Economic Additive Manufacturing using Water Atomized Stainless Steel Powder

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Abstract

316L stainless steels are highly corrosion resistant steels utilized in applications ranging from handling chemicals in the process industry, pharmaceuticals, medical implants, to automotive applications. This stainless steel is characterized by good formability, weldability, and exceptional toughness. Primary alloying elements, chromium, nickel, and molybdenum provide exceptional resistance to corrosion. Due to these desirable qualities, 316L is an attractive alloy for Additive Manufacturing (AM). Essential powder characteristics (e.g. flowability, morphology) for AM are still being developed and understood. Gas atomization (GA) is the principle production route for powder aimed towards AM. Water atomization (WA) is another means to produce powder, albeit, with morphological and chemical characteristics slightly different to GA powder. This paper presents the morphological, microstructural, and mechanical properties of WA compared to GA 316L after being processed via Selective Laser Melting. The manufacturing process chain is developed to produce small series of complex parts and prototypes for automotive applications.

Introduction

As additive manufacturing becomes a highly utilized system for research based projects and industrial applications, developments will be made to optimize machine capability and productivity. One of the main topics of development focuses on the quality and characteristics of the powder material used in the system. AM systems as of today require feed material to meet very strict specifications on powder size, morphology, and chemistry to ensure a high confidence in repeatability. This leads to the cost of acceptable powder for AM to greatly exceed standard powder prices for the PM industry. Soaring powder cost for AM hinders the commercialization and limits industrial developments to high value markets such as medical and aerospace fields. Confidence in the integrity of parts fabricated via additive manufacturing is based on the powder characteristics determined by the systems manufacturers themselves. These characteristics vary slightly between manufacturers; however, the two most prominent qualities that dictate high density part fabrication are particle size and sphericity.

To achieve these powder characteristics, gas atomization is a widely used technique for powder production. Due to the low solidification rate, the resulting powder is highly spherical and coupled with the proper gas pressure; the yield can be optimized for producing powder sizes for a large spectrum of AM systems. However, the same can be said about the water atomization process. Even though the atomizing jet is water instead of gas, jetting pressures can be varied anywhere from 2000 to 10,000 psi to obtain desired size ranges and degrees of sphericity. This removes the assumed limitations of water atomized powder and reduces the differences between water and gas atomized powder to chemical composition differences, including oxygen levels.

The Atomization Process

Stainless steel powders are produced by melting the feed material in an induction furnace followed by pouring from the induction furnace into a crucible which is positioned directly above the atomizing jets. As the atomizing jets hit the molten stream, the turbulence created segregates the stream into powder droplets which then rapidly solidify into powder particles. The powder is then collected in a chamber as a water/powder slurry, which is then pumped to a de-watering module. After the powder is de-watered, it will contain approximately five to six percent moisture. This level necessitates the need for a drying step which can be accomplished by a number of different methods. Finally, depending on the material size required for its particular use, the yield from the atomization process will be sorted to a final particle size. [4][9]

Water atomization

When analyzing the production path of water atomized powder, it is very important to begin with the raw materials. Firstly, the melting procedure of stainless steel meant to be water atomized is quite different to that of cast and wrought stainless steel processes. As the raw material is melted in an induction furnace, little refining can occur and certain elements cannot be removed.[4] This means that the carbon in the raw material remains in the final product, facilitating the necessity for low carbon feedstock. Likewise, manganese is not removed in the process meaning that the raw material must also meet maximum requirements for acceptable content. Controlling the manganese in the raw material is important to reduce the oxidizing effects that occur during the water atomization process.[3] These two limiting factors influence which type and volume of raw materials are allowed to be used for producing water atomized powder.

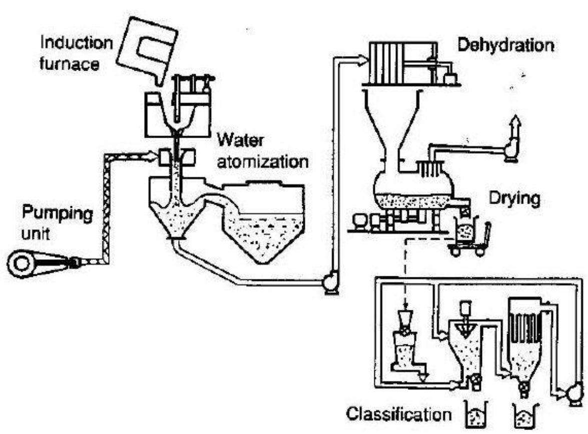


Figure 1. Schematic of the water atomization process[1]

The second factor which differentiates water atomization from gas atomization is the resulting particle shape. Water atomized powder is highly irregular in comparison to gas atomized powders. This is due in most part to the relative cooling and spheroidization rates. Water atomized powders tend to be more irregular because the cooling rates are 10 to 100 times larger than gas atomized powders.[4] The product shape from water atomization can be altered depending on the atomizers water jetting pressures and the jets angle to the melt.[4] Changing these can have significant effects on the atomization's processes yield and on the overall shape of the powder.

