EVALUATION OF A CARBON FIBRE POWDER SCRAPER USED IN METAL ADDITIVE MANUFACTURING

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ABSTRACT

Powder Bed Fusion (PBF) is an Additive Manufacturing process which builds parts, layer by layer, by melting the cross-section of the part onto a powder layer. Aeroswift is a PBF machine, designed and built in South Africa. A powder scraper was designed which would be flexible, work for extended periods of time and have the ability to operate at high temperatures. In this study, the process of development toward carbon fibre scrapers and the evaluation for comparison to commercially available scrapers is explained. Results showed that the carbon fibre powder scraper is comparable to commercially available scrapers and is a viable solution for Aeroswift.

1. INTRODUCTION:

Powder Bed Fusion (PBF) is an Additive Manufacturing (AM) process that produces a part by building it layer by layer. This is done by melting the cross-section of the part onto a powder layer, using an energy source and scanning method. The energy source is either a laser called Selective Laser Melting (SLM), or an electron beam named Electron Beam Melting (EBM). The build platform moves down by one layer thickness (typically between 20 and 50 µm), a new powder layer is added and the next cross-section is scanned. This process is repeated until all the cross-sections of the part are scanned and a completed component printed. The cross-sections are obtained by running the CAD model through slicing software, Chua [1].

Aeroswift is an SLM machine, designed and built in South Africa by the NLC and Aerosud ITC, which has a build volume of 2000 x 600 x 600 mm^3, which is much larger than current commercially available machines. Due to the large width of the build platform and other factors, such as preheating to 600^oC, a custom powder scraper was designed. The quality of a powder layer is very important in PBF processes and influences the surface roughness of a built part and, to a certain extent, its dimensional accuracy and density. This powder scraper had to fulfil the following specification:

1. High operating temperature: the machine has a preheat temperature of up to 600^oC.
2. Flexible: due to known defects in PBF, such as warpage, Vorsa et al. [2] and balling, Kruth et al. [3]), a flexible powder scraper is required that would be able to deal with these defects without failing.
3. Durable: the powder scraper should be able to operate for extended periods, as at full capacity, a build could be as many as 12 000 layers.
4. Consistent powder layers: consecutive powder layers should not differ much from the previous layer.
5. Smooth surface: the powder layers produced should have a good surface roughness and should be uniform throughout.

A carbon fibre brush powder scraper was designed and manufactured and after its implementation, test builds were conducted for parameterisation. Excessive roughness of consolidated layers caused premature failure of the powder scraper. It was uncertain whether the failure was due to unsatisfactory powder layers or due to the lack of optimised process parameters. Thus, a quantitative method was needed to determine the quality of the powder layer, to show if the layer produced by the powder scraper was sufficient or not. The quality of the powder layer refers to the flatness (surface roughness) of the layer.

Therefore, the research objectives are:
- Devise a method for a quantitative evaluation of the performance of a powder scraper.
- Use the devised method to evaluate the carbon fibre powder scraper developed for the Aeroswift system.

2. LITERATURE

2.1 Powder layer monitoring

A literature survey revealed only one method that addresses the monitoring of a powder layer. This was done by Craeghs et al. [4] and is used in many commercial machines today. The method uses a camera and lighting from different sides of the powder bed. Photographs are taken of every layer for each individual light, while the others are off. The lights illuminate the powder bed from a side and cause defects to cast shadows on the powder bed. The photographs are converted to grey scale images and each layer's images are analysed. Five lines are taken across the images (in the direction of the light) and averaged. Each point in the line has a grey scale value and a graph of the grey scale values is plotted with a set threshold. If a grey scale value exceeds the threshold, the system either re-scrapes the layer or calls for user intervention. A schematic of this method is shown in Figure 1.

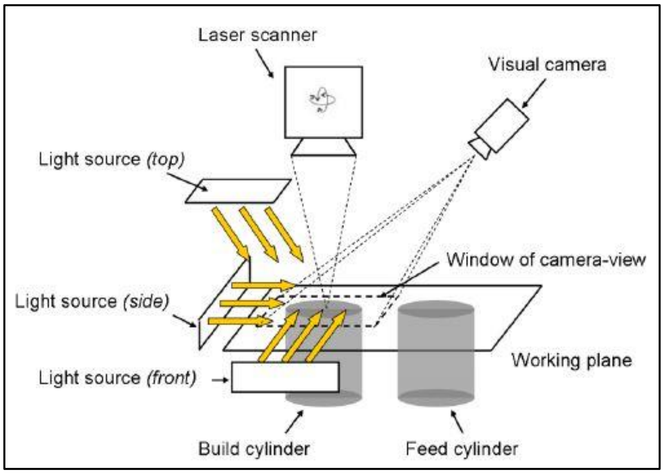

Figure 1: Visual inspection of powder layer, Craeghs [2]

