# Microstructural and mechanical behavior of Additively Manufactured 718 ODS alloys after ageing treatment

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**Abstract**: The high-strength oxide-dispersion strengthened (ODS) alloys are potential candidates for high temperature turbine blades or high-temperature creep resistant materials. The full capabilities of the additively manufactured ODS alloy is still being researched. Through analyzing mechanical properties and microstructures in the as-printed, homogenized, and aged states, a better understanding can be developed. This study can lead to the design and optimization of ODS Ni alloys with advanced high temperature creep resistance.

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## Background

718 Inconel is a nickel-chromium alloy with high corrosion and oxidation resistance as well as high strength and weldability. It is most used for extreme temperature applications, like the aerospace and aviation industries. Oxide dispersion strengthening (ODS) was used to improve the mechanical strength of 718 alloy. Yttria ($Y_2O_3$) and Chromia ($Cr_2O_3$) were the chosen oxides. This study utilized Direct Energy Deposition (DED) to produce samples for microstructural and mechanical characteristics. Ageing treatment was performed to evaluate the evolution of mechanical behaviors.

| Elements | Ni | Cr | Nb | Mo | Ti | Co | Al | Fe |
|---|---|---|---|---|---|---|---|---|
| Composition (wt.%) | 50-55 | 17-21 | 4.8-5.5 | 2.8-3 | 0.65-1.15 | 1 | 0.2-0.8 | Balance |

*Table listing Elemental Composition of Inconel 718* [1]

There are three primary objectives for this study

1. Evaluate microstructure and mechanical behavior of ODS 718 alloys produced by DED.
2. Identify the influence of oxides on microstructure and mechanical properties.
3. Evaluate microstructural and mechanical properties after ageing treatment.

Homogenization: 1,200°C/2h
Ageing: 720°C/8h, 620°C/8h

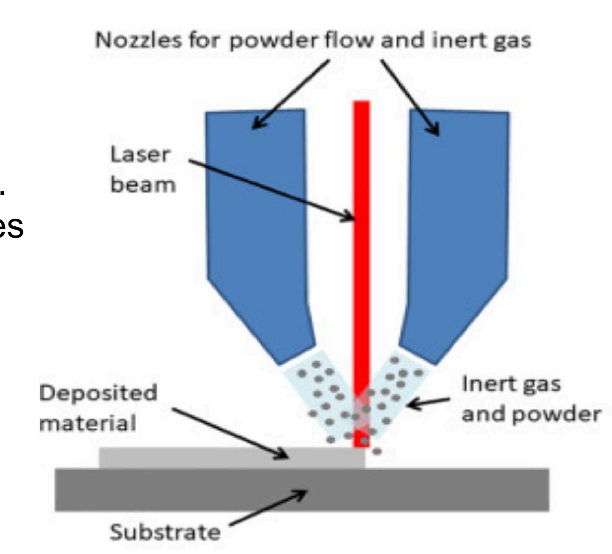



*Figure portraying DED layering technique* [2]

## Sample Preparation & Methods

**Sample Preparation**
Alloy-718 powder was mixed via ReasonantAcoustic mixing in a LabRam II apparatus.

Additive manufacturing was done with a FormAlloy XS DED printer

**ODS Alloy**
Laser Scanning Speed: 700 mm/min
Laser Power: 600 W

Tensile coupons were prepared for mechanical testing. Disk coupons were prepared for microstructural testing and heat treatment.