Gas Atomization

Contrary to the melting in water atomized powder, usually melting for gas atomization occurs either under a protective atmosphere or vacuum. This limits the amount of oxidation and nitrogen pick up from the air during the melting process. Due to the fact that oxidation is hindered during the process, there is no longer a strict manganese maximum dictated by the fear of severe oxidation of the metal.[3] During the actual atomization of molten powder, turbulence is introduced into the molten stream by gas jetting. These gases can be air, nitrogen, argon, and helium. Unlike water atomization, where particle size is dictated by water jetting pressures, the gas to metal ratio is the primary control for particle size. The process may also lead to atomizing gas being entrapped in the metal powder during atomization resulting in pores; this is especially noticeable when atomizing with argon. These pores may be a result of particles colliding during atomization and entrapping the gas.[4][9]

Flowability (Avalanche Angle Test)

Powder flowability is one of the topics of concern when producing parts meant to be fully dense. However, a powder's flowability being regarded as the main factor in ensuring consistent layering in the machine is rather obtuse and does not fully represent the dynamics of the spreading. If the powder isn't spread in a consistent and even manner, then porosity can be introduced into the part; compromising the mechanical properties. Measuring the flowability of powders used in SLM systems is limited in techniques in this point in time to traditional methods of flow qualification, e.g. Hall and Carney flow cups. For SLM grade powders, these methods may not be as accurate as they are for other P/M applications. A study conducted by Fraunhofer ILT identifies a method called the Revolution Powder Analysis, detailed in Figure 2. By rotating a cylinder with powder inside of it, a camera observes and records the angle at which the powder begins to "avalanche". This angle can be recorded as many times as the user requires; the study deems that 150 data points is an acceptable representation of the avalanche angle.[13] The significance of this test is the mechanics behind determining the avalanche angle. A similar angle can be observed as the SLM systems spread individual powder layers. This makes it quite more relatable to the process compared to typical flowability measurement methods.

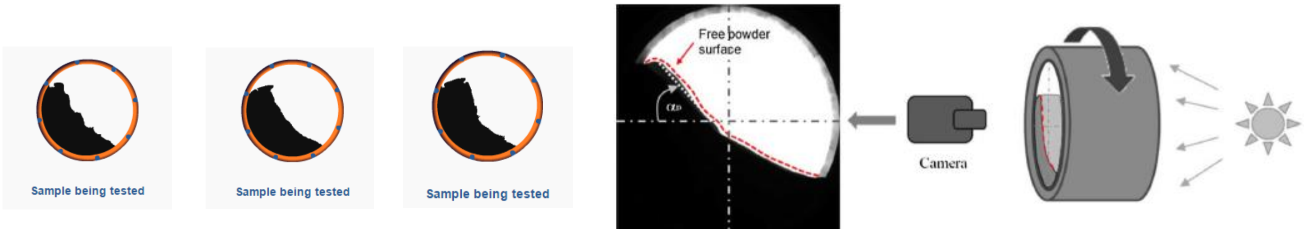


Figure 2. Schematic of the Powder Revolution Analyzer and how it functions[13]

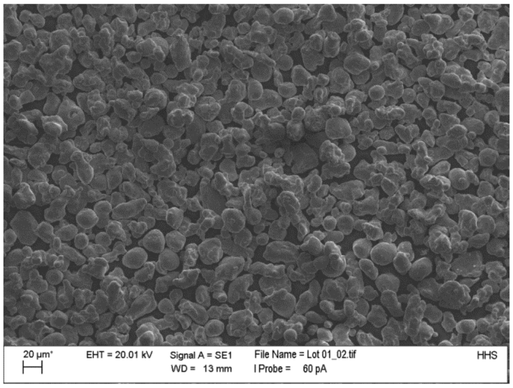
This test was conducted on the range of powders listed in Table 1 to emphasize the differences in avalanche angles between powders of different sizes and manufacturing methods. This study highlights an iron powder type with a high avalanche angle yet was still able to be processed in an SLM system. This angle is deemed to be the maximum avalanche angle without compromising the machines ability to process the powder. This angle is fixed at 54.30 °. Water atomized and gas atomized 316L powder was tested and the results are tabulated in Table 1. It should be noted that the higher the avalanche angle, the worse the powder flowability.

Powder Batch/Type	Average Avalanche Angle [°]	Apparent Density (g/cm^3)	Flowability	Comments
Fe Powder[1]	54.30	3.19	Hall: NF Carney: NF	D50: 23.80 µm
Proprietary powder material	58.50	N/A	N/A	D50: 310 µm, poor flowability
Ti 6-4	34.00	N/A	N/A	20-63 µm, good flowability
WA 316L A	50.30	2.57	Hall: NF Carney: NF	D50: 24.10 µm
WA 316L B	46.06	3.09	Hall: 34 seconds	D50: 24.60 µm
WA 316L C	44.80	3.56	Hall: NF Carney: 4.7 seconds	D50: 24.40 µm Powder used to produce test specimens
GA 316L	38.30	4.24	Hall: 21.5 seconds	D50: 32.10 µm

Table 1. Comparison of various powder types and their respective avalanche angles, apparent densities, and flow

Fe Powder is the powder Fraunhofer was able to process with the highest avalanche angle. The powder which is used in the industry with the highest confidence is gas atomized powder and this was recorded as having an avalanche angle of 38.30°. A proprietary powder which yielded poor results from standard flow testing was also tested by the powder revolution analyzer resulting in an avalanche angle of 58.50°. This angle falls above the limit set by the Fe powder and was therefore deemed too poor in quality to be processed in the SLM.

