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Investigation for Hardening of Cast Iron using Low-Power Fiber Laser

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Abstract*— New developments in industry initiate the need to identify newer process/ source for carrying out various tedious applications. Both conventional and non-conventional machining processes are accordingly updating in context with these recent trends. Laser surface hardening (non-conventional machining process), a solid state phase transformation hardening is neither an exception to this. Various researchers have elaborately discussed the importance and implications observed during this process. Cast iron, normally used in various automobile parts is subjected to wear due to sliding contact and hence the selective hardening of mating surface needs to be carried out. Hence, an experimental study of solid-state phase transformations during the laser surface hardening of cast iron is conducted. In this, a fiber laser of power 100 W in continuous-wave (cw) and pulsed mode is used in conjunction with a beam integrator. The process parameters viz; beam power, beam diameter, travel speed and pulse time are varied to study their effects on geometry, dimensions and hardness of heat affected zone.

Index Terms— **Laser, Heat Affected Zone, Micro hardness.**

I. INTRODUCTION

In various engineering applications gray Cast Iron needs to be hardened by changing its microstructure to improve functional characteristics, such as reduce friction, wear etc. The case hardened depth of several millimeters is obtained by conventional methods of hardening the surface of ferrous materials which includes flame and induction hardening. This requires rework or refinishing because of the significant thermal distortion of the components [1], [2]. In laser surface hardening a focused laser beam interacts with the material and heats up the layer depending on its power, physical properties of the material, optical and kinematic conditions. The heated thin layers of surface do not require additional cooling since the bulk of the material serves as a sink. The desired micro-structural changes can be achieved quickly due to heating and cooling cycle attained. Most attractively, laser surface hardening generates low thermal distortion so refinishing of the part can be almost eliminated. The fig. 1 below shows domain for different laser material processing techniques as a function of laser power and interaction time. These processes are divided into three major classes; namely involving only heating, melting and vaporizing. It is evident that low power density heating is required in hardening as the process is carried out without melting of material. On the other hand processes based on melting viz, glazing, cladding, and welding require high power density. Similarly, cutting, drilling and similar machining operations remove material in vapour state hence needs to deliver a substantially high power density within a short interaction / pulse time.

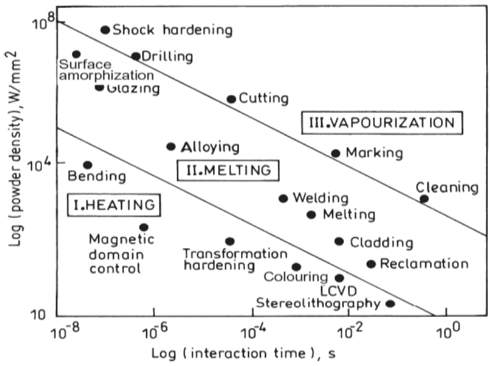

Fig. 1: Different Laser Material Process in Terms of Power Density as Function of Interaction Time

In equilibrium transformation sufficient time is available for diffusion to occur, while during non-equilibrium transformation, time involved is less and process is carried out at conditions far from equilibrium. In laser processing, small amount of region absorbs the energy resulting into high heating and cooling rates and the process is a non-equilibrium transformation which results in formation of hard martensite phase [4]. Fig. 2 shows the solid state decomposition of austenite on cooling. This curve is constructed for conditions of cooling, rather than isothermal transformation. It illustrates that with a very low cooling rate, sufficient time is available for formation of the phases predicted by the equilibrium diagram. As the cooling rate increases, metastable phases such as martensite are able to form.

