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Effect of LST parameter on surface morphology of modified copper substrates

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KEYWORDS

Surface texturing
Laser surface texturing
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Resolidified material
Surface roughness

ABSTRACT

This study aimed to investigate the effect of laser surface texturing (LST) parameter on the surface morphology of copper substrate. The results of different loop number (L1 to L5) on the resolidified material of micro-dimpled surface modified copper substrate were examined. The micro-dimple with a diameter of 100 μm was produced via LST process by varying the dimple distance at 100 μm and 180 μm. The resolidified material that was formed after the surface texturing process was analysed using 3D measuring laser microscope. Based on the data collected, the dimple was successfully engraved on the copper substrate. The increasing number of loop increase the quantity of the melted material which lead to higher amount of resolidified material and surface roughness.

1.0 INTRODUCTION

In recent years, laser surface texturing (LST) has been developed to produce microscale surface geometry and texture on different kinds of materials such as polymers, metals, ceramics and composites (Wahab et al., 2016). This process involves developing specific patterns on a surface to improve the material's performance. LST is applied in various fields including optical (Wang et al., 2018), biomedical (Riveiro et al., 2018), tribology (Singh et al., 2019) and micro-electromechanical system (MEMS). Laser types utilized in LST are Nd:YAG laser (Hlinka et al., 2017), excimer laser (Zamharir et al., 2014), fibre laser (Demir et al., 2013; Sugar et al., 2016) and

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CO_2 laser (Singh et al., 2019). Nd:YAG laser is a complex crystal shape which is used as a lasing medium for solid-state lasers. This type of laser is usually used for materials that need a low-pulse repetition rate and high-pulse energy. Excimer laser is ultraviolet laser that uses a combination of a noble gases including argon, krypton or xenon. It is normally applied for production of microelectronic devices, micro-machining ceramics and semiconductors. Fibre laser used shorter wavelength radiation compared to other type of laser. CO_2 laser is a molecular laser that consists of carbon dioxide, helium and nitrogen gases. It is widely applied in heat treatment, welding and laser machining.

LST process is one of the simplest techniques exists to alter the surface topography and its performance (Ibatan et al., 2015; See, 2015). During laser texturing, the laser beam is focused onto the material surface to fabricate micro-features such as micro-dimples, micro-pillars and micro-protrusions (Singh et al., 2019). The radiation emitted by laser beam will be absorbed by the topmost layer of material surface, which then heated the material up. This process lead to the melting and ejection of the material onto the surface which then produce the micro-features (Riveiro et al., 2018). This paper presents an experimental study of micro-dimples fabrication via laser surface texturing and analysis of resolidified material to show the effect of laser surface texturing parameter on the surface morphology of copper substrate.

2.0 EXPERIMENTAL PROCEDURE

A flat copper substrate (15 mm × 15 mm × 1 mm) was selected as the test materials. The surfaces of copper substrates were ground using 1000-grit sandpaper and polished with alumina polishing paste. LST process (Figure 1) were used to fabricate dimple texture with a diameter of 100 μm on the polished copper substrates. The LST were applied on the test samples with a wavelength of 1064 nm Ytterbium Fiber laser, scanning speed of 300 mm/s, laser power of 18 W and repetition rate of 20 kHz. The dimples were engraved on the surface by using five different numbers of loop (L1 to L5). The number of loop is the repetition used for the laser beam to fabricate the dimple on the same spot. Two different types of samples were prepared which was varied by dimple distance, D that were set at 100 μm and 180 μm. The resolidified material were then analysed via 3D measuring laser microscope (Olympus OLS5000).

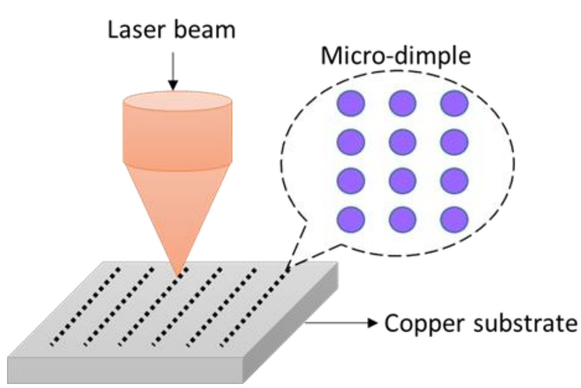


Figure 1: Schematic diagram of LST.

3.0 RESULTS AND DISCUSSION

From the results, it can be seen that the dimple textures were arranged evenly on the surfaces and heat affected zone was formed around the dimple. The heat affected zone was resulted from the thermal process during the surface texturing. When the heat from laser radiation is absorbed by the copper, thermalization process occurred and resulted to the rising of the temperature. This phenomenon promotes melting of the copper substrate. The melted copper was then ejected to the surface and formed bulges (Figure 2) around the dimple once resolidified (Riveiro et al., 2018). The amount of bulges formed on the surface for both types of samples was observed to be increased when the number of loop was increased. This was clearly seen in the images for L1 to L5 for both type of samples as shown in Table 1.