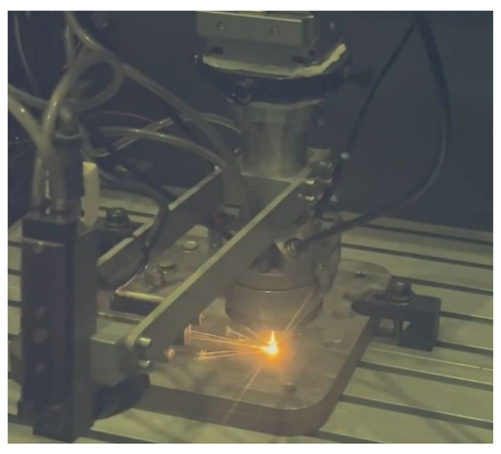
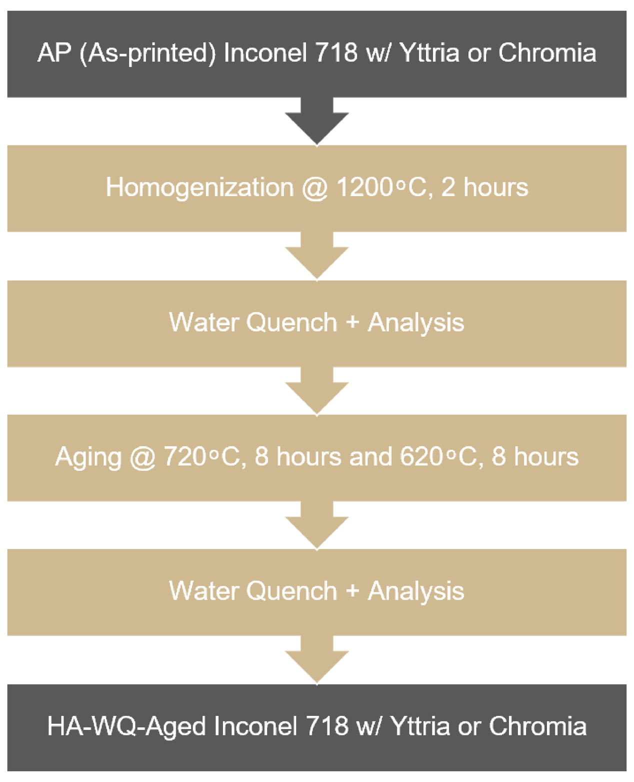


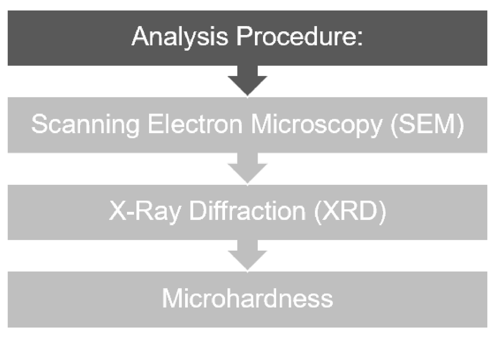
*Image of DED Printing of Samples Used in this Study*

**Test Methods:**

- Scanning electron microscopy (SEM) and Energy dispersive X-ray spectroscopy (EDS) was done on the Quanta 650.
- Vickers's hardness testing was done on the Leco Vickers Indenter
- X-ray diffraction (XRD) was done on the Bruker D8 focus diffractometer
- Tensile testing was done on the Sintech 30/D