This method, however, does not analyse the powder layer in a quantitative way. It only shows if a layer falls within a certain specification or not. By calibrating the size of a shadow of an object with a known height, it is possible to calculate the height of the defects in a powder layer using the same set-up, by measuring the size of the shadow cast. However, the resolution achievable this way is only about 100 μm/pixel, due to the resolution of the cameras and the width of the powder bed. This means that shadows of different-sized defects will possibly be represented by the same number of pixels in an image.

2.2 Laser Line Scanner

A Laser Line Scanner (LLS) is a device that measures the profile of a line on a surface and gives the x- and z-coordinates as an output. The z-coordinates are calculated by using triangulation of the laser light reflected off a surface onto a highly sensitive sensor matrix, Micro Epsilon [5]. The one used in the project is a Micro-Epsilon's ScanCONTROL 2960-50/BL, which has an x- and z-resolution of 40– and 4 μm respectively, Micro Epsilon [6]. The only downside of the device is that it can only measure a 60 mm line per instance.

3. METHODOLOGY

A literature study was conducted to investigate possible solutions to the first research objective. In the study, no literature could be found on the qualification of powder scrapers used in AM. However, two viable solutions were identified: the first being that from the research done by Craeghs et al.[3], and the second being an LLS. After further investigation it was determined that LLS is the better option, as the camera and light method is not as accurate.

It was decided that five powder scrapers would be tested: three Aeroswift carbon fibre scrapers, a commercial carbon fibre powder scraper and a solid blade scraper manufactured from high speed steel. Three Aeroswift scrapers were tested to show repeatability. The commercial carbon fibre scraper was tested to compare the Aeroswift scraper to a carbon fibre scraper used in the industry, as they have been proven to work. The commercial carbon fibre brush's dimensions are comparable to that of the Aeroswift carbon fibre brush scraper, except for its length, which is much shorter. It is generally recognised that a solid blade scraper produces a near-perfect layer due to its edge being machined straight and sharpened. The solid blade was tested to show what a "perfect" layer would look like and to see how much a carbon fibre scraper's performance differs. Thus, if the chosen method of quantification works, there will be a distinct difference between the performance of the carbon fibre powder scrapers and the solid blade scraper.

3.1 Experimental set-up

An x-y welding table was utilised for the test set-up. The table was modified to incorporate the Aeroswift powder scraper. The same type of brackets used on the Aeroswift scrapers was used to mount the commercial carbon fibre scraper as well as the solid blade. This made changing between powder scrapers easy. The LLS was mounted on a motorised translation stage, for linear movement in the x-direction, and a carriage was used for the y-direction travel of the powder scraper to scrape the layers of powder. The carriage runs on high-precision rails and was disconnected from the motor to reduce the vibrations caused by the motor. The scraping was thus done by dragging the carriage by hand. A laptop was used to run the LLS's software and motion control software for operating the motor of the translation stage. Spherical titanium (Ti6Al4V) powder was used with a particle size distribution of 20-60 µm. Two titanium plates were used as base plates for the powder scraping. Refer to figure 2 to see the test set-up.