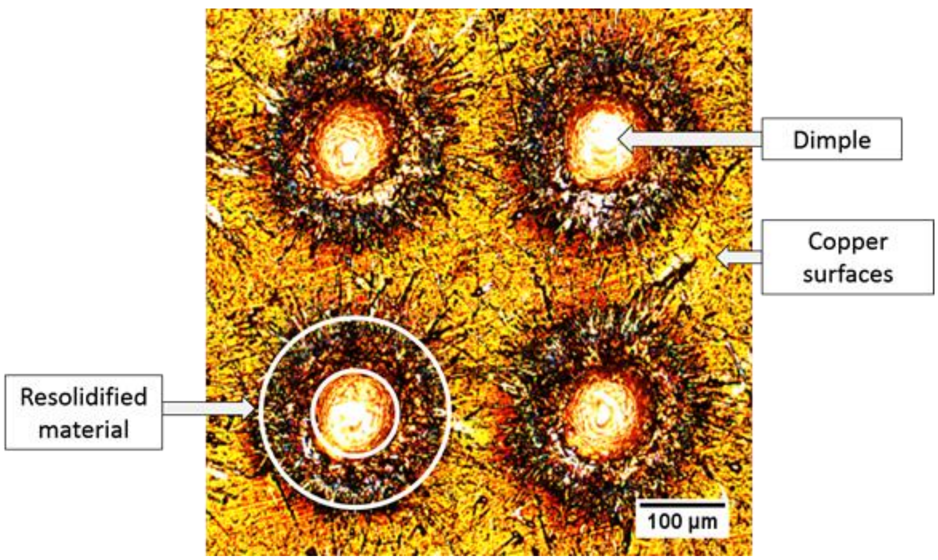
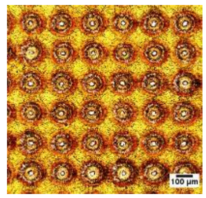
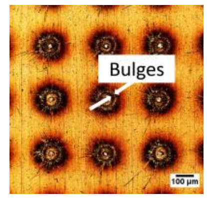
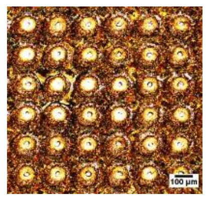
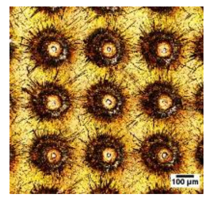
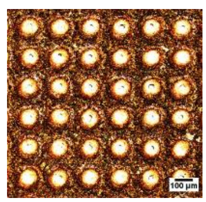
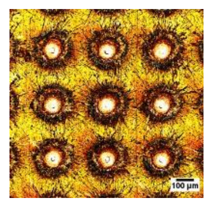
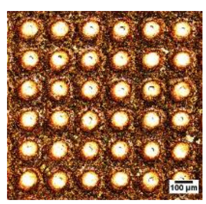
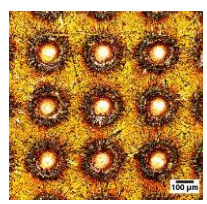
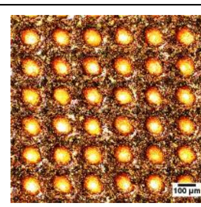
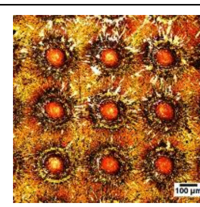


Figure 2 : Resolidified material formed around the dimple on substrate surface.

From the images shown in Table 1, it can be seen that L1 has the smallest amount of bulges compared to other loop for both types of sample. As the loop increases, the bulges become thicker and its size also becomes larger. The bulges become clearer and much easier to be seen in L5 for the sample of 180 µm. These findings were supported by the quantitative analysis of the amount of resolidified material formed on the textured copper surface which was shown in Figure 3. The resolidified copper which was formed around the dimples had increased when the number of loop increases as shown in Table 1. As stated earlier, the increasing number of loop allows longer exposure time and increases the quantity of molten copper. Thus, more melted copper will be ejected onto the surface during the LST process. This melted copper will re-solidify around the dimples which can affect the surface finish and morphology of the substrate.

Table 1: 2D images for micro-dimple surface modified copper.

Number of loop, L	**Dimple distance, D (μm)**	
	100	**180**
L1	 (a)	 (b)
L2	 (c)	 (d)
L3	 (e)	 (f)
L4	 (g)	 (h)
L5	 (i)	 (j)

The melted material produced by laser and copper substrate interaction led to a major problem in surface texturing (Hanon et al., 2012). Irregular shape of the bulges or resolidified material formed on the surface and incomplete ejection of the molten material to the surface affect the shape and the depth of the dimple. When the re-solidification process occurs on the surface, the ejected material might partially close the dimple opening. This will affect the circularity of the dimple as the dimple opening become smaller and caused irregularity of the dimple shape. Other than that, at the end of the laser–substrate interaction, the molten copper tends to return back into the dimple due to the gravitational force (Vora et al., 2012). Low ejection pressure also leads to the molten copper to re-solidify inside the dimple. This will result to the inconsistency of the dimple volume and depth.

