

Investigation of Al-Cu using different preparation methods on the Amazemet RePowder machine

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Abstract. Additive manufacturing is an important means of product prototyping and main production process such as in jewelry where shaping may be difficult. With most powders being imported and expensive, there is need to locally produce powder from extracted metal, scrap materials and used powders for additive manufacturing. Al-10Cu (wt%) rod and powder were prepared using the Amazemet rePowder system. A 90:10 by mass mix of pure aluminium and pure copper was used as feedstock for both rod and powder. The rod was melted using arc melting and the powder was produced by ultrasonic induction atomisation. The rod and powder were analysed using XRD and SEM. Results shows the same composition, phases and microstructure were achieved in the rod and powder forms of the Al-10Cu (wt%) alloy.

1 Introduction

Additive manufacturing (AM) is a rapidly growing industry around the world. One of the most used feedstocks for AM is spherical metal powder [1, 2, 3]. South Africa has an abundance of mineral resources [4], unfortunately, when metal powder feedstock is needed for AM, it has to be imported. Importing is not only costly in terms of price but also time wise as the lead times are long. Thus, to support the small scale development of the local additive manufacturing market, there is a need to create capability and capacity producing suitable powders locally. These powders need to be of high quality, with specific particle size and shape, depending on the type of AM technology. Often when a build is incomplete or results in an unsatisfactory product, the part is scrapped. In addition, especially with powder bed AM processes, there is scrap powder that cannot be reused. If these waste materials can be recycled into re-usable powder, it would lead to reduction of life cycle waste material for AM processing.

Common types of atomisation are gas, plasma and water atomisation. Gas atomisation is currently one of the leading methods for LPBF feedstock [5]. Gas atomisation is the process in which the liquid metal is dispersed by a high-velocity jet of air, nitrogen, argon, or helium [3]. The drawback of gas atomisation is that it requires high volumes of gas, at high pressure where, the particle size distribution (PSD) is controlled by the gas pressure. Current gas atomisation systems are limited by the melting temperature of the required powder alloy. Similarly, water atomisation depends on jets of water which hit a stream of liquid metal and

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form particles. The cons of the latter are that the particles can oxidize when they encounter the water, the particles are not all spherical and have porosity due to rapid cooling caused by the water jet [5, 6, 7].

The Amazemet rePowder system allows one to make powder by ultrasonic atomisation using different feeds and has three different processing systems: induction module, arc module and wire feeding module [8]. From this PSD $d_{50} = 15\text{-}75\ \mu\text{m}$ can be produced which is suitable for laser powder bed fusion (LPBF) printing [2, 9]. Rods or buttons can be made using arc melting module. Melting and powder production can be done using the arc module for high melting temperature alloys or induction module which uses bottom pouring technique for alloys with melting temperature up to 1300°C under inert environment. The machine uses ultrasonic energy to atomise the molten metal into powder. Ultrasonic atomisation is a process where a liquid is broken down into a fine mist of droplets by exposing it to a vibrating surface (sonotrode) emitting ultrasonic frequencies [10]. With the Amazemet rePowder system any form of material can be broken down into pieces and melted into rods or wire to be atomised. The powder formed is spherical and this is preferred for LPBF, as spherical particles have better flowability, reduced porosity and enhanced packing density [11]. A study done by Balasz et. al. [12] compared gas and ultrasonic atomisation for a common alloy Ti6Al4V, they found that the powder from ultrasonic atomisation gave a better production yield, good sphericity, good flowability and high density. Balasz et.al. also noted that the PSD for ultrasonic atomized powder is narrower than gas atomisation [12].

The purpose of the study was to evaluate the Amazemet rePowder production processes while producing an aluminium- 10 (wt%) copper (Al-10Cu) alloy in rod and powder form. The composition was selected as it is known to be used in the automotive and aviation industry, however it must be noted that the alloy is not usually used in its cast form and usually has post processing steps [13]. Certain grain structures of materials like Al-Cu alloys can be useful in different applications, for example mechanical properties of intermetallic phases. Pure copper and aluminium pellets were used as the initial feedstock materials as these metals are affordable and readily available. The microstructures and phases that formed after casting the rod using the arc melting and using the induction furnace and ultrasonic atomisation to produce the powder were studied.

2 Experimental procedure

Experiments were carried out using the Amazemet rePowder system (Figure 1). The system uses a highly controlled inert environment within the chamber to melt alloys of any composition. Ultrasonic vibration atomisation technique is used to make powder from rods, buttons or wire that can be used for AM. This system has two options in which melting of material can be conducted: an induction furnace and an arc melting chamber. The induction furnace can currently melt materials under inert gas atmospheres with melting temperatures up to 1300°C whereas the arc melting chamber can handle up to 3500°C and both operate under vacuum. The composition of Al-10Cu (wt%) was chosen as it is a known alloy. It is expected that the alloy will have two phases: α -Al solid solution and θ -phase Al_2Cu intermetallic compound [14-17].



