

**THE CHANGE AND TRANSFORMATION OF MECHANICAL CHARACTERISTICS
OF ALLOYS UNDER THE PLASMA INFLUENCE**

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Abstract

Experiments on the dense plasma focus device PF12 have been carried out to investigate the effect of a powerful deuterium plasma stream on various steels and tungsten. The appearance of microroughness on the specimens surface was investigated. Due to the plasma effect, different surface structures, such as vaporization and deposition of metal on the surface appeared.

Key words: power flux density of plasma, surface roughness, defects on metal surfaces

1. INTRODUCTION

One of the key fields in physics of functional materials for fusion facilities is the research of microscopical changes of the physical and mechanical characteristics of materials under the devastating influence of ions. The topical aim is to find such materials as can stand a durable plasma and heat flux without extensive structural changes on their surface [1-4]. It is known that, depending on the circumstances, the surface layers can be eroded, evaporated, recrystallized, and covered with different defects: holes, bubbles, wavelike structures, cracks etc.

To carry out experimental research with powerful plasma streams plasma focus (PF) devices have proved effective [4, 5]. As compared to possible applications at thermonuclear reactors, the PF facilities are small and cheap. We have experienced on the PF12 device at Tallinn University, which is characterized by the maximum pulse energy of 12 MJ and the energy of plasma ions up 100 MeV, i.e. that of thermonuclear reactions.

In this work we will evaluate the roughness of the specimens' surface as depending on the plasma power flux, irradiation regime, and exposition time. Pimenov et al [1,2] have considered a specific damage factor as a function of these characteristics. A detailed study of the relations of microtopology (microgeometry) of surfaces and their characteristics is expected to yield a better assessment of the damage factor of materials, which enables a comparison of effects of irradiation carried out by different types of plasma devices. For practical purposes the dependence of surface damage on the composition of materials is the most topical. Tungsten, beryllium and CFC are considered as functional materials for ITER, but for inertial confinement fusion reactors stainless steels are also considered. As Pimenov etc. [2] have shown, the most promising steels are low-activation ferritic-martensitic steels as these surfaces are less damaged after plasma irradiation than austenitic steels. The

main aim of our work is to specify how micro-roughness and, the area of damages on surfaces irradiated by high-temperature plasma depends on the characteristics of the plasma. In this work ferritic-martensitic steels BS 183A and BS 92B are studied in parallel with tungsten. The composition of the steels is comparable with steels Eurofer 97 and HT9, which are considered as construction materials for the next generation fission and fusion reactors [6, 7].

2. MICROGEOMETRY AND MICROTOPOLOGY OF MATERIAL SURFACES

2.1 Radiation conditions and surface defects

Samples of low-activation ferritic-martensitic steels were irradiated in a dense plasma focus device PF-12 (Tallinn University) by fast ions (with an energy of 1-100 keV) and plasma streams (energy 0.1-1 keV) with power flux density $q=10^6$ - 10^7 W/cm² and the duration of plasma pulses about 100 ns. The metal alloy samples were in the form of 1 x 1 x 0.2 cm³ plates, 2 types of low-activation stainless steels (BS 183A and BS 92B, for the chemical composition see Table 1) and tungsten. To gain different regimes and power flux densities, the samples were placed at 3 different distances from the anode: 3.5, 6.5 and 10.5 cm. The number of plasma shots to the target samples varied from 2 to 9. Tungsten, which was used as the reference metal, was irradiated at distance 6.5 cm.

Steel	BS 183 A	BS 92 B
C	0.172	0.15
Si	0.37	0.42
Mn	0.35	0.42
P	0.016	0.021
Cr	12.14	15.92
Mo	0.12	0.17
Ni	1.85	2.12
Co	0.036	0.04
Cu	0.93	0.13
Nb	0.006	0.006
Sn	0.003	0.006
V	0.09	0.07
W	0.006	0.02
In minute amounts: S, Al, Ca, N, O		

Table 1. Chemical composition of the steels studied (in %).

