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Particle adhesion assessment based on a diverted use of LASer Shock Adhesion Test (LASAT) to apply inertia force relying on dynamics of the sample macroscopic surface.

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ABSTRACT

Laser-assisted surface structuring was developed at CERN for the treatment of the inside wall of the vacuum system of the Large Hadron Collider (LHC). 50- μm -deep grooves were created by material ablation while the laser scanned the surface. A part of this material was redeposited as micrometer-size particle aggregates. This two-scale rugosity efficiently traps electrons. During the operation of the LHC, the surface is submitted to high electromagnetic forces and cooling cycles which might deteriorate its performances. Accelerations of the surface in the order of 350 000 g are expected to be induced by these electromagnetic forces.

The LASer Shock Adhesion Test (LASAT), initially developed to assess the adhesion of coatings by spallation, was used to accelerate the surface of treated samples, in order to reproduce stress states similar to those generated by the electromagnetic forces. Pressure shock waves generated by nanosecond laser irradiation produce sharp velocity variations of the surface. Decelerations and, therefore, applied inertial forces were evaluated from the dynamics of the sample macroscopic surface, whose velocity evolution was measurement by VISAR (Velocity Interferometer System for Any Reflector) with a time resolution smaller than 1 ns.

Once the test set-up was calibrated, the collect and the analysis of detached particles allowed the quantification of ejected material as a function of the applied mechanical stresses.

Keywords: laser shock, LASAT, adhesion, spallation, acceleration

1. INTRODUCTION

In the Large Hadron Collider (LHC), at CERN, two proton beams are accelerated and brought into head-on collisions in different parts of the ring, where gigantic detectors collect the newly formed particles. To avoid collisions with the gas molecules present in the accelerator, particle beams circulate in an ultra-high vacuum chamber, partly cooled to 1.9 K. Electron multipacting leading to electron cloud formation in the vacuum system has been identified as a major limiting factor for the beam quality and a critical source of heat-load on the cryogenic system in the LHC [1]. Laser-assisted

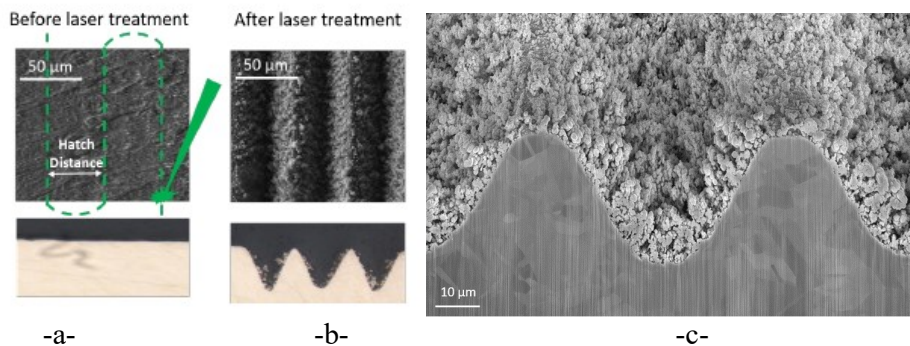


Figure 1. a- original surface top and cross section views and scanning pattern of the laser head. b-surface after the laser texturing, c-SEM cross section of the sample textured surface with particles redeposition

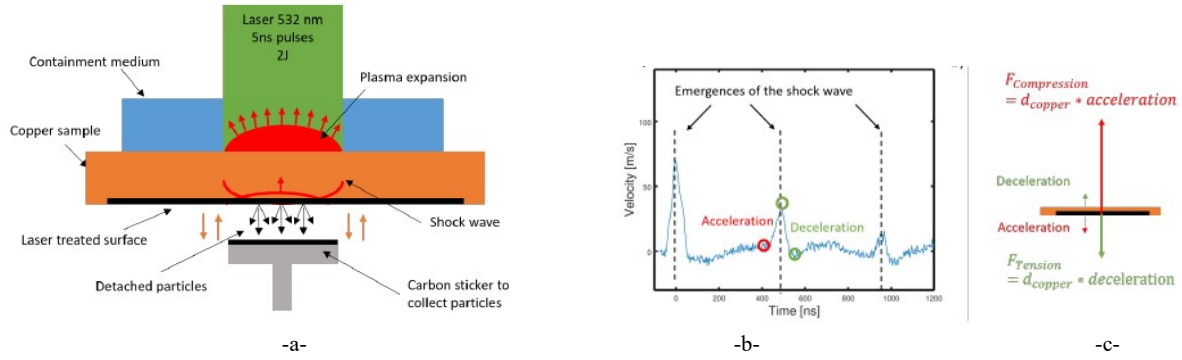


Figure 2. a-Sketch of LASAT setup for the assessment of particle adhesion on a laser-treated surface, b-Velocity measured on the free surface of an untreated 1-mm-thick copper sample, with tape as confinement media, at the power density of 2.72 GW.cm², c-Sketch of the sample submitted to acceleration and deceleration, showing inertia forces in tension or in compression

surface structuration is a promising electron-cloud mitigation technique, as it could be directly applied *in-situ*, in already installed chambers.