[1] Internal Study conducted by GKN Sinter Metals and Fraunhofer ILT [13]



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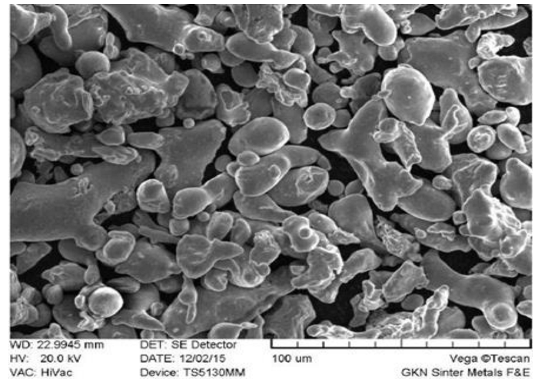

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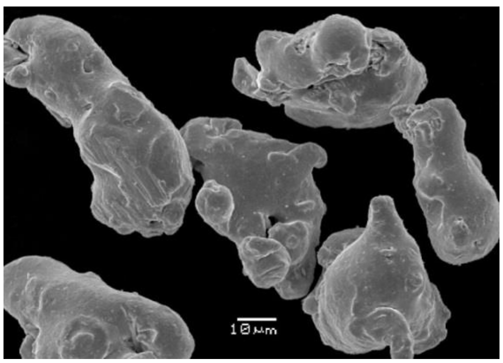

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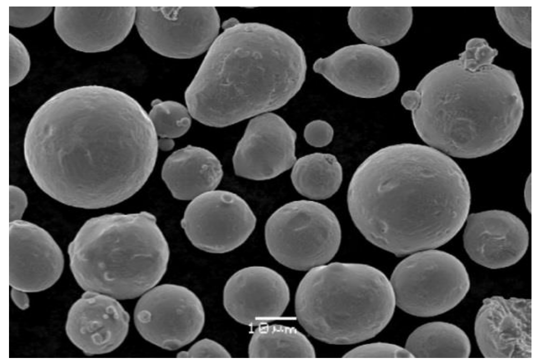

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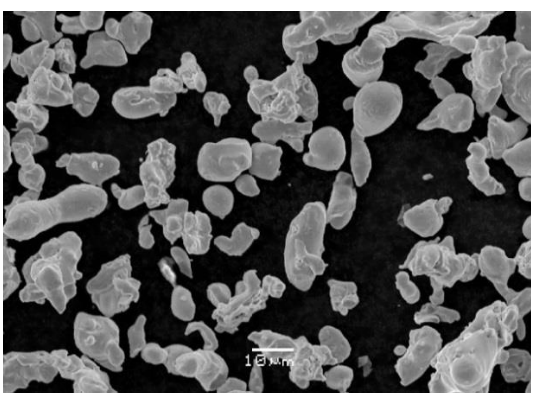

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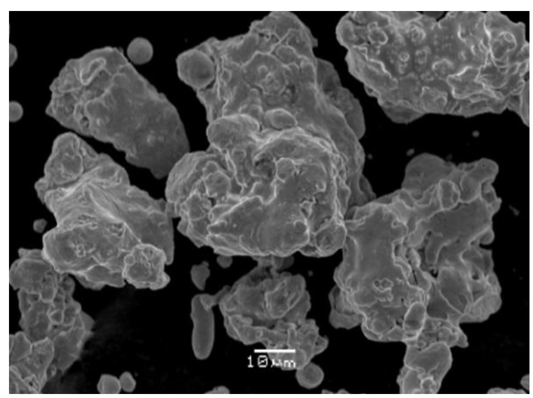

(f)

Figure 3. (a) Fe powder morphology[13]; (b) water atomized 316L C morphology; (c) water atomized 316L atomized C morphology; (d) Gas atomized 316L morphology; (e) water atomized 316L A morphology; (f) water atomized 316L B morphology

Comparing it to the traditional flow tests from Hall and Carney cups, there would be no observable difference between the Fe powder and the proprietary powder because they exhibited no flow. The avalanche angle distinguishes the two powders and provides a more refined measurement as to the characteristics dependent on functionality in an SLM system. The performance of the powder in this test can be related to two factors which are also important influences in traditional flowability tests. The particle size and shape play significant roles in the results achieved from both traditional flowabiliity tests and the powder revolution analysis.

As seen in Figure 3a, the Fe powder is quite irregular in shape. Water atomized powder's morphology is also irregular but from the micrographs it can be determined that the Fe powder maintains a higher level of irregularity. Figure 3d depicts the morphology of the gas atomized powder. Due to the lower solidification rate, gas atomized powder is very spherical, leading to increased flowability and apparent density, making it optimal for current SLM systems. The second factor influencing powder flowability is the particle size. Finer powders have a much more difficult time flowing due to higher surface areas and Van der Waal's forces compared to slightly coarser powders. As outlined in Table 1, WA 316L C has a D50 of 24.40 µm and GA 316L has a D50 of 32.10 µm.

These two factors are essential in not only describing the flowability measurements in the standard procedure, but also in the determination of the avalanche angle which shows a distinct correlation between a powders flow, and the powders behavior in the SLM system. Even with these significant differences in shape and size distribution, the influences are not substantial enough to disallow the utilization of water atomized powder in SLM systems because, as stated, the avalanche angle falls well below the limit set by the Fe Powder, depicted in Figure 4.

