Effect of the Laser Shock Processing on Wear Resistance of Brass Alloy

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ABSTRACT

Laser shock processing (LSP) is becoming an important surface treatment to induce a compressive residual stress field, which improves micro-hardness, fatigue and fracture properties of components. In this work, we examine the effect of laser shock processing on the surface micro-hardness and wear resistance of brass alloy. After LSP treatment, micro-hardness values increased by 97% at the metal surface and decreases gradually with distance below the surface. It is observed that LSP impact can improve the wear resistance of brass, where the wear rate is reduced by 79% compared with the untreated LSP specimens due to work hardening and compressive residual stress of LSP impact. From SEM micrograph analysis of worn surface, the grooves and compacted debris of LSP treated sample are smaller and less than these untreated LSP samples.

Keywords: Laser Shock Processing, Wear Resistance, Brass Alloy.

تأثير الصدمة بموجة الليزر على زيادة مقاومة البلى لسبيكة البراص

الخلاصة

المعاملة بواسطة موجة الصدمة المتولدة بالليزر اصبحت اكثر طرق المعاملة اهمية نضرا لما تضيفه للمادة من اجهادات انضغاط وصلادة ومقاومة الكلال والكسر. في هذا العمل , تم اختبار تاثير المعاملة بموجة الصدمة المتولدة بالليزر على صلادة ومقاومة البلى لسبيكة البراص.بعد اجراء المعاملة بموجة الصدمة المتولدة بالليزر لسطح السبيكة, قييم الصلادة ارتفعت 97% عند السطح وتنخفض تدريجيا كلما ابتعدنا عن السطح. تمت الملاحظة ان المعاملة بموجة الصدمة المتولدة بالليزر يمكن ان تزيد من مقاومة البلى لسبيكة البراص حيث قل معدل فقدان الكتلة بمقدار 79% مقارنة مع العينات الغير معاملة بالليزر بسبب عملية التصليد واجهادات الانضغاط المتولدة بالسطح. تصوير المجهر الالكترونيلسطح المادة المعرض لاختبار البلى اضهر ان الاغاديد والمخلفات المنضغطة على السطح اصغر واقل في العينات المصلدة بالليزر منها للغير مصلدة.

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INTRODUCTION

In the field of surface treatments, with the advent of high-power lasers, laser shock processing (LSP) has emerged as a new and very promising technique to increase the resistance of metals and alloys to fatigue, wear and corrosion [1,2]. Unlike other laser applications, LSP is not a thermal rather a mechanical process for treating materials [3]. It involves a high-energy laser beam combined with suitable overlays to generate mechanical pressure waves of up to 6–10 GPa on the surface of a metal [4]. Once the peak pressure exceeds material yield strength, the transient shock pressure causes severe plastic deformation, refined grain size, compressive residual stresses, and increased hardness at the surface and in the subsurface. As a result, the mechanical properties on the workpiece surface are enhanced [5]. The depth of the laser processed zone depends mainly on the laser power intensity, pulse length, and material properties [6]. Considerable research studies were carried out to examine the laser shock processing. A review of laser shock processing and examination of mechanical properties of metallic material and microstructural changes in the laser-irradiated region was carried out by I. B. Roman et al. [7].They indicated that laser shock processing had great potential as a means of improving the mechanical performance of components. Sanchez-Santana U. et al. [8] investigated the effect of LSP surface treatment on the wear and friction of 6061-T6 aluminum alloy. They showed that LSPreduces wear rate due to the compressiveresidual stress field induced.

LSP PROCESS PRINCIPLE

The principle of Laser Shock Processing can be described as shown in Figure (1) The metallic sample surface to be treated is first locally coated by an absorbing layer (typically a black paint) and completely immersed in water as confining layer [9,10]. The absorbing or opaque overlay is used to increase the absorbability of incident laser and to protect the metal's surface from ablation and melting; a thin layer of it vaporizes on absorption of laser energy [7, 11]. When the laser pulse from Q-switched laser with sufficient intensity (>GW cm^{-2}) for a very short time durations (<50 nsec) is directed onto the surface to be treated, it passes through the transparent overlay and strikes the sample [12, 13]. Short laser pulse is focused onto the sample. Immediately the absorbing layer and a thin metal surface layer is vaporized and formed plasma due to vapor ionization and heated by absorption of laser energy [14, 15]. The plasma continues to strongly absorb the laser energy until the end of energy deposition [16]. Water tends to confine the energy and increases the pulse pressure intensity against the base metal [17]. The rapidly expanding of plasma is trapped between the surface of the metal material and the transparent confining layer (the water) see Figure (12) [9, 10].Then creating a high amplitude (more than 1Gpa), short duration pressure pulse which propagates into the metal material as a shock waves [21].In other wards the sudden, high pressure against the surface of the workpiece causes a shock wave to propagate into the material. If the peak stress of this shock wave is above the dynamic yield strength of the material, the material yields and plastically deforms [20].While the pressure of the shock wave exceeds the dynamic yield strength of the target metal. The shock wave can induce microstructural changes, cause a high increase of dislocation density and twins, generation of point

