Characterizing the Effect Of Laser Power On Laser Beam Formed Titanium Sheets

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***Abstract*—Laser forming is a new advanced technology in manufacturing for the bending of sheet metals and the joining of metallic components in automobile, microelectronics and the aerospace industries. In the laser forming process, various factors such as the laser parameters and the material properties need to be considered in order to achieve optimum properties after laser forming. This paper reports the effects of the laser power on the resulting curvatures of the laser beam formed Titanium sheets. The laser formed samples were characterized through the microstructure and the mechanical properties. The results obtained during the microscopic evaluation of the specimen showed that the grain sizes of the formed samples increases and is proportional to the laser power employed to form the samples. It was also found that the Vickers microhardness is directly proportional to the laser power and the radius of curvature increases with a decrease in the Laser power. Hence, the grain size is also directly proportional to the Vickers microhardness of the sample**

***Keywords*—** Laser forming, laser power, beam diameter, microstructure, microhardness, titanium sheets.

I. Introduction

The last two decades have been marked by the introduction of laser beam forming (LBF) as a new manufacturing process. The first work on laser forming of sheets was reported and attributed to Namba in 1985 [1]. Laser forming is a non-contact flexible forming technique of forming sheet metal components [2]. The sheet metal is formed by internal thermal stress induced by the laser [3]. Originally, laser forming was used as an alternative to standard manufacturing in the automobile and the aerospace industry, given the fact that it eliminates the need to use specialized dies, and reduced setup time. It also made it possible to trim, drill and weld just after the forming process. This process can be considered as a green technology as there is no pollution involved. The laser power, laser spot diameter, scanning velocity and the scanning path are some of the parameters that influence the LBF process. There are five (4) main mechanisms involved in the laser forming process, this include: the Temperature Gradient Mechanism (TGM), Buckling Mechanism (BM), Upsetting Mechanism (UM), Point Mechanism and the Coupling Mechanism (CM). These mechanisms have been fully discussed in [4]. LBF also finds its application in versatile industries from small-scale to large scale industries such as aerospace, automobiles, ship buildings and micro electronics industries [5-6]. The behaviour of a metal during a laser forming process depends on a definite and appropriate combination of the laser processes parameters [5], these include the laser power, the beam spot diameter, the scanning speed, the pulse duration, the pulse frequency and the sheet thickness. The clamping system and the shield mechanism also play significant roles in achieving optimum results in laser forming. Moreover, it also depends on the material and the geometric parameters. The laser forming process has been studied in diverse applications of many materials including mild steel, stainless steels, aluminum and aluminum alloys, titanium and its alloys

Several efforts have been put in place to explore the effects of laser forming on sheet metals. Different types of materials have been laser formed and characterised. Maji et al., [5] investigated experimentally a pulse laser bending of AISI 304 stainless steel and studied the effects of the LBF process parameters. They found that the bending angle increased with an increase in the laser power and pulse duration but decreased with an increase in the scanning speed and the beam spot diameter. The most favourable process parameter to obtain a maximum bending angle was also found to be the optimum pulse frequency. Jamil et al., [7] investigated numerically the effect of rectangular beam geometries with different transverse width to length aspect ratio on laser bending processes of thin metal sheets which is controlled by buckling mechanism. They found that the geometry of the beam is very important and there is a relationship between the temperature distribution and the buckling. They concluded that the buckling effect generates an opposite curve profile which presents a convex curve along the transverse direction and concave along the scanning path of the sheets.

Chen et al., [8] conducted a research based on the effects of laser-induced recovery process on conductive property of SnO_2: F thin films. They found that when the laser power is smaller than 2.0 kW, the crystallite size seems to be invisible, but in contrary when the laser power is greater than 2.0 kW, the crystalline become enlarged. They concluded that laser power has an influence on the mechanical properties of the material. Akinlabi et al., [9] also investigated the laser beam forming of 3 mm of steel sheets and found that the LBF process modified the microstructure of the parent material. Moreover, the formed samples exhibited a major increase in the microhardness with about 42% increase and thus the tensile strength and the yield strength of the material were also improved. Similar results were also achieved by some other researchers [10] [11]. Walczyk et al., [1] conducted a research on laser bending of Titanium sheets (Ti-6Al-4V). They found that laser bending is as an alternative method to hot brake forming. They demonstrated the controllability over various laser parameters, bend geometries and material properties by identifying the process and response variables and their mutual relation. ANOVA and Taguchi methods were used to analyze the results. They concluded that the bending effect for a single laser pass was able to be controlled with simple changes to the power settings of an Nd:YAG laser, the workpiece and the feed rate. The bending angle was found to increase linearly with the number of laser scans over the same scan path.

