Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com

Effect of powder flowrate on the microstructure of *FeCrV15* clad, developed *via* the laser cladding technique

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ARTICLE INFO

Keywords:
High carbon ferrochrome
Powder flow rate
Specific laser beam power

ABSTRACT

Steel utilized in mining and tillage devices is highly susceptible to wear and corrosion attacks due to its poor tribological property when presented to unfavorable working conditions common to mining and tillage activities. This leads to an intensified research activity to improve its properties. The blend of chromium carbide and vanadium carbide (VC) reinforcement in iron-based hard-facings has dramatically improved the wear and corrosion resistance of the devices subjected to adverse abrasive and impact conditions. This comparative study deposited high carbon ferrochrome FeCrV15 coating on steel baseplates to form Cr-rich carbide and vanadium carbide in-situ at two different powder flow rates: 5 g/min and 6 g/min. The effect of the powder flow rate on the morphology of the precipitated carbide, the hardness of the coatings, and the specific laser beam power of the individual grain of powder was examined and compared.

1. Introduction

The poor tribological property and high susceptibility of steel used in mining and tillage tools to wear and corrosion attacks when presented to unfavorable working conditions have resulted in increased research intensity to improve the materials properties and service performance [1–3]. The material loss, resulting from grating wear which occurs due to the hard particles of the soil scouring the surface of tillage tool material at a relatively high speed, is evident. The functioning bits of cultivating machines, soil cultivators, smashers, and mining machines are exposed to dynamic stacking and synthetic substances present in the soil, damaging the instrument's material [4–6]. Worn tillage tool requires higher power for cultivation, higher (fuel) cost for machine operation and more time to replace worn or damaged tools [7]. The devices' material should be of high strength and exceptionally impervious to grating wear given its immediate contact with hard abrasive particles in the soil. Corrosion of soil tillage devices would correlate to the mechanical and microstructural properties of the devices' materials. The conventional materials used in agricultural industries and metallurgical mining are carbon steel. Mild steels are metallic materials commonly utilized to fabricate critical parts of agricultural tools and implements; they are generally exposed to fluid such as acid, base, water etc., in agricultural soil and or air during application. Metal ions from mild steel go into the solution at anodic territories in a sum chemically proportional to the responses at cathodic zones, increasing its high vulnerability to localized corrosion attacks. In the acidic media, the responses continue quickly from the anodic areas causing steel surface debasement. These kinds of corrosion are frequently described as crevice corrosion, pitting corrosion or uniform corrosion [8,9]. It will, in general, continue equally over the whole surface of any uncoated part and, in the long run causing a general diminishing of the metal. The Corrosion of the engineering component can initiate a permanent deterioration, which can eventually make the component useless or prone to sudden catastrophic failure. The loss of a minimal material causes severe deterioration in the general performance of an extensive engineering system. Suddenly, brittle fracture, fatigue, or stress-corrosion cracking can initiate a catastrophic failure [10].

To reduce the wear rate and prolong the service life of tools subject to the adverse working condition, the researchers have carried out several experimentations and discovered that the combination of chromium carbide and vanadium carbide (VC) reinforcement in iron-based coatings has brought about a significant advancement in the wear and corrosion resistance of devices subjected to adverse abrasive and impact conditions. The formation of Cr-rich eutectic carbides, eutectic VCs, and primary VCs remains in opposition against the penetrating

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https://doi.org/10.1016/j.matpr.2022.02.093
2214-7853/© 2021

