Feasibility of using Laser Enabled Net Shaping to manufacture WC-Fe alloys

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Abstract

Laser Enabled Net Shaping technology in the manufacture of cemented tungsten carbides is challenging and many scientific gaps still need to be addressed to ensure commercial viability. In this study the feasibility of using LENS® to produce cemented tungsten carbides having a steel binder was investigated. A full factorial design of experiments (DoE) was used in order to configure the LENS® process parameters which were varied, namely, powder feed rate, traverse speed, and laser power. Single wall samples were deposited and characterized using scanning electron microscopy (SEM), electron dispersive x-ray spectrometry (EDS) and X-ray diffraction (XRD). Vickers micro-hardness, surface roughness measurements, and porosity of the samples was also done.

1. Introduction

Cemented tungsten carbides accounted for more than 50% of the global tungsten consumption in 2016 [1]. Conventional manufacturing of cemented tungsten carbides incorporates powder metallurgy processes which include powder milling, powder consolidation, compaction and sintering [2]. One disadvantage of conventional sintering is the long production times, where the sintering cycles can take ~ 15 -20 hours thus leading to longer production times [3]. Grain coarsening due to solution re-precipitation of WC crystals also occurs which then has a negative impact on the mechanical properties of the component [4]. In addition the dissolution of WC leads to the formation of intermediate phases and formation of the brittle eta (η) phase due to the deficiency of carbon [5]. These disadvantages may be overcome by employing additive manufacturing (AM) processes such as Laser Engineered Net Shaping (LENS®). This technology is an extension of rapid prototyping whereby direct manufacturing of metallic parts can be carried out. The LENS® operation starts from a computer aided design (CAD) model, which is then divided into thin orthogonal layers in the Z-axis [6]. The data for each thin layer is translated into laser scanning paths to fabricate a single layer. The layers are fabricated by first generating an outline of each feature and filling it up on a repetitive basis [6]. The feature which distinguishes the LENS® process from the rapid prototyping process is that it can fabricate components directly from structural metals. The advantages of the LENS® process compared to the conventional powder metallurgy processes is that there seems to be minimum dilution due to the low heat input, and it is characterized by high cooling rates which prevents grain growth, decarburization and promotes faster manufacturing times [7]. The aim of this study was to explore the viability of depositing WC in a Fe-alloy binder using the LENS® technology. The influence of process parameters such as laser power, powder feed rate and traverse speed were investigated.

2. Experimental Procedure

2.1 Feedstock Powders

Two feedstock powders were used during the LENS® deposition process. The first powder was a spherical WC with a particle size of -90+45 µm (Zhuzhou Jiangwe Boda Hard-facing materials Co., Ltd). The second powder was a gas atomized Fe-alloy powder with a particle size of -125+53 µm (Sandvik Osprey Ltd). The powders were blended in a rotary mill for 4 hours at a speed of 68.75 revs/min. The mixture composition comprised of 90% WC and 10% Fe-alloy powders.

2.2 Process Description

A LENS® 850-R system (OPTOMEC) with a 1 KW IPG fibre glass laser was used to deposit WC-10wt%Fe-alloy thin wall samples onto grit blasted mild steel substrates. During deposition the powders were delivered into the path of the laser beam by an argon gas stream. The layout of the LENS® process is shown in Figure 1. The part shape was controlled by a pre-programmed CAD model. In this study thin wall samples having a length of 25.4 mm comprising of 40 layers were built. The process parameters namely laser power, laser speed and powder feed rate were configured using a full factorial design of experiments (DOE), with Table 1 listing the parameters employed.

