THERMAL STABILITY OF LASER TREATED DIE MATERIAL FOR SEMI-SOLID METAL FORMING

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ABSTRACT: This paper presents laser surface modification work performed to improve the lifetime of die materials. Die material AISI H13, with typical hardness in the range of 42 to 48 HRC, offers high wear and corrosion resistance. However the cyclic high temperature conditions along with exposure to high viscosity molten metal in semi-solid forming cause the die to wear and crack with resultant shortened die lifetime. In this study, the thermal stability of die material at elevated temperature was investigated through micro-hardness testing and a metallographic study. AISI H13 samples were laser glazed using CO_2 continuous wave mode laser with 10.6 µm wavelength. Samples were attached to a specially designed rotating chuck to enable it to be rotated at speeds up to 1500 rpm and allow flat surface glazing to take place. The micro-hardness was measured for as-glazed samples and annealed samples which were held at temperatures ranging from 550^{o}C to 800^{o}C with 50^{o}C intervals. The metallographic study conducted examined the formation of three zones at different depths which were the glazed zone, the heat affected zone and the substrate. As a result of rapid heating and cooling from the laser glazing process, a metallic glass layer was developed which exhibited an average micro-hardness of 900 HV when exposed to 3.34E+10 W/m^2 laser irradiance within a range of 3.64 to 5.66 ms exposure time. Crystallization in glazed zone increased as the annealing temperature increased. As the annealing temperature reached above approximately 600^{o}C, the micro-hardness decreased to approximately 600 HV (equivalent to approx. 54 HRC) due to local crystallization. These findings show potential direct application of glazed dies for non-ferrous semi-solid forming and the requirement for thermal barrier protection for application at higher temperatures.

KEYWORDS: Laser glazing, thermal stability, micro-hardness, annealing and die material.

1 INTRODUCTION

Laser glazing has been studied as a way of surface hardening on die, in order to overcome the premature failure of die application in semi solid casting by developing an amorphous layer on the surface. Though there is current approach such as coating implemented in sustaining the die application, the difficulties are to meet the six requirements of effective coating; excellent bonding, adequate thickness, absence of flaws, suitable mechanical properties, thermal shock resistance and high temperature stability [1].

In semi-solid processing, the forming temperatures are considerably lower than in liquid metal die-casting which can extend die life. Die material AISI H13, with typical hardness in the range of 40 to 50 HRC [2], offers high wear and corrosion resistance. The cyclic high temperature conditions along with exposure to high viscosity molten metal in semi-solid forming would cause the die to wear and crack with resultant shortened die lifetime. Though H13 steels be able to withstand the relatively high working temperatures involved, however when the temperature is above 600°C, the dies are easy to wear and collapse, so the die life at high temperature is not long enough [3].

In previous work [1], laser glazed steel surface exhibited enhanced hardness property as much as 30% compared to the substrate as a result of fine grains and secondary carbides formation. Reviewing other study on laser glazing [4], a thin layer of laser glazed surface possessed hard non-equilibrium microstructures that were intimately bonded to the substrate, and the modified region itself. A number of phases were present during the process due to rapid solidification and rapid cooling. However, referring to Yang et al [6], an amorphous layer was developed through laser glazing process even at multi pass region where overlapped zones did not recrystallize during the consequent laser pass. To improve the die lifetime, surface modification using laser glazing was investigated in this work. The thermal stability of die material at elevated temperature was investigated through microhardness testing and metallographic study. The combination of wear resistance, high strength and thermal stability can increase significantly the lifetime of the die and therefore decrease unit production cost.

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2 EXPERIMENTAL

AISI H13 samples prepared in this study were laser glazed in as received condition. The chemical composition of AISI H13 detected from the energy-dispersive X-ray spectroscopy is in Table 1.

A specially designed rotating chuck is attached to a moving bed beneath the laser head which produce both rotational and linear movement of the sample as shown in Figure 1. Samples were glazed by continuous operating mode of CO_2 laser. The laser system specifications are detailed in Table 2.