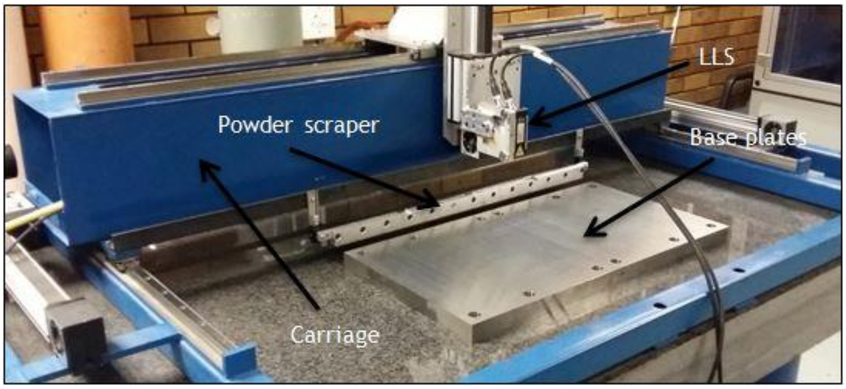

Figure 2: Test set-up

3.2 Experimental procedure

The powder used in the tests was dried at 120 °C to ensure optimum flowability for the tests. The scraper was aligned with the base plates and the scraping height set to scrape a layer more or less 0.5 mm thick. The LLS was mounted on a bracket that was machined in a way so that the laser line was parallel to the powder scraper and level with the build plate. Powder was dropped in front of the scraper and scraped over the base plates by dragging the carriage by hand. Nine line profiles were captured, while the y-position remained unchanged, with the LLS to cover a straight line with a total length of 540 mm. The carriage was then moved by hand to a new y-position to measure a different line across the powder layer. This was done for three separate lines in random y-positions. After all nine measurements were captured for each of the three lines, more powder was added in front of the powder scraper and a new layer was scraped. The new layer was then measured in the same way and repeated for a third layer. The data obtained was processed in Microsoft Excel. For each of the nine line measurements the following was done in Excel:

- A graph of the x- and z- coordinates was created to show the line profile.
- A best-fit linear line, called a median line, was drawn on the graph and the equation for the line was acquired.
- The distance for each point in the line profile to the median line was calculated using the equation and the x-coordinates.
- For each point it was determined if that point was a peak or a valley.
- The total number of peaks and valleys was calculated.
- The distribution of peaks given inside 25 µm intervals (0-25 µm, 25-50 µm, etc.) was then determined.

4. RESULTS AND DISCUSSION

Due to the way in which the LLS software exports the data, three data sets per line were obtained. These were averaged into one Excel file and then processed. The performance of the scrapers were given in the number of peaks that fell out of specification. In this case, the specification was that defects or peaks should be smaller than one-and-a-half times the thickness of one layer, which was 50 µm. The out-of-specification size distributions were thus 75-100 µm, 100-125 µm, etc. Figure 3 shows a typical graph of the line profile, the best-fit line and its equation. Line section 7 was chosen as it was a good representation.

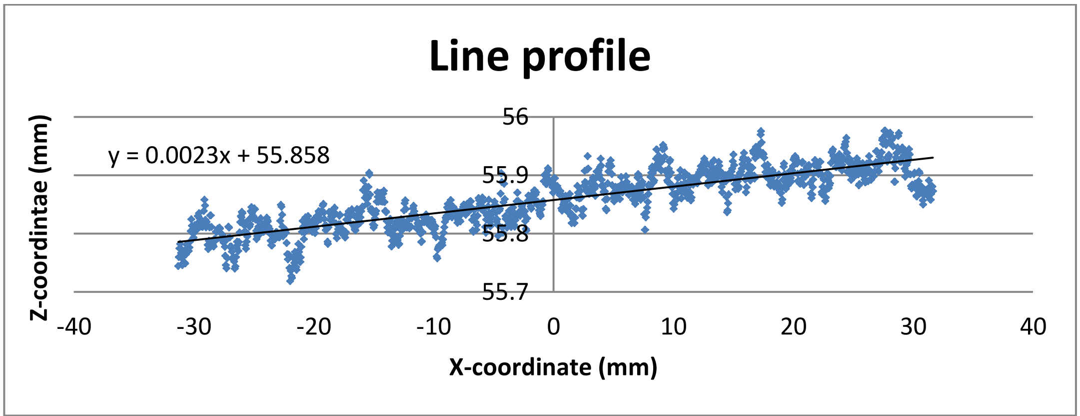

Figure 3: Line section profile of an Aeroswift scraper

Tables 1 and 2 show the number of peaks within a size range for all three corresponding line sections across all three layers.

Table 1: Aeroswift scraper 2 - all data for line section 7

	Layer 1			Layer 2			Layer 3		
Peak size distribution (µm)	**Line 1**	**Line 2**	**Line 3**	**Line 1**	**Line 2**	**Line 3**	**Line 1**	**Line 2**	**Line 3**
0-25	79	86	89	75	77	86	80	89	94
25-50	72	55	65	68	77	72	68	59	66
50-76	11	16	8	9	12	14	11	8	8
75-100	0	0	0	1	0	1	1	0	1

Table 2: Aeroswift scraper 2 - all data for line section 5

	Layer 1			Layer 2			Layer 3		
Peak size distribution (µm)	**Line 1**	**Line 2**	**Line 3**	**Line 1**	**Line 2**	**Line 3**	**Line 1**	**Line 2**	**Line 3**
0-25	56	41	53	67	53	53	52	50	60
25-50	45	59	46	50	57	54	49	52	43
50-75	28	30	32	37	24	33	39	33	42
75-100	9	10	9	7	11	9	7	10	6
100-125	1	0	0	0	1	0	0	1	0
125-150	1	0	0	0	0	0	0	0	0

Tables 3 to 7 show the results of the powder scraping tests. The tables show the line that had the least number of out-of-specification peaks, the line that had the most out-of-specification peaks and the average between all nine line sections. The range 0-25 and 25-50 µm is ignored, but still added to show the comparison of in-specification peaks.

