Tribological characterization of the drill pipe tool joints reconditioned by using welding technologies

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Abstract: Drill pipe is a seamless steel pipe with upset ends fitted with special threaded ends that are known as tool joints. During drilling operations, the wall thickness of the drill pipe and the outside diameter of the tool joints will be gradually reduced due to wear. The present research work investigate the possibility of reconditioning the drill pipe tool joints by hardbanding with a new metal-cored coppered flux cored wire, Cr-Mo alloyed, using the gas metal active welding process, taking into considerations two different hardbanding technologies, consisting in: hardbanding drill pipe tool joints after removing the old hardbanding material and surface reconstruction with a compensation material (case A), and hardbanding tool joint drill pipe, without removing the old hardbanding material (case B). The present paper brings forward the experimental researches regarding the tribological characterization of the reconditioned drill pipe tool joint by performing macroscopic analyses, metallographic analyses, Vickers hardness measurement, chemical composition measurement and wear tests conducted on ball on disk friction couples, in order to certify the quality of the hardbanding obtained by different technological approaches, to validate the optimum technology.

Keywords: tool joints, reconditioning, welding, wear rate.

1. Introduction

Drill pipes represent about 90 \% \ldots 95 \% of the total length of the drill string, being the major component of the entire drill string, which makes their durability to be essential for the economical drill work efficiency [1].
Drill pipe is a seamless steel pipe with upset ends fitted with special threaded ends that are known as tool joints. The drill pipe has two tool joints, one female called a box and the other male called pin, these joints allows to connect of each drill pipe segment to the next segment [2, 3, 4, 5, 6, 7, 8]. The drill pipe configuration and the main elements (tool joints, pipe body, upset and welding zone) are specified in figure 1.

![Figure 1. Drill pipe, [2].](image1)

The drill pipes are used to connect the rig surface equipment with the bottomhole assembly and the bit, to transmit the rotary motion from surface to the bit, and conduct the drilling fluid to the bit, thus it plays a vital part in the successful drilling of oil and gas wells.

During drilling operations, the drill pipes are subjected to torsion, tensile/compression, internal pressure, external pressure and bending. At the same time, due to the different environments, the drill pipes are subject to degradation processes resulting in their rejection. Two of the degradation processes that lead to the rapid decline in lifetime are abrasive wear of the external surfaces (due to the friction between the tool joints drill pipes with the inner surface of the casing – see figure 2) and internal corrosion (due to the passage of drilling fluids through drill pipe), [6, 7, 9, 10, 11, 13]. To improve the wear resistance, optional, the drill pipes are delivered with hardbanded tool joints, as shown in figure 3, [12].

![Figure 2. Schematic representation of the wear sources for drill pipes, [11].](image2)

![Figure 3. Hardbanded drill pipe tool joint, [12].](image3)

In the exploitation period, the wall thickness of the drill pipe and the outside diameter of the tool joint will be gradually reduced by wear. This decrease the strength properties of drill pipe due to pipe cross sectional area reduction or tool joint shoulder area reduction. For this reason, API classifies drill pipe according to degree of wear based on dimensions, surface damage, and corrosion, [2, 3, 4, 6, 7]. Depending on the existing wear at some point, in order to avoid the downgrade of the drill pipe to a degree of past (class) lower resistance, frequently, are applying the reconditioning of the drill pipe tool joint.

Based on this, the present research work investigates the possibility of reconditioning the drill pipe tool joint by hardbanding with a new metal-cored coppered flux cored wire, Cr-Mo alloyed, using the gas metal active welding process, taking into considerations two different hardbanding technologies, consisting in:
hardbanding drill pipe tool joint after removing the old hardbanding material and surface reconstruction with a compensation material;
- hardbanding tool joint drill pipe, without removing the old hardbanding material.

The present paper brings forward the experimental researches regarding the tribological characterization of the reconditioned drill pipe tool joint by performing macroscopic analyses, metallographic analyses, Vickers hardness measurement, chemical composition measurement and wear tests, to certify the quality hardbanding obtained by different technological approaches, to validate the optimum technology.