Further investigations in this field of study have been extended to attempts to simulate the process [12], [13], [14], [15]. Zhang et al., [15] investigated the Finite Element stimulation of laser bending of sheet metals. They found a good correlation between the simulations and the experiments conducted. Their results showed that the peak temperatures of the upper surface increase when the laser power or the path curvature increases, but decreases with the increase of the laser spot diameter or the scanning velocity. They also found that when the laser energy density increases, the peak temperatures also increase. Finally, they found that the curvature resulting from bending increases when the laser energy density or the path curvature increases.

Laser power is an important parameter in LBF processes. The variation of laser power is generally restricted by other processing conditions [7] and may influence more or less the properties of a material. Laser power is often used to reduce the yield strength in high temperature of a material [16]. In this research study, the effect of the laser power was evaluated by characterising the evolving microstructure and the microhardness of the formed samples. The methodology is presented in section two while and the results and the discussions are presented in subsequent sub sections of the paper.

II. EXPERIMENTAL SET UP

The forming of the Titanium alloy - Ti-6Al-4V sheets was accomplished on an Nd: YAG laser equipment at the National Laser Centre of Council for Scientific and Industrial Research (NLC-CSIR), Pretoria, South Africa. The titanium sheets were of 90 mm x 30 mm x 15 mm in dimension. The flat samples were placed in an open mould as presented in Fig. 1.

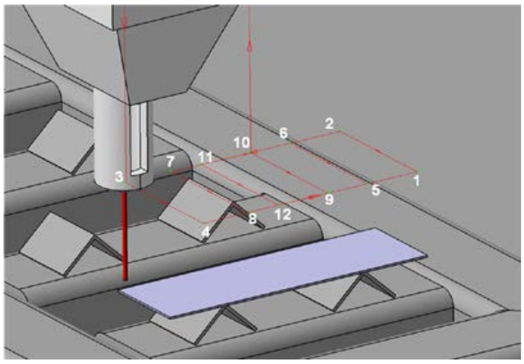

Fig. 1: Schematic of LBF experimental set up [17]

The laser system was set at different powers of 800W, 1000W and 1200 W was employed with optimised constant settings as stated below:

- Beam diameter, d = 12 mm
- Number of scan, N= 5 passes
- Scanning velocity, V= 0.05 m/s

The formed samples were then cooled using the argon gas.

After forming, the formed samples were sectioned at the centre at a point representing the point of maximum deformation for evaluation. The samples were mounted hot polyfast resin, grinded and polished according to ASTM standard [18]. Kroll's reagent was used as the chemical etchant. The microstructures of the cross sections were observed under the optical microscope (Olympus BX51) to evaluate the resulting microstructure. The grain sizes were also measured using the measurement tools on the optical microscope. Finally, the Vickers microhardness was measured using a Vickers hardness indenter machine according to ASTM standard [19]. A 500 gf was employed with 15 seconds dwell time.

III. RESULTS AND DISCUSSION

The results obtained and the correlations observed are discussed in this section.

A. *Macro appearances of the formed sheets*

The macroscopic observations of the formed samples at 800W, 1000 W and 1200 W are illustrated in Fig. 2 (a) to (c). The degree of smoothness / coarseness of the Heat Affected Zone (HAZ) were observed and characterised.

