The Influence of Scanning Speed and Number of Scans on the Properties of Laser Formed Steel

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ABSTRACT

Laser Beam Forming (LBF) process is an emerging and new forming method that generally requires brute force to forge the steel into the desired shape instead of using conventional methods. This study investigates the changes that occur in low carbon steel through the laser beam forming process. The parameters under investigation include variable scanning speed and number of scans at fixed laser intensity. The effect of these laser parameters on the chemical composition and properties of low carbon steel is assessed through characterisation of both the as received and LBF formed specimens. Characterizations of the laser formed steels were studied using microstructural analysis and micro hardness profiling. The results show that there is a significant increase in the mechanical properties of the LBF formed materials. Scanning power and the number of scans have a noticeable effect on the curvature achieved in the formed samples.The results obtained will contribute towards the further optimization of laser forming methods for steel for the optimization of the properties of steel using Laser Beam Forming process.

Keywords: Laser Beam Forming, scanning speed, laser power, mechanical, microstructure, micro hardness, number of scan

1. INTRODUCTION

Laser is an important technology with exciting properties that makes it highly valued in most human endeavor. The importance of laser in engineering in general cannot be over emphasized and in material processing. Laser Beam Forming (LBF) is a process that is used for the shaping of metallic as well as non-metallic components .This is achieved by introducing thermal stresses into the surface of the material by irradiation with a defocused laser beam [1, 2]. Laser forming enables flexible shaping of metallic components without mechanical contact, for rapid prototyping, creating complex 3D-shapes and removing distortion [3, 4]. Laser forming does not require the use of mechanical forces to shape a metal, but relies on the introduction of thermal stresses to the surface of a work piece, which in turn induces plastic strains and bending of the material results in local elastic plastic buckling [5]. Thermal stresses are induced through the high localized heating of the material as the laser beam is guided across the sheet surface [6]. The chosen path and properties of the laser are dependent on the desired forming result. In the simplest case the laser may make contact with the sheet metal at a point, or in other cases it may be a straight line across the whole part [7]. For spatially formed parts and extrusions, the laser paths could be very sophisticated radial and tangential lines [8, 9]. The process has a potential to play a significant role in the aerospace, automotive shipbuilding and micro-electronics industry and able to produce metallic, predetermined shapes with minimal distortion [10, 11]. This research is aimed at improving understanding of the best combination of the laser parameters between laser scanning speed, and the number of laser scans, and specific properties of a laser formed. The results obtained will contribute towards the further optimization of laser forming methods for steel for the optimization of the mechanical properties of the steel. The research will help draw a relationship between the material properties and the laser properties.

2. EXPERIMENTAL MATERIAL AND PROCEDURES

The selected material used for this research work is a mild steel sheet metal with a thickness of 3mm having a chemical composition presented in Table 1. Each Sample was cut to the same 50mm by 200mm dimensions to ensure that each sample would have the same starting parameter. The laser forming process was carried out on the mild steel specimens using different laser speed, number of scans, and laser power by a Koka robotic with a laser beam 4.4 Kw Nd :YAG Shown in Fig.1. Table 2 shows the laser experimental matrix of laser parameters used. The composition of the steel was carried out on the as-received and LBF specimens with emission spectroscopy using Quantron Advanced Analytical System to determine the impact of the laser on the material properties of the mild steel. Microstructure characterization of the as received and laser formed materials were conducted to gain the structural configuration of the sample using optical electron microscopy to determine the effect that the laser beam has on the structure of the materials. The Vickers micro hardness was measured on the processed materials using a micro hardness tester with a load of 300 g and using a dwell time of 15 s.

