Nuclear Materials and Energy 000 (2016) 1–6

Contents lists available at ScienceDirect

Nuclear Materials and Energy

journal homepage: www.elsevier.com/locate/nme

Laser re-melting of tungsten damaged by transient heat loads

Th. Loewenhoff[a,*], J. Linke[a], J. Matějíček[b], M. Rasinski[a], M. Vostřák[c], M. Wirtz[a]

[a] Forschungszentrum Jülich, 52425 Jülich, Germany
[b] Institute of Plasma Physics, Za Slovankou 3, 18200 Praha, Czech Republic
[c] University of West Bohemia, Univerzitní 8, 30614 Plzeň, Czech Republic

ARTICLE INFO

Article history:
Received 27 November 2015
Revised 1 April 2016
Accepted 5 April 2016
Available online xxx

Keywords:
Plasma facing material
Laser surface remelting
Transient heat load
Tungsten

ABSTRACT

In the current study, a solid state disc laser with a wavelength of 1030 nm and maximum power of 5.3 kW was used to melt the surface of pure tungsten samples (manufactured according to ITER specifications by Plansee SE). Several combinations of laser power and traverse velocity were tested, with the aim of eliminating any pre-existing cracks and forming a smooth and contiguous resolidified surface. Some of the samples were previously damaged by the electron beam simulation of 100 THLs of 0.38 GW/m² intensity ($\Delta t = 1$ ms) on a 4×4 mm² area in the JUDITH 1 facility. These conditions were chosen because the resulting damage (crack network) and the crack depth (~200–300 µm) are known from previous identical material tests with subsequent cross sectioning. After laser melting, the samples were analyzed by SEM, laser profilometry and metallographic cross sectioning. A closed surface without cracks, an increased grain size and pronounced grain boundaries in the resolidified area were found. Profilometry proved that the surface height variations are within ±25 µm from the original surface height, meaning a very smooth surface was achieved. These results successfully demonstrate the possibility of repairing a cracked tungsten surface by laser surface re-melting. This "laser repair" could be used to extend the lifetime of future plasma facing components.

1. Introduction

Transient heat loads (THLs) during the operation of a fusion reactor pose a threat to the structural integrity of plasma facing materials. Research on the impact of THLs on tungsten surfaces showed deterioration that increased from surface roughening to cracking and finally melting. Typically a higher intensity, a higher number of THLs or a higher material temperature lead to more severe deterioration up to a level at which a single THL leads to melting [1–4]. Techniques like mitigation of transient events or conversion of plasma energy into radiation by massive gas injection are used to lower the intensity of THLs in order to achieve conditions that allow a long(er) life time of plasma facing materials and components. However, it was shown that relatively moderate THLs of 0.27 GW/m² ($\Delta t = 0.5$ ms) can lead to cracked surfaces after 10^5 and more pulses [4] and microstructural fatigue processes start already at even lower power densities of 0.14 GW/m² [5]. For ITER more than 10^6 transient events in the form of edge localized modes are expected and a DEMO could achieve more than 10^9 per full power year (at a frequency of 50 Hz). Even under pure stationary heat load cyclic operation can lead to fatigue cracks on the surface. Hence it can be expected that the surface of plasma facing materials will not stay pristine after long operation. It is currently unclear whether or not these damages have an influence on reactor operation (and to which extent). However, the possibility to locally repair damaged areas by remote tools (e.g. a laser [6]) would be an interesting option. The use of a laser tool for this purpose has several advantages, especially in a neutron activated environment: It is a contactless method; there is no need to have the laser itself in the reactor chamber; many different types of lasers are commercially available and provide energy input into material with high precision and control; it does not create dust by abrasive processes. This study presents a first investigation on the feasibility of surface repair by laser on a proof-of-principle level.

2. Experimental conditions

The experimental setup is shown in Fig. 1. The laser light from a solid state disc laser (Trumpf TruDisk 8002, wavelength 1030 nm) is guided by a fiber to an optical deflection system (focal spot 0.8 mm) on a robot arm. Samples are placed in a crucible below which is flushed with argon to prevent oxidation.