2. Reconditioning, results and discussions

2.1. Hardbanding specification

The tool joints drill pipe subjected to reconditioning process were manufactured by steel AISI 4145H, with the chemical composition, according to API standards, presented in table 1, [6].

| Chemical composition of the steel AISI 4145H. |
|---------------------------------------------|
| Chemical element, (wt.%)                    |
| C    | Si    | Mn    | P    | S    | Cr    | Mo    | Ni   |
| 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 |

The metal active gas welding process (GMAW) was used for drill pipe tool joint hardbanding. The shielding gas used was 82 % Ar and 18 % CO₂. The welding equipment had the devices necessary to grip and rotate the drill pipe, to grip and oscillate the welding torch parallel to the drill pipe tool joint surface, and to incline the welding torch, in the direction of the rotation. The drill pipe tool joints were reconditioned in two different technological approaches, as follows, [5]:

a) hardbanding drill pipe tool joint with a metal-cored coppered flux cored wire, Cr-Mo alloyed, after removing the old hardbanding material and surface reconstruction with a copper coated basic flux cored wire, like compensation material;
b) hardbanding drill pipe tool joint with a metal-cored coppered flux cored wire, Cr-Mo alloyed, without removing the old hardbanding material.

The chemical composition and the deposit mechanical characteristics for the hardbanding material (metal-cored coppered flux cored wire, Cr-Mo alloyed, of 1.6 mm diameter) and also for the compensation material (copper coated basic flux cored wire of 1.6 mm diameter) used are presented in table 2 and table 3, according to the manufacturer specifications.

| Chemical composition of the deposit. |
|--------------------------------------|
| Type of filler material              |
| Compensation material                |
| C | Mn | Si | P | ≤0.01 | ≤0.01 |
| 0.05 | 1.2 | 0.3 | - | - |
| Hardbanding material                 |
| 0.45-0.85 | 1.60-2.20 | 0.50-1.00 | ≤0.02 | ≤0.02 | 5.0-7.0 | 0.45-0.85 |

| Mechanical characteristics of the deposit. |
|--------------------------------------------|
| Type of filler material                    |
| Compensation material                      |
| Yield strength               | Tensile strength | Elongation | Impact energy | Hardness |
| $R_{p0.2}$ | $R_m$ | $A_5$ | KV at -40°C | HRC |
| ≥ 420 | 500-640 | ≥ 25 | ≥ 80 | - |
| Hardbanding material                    |
| - | - | - | - | 57-62 |
2.2. Results and discussions

The reconditioned tool joints drill pipe was tribological characterized in order to verify the deposition quality obtained by different technological approaches. The deposition quality was verified by: macroscopic analyses, metallographic analyses, Vickers hardness measurement, chemical composition measurement and wear tests. The experimental researches were made on two samples (A and B - as presented in figure 4), cut from the tool joints drill pipe hardbanded and prepared by polishing and metallographic etching with chemical reactive. The samples A and B were cut from tool joints drill pipe hardbanded in different technological approaches, as follows, [5]:

a) sample A – cut from drill pipe tool joint reconditioned by hardbanding with a metal-cored coppered flux cored wire, Cr-Mo alloyed, after removing the old hardbanding material and surface reconstruction with a copper coated basic flux cored wire, like compensation material;

b) sample B – cut from drill pipe tool joint reconditioned with a metal-cored coppered flux cored wire, Cr-Mo alloyed, without removing the old hardbanding material.

![Figure 4. Metallographic samples for macroscopic analyses: 1, 2, 3 - locations for metallographic samples used in optical microscopy analyses.](image)

2.2.1. Macroscopic analysis. The macroscopic analyses consisted in investigating with the naked eye (standard visual examination) and magnifying glass (magnifications of up to 10X) of the drill pipe tool joint hardbanded. The investigations, also made on the metallographic samples cut from the drill pipe tool joint hardbanded, have found the following:
- there were no cracks visible in the hardbanded layers;
- the adhesion between the substrate (parent metal) and the hardbanded layers is good (without discontinuities, porosities etc.);
- the adhesion between two adjacent rows and between two successive layers is good (without discontinuities, porosities etc.);
- the compensation layer applied to the drill pipe tool joint (Sample A) is executed correctly from the dimensional point of view, without cracks or pores in the transition to the substrate (parent metal).