Fig. 1. Amazemet RePowder system.

Pure aluminium and copper pellets (Figure 2a) were weighed to make up 100g of Al-10Cu (wt%) and melted in the induction furnace at temperature of 1100°C. The chamber was perched with Argon at least three times by attaining vacuum of 4×10^{-1} mbar each time before filling with gas. Molten material was atomized using bottom pouring into atomisation chamber also filled with argon gas and onto a plate vibrating at frequency of 40 kHz to produce the powder (Figure 2c). Because this is happening in a chamber filled with argon gas at room temperature, some (but minimal) of the particles may fuse, and thus form ellipse shapes due to rapid cooling instantly after coming into contact. The induction furnace was ideal for the purpose due to the low melting temperature of Al-Cu alloy. The arc melting system was used to produce a rod of 50g (Figure 2b) of the same alloy composition. The arc can produce high temperature in excess of 3500°C. The arc temperature can be controlled using current adjustment which controls the arc length and can adjust the positioning of the arc to be close or further from the sample. There is no way to measure the exact temperature at which the sample starts to melt, the only parameter that is controlled is the current which controls the size of the torch and intensity of heat. However, the tip of the arc electrode has temperature up to 3500°C. For this alloy the current used was between 100-150A. The details are summarized in Figure 3.

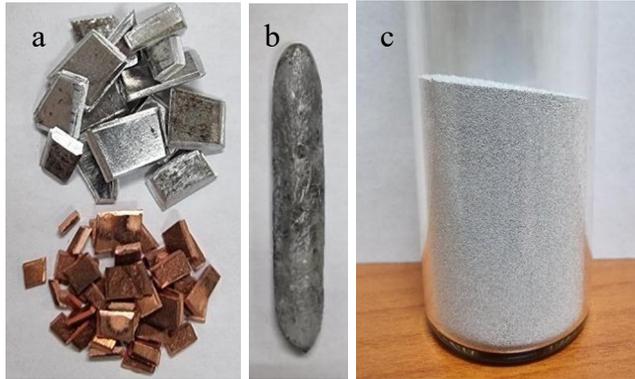


Fig. 2. Images of the (a) Al (top) and Cu (bottom) pellets used to produce the (b) Al-10Cu (wt%) rod and (c) Al-10Cu (wt%) powder.

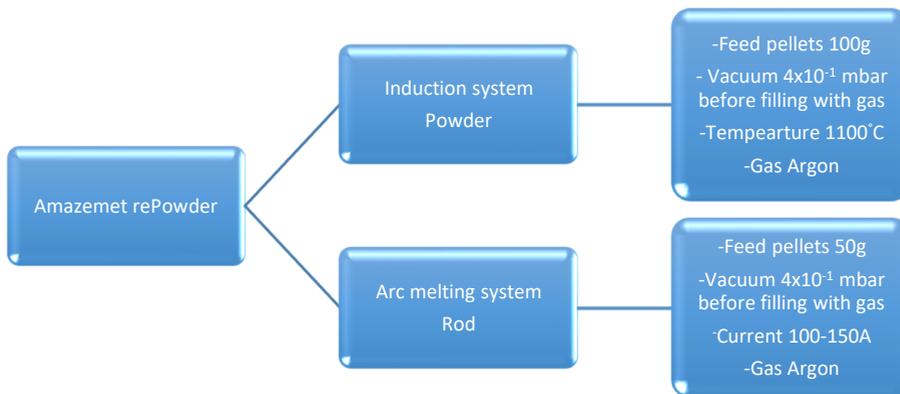


Fig.3. Overall process flow.

A unique feature of the system is that materials are molten under an extremely inert environment in which samples can be rotated without opening the machine in the arc-melting unit. Thus, both systems were used under vacuum and flushed with argon gas to prevent oxidation. The combination of the arc system and the induction in this case can be comparable because both systems result in molten material being formed. Both systems produce homogeneous mix.

To analyse the powder, SEM was done in back scattered electron (BSE) and secondary electron (SE) mode on the particles. Compositional analysis was done with energy dispersive X-ray spectroscopy (EDS) detector. The powder was mounted, ground and polished to analyse the cross section of the particles on the SEM and used to determine the size and shape of the particles. The powder particle shape and size were analysed using the Tescan Integrated Mineral Analyzer (TIMA) which is a software that is integrated with the SEM. It scans the mounted powder sample and produces the shape and particle size data. For the rod, the sample was cut, mounted, ground and polished before analysis on the SEM. XRD was done on both samples using the Bruker D8 advance with a cobalt radiation source. The Diffrac Plus EVA program was used to analyse the scans for the phases.