Table 1: The Chemical Composition of the As Received Material

Elements	C	So	Mn	P	S
% by weight	0.025	0.029	0.222	0.0084	0.0082
Elements	Cr	Mo	Ni	Al	Fe
% by weight	0.012	<0.0050	0.0038	0.050	99.59

Table 2**:** Experimental Matrix

Sample	A		B		C	
	A-1	A-2	B-1	B-2	C-1	C-2
Power (W)	2 400	2 400	3 600	3 600	1 800	1 800
Beam	12	12	12	12	12	12
Number of Scans	3	5	3	5	3	5
Scan Speed (m/s)	0.08	0.08	0.11	0.11	0.045	0.045

Figure 1: Experimental set up

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Curvature and laser parameters

In order to understand the relationship between the laser parameters and the curvature of the formed materials Fig.2 shows the results of effects of power and scanning speed on curvature of the mild steel samples. Table 3 shows the radius, length and curvature diameter of the mild steel after laser beam forming. Increasing in the number of scans has a resulted in a decreased radius of curvature i.e. increased bending angle achieved in the samples. This can be due to the longer periods the laser irradiated the surface of the material, thus giving more time for the heat from the surface to penetrate deeper into the sample resulting in a higher deformation. therefore this shows that the laser power is the main contributor to the levels of curvature and the slower scanning speed allows for more heat to be absorbed by the sample which resulted in greater temperature difference in the material, causing the plastic deformation.

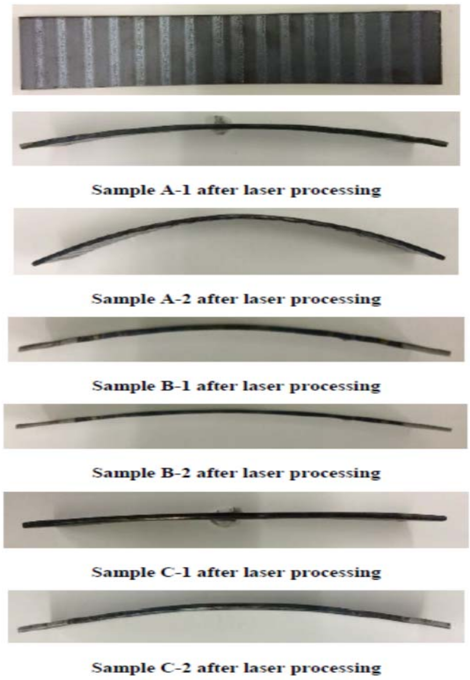

Figure 2: Samples after laser processing

Table 3: The radius, length and curvature diameter of the mild steel after laser beam forming

Sample	Width	Height	Radius (mm)	Length (mm)	Curvature Diameter (mm)
A-1	200	10	505	201.3307	1010
A-2	196.5	17.5	284.5518	200.63	569.1036
B-1	201	12	426.8438	202.905	853.6876
B-2	189	28.5	170.9211	200.2596	341.8422
C-1	201.5	4	1270.82	201.7117	2541.6406
C-2	199	11	455.5114	200.6175	911.0228

3.2 The chemical composition

The chemical composition of the as received specimen can be seen in Table 1. This can be compared to the chemical composition after LBF seen in Table 4. From the table, it shows that there is a significant increase in C, So, S, Cr, Mo, Ni and Al as a result of laser forming. The increase in the carbon content shows that the steel should experience an increase in its hardness. The increase in Chromium also helps increase the hardness, tensile strength, and for corrosion resistance. All the increases in the element should help improve the material properties.

Table 4: The Chemical Composition of LBF Component after formed

Elements	C	So	Mn	P	S
% by weight	0.138	0.140	0.021	0.050	0.125
Elements	Cr	Mo	Ni	Al	Fe
% by weight	0.049	0.123	0.064	0.125	98.41

3.3 Microstructure evaluation

From the microstructure evaluations of LBF, the materials showed a significant grain size reduction that is induced by the heat of the laser. In fig. 3 the laser scanning position can be seen at point 1.This area is directly affected by the heat produced by the laser. The greatest grain reduction is evident in the areas that fall into the heat affected zone (HAZ). There is also a clear boundary between the HAZ and the non-HAZ areas, as shown in the area of point 3. The non-heated affected areas are seen beyond the boundary, shown at point 4.