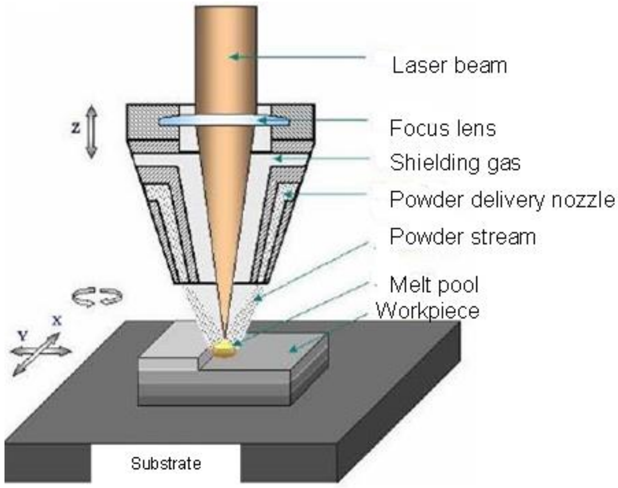

Figure 1: Layout of the LENS deposition process [8].

Table 1: Experimental parameters

Parameters	Range
Laser power (W)	150, 200, 300, 400
Laser speed (mm/s)	3, 6.4, 8.5, 12.7
Powder feed rate (g/min)	7.3, 10, 12.2
Laser spot size (mm)	1.4
Z-increment (mm)	0.2
Working distance (mm)	8

2.3 Materials Property Characterization

The particle size distribution of the feedstock and blended powders was measured using a Malvern Mastersizer. Vernier Calipers were used to measure the height of the deposited single wall samples at five different positions. Phase analyses were done using a Bruker D2 x-ray diffraction (XRD) machine. Surface roughness was measured using a Surtronic S128 Duo Surface Roughness Tester. Micro-Vickers hardness measurements were done using a FM-800e micro-Vickers hardness machine. The samples were polished for optical and electron microscopy and some samples were etched with Murakami's etchant to reveal the microstructure. Powder morphology and microstructural characterisation of the thin walls was done using a Camscan Maxim 2000 Scanning Electron Microscope (SEM).

3. Results and Discussion

3.1 Powder Characterisation

Figure 2 shows the morphology of the as-received and blended powders. The WC powder had a spherical morphology while the Fe-alloy powder displayed a spheroidal and spherical morphology. The XRD patterns of the Fe-alloy and WC powders are shown in Figures 3 and 4 respectively. The Fe-alloy powder showed only the standard peaks with no additional phases. The WC powder comprised of WC and W_2C phases.

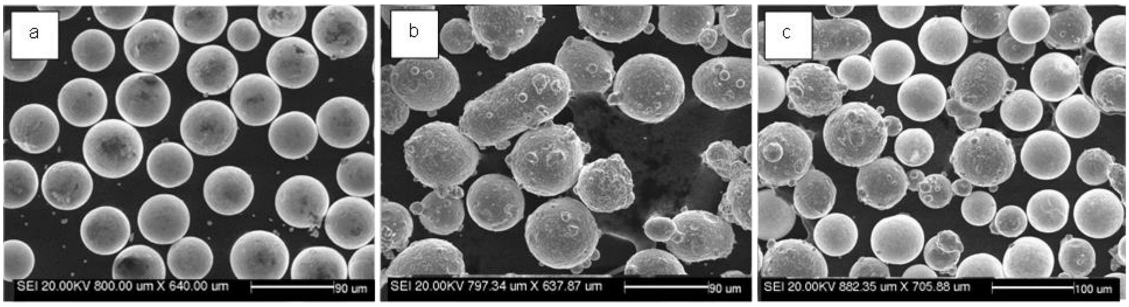

Figure 2: Morphology of (a) WC powder, (b) Fe-alloy powder, (c) WC–10wt% Fe-alloy powder.

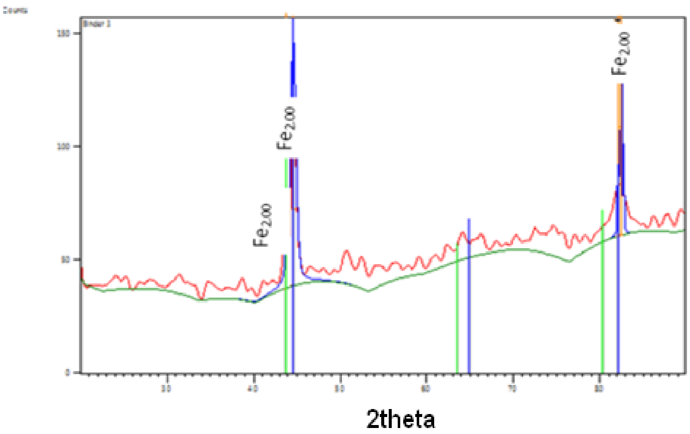

Figure 3: XRD pattern of the Fe-alloy powder.