2.2.2. Metallographic analyses by optical microscopy. The analyses by optical microscopy were performed on metallographic samples cut from the sampling locations (1, 2, 3) as indicated in figure 4. The metallographic samples, presented in figure 5 were embedded in polymeric material (resin) and special prepared by polishing and metallographic etching with chemical reactive - NITAL 5%, for examination by using the optical microscope OLYMPUS BX 60M.

In figure 6 are presented the microstructure images of the hardbanded layer, compensation layer, heat affected zone and parent metal, obtained after metallographic analysis of the Sample A (sample cut from the drill pipe tool joint reconditioned by hardbanding with a metal-cored coppered flux cored wire, Cr-Mo alloyed, after removing the old hardbanding material and surface reconstruction with a copper coated basic flux cored wire, like compensation material).
In figure 7 are presented the microstructure images of the hardbanded layer, heat affected zone and parent metal, obtained after metallographic analysis of the Sample B (sample cut from the drill pipe tool joint reconditioned by hardbanding with a metal-cored coppered flux cored wire, Cr-Mo alloyed, without removing the old hardbanding material).

The metallographic analyses by optical microscopy of the hardbanded samples A and B (figure 6 and figure 7) shows the following:
- the parent metal has a very fine sorbitic structure outside the heat affected zone;

Figure 5. Samples for metallographic analysis using optical microscopy.

(a) Hardbanded layer.  
(b) Compensation layer.  
(c) Heat affected zone.  
(d) Parent metal.

Figure 6. Microstructure images of the Sample A, starting from the surfaces of the hardbanded layer until the parent metal.
- the parent metal in the adjacent weld bead area (transition area to the parent metal) has an acicular martensitic structure and there were no cracks and discontinuities visible;
- the fusion line has a small thickness and the nearly area has an inferior bainitic structure;
- the adhesion between the substrate (parent metal) and the hardbanded layer is good (no discontinuities are visible);
- the hardbanded layer shows a typical structure for weld deposits with alloys that contains chemical elements which form carbides.

![Hardbanded layer](image1)
(a) Hardbanded layer.
![Heat affected zone](image2)
(b) Heat affected zone.

![Parent metal](image3)
(c) Parent metal.

**Figure 7.** Microstructure images of the Sample B, starting from the surfaces of the deposited layer until the parent metal.

### 2.2.3. Determination of the chemical compositions for parent metal and hardbanded layer.

In order to establish the chemical composition of the parent metal and the hardbanded layer, the investigations were performed with FONDRY MASTER PRO type laboratory spectrometer. The results obtained are shown in table 4.

**Table 4.** Chemical composition of the parent metal and hardbanded layer.

| Sample | Chemical element, (wt.%)| C  | Si  | Mn  | P   | S   | Cr  | Mo  | Ni  | Al  |
|--------|-------------------------|----|-----|-----|-----|-----|-----|-----|-----|-----|
|        |        Parent metal      |    |     |     |     |     |     |     |     |     |
|        |          A              | 0.3979 | 0.3132 | 1.168 | 0.0074 | 0.0072 | 1.163 | 0.3903 | 0.1064 | 0.031 |
|        |          B              | 0.3937 | 0.2956 | 1.178 | 0.0076 | 0.00474 | 1.145 | 0.3659 | 0.1147 | 0.0266 |
|        |        Deposited layer  |    |     |     |     |     |     |     |     |     |
|        |          A              | 0.3042 | 0.6899 | 1.771 | 0.0114 | 0.0085 | 4.359 | 0.3554 | 0.0233 | 0.0321 |
|        |          B              | 0.3198 | 0.5834 | 1.539 | 0.0116 | 0.0048 | 4.811 | 0.4757 | 0.0581 | 0.0324 |
The quantitative chemical composition analysis by optical emission spectrometry of the parent metal and the deposited layer revealed the following:

- the chemical composition of the parent metal corresponds to the steel utilized for manufacturing of tool joint drill pipe, with the observation that, the carbon content is below the lower limit recommended for steel 4145H as presented in table 1;
- the chemical composition of the hardbanded layer is similar for sample A and B, being closer to the specifications indicated by the manufacturer of the hardbanding material regarding the chemical composition of the deposit; it is noted that the percentages of C, Cr, Mo are equal or less than the lower limit reported by the manufacturer (see table 2). This difference may be due to the fact that in the present researches the hardbanding were performed in a single layer, and the manufacturer of the hardbanding material does not specify after how many layers the chemical composition was determined.