The surfaces of the irradiated specimens were investigated by using scanning electron microscopy (SEM) at Tallinn University of Technology. The irradiated surface area was investigated by using backscattered and secondary electrons, which revealed the microtopology of the surfaces and allowed to estimate the area and surface density of the defects. While secondary electrons reveal the microtopology, the backscattered electrons are better indicators of reveal defects, especially holes and

microcracks better. The micro-roughness of material surfaces before and after irradiation by plasma was investigated by a Perthometer Concept MFW 250 (Mahr) at Tallinn University of Technology. As could be seen from a careful analysis of the sample surfaces, irradiation by plasma leads to substantial impairments and erosion of the surface layers of the metal alloys connected with melting, vaporization, recrystallization and development of holes, bubbles, cracks etc. The irradiated and melted surface has a wave-like structure (see Figure 1) with the wavelength of about 80-100 nm and a height of waves of 0.48-2.72 μm . In Figures 2-12 the SEM-pictures of the plasma irradiated samples are given.

As can be seen, the stainless steel BS 92B has developed more defects than BS 183A. On the other hand the surface of the steel BS 183A appears to be just melted, while the surface of BS 92B appears in addition to be covered with steel sputters. This may be due to a higher percentage of tungsten in the steel BS 92B, which affects brittleness and ductility. Surface damaging is estimated by a parameter which characterizes the (micro)roughness of the surface. It has been established that due to repeated remelting and recrystallization in irradiated surface layers structures of a submicron and nanometric dimension will appear, as well as structures with characteristic dimensions of 1-100 μm .

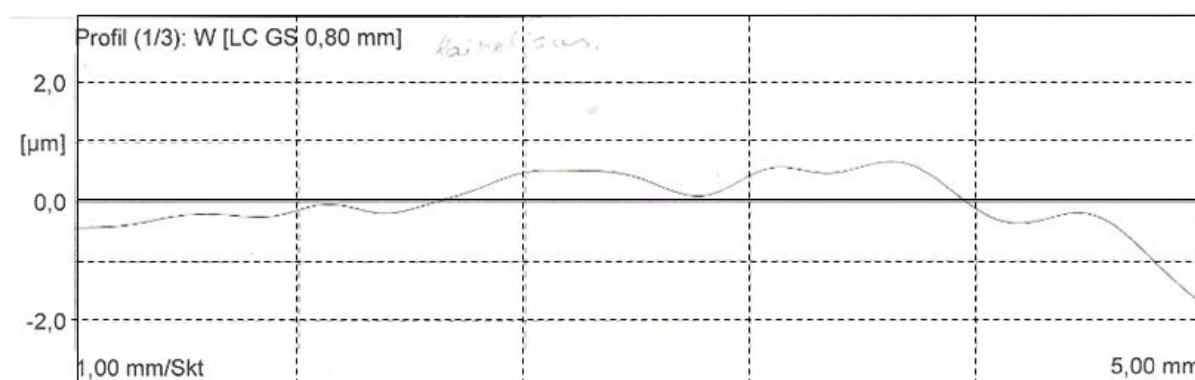


Figure 1. Wavelike structure of the stainless steel BS 183 A after irradiation, 2 shots, distance from the anode 10,5 cm .

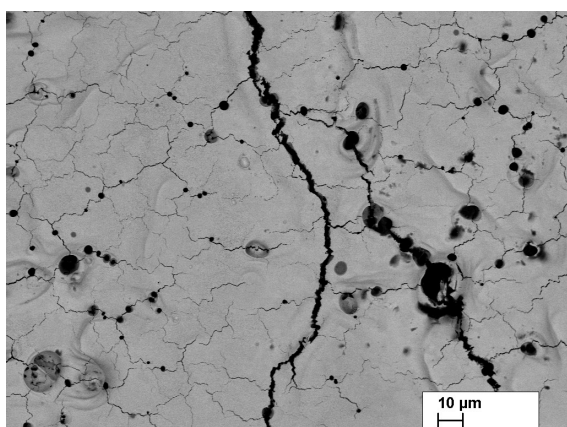


Figure 2. Tungsten (4 shots, distance 6.5 cm). Picture by backscattered electrons.