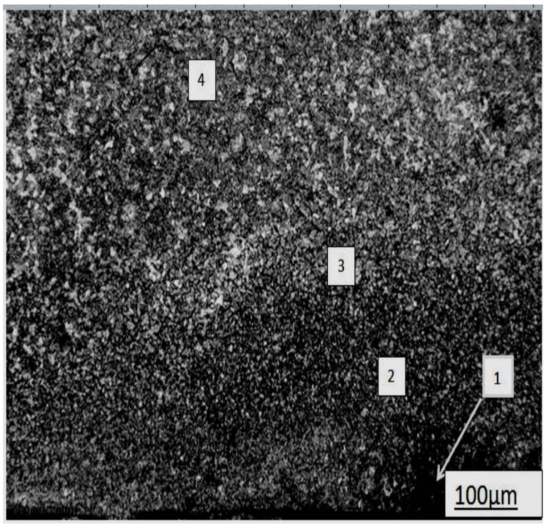

Figure 3: Grain reduction experienced from the centre to edge of sample

An evaluation of the microstructure of as received and LBF materials were conducted, the results are shown in fig. 4 and fig.5. It was established that the microstructure of the mild steel plate consisted of fine grains of ferrite as seen in fig.4. The as received material consisted of equiaxed ferrite matrix grains. The parameters used during the laser forming process have a significant influence on the temperatures and the cooling of the samples. It is important to note the laser power, number of scans and the scanning speed as each of the parameters will induce different temperatures at the surface of the material as well as the depth at which the temperature penetrates and affect the inner structure of the material. These effects are clearly evident from the microstructural observations of the laser formed samples relative to the microstructure of the as received material. These microstructural changes are due to the process of heating the material above its upper transformation temperature whereby the ferrite grain re-crystallizes. Fig. 5 shows sample A-1, has a significant change in the microstructure of the sample after the laser irradiation. The microstructure obtained with the laser parameters is pearlite with a small amount of austenite. The change in the microstructure indicates that the sample reached a high enough temperature and cooled fast enough to maintain the Austenite structure.

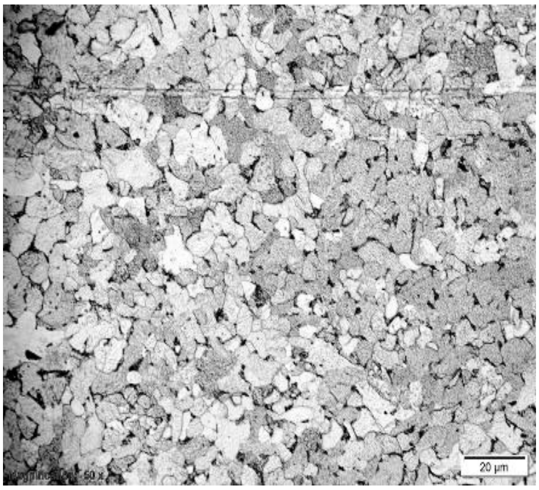

Figure 4: Optical micrographs of Parent material

In fig. 5 sample A-2 shows the grain has become slightly larger and elongated as seen in sample A-1. Sample A-2 underwent a greater number of scans (x5) when compared to sample A-1. It therefor would have experienced higher temperatures. This implies that sample A-2 experience a greater microstructural change compared to sample A-1. Due to the melting and rapid cooling at the top surface, there is pearlite austenite as well as a small amount martensite present. Sample B-1 also shows evidence of an elongated grain. This material experienced higher temperature in the surface of the material but a faster scanning speed was used, thus reducing the possibility for the heat to penetrate deeper into the material. It is clear that there is ferrite, pearlite austenite present in this material. The ferrite and pearlite in this sample are apart, which suggests the heating and cooling did not have as much as an effect on the area where the ferrite is more present. This sample is expected to have an increased hardness and strength due to its microstructural changes. Sample B-2, which received a greater number of laser scans relative to sample B-1. This sample would have experienced higher temperatures for a longer period of time, and the possibility for the temperature changes to have a greater effect on the structure of the material. This sample has shown evidence of the formation of pearlite, austenite and martensite. Although a small amount of martensite has formed it shows that there was sufficient heating and cooling achieved by the laser forming process. The phase changes that occurred in this particular sample will improve the hardness and strength of the material. Sample C-1, which received the lowest laser power at 1800, experienced relatively lower temperatures during laser irradiation. This particular sample has ferrite, pearlite and austenite present. The lower amounts of austenite are due to the lower temperatures, as well as less amount of laser scans done over the sample. This therefore did not allow the pearlite to transform into austenite. It is clear that a higher temperature is needed to form more austenite, as illustrated in the iron phase diagram. Sample C-2, where the grain has become slightly larger and elongated. This sample received a greater number of scans (x5) relative to sample C-1. The higher number of scans would induce a higher temperature in the sample. The higher temperature changes introduced pearlite and austenite into the structure of the sample. It is however clear that this sample has not achieved an as significant microstructural change as the samples A and B. This microstructural changes may be explained by the process of heating the steel component above its upper transformation temperature and the cooling thereby re-crystallizing the ferrite grains. The microstructure is now transformed to elongated grains.