defects, phase transformations, precipitation, and influence the surface roughness of the material as well as plastic deformation occurs and produce favorable high residual surface compressive stresses causing modification of the near-surface microstructure and mechanical properties such as fatigue ,wear and corrosion resistance [7,18,,19].

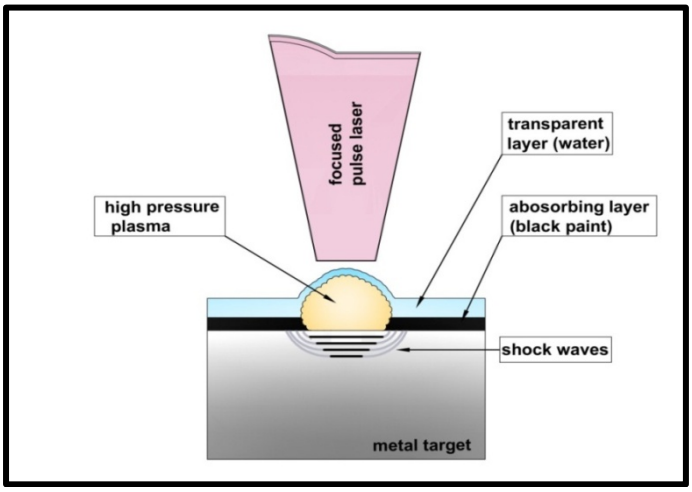


Figure (1) Schematic representation of the laser shock processing metal target with absorbent, water layers and shock wave generation by laser beam.

EXPERIMENTAL PROCEDURE

Sample preparation

The samples were manufactured from naval brass ASTM B21 alloy. All samples were cut into disk shape with diameter of 2.4 mm and thickness of 3 mm.The chemical composition of the brass alloy are shown in Table(1) . Prior to the laser shock, the samples were polished with SiC paper with different grades of roughness ranging from 400#, 600#, 800#, 1200#, 1600# to 2000# and thin polished by diamond best with lubricated liquid on cloth paper, followed by washing in deionized water and ethanol was used to degrease the sample surface in order to be used in LSP experiments.

Table (1) Chemical Composition of brass alloy.

Composition	**Zn**	**Pb**	**Sn**	**P**	**Fe**	**Ni**	**Si**	**Sb**	**Co**	**Al**	**Cu**
Per. (wt. %)	40.2	0.06	0.15	0.007	0.04	0.14	0.001	0.007	0.002	0.02	Bal.

LSP setup

The LSP experiments were performed using a Q switched Nd: YAG laser operating at 1 Hz with a wave length of 1064 nm and the FWHM of the pulses was 10 ns. A convergent lens is used to deliver 1 J. Spot diameter was 1 mm. The pulse density was used 500 pulses/cm^2. Specimens were emerged into a water bath when they were irradiated. Water was the confined medium whit thickness of 3mm.

The experimental setup for laser shock processing as shown in Figure (2). During LSP impact, the laser beam was perpendicular to the sample surface all the time, and the water layer was replaced after each line impact to keep the water purity. Control of water purity is important in order to avoid the formation of water bubbles or the concentration of impurities coming from the material ablation due to laser treatment. The overlapping rate was 50% between two adjacent spots in order to ensure no blind area at the LSP shocked region as shown in Figure (3) and the pulse density was 500 pulse/cm^2.