3 Results and discussion

The XRD results in Figure 4 indicated that two phases were present in the powder and rod samples: a solid solution of Al and intermetallic compound θ -Al₂Cu. The peaks for Al in the rod were smaller, indicating that there was less of this phase in the rod compared to the powder. There was one unmatched peak for the rod at $\sim 30^\circ$ 2Theta position which matched with graphite which is in the resin the sample was mounted in. The cubic Al phase has $a=b=c=4.083\text{\AA}$ and the tetragonal θ -Al₂Cu phase has $a=b=6.067\text{\AA}$ and $c=4.877\text{\AA}$.

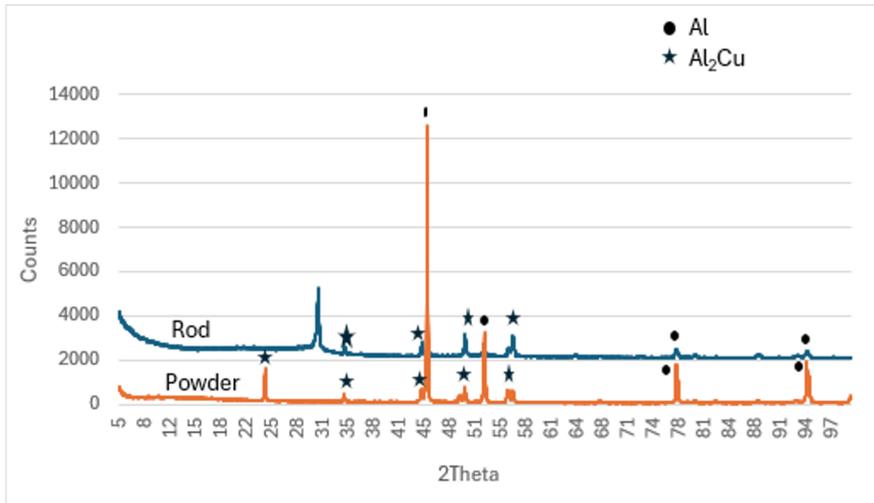


Fig. 4. XRD patterns for Al-10Cu (wt%) rod and powder.

PSD of the powder was analyzed and the results showed that 90% of the powder was less than $70\ \mu\text{m}$ as shown in Figure 5 (Table 1). This particle size renders it suitable for AM, and specifically laser powder bed fusion (LPBF) printing, which requires the particle size range of $15\text{--}75\ \mu\text{m}$. The Amazemet rePowder system is designed to minimize waste and enable recycling. Hence after sieving of the powder, the bigger particles can be melted back into a rod and then atomized into powder to ensure there is no waste of material. Recycle of the material can be done when specialized powders are made, if it is readily available it may be cheaper to purchase new powder. Figure 6 shows the ellipse ratio (the smaller size of the particle divided by the bigger size of the particle shape) with 0 being non spherical and 1 spherical, the graph shows that most particles were spherical which would make them ideal for LPBF printing because they will flow readily.

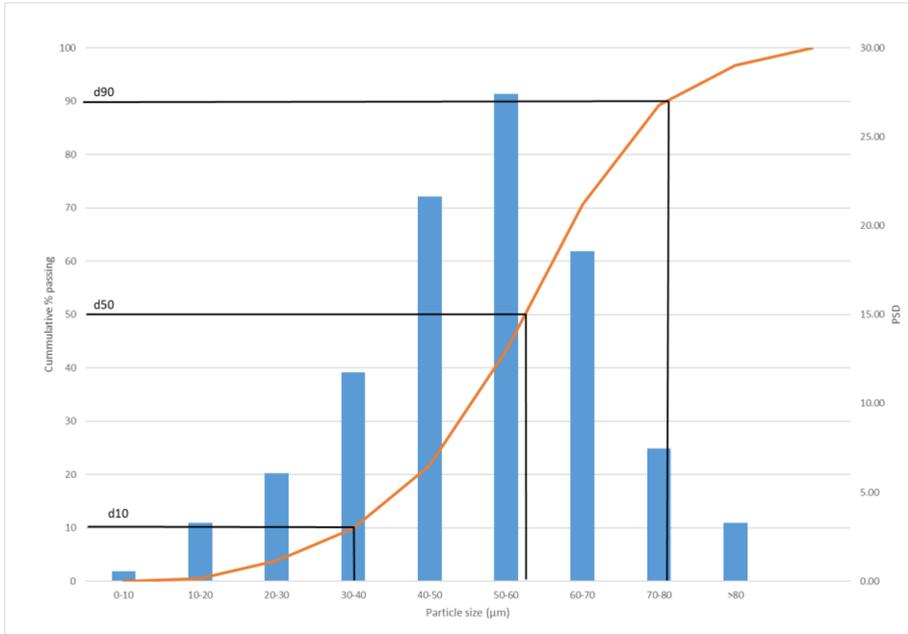


Fig. 5. Graph showing PSD for the powder.