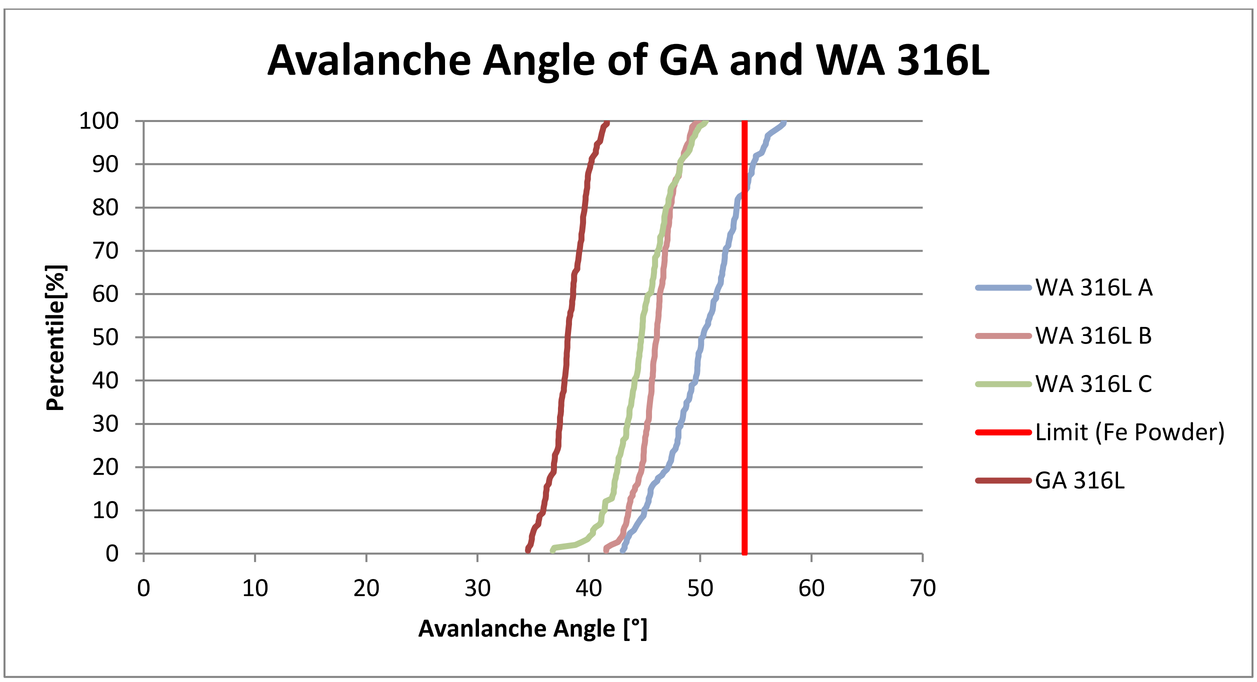

Figure 4. Graph depicting the behavior of the avalanche angle for each powder

Densification of Gas Atomized and Water Atomized 316L Powder

Part density is one of the typical barometers used in determining whether or not the material produced will yield expected mechanical properties. Producers actively seeking high mechanical properties normally aim for parts as close to the theoretical density of the material as possible. This leads to part density being a major focus during the SLM production process. Currently, final part density is correlated not only to the process laser power and scan speed, but also the powders flowability; if the powder has the ability to spread well and unperturbed across the layer, then the presence of porosity should be minimized.[10] Yet, Figures 5a and 5b show porosity images of both a gas atomized powder part and a water atomized powder part. Even though flow rate of the water atomized powder is different than the gas atomized powder, the process parameters had the ability to adapt to the powder and print nearly fully dense bars. By optimizing the laser power, hatch distance, exposure time, and several other process parameters, the water atomized 316L powder results highly compare to that of the gas atomized powder. [11]

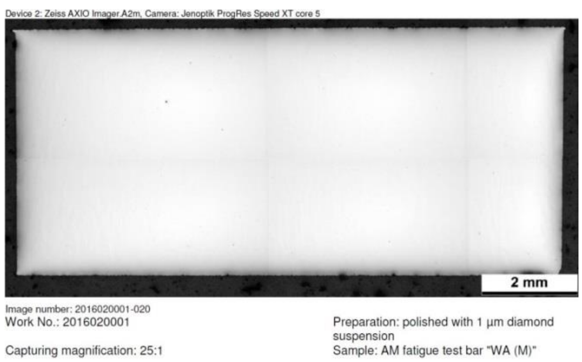

Figure 5. a) Picture of water atomized 316L test piece produced in the Renishaw AM250 showing porosity; scale of 800 µm

b) Picture of gas atomized density cube produced in the Renishaw AM250 showing porosity; scale of 100

The levels of porosity are similar when looking at the photo micrographs. Table 2 shows the densities as calculated via Archimedes principle and between the two, they are fairly close and exceed the minimum density of 99.5% of the theoretical density.

Production method	Average %Theoretical density	Standard Deviation
GA	99.84%	0.13
WA	99.77%	0.15

Table 2. Comparison of densities from test specimens produced from water and gas atomized

Mechanical Results

Tensile test specimens were produced from both water atomized and gas atomized 316L powder.