The resolidified materials are usually polished off before proceeding to another experiments in order to maximize the effectiveness of the micro-textured surface (Hu et al., 2012; Kovalchenko et al., 2005; Ripoll et al., 2013). Some studies were carried out to report the influence of the resolidified material on several applications. Greiner et al., 2015 studied about the influence of the bulges under two different conditions which were dry and lubricated conditions. It was reported that there was an increase in friction under dry condition. Meanwhile for lubricated condition, the friction decreases. Several researchers also stated that the resolidified material on samples help to decrease wear (Mishra & Polycarpou, 2011) and friction (Amanov et al., 2013). Rapoport et al., 2008 investigated about friction and wear of MoS2 films on laser textured steel surfaces. He reported that the surface with bulges had a better adhesion of solid lubricant as compared to the surface without the bulges. However, it was found that large amount of resolidified material led to micro cracks on the machined surface and resulted the fatigue failure of friction pair. Hence, the resolidified material on substrate surface will be beneficial in engineering practice depending on the targeted application.

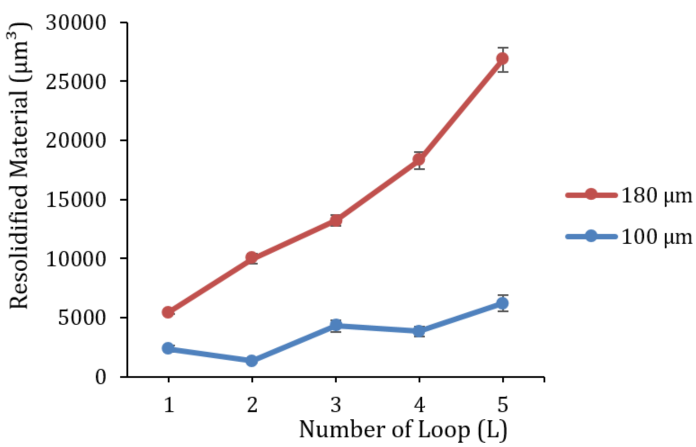


Figure 3 : Resolidified material for different number of loop.

The formation of resolidified material on copper surface resulted to the increment of surface roughness. Figure 4 shows the surface roughness of dimpled surface modified copper. It was clearly shown that the surface roughness increased steadily as the number of loop increases for both types of samples. For L1, the surface roughness, R_a was found in the range of 4.568 μm for 100 μm sample whereas the 180 μm sample was in the range of 2.767 μm. A similar behaviour was shown by L5 which is the highest surface roughness, R_a was achieved in both types of samples. The surface roughness, R_a was around 26.002 μm for the sample of 100 μm and 15.983 μm for the sample of 180 μm. It can be seen that the surface roughness for 100 μm sample was higher than 180 μm sample. As the distance between dimples is shorter, the resolidified material was grown overlapped which led to more irregularities on surface and hence, influences the surface roughness (Ma et al., 2013; Viana et al., 2015).

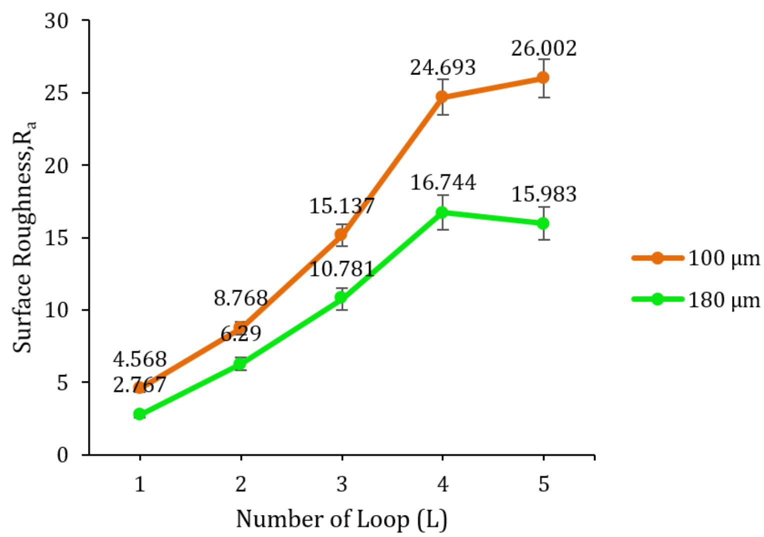


Figure 4 : Surface roughness of dimpled surface modified copper.

In this study, the laser parameter strictly influenced the surface morphology of copper substrate subjected to the variation of number of loop. During laser – substrate interaction, the temperature will increase and the copper substrate changes its phase from solid to liquid. Similarly, the molten copper changes its phase from liquid to solid during cooling cycle. This process generates rough and irregular surface texture of the modified surface copper substrate.

4.0 CONCLUSION

The effects of laser loop on the formation of resolidified material on copper substrate have been investigated. The formation of bulges on the surface affect the morphology of the copper substrate. Longer exposure time between the laser beam and the substrate produced high amount of resolidified material and increased the surface roughness. The existence of this resolidified material will reduce the quality of surface finish of the copper substrate and leads to some damages to machinery parts. However, at the same time, in some cases, the rough surface could be beneficial in reducing surface friction in order to mitigate wear problems.

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