary from about 76 mm to 279 mm and greater [1, 2, 3, 4].
In the exploitation time, the drill collars are subjected to torsion, tensile/ compression, internal pressure, external pressure and bending. Two of the degradation processes that reduce durability are abrasive wear of the external surfaces (due to the friction between the drill collars with the inner surface of the casing or the open hole wall) and internal corrosion (due to the passage of drilling fluids through drill collars), [2, 3, 4, 5, 6, 7]. It is important to evaluate the friction behaviour of drill collars because if the wear is advanced, the drill string can slip from the elevator shoulder (device used for handling the drill string) and fall into the borehole [2, 3, 4, 7]. Usually surfaces exposed to friction with casing are reconditioned or hardbanded by applying different alloys that contains carbides. [1, 2, 3, 7, 8].

The aim of this work is to evaluate the tribological behaviour of drill collars- casings friction couple. Thus, paper presents the drill collars parent material, reconditioned and casing pipe chemical composition, microstructures, hardness and friction tests. For friction tests were prepared samples extracted from new and reconditioned drill collars and from casing pipes and tested on a universal tribometer.

2. Experimental tests

2.1. Samples preparations

Samples were extracted from real drill collars and casing. In order to not modify the material proprieties during extraction process a water jet cutting machine was used. In figure 1 it is presented the pictures of water jet cutting.

![Water jet sample cutting.](image1)
![Drill collar.](image2)

**Figure 1.** Extraction the samples from drill collars.

After extraction samples were manufactured by milling and then by grinding with some non-intensive cutting regimes and in the presence of cooling fluids.

2.2. Determination the chemical composition

The chemical composition of the parent material and the deposited layer for tested reconditioned drill collars, were obtained with FONDROY MASTER PRO type laboratory spectrometer. The chemical composition results are presented in table 1, [7].
Table 1. Chemical composition of the parent metal and deposited layer.

| Chemical element, (wt.%) | Parent material | Deposited layer |
|--------------------------|-----------------|-----------------|
| Fe | 96.1 | 95.4 |
| C | 0.488 | 0.479 |
| Si | 0.277 | 0.319 |
| Mn | 1.086 | 1.289 |
| P | 0.018 | 0.017 |
| S | 0.160 | 0.014 |
| Cr | 0.323 | 0.347 |
| Mo | 0.182 | 0.555 |
| Ni | 0.017 | 0.022 |
| Al | 0.220 | 0.019 |
| Co | 0.0005 | 0.018 |
| Cu | 0.0079 | 0.0005 |
| Nb | 0.0054 | 0.0088 |
| Ti | 0.0005 | 0.0053 |

In table 2 it is shown, according to API and ISO standards, [4, 5, 6], the chemical composition of drill collars made of AISI 4145H and for casing, made of API 5CT N80-1 spectrometer measured values.

Table 2. Chemical composition of the steel AISI 4145H and N 80-1.

| Material | Chemical element, (wt.%) |
|----------|-------------------------|
| AISI 4145H | C | 0.43-0.49 | 0.10-0.35 | 0.85-1.10 | max. 0.035 | max. 0.040 | 0.80-1.10 | 0.15-0.25 | max. 0.25 |
| Casing | N 80-1 | Si | 0.16-0.35 | 0.31-0.65 | 1.64 | 0.015 | 0.015 | 0.14 | 0.12 |

The chemical composition obtained for parent material and deposition layer presented in table 1 are quite similar with the imposed standard values [4, 5].

2.3. Hardness measurements

The hardness tests were performed with an EMCO – DURASCAN 20 type micro hardness machines at a load 0.5 kgf. At the drill collars the microhardness HV0.5 variation with the distance from the deposited layer to the parent metal is presented in figure 2, [7], and for N80-1 casing in figure 3.

Figure 2. Microhardness HV0.5 variation at hardbanded drill collars samples, [7].

Figure 2 show that at hardbanded (reconditioned) drill collars samples the hardness is almost the same in deposited layer, heat affected zone (HAZ) and parent material AISI 4145H, respecting standard specifications [4, 5, 6].
Based on the average of 5 measured values the hardness obtained for the N80-1 samples material was 270 HV 0.5.

### 2.4. Analysis by optical microscopy

The analyses by optical microscopy were performed on metallographic prepared samples drill collars material AISI 4145H, hardbanded drill collars and from casing N80-1. Specimens were prepared by polishing and metallographic etching with chemical reactive (NITAL), and analyses were performed with OLYMPUS BX60M type metallographic microscope. In figure 4 are presented the specimens microstructure images obtained.

The investigations have found the following:
- the AISI 4145H material drill collar specimen has a sorbitic structure;
- the hardbanded drill collar in deposited layer material specimen shows a typical dendritic structure for weld deposits with alloys that contains chemical elements which form carbides;
- the casing N80-1 specimen material has a ferrite-pearlite structure.