To ensure the exposure time and power density affecting the surface as referred to previous works [4-8], the rotation speed was kept constant at 1500 rpm which allowed the exposure time to increase as the surface radius decreased. The laser started at the edge of the sample with maximum radius of 20 mm and stopped prior the centre point to avoid accumulation of high concentration laser energy.

Samples were sectioned and metallographic preparation was done through grinding, polishing and nital (2-10%) etching. Formation of glazed layer was examined under Scanning Electron Microscope (SEM) which also achievable for depth and grain size measurement. The difference of microhardness property in laser glazed surface and annealed samples was measured using Vickers test at 981 mN load. Annealing process was conducted at various temperatures of 550°C, 600°C, 650°C, 700°C, 750°C and 800°C. Samples were annealed for 15 minutes and cooled in ambient air to observe the effects of elevated temperatures on the laser glazed surface properties including the structure and hardness.

Table 1: *Chemical composition of AISI H13*

Element	C	Mn	Si	Cr	Ni	Mo	V	Cu	P	S	Fe
wt %	0.32-0.45	0.20-0.50	0.80-1.20	4.75-5.50	0.30	1.10-1.75	0.80-1.20	0.25	0.03	0.03	balance

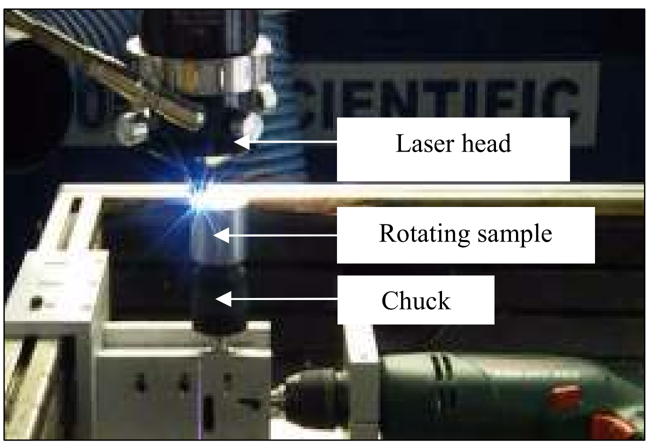

Figure 1: *Laser glazing apparatus*

Table 2: *Laser system specifications*

Power	1.2 kW
Beam geometry	Circle
Focal position	Surface
Spot size	0.2 mm
Assist gas	Argon
Laser beam mode	TEM_{00}
Laser wavelength	10.6 µm

3 RESULTS AND DISCUSSION

3.1 EFFECT OF EXPOSURE TIME ON GRAIN SIZE

Development of grain size in laser glazing process is depends on the cooling rate. Without a particular thermal modeling or thermal imaging camera to determine the temperature gradient, the cooling rate is estimated by calculating the exposure time. Due to radial change of the sample through the process, a range of exposure time was gained which result in variations of grain size.

Figure 2 shows an SEM back scattered detector micrograph of as received H13 tool steel with a magnification of 7.92 kX. From the micrograph, it is found that the as received H13 tool steel has grain size approximately 3-9 µm.

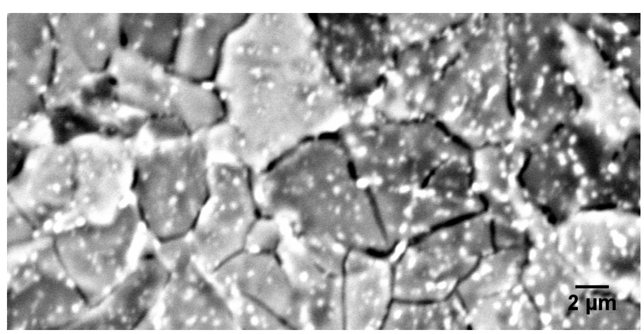

Figure 2: *SEM back-scattered detector micrographs of as-received H13 (7.92 kX magnification)*