Powder Type	Emod GPa	0.2% Yield MPa (TSI)	UTS MPa (TSI)	% Elongation	Hardness (HRB)
WA 316L	150 ± 9	475 ± 16 (34±1)	611 ± 7 (44± .5)	32 ± 3	89
GA 316L	147 ± 14	483 ±26 (35± 2)	624 ± 10 (45±1)	34 ± 1	94
ASTMA240 plate,sheet, strip annealed	Not listed	172 (12) min	483 (35) min	40 min	95 max
MIM 316L	193 min	138 (10) min	448 (32) min	40 min	67 min
Cast CF3M[2]	Not listed	186 (13.5) min	428 (31) min	30 min	Not listed

Table 3. Mechanical properties of water atomized and gas atomized powder parts compared to that of MIM and Cast 316L Stainless steel

(a) **(b)**

Figure 6(a) Picture of gas atomized tensile test specimens; (b) Picture of water atomized tensile test specimen

Tensile test specimens were produced from both water and gas atomized 316L stainless steel under process parameters optimized for each powder to ensure full density was achieved. Each build contained 12 tensile specimens produced in the XY plane, similar to the layout of Figure 6b. The data in Table 3 represents the mean value testing data for the mechanical testing of the corresponding material production type.

Tensile testing of the water and gas atomized parts yielded values exceeding the ASTM A240 standard. The yield strengths of the water atomized parts and gas atomized parts are 475 ± 16 MPa and 483 ±26 MPa respectively; UTS are recorded as 611 ± 7 MPa and 624 ± 10 MPa respectively. A possible reason for the varied standard deviation observed in both water and gas atomized mechanical results is the variability in surface roughness. Water atomized powder tends to have a rough surface, even more so

[2] Conditions for Cast CF3M are in the annealed state at 1040 C° (1904 F°)

than gas atomized powders, but the roughness for either case was not determined and remains a variable which has a slight influence in testing consistency.

The resulting data reflects the consistency of the production method and highlights the similarities while also alluding to the apparent differences. Values for the elastic modulus, yield strength, ultimate tensile strength, elongation, and hardness vary slightly, and this variation may be related to the overall difference in elemental constituency in the powder used. A comparison to ASTM A240 is listed in Table 3 as a barometer to the accepted mechanical properties for annealed plate, sheet, and strip 316L material. These values are greatly exceeded with the exception of the hardness which falls below the required maximum. Gas atomized 316L's material specifications in terms of alloying element percentages falls within ASTM standards, however, the water atomized 316L does not meet the required criteria; the silicon weight percent is higher than the required maximum. This may be responsible for the difference in the mechanical properties from SLM produced tensile bars from gas atomized and water atomized, and ASTM A240 results.

Chemistry of 316L Stainless steel

The difference between production methods of stainless steel powder tends to heavily focus on the morphology of the resulting powder. Gas atomization is accepted as the production route for producing spherical powder particles and water atomization yields powder particles of irregular morphology; yet by altering atomization parameters and tailoring the process, water atomization is capable of producing nearly spherical powders. This characteristic, while important to consider during the development of parts via additive manufacturing, is not the only fundamental variation between the two resulting powder products. Analyzing the powder compositions of both the gas atomized 316L and water atomized 316L, it becomes abundantly clear that the alloying elements vary in wt% quite significantly.

Type (316L Powder)	C	S	O	N	P	Mo	Si	Cr	Ni	Cu	Mn	Fe
WA	0.012	0.011	0.360	0.025	0.02	2.33	0.89	17.25	12.86	0.03	0.07	66.15
GA	0.026	0.006	0.042	0.094	0.02	2.30	0.50	17.10	12.87	0.14	1.31	65.60
CAST	0.03	0.03	0.004	0.080	0.045	2.00-3.00	0.75	16.00-18.00	10.00-14.00	0.30	2.00	remainder

Table 4. Comparison of Chemistry between water atomized, gas atomized, and cast 316L stainless steel powder

Type (316L part)	C	S	O	N
WA 316L	0.014	0.006	0.19	0.02
GA 316L	0.018	0.005	0.05	0.09

Table 5. Comparison of chemistry between gas atomized and water atomized parts produced in the Renishaw AM250

Oxidation (oxygen, manganese, silicon)

As a dissolved gas, oxygen lowers the impact strength and reduces the fatigue life of SLM produced parts by forming SiO_2, MnO, and Cr_2O_3. The water atomization process introduces higher levels of oxygen compared to gas atomization. This increased level of oxygen has the ability to react with surface-active elements in the molten droplets and form an oxide layer on the powder surface.[1] This oxide layer may then affect mechanical properties of fabricated parts and the flow properties of the powder, a characteristic assumed to have great influence on the resulting parts produced via additive manufacturing.

Manganese and Silicon

As mentioned previously, silicon and manganese influence the surface oxidation of the powder particles. In gas atomizing, where both the melting and atomizing are usually done under vacuum or under an inert atmosphere, the effects of these elements are minimized. During water atomizing, the water impinges on the molten metal stream. Usually the point at which the stream and the water converge occurs in an inert atmosphere. However, the water dissociates forming hydrogen and oxygen. The oxygen reacts with surface-active elements in the molten droplets and forms an oxide layer on the surface of the powder.[1] Two of the key elements that affect this surface oxidation are silicon and manganese. Figure 7 shows the relationship between the silicon and manganese levels versus the oxygen content (surface oxygen) of stainless steel powders. Manganese, which tends to segregate to the surface of the powder, is highly oxidizeable. Therefore, at higher manganese levels, the surface oxidation is increased (low values of the silicon minus manganese levels). When silicon is oxidized on the surface, it promotes the formation of a glassy oxide, which is difficult to penetrate. Therefore high values of silicon (high values of the silicon minus manganese chart) lead to a lower level of surface oxidation.

