High Temperature Oxidation Behavior of 3D Printed, HIP and Wrought AFA25 Specimen Alloys

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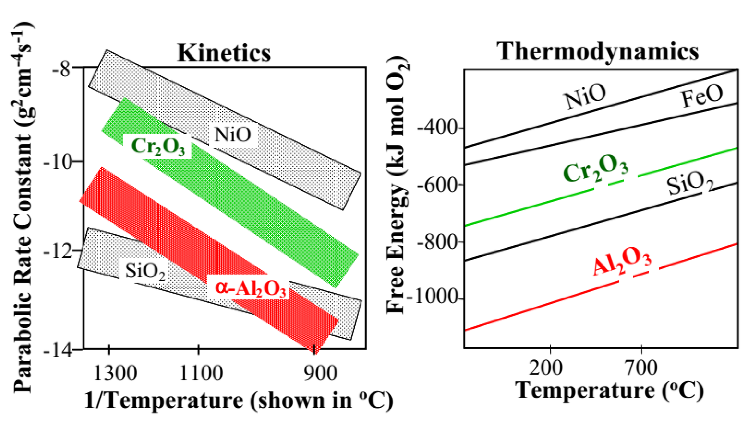
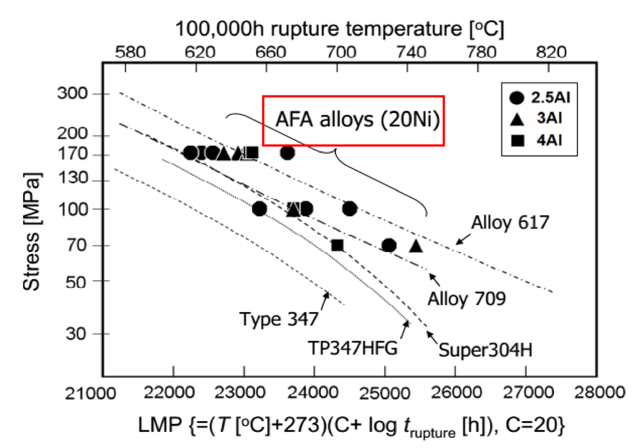
Objective

Investigating the influence of manufacturing technologies like wrought, Hot Isostatic pressing (HIP) and Additive manufacturing (AM) on the microstructure and high temperature oxidation behavior of Alumina Forming austenitic (AFA25) alloy.

Background

- A new family of ***alumina forming austenitic stainless** steels* is under development at *Oak Ridge National Laboratory* during the past 30 years.
- AFA 25 stainless steel alloy is known for its excellent corrosion and creep resistance properties at high temperatures [1].
- The excellent high temperature corrosion property of AFA25 is due to the formation of an adhesive protective aluminum oxide (Al_2O_3) scale layer on the alloy's surface [2].
- Al_2O_3 layer provides better oxidation resistance for longer service life at the higher temperature as compared to the chromium oxide layer (Cr_2O_3), which forms on Ni and Fe base alloys [2].





Challenges of AFA stainless steel Alloys

- Al addition is a major complication for strengthening
- Strong BCC stabilizer/delta-ferrite formation (weak)
- Want to use as little Al as possible to gain oxidation benefit
- Keep austenitic matrix for high temperature strength
- Introduce second phase for precipitate strengthening

Options for Al_2O_3 Forming Alloys

- FeCrAl alloys: Open body-centered cubic structure is weak
- Not suitable for most structural uses above 500 °C
- Ni-Base alloys/Superalloys: too costly
- 5 to 10 times greater cost than stainless steels
- Typically use Al_2O_3 forming coatings or surface treatment
- Not feasible for many applications

Experimental Procedure

Sample Preparation

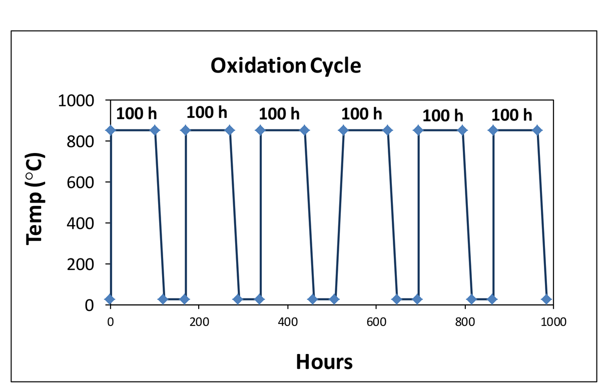
- Grinding Alloy up to 600 SiC
- Ultrasonic Cleaning in Acetone (5 min)
- Store in desiccator for > 1 day
- Weight the sample for 3 times

