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Study on Enhancing Mechanical Properties of Tin Bronze Alloy Using Laser Technique

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ABSTRACT

This work aims to find low-cost ways and means to improve some special characteristics of the samples used. Tin bronze samples were prepared and machined with dimensions of 15mm×15mm×20 mm for surface roughness and micro hardness tests and machined as two cylindrical bars with diameters of 20 and 15 mm and length of 170 mm for torsion test. Laser shock processing by Nd-YAG laser with wavelength of 532 nm and transparent confinement layer was used to modify the sample surface to improve the surface roughness and micro hardness .The enhancement of torsion strength was achieved by Nd-YAG laser treatment without confinement layer. Different exposure times and laser effect distances were used to achieve the purpose of this work. The torsion strength results exhibited that the values increased with percentage of 44% at the best case, whereas the values of surface roughness increased by twofold. Finally the laser treatment improved the micro hardness by 53%.

Keyword: Tin Bronze, Micro Hardness, Laser Shock Processing, Torsion Strength, Exposure Time, Roughness.

1. INTRODUCTION

To date, the success of copper alloy in different industrial applications has been based largely on tin bronzes. Tin bronzes vary widely in the composition and the industrial requirements for tin bronzes come from the request for these materials in many fields of technology such as gears, pump components, marine fittings, valves, and potable water applications [1-4].

More recently, surface treatment technologies have become important increasingly in industry to reduce costs and avoid the need for expensive materials [5-8]. Chin Wei Chang and Chun Pao Kuo [9] utilized a new technique to improve the surface properties namely, laser assisted machining, which shows that laser assisted machining produces a better surface quality than conventional machining. The laser is characterized by the provision of substantial amounts of energy in confined regions from materials in reaching the desired reaction, this energy will be absorbed by nearby surface of metal and the surface chemistry will be processed [10-14]. Laser processing (LP) is an innovative surface treatment, using mostly Nd-YAG laser with a power density, as much as several tens of GW/cm^2 are used [15]. The solid surface hardening by laser treatment represents the structural transformations of the material. This can be established by irradiating the surface with a laser pulse, leading to improve the mechanical properties such as tensile strength, micro hardness, and torsion resistance [16]. LP, which represents a modern way for the surface treatment, can be defined as a mechanical process based on introducing deep compressive residual stresses by shock waves that generated through shedding laser pulses with high-power intensity on the surface target [17,18].

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Laser beam, which has found increasing application in recent years in the surface modification of metals such as Laser Shock Processing (LSP), has been proposed as a competitive alternative technology to classical treatments for improving fatigue and wear resistance of metals. We present the configuration and results in the LSP concept for metal surface treatments with different samples [18,19]. The results indicated that LP has great potential as a mean of improving the mechanical performance of components, consistent with. Sanchez-Santana U. *et al*. [20,21]. The interaction of the laser light and its movement over the surface, can achieve very rapid heating of metal work pieces, subsequently, very rapid cooling down or quenching can also be achieved, and the cooling rate, defines quenching conventional hardening [22,23]. Considerable research studies were carried out to examine LPS. A review of LPS 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*. [24].

This work is distinguished from other works, as the laser has been used as a tool to improve the mechanical properties of the used alloy, thus reducing economic cost and improving quality. In addition, this method represents a non-destructive method to increase the torsion strength, as well as this method not effect on the shape and structure of the samples. It can be say that the using of the laser treatment represents a precise and focused method to improve the mechanical properties of tiny areas of samples surface.

2. EXPERIMENTAL APPARATUS AND METHODS

2.1 Experimental Set Up

The basic setup of (LP) is shown in Figure 1. The tin bronze sample surface is treated initial coating with an absorbing layer and completely immersing in distilled and deionized water. The absorber layer (opaque) acts as a sacrificial material to avoid a reflection of laser beam and thermal effect from the surface heated by laser. When the laser with sufficient intensity is directed onto the sample surface to be treated, the surface of the sample is modified and becomes harder. A high-powered laser is focused on the sample .The absorbing and thin surface layers are immediately vaporized, forming plasma. The plasma continues to strongly absorb the laser energy until energy deposition. The LP parameters include exposure time and laser effect distance. A transparent overlay, Double Distilled Deionized Water (DDDW), is used to confine the plasma expansion and obtain the required pressure.