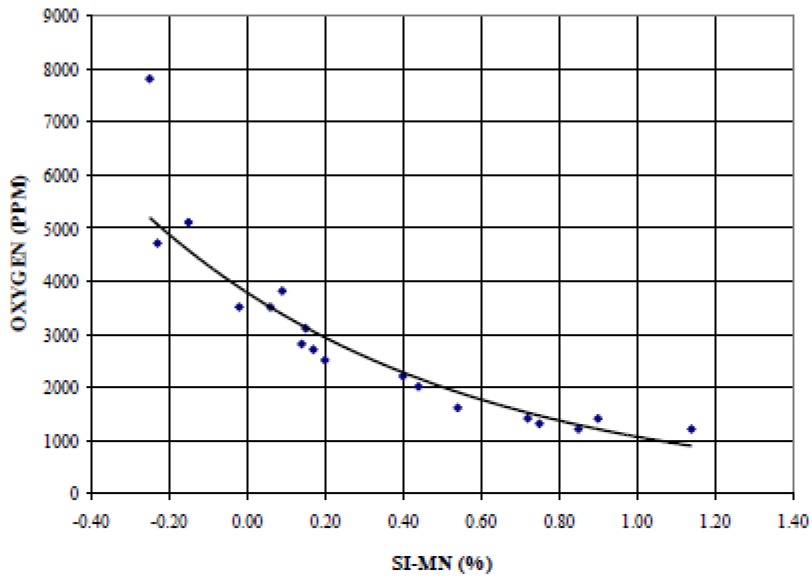

Figure 7. Relationship of silicon and manganese to oxygen content[1]

In the case with higher manganese levels, the oxide film that forms on the surface is significantly thick. When analyzing the chemical data from the gas atomized and water atomized powder, the Si-Mn (%) calculations are -0.8 and 0.82 respectively. The value for the gas atomized powder can be so low because of the allowable composition of manganese in the melt. There is no oxygen in the system; hence no MnO can form on the surface.

<u>Nitrogen influence on stainless steel</u>

Nitrogen is well known as an alloying element used by wrought stainless steel producers aiming for improved mechanical properties. Yet, in conventional powder metallurgy, high levels of nitrogen are usually avoided since they are responsible for the increase in hardenability due to solid solution hardening. This leads to a reduction in green density which is a significant factor in the compaction of P/M components and therefore in conventional water atomized powders the nitrogen content is kept low.[1] Nitrogen also plays a significant role in the corrosion resistance of 316L by interacting with both the chromium and molybdenum present in 316L. Excessive amounts if nitrogen can lead to the formation of chromium nitrides, depleting the matrix of chromium and leading to poor corrosion resistance.[2] Figure 8 shows the formation of nitrides in a conventional P/M 316L stainless steel.

In typical gas atomized stainless steel, the nitrogen content is considerably higher than the water atomized. This is due to two factors. Since melting and atomizing occurs under an inert atmosphere and the influence of manganese (as described in the previous section) is not as important, the raw material used for melting is generally scrap sourced from the wrought industry, which typically has nitrogen contents of 0.08%.[3] Additionally, it is common for this grade of powder to be atomized with nitrogen so there is an additional increase from the atomizing gas.

From the measured yield strength and ultimate tensile strength of both the gas atomized and water atomized 316L test samples, a distinct difference is noticeable even though the same process environment was kept for both methods and the acceptable process settings for full densification were completed. Previous work on the compositional effects of stainless steel mechanics indicates a factor with overwhelming influence on the resulting properties being nitrogen. From Table 3, the gas atomized 316L tensile tests demonstrate higher yield strength than that of the water atomized counterpart. While, comparing the chemical compositions and hardness of the two, it is clear that there are discrepancies there. Solid solution strengthening of low-carbon stainless steels with interstitial nitrogen has been shown to improve yield strength.[7] The gas atomized 316L powder which was used in the Renishaw AM250 is measured as 0.094 wt% and the water atomized powder is measured at 0.025 wt%. Future work may include the addition of nitrogen to the water atomized powder through nitrided ferro-chromium to asses if the main property difference is due to the nitrogen content.