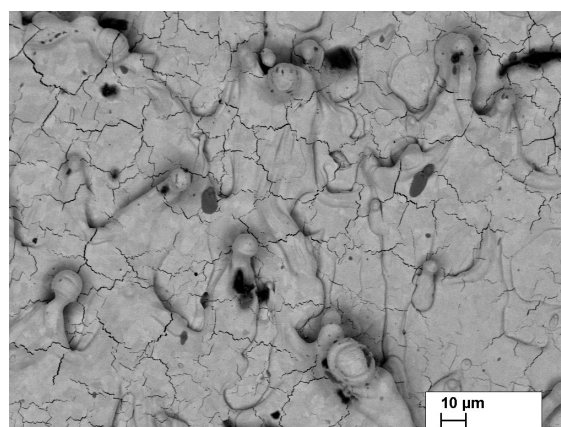


Figure 3. Tungsten (2 shots, distance 6.5 cm). Picture by backscattered electrons.

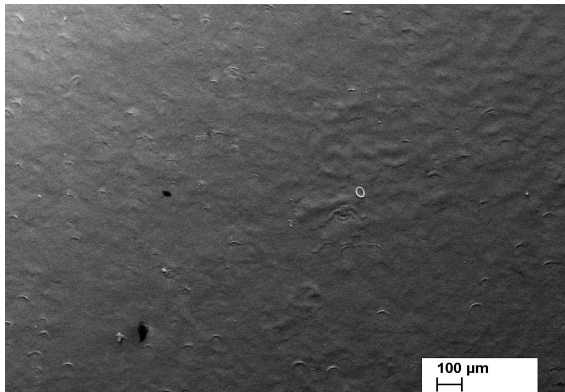


Figure 4. Steel BS 92 B,
(9 shots, distance 10.5 cm)
Picture by secondary electrons.

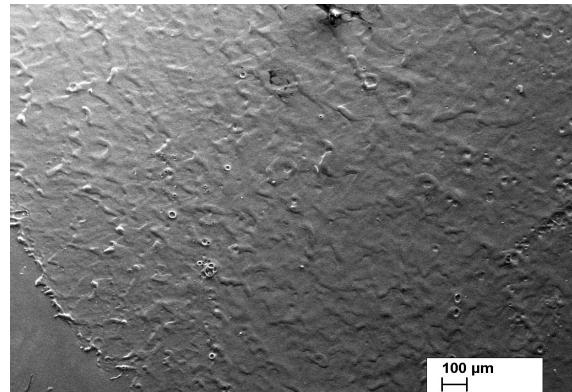


Figure 5. Steel BS 92 B,
(2 shots, distance 10.5 cm)
Picture by secondary electrons.

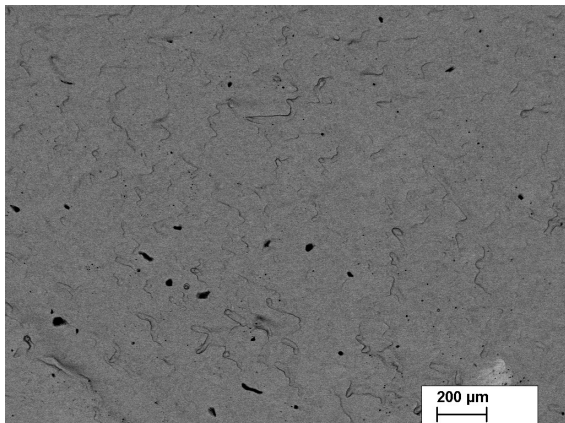


Figure 6. Steel BS 92 B,
(8 shots, distance 6.5 cm)

