Ion-Beam Surface Modification of Strut Dowel Used in ITER PF Support∗

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Abstract In this paper, surface modification of the strut dowel used in ITER PF support is reported. Different ions (nitrogen/titanium) with different doses are implanted into the surface of strut dowel. The result of Auger Electron Spectroscopy (AES) indicates that nitrogen can be implanted more deeply than titanium under the implantation condition of 60 kV accelerating voltage and a dose of \(8 \times 10^{17}/\text{cm}^2\) nitrogen. Surface Micro Hardness (SMH) and wear resistance are improved remarkably. Further SEM observation shows that there are no obvious scratches and damages after wear test.

Keywords: ITER, PFCS, dowel, ion-beam implantation

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1 Introduction

Poloidal field coil supports (PFCS-3/4) are one of the ITER magnet support components, which will be supplied by China [1]. The support strut dowel withstands the weight of the poloidal field coils and part of the vacuum chamber and will operate for 20 years. It could induce rotation and/or shift of support strut dowel during discharge [2]. The total weight of PF3 and PF4 is estimated up to 70 tons [3], and these supports are suspended via a strut dowel by the TF coil base, as shown in Fig. 1. The strut dowel should survive very harsh environment, such as extremely low temperature, huge stresses (forces) and neutron irradiation. The electromagnetic forces owing to plasma discharge may not only increase the load, but also lead to the movement of the strut dowel [4]. Therefore, the surface of strut dowel needs to possess satisfactory tribological property. Due to the non-boundary modification of microstructure and the formation of hard alloys on the surface [5], ion implantation in metals is conceived of as a versatile technology to improve the tribological property and corrosion resistance of metals and alloys used in industries.

Nitrogen has been by far the most investigated element in ion implantation studies, mainly due to its ability to harden steels and other engineering materials and the high ion current yield that can be obtained with most commercially available ion sources [6]. Besides nitrogen, the property of titanium implantation on steels is also focused on because of its strength weight ratio, good corrosion resistance and non-magnetism [7].

Different reasons have been proposed to explain the improvements observed in ion implanted materials, including the phase formation, diffusion, trapping with vacancies, dislocations and other second phase particles during irradiation [8,9]. In this study, nitrogen and titanium were applied to improve the surface condition of the strut dowel.

Fig.1 PF3-PF4 support structure (color online)

2 Experiments

316LN austenitic stainless steel plates were cut into 10 mm×10 mm×5 mm coupons, mechanically pol-
ished, cleaned with alcohol ultrasonically, and dried. Nitrogen ions implantations were conducted on metal ion implanter in the Plasma Laboratory of Southwestern Institute of Physics (SWIP). The energetic titanium ions were produced by MEVVA ion source in which the highly ionized plasmas were produced by cathodic vacuum arcs. Then, the charged ions formed in the plasma can be extracted and accelerated by the strong electric field between extraction electrodes. The vacuum in the implantation chamber was $2 \times 10^{-5}$ Pa and the titanium cathode was 99.8% pure. The implantation parameters are listed in Table 1.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Ion</th>
<th>Implantation voltage (kV)</th>
<th>Dose (ions/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1#</td>
<td>N</td>
<td>60</td>
<td>$6 \times 10^{17}$</td>
</tr>
<tr>
<td>2#</td>
<td>N</td>
<td>60</td>
<td>$6 \times 10^{17}$</td>
</tr>
<tr>
<td>3#</td>
<td>N+Ti</td>
<td>60+40</td>
<td>$3 \times 10^{17}+3 \times 10^{17}$</td>
</tr>
<tr>
<td>4#</td>
<td>N+Ti</td>
<td>60+40</td>
<td>$6 \times 10^{17}+6 \times 10^{17}$</td>
</tr>
</tbody>
</table>

Near-surface structure of the implanted samples was analyzed using a Philips XRD ray diffractometer with Cu-ko radiation. The implantation thickness was studied by Auger Electron Spectroscopy (AES, PHI650). Hardness measurement was carried out in HXD-1000TMC/LCD Vickers hardness tester with a load of 25 g and 50 g, respectively. Tribological test was conducted on a MS-T3000 with a ball on disk configuration under dry sliding conditions. The counterface was a 6 mm diameter GCr15 steel ball using a normal load of 100 g, and a rotating speed of 500 r/min was used for 10000 circles. The worn surface morphologies relative to the wear behavior was identified using a JSM-5900L Scanning Electron Microscope (SEM). Metallurgical microscope BX51M (OLYMPUS) was used to observe the surface morphology of GCr15 samples after corrosion.