Table 3: Aeroswift scraper 1

Peak size distribution (µm)	Best-performing line (number of peaks)	Worst-performing line (number of peaks)	Average (number of peaks)
0-25	74	35	65.3
25-50	64	38	57.6
50-75	16	37	22.8
75-100	0	14	5.2
100-125	0	8	1.2
125-150	0	0	0
150-175	0	2	0.2

Table 4: Aeroswift scraper 2

Peak size distribution (µm)	Best-performing line (number of peaks)	Worst-performing line (number of peaks)	Average (number of peaks)
0-25	79	56	73.7
25-50	72	45	61.2
50-75	11	28	17.6
75-100	0	9	2.9
100-125	0	1	0.2
125-150	0	1	0.1
150-175	0	0	0

Table 5: Aeroswift scraper 3

Peak size distribution (µm)	Best-performing line (number of peaks)	Worst-performing line (number of peaks)	Average (number of peaks)
0-25	80	52	71.6
25-50	68	49	63.1
50-75	11	39	20.8
75-100	1	7	2.8
100-125	0	0	0.1
125-150	0	0	0
150-175	0	0	0

Table 6: Commercial carbon fibre scraper

Peak size distribution (µm)	Best-performing line (number of peaks)	Worst-performing line (number of peaks)	Average (number of peaks)
0-25	79	37	61.4
25-50	66	67	59.1
50-75	13	35	20.4
75-100	0	3	3.3
100-125	0	1	0.8
125-150	0	0	0.2
150-175	0	0	0

Table 7: Solid blade scraper

Peak size distribution (µm)	Best-performing line (number of peaks)	Worst-performing line (number of peaks)	Average (number of peaks)
0-25	82	96	97.4
25-50	67	56	60.3
50-75	3	12	7.6
75-100	0	0	0.1
100-125	0	0	0
125-150	0	0	0
150-175	0	0	0

From the results it can be seen that the solid blade powder scraper performed much better than the Aeroswift and the commercial carbon fibre powder scraper. It had no peaks above 100 µm and in the 75 -100 µm range there was only one (79 µm) peak. This confirms that the method of qualification is suitable. A solid blade scraper could, however, not be considered for use in Aeroswift as it is inflexible and any misalignment of the build platform or defects in a build would damage the blade or cause it to jam.

Another observation made was that the data obtained for each corresponding line section did not vary by much. For instance, if the data for line section 7 showed good results, it would do the same for all line section 7's across all three layers. The numbers of peaks do vary between datasets, but not in a significant way. A line section that gave good results did not change between different layers or lines.

The Aeroswift scrapers performed comparably to the commercial carbon fibre scraper if the average number of peaks within certain size distributions is compared: For the commercial carbon fibre scraper, 20.4 in the 50 - 75 µm range and 3.3 in the 75 - 100 µm range, compared to 22.8 and 5.2 for Aeroswift scraper 1, 17.6 and 2.9 for Aeroswift scraper 2 and, 20.8 and 2.8 for Aeroswift scraper 3. If the best-performing lines of the two scrapers are compared, they also perform similarly (13 and 0 vs. 16 and 0, 11 and 0 and, 11 and 1). However, when considering the worst-performing line, the commercial carbon fibre scraper performed better. This could be due to the manufacturing method of the scrapers. The Aeroswift scrapers are made by hand in a non-automated way. The commercial carbon fibre scrapers, however, are produced in higher volumes and possibly manufactured in an automated process, which would be more consistent.

5. CONCLUSION

It is thus concluded that an LLS can be used to quantitatively evaluate the performance of a powder scraper and that this method can be used to evaluate the custom carbon fibre brush powder scraper used in the Aeroswift system. This scraper achieved comparable performance to a commercially used carbon fibre brush scraper. However, there were some inconsistencies across the line sections and it is suggested that the manufacturing process be changed to improve the performance of the Aeroswift scrapers even more.

This project did not take into account the durability of the powder scraper and it is suggested that this be investigated in future work. Even though the durability of the Aeroswift scrapers have not formally been tested, these scrapers have successfully been used in a few builds with more than 2000 layers. The durability tests should also be done at high temperatures to investigate the performance of the Aeroswift scrapers if high preheat temperatures are used. For durability reasons, the solid blade scraper was not a potential solution for the Aeroswift system.

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