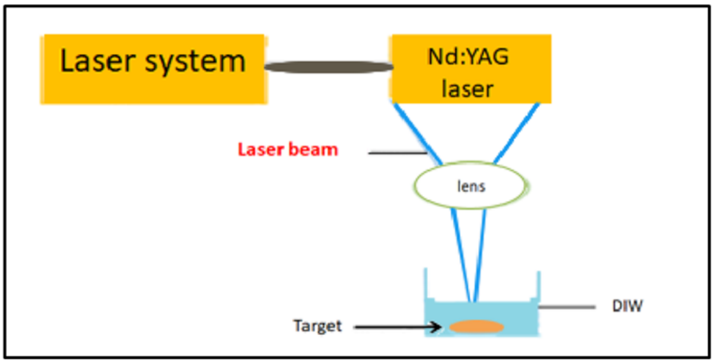

Figure 1. The essential features of Nd-YAG laser.

2.2 Sample Preparation

Tin bronze alloy 2024-T3 was machined as a rectangular shape with dimensions of 15mm×15mm×20 mm for surface roughness and micro hardness measurements, and the torsion test samples were formed into two cylindrical shaft shape with diameters of 20 and 15 mm and length of 170 mm as shown in Figure 2. The chemical composition of tin bronze alloy samples was deter minted by x-ray fluorescence techniques, as shown in Table 1. All samples were polished by grinding machine with different grades of metallographic paper, polished by diamond paste with lubricated liquid on cloth paper, and cleaned with distilled water and ethanol. Figure 1 show the experimental setup Nd-YAG laser had with different exposure times, the laser effect distance varied from 4 to 10cm with a wavelength of 532 nm, and laser power was 500mw. DDDW with different depth were used as a confining layer and black paint (absorber layer) with a thickness of 25 μm was used to protect the sample surface from thermal effect and to avoid the reflection of laser beam and dispersion of laser power. During laser – sample interaction, the laser beam was perpendicular to the sample surface, and the DDDW was replaced after each process to preserve the water purity and to obviate formation water bubbles or the impurities derived from the material ablation from laser treatment, consistent with [25].

Table 1 Chemical composition of tin bronze alloy used in this work

Element	**Zn**	**Pb**	**Sn**	**P**	**Mn**	**Fe**	**Ni**	**Si**	**Sb**	**Al**	**Cu**
wt%	0.014	0.003	7.87	0.019	0.005	0.008	0.002	0.001	0.006	0.005	**Bal.**

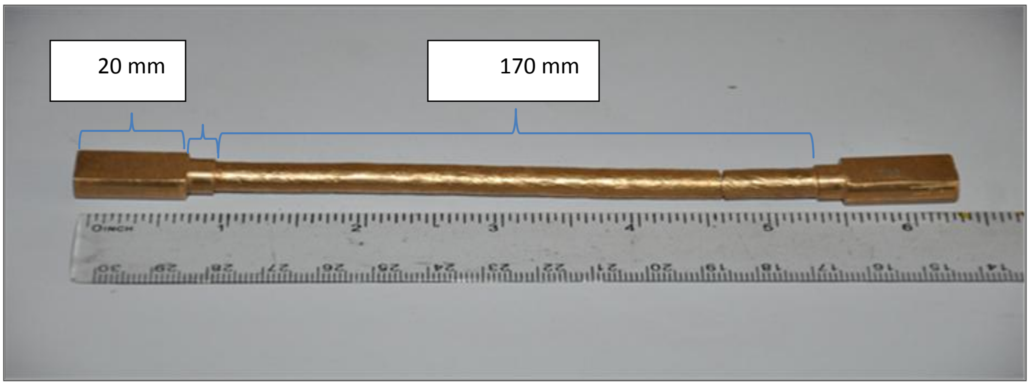

Figure 2. Metal Sample after torsion testing.

2.3 Torsion Test

In wide variety areas of engineering applications, materials are sometimes subjected to torsion in services, such as drive shafts, axles and twisted drills. Moreover, structural applications such as bridges, springs, car bodies, and airplanes are randomly subjected to torsion. The samples are irradiated to laser at different laser effect distances and different exposure times and then subjected to torsion testing machine.

2.4 Surface Roughness

Surface roughness was measured for each sample using "Digital Surface Roughness Tester TR-220". The measurements of mean arithmetic roughness were conducted with each experimental parameter such as laser effect distance and exposure time. All surface roughness measurements were carried out before and after laser treatment.

2.5 Micro hardness

The micro hardness of tin bronze alloy samples was measured by using the Vickers hardness method with "Digital Micro Vickers Hardness Tester TH714". The measurements of micro hardness were conducted with each laser factors such as laser energy, repetition rate, water layer depth and number of laser pulses. The measurements were conducted with load of 9.8 N for 15 seconds. Three readings were taken carefully for each sample and then averaged to evaluate the optimum value.