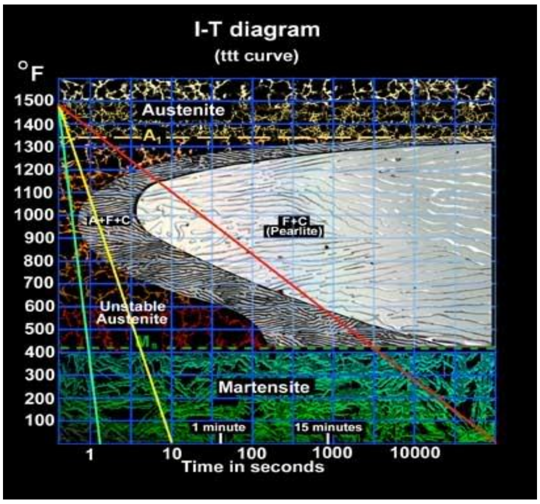

Fig. 2: TTT Curve – Principle for Martensite Formation

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Previous researchers have communicated utilization of continuous wave CO_2 and pulsed Nd:YAG lasers[5]. CO_2 laser exhibits a low coupling interaction with metal materials due to the relatively longer wavelength (10.6 µm) of laser. Thus, painting of work piece is necessary to increase the absorbing rate before exposing to laser radiation. This needs additional procedure in the product line and also brings issues such as pollution and hazardous effects to the environment. Pulsed Nd-YAG laser is emerging as a competitive tool in surface modification due to the shorter wavelength (1.06µm) and high absorbing rate of the metal materials but with very high powers (1 to 3 kW) it leads to higher cost of equipment [6]. The motive of current work is to examine the surface hardened layers obtained using very low power pulsed and CW Fiber laser (100W) of wavelength (1.09µm). Fiber lasers are 15 times efficient than the conventional lasers. The unique design of fiber lasers require less cooling or only air cooling and require no consumables such as lamps or bars to replace thus can be considered as less capital equipment.

II. EXPERIMENTS

Gray cast iron widely used for automobile parts is chosen in this study because its microstructure is simple and the phase transformations during surface hardening are easy to understand. The composition of the cast iron used is shown in Table I and the work-piece with following dimensions 20 mm long, 10 mm wide, and 5 mm thick was selected. The range of power of the laser beam selected for experimentation was 18 to 28 W and the travel speed of the work-piece 0.1 to 0.6 mm/s for CW laser beam and 50 to 95W with 50 to 200 ms pulse width for pulsed beam. Beam diameters are selected by conducting series of experiments with defocused beam in above and below region of the beam from the focussed beam diameter. By varying the beam power and the travel speed/pulse time, heat-affected zones of various depths were obtained. A summary of the beam powers and the interaction time used is given in Table II and Table III. After surface heat treatment the work-piece were sectioned transverse to the direction of travel, polished, and etched with 4% Nital. The microstructures of the heat-affected zone were examined and the microhardness and the size of the heat-affected zone were measured. Table II and III are shown in Appendix.

Table I: Composition of Work-Piece Material.

Specimen	Components						
	C	Mn	Cr	Si	Cu	P	Mo
Gray Cast Iron	3	87	95	5	36	50	12

III. RESULT AND DISCUSSION

The experimental results obtained indicate substantial rise in hardness as compared to that of the parent material endorsing the feasibility of laser hardening using fiber laser. From the micro hardness examination, it is apparent that the micro hardness level in the hardened layer averages about 900 HV. It is significantly higher than that at the substrate region, which averages about 200 HV. It is significantly higher than that at the substrate region, which averages about 200 HV. The increased hardness of laser processed specimens is matching with the hardness of martensite and confirms phase transformation. Table II shows the typical geometric dimensions of specimens processed with CW laser source for various powers and scanning speeds. The faster the scanning speed, the lesser is the interaction time between the laser beam and the specimen. This results into less heat input and the less transformation zone as observed in specimen 3. Table III indicates microstructures for specimens processed using pulsed mode of laser source. The power was kept constant and pulse width was varied, resulting into variation in energy density. Shorter pulse width results into shallower hardened depth and increased hardness value as cooling rate has increased.