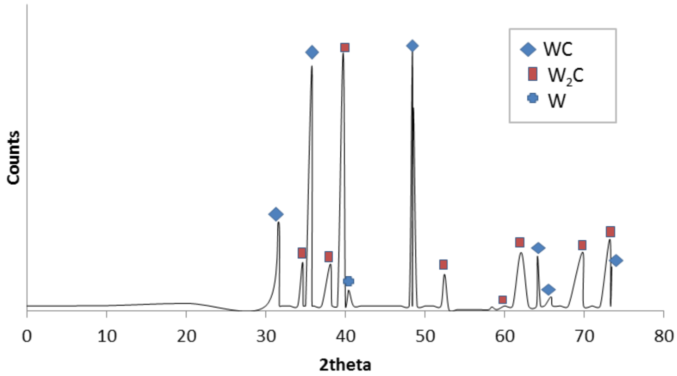

Figure 4: XRD pattern of the WC powder.

3.2 Influence of the LENS® Process Parameters

An increase in laser power leads to an increase in heat input, as shown by Equation 1. An increase in heat input results in more powder being melted in the molten pool leading to an increase in sample build height. Figure 5 shows the influence of laser power on sample build height at different traverse speeds and feed rates, while Figure 6 shows the XRD patterns for samples produced under the same parameters with only the laser power being varied. An increase in temperature resulted in the intensity of the Fe-W-C peak increasing.

$$HI = \frac{Power \times 60}{travel\ speed\ (mm/min)} \qquad \text{Eq. 1}$$

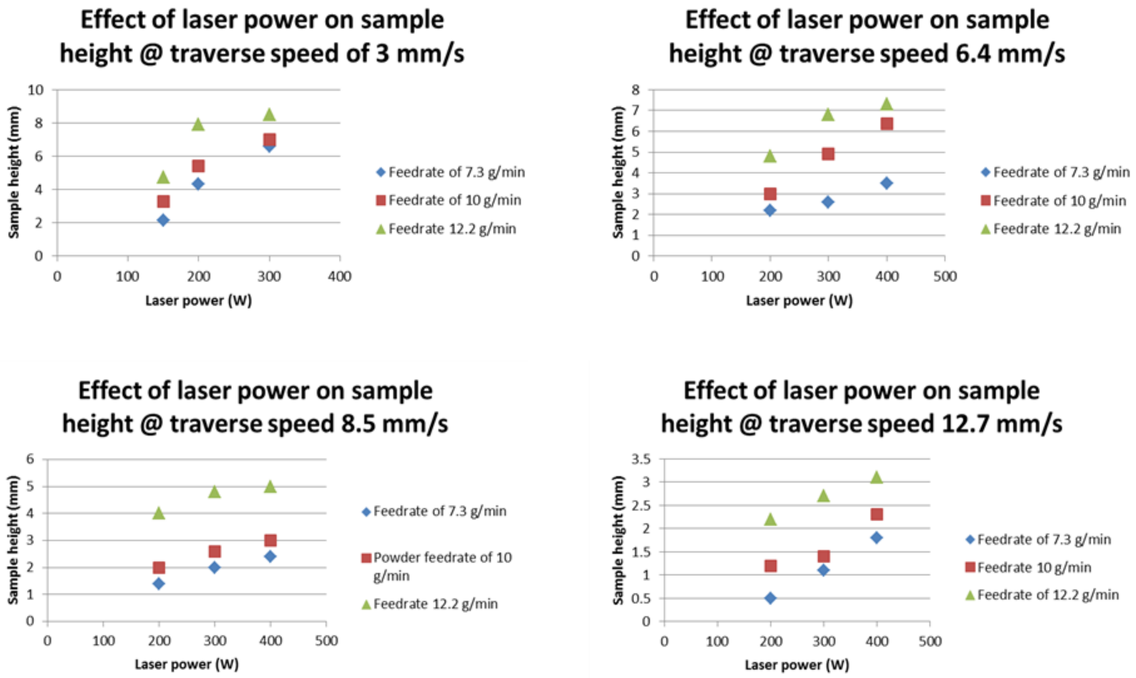

Figure 5: Effect of laser parameters on sample height.

