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Ultrasonic Powder Atomization for Additive Manufacturing

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Abstract. The following article presents a special case of metal powder production, ultrasonic metal atomization. In this case, ultrasound technology is based on the capillary wave phenomenon. We verify the suitability of the produced powders for 3D metal printing with various tests. In the case of prints with a metal powder bed fusion (PBF), the properties of the raw material of the powder are extremely important. The main results of the tests carried out in the article (SEM images, EDS composition analysis, sieve analysis) were described.

Keywords: Ultrasonic, Ultrasonic atomization, Atomization, Metal powder, Additive manufacturing

Introduction

The characteristics and properties of metal powders of different compositions serving as the raw material for AM are extremely important. Many literatures deal with the behaviour of powders used in AM during printing. Nowadays, simulation software is also available for tests, since the properties of the powder are greatly influenced by the distribution of their particle size [1].

The available literature background of the "Ultrasonic" metal powder production technology is quite incomplete. The equation by Lang [1], written down in the 1960s, is still valid for ultrasonic metal sputtering, which is applied to the theoretical calculated particle size. There are many literatures that use this equation as a basis for their investigations. In some parts of my thesis, I reviewed the literature dealing with these equations.

1. Materials and methods

During the atomization process, capillary waves are formed on the surface of the liquid. The wavelength depends on the magnitude of the frequency, the energy distribution and the physico-chemical properties of the liquid. The most important factors are the density and surface tension of the liquid at the liquid-air interface. If the liquid begins to oscillate due to the vibration, the peaks of the capillary waves separate as droplets [2][3][4].

Unlike conventional sputtering, ultrasonic sputtering can be more energy efficient (based on proper design and operation), only electrical energy needs to be transmitted to a piezoelectric vibrating plate. There are no moving parts in the design of the atomizer, only mechanical vibrations which generated by

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the electrical energy supplied to the vibrating platform. This mechanical vibration must be used to produce the droplets.

Ultrasonic sputtering can be achieved simply by vibrating a liquid layer with a piezoelectric crystal at a high frequency (usually in the frequency range between 50 kHz and 3 MHz) [5].

Two main hypotheses can explain the separation of droplets from the vibrating surface: the increasing instability of the capillary wave pattern formed on the surface of the liquid film layer, or the cavitation phenomenon [6].

During the tests, the atomization experiments were carried out on iron based raw materials. We used two types of raw materials, a highly alloyed 1.4551 type steel and an unalloyed steel raw material.

1.1. Capillary wave hypothesis

According to Taylor's instability criteria, the occurrence of atomization based on the capillary wave hypothesis can be verified by visual observation Taylor [7] (1950). This hypothesis considers the formation of capillary waves consisting of wave crests and wave craters on the vibrating surface. Atomization occurs when unstable oscillations separate the crests of capillary waves at the surface from the liquid. In this case, the droplet formation is at the peak and the droplet size will be proportional to the wavelength. Capillary wavelength typically decreases with increasing frequency; hence, finer droplets are formed at higher frequencies.

According to the capillary wave hypothesis of Rayleigh [8] (1945), Figure 1., on the surface of a solid resonator, the moistening liquid film layer is vibrated vertically by the resonator, as a result, a checkerboard-shaped pattern is formed from the standing capillary waves. This phenomenon is observed when the vibration amplitude exceeds the critical value. After a further increase in amplitude, the liquid ligament separates, and the droplets are separated from the chests of the capillary waves.