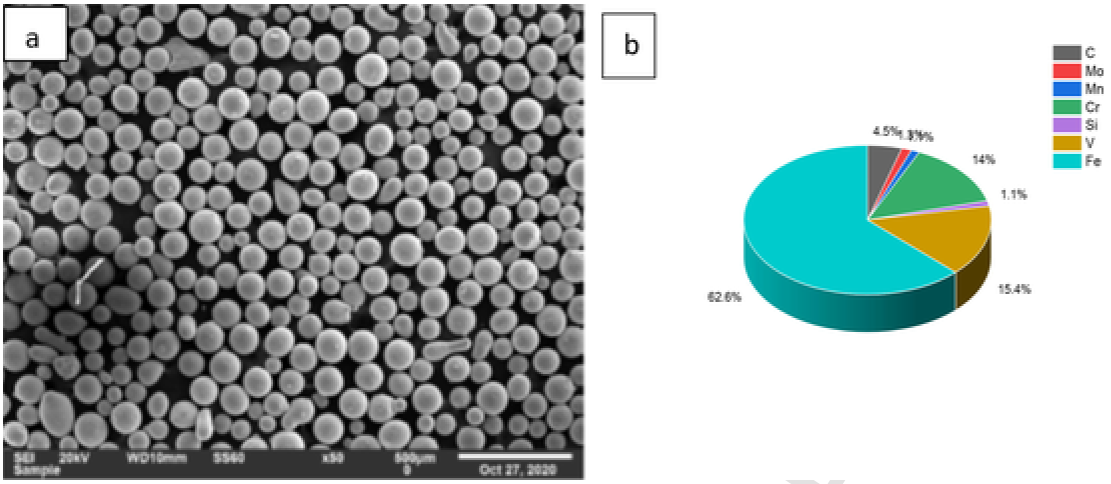


Fig. 1. High carbon ferrochrome (FeCrV15) powder a) SEM image b) percentage weight composition.

grinding medium [2,11]. They help to enhance the grain refinement, leading to high toughness and enhanced wear resistance [12]. Laser additive manufacturing technology (laser cladding) has been one of the techniques by which these carbides can be deposited on the surface of the tools.

Aramide *et* al. [2] studied vanadium-chromium carbide's influence on the microstructural formation and hardness of laser deposited coatings on steel baseplates. The authors investigated the effects of both laser beam power and scanning speed (while keeping the powder flowrate constant) on the coatings' microstructure's carbide formation and discovered an improved enhancement in both the hardness and microstructure formation. Aramide *et al.* [12] investigated the effect of extra chromium addition on the mechanical behavior of *FeCrV15* laser coatings. They recorded reduced carbide precipitation, increased coarse grain formation in the microstructure, lowered hardness, and a higher corrosion rate in the produced coating than *FeCrV15* coating without extra chromium. Akinlabi and Akinlabi [13] studied the effect of varying the powder flow rate on TiC laser deposit on Ti6Al4V substrate. It was discovered that the hardness and the number of pores increased while the grain size decreased with an increase in the powder flow rate. Our previous work [2,12,14] identified the representation of Cr-rich, eutectic VCs and primary VCs. This work intends to explore the effect of powder flow rate on the precipitations of primary VCs, eutectic VCs, and Cr-rich carbides in the microstructure and hardness of FeCrV15-reinforced clad on steel baseplate [2].

2. Materials and methods

2.1. Materials and the processing equipment

In this study, high carbon ferrochrome FeCrV15 claddings were deposited on steel baseplates through the laser additive manufacturing (laser cladding) technique at two different powder flow rates, *viz*: 5 g/min (sample A) and 6 g/min (sample B). The particle size distribution of the FeCrV15 powder used in this experimentation is $-150 + 50\ \mu m$, supplied by WearTech in South Africa with a purity of as received well above 99%, SEM image and percentage weight composition of the powder is represented by Fig. 1. A 3 kW Continuous Wave (CW) IPG Fibre laser system and a DPSF-2 type coaxial powder feeder were used in the experiment, with argon as both the carrying and shielding gas at 2 L/min and 15 L/min, respectively. Deposits of five tracks and three layers with 50% overlaps were made on the steel baseplates; see Table 1 for the laser parameters used and Fig. 2 for the pictorial representation of the laser head and process.

Table 1
The samples, powder, and laser processing parameters.

Samples	Laser Beam power (W)	Scanning speed (mm/s)	Powder used	Powder feed rate (g/min)
A	1200	8	FeCrV15	5
B	1200	8	FeCrV15	6

