Optimization of Surface Modification for Additively Manufactured AlSi10Mg Using a Vibratory Polishing Surface Finisher

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Abstract. Surface morphology is a significant aspect of a solid material, whether for aesthetic or functional purposes and currently, through different surface modification methods, developments have been dedicated into advancing metallic materials to improved surface characteristics. Additively manufactured aluminium alloys have demonstrated an extensive choice of appropriate characteristics for different uses desired for the aviation and space industry. However, the surface hardness and tribological properties are insufficient in these materials due to the fact that when one property is enhanced one is compromised especially after thermal treatment. This makes the significant development and modification of the surface properties very imperative for existing and forthcoming engineering applications. There are many types of surface modification techniques used, in this paper an optimization of the barrel finishing that uses ceramic polishing media for commercially build SLM produced AlSi10Mg will be explored. Gloss value, surface roughness and other characteristics will be characterized.

1. Introduction

Aluminium alloys' surface modification approaches used to be classified in three categories which were mainly alloying which was to form a hard film on the aluminium surface, the second category was the coating which had to do with the use of hard material to cover the aluminium surface and the third category which was the combination of alloying and coating of the aluminium surface [1]. These were the conventional methods approach of surface modification. Today there are other procedures used for surface modification that are still under development especially for the currently progressing manufacturing technology of Additive Manufacturing (AM).

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However, as concurred by Artzy et al, the mechanical characteristics of AM components suffer from porosity and rough surfaces due to their anisotropic nature and powder melting and remelting leading to near-net shape surfaces [2, 3]. Their introduction for viable resolution is deferred due to their insufficient surface hardness and tribological characteristics. The quality and the characteristic of the final product is highly affected by all the parameters involved in this process such as laser powder and scanning speed. Thus, for current and future operations, the modification and development of surface characteristics is very vital [2, 4]. Components manufactured by Additive Manufacturing (AM) Laser Powder Bed Fusion (LPBF) method are frequently tremendously rough. It was demonstrated that in adding to aesthetical insinuations, fatigue life of a component is reduced by the surface roughness relative to conservative metals, predominantly under low load high cycle circumstances [5]. It was further described how the amount of localized stress, that result in the crack initiation site is increased by each valley on the AM surface which from there crack propagation can happen under operation of cyclic loads [6]. Numerous convergence microcracks can thrive across surface defects lead to the failure of the component [7]. Surface roughness is frequently complex than what is commonly tolerable in additively manufactured materials due to the layer-by-layer build-up of components through laser beam melting.

Therefore, to meet the practical surfaces excellence necessities, this typically high roughness requires finishing through numerous procedures. One surface finishing procedure step cannot attain the required surface quality as established by practise [8]. This investigation evaluates the parameters for the surface modification of Selective laser melted AlSi10Mg post processing using a vibratory grinding procedure. For the historical 50-60 years, surface polishing, scraping, texturing, edge finishing and burnishing has been carried out on the vibratory grinding as a handy surface treatment procedure [9]. The vibratory finishing is projected to alter surface characteristics of a component without disturbing the geometrical precision and characteristics of the bulk material hence it is classified into one of the mass finishing developments as a distinctive near net shape surface modification and development methods. Relative to medium motion, surface modification and material elimination, ultimate information of the vibratory finishing has not been meticulously established and finishing procedures are mostly industrialised through trial and error on the shop floor. Insufficient mathematical models exist, and comparatively fewer scientific investigations have been reported with regards to the vibratory finishing [9].