First, samples of generic pure (~99.9%) tungsten were used to find good laser parameters for the melting process. A number of combinations of process parameters – laser power, focal spot size and scanning speed – were tested. These led to varying

* Corresponding author.
E-mail address: T.Loewenhoff@fz-juelich.de (Th. Loewenhoff).

http://dx.doi.org/10.1016/j.nme.2016.04.004

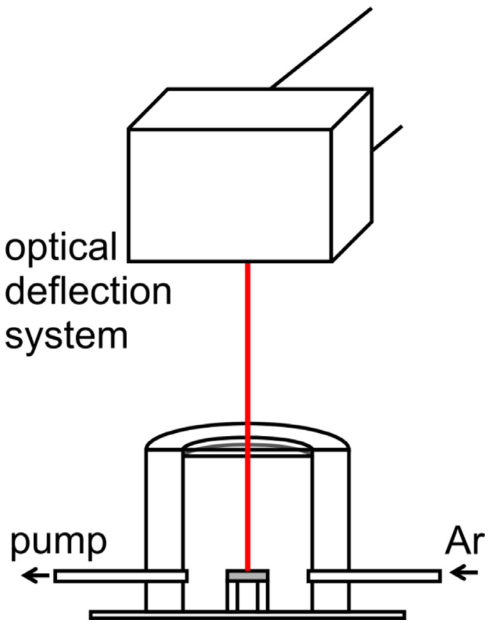

Fig. 1. Experimental setup: The optical deflection system on top guides the laser beam onto the sample surface below. The samples are placed in a crucible (a cross section is shown) which is flushed with argon to prevent oxidation.

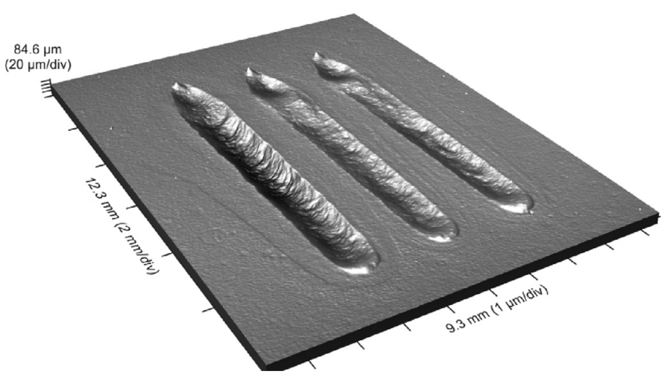

Fig. 2. Surface topology measured with a laser profilometer. The height scale is enhanced by a factor of five to make the three laser tracks clearly visible. Line scans with true heights are shown in Fig. 3. The laser power was 3 kW in all three cases, the velocities varied: 3, 4 and 5 mm/s (from left to right).

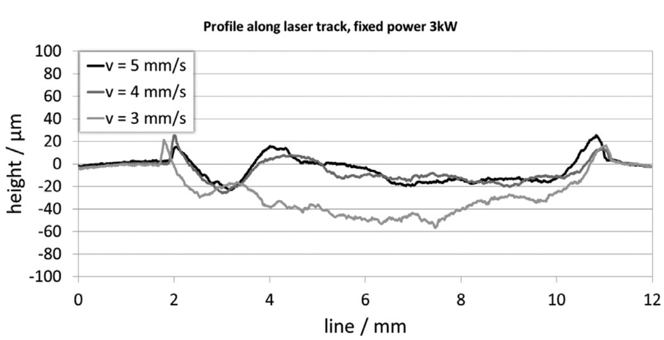

Fig. 3. Line scans measured with a profilometer showing the height profile of three laser melt tracks (Fig. 2). The laser power was always 3 kW.