3. RESULTS AND DISCUSSION

3.1 Torsion Results

Figure 3 represents the relationship between the twist angle and the torque when the samples were exposed to laser radiation for eight minutes at various distances of the laser effect time .This figure shows that the samples without laser treatment are fractured at an angle of 53.89 and torque force of 569 Nm. The samples which were exposed to the laser were broken at the biggest angle of 57.9 and torque of 630 Nm at the laser distance effect of 6 cm. The samples which were exposed to laser at distance of 4cm revealed the highest value of torsion resistance (681Nm) and the biggest twist angle of 67 °C. The increase in torque and twist angle of samples exposed to the laser because of the increased surface hardness were achieved by the pressure generated by the laser waves, as well as the thermal effect of the laser beams. This effect increases with increasing the exposure time and decreasing the distance between the sample and laser source. Figure 3 shows the same relation. However, at the fixed laser effect distance and variable exposure time, the exposure time of eight minutes, rather than the exposure time of ten minutes, exhibited best torque and twist angle values. This behavior may be caused by the thermal effect of laser beam caused internal fine cracks or micro dislocations.

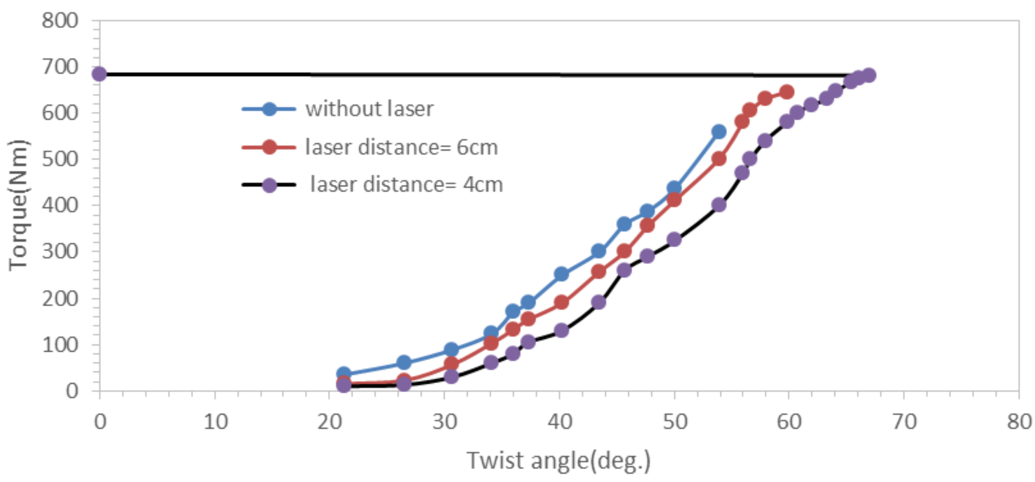

Figure 3. Torque force as a function of twist angle of 8 minutes exposure time with and without laser treatment.

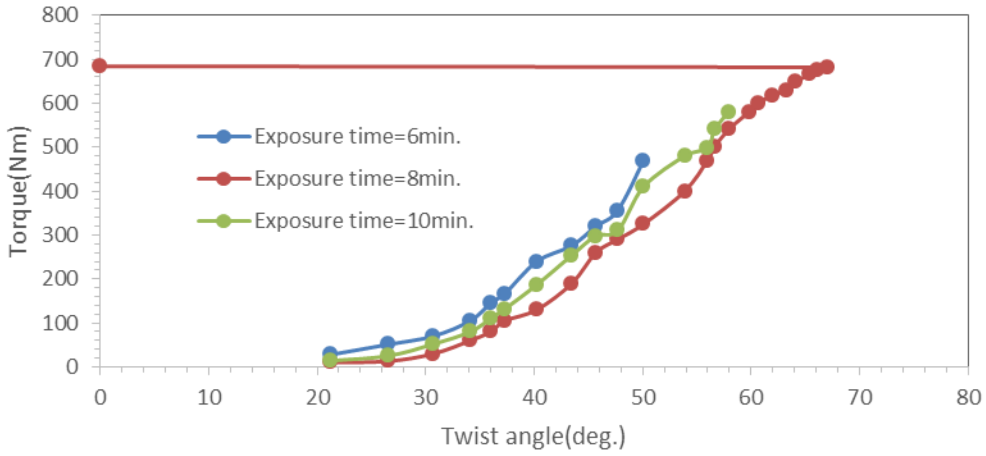

Figure 4. This curve compare between the Torque forces as a function of twist angle of 4 cm distance from the laser source with 8 minutes exposure time.

3.2 Surface Roughness Results

The relation between the surface roughness values and the laser treatments can be seen in Figure 5. The laser effect is very clear. This effect on the value of the roughness with increasing laser exposure time up to eight minutes and laser distance effect of 4 cm represents the highest value for surface roughness. This behavior may be explained by the following: increase the exposure time by more than a certain limit leads to increased pressure on the sample surface and reduces the ablation which causes surface roughness.