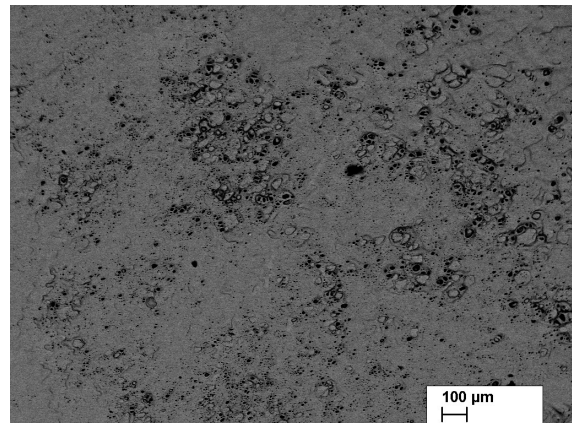


Figure 7. Steel BS 92 B,
(2 shots, distance 6.5 cm)

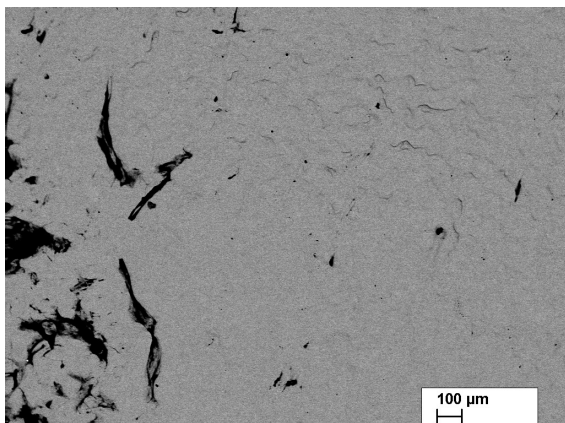


Figure 8. Steel BS 92 B,
(4 shots, distance 3.5 cm)

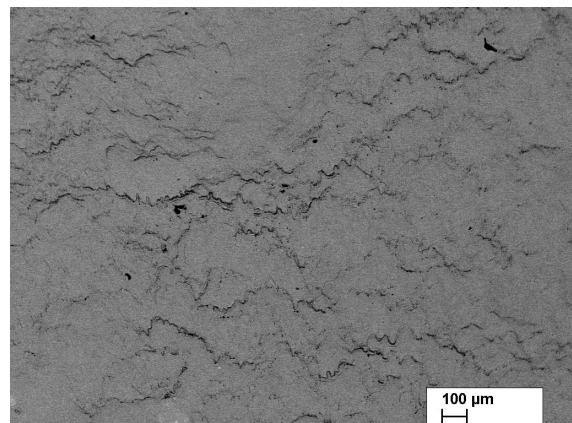


Figure 9. Steel BS 92 B,
(2 shots, distance 3.5 cm)

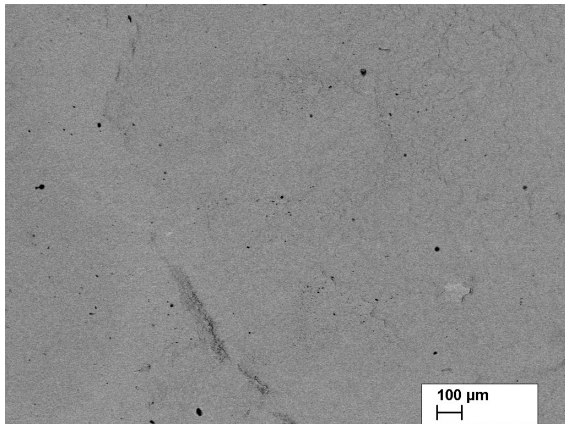


Figure 10. Steel BS 183A,
(9 shots, distance 10.5 cm)