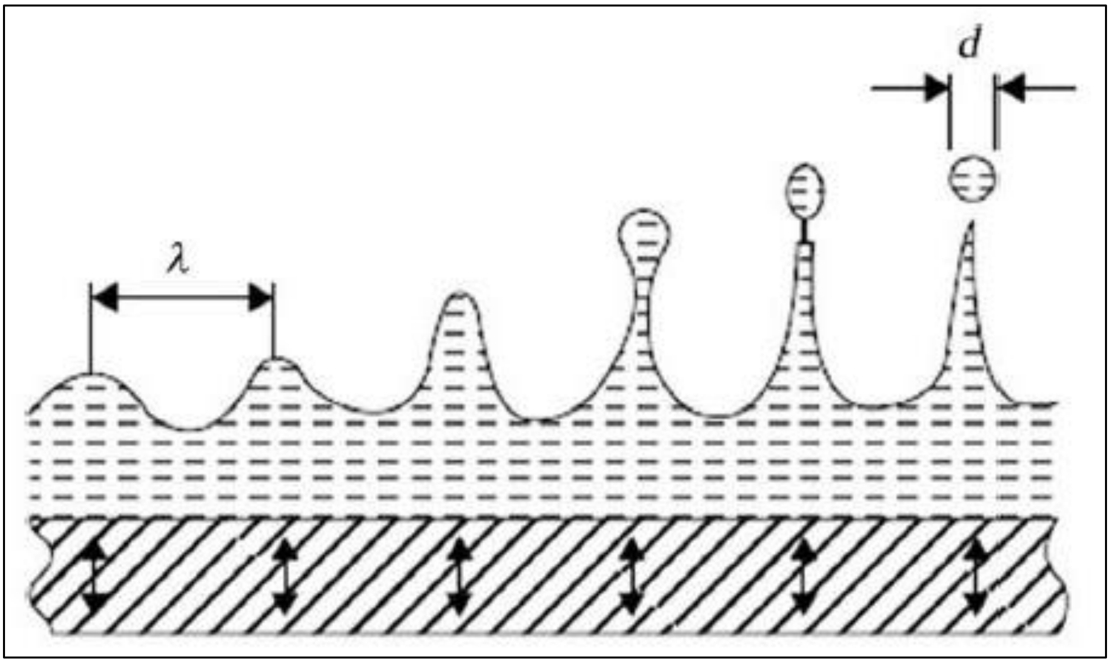

Figure 1. Representation of the capillary wave phenomenon [9].

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The key parameter is λ, the capillary wavelength. Rayleigh [8] stated that where σ is the surface tension of the liquid; ρ is the density of the liquid; and ν is the oscillation frequency.

$$\lambda = \left(\frac{2\pi\sigma}{\rho\nu^2}\right)^{1/3} \tag{1}$$

If the oscillation frequency in the liquid is half of that experienced in the solid resonator, then in this case *f* is the ultrasonic frequency.

$$\lambda = \left(\frac{8\pi\sigma}{\rho f^2}\right)^{1/3} \tag{2}$$

Photographs of surface disturbances by Lang [1] (1962) confirmed that the disturbances were nothing more than a pattern of crossed capillary standing waves. Furthermore, the wavelength of these patterns strongly depends on the frequency, thus clearly supporting the capillary wave hypothesis.

2. Results and discussion

In scanning electron microscopic examinations, the deviation of the basic powder particle size/particle fractions is noticeable, which leads to the conclusion, which is also clearly visible in the images, several fractions are present in the system. The SEM images show the differences between new and reused metal powder [10].

To determine the more precise values, I used a sieve analysis, with the help of which I was able to assign specific values to the individual fractions. The diagrams clearly show the main fraction, which is present in the system in a proportion of over 60% [11].

Figures 2 and 3 show the powder samples at a higher magnification. In the 250x magnification, surface defects, bumps, and protrusions are clearly visible, which impair the uniform layering property important for printing in this case of powder flow.