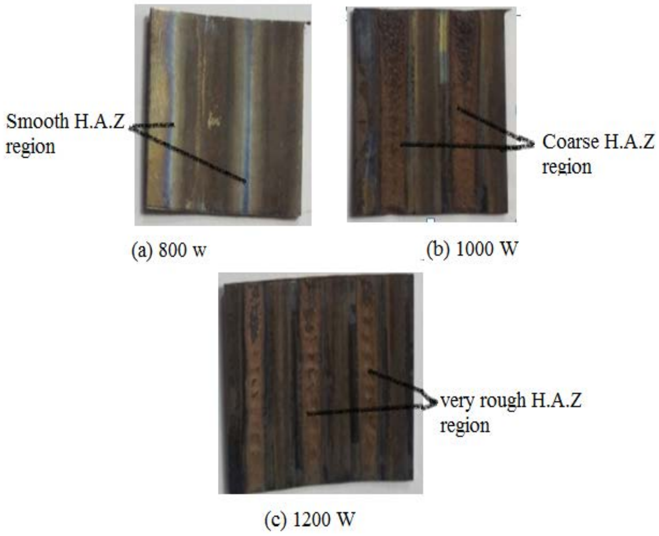

Fig. 2: The macroscopic photo of the formed samples

From the Figures, it is observed that typical flow lines are found in the region scanned by the Laser. The macrographs show that the flow line present a rough aspect which increase with an increase of the laser power as seen in Figure. The formed sample at 800 W possesses a smooth surface and bent lightly as the relatively small power is applied. The sample formed at 1000 W sample presents a semi-rough pattern that is not as smooth compared to the sample formed at 800 W when touched and finally the sample formed at 1200 W has much larger deformations (bulging) that can be seen and felt much more evidently due to the laser path. The dark region (discoloration) associated with the samples formed at 1000 W and the 1200 W laser powers is the path which the laser has scanned over and also appear susceptible to rust.

B. *Effects of the laser power on the resultant curvatures*

The corresponding radius of curvatures of the triplicate samples are presented in Table 1.

Table 1: Laser power and the resultant radius of curvatures

Laser Power (W)	Average radius of curvature (mm)			
	R1	R2	R3	Mean
800	157.08	164.30	164.30	161.89
1000	138.67	138.67	141.78	139.70
1200	109.60	112.0	109.60	110.42

From the Table, it is observed that as the laser power increases, the radius of curvature decreases. Hence, the laser power is inversely proportional to the radius of curvature. From the results obtained, a conclusion can be drawn that as you increase the power of the laser, the beam tends to increase the bend on the material thus decreasing the radius of curvature. The increase in power will lead to an increase in temperature gradients in the heating phase of the laser forming experiments. Greater compressive stresses are developed due to the increased laser power. This greater stress will lead to larger thermal contraction of the top surface during the cooling phase which causes the part to increasingly bend upwards as the laser power is increased thus reducing the radius of curvature. Thus, there is an inverse relationship between the power of the laser and the radius of curvature.

As the power increases, laser-material interaction increases. The heat transferred by the laser beam is high and thus the sheet metal is allowed to bend more when the power increases. Similar conclusions were made in [18]. From this research study, they concluded that an inverse relationship exists between the measured curvature and the laser power. As the laser power increases, the radius of curvature becomes smaller, having the two ends of the plate more closely. Hence, the laser power has positive effect on the deformation of the Titanium sheets.

C. *Microstructural evaluations*

The microstructures of the cross sections of representative samples of the parent material and the formed samples the formed samples at 800 W, 1000 W and 1200 W. are presented in Fig. 3 (a) to (d) respectively.