Pico-second pulsed laser irradiation of copper in a parallel pattern creates grooves by material ablation. A part of the ablated material is redeposited as particle aggregates. This two-scale roughness decreases the Secondary Electron Yield (SEY) of surfaces, governing the multiplication of the electrons in the beam chamber, by geometrical effects. Nevertheless, the rugosity increase comes with detrimental effects on other surface functionalities, such as the increase of the surface electrical impedance and the possible creation of dust coming from the detachment of the microstructures created by the laser treatment. During the operation of the LHC, the surface is submitted to electro-mechanical forces (around 30 N.mm⁻³) and cooling cycles from room temperature to 4 K, which may affect the integrity of the structuration and alter the efficiency of the treatment. Experimental methods have been developed to apply a non-contact force on the structured surface in order to characterize the adhesion of the microstructures on the surface. In particular, a test set-up based on the use of laser shock generation to induce localized controlled acceleration forces on the samples have been implemented to evaluate the ability of the technique to quantify detrimental extraction of redeposited particle aggregates.

2. MATERIALS DESCRIPTION

Oxygen Free Electronic copper coupons of 1 mm thickness representative of the LHC inner wall were submitted to laser treatment for surface texturing at University of Dundee using the same parameters as a robot assisted *in-situ* on a beam screen at CERN. A diode pumped Nd:YAG laser at 532 nm wavelength, at 200 kHz repetition rate, 10 ps pulsed gaussian beam, 52 μm diameter with an energy of the order of 20 μJ causes the partial ablation of the material. About 50 μm wide grooves with a depth limited to 30 μm are carved on the surface of 15x15 mm² writing a pattern of parallel one directional grooves. Top views SEM images qualitatively evidences the particle redeposition associated with this laser treatment (cf Fig. 1).

3. EXPERIMENTAL PROTOCOL

The acceleration that leads to inertia force equivalent to Lorentz forces expected during the quench of the supraconducting magnet surrounding the vacuum system, inherent in the operation of the LHC (around 30 N.mm³) is in the range of 350 000 g. In order to submit these textured coupons to extreme accelerations as endeavored in LHC environment, the use of laser shock technique has been thought as a possible controlled experimental environment. The LAser Shock Adhesion Test (LASAT), initially developed to assess the adhesion of coatings by spallation [2], was diverted here to accelerate the surface of treated samples. Pressure shock waves generated by nanosecond laser irradiation produce sharp velocity variations of the surface opposite to the loading. Deceleration and, therefore, applied inertia force were evaluated from the dynamics of the sample macroscopic surface. The LASAT is a contact-less method to determine the adhesion of coatings, based on spallation phenomena. Coating thickness can vary from few μm to several mm, depending on the laser set-up characteristics. As illustrated in figure 2, during LASAT, a high power pulsed nanosecond laser is focused on the front side of the sample. The high energy delivered in a short time is absorbed by a

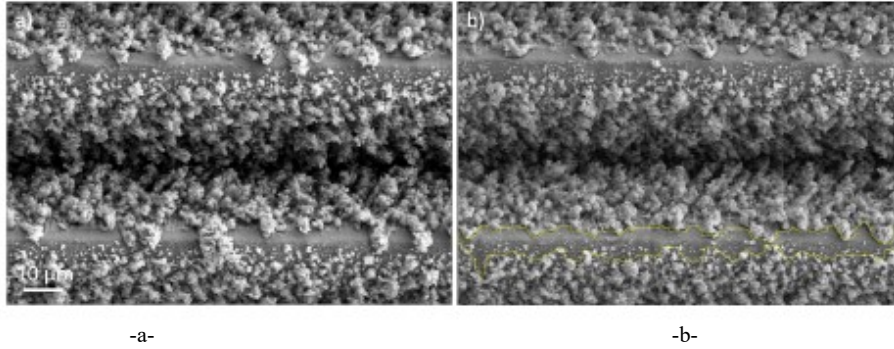


Figure 3 SEM top views of the treated surface a) in an area non ejected by the laser shock, b) in an area ejected by the laser shock (corresponding inertia force of 8.6 kN.mm³). The yellow line highlights an uncovered area on the groove top

thin material layer and triggers sublimation, vaporization and ionization of the irradiated surface. The fast plasma expansion produces a high pressure shock pulse and triggers a compressive shock wave on the front side of the sample. The incident compressive shock wave propagates across the sample and is reflected on the opposite surface (i.e. rear free surface). The superposition of the incident and reflected waves can generate a tensile stress, which can lead to material failure or to internal interfaces decohesion of. A transparent confinement layer is added to confine and delay the plasma expansion, in these conditions the induced pressure is reported to be an order of magnitude greater and the shock wave duration up to 3 times longer than in the direct irradiation regime at the same power density [3]. In this work, the dynamic behavior of the free opposite surface (i.e. the acceleration and deceleration of the macroscopic surface) was used to generate inertia forces on the particles present on the surface.