2.2.4. Vickers hardness measurement. The hardness tests were performed with EMCO – DURASCAN 20 type hardness machines at a load of 49.05 N (HV5). For each sample (A and B), three rows of hardness were measured, each of them starting from the hardbanded layer, on a perpendicular direction, to the parent metal (Row 1, Row 2, Row 3), maintaining a measurement indentation distance of 0.2 mm. The hardness values obtained are presented in table 5.

| Zone of measurement       | Sample A HV5 (kgf/mm$^2$) | Sample B HV5(kgf/mm$^2$) |
|---------------------------|---------------------------|---------------------------|
|                           | Row 1 | Row 2 | Row 3 | Row 1 | Row 2 | Row 3 |
| Hardbanded layer          | 512   | 520   | 510   | 580   | 603   | 591   |
|                           | 501   | 511   | 509   | 591   | 623   | 602   |
|                           | 504   | 503   | 520   | 593   | 665   | 631   |
|                           | 500   | 499   | 517   | 601   | 654   | 645   |
|                           | 498   | 543   | 516   | 623   | 643   | 651   |
|                           | 523   | 523   | 512   | 641   | 638   | 647   |
|                           | 531   | 531   | 515   | 660   | 632   | 629   |
|                           | 539   | -     | -     | 637   | 629   | 631   |
|                           | -     | -     | -     | 629   | -     | 625   |
| Heat Affected Zone        | 217   | 220   | 225   | 356   | 395   | 394   |
|                           | 212   | 198   | 207   | 351   | 379   | 385   |
|                           | 207   | 200   | 210   | 362   | 382   | 363   |
|                           | 209   | 505   | 207   | 369   | 373   | 365   |
|                           | 203   | 212   | 209   | 353   | 376   | 362   |
|                           | 212   | 199   | 211   | 360   | 364   | 359   |
|                           | -     | -     | -     | 365   | -     | -     |
| Parent metal              | 303   | 328   | 305   | 315   | 289   | 317   |
|                           | 298   | 277   | 307   | 323   | 295   | 322   |
|                           | 300   | 294   | 310   | 317   | 312   | 309   |
|                           | 310   | 285   | 300   | 312   | 320   | 313   |
|                           | 307   | 279   | 298   | -     | -     | -     |
| Rockwell hardness of the  | Sample A | 50HRC | Sample B | 56HRC |
| hardbanded layer (obtained |           |       |           |       |
| by Vickers hardness       |           |       |           |       |
| conversion of the average  |           |       |           |       |
| value)                    |           |       |           |       |

The hardness measurements showed the following:
- the hardness of the hardbanded layer is relatively constant on thickness layer;
- the hardness value for Sample A (50HRC) has a lower value than the one usually recommended, perhaps due to the reconstruction of the tool joint drill pipe, after removing the old hardbanding, with a compensation material having a low carbon content (0.05% C), which resulted in a dilution of the hardbanding layer.
- the hardness value for Sample B (56HRC) corresponds, to the requirements applied worldwide for the protection of the drill pipe tool joint hardbanding by welding, and to the manufacturer's specifications for hardbanding material of 57-62 HRC;
- it can be noted a gradual passage from the hardness of the deposited layer to the hardness of the heat affected zone and parent metal.

2.2.5. Wear tests. Wear tests were performed on ball-on-disk couples on a CSM type tribometer [13, 14, 15], disk samples were made also from drill pipe tool joint parent material AISI 4145H (not reconditioned) and samples with hardbanded layers (Sample A and Sample B). Samples A were cut from the drill pipe tool joint reconditioned by hardbanding with a metal-cored coppered flux cored wire, Cr-Mo alloyed, after removing the old hardbanding material and surface reconstruction with a copper coated basic flux cored wire, like compensation material. Samples B were cut from the drill pipe tool joint reconditioned by hardbanding with a metal-cored coppered flux cored wire, Cr-Mo alloyed, without removing the old hardbanding material.

The working conditions were:
- normal load of 2N;
- disks of AISI 4145H and of reconditioned by welding (hardbanded layer - samples A and B);
- Ø 6 mm ball of steel 100Cr6;
- sliding speed of 0.200 m/sec.;
- friction length 200 m;
- dry friction at temperature of air of 20°C and RH=57%.