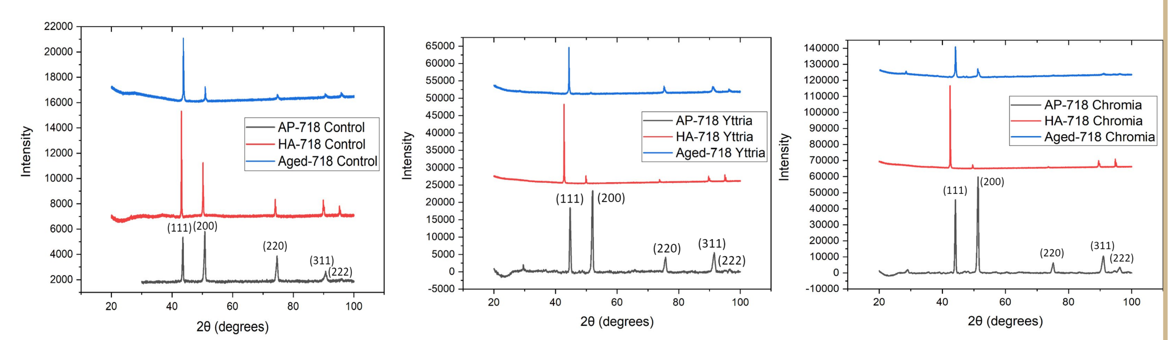
**Heat Treatment:**



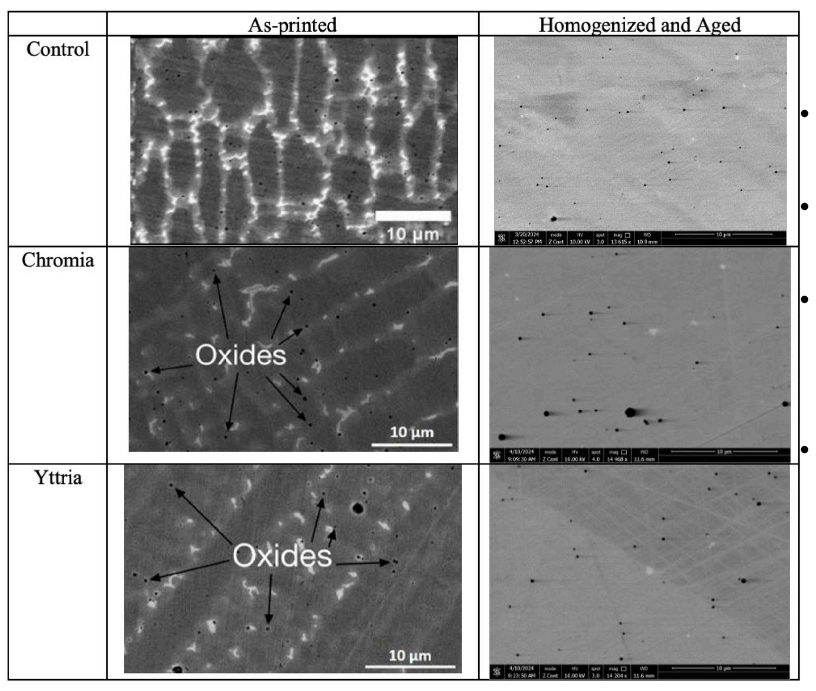

## Results

**XRD:**




- There is a significant drop in intensity in both the yttria and chromia ODS alloys after homogenization and aging, indicative of recrystallization and formation of more uniform grain structure.

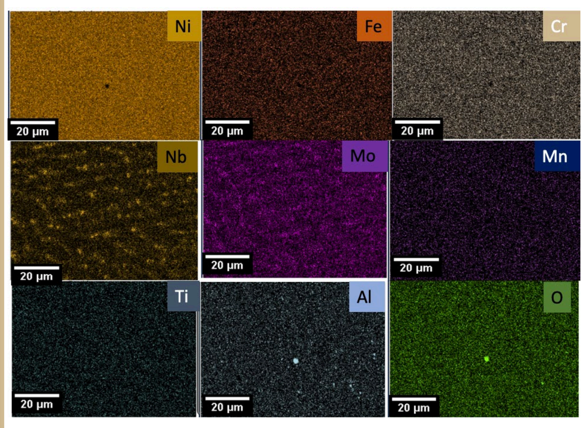
**Microstructural Analysis**
**SEM:**



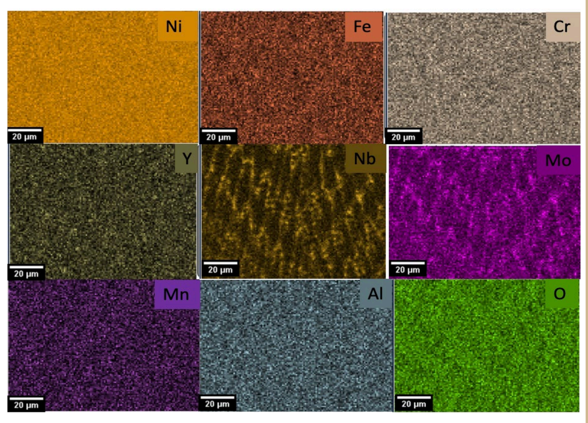

- Chemical segregation of $Ni_3Nb$ can be seen in the as-print alloy.
- From EDS below, the heavier elements are Nb and Mo
- Once homogenized and aged, micro-segregation and Laves phases can be largely eliminated.
- Homogenization and dispersion of oxides (shown as black dots) was observed.