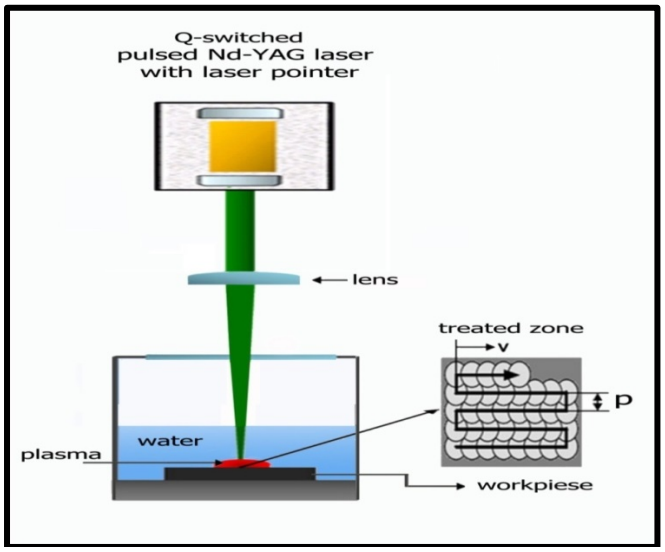
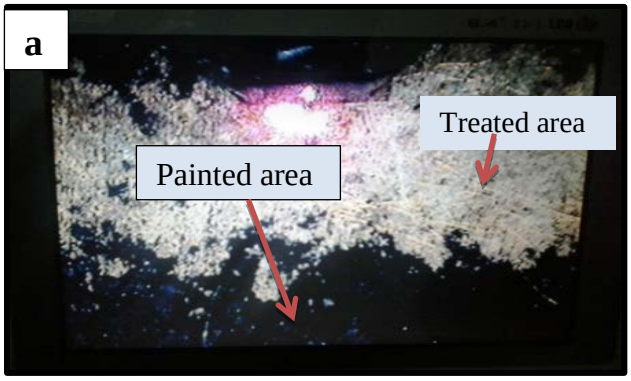


Figure (2) Schematic diagram of the experimental setup for laser shock Processing and the irradiation pattern on a sample.



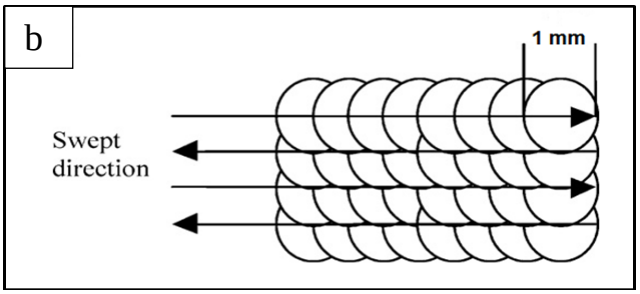


Figure (3) Optical image showing the treated sample (a) and scheme of the treated area (b).

The measurements

Measurements of Micro-hardness

The micro-hardness variations prior to and after LSP of brass and Aluminum alloy 2024-T3 was measured using the Vickers hardness method with " Digital Micro Vickers Hardness Tester ESEWEY" Model EW422-DAT.2012-UK production was used in UKM Malaysia University as shown in Figure (3-10). The measurement was made with 200 g load and 15 sec hold time. Five measurement readings were taken and averaged to one value required to establish a suitable micro-hardness profile in the hardened layer andconsequently, a reliable micro-hardness variation. Micro-hardness was measured at the impact center of overlapping lines.

Wear Test

The wear rate has been calculated by following the weighing method in which wear testing system of flat sample consists of hard disc made from material type CK-45. The hardness of rotated hard disk about = 60±5 HRC, rotating of 900 rpm by multi speed electrical motor. The sample was subjected to a direct attachment with the rotating disk for 10 min and under applied normal load of 1 kg as shown Figure (4) and this operation repeated 6 times. The mass of the specimen was weighted before and after operating the system by using a sensitive electronic balance type (KERN) with accuracy of 10^{-4} g.

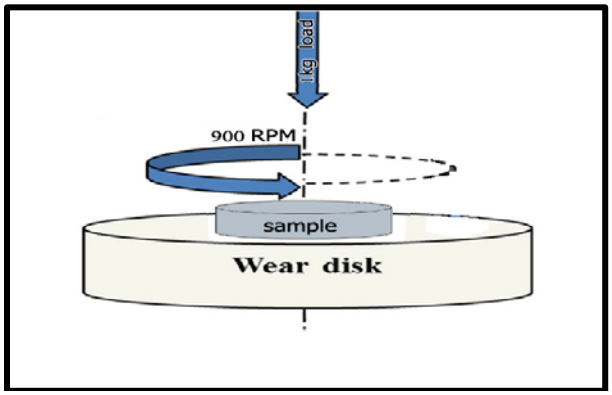


Figure (4) Schematic of wear flat system test.