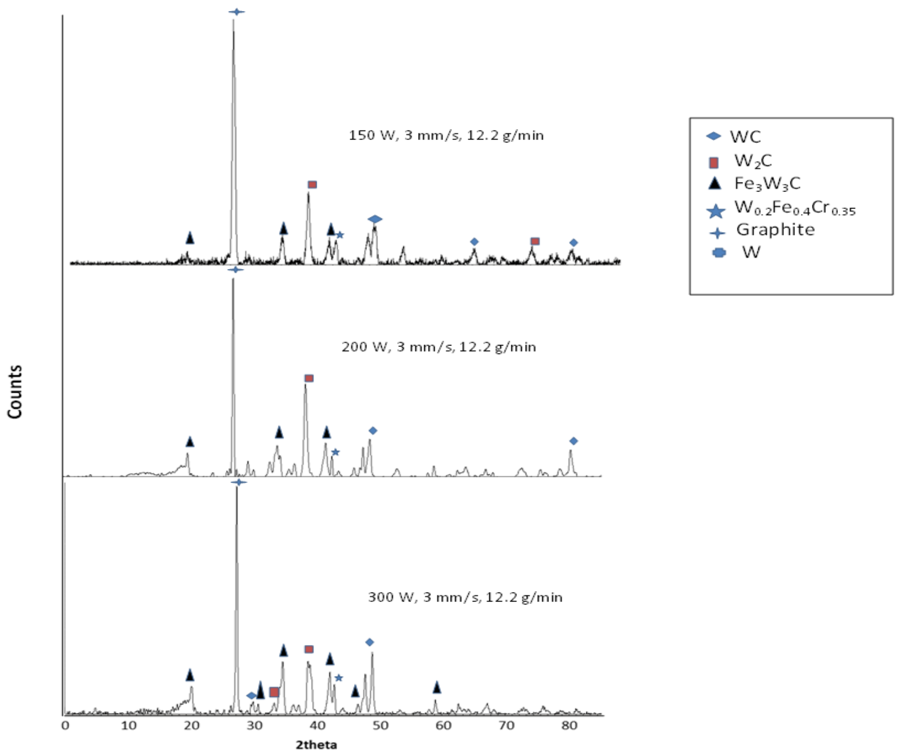

Figure 6: XRD patterns showing influence of laser power.

From Figure 5 it can be deduced that as the powder feed rate increased the build height increased, with a feed rate of 12.2 g/min giving the highest walls under all laser parameters tested. A low powder feed rate leads to less powder being introduced to the molten pool, hence less powder being melted. This causes the height of the sample to be less than the set z-increment. Since the laser head moves up by the set z-increment this causes an increase in the working distance and results in a de-focused laser beam. Thus the powder feeding path does not align with the laser beam and less powder is melted leading to a small sample height. The figure also shows that as the traverse speed increased the build height decreased. This is because at high traverse speeds there is insufficient time to melt all the powder in the molten pool.

An increase in the laser power resulted in a decrease in hardness as shown in Figure 7(a) for a constant powder feed rate of 12.2 g/min. Figure 7(b) shows the influence of heat input on sample surface roughness for selected parameters. When the laser power and powder feed rate were kept constant then the surface roughness increased as the traverse speed increased. When the traverse speed and powder feed rate were kept constant then the surface roughness appeared to decrease as the laser power increased.