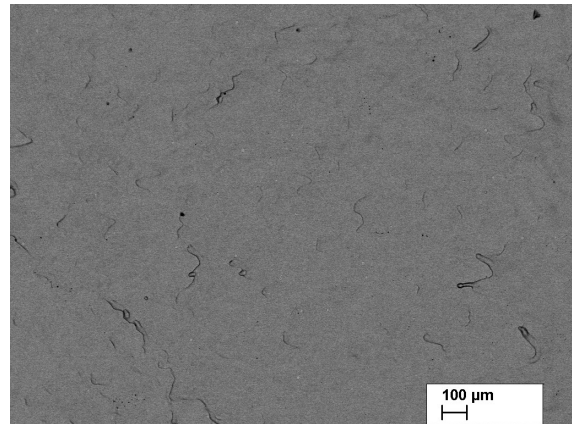


Figure 11 Steel BS 183A,
(2 shots, distance 6.5 cm)

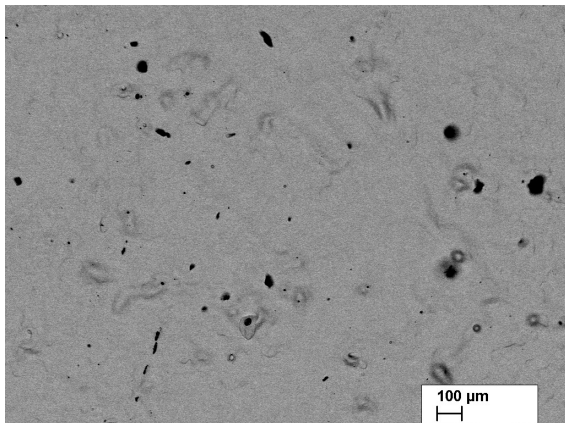


Figure 12 Steel BS 183A,
(8 shots, distance 6.5 cm)

In Table 2 the microroughness parameters of the irradiated surfaces are given. It can be seen these depend on the number of pulses as well as on the distance from the anode. Though, it should be noted, that as some layers have vaporized, the roughness applies to the extant surface layer only. For example, as can be seen from Table 2, the average roughness of tungsten is greater than of the steels irradiated in the same conditions, but in case of the steels, with every shot a layer of about 1-2 μm is vaporized while in the case of tungsten the thickness of the vaporized layer is about 4 times thinner.

	distance, cm	pulse	R_a , μm
	10,5	5	0,472
BS 183 A	10,5	9	0,631
		2	0,392
	6,5	8	0,596
		2	0,655
BS 92 B	10,5	9	0,77
		2	0,184
	6,5	8	0,789
		2	0,556
	3,5	4	0,817
		2	0,913
W	6,5	4	1,263
		2	

Table 2. Roughness of the specimens surfaces R_a .

2.2 Stationarity of surface micogeometry

Microtopology and –geometry have also been evaluated by profile. To acquire as much information as possible, it has been assumed, that all profile lines include whole statistical information about microgeometry. For profile lines measured by the perthometer at least five lines by different ways have been taken. Geometry of the irradiated surface, average height of the defects can be evaluated by the profile parameter R (see Figure 13, 14), but also by average distance of the major defect peaks, which can be found better by spectral analysis of the profile lines. It has been shown theoretically that the harmonic of the lowest order can give an information about the average deviation of the surface from planes, but the second and the third harmonic can give an information about the wave-likeness of the surface [8]. Therefore, the profile spectrum may give valuable information about the roughness of the irradiated surface. Spectral density of the power of the oscillations allows one to evaluate the change of the physical properties of the materials.