The wear rate was calculated according to the following equation:[23]

Hard disk

$$W.R = \frac{w}{\pi DMT}\ g/cm \qquad \text{….. (1)}$$

Where W.R: wear rate (g/cm)
W: weight loss (gm), and $W = W_1 - W_2$
W_1: weight before test, W_2: weight after test
D: disk outside diameter (cm).
M: sliding speed (r.p.m.).
T: running time (min.).

Morphology analysis

Scanning Electron Microscope (SEM) type (FESEM, SUPRA TM 55vp Zeiss, England product) was used to analyze surface morphology of all specimens before and after LSP treatment and all mechanical tests. The measurements were conducted in UKM Malaysia University.

RESULTS AND DISCUSSION

Micro-hardness results

Micro-hardness distribution profiles of the brass specimen cross section is shown in Figure (5). First far from the surface at a distance of 0.8–1.0 mm from surface, for untreated material, the micro- hardness takes a constant value of 122 HV. After LSP, the micro- hardness on surface increases and reaches a larger value of 240.6 Hv. In comparison to untreated material the micro-hardness increased by as much as 97%. Because the reaction of the laser shock wave and the metal target will be generated near the target surface, leading to the generation of the dislocation and the microstructural deformation near the surface. However, the increase in hardness was reported to be caused by an increase in the dislocation density after LSP. Below the surface, micro-hardness gradually decreases with the increase in the distance to the treated surface for and decreases to base metal values at 0.9 mm from the surface, that means the shock hardening effect decreases with increasing distance from the surface. This is due to the rapid decrease in peak pressure of the shock wave as it propagates into the metal.

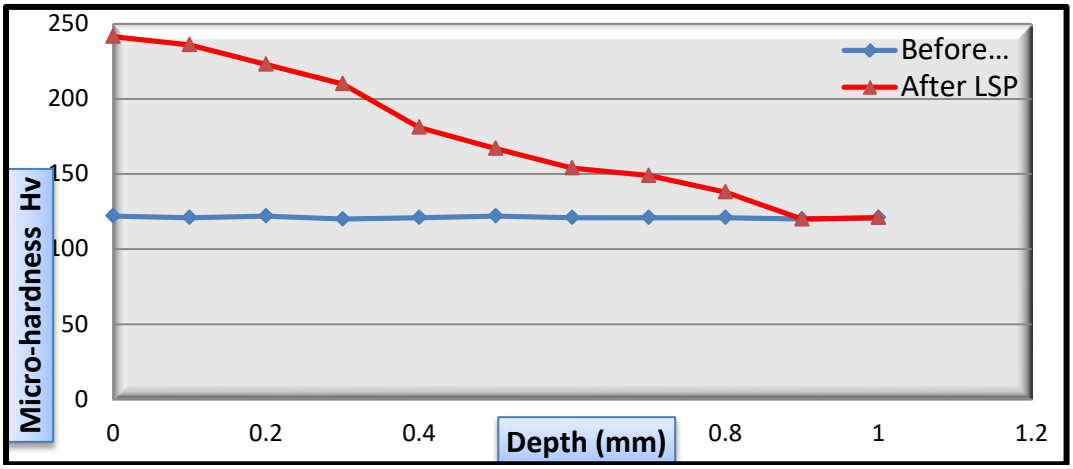


Figure (5) Micro-hardness distribution on the Brass specimen cross Section before and after LSP.

Wear Resistance Results

The wear test samples has been treated with the spot size , laser energy and water layer thickness at the optimum values of 1mm, 1J and 3 mm, respectively.

Mass Loss

Figures (6) summarize the mass loss of the brass specimens before and after LSP treatment, and it is observed that the mass loss reduced from 64.2×10^{-3} to 13×10^{-3}gm for untreated and treated samples respectively at the same time of 60 min. That means the mass loss is reduced by about 79% with LSP treatment. This behavior can be attributed to work hardening of surface layers due to plastic deformation induced by shock waves and consequent enhancement in material strength.