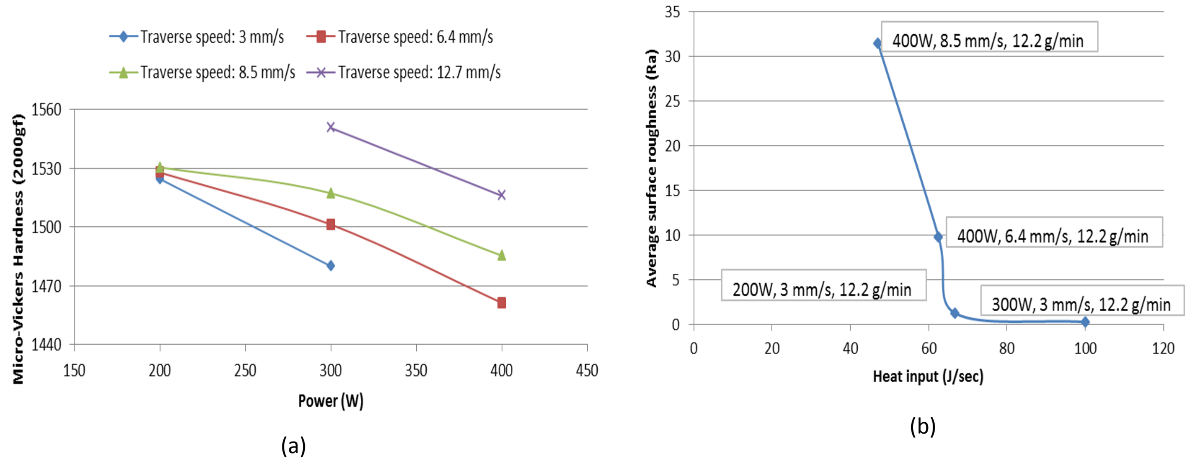

Figure 7: (a) Influence of laser power on micro-hardness, (b) Influence of heat input on surface roughness.

Figures 8 to 10 shows some of the microstructures and porosities which were obtained under various laser parameters. Generally the microstructure of all the walls comprised of a bright surface zone where the final deposition occurred. This surface zone thickness increased with an increase in laser power and was rich in the WC phase. Below the surface zone there was a mixed zone comprising of both the WC and Fe-alloy binder. Figure 8 shows the microstructure of a sample deposited at a laser power of 400W, traverse speed of 8.5 mm/s and powder feed rate of 7.3 g/min. Due to the high melting point of WC, the original spherical shape was maintained following deposition. Elemental point analysis was conducted using EDS in order to identify the different features as shown in Figure 9. For this sample the likely phases are primary WC, W_2C, Fe_3W_3C and the Fe matrix. Figure 10 shows that an increase in powder feed rate leads to an increase in porosity for a wall. This is because a greater volume of particles are injected simultaneously into the laser and particles are not completely melted.

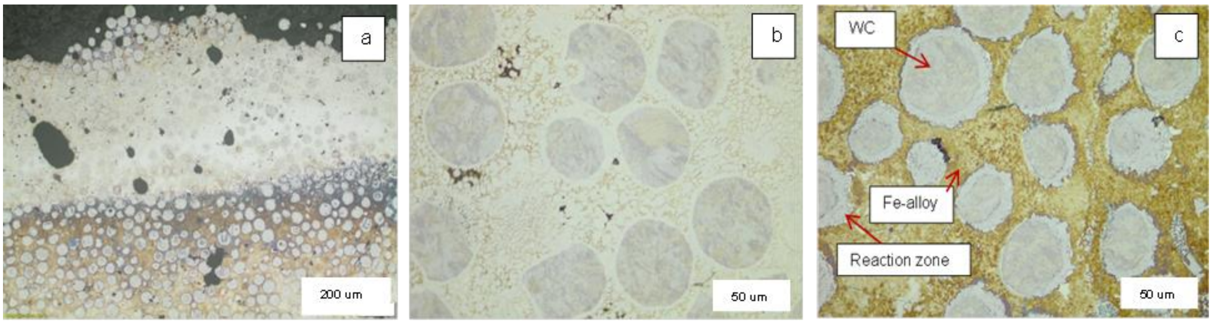

Figure 8: Microstructure of (a) thin wall (b) surface zone, and (c) mixed zone.