2. Experimental procedure

2.1 Specimen Production

The AlSi10Mg tensile samples were produced by Selective Laser Melting (SLM) SLM Solutions M280 at fixed parameters of; 150W power, 1000 mm/s scan speed, 50 μm hatch spacing and 50 μm powder layer thickness. The samples were built vertically. A spring-mounted open compartment comprising of granulated media is what a typical vibratory finishing system entail. It is attached with a vibratory motion generator on the compartment which usually comprises of one or two rotating shafts with eccentric weights [10, 11]. Frequency and amplitude of vibration, the shape,

size, and characteristics of the media as well as the amount and form of lubricant are the key vibratory finishing development variable quantity. The eccentric weights and the speed of the drive motor are used to control the vibration amplitude and frequency of the surface finisher correspondingly to fluidize the media and produce complex flow fields within the compartment. Entrainment of the samples to be polished by the flowing media takes place which cause them to experience a gentler comparative speed [12, 13]. Nonetheless, in the past 50-60 years a wide body of industrial involvement and pragmatic data has been accumulated about its use.

2.2 Characterization Technique

The samples were surface finished using the High Energy Harperizer polishing machine. Before vibratory polishing, the samples were sand blasted to remove excess powder. The samples were rough polished using 10x10 mm angle cut ceramic media which was filled to the capacity of 70% of the tumbler, few drops of the LC13 polishing liquid and some water, enough to reduce the viscosity of the mud that accumulates in the tumbler during impact. The significance of the different media is that ceramic media is for heavy impact on the sample while the plastic media is good for softer material such as aluminium and the zirconia balls have low abrasion. The selected samples were further fine polished using 6x6 mm pyramid cut plastic media and a mixture plastic media and 4x4 mm zirconia balls, with a little bit of MH88. A profilometer fitted with a stylus arm was used to measure the surface roughness before and after polishing according to the specifications of the international standard ISO 4287 terms.

Fig. 1: Different sample media (a) ceramic media angle cut 10X10mm, (b) plastic media pyramid cut 6X6mm, (c) zirconia balls 4X4mm mixed with) plastic media pyramid cut 6X6mm

3. Results and discussion

3.1 Structural Analysis

Figure 2 below is the initial image of the unpolished sample with the roughness of 10.01± 2.71um. This surface roughness is withing the specific range of cleaned as built SLM produced AlSi10Mg components of 6-10 um according to the EOS material data sheet. Figure 3-5 below are the images of the samples polished at the velocities of 160, 170 and 180 RPM for 1, 2 and 3 hours respectively using the different media above relatively. The samples were taken using the stereo microscope at 200 magnifications.

Fig. 2: Unpolished sample at 200 magnifications

Figure 3 demonstrate the polishing image results at 160RPM. It is observed in the images (a, b, and c) of all the images that any kind of contact of the sample to the vibratory finishing process is bound to bring forth some substantial transformation to the macrostructure. This is due to the media pebbles diverse interaction with the sample surface which maybe a combination of normal impact resulting in required surface depression and transversal impacts accountable for debris erosion [14]. Images (d, e, and f) shows micro-pits and micro-sleets where (e) is worse. Images (g and h) show smoothness after the final stage of polishing though uneven in comparison to (i) which is smoother. According to Sagbas, these samples have a surface with dimples [6].