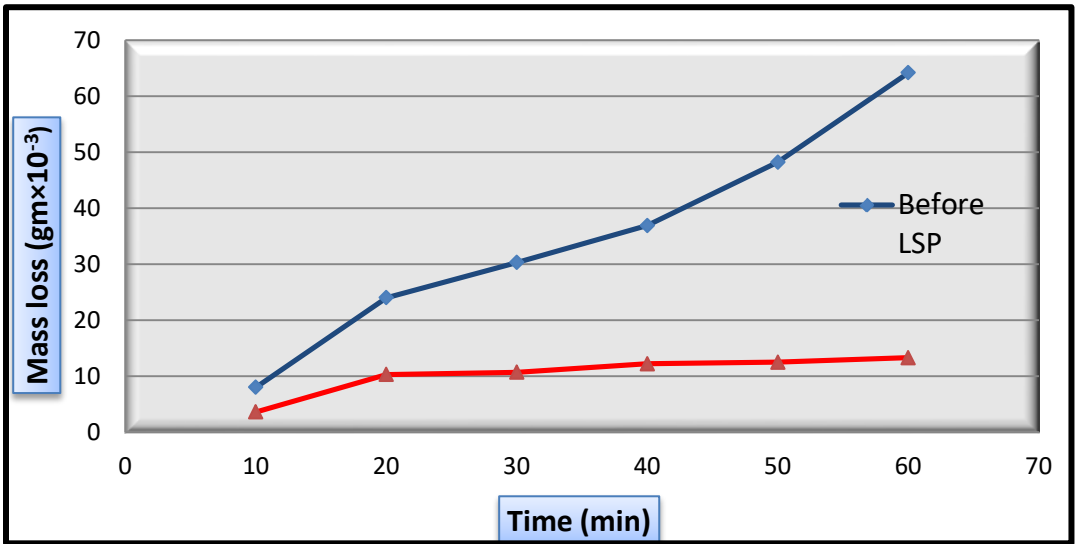


Figure (6) Variation of the mass loss of Brass specimens before and after LSP treatment with time.

Wear Rate

Variations of wear rate for brass with time are shown in Figure (7). This Figure reveals that the little difference in wear rate between the treated and untreated samples occurs during the first 20 min interval. The wear rate decrease from (17.6×10^{-8}gm/cm) to (7.59×10^{-8}gm/cm) , which shows that the LSP effects are most manifested in the material furthest from the sample surface. The gradual decrease in wear-rate difference between the treated and untreated samples over the extended test duration may be related to wear regime transition from severe to mild, after 20 min. In other words the wear rate during the initial period remains low, almost to the level close to that of the later period. These results demonstrate that the severe wear rate during the early period of abrasion can be substantially reduced by properly applying LSP on brass.

After 60 min of wear test, it can be noted that wear rate has decreased from 15.7×10^{-8}gm/cm for untreated LSP sample to 3.26×10^{-8}gm/cm for treated LSP sample. That is because the direct relation between grain size and wear resistance of metal materials, after LSP, the grain size decreases in the micrometer regime near surface by dislocation movement leading to substantial hardening of metal materials, as a result of the wear rate decrease. That means the wear resistance of the treated LSP sample is superior to that of the untreated LSP sample after wearing for a period of time. Similar results are also reported for LSP of duplex stainless steel by J.Z. Lu et al.[22] and of AISI 8620 steel by H. Lim et al. [23].