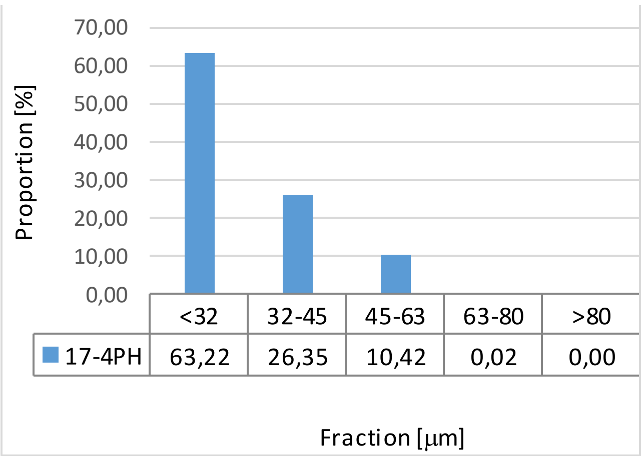

Figure 2. Sieve analysis distribution of 17-4PH steel powders

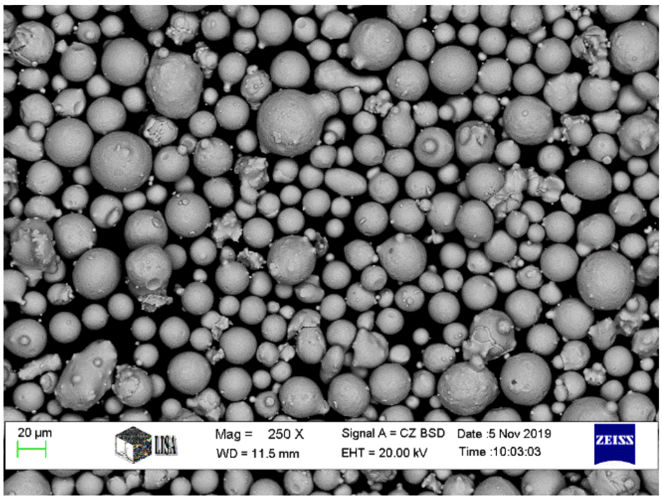

Figure 3. SEM image of 17-4PH steel powders

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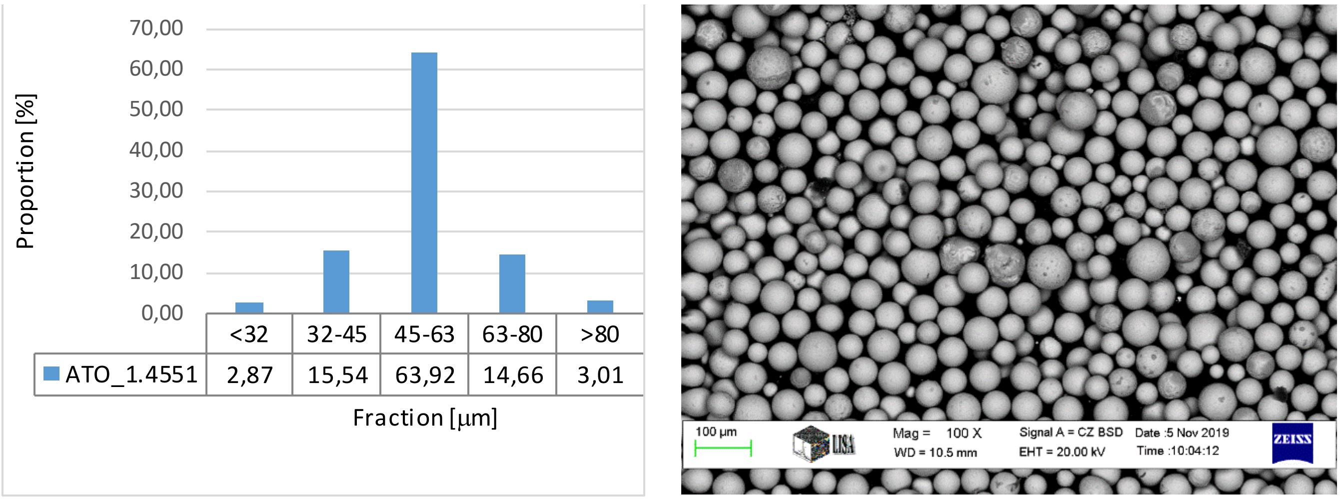