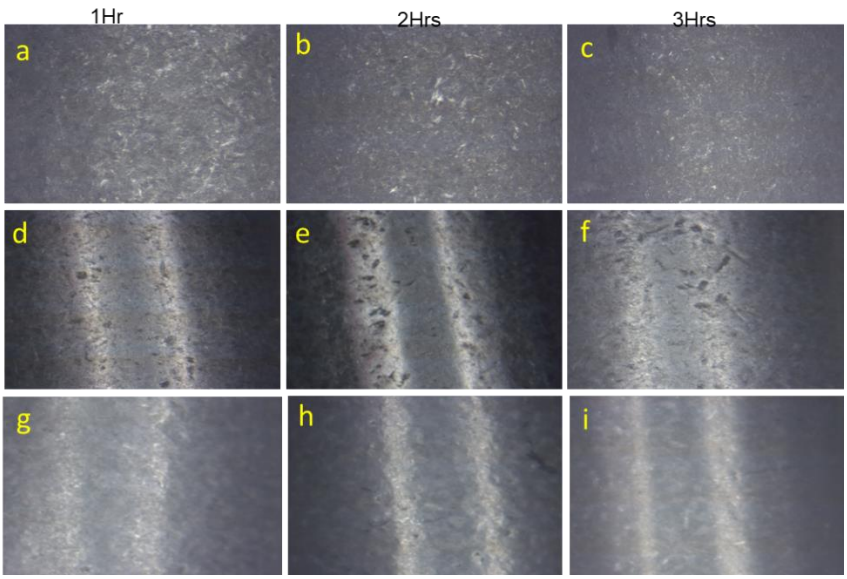

Fig. 3: Microstructural images for samples polished at 160RPM at various hours (a,b,c) ceramic media angle cut 10X10mm, (d,e,f) plastic media pyramid cut 6X6mm, (g,h,i) zirconia balls 4X4mm mixed with) plastic media pyramid cut 6X6mm with (a,d,g) polished for 1 hour, (b,e,h) for 2 hours and (c,f,i) for 3 hours

Figure 4 demonstrate the polishing image results at 170RPM. Significantly improved results are observed relative to the image results of samples polished at 160RPM. This is particularly evident in the images d,e and f. The sample polished at 170RPM for 2 hours demonstrates substantial smoothness comparative to the ones polished for 1 hour and 3 hours. The sample polished for 1 hour shows some micro-sleets while the one polished for 3 hours shows what looks like micro-pits. A lot of applications require a surface finish of at least 0.8 um or less Ra values by grinding or milling since stress concentration, fracture initiation acceleration and dissemination, increased friction, abrasive elements, and wear encouraged by complex surface roughness are not suitable for a lot of mechanical applications [5, 12, 15].

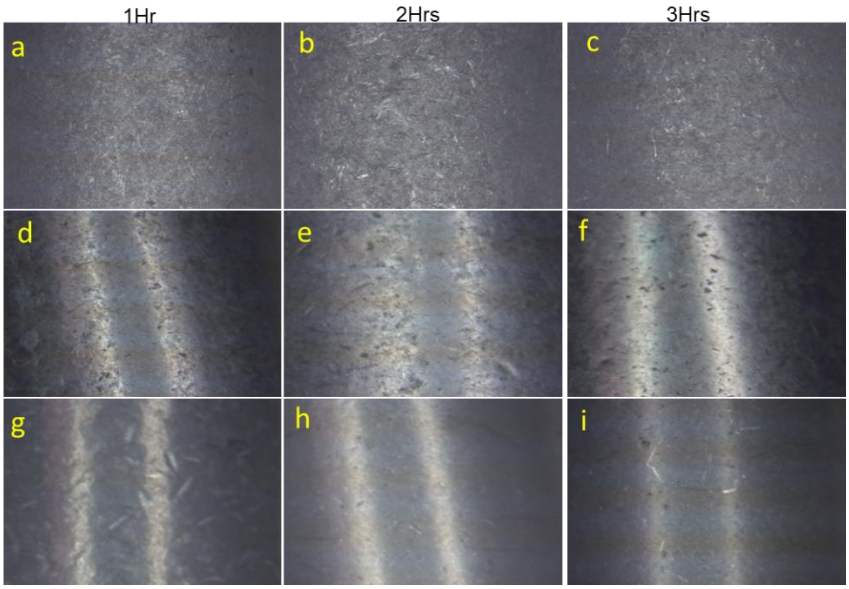

Fig. 4: Microstructural images for samples polished at 170RPM at various hours (a,b,c) ceramic media angle cut 10X10mm, (d,e,f) plastic media pyramid cut 6X6mm, (g,h,i) zirconia balls 4X4mm mixed with) plastic media pyramid cut 6X6mm with (a,d,g) polished for 1 hour, (b,e,h) for 2 hours and (c,f,i) for 3 hours