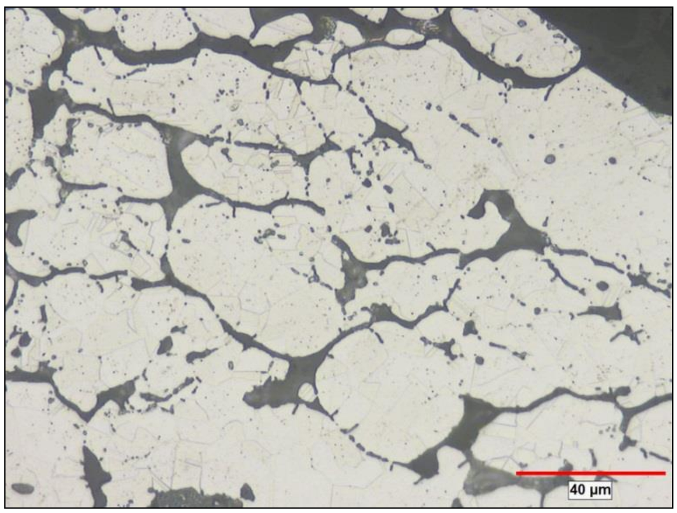

Figure 8. Picture of a 316L test piece microstructure highlighting the effects of nitrides on the microstructure

Microstructural Analysis

Figure 9 (a-d) shows the microstructures of both gas atomized and water atomized test specimens produced with process parameters optimized for full densification. The track patterns between the two microstructures show great similarity in behavior and size. An interesting note is the definition of the laser tracks and the larger area of dark regions in the gas atomized microstructure. Grain growth appears to propagate through the laser tracks and continue through the part only slightly deflecting at laser track boundaries (highlighted by the red arrows) if at all. What is visible and characteristic of additive manufactured parts is the lamellar grain structure (highlighted by the green arrows) in the direction of the flow of heat.[12] This, although more apparent in the water atomized microstructure seems a bit disjointed in the gas atomized microstructure. This may be due to the high definition of the laser tracks, potentially increasing the amount of energy required for a grain to grow through the laser track’s boundary. This may also be due to the differences in chemistry between the water atomized and gas atomized powders.

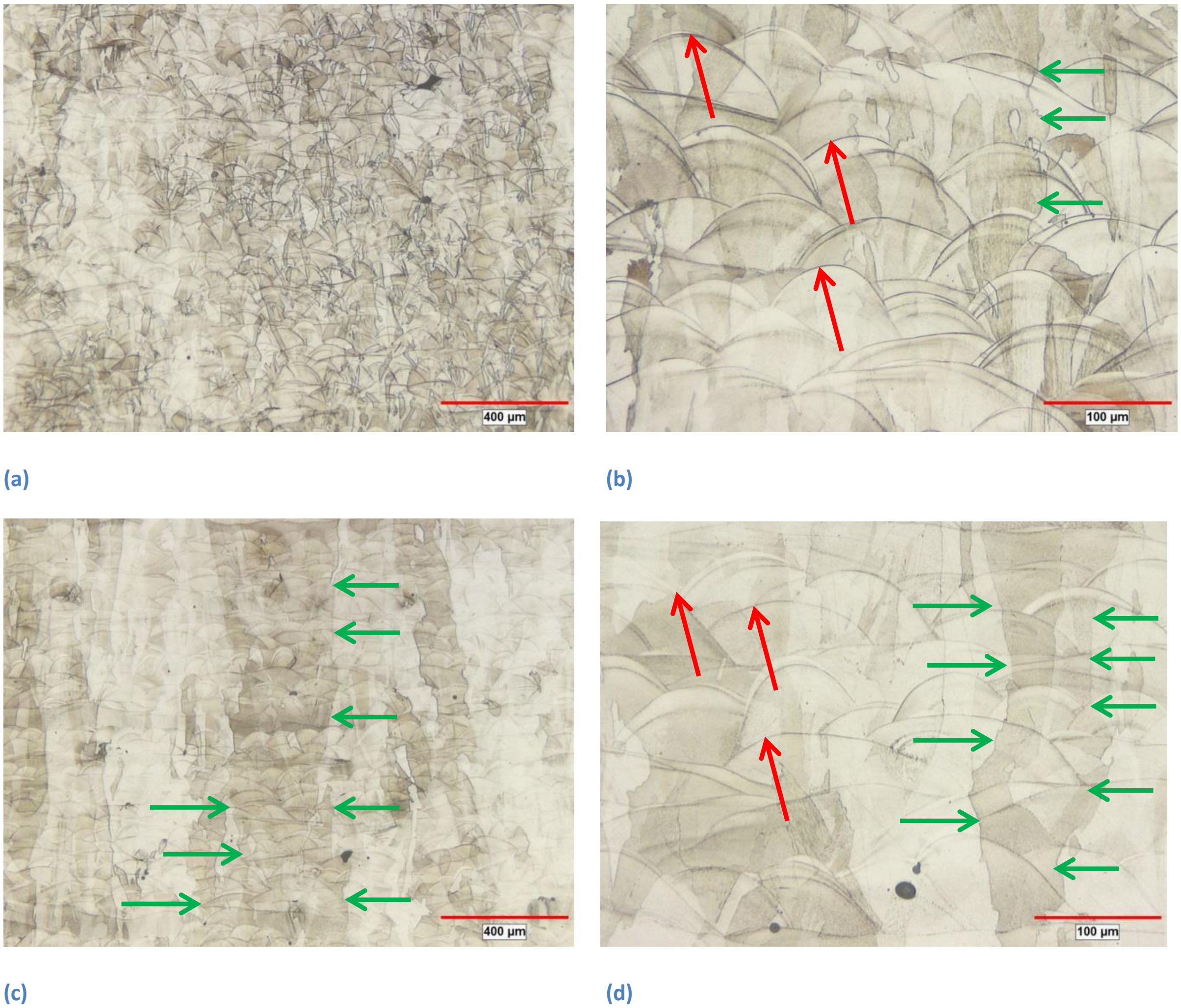

Figure 9. Pictures of the microstructure of (a) part produced from gas atomized 316L powder with 400 µm scale; (b) part produced from gas atomized 316L powder with 100 µm scale; (c) part produced from water atomized 316L powder with 400 µm; (d) part produced from water atomized 316L powder with 100 µm

