Nitrogen vs Argon Atomisation of 17-4 PH Stainless Steel and its effects on AM Processing

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Background on 17-4 PH (Stainless Steel)

17-4 PH is a martensitic, precipitation-hardenable stainless steel widely used in aerospace, petroleum, and chemical processing industries. This 17-4 PH alloy utilises a martensitic microstructure infiltrated with fine particles to optimise the mechanical properties. It contains large amounts of chromium, nickel and copper to generate good corrosion resistance and mechanical properties at elevated temperatures (up to 300 °C).

This material is heat-treatable to increase the hardness, ultimate tensile strength, and yield strength. The typical heat-treatment cycle of 17-4 PH begins with a high temperature austenisation treatment (1040 °C for 1 hour) to allow super saturation of alloying elements into the matrix. This material is then air cooled to form a martensitic microstructure. Fine, copper-rich particles are precipitated by an age-hardening step (482 °C for 1 hour) to improve the alloy's strength.

Why is the atomisation process important?

The effect of atomising gas on the properties of metal powders, in conjunction with the specific additive manufacturing process parameters, plays a key role in the ultimate microstructure and mechanical properties of fabricated parts as demonstrated in this Selective Laser Melting (SLM) study. Using an inappropriate combination of powder and process can result in the expected final properties of a component not being fully realised.

Effect of selection of powder atomisation gas and AM process parameters on 17-4 PH Stainless Steel

17-4 PH can be atomised using argon or nitrogen, however, the resulting microstructure of 17-4 PH must be martensitic to deliver the optimum mechanical properties.
Atomising 17-4 PH with argon will deliver a powder with the desired martensitic microstructure, whereas nitrogen gas atomisation will deliver an austenitic microstructure. Whether the powder is atomised using argon or nitrogen, subsequent processing of the powder with an argon SLM processing gas will still deliver a martensitic part that can be heat treated to produce enhanced mechanical properties. However, using argon for both atomisation and processing will deliver optimum hardness, ultimate tensile strength, and yield strength values. Using nitrogen for both processes will result in the austenitic microstructure with no observed increase in desired mechanical properties.

The study

17-4 PH powders were created using two different atomisation gases, nitrogen and argon[1]. The chemistries of both powders were within the 17-4 PH specification. Preliminary powder cross sections of the argon atomised powder revealed a martensitic microstructure while the nitrogen atomised powder was austenitic.
Four total builds were completed to study the effect of powder atomisation process and machine environment on the resultant microstructure as shown in Table 1.

Table 1 - Test plan and resultant microstructure

Build	Powder Atomisation Gas	SLM Processing Environment	Resultant Microstructure
1	Argon	Argon	Martensite
2	Argon	Nitrogen	Martensite
3	Nitrogen	Argon	Martensite
4	Nitrogen	Nitrogen	Austenite

All builds that used argon as either the atomisation or SLM processing gas had a martensitic microstructure. The hardness data for these four materials are shown in Table 2. The hardness of the builds with a martensitic structure increased to over 400 HV following heat treatment. However, the build that used nitrogen as the atomisation and processing gas contained a large volume fraction of retained austenite that had no change in hardness.

Nitrogen is a small, interstitial element that, in low concentrations, is soluble in the face centred cubic (FCC) austenite matrix that is normally observed at high temperatures[2]. A study by Biggs and Knutsen[3] suggests that steels with a higher concentration of nitrogen have a higher stacking fault energy which inhibits the nucleation of martensite.

This shows that increasing nitrogen concentration, even by small amounts, will reduce the amount of martensite at room temperature and thus affect the heat treatability of the material.

Summary

When the powder is atomised in a nitrogen atmosphere, and then processed within a nitrogen atmosphere, it is plausible that the nitrogen content increases to the point at which it starts to inhibit the martensite formation.

Although the two feedstock materials had only small differences in chemistry, the change in powder production processing route and SLM fabrication conditions resulted in significant differences in the final mechanical properties. This was attributed to different microstructures obtained using different processing routes.

It is clearly important to understand the effect that powder production methods and AM processing parameters can have on the resulting component microstructure.

LPW's highly-trained team understands the behaviour of powders processed under different conditions and can recommend the appropriate powder to achieve the required mechanical properties. LPW can supply both nitrogen and argon atomised 17-4 PH powders.

Table 2 - Comparison of material hardness 'as-built' and after heat treatment

Build	Hardness (as-built) [HV]	Hardness (after HT) [HV]
1	277	424
2	Not reported	406
3	292	406
4	235	235

[1] L. E. Murr et al., "Microstructures and properties of 17-4 PH stainless steel fabricated by selective laser melting," J. Mater. Res. Technol., vol. 1, no.3, pp.167-177, 2012.
[2] G. Krauss, Steels: Processing, Structure, and Performance. Materials Park, OH: ASM International, 2005.
[3] T. Biggs and R. D. Knutsen, "The effect of nitrogen on martensite formation in a Cr-Mn-Ni stainless steel," J. Phys. IV, vol. 5, pp. 515–520, 1995.