Figure 4. ATO powder sample 1.4551 steel in 100x magnification

The result of further tests is the evaluation of the SEM images of the powders produced with the ATO lab equipment showed in Figures 4 and 5. What I have already experienced, from the powder production results of the previous semesters, is that with the ultrasonic powder production technology, the shape of the powder grains is spherical and the powder grains are compact. The current experimental powder production was made from raw materials with a different composition, which is also reflected in the results. Instead of the former 1.4551 steel raw material, an unalloyed steel wire was sputtered. The results of the exact compositional EDS measurements are shown in Figures 8, 9 and 10.

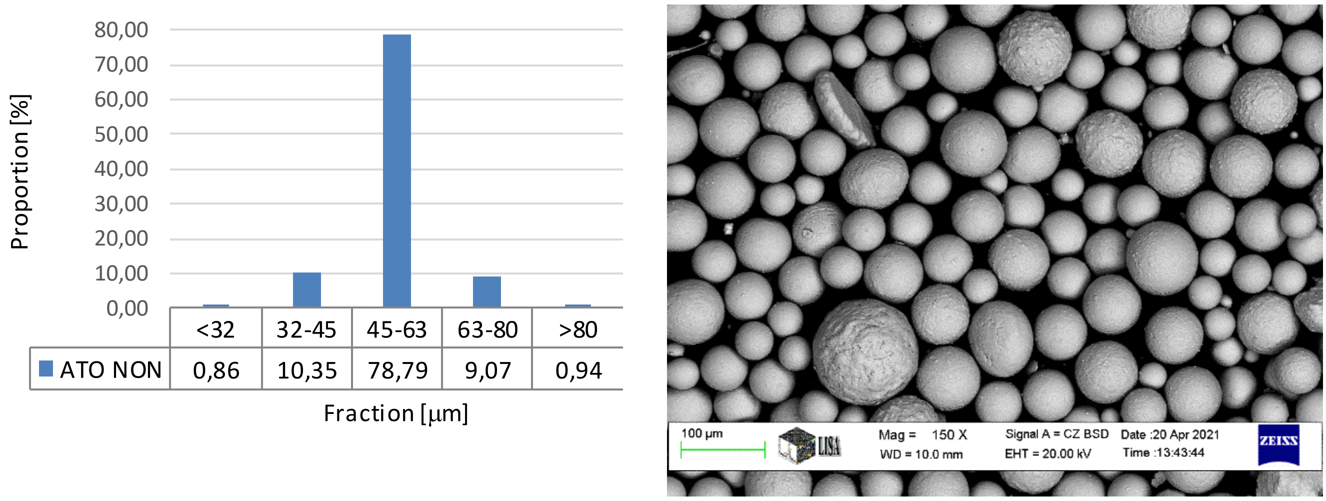

Figure 5. ATO powder sample NON Alloy steel in 150x magnification

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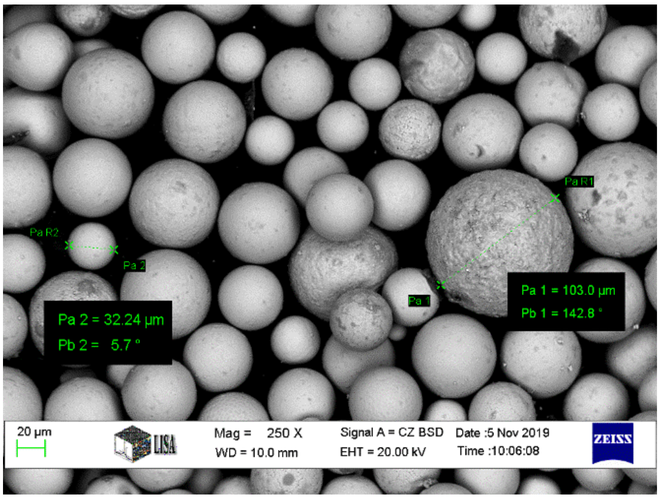