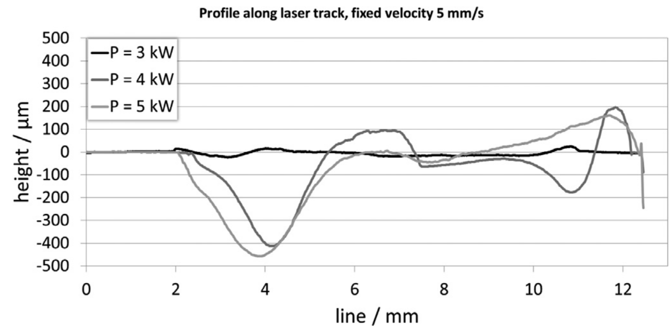

Fig. 4. Line scans measured with a profilometer showing the height profile of three laser melt tracks with fixed velocity of 5 mm/s, but different laser power: 3 kW (same profile as in Fig. 3), 4 kW and 5 kW.

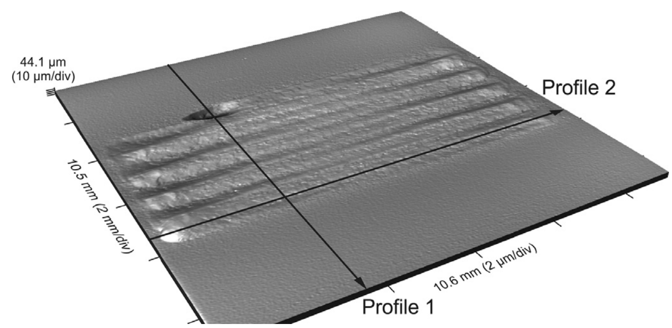

Fig. 5. Surface topology of sample F3 measured with a laser profilometer after thermal shock cracking and subsequent LSR ("repair"). The height scale is enhanced by a factor of five to make the laser tracks clearly visible. Line scans of the indicated profiles 1 and 2 with true heights are shown in Fig. 6.

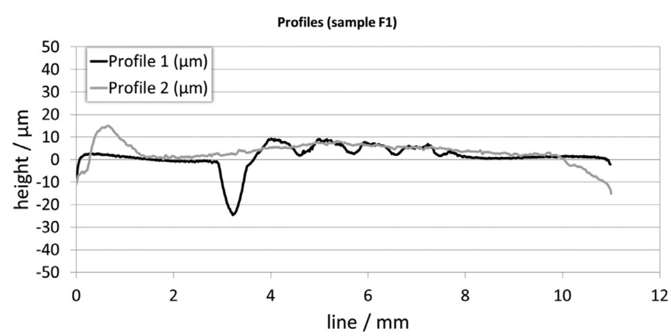

Fig. 6. Line scans of the surface elevation of sample F3 for the two profiles indicated in Fig. 5. The largest deviation from the original surface height occurred in the beginning and end of the laser track.

v degree of melting. After a visual inspection, the most promising settings, producing a smooth remelted layer of sufficient size, were selected. After that, samples of tungsten produced according to ITER material specifications were used [7] that were previously exposed at room temperature to 100 pulses of 1 ms duration and 0.38 GW/m² intensity in the JUDITH 1 electron beam high heat flux facility in Forschungszentrum Jülich [8]. This THL exposure damaged the samples in a defined way: a crack network developed with a known crack depth of 150–300 µm [9]. One of the goals of the laser surface re-melting (LSR) was to achieve melting to this depth to remove the cracks completely. The samples were blocks of about $12 \times 12 \times 5$ mm³ and the damaged area was 4×4 mm² (more details about the e-beam loading can be found in [9]). All samples were ground and polished to mirror finish to get defined starting conditions. Three cracked samples were finally treated with the most promising LSR procedures. They were analyzed by non-destructive post-mortem analyses, two also by destructive post-mortem analysis. The remaining sample was tested in JUDITH 1 to assess the thermal shock performance of the resolidified surface using again 100 e-beam pulses as described above, but with a low power density of 0.1 GW/m². After analysis of the surface a second test with 0.38 GW/m² was done.

Post-mortem analyses were done using scanning electron microscopy (SEM) and laser profilometry (KF3 sensor from OPM Messtechnik GmbH). Other analytical methods (focused ion beam

Please cite this article as: Th. Loewenhoff et al., Laser re-melting of tungsten damaged by transient heat loads, Nuclear Materials and Energy (2016), http://dx.doi.org/10.1016/j.nme.2016.04.004