In figure 8 it is shown the friction coefficients values results obtained on ball-on-disk tribometer.

![Figure 8. Friction coefficients vs. sliding distance.](image-url)
In table 6 it is presented the wear rates obtained for tested materials on CSM microtribometer.

| Material type | Parent material | Sample A- | Sample B- |
|---------------|-----------------|-----------|-----------|
|               | AISI 4145H      | Reconditioned by welding | Reconditioned by welding |
| Disk wear rate coefficient, (mm³·N⁻¹·m⁻¹) | 5.357E-005 | 2.689E-005 | 3.695E-006 |
| Ball wear rate coefficient, (mm³·N⁻¹·m⁻¹) | 1.358E-007 | 1.030E-007 | 2.681E-008 |

As we can see from figure 8 and table 6 the results obtained show that recondition by hardbanding with a metal-cored coppered flux cored wire, Cr-Mo alloyed, after removing the old hardbanding material and surface reconstruction with a copper coated basic flux cored wire, like compensation material deposition layer behavior at wear is quite similar (a little bit smaller) with the parent material and friction coefficients are smaller almost on entire sliding length, only at the last 20 m the friction coefficients becomes greater. For sample B reconditioned by hardbanding with a metal-cored coppered flux cored wire, Cr-Mo alloyed, without removing the old hardbanding material, friction coefficients in dry friction conditions and wear rate coefficients are significative smaller.

3. Conclusions

Reconditioning of the drill pipe tool joint by hardbanding with a metal-cored coppered flux cored wire, Cr-Mo alloyed, after removing the old hardbanding material and surface reconstruction with a copper coated basic flux cored wire (compensation material) and by hardbanding with a metal-cored coppered flux cored wire, Cr-Mo alloyed, without removing the old hardbanding material, using the gas metal active process (GMAW), allows to obtain of relatively smooth layers, without cracks or pores.

The hardness of the hardbanded layer is relatively constant on the thickness layer, with a gradual passage from the hardbanded layer to the heat affected zone and parent metal. The hardness of the drill pipe tool joint hardbanded, after removing the old hardbanding material and surface reconstruction with a compensation material, has a lower value (50HRC) than the one usually recommended (57-62HRC), possible when the compensation material used has a low carbon content (0.05% C), which resulted in a dilution of the hardbanding layer. The hardness of the drill pipe tool joint hardbanded (56HRC), without removing the old hardbanding material, corresponds to the requirements applied worldwide for the protection of the drill pipe tool joint hardbanding by welding, and to the manufacturer's specifications for hardbanding material of 57-62 HRC.

The microstructure of the hardbanded layer is similar for all two different technological approaches regarding the reconditioning process of the drill pipe tool joints, and consists in fine Cr and Mo carbides uniformly distributed in a fine tempered martensitic network. All heat affected zones have an identical inferior bainitic microstructure, caused by annealing treatment produced by hardbanded layers. The heat affected zone is narrow and provides a gradual transition from the parental metal to hardbanded layer. The parent metal has a very fine sorbitic structure outside the heat affected zone, being non-affected by the hardbanding processes, using the welding technologies. The hardness of the parental metal is 277 - 328 HV5, which corresponds to the standard regulations for drill pipe tool joints (30-36 HRC), [6, 7].

The result of experimental researches regarding the tribological characterization of the reconditioned drill pipe tool joints by macroscopic analyses, metallographic analyses, Vickers hardness measurement, chemical composition measurement and wear tests, certify the quality hardbanding obtained by two different approaches regarding the hardbanding technologies, as follow:
- both approaches regarding the hardbanding technologies are valid for reconditioning of the tool joints drill pipes with a metal-cored coppered flux cored wire, Cr-Mo alloyed, using the gas
metal active process (GMAW), only if for the surface reconstruction is chosen another compensation material to avoid the dilution of the hardbanded layer;

- hardbanding drill pipe tool joint without removing the old hardbanding material increase drill pipe tool joints and casings durability and efficiency because wear and friction coefficients obtained were significative smaller than new drill pipe tool joints and reconditioned drill pipe tool joints by method A.

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