Figure 5 demonstrate the polishing image results at 180 RPM. Images (g,h, and i) show substantial smoothness relative to samples images polished at 160 RPM and 170 RPM. No micro-pits or micro-sleets are seen on the final polishing stage for all the samples of different hours. On the second polishing stage, lots of micro-pits are observed on (d) comparatively to (e and f), while (f) appears lustrous. At this speed of 180 RPM, the increase in temperature in the tumbler was recognised and the sticking of the media to the walls of the tumbler. This indicated that this is the optimum speed for acquiring efficient results, as exceeding this speed will obtain very little to no effect on the surface quality of the material. It was concurred by Mahmoud that surface roughness is exceedingly affected by the rotation speed, where due to thermal softening as a result of temperature increase, more penetration and increase in material removal rate volume is experienced due to extreme rotation speed [5, 6].

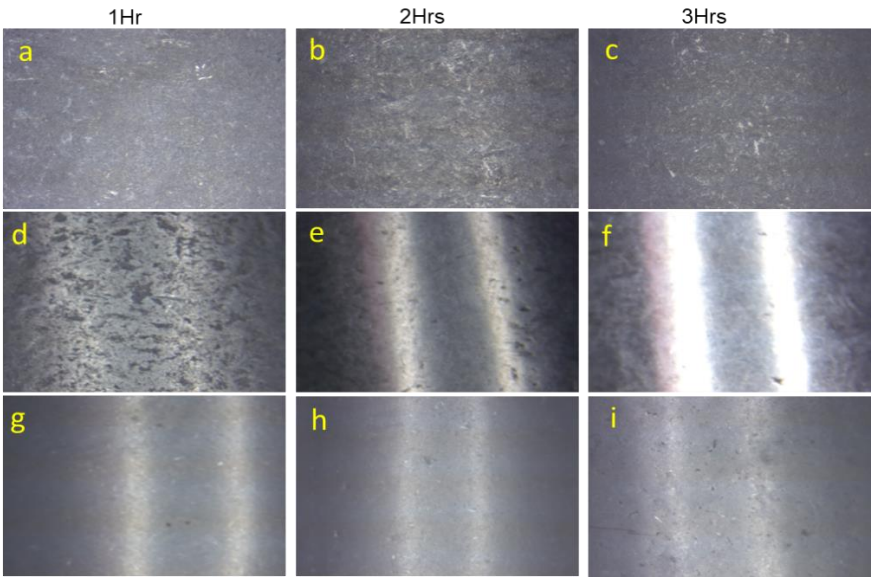

Fig. 5: Microstructural images for samples polished at 180RPM at various hours (a,b,c) ceramic media angle cut 10X10mm, (d,e,f) plastic media pyramid cut 6X6mm, (g,h,i) zirconia balls 4X4mm mixed with) plastic media pyramid cut 6X6mm with (a,d,g) polished for 1 hour, (b,e,h) for 2 hours and (c,f,i) for 3 hours

3.2. Surface Measurements Analysis

Results of the surface roughness measurements and graphs for the various parameters are demonstrated below. No correlation between the speeds used and the time interval used in terms of surface roughness measurements, but it is observed that the system is very efficient in effective sample polishing as the surface roughness has been reduced from Ra 10.01± 2.71 um down to Ra 0.35± 0.07 µm. This lack of correlation in terms of speed and time interval is due to the fact that surface roughness is reliant on a number of aspects like material, particle size of the powder, scanning parameters, scanning approach, thickness of the layer as concurred by Kamarudin et al. [16], before the surface modification aspect, which entails the frequency and vibration amplitude, the shape, size and characteristics of the media as well as the quantity and nature of lubrication used which are the key vibratory finishing procedure variable quantity [9].