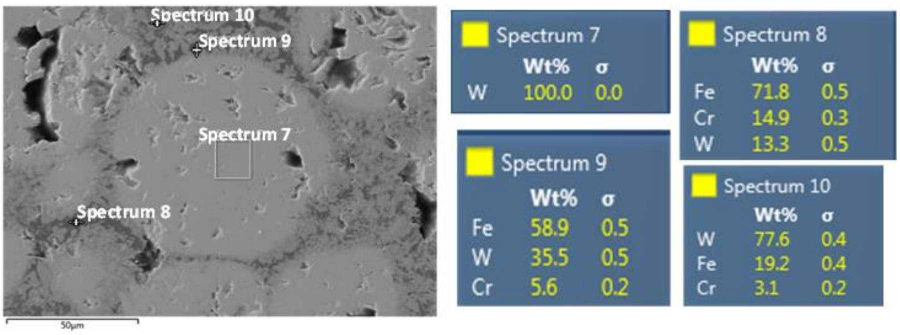

Figure 9: EDS point analysis of a mixed zone

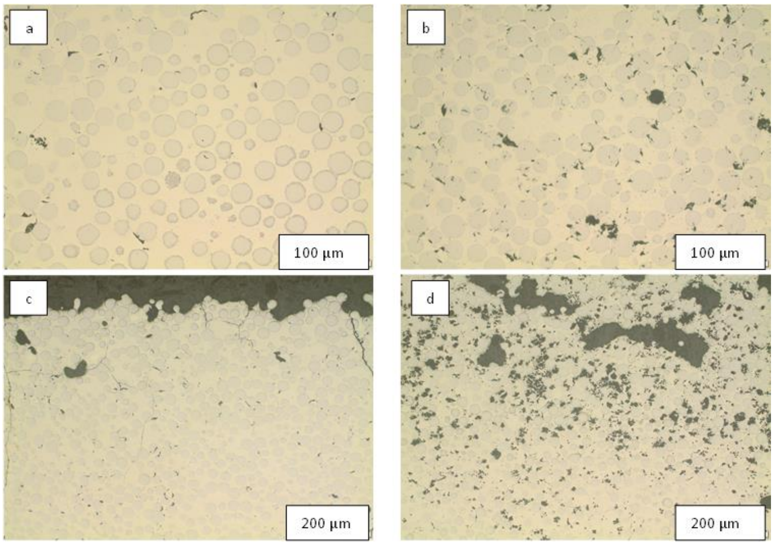

Figure 10: Porosity (ASTM B276) of sample fabricated @ 200 W, with powder feed rate of (a) 7.3 g/min (type B04 (0.06%)) and (b)12.2 g/min (type B06 (0.2%)); @ 300 W, with powder feed rate of (c) 7.3 g/min (type B04 (0.06%)) and (d)12.2 g/min (type B06 (0.2%)).

4. Conclusions

Thin wall WC-10wt%Fe-alloy samples were deposited using the LENS® process. The effect of process parameters namely laser power, powder feed rate and traverse speed were investigated. An increase in laser power resulted in an increase in the sample build height. This is because an increase in laser power leads to an increase in heat input and more powder being introduced into the molten pool. An increase in laser power also led to the decrease of the average hardness of the deposited samples. A high heat input resulted in a decrease in the sample surface roughness. At high heat inputs slow cooling rates are experienced giving rise to grain coarsening of the binder grains and dissolution of the WC grains into mixed phases and hence a reduction in the hardness. The last layers which were deposited were rich in WC. An increase in powder feed rate resulted in an increase in sample build height and an increase in porosity. An increase in traverse speed resulted in a decrease in the sample build height. Further work is still being done on the project.

5. Acknowledgments

The work contained in this paper is supported by the Department of Science and Technology and the National Research Foundation in South Africa. The Council for Scientific and Industrial Research, South Africa is acknowledged for the use of their facilities.

6. References

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