Effect of deformation on dry sliding wear behavior of 13Cr5Ni2Mo supermartensitic stainless steel

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Abstract: During drilling, the tubings are subjected to tensile, compressive and torsional stresses. In this present work, the effect of deformation on wear of 13Cr5Ni2Mo SMSS in dry conditions is investigated using the tensile test. All samples were taken for the calibrated area of the 2%, 10% and 15% deformed specimens. The tribological tests were carried out at room temperature under a 6N against an alumina ball. The results showed that the deformed samples have the highest wear rate. Maximum wear rate was obtained for 2% deformed samples. This state can therefore affect the reliability of the material. The wear mechanisms involved were observed by scanning electron microscopy.

Keywords: SMSS, Mechanical properties, Deformation, Wear, Friction.

1. Introduction

Since the 1990s, the oil industry has developed new corrosion-resistant alloys for pipelines and offshore applications [1]. New 13Cr weldable martensitic grades, called “Super 13Cr” have been developed. The steels are especially applied to flow lines transporting crude oil or gas at high pressures and temperatures [2]. 13 Cr supermartensitic stainless steel exhibits a high strength, good corrosion resistance and superior weldability at compared to the conventional martensitic steel [3]. It is considered a crucial material for heavy-duty equipments [1].

In the drilling sites, the supermartensitic satinless steel tubing are threaded together. During drilling operation, tubings are in interaction with the well borehole (casing and/or roch) which may lead to severe vibrartions [4]. Indeed, the tubings are subjected to tensile, compressive and torsional stress. After the large cycles of use, the tubing can be subjected to severe wear. Mostly, it can be attributed to the deterioration in tubings due to the synergistic effects that lead to the plastic deformation which is inducted by the claming and the corrosive action while using muddy waters [5].

Several studies have reported on the microstructure and the mechanical properties of supermartensitic steels [6-8]. However, there is no information about the wear and the friction tests of supermartensitic stainless steel after plastic deformation. Therefore, the present study is focused on evaluating the tribological behavior of 13Cr5Ni2Mo supermartensitic stainless steel after tensile test at different deformation rates 2, 10 and 15 % respectively. Wear tests are carried out under dry using a ball-on-disk tribometer on polished samples with an average roughness of 1.06 μm against alumina (Al₂O₃) ball as a counterface.
2. Material experimental procedure

The material for study was delivered in the tubing form with dimensions 12000 mm x 88.9 mm x 6.3 mm. Samples were cut from a new pipe. The chemical composition as determined by X-ray fluorescence spectroscopy and IR spectroscopy is shown in Table 1.

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Cu</th>
<th>Mo</th>
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<tr>
<td>0.017</td>
<td>0.411</td>
<td>0.22</td>
<td>0.010</td>
<td>0.004</td>
<td>12.85</td>
<td>5.38</td>
<td>0.44</td>
<td>2.18</td>
</tr>
</tbody>
</table>

Table 1 Chemical composition of supermartensitic stainless steel studied (wt. %).

The tensile tests were carried out until rupture, at 2%, 10% and 15% respectively using a Zwick machine Z1200 testing machine according to EN ISO6892-1 norm. All tests were conducted at room temperature. The tensile specimens were cut in the longitudinal direction of the tubing (Fig. 1a). The dimensions of specimens are: The thickness \( e = 6.3 \) mm, the width \( b = 20 \) mm, the length is \( L_1 = 300 \) mm and the length of the calibrated part \( L_2 = 90 \) mm, with a radius of curvature \( r = 25.4 \) mm (Fig. 1b).

![Fig. 1 Tensile tests samples.](image)

The specimens were treated quenched at 850 °C followed by 1250 °C respectively in oil bath to obtain the best homogenization. This is followed by double tempering at 650°C in air to room temperature (Fig. 2). A horizontal tube furnace under a protective argon flow atmosphere is used for all thermal treatments.

![Fig.2 Thermal treatment applied to 13Cr5Ni2Mo SMSS.](image)

All tribological tests were performed on the calibrate area on the 2%, 10% and 15 % deformed specimens respectively using TRB-S-DE-0000/CSM tribometer using ball-on-disk configuration under dry conditions. All tests were carried out at room temperature under a 6N load against an alumina ball 6 mm in diameter. A linear speed of 0.02 m/s is applied at 6 N for a total sliding distance of 20 m. The wear mechanisms and the chemical elements on the worn surface of the tested samples are investigated by a scanning electron microscope (SEM) type JEOL GSM- 5900LV equipped with energy dispersive X-ray spectroscope (EDX).
3. Results and discussions
3.1. Mechanical properties