**EDS: As-printed alloys**

$Cr_2O_3$

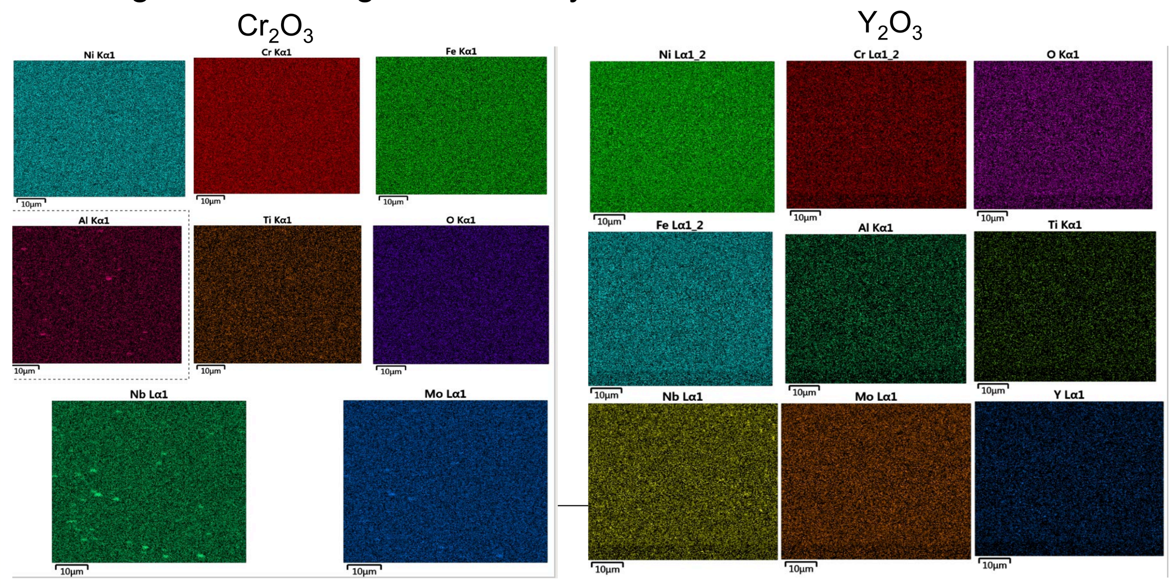



$Y_2O_3$



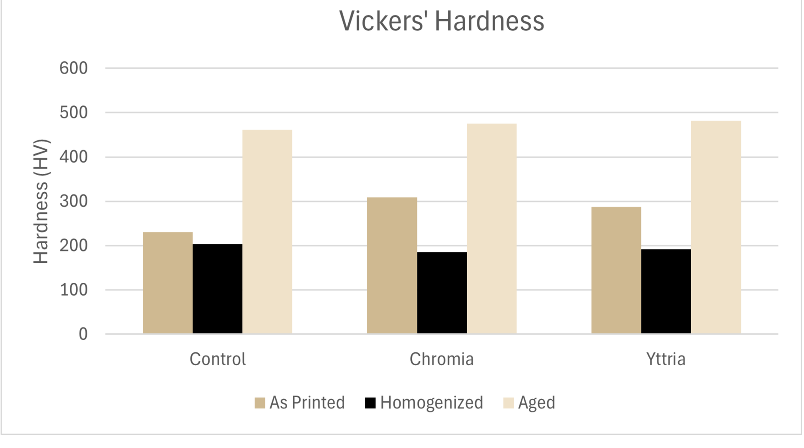

Homogenized and aged ODS alloys

$Cr_2O_3$ $Y_2O_3$



- Nb and Mo microsegregation are observed in the as-printed samples.
- Chromia sample also shows an alumina particle created when chromia reacts with Al. Yttria showed no chemical reactions as it is stable at high temperatures.
- When looking at the homogenized and aged samples, the pattern is mostly eliminated. EDS was used to ensure the heat treatment was successful.