### 3 Results and discussion

Fig. 2 shows XRD patterns of the samples after nitrogen and titanium are implanted. Both $\gamma_N(111)$ and $\gamma_N(200)$ are distinctly formed in the single nitrogen implanted samples and faintly existed after being co-implanted. There is a shift of the diffraction peak of $\gamma_N$ towards the low angle side in the nitrogen implanted samples, implying a lattice expansion. The faint diffraction peak of Fe$_3$N(110) is formed in sample 1# and becomes more significant in sample 2#. It is one of the hard precipitates formed after nitrogen implantation which has been thoroughly reported [10–12]. The weak diffraction peak of $\alpha$-TiN$_{0.3}$(002) is noticed in co-implanted samples, which is also beneficial for improving the tribological property of stainless steels [13].
The variations in microhardness for both the unimplanted and implanted samples are shown in Fig. 4. A more obvious increase in microhardness is observed in implanted samples than that in unimplanted one. The increase is up to 60% at the dose of \(8 \times 10^{17} \text{N}^+ / \text{cm}^2\) for the two loads of 25 g and 50 g. The increase in microhardness of the surface after nitrogen and titanium implantation is closely related to the formation of nitride, ferritic and carbide phases such as \(\gamma \text{N}, \text{Fe}_3\text{N}, \alpha\text{-TiN}_{0.30}\). The increase in co-implantation is less than that in single nitrogen implantation, which can be attributed to the decrease of hardening phases.

In order to further confirm the wear resistance after ion implantation, SEM analysis is carried out to observe the changes in the surface morphology of samples after a wear test, as shown in Fig. 5. The samples are worn 10,000 times continuously by a 6 mm-radius GCr15 steel ball, and the rotation speed is 500 r/min with a load of 100 g. After the wear test, severe abrasion is found on the surface of the unimplanted samples with its wear track being of furrow shape and plastic deformation, adhesion and flake being visible. The wear track of the implanted sample is narrow, and the main wear mechanism changes from adhesive to ploughing wear. In addition, damages and crinkles are observed in sample 3# and 4#. In sample 2#, the surface seems to be more compact and uniform, and the homogeneous surface has fewer pores and defects after a high dose of single nitrogen has been implanted. It can be concluded that ion implantation can increase the wear resistance of samples, and the effect of co-implantation of nitrogen and titanium is worse than that of the single nitrogen implantation.

The average load on each strut dowel is larger than 70 tons in ITER project, which cannot be realized in this experiment. Therefore, a load of 10 kg/cm\(^2\) is applied to simulate the real working condition according to the results of analysis. Table 2 shows the corrosion diameter of GCr15 and the load pressure of unimplanted and implanted samples after corrosion test. The load pressure on all samples is above 10 kg/cm\(^2\), which meets the requirement of ITER project.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Corrosion diameter of GCr15 (mm)</th>
<th>Load pressure (kg/cm(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>base</td>
<td>0.854</td>
<td>17.46</td>
</tr>
<tr>
<td>1#</td>
<td>0.866</td>
<td>16.98</td>
</tr>
<tr>
<td>2#</td>
<td>0.911</td>
<td>15.34</td>
</tr>
<tr>
<td>3#</td>
<td>0.850</td>
<td>17.62</td>
</tr>
<tr>
<td>4#</td>
<td>0.868</td>
<td>16.90</td>
</tr>
</tbody>
</table>

4 Conclusion

By nitrogen ion implantation, a large number of strengthening phases have been produced. It means that an accelerating voltage of 60 kV with the dose of nitrogen of \(8 \times 10^{17} / \text{cm}^2\) is the optimal implantation condition, under which the wear resistance and microhardness would be improved remarkably. After wear
test, there are no obvious scratches and damages on the surface of samples. A conclusion can be drawn that the nitrogen implantation is an effective method to improve the reliability of the strut dowel, and the parameters mentioned above can be selected to modify the surface of ITER PF support strut dowel.

References

11 Venugopalan R. 1999, Biomaterials, 20: 1709
12 Muthukumaran V. 2010, Materials and Design, 31: 2813
13 Gelson B. 2010, Materials Chemistry and Physics, 124: 443
17 Budzynski P. 2003, Vacuum, 70: 417

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