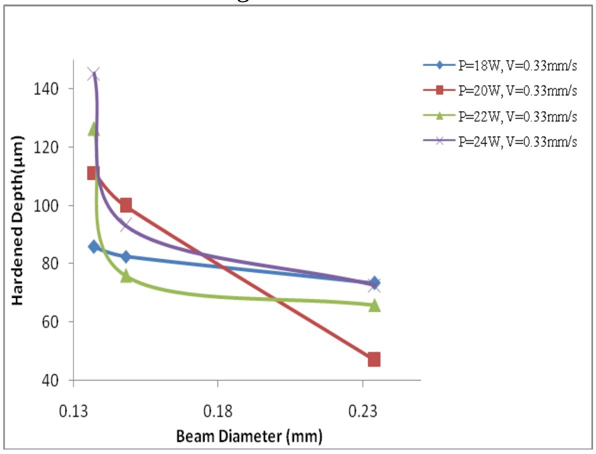

Fig. 3: Beam Diameter V/S Hardened Depth

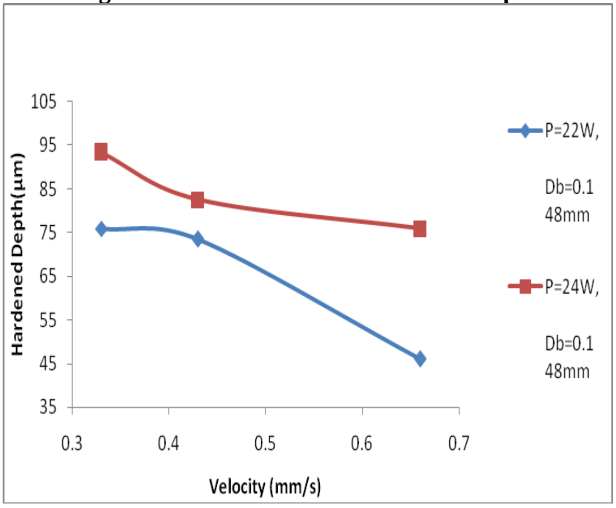

Fig. 4: Velocity v/s Hardened Depth

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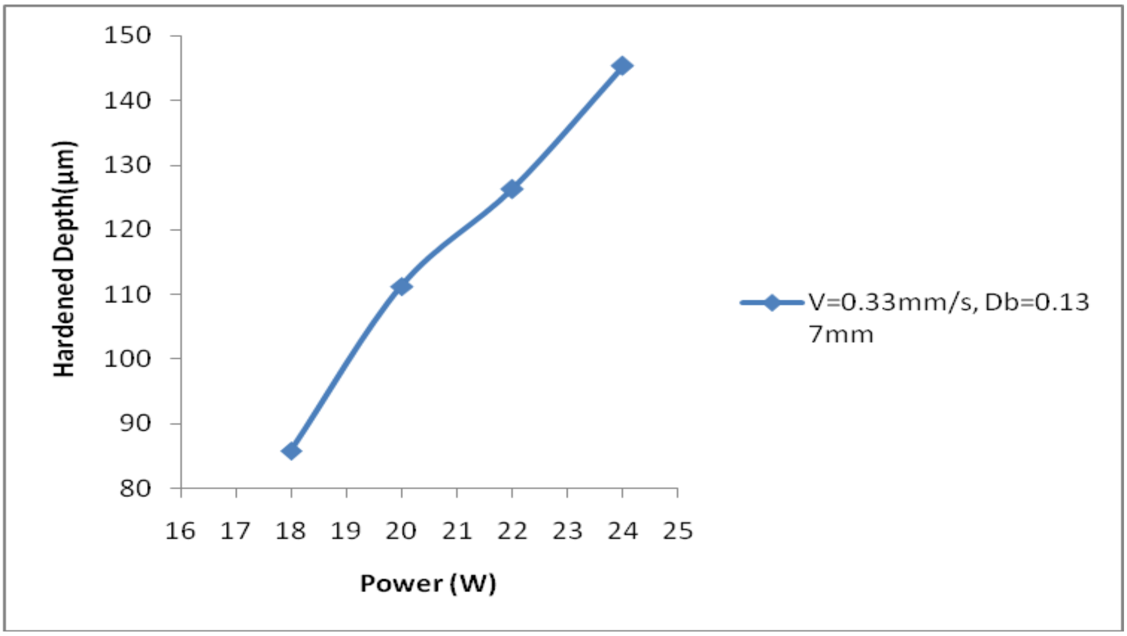