Table 1. Percentage of PSD

	Particle size (µm)
d10	36
d50	65
d90	78

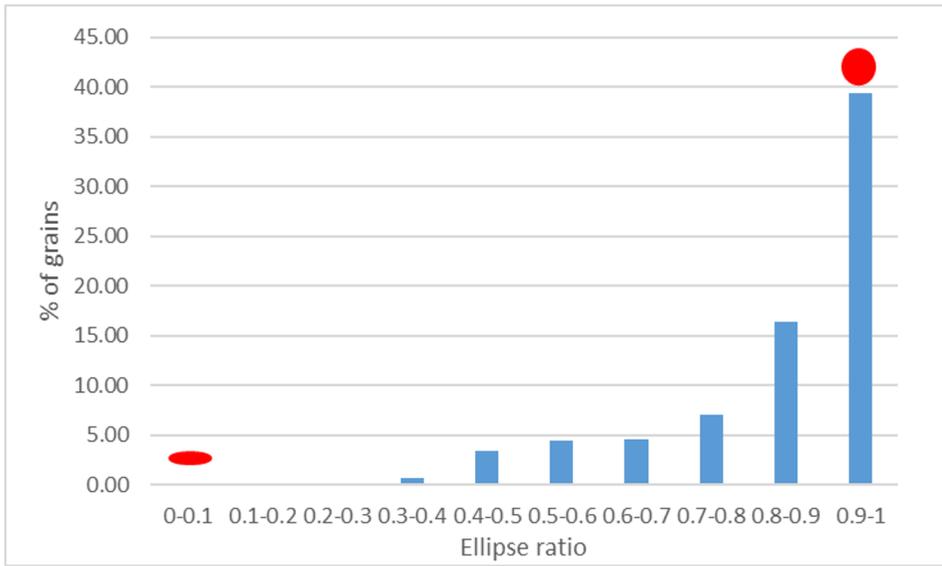


Fig. 6. Graph showing the particle shapes of the powder.

Figure 7 shows that most of the powder particles were spherical and there were some elongated particles, which could have joined due to quick particle cooling. The elongated particles appear to have formed from spherical particles that bond together during the atomisation process. However, the percentage of elongated particles is small compared to required spherical shapes, as shown in Figure 6.

Figure 7 gives SEM images of Al-10Cu (wt.%) powder, showing spherical powder at (a) low magnification and (b) high magnification. The high magnification image (Figure 7b) shows the powder particle surface, revealing a dendritic microstructure. EDS analysis of the powder confirmed the darker phase in Figure 8(b) to be Al solid solution (95.7Al14.3Cu wt.%) and the lighter could be θ -Al₂Cu (62.3Al37.7Cu wt.%) intermetallic phase. The EDS for the rod showed the same phases Al (96.2Al3.8Cu wt.%) and θ -Al₂Cu (64.9Al35.1Cu wt.%). The cross sections of the rod and powder are seen in Figure 8 where it shows that the microstructures of the powder and the rod are the same and have the same phases of Al and θ -Al₂Cu with similar compositions. Depending on the binary alloying conditions, it is expected that Al-5Cu (wt%) would form a combination of Al and θ -Al₂Cu seen as dendrites [14-17], the Al-10Cu (wt%) showed the same phases. It is evident from these microstructures that the detrimental coarsening network of θ -Al₂Cu phase is more severe (covering a larger area) in the rod sample whereas it contained within approximately 50-70 micron-sized particles. As a result of the shorter coarsening network within the powder particles, it is anticipated that the θ -Al₂Cu phase will be less detrimental and more beneficial to strengthening this alloy upon additive manufacturing process.

Fast cooling of molten alloys results in fine grain sizes compared to coarse grains when slow cooled. In this work, the rod grain sizes in Figure 8 (b) are much bigger compared to those in powder particles in Figure 8 (a). When melting the sample in the arc furnace, the sample is sitting on a copper hearth that is continuously cooled with water flow from a chiller at 17-18°C. However, the cooling rate of the rod after the arc has been switched off will be much slower compared to fine particles sizes that are cooled in the steel atomisation chamber that is also continuously cooled from the same chiller and in argon atmosphere. The smaller particle sizes will mean faster cooling rate within a very small molten pool of 30–75 μ m, and thus the finer grain sizes.