Figure 6. ATO powder sample 1.4551 steel at 250x magnification

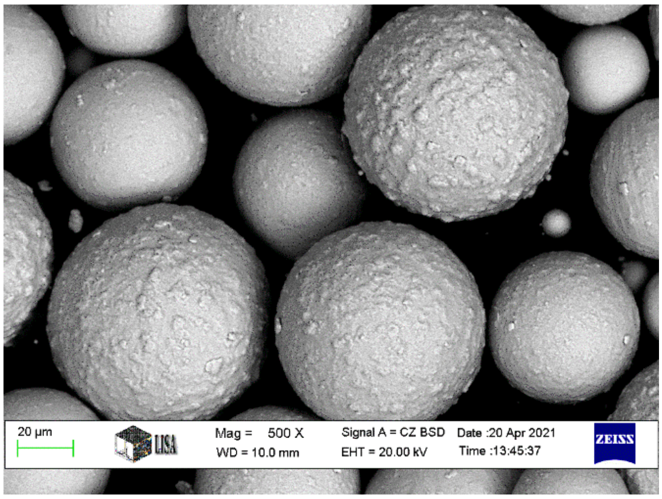

Figure 7. ATO powder sample NON Alloy steel in 500x magnification

EDS tests have repeatedly proven that the composition of metal powders does not change either during powder production or during 3D printing. In both cases, the procedures take place in an inert atmosphere, which prevents unwanted oxidation.