Fig. 5: Power v/s Hardened Depth

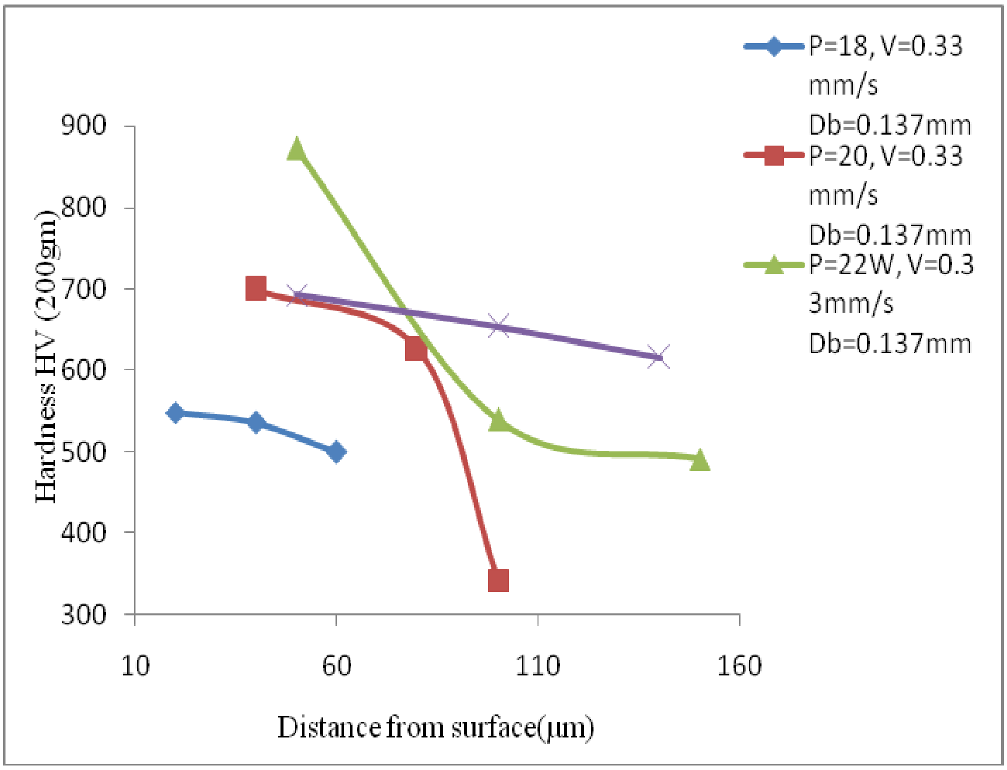

Fig. 6: Hardness Profiles in Samples Processed Under Different Processing Speeds

Graphs of hardness (Fig 4 to 6) versus various process parameters were traced in order to understand the influence of variation of these parameters on the resulting hardness value. The slopes of the fitted lines are nearly equivalent to each other which indicate that the increase in hardened depth is due to increase in power density. The hardness depth decreases with increase in velocity as the interaction time reduces.

IV. CONCLUSION

Application of low power fiber laser (100W) for effective restructuring of Cast iron surfaces and growth of its micro hardness has been explored and found commercially viable.

On selecting optimum process parameters for laser hardening micro hardness up to significant depth can be obtained without melting. If further laser power is increased melting of work piece material can be observed resulting into recast layer which further attributes to increase in hardness [7]. Evaporation of cast iron at higher power results into formation of micro-channel/ dimples on the surface. If the micro-channels/dimples are retained; narrow pockets are formed that can serve to store the lubricant which can enhance lubrication effect. Thus, application of low-power lasers in a number of cases (despite smaller speeds of processing) can appear economically more favorable as it avoids post process machining / correction of surface with minimum distortion (due to low power thermal process) in comparison to expensive large-sized powerful CO_2 (up to 10 kW) and Nd: YAG lasers used nowadays.

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Appendix

Table II: Laser-processing parameters and experimental results (CW)

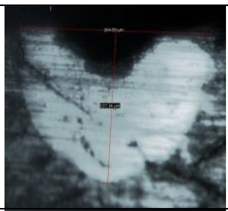
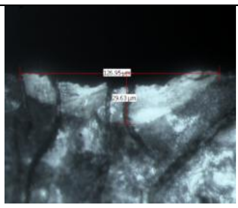
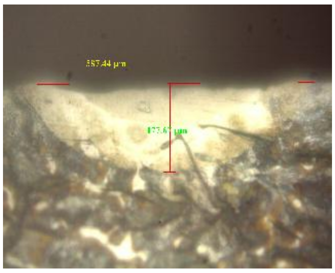
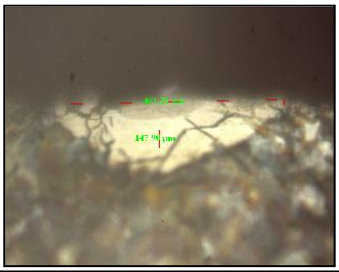
Specimen no	Microstructure	Power (W)	Velocity (mm/s)	Beam Diameter(mm)	Width (µm)	Depth (µm)	Average Hardness $HV_{(200gm)}$
1		22	0.33	0.11	148.57	127.3	634.2
2		24	0.33	0.10	212.95	130.27	654.1
3		24	0.43	0.195	126.92	30	633

Table III: Laser-processing parameters and experimental results (Pulsed)

Sr.No.	Image	Power (W)	Pulse Width (ms)	Width (µm)	Depth (µm)	Hardness $(HV)_{0.2}$
1		90	150	587.4	177.6	723
2		90	100	461.2	147.9	1062.2