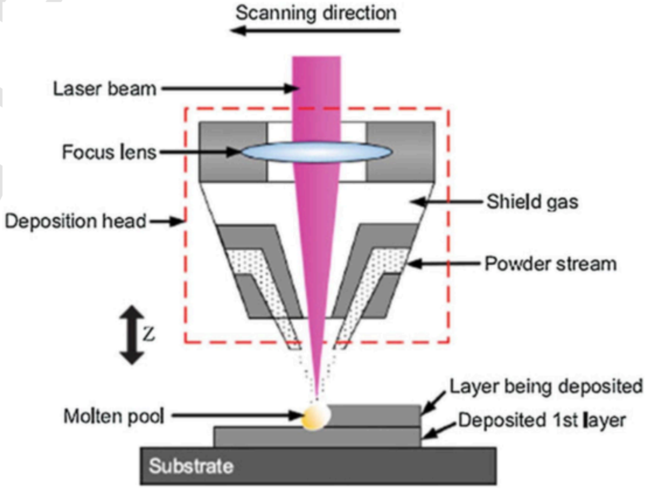
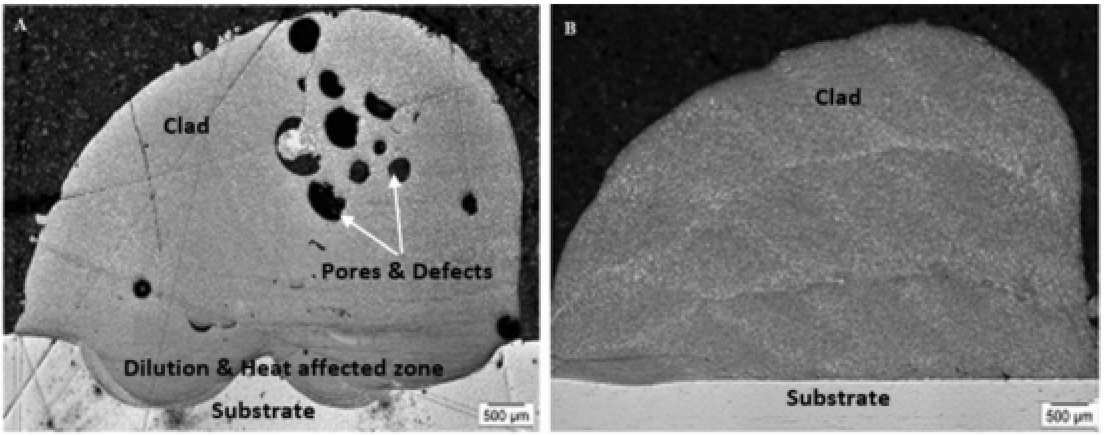


Fig. 2. The schematic diagram of the laser head and process.

2.2. Image processing and characterization

Before the microstructure was inspected, the developed samples were first ground and polished, logically using the Silicon carbide paper from 80, 380, 1200, and 1400 coarse sandpapers. Test surfaces were later polished on polished discs with 1 µm, 0.9 µm, and 0.3 µm alumina powder to accomplish a mirror surface. A modified Fry's Reagent (150 ml H_2O, 50 ml HCl, 25 ml HNO_3 and 1 g $CuC\ell_2$) solution was the etchant used on the samples. Various samples were then examined with an Optical Polarizing Microscope (OPM) and Scanning Electron Microscope furnished with Energy Dispersive Spectroscopy (SEM/EDS). The hardness profile of the clad was done with a fully computerized FM-ARS900 Vickers testing machine (Future-Tech Corp., Kanagawa, Japan) with a load of 300 g, which was taken from the top of the clad down to the core of the substrates at a spacing of 200 μm.



Sample A

Sample B

Fig. 3. Effect of powder flow rate on the melt bead features.

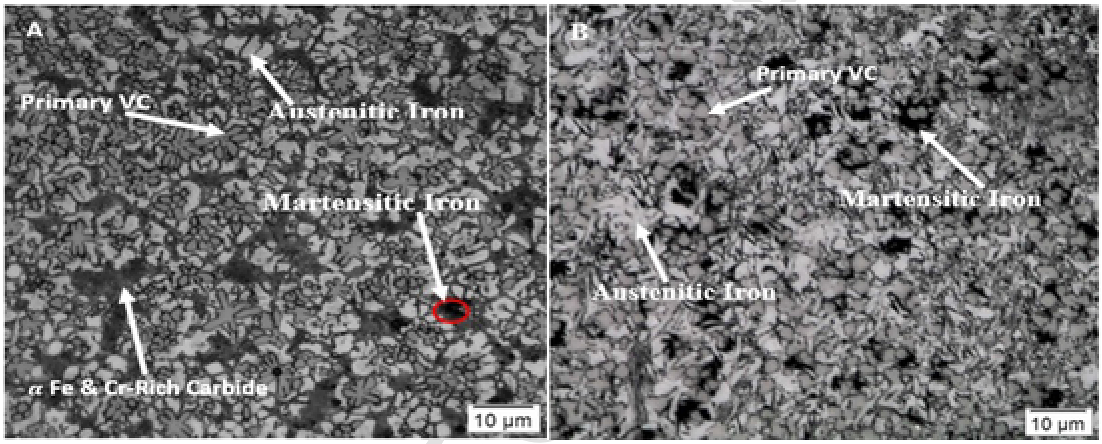


Fig. 4. Starlike and rounded precipitates of primary VCs.