**Microhardness Results**

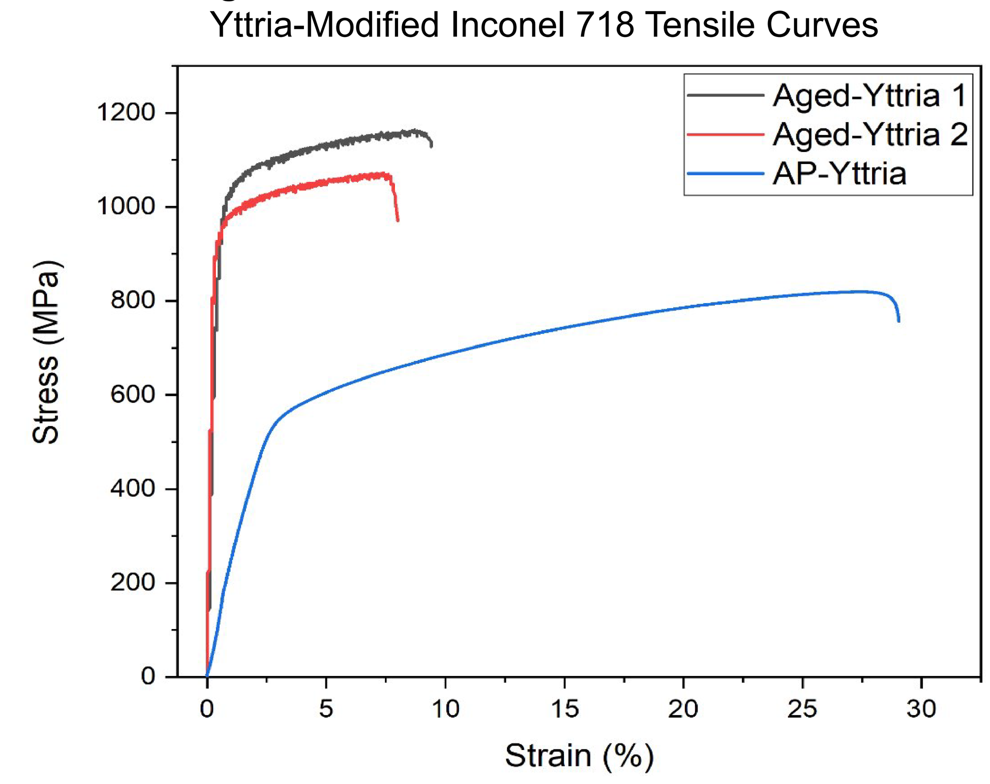


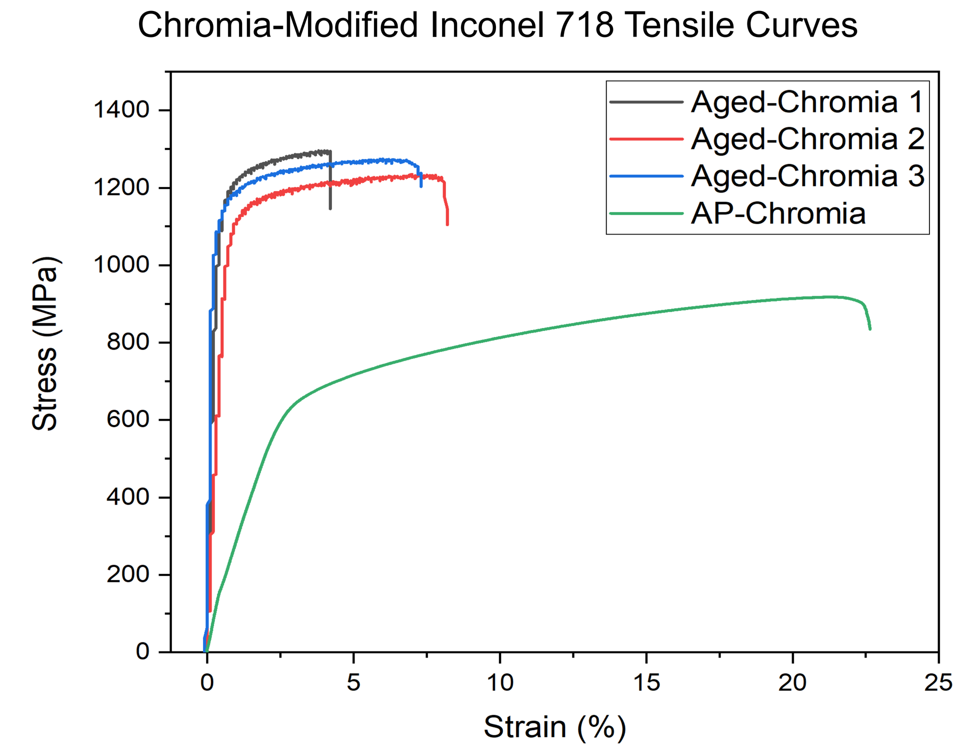

| | Control (HV) | Chromia (HV) | Yttria (HV) |
|---|---|---|---|
| As-Printed | 231.0 | 309.1 | 287.0 |
| Homogenized | 204.2 | 185.8 | 191.5 |
| Aged | 460.8 | 475.7 | 481.7 |

- The control sample had the smallest decrease in strength after homogenization and the largest increase in strength after aging

## Results Cont.

**Tensile Strength:**




| Material | Inconel 718 + Yttria 1wt.% | | | Inconel 718 + Chromia 1.75wt.% | | | |
|---|---|---|---|---|---|---|---|
| Sample ID | AP | Aged-1 | Aged-2 | AP | Aged-1 | Aged-2 | Aged-3 |
| Young's Modulus (GPa) | 205 | N/A | N/A | 256 | N/A | N/A | N/A |
| Tensile Strength (MPa) | 537 | 892 | 848 | 630 | 962 | 965 | 1053 |
| Ultimate Tensile Stress (MPa) | 819 | 1165 | 1059 | 918 | 1296 | 1229 | 1272 |
| % Elongation | 29 | 9.3 | 8 | 23 | 4.1 | 8.2 | 7.3 |

- Significant increase in yield strength(50-60%) in both types of aged ODS alloy.
- Ultimate Tensile Strength (UTS) largely improved in both sample sets as well.
- Elongation to fracture dropped by around 60-70% in both sample sets after ageing
- Chromia ODS alloys showed more strengthening than Yittria ODS alloys after ageing.