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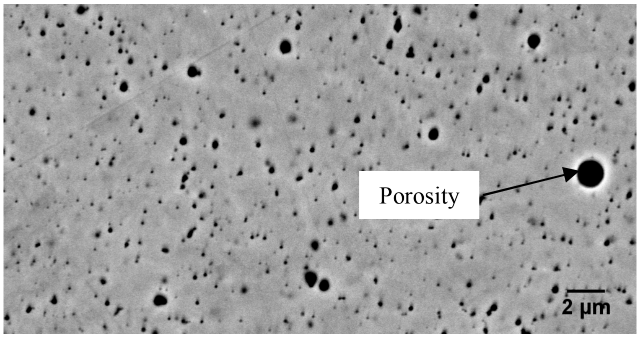
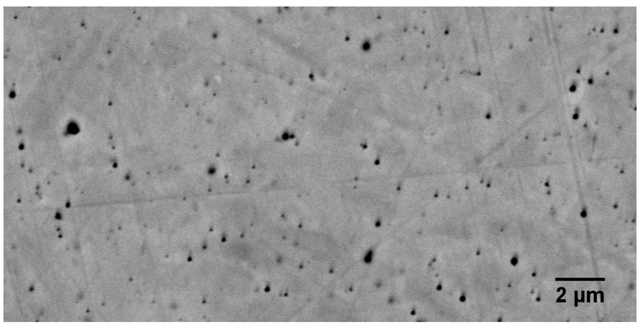


(a)



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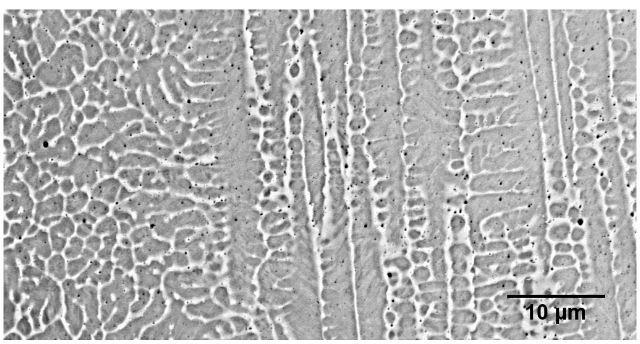

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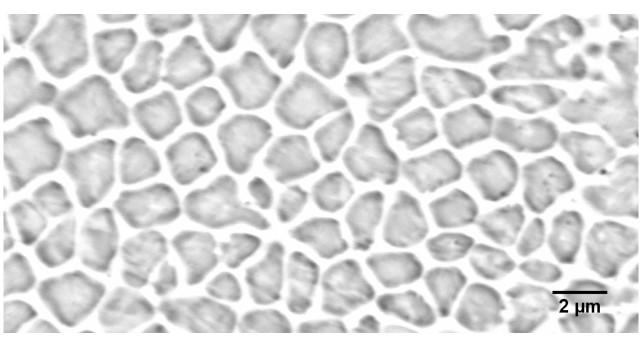

(d)

Figure 3: *SEM back-scattered detector micrographs of grain size in laser glazed tool steel at exposure time of (a) 4.63 ms (9.14 kX magnification), (b) 3.64 ms (11.73 kX magnification) (c)1.82 ms (4.70 kX magnification)and (d)less than 1.82 ms (12.88 kX magnification).*

Micrographs in Figure 3 show the increasing grain size towards the edge of the sample as a result of decreasing exposure time. The amorphous structure in Figure 3(a) and (b) is resulted from exposure time between 3.64 ms to 5.66 ms, whereas nano gain size was observed in micrographs in Figure 3(c) and (d) with exposure time ranging from 2.31 ms to 2.68 ms. Longer exposure however developed plenty of large porosity, and tribological defects as pointed out in Figure 3(a). In Figure 3(c) and (d), less exposure time would cause insufficient energy to melt the entire surface which exhibits nano to micron grain size (200-2000nm). Porosity was also avoidable in Figure 3(d) as less laser energy irradiated on the surface. Figure 2(e) depicts the as-received H13 grain size (3-9) for comparison mean.