Table 1: Surface roughness per time interval at 160RPM velocity in (um)

Velocity Interval (RPM)	Unpolished	Ceramic Angle Cut (10x10mm)	Plastic Pyramid Cut (6x6mm)
	10.71± 2.17		
160/1 Hr		1.70± 0.07	0.68± 0.19
160/2 Hrs		1.39± 0.14	0.81± 0.30
160/3 Hrs		1.26± 0.16	1.62± 0.14

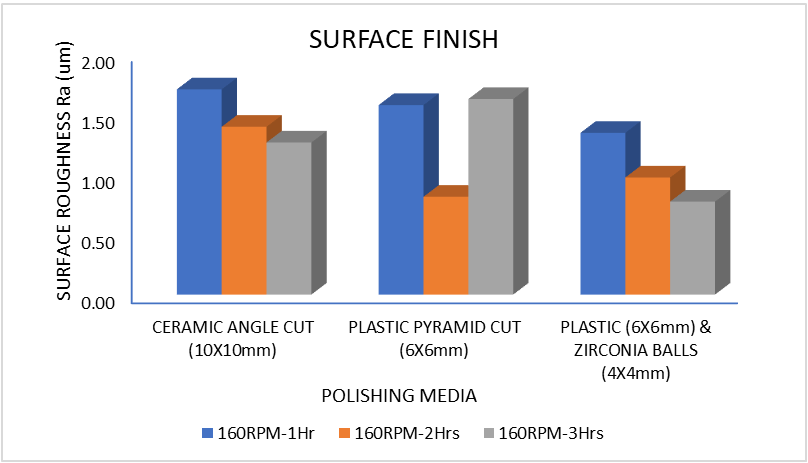

Figure 6: Surface roughness per time interval for various media polish at 160RPM

The surface roughness results for the 160RPM are demonstrated above. Though the surface roughness is reduced significantly from the unpolished sample, it is observed in the graph that each sample is never polished uniformly throughout. This is due to the media free-fall impact with the surface of the sample which only affects a single crater by a tiny force magnitude [14]. According to Groover and Domblesky, this is because of the specific energy of a material, which is the comparative effortlessness or struggle of debris removal for each material hardness and for aluminium 0.7N-m/mm^3 was reported [10]. To improve the quality of the surface and material removal rate, Mahmoud suggested that the media size be enlarged as these relays with improved movement of the abrasive suspension of media and liquid. It is also true that bigger sized media holds more mass, inertia and punching action. It eradicates more debris during the polishing process, as a result of more pressure applied thereby cultivating the quality of the surface [5].

Table 2: Surface roughness per time interval at 1670RPM velocity in (um)

VELOCITY INTERVAL (RPM)	CERAMIC ANGLE CUT (10X10mm)	PLASTIC PYRAMID CUT (6X6mm)
170/1 Hr	1.50± 0.09	2.20± 1.95
170/2 Hrs	1.26± 0.11	1.04± 0.14
170/3 Hrs	1.96± 0.43	0.49± 0.27