High Temperature Test

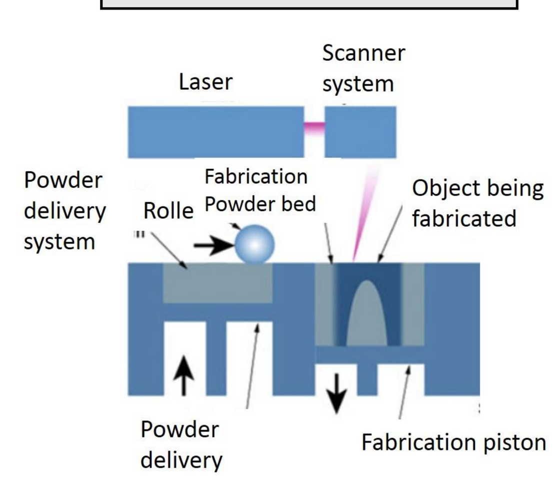
- Temperature: 850 °C
- Environment: Air
- Time: 100, 200, 300, 400, 500 & 600 h

Cross sectional analysis

- Pt sputter coating
- Cu electroplating (≈ 50 µm thick layer)
- Cold mounting for cross sectional analysis
- Grinding up to 1200 SiC
- Polishing up to 1 µm
- Characterization:
- Cross section observation: **SEM/EDAX**



Selective Laser Melting

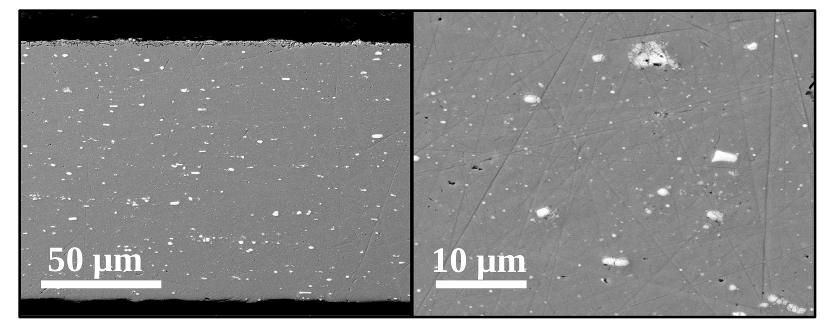


- 16 AM-AFA alloys were prepared with Selective Laser Melting (SLM) technique using a wide range of AM parameters: Laser intensity, Hatch, focus and speed were varied.

Results and Discussion

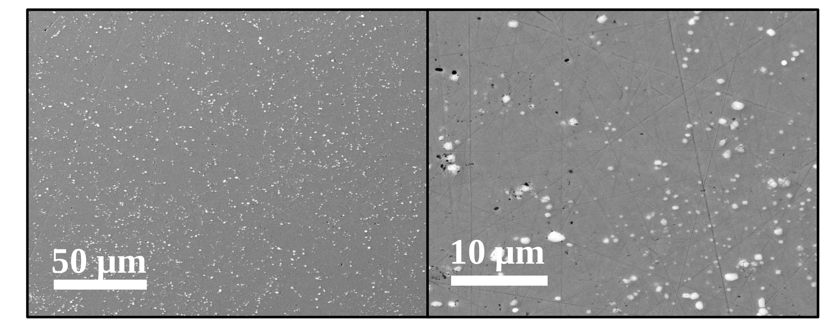
1. SEM Characterization Before Oxidation

A. As received wrought AFA 25



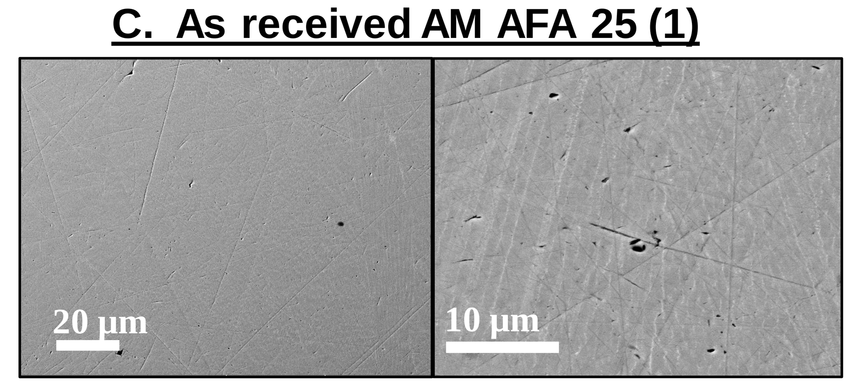
- Bright particles: Nb and Mo rich (EDX)
- Darker phases: pores or Al rich