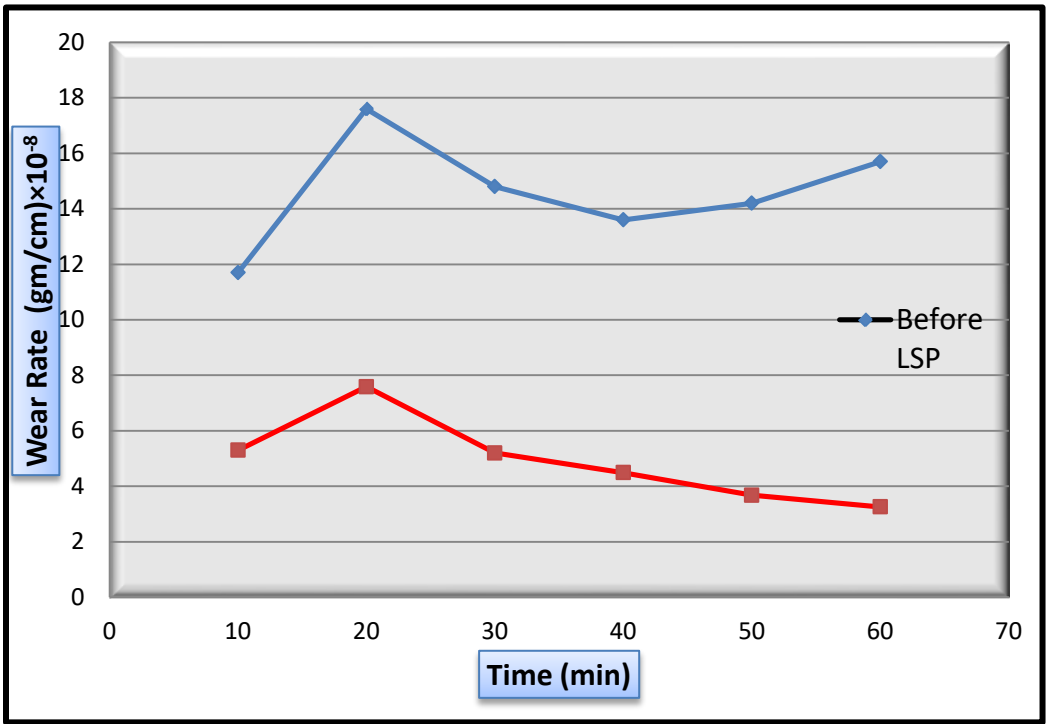


Figure (7) Variation of wear rate of Brass before and after LSP treatment with time.

Wear surface SEM

Figures (8) shows the SEM micrographs of brass treated and untreated LSP worn surfaces samples after sliding wear at room temperature. From these micrographs, it is clear that grooves running parallel to each other in the sliding direction are formed distinctly. There is plenty of bigger compacted debris in the worn surface of the untreated sample, whereas smaller compacted debris can be found in worn surfaces of LSP treated samples. It is important to notice that, compared with the groove in the worn surface of the LSP treated sample; the width and the depth of the groove are bigger in the worn surface of the untreated LSP sample.

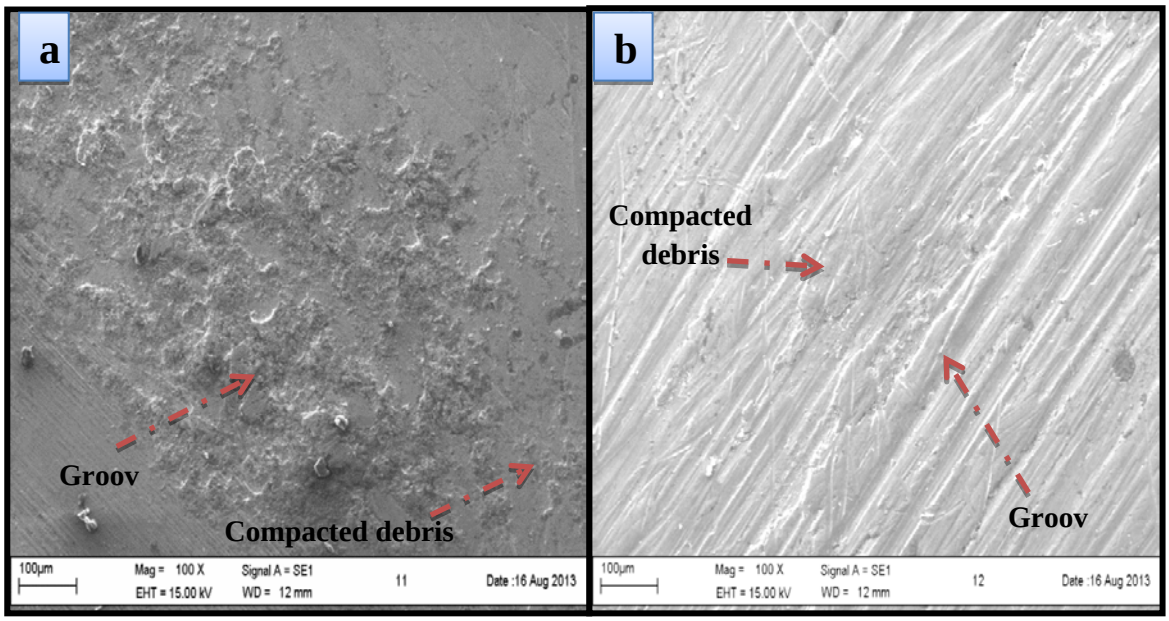


Figure (8) SEM micrographs of worn surface of brass samples A) Before LSP treated B) after LSP treated.

CONCLUSIONS

1- LSP can clearly improve the micro-hardness of the LSP treated region in near-surface layer, and the micro-hardness of the predicted stress is highest at the surface and decreases gradually with distance below the surface.

2- From wear test, it is demonstrated that LSP applied wear rate could be reduced by 79% from that of untreated LSP samples.

3- SEM micrograph show that, the grooves and compacted debris in LSP treated sample is less and smaller than in untreated LSP sample.

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