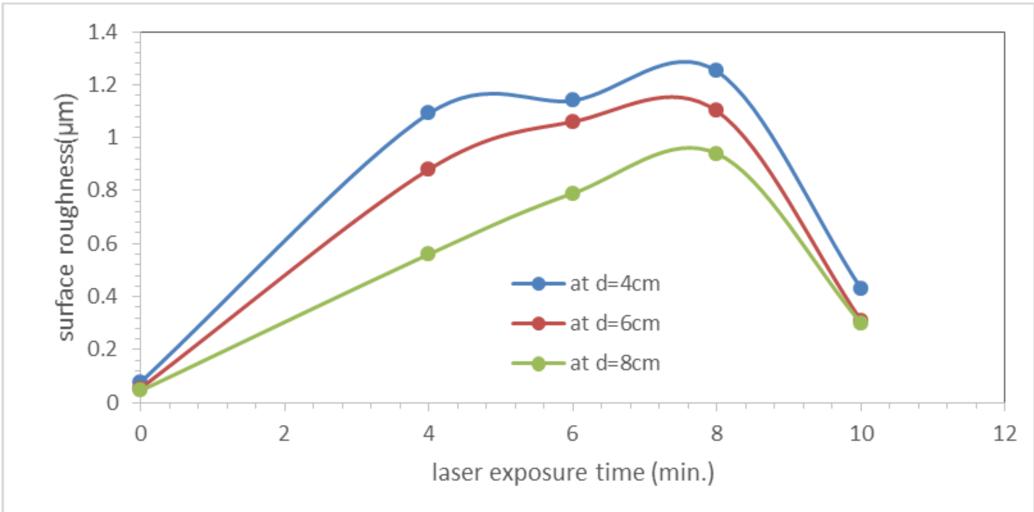

Figure 5. Surface roughness versus laser exposure time for 4 cm, 6cm and 8 cm distances from laser source.

3.3 Micro hardness Results

Figure 6 represents the micro hardness as a function of laser exposure time at different laser effect distances. A closer view of this correlation shows that the micro hardness of the samples increases with increasing exposure time to lasers and decreases the distance that separates the sample from the laser source. This behavior continues up to the eighth minute of exposure time at which the hardness goes up to a higher value and then starts going down.

The reason for this is that the increase in the pressure of the laser wave on the surface of the sample continues up to a certain limit and then overcomes the thermal effect of the laser beam which may be causing fine cracks , this agrees with reference [26] .

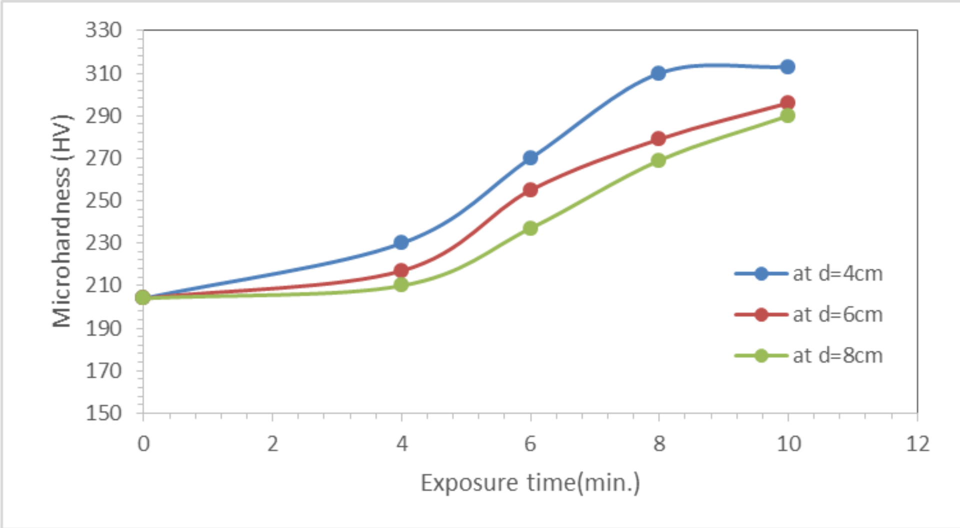

Figure 6. Micro hardness versus laser exposure time of 4 cm, 6 cm and 8 cm of distance from laser source.

4. CONCLUSION

The torsion test results showed that laser treatment is an effective treatment technique for improving the torque force of sample alloy from 539 to 630Nm at the effect distance of 6 cm. When the effect distance decreased to 4cm, the torsion resistance increased to 681 Nm. The results showed an improvement in the values of hardness and increase in percentage of 53% at the effect distance of 4cm. This behavior applies to surface roughness. The influence of the laser effect distance can be deduced from the resistance of the lasers and the hardness and roughness values, which increased by in varying degrees about11% to 43% when the laser effect distance decreased from 8 to 4cm.

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