## Conclusion

- XRD scans indicated a consolidation into the (111) crystallographic orientation, especially within ODS alloys, suggesting success during homogenization, and continued development of this phase through aging
- SEM and EDS showed the almost complete elimination of the microsegregation, indicating that the samples underwent successful heat treatment.
- Microhardness showed a sizable increase in hardness with ODS as-printed, which while still remaining harder after aging, was weaker than the control in the intermediate heating phase
- Tensile data suggested a substantial strength increase is available by merging both ODS alloys and a proper heat-treatment method, which while developing a more brittle material, could have several potential aerospace applications.

## Acknowledgements & References

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**References**

[1] Pratheesh Kumar, S., Elangovan, S., Mohanraj, R., & Ramakrishna, J. R. (2021). A review on properties of Inconel 625 and Inconel 718 fabricated using direct energy deposition. Materials Today: Proceedings, 46, 7892–7906. https://doi.org/10.1016/j.matpr.2021.02.566
[2] Sing, S. L., Tey, C. F., Tan, J. H. K., Huang, S., & Yeong, W. Y. (2020, January 1). 2 - 3D printing of metals in rapid prototyping of biomaterials: Techniques in additive manufacturing (R. Narayan, Ed.). ScienceDirect; Woodhead Publishing. https://www.sciencedirect.com/science/article/pii/B9780081026632000022