3. Results and discussion

The results show defects and pores on sample A produced at a 5 g/min flow rate, with a higher heat-affected zone and more dilution of the deposit into the substrate. Fig. 3**A** represents this phenomenon. In contrast, Fig. 3**B** represents sample B, produced at a 6 g/min powder flow rate, with minimum dilution, low heat affected zone, and no defect.

Moreover, the microstructure of sample A shows starlike grain precipitates [2,11,12] of primary vanadium carbides (VC), see Fig. 4**A**. This is due to a higher specific laser beam power [11] on the individual grain of the powder in the melted bead during the cladding process because of the lower volume flow of the powder into the melted bead, which was also responsible for the high heat-affected zone and the defect observed. In contrast, round-shaped grains of primary vanadium carbide precipitates are formed in sample B, see Fig. 4**B**. The higher volume powder flowing into the melted bead lowered the specific laser beam power [11] on the individual grain of powder. Moreover, a closer look into the micrographs presented in Fig. 4**B** shows a more densely packed microstructure with carbide rich phase, which is responsible for a higher hardness of sample B with 1000 HV 0.3, whereas sample A has an average hardness of 828 HV 0.3, which is attributed to a less densely packed carbide rich phase in its microstructure. The hardness profile of both samples is represented in Fig. 5.

4. Conclusion

The high carbon ferrochrome FeCrV15 deposit on a steel baseplate was developed through laser cladding. The effect of the powder flow rate and specific laser beam power on the microstructure and hardness of the coatings were investigated. The lower powder flow rate resulted in reduced precipitation of the carbide phases and higher specific laser beam power on the individual grain of the powder, affecting the morphology of the precipitated primary VCs in the microstructure and lowering the clad's hardness.

CRediT authorship contribution statement

Basiru Aramide: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Rotimi Sadiku:** Project administration, Resources, Supervision, Writing – review & editing. **Patricia Popoola:** Project administration, Resources, Supervision. **Sisa Pityana:** Project administration, Resources, Supervision, Validation. **Tamber Jamiru:** Project administration, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

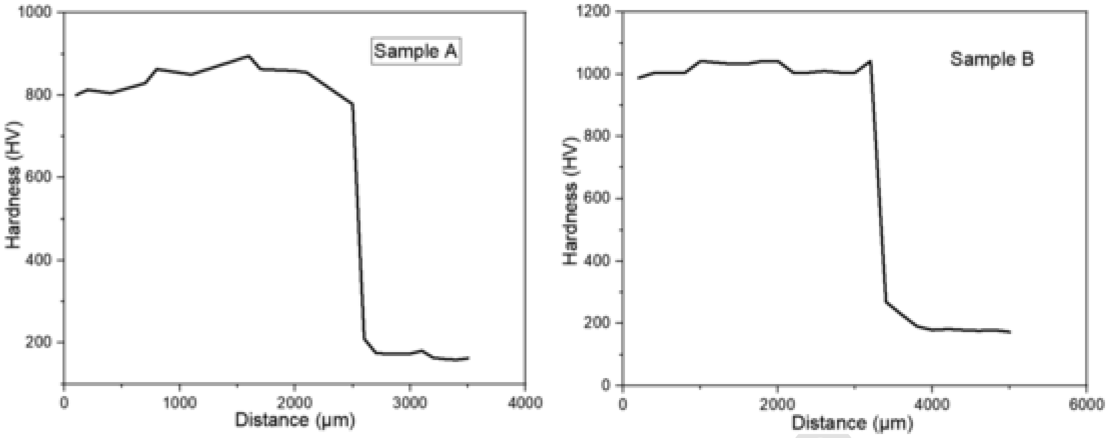


Fig. 5. The hardness profile of the samples.

Acknowledgment

The authors acknowledge the financial support from Tshwane University of Technology (TUT), Pretoria, South Africa, without which this work would not have been possible.

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