3.2 MICROHARDNESS OF LASER GLAZED H13

As a result of rapid heating and cooling, a treated layer was developed on the tool steel surface which exhibited an average micro-hardness of 900 HV (equivalent to approximately 67 HRC). It can be seen in Figure 4, an increase in hardness from 800 HV to 1200 HV were achieved in the treated surface. At room temperature, 1200 HV is the maximum hardness that was achieved within the treated region. Then the hardness value start decreasing from 1200 HV to 300 HV when reaching deeper into the substrate. 300 HV is the hardness for the as received H13 tool steel. Understanding the micromechanisms of the crystallization to impede or control crystallization is therefore prerequisite for most applications, as the stability against crystallization determines their effective working limits [8].

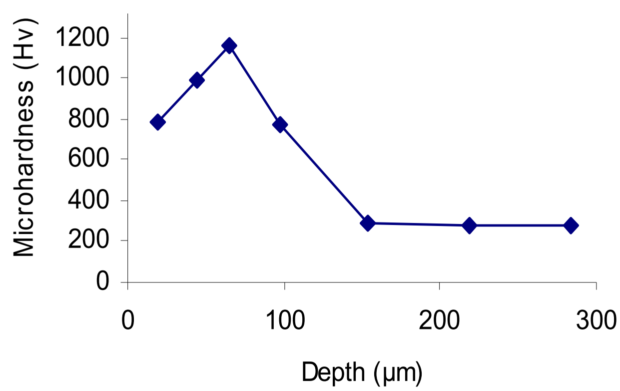

Figure 4: *Microhardness of glazed layer at room temperature*

3.3 THERMAL INSTABILITY OF LASER GLAZED SURFACE

A striking increase of the surface hardness is significant to endure wear and elevated temperature applications. In spite of that, the amorphous material formation is instable when sufficient temperature is applied. This is due to

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crystallization of the amorphous layer at various annealing temperature which presented by changes in microhardness property.

Figure 3 indicates as the annealing temperature reached above approximately 600°C, the micro-hardness decreased to approximately 600 HV (equivalent to approx. 54 HRC) due to local crystallization. Basically, the crystallization in glazed zone increased as the annealing temperature increased.

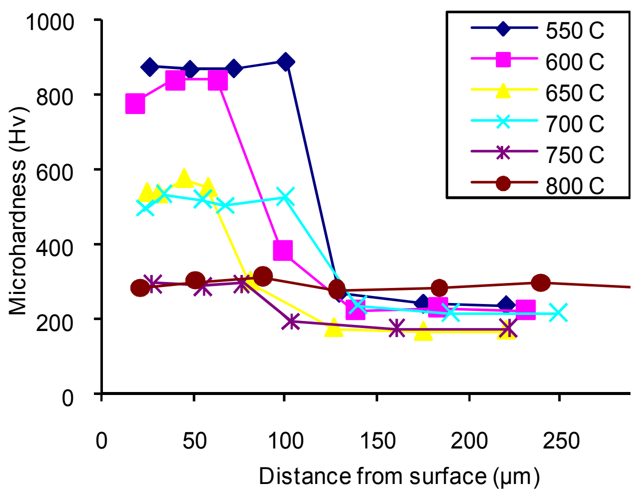

Figure 5: *Microhardness as a function of the distance from surface at different annealing temperature.*

Parallel with previous works of Nieh and Wadsworth [10], the changes of mechanical properties in amorphous metal are characterized by inhomogenous and homogenous deformation at low and high temperature respectively. Due to stability of crystal structure, a consistent deformation occurred as shown by Figure 5 where at 800°C annealing temperature, the microhardness of the laser glazed layer is consistently at ~280HV along the depth. This indicates a fully crystalline structure was transformed at 800°C as well as increasing grain structure. Temperatures less than 800°C affecting the surface to exhibit inconsistent microhardness especially at approximately less than 100μm depth probably due to metastable structure of laser glazed surface.

4 CONCLUSION

This study is beneficial in pointing out the effective working limit for laser glazed die surface through observation and measurement of surface structure and hardness. These findings also show potential direct application of glazed dies for non-ferrous semi-solid forming and the requirement for thermal barrier protection for application at higher temperatures.

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