### 2.5. Friction tests

Friction tests were performed on plane-on-disk couples on a CSM type tribometer [8, 9, 10], disk samples with dimensions Ø 40x3 mm were made of drill collars 4145H material, and of hardbanded drill collars material. Plane static partner in tested friction couples has a cubic shape with dimensions 4x4x4 mm, and were made of casing N80-1 material. In figure 5 it is shown the picture of friction couple positioning during the tests on CSM tribometer.
Figure 5. Plane-on-disk friction couple.

The working conditions were:
- normal load of 1N, 2N and 4N;
- disks of AISI 4145H and of reconditioned by hardbanding drill collars materials;
- cubes of N80-1 casings material;
- sliding speed of 0.100 m\(\cdot\)s\(^{-1}\) and 0.200 m\(\cdot\)s\(^{-1}\);
- friction length 100 m;
- dry friction at temperature of air of 20\(^\circ\)C and RH=55%.

At the start and at the end of each test the temperature was measured and recorded by using an infrared thermographic camera, type FLIR E50 which was focused to the friction surface. In figure 6 it is shown the friction coefficients values results obtained on plane-on-disk tribometer for disks of 4145H drill collars-N 80-1 materials couple at sliding speed of 0.100 m\(\cdot\)s\(^{-1}\) and in figure 7 at 0.200 m\(\cdot\)s\(^{-1}\).

Figure 6. Friction coefficients vs. sliding distance for couple materials AISI 4145H drill collars-N80-1 casing at sliding speed of 0.100 m\(\cdot\)s\(^{-1}\).
Figure 7. Friction coefficients vs. sliding distance for couple materials AISI 4145H drill collars-N80-1 casing at sliding speed of 0.200 m∙s⁻¹.

In figure 8 are the friction coefficients values for disks of hardbanded drill collars material at sliding speed of 0.100 m∙s⁻¹ and in figure 9 at 0.200 m∙s⁻¹.

Figure 8. Friction coefficients vs. sliding distance for couple materials hardbanded drill collars- N80-1 casing at sliding speed of 0.100 m∙s⁻¹.
Figure 9. Friction coefficients vs. sliding distance for couple materials hardbanded drill collars- N80-1 casing at sliding speed of 0.200 m∙s⁻¹.

Friction coefficients curves presented in figures 6, 7, 8 and 9 are quite similar for tested friction couples with a small increase of obtained values for couple materials hardbanded drill collars- N80-1 casing (0.27-0.39) instead of (0.19-0.34) for couple materials AISI 4145H drill collars- N80-1 casing. The sliding speed has a very small influence on both tested friction couples with a very small reduction at 0.2 m∙s⁻¹. The normal load influence at couple materials AISI 4145H drill collars- N80-1 show that friction coefficients values has a very small increase with load increasing meanwhile at couple materials hardbanded drill collars- N80-1 casing were a very small increase of friction coefficients were obtained at 2N load instead of 1N and 2N loads. These behaviors are due the small differences of chemical compositions of the AISI 4145 drill collars and hardbanded drill collars materials disk samples with the presence especially of cupper in the second one material disk samples.

In table 3 are presented the images of temperatures measured values at the start at the end of each friction tests. The spot of infrared thermographic camera, as shown in images, was focused on friction surface.

**Table 3.** Temperature values at the start and at the end of friction tests.

| Working parameters | Friction couple materials | Spot temperature at friction surface, (°C) |
|--------------------|---------------------------|------------------------------------------|
| Normal load (N)    | Disk of AISI 4145H- Cube of N80 | Disk of hardbanded drill collars-Cube of N80 |
| Sliding speed (m∙s⁻¹) | Initial | Final | Initial | Final |
| 1                  | 0.100 | | | |
Analyzing the spot temperatures values presented in table 3 we could observe that both tested couple materials, at the same friction tests parameters, presents similar increase of the temperatures between the start and the end of tests. For friction tests conditions, these temperatures differences increase with sliding speed and with normal load.

### 3. Conclusions

Tribological behaviour of AISI 4145H and reconditioned by hardbanding drill collars materials in couple with N80-1 casing material is almost the same. This conclusion was confirmed by the results obtained after chemical composition determination, hardness measurements, optical microscopy analysis and friction tests.

The friction coefficients values curves obtained presents a small increase of obtained values for couple materials hardbanded drill collars- N80-1 casing (0.27-0.39) instead of (0.19-0.34) for couple materials AISI 4145H drill collars- N80-1 casing. The sliding speed has a very small influence on both tested friction couples with a very small reduction at 0.2 m·s⁻¹. The normal load influence at couple materials AISI 4145H drill collars- N80-1 show that friction coefficients values has a very small increase with load increasing meanwhile at couple materials reconditioned by hardbanding drill collars- N80-1 casing were a very small increase of friction coefficients were obtained at 2N load instead of 1N and 2N loads. These behaviours are due the small differences of chemical compositions of the AISI 4145 drill collars and hardbanded drill collars materials disk samples with the presence especially of copper in the second one material disk samples.

The spot temperatures values at both tested couple materials, at the same friction tests parameters, presents similar increase of the temperatures between the start and the end of tests. For friction tests conditions, these temperatures differences increase with sliding speed and with normal load.
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