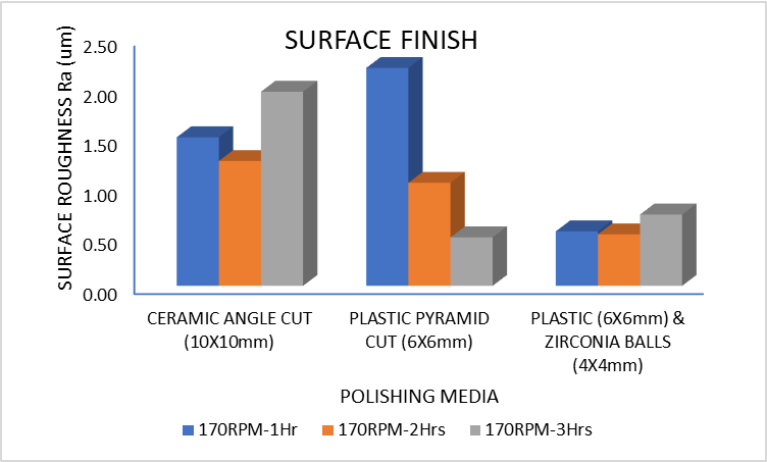

Fig. 7: Surface roughness per time interval for various media polish at 170RPM

Figure 7 demonstrate the surface roughness results for the 170RPM. The instability of the surface roughness data is observed in all the sample graphs as a consequence of the polishing inhomogeneity and different purpose of the different media. The second polishing stage shows to have the purpose of revealing the micro-sleets and micro-pits as observed in the micro-images which usually increases the surface roughness, and the final polishing stage smooths out the micro-sleets and micro-pits. Domblesky concurs that the rate of removal of the debris is significantly constant for each media as well as individual material [10]. Only the sample polished at 170RPM for 2 hours demonstrates consistency in the reduction of the surface roughness relative to the other samples. This is as a result of less micro-sleets and micro-pits revealed by the second polishing stage.

Table 3: Surface roughness per time interval at 180RPM velocity in (um)

VELOCITY INTERVAL (RPM)	CERAMIC ANGLE CUT (10X10mm)	PLASTIC PYRAMID CUT (6X6mm)
180/1 Hr	1.70± 0.10	0.53± 0.11
180/2 Hrs	1.42± 0.06	0.38± 0.05
180/3 Hrs	1.65± 0.06	0.31± 0.05

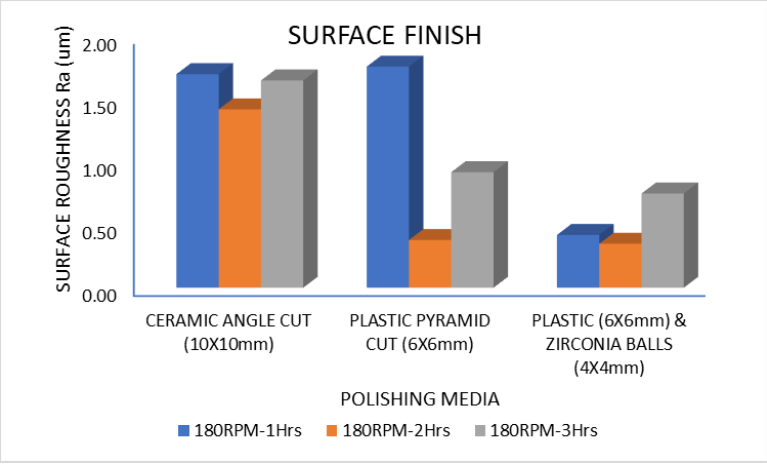

Fig. 8: Surface roughness per time interval for various media polish at 180 RPM

Figure 8 demonstrates the surface roughness for samples polished at 180 RPM for various hours. All the samples polished at 180 RPM demonstrate on the final polishing stage substantially reduced surface roughness relative to the samples polished at 160 RPM and 170 RPM. Even though this is the case it is also seen that in that the sample polished at 180 RPM for 2 hours has significantly smooth surface roughness relative to all the samples in its category. This is also corresponding to what is seen in the micro images. These practical surface roughness prove to be within the range of other tested surface roughness results for a barrel finisher which is within 0.80 and 0.20 um and electropolishing which ranges within 0.80 and 0.10 um for metal materials which are according to the ISO 4287/1, international standard organization, 1984 [17], but these results are greater than those acquired on machined surfaces which is usually 0.005 um or less [18].

4. Conclusion

All the samples polished at 170 RPM and 180 RPM surpassed at least the minimum technical application requirements of below 0.8 um surface finish even though the machining standard was not reached. It may be suggested that the final polishing stage be done for a longer duration of time to acquire the machining standard. The first two polishing stages should be done for a shorter duration of time in order to avoid

excessive loss of material volume which may lead to loss of component geometry. It is concluded in this investigation that the suitable speed for polishing AlSi10Mg parts should be 170 RPM or 180 RPM and not beyond. This is because already at 180 RPM, temperature increase was detected as well as the media beginning to set on the wall especially for the first two polishing stages. This may cause more roughness because of the groove and the media scraping which may lead to less effective interaction with parts being polished. All the different media is suitable for polishing SLM produced AlSi10Mg. 96.5 % surface roughness reduction has been successful achieved.

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