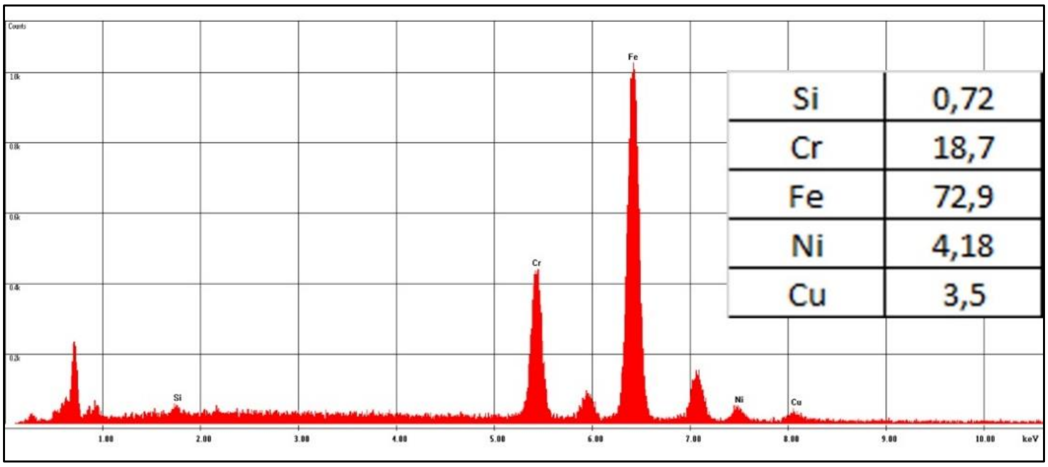

Figure 8. Oerlikon 17-4PH powder sample EDS result

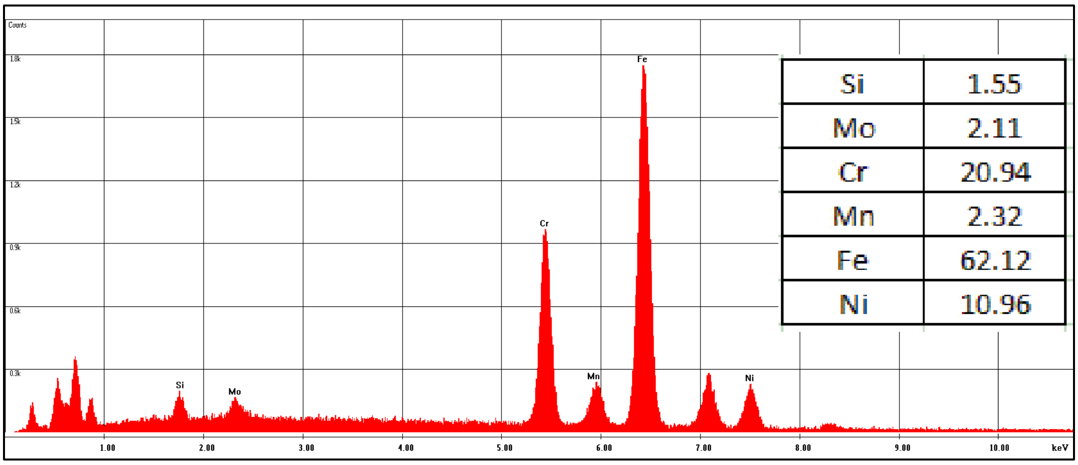

Figure 9. 1.4551 powder sample EDS result

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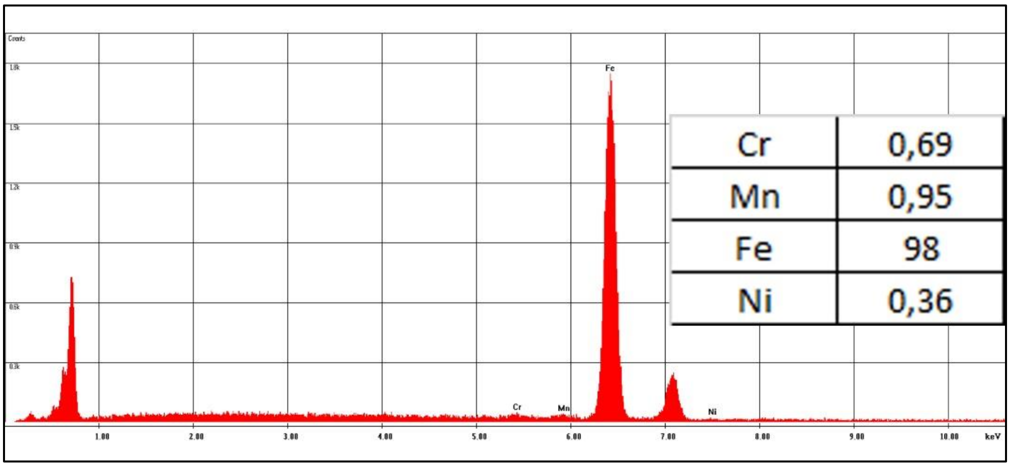

Figure 10. ATO NON Alloy powder sample EDS result

The measurement results allow us to conclude that the properties of the raw material will most likely be found on the printed geometry as well. The printed geometry shows the fabric structure typical of base alloys after heat treatment. To examine these findings, additional printing and heat treatment measurements are required.

3. Conclusion

The basis of the experiments carried out in this article is additive manufacturing technology (AM), including metal 3D printing and the production of the necessary metal powders. Based on my experience so far, the steel metal powder produced by the ATO lab ultrasonic metal sputtering equipment has suitable quality for 3D printing. Based on preliminary experiments, the composition of the dust particles does not change during the atomization process. Basic tests of the produced metal powders were also carried out (sieve analysis, light microscope, SEM, EDS, hardness measurement).

- Based on the results of the sieve analysis, the powder production is adequate and the separated powder fractions are suitable for 3D metal printing.
- The SEM images confirmed the sphericity of the particles, which was produced by ultrasonic powder production. As a result, the initial porosity of geometries - printed from this powder - can be reduced.
- The EDS tests showed the change in the composition of the powders. Neither powder production nor printing significantly changes the composition of the powders.

There are several options for powder production. One solution to this is ultrasonic atomization, as a result of which good surface quality and spherical powders can be produced. These powders are suitable for metal powder bed fusion technology.

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