The density of particles on treated surface decreases after application of mechanical stresses, and detached particles were then collected on a carbon sticker for further analysis. Figure 2 illustrates how LASAT setup was used to assess the detachment of the particles, illustrating the direction of inertia force applied on the particles depending on the dynamics of the sample macroscopic surface during a laser shock. For each emergence of the shock wave at the free surface, a velocity peak is measured. During the acceleration phase, the surface moves down and the inertia forces acting on particles push them toward the surface. On the other hand, during deceleration the inertia forces pull particles away from the surface. For every experiment, the maximum acceleration/deceleration is obtained on the first shock emergence; therefore, they were estimated by considering the first peak velocity VISAR signals [4]. Using various laser configurations by varying laser intensity from 0.5 to 6 GW/cm² (i.e. confinement breakdown limit), the analysis of the VISAR signals opposite face of the loading allowed to map the acceleration/deceleration range achieved with our laser conditions. Inertia forces pulling particles out of the sample macroscopic surface during laser shocks were calculated based on the deceleration values, as given in equation (1) below:

$$F_{Vol} = a \cdot d_{copper} \quad (1)$$

where a is the deceleration measured on the macroscopic surface, $d_{copper} = 8960 \text{ kg.m}^3$ the copper density and F_{Vol} the inertia force (a force density i.e. a force per unit volume). Based on equation (1), the inertia forces applied on particles have been calculated in the configurations which were used for the mechanical characterization of the laser treated samples. According to free surface velocity measurements on a 1-mm-thick copper sample, with water confinement, a range of inertia forces was estimated between 4.6 and 8.6 kN.mm³ for laser irradiation respectively between 1.4 and 4.8 GW/cm²

4. ANALYSIS OF EJECTED PARTICLES

Postmortem inspection has been performed on textured free surface submitted to the experimental extreme inertia forces of the laser shock (cf Fig 3) as well as on the detached particles collected on carbon stickers placed in front of the textured surface. On the stickers, Automated Particle Analysis was performed to evaluate particle size distribution (cf Fig 4-b) and cumulated detached particle mass (fig 4-a).

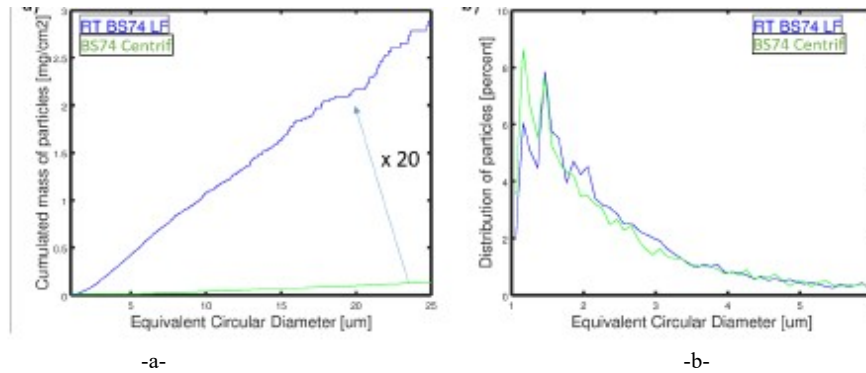


Figure 4 Comparison of extraction techniques (centrifuge in green and LASAT in blue) applied to BS74 samples, at room temperature. a) Cumulated mass per square centimeter, b) Particle size distribution

Figure 4 compares the results obtained for identical samples submitted to the following extraction techniques, at room temperature:

- low power density laser shock, generating 20-ns-long inertia force of $31.9 \text{ kN}\cdot\text{mm}^{-3}$
- 40000 RPM centrifugation, generating a static load of $12 \text{ N}\cdot\text{mm}^{-3}$

The total detached mass was 20 times higher for low power density laser shocks than for centrifugation. However, no significant difference could be noticed in size distribution between the two extraction techniques. To conclude, a large range of particle detachments can be obtained applying different extraction techniques. Due to the higher magnitude of forces applied on particles, laser shock could detach significantly much more particles than centrifugation. It should be noticed that accelerations generated with the laser conditions available were 1000 times higher than the ones expected in LHC environment, acting such as a security coefficient in dimensioning. The effect of changing laser shock parameters (such as power density or the temporal beam profile) on the number of detached particles has been analysed as well.

CONCLUSION

An original diverted use of the LASAT technique has been experimented to apply non-contact forces on small particles to assess their adhesion after redeposition on a laser textured surface material put into the extreme conditions environment of LHC. Estimation of particles mass and size distribution upon huge accelerations could be achieved. The inertia forces generated with the laser facility on hand were much too high compared to the LHC environment. But variations on the laser shock generation and propagation could be advantageously proposed to complete classical centrifuges traditional tests, particularly in opening possibilities to test under cryogenic temperatures the particles ejection as it is the case in extreme conditions such those of LHC.

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