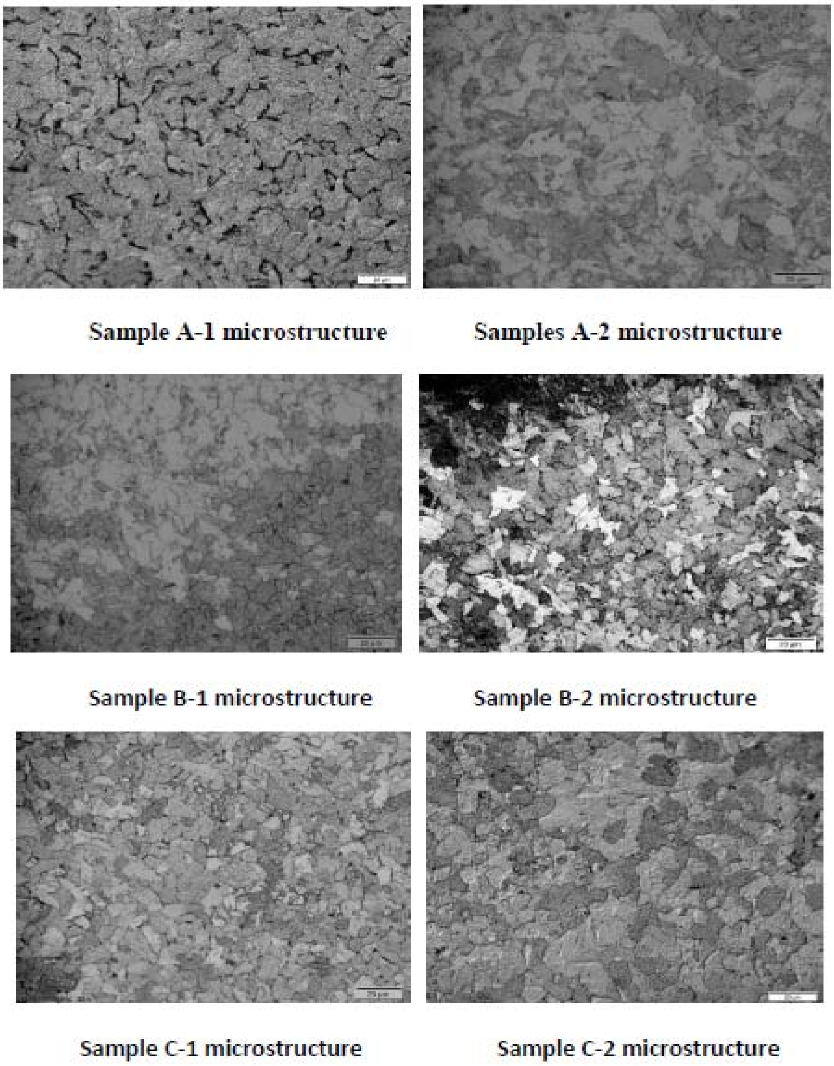

Figure 5: Optical micrographs showing the microstructure of laser beam formed materials