Examples of stress-strain curve of 13 Cr supermartensitic stainless steel are exhibited in Fig.3. It can be seen that the stress-strain behavior of samples is approximately linear at a stress value less than 670 N/mm. A stress peak of about 10% deformation is reached then the stress level has decreased. From 21 % of deformation, the final fracture is initiated. The mechanical properties obtained for 13 Cr SMSS samples was found to be 720 MPa for yield strength, 776 MPa for tensile strength and 19 % elongation. The tensile test results of the mechanical properties of SMSS after quenching followed by double tempering agree to standards requirements for 13 Cr supermartensitic stainless [9]. In order to study the effect of deformation on tribological behavior of 13 Cr SMSS, the tensile tests are carried out in the plastic deformation zone according to the tensile curve. The deformations are 2%, 10% and 15%, respectively.

![Fig.3 Stress-strain curve of 13Cr5Ni2Mo SMSS.](image)

3.2 Tribological behaviour

Fig.4 shows the variation of the coefficient of friction of the 13 Cr5Ni2Mo supermartensitic stainless steel samples testing after plastic deformation at 6 N load. All curves exhibits a similar behavior. The COF increased during initial the stage (running-in-period) and remained constant in the steady state period. It can be seen that the plastic deformation have an significant effect on the COF [10]. Indeed, the coefficient of friction increased after plastic deformation (table.2). It can be also observed that the COF decreased with the increasing deformation rate. Morover, the higher COF is obtained at 2 % deformation.
Fig. 4 Friction curves evolutions of 13Cr5Ni2Mo SMSS.

Table 2 COF results of 13Cr5Ni2Mo SMSS.

<table>
<thead>
<tr>
<th>Specimens/load</th>
<th>COF (µ)</th>
</tr>
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<tbody>
<tr>
<td>Without deformation-6N</td>
<td>0.75</td>
</tr>
<tr>
<td>2% def-6N</td>
<td>0.85</td>
</tr>
<tr>
<td>10% def-6N</td>
<td>0.81</td>
</tr>
<tr>
<td>15% def -6N</td>
<td>0.77</td>
</tr>
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</table>

Fig. 5 gives the specific wear rate for 13Cr5Ni2Mo supermartensitic satinless stell without deformation and with deformation conditions respectively. It can be observed at 6 N load that the specific wear rate without deformation samples is lower as compared to that samples that have undergone plastic deformation. This state can be explained to the transformation of austenite and formation of martensite [11].

Fig. 5 Specific wear rate of 13Cr5Ni2Mo SMSS as function of load.
Figs. 6 (a, c, d, e) shows the SEM images of the wear tracks morphologies for all samples tested. In all cases, the wear cracks can clearly be observed suggesting that the abrasive wear phenomenon is predominant during the wear tests. This is well described by the parallel grooves in the sliding direction. Sever plastic deformation is observed on the surface of all specimens studies suggesting an adhesive wear. In this case; the atoms of the contacting surfaces are very close to each other [12]. So, with increasing load, the oxide debris formed in dry sliding, contributed to localized delamination described by flake-like debris. An oxidation on the wear track surface, caused by the presence of chemical elements (chromium, molybdenum, nickel and carbon), is well established by EDS /SEM analysis (Fig. 6b-6f) [13].

Fig. 6 SEM micrographs showing the wear track on 13Cr5Ni2Mo SMSS under dry conditions at different state of deformation, a) without deformation, c) 2% def, d) 10% def, e) 15% def, b) EDX without deformation in point “1”, f) EDX 10% deformation in point “2”.

4. Conclusion

In the present work, the effect of plastic deformation on tribological performances in air at 6 N load of 13Cr5Ni2Mo SMSS against alumina ball is evaluated. The following conclusions can be drawn from this study which is summarized as follows:

1. Wear tests revealed that SMSS deformed samples showed the highest COF whereas it presented the lowest COF for undistorted samples. The higher COF is obtained at 2% of deformation.

2. 13Cr5Ni2Mo undistorted samples exhibited better tribological behavior as compared to that deformed samples as it showed low specific rates as compared to deformed samples.

3. The specific wear rate showed a value of 3.1 X 10^-3 mm^3/N.mm form undistorted samples, 15.5 X 10^-3 mm^3/N.mm at 2% deformation, 7.7 X 10^-3 mm^3/N.mm at 10% deformation and 3.5 X 10^-3 mm^3/N.mm at 15% deformation.

4. In all cases, SEM/EDS analysis revealed that the involved wear mechanisms of 13Cr5Ni2Mo SMSS are abrasion, adhesion, oxidation and delamination.
References