Differences between Water Atomized 316L Powder

Three batches of water atomized powder are represented above in the morphology pictures and from Table 1 listing the avalanche angle, apparent densities, and flowability. Although only one of the batches was used directly in the Renishaw to produce test pieces and parts, a correlation can be made between the powders and their respective qualities. Water atomized 316L C is the powder which was used in the Renishaw and can be used as an indicator for other water atomized characteristics and their potential feasibility for use in SLM systems. From the SEM pictures of the three batches of water atomized powder, it is quite apparent how irregular the powder is especially in comparison to the gas atomized powder in the same Figure 3d. Between the water atomized powder A, B, and C, there is a noticeable degree of sphericity discrepancy; this is due to the processing parameters mentioned earlier. By changing water jetting pressures, various levels of sphericity can be achieved.

Another factor to consider with flowability is the surface texture of the powder particles. All three water atomized powders exhibit a varying degree of surface texture which can affect flow characteristics. This property is another which may be influenced by water jetting pressures. Bearing in mind all of these characteristics, gas atomized powder is vastly different. However, even though shape and flowability is quite different, the avalanche angles still fall within the threshold observed by the testing conducted on the Fe powder. What should not be neglected though is each powder's apparent density. The apparent density of WA 316L A is 3.56 g/cm^3 and may be a telling property as to a powder's functionality in SLM systems. The apparent density of the Fe powder is 3.19 g/cm^3 and if we treat this powder as the bare minimum for qualities acceptable in SLM systems then the apparent density should not fall lower than 3.19 g/cm^3. The water atomized 316L C powder does not meet this criteria yet the avalanche angle, 50.30°, is below the set limit, 54.30°, not completely eliminating this powders capabilities. This further strengthens the idea of a measuring process slightly more tuned to differences in powder quality because both the Fe powder and water atomized 316L C exhibit no flow, yet the Fe powder functions in an SLM system.

The economic potential of the water atomization process is also altered in accordance to the jetting pressures. Acquiring a more spherical powder with higher jetting pressures increases the cost of the powders manufacture route. This facilitates the research currently being done; finding the acceptable point where powder quality is tailored so that the machine can run unperturbed while promoting acceptable part production. This must be regulated in tandem to keeping in mind that the powder does not require perfect spherical shape and high flowability, but instead a symbiotic relationship between morphology, apparent density, and flowability; drawing from the strengths of each characteristics and mitigating the drawbacks from each as well

Conclusion/Discussion

Gas atomized powder is assumed to be the powder most suited for additive manufacturing due to morphology and flow qualities. Yet, it should not be assumed that additive manufacturing systems cannot process material with physical qualities similar to that of water atomized powder. Full density parts have been built by optimizing process parameters to meet the needs of water atomized powder. By adjusting the laser power, laser speed and spreading speed, significant similarities can be made between parts produced by water atomized 316L and gas atomized 316L. It must also be kept in mind that potential differences of mechanical properties between gas and water atomized powder may be a result of the varying chemical compositions. The atomization processes for gas and water not only differ in their jetting medium but also in the melting and atomization steps.[4] This necessitates the raw material to meet levels of composition so as to facilitate the atomization process and reduce contamination in the part; that is, ensure that maximums for elements are not breached. Varying levels of chemical composition in water and gas atomization can play a significant role not only in mechanical properties, but also in the corrosion resistance of the 316L, a very important characteristic which influences manufacturers to choose this stainless steel.[8][7] Differences in chemistry can affect the levels required for corrosion resistance, potentially compromising 316L's utilization in the medical industry. Biocompatibility applications are heavily reliant on the material's corrosion characteristics; it is not only responsible for the structural stability of the medical component, but may also lead to the release of Ni, which has been identified as severe cause of tissue inflammation.

The results for tensile testing from the gas atomized 316L and the water atomized 316L are very close, implying that water atomized powder can closely mimic the expected values from gas atomized powder even though processing means are different. Restrictions on powder may need to be relaxed as more sophisticated testing methods are introduced geared towards powders to be used in AM systems. One such method is the Powder Revolution Analyzer. Currently, powders are being neglected because of their flowability results from Hall and Carney flowmeters. Yet, this may unfortunately eliminate powders actually capable of being processed by AM, specifically SLM because of the powder sizes and their propensity to have poor flow.

Even though mechanical properties are extremely relatable between water atomized powder and gas atomized powder, surface roughness still tends to be an issue with produced parts. At the moment this issue isn't a hindrance to water atomized powders because post processing is completed on all AM parts regardless of the material and the material's production route; whether plasma atomized, gas atomized, or plasma spheroidized powder. As stated previously, the process parameters were optimized for processing water atomized powder. This alteration of the parameters in comparison to the parameters of gas atomization may lead to build times being slightly longer then processing times for gas atomized powder. It is unknown how much of a difference in time part production would be, but based on the changed parameters, the difference cannot be so significant that it discredits the feasibility of utilizing water atomized powder for AM.

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