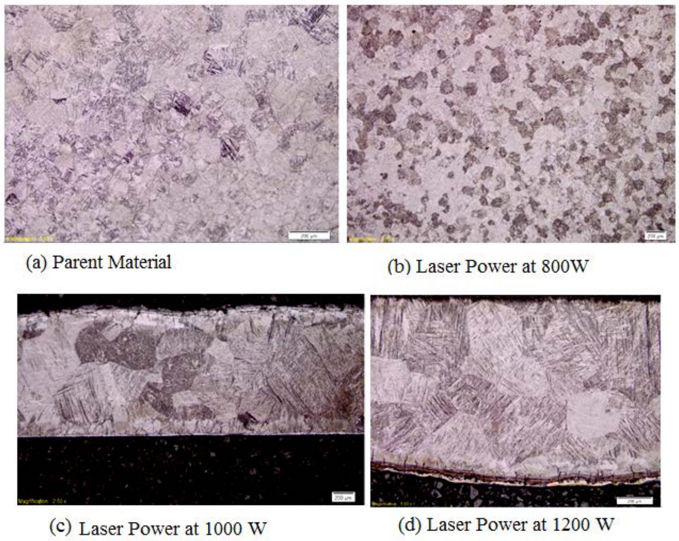

Fig. 3: Cross section of the parent material and the formed samples

From Fig. 3, it is observed that the grain sizes of the parent material are the smallest. The grain sizes of the formed samples after the laser forming at 800 W increases subsequently from the 800 W to the samples formed at 1200 W respectively. Thus, it can be concluded that the increase in the power of the laser led to an increase in the sizes of the grains. This can be explained by the fact that at higher power, the laser beam becomes hotter and this causes a greater expansion and dispersion of the grains. However, at 1200 W, the primary α phase embedded in the transformed β phase results into the α' martensitic structure observed in the microstructure.

D. *Grain size characterisations*

The measurement of the grains was achieved by using the measurement tool of the software of the microscope. The average individual grain size of five measurements for the formed Titanium sheets at 800 W, 1000W and 1200 W are presented in Fig. 4 for the cross-sections of the samples.

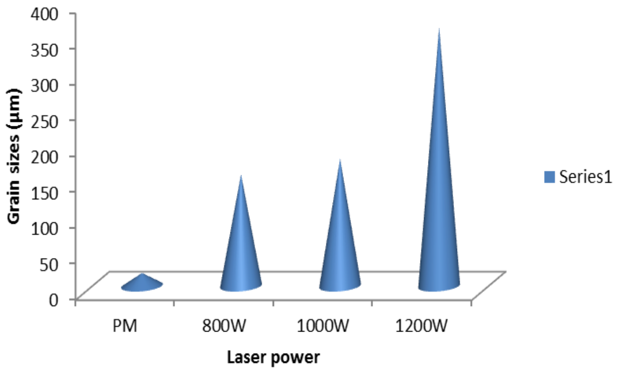

Fig. 4: Grain size characterisations

From the results obtained in Fig. 4, it was observed that the grain sizes of the microstructural zones of the cross sections increase with an increase of the laser power. This resulted in the formation of recrystallized grains in these regions. It should be noted that there are some regions where grains could not be measured due to plastic deformation; hence these grains were measured where they were visible.

E. *Microhardness profiling*

The Vickers microhardness profiles of the parent material and the laser formed samples are presented in Fig. 5.

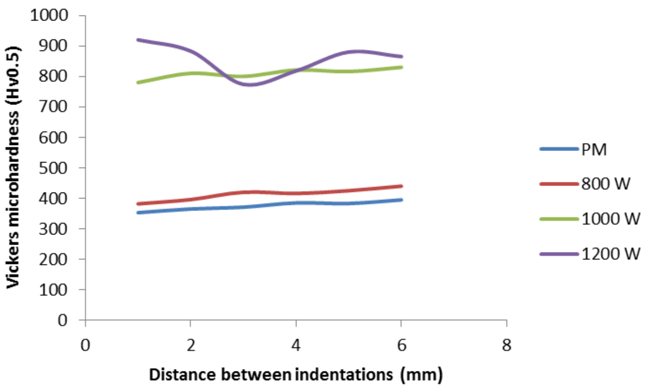

Fig. 5: Vickers hardness indentations

From Figure 5, the Vickers Microhardness test revealed an increase in the microhardness of the formed samples as the laser power increases; the hardness of the sample formed at 1200 W being the highest. This is expected due to the presence of the martensitic structure found in this particular sample.

IV. Conclusion

The laser forming of titanium alloy grade 5 – Ti6Al4V sheets were successfully conducted at varying laser powers and characterised. The following conclusions can be drawn:

- The surface temperatures of the sheet metal increases with an increase in the input power resulting in different degrees of surface finishes observed on the laser formed samples. The sample formed at a very high laser power of 1200 W being the roughest.
- The resultant radii of curvatures are inversely proportional to the laser power. That is, as the laser power increases, the radius of curvature decreases.
- Microstructural characterisations revealed that the average grain sizes increase with an increase in the laser power due to an increase in the laser-material interactions leading to the deformations of the grains. Martensites were observed in the samples formed at 1000 and 1200 Watts respectively.
- Consequently, the Vickers hardness of the formed samples increases as the laser power increases compared to the parent material.

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