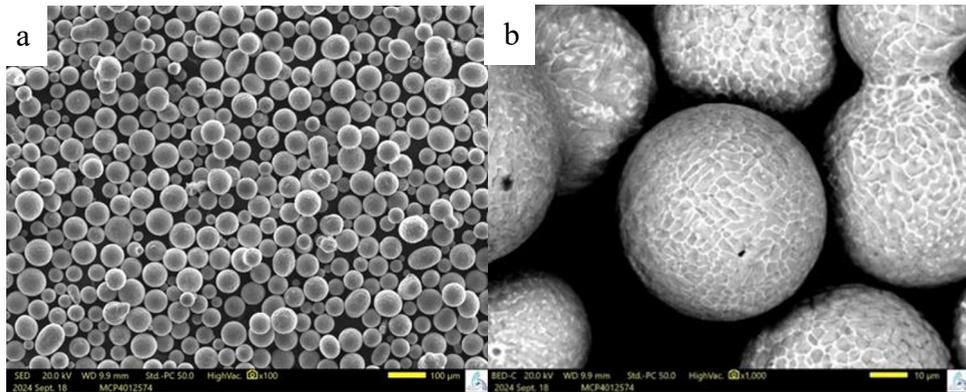


Fig. 7. SEM images of Al-10Cu (wt.%) showing (a) SE of spherical particles produced powder at low magnification and (b) BSE high magnification of dendritic structure on a particle with Al (dark) and light (Al₂Cu).

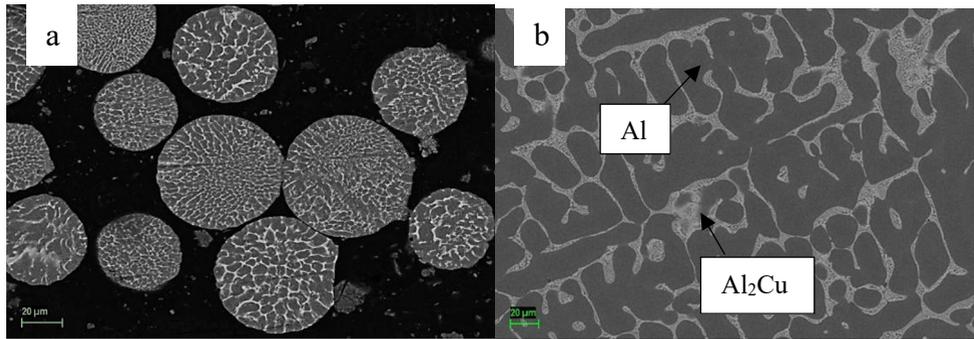


Fig. 8. SEM images of Al-10Cu (wt.%) showing the cross section of (a) powder and (b) rod with Al₂Cu (light) and Al (dark) phases.

4 Conclusion

This article presents a technique and demonstrates that alloy powder particles can be produced for the feedstock in additive manufacturing. With a required particle size of 25-75 μm as standard for LPBF, it is desirable to have pre alloyed powder as a feedstock. The experiment carried out using the Amazemet rePowder system comparing samples produced from the arc system (rod) and the induction system (powder) show the same microstructures of the alloy have been produced. That is; both techniques formed the same homogenous alloy which consisted of Al and θ -Al₂Cu with the rod and powder having the same dendritic microstructure.

It can be concluded that both methods provide the same outcome of a homogenous alloy in different forms. The mix of the solid solution Al and intermetallic θ -Al₂Cu have a significant effect on the mechanical properties of the alloy. However, this article only concentrated on showing the microstructure of a rod and that of powder particles and affirm the importance of pre alloying of powder feedstock for AM. The PSD and the sphericity of the particles shows that the particle shall be suitable for metal AM printing, however, this shall have to be tested in which the microstructure of the AM parts shall also be analysed.

It is important to note that AM of this powder shall have to be explored fully in terms of parameters that will control the laser power and exposure time to have a homogeneous and dense print layers. Thus, the printing shall in turn test the flowability of the particles.

Additionally, the product from AM printing would need to be tested to determine if θ -Al₂Cu phase will be less detrimental and more beneficial to strengthening this alloy upon AM process. Powder can also be formed using the arc system which allows for higher melting temperature material. The results of this study have shown that the system can produce, spherical powder with a good PSD and alloyed with a microstructure same as that in a rod.

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