3.4 Hardness tests

The micro hardness measurements recorded in each of the samples are shown in Fig.6 and Fig.7. The results showed that the Vickers micro hardness of the as-received material ranged from 110 to 130 HV, whereas the LBF samples ranged from 140 to 180 HV. The as received material has a lower HV value throughout the length of the test sample. This is due to the prominence of the softer ferrite structure. The LBF samples underwent a significant structural change as a result of the laser heating and cooling of the mild steel, as illustrated by the changes in microstructure as well as the hardness testing results. The increased hardness of the samples corresponds with the introduction of pearlite, austenite and martensite into the structure of the laser formed samples. The increase can also be attributed to the plastic deformation experienced by the material. The laser forming process has shown that is has a positive effect on the material. The increased hardness in the samples also has a relationship to the curvature achieved. This relationship can be due to the plastic deformation, generally the samples with a greater plastic deformation showed to have a greater hardness value when compared to the samples with less curvature. Plastic deformation is one of the ways to strengthen a material, thus during the laser forming process the plastic deformation have increase the hardness of the material.

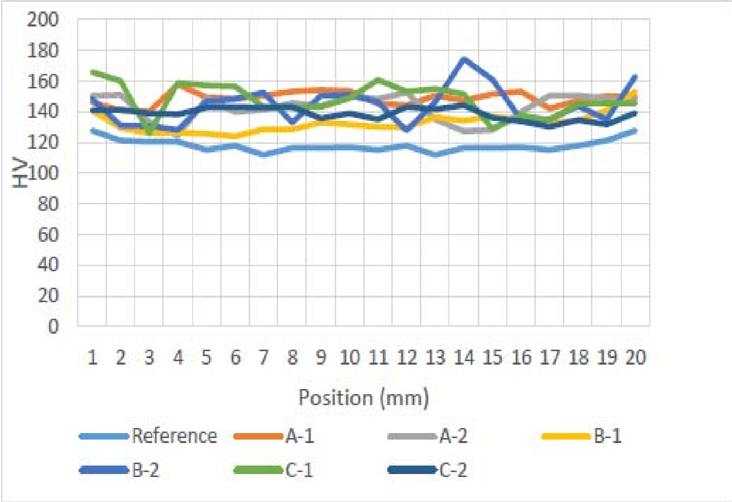

Figure 6: Comparison of the hardness over the different position of each sample

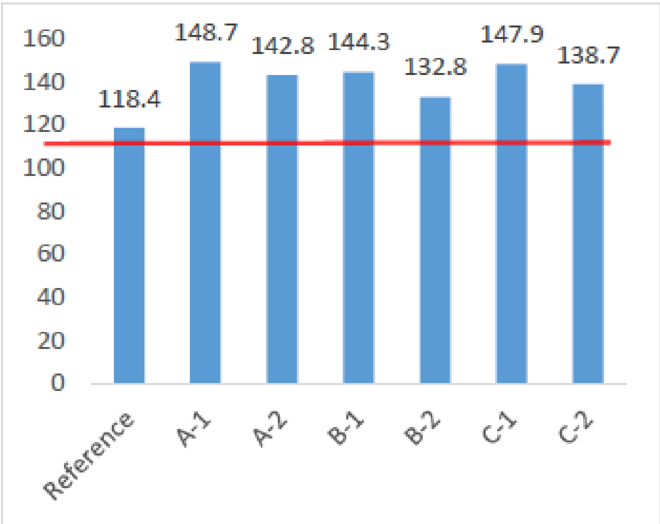

Figure 7: Comparison of the average hardness of each sample

4. CONCLUSIONS

The following conclusions can be drawn from this work:

1. The LBF process has a significant effect on the properties of the formed mild steel
2. Scanning power and the number of scans have a noticeable effect on the curvature achieved in the formed samples.
3. The microstructure evaluations of LBF materials showed a significant grain size reduction that is induced by the heat of the laser.
4. The number of scans also showed to have an influence on the hardness of the materials.

5. The scanning speed did not show any definitive influence on the hardness of the material but this can be accompanied by the increased power with the decreased scanning speed.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Council for Scientific and Industrial Research (CSIR) in Pretoria, South Africa, for allowing us to use their facility. The National Research Foundation (NRF) and Faculty of Engineering and the Built Environment, Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa are acknowledged for the award of the research funds to support this study.

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