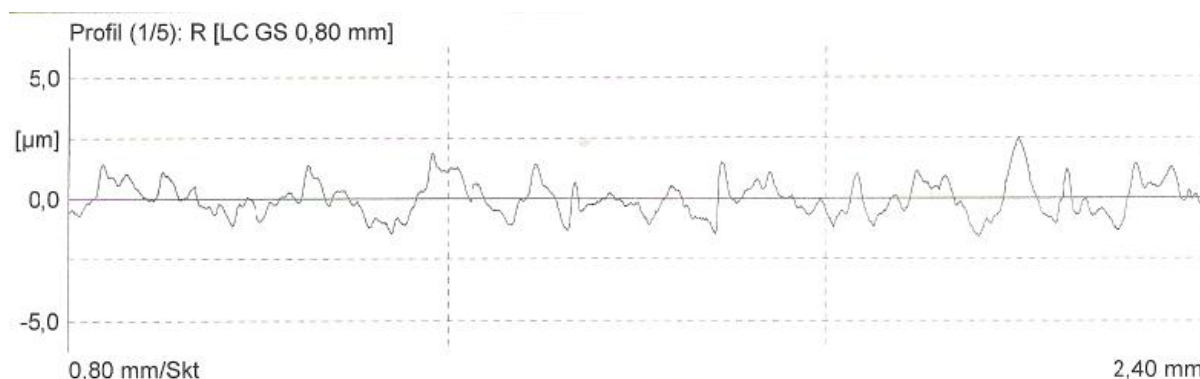


Figure 13 Profile of the Steel BS 183A, $R_a=0,776 \mu\text{m}$, number of shots 2, distance from anode 10,5 cm.

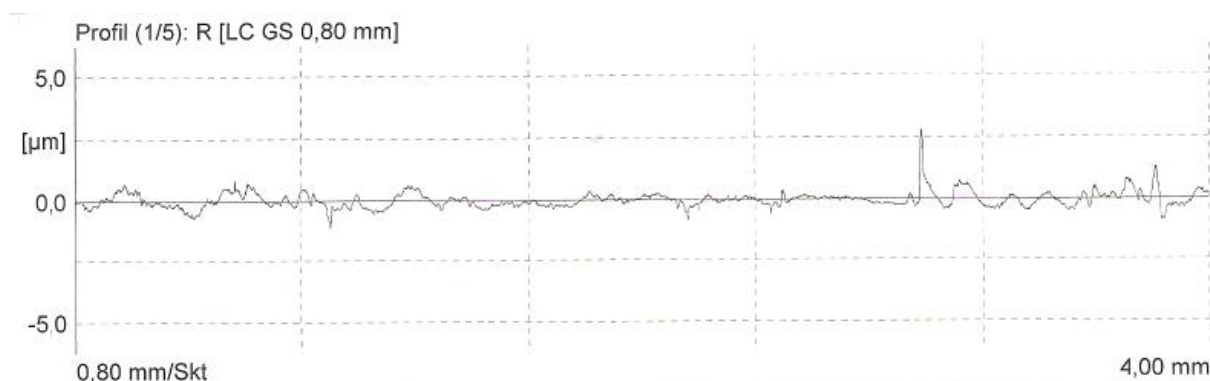


Figure 14 Profile of the Steel BS 183A, $R_a=0,532 \mu\text{m}$, number of shots 2, distance from anode 10,5 cm.

3. CONCLUSIONS

The experiments carried out and the analysis of the measurements allow us to formulate the following results. It has been shown that the influence of a high temperature deuterium plasma flow modifies the surfaces of materials — stainless steels and tungsten. Current research reveals that in all specimens analysed here, the damage factor is in correlation with the number of plasma flux shots, and therefore also with the power density of the plasma flux. Our results show that change of the distance inessentially affects the microtopology of the irradiated layers. The thickness of the evaporated layers has not been measured in all cases. Evaluation of the spectral power density of the roughness change allows us better to estimate all physical quantities playing a role in the damage factor of the irradiated surface. Due to lower percentage of tungsten in steel BS 183A, the surface layer of the steel is melted in total, while the surface of steel 92B is covered also with other defects.

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