B. As received HIP AFA 25

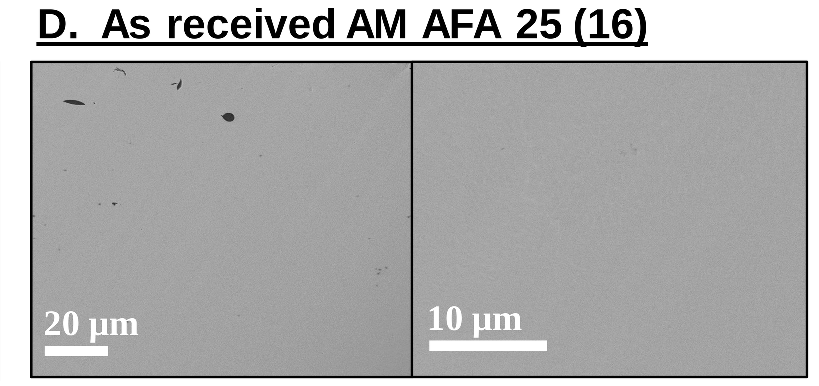


- Higher fraction of Nb rich particles in HIP alloy

C. As received AM AFA 25 (1)



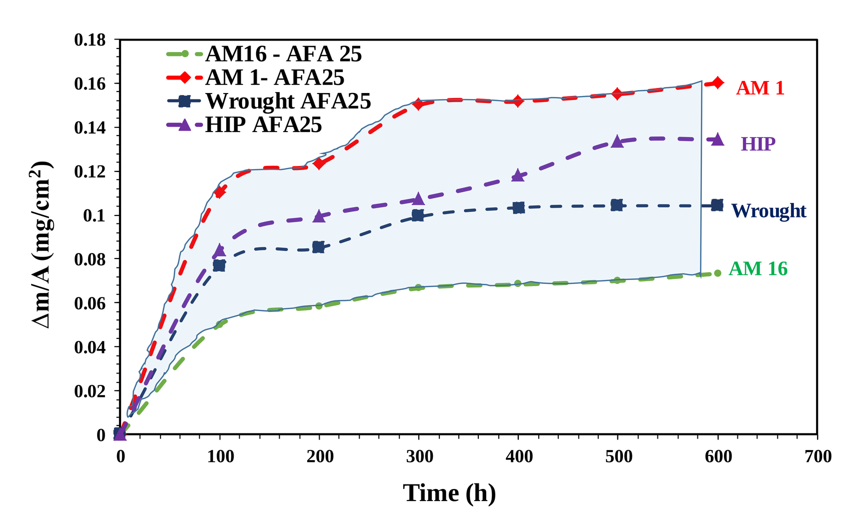
D. As received AM AFA 25 (16)



- AM alloys had uniform microstructure which was attributed to the fast cooling rates involved in the AM process
- The microstructure of fine precipitates depends upon the AM processing parameters.

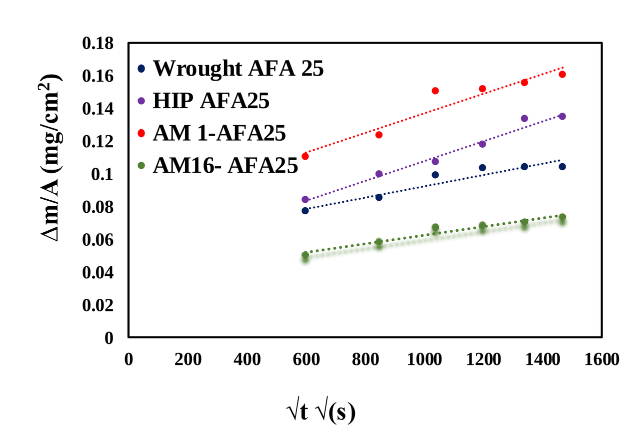
2. Oxidation Test

A. Mass measurement



- Mass gain per unit area for wrought and HIP AFA 25 along with that of AM AFA 25. The mass gain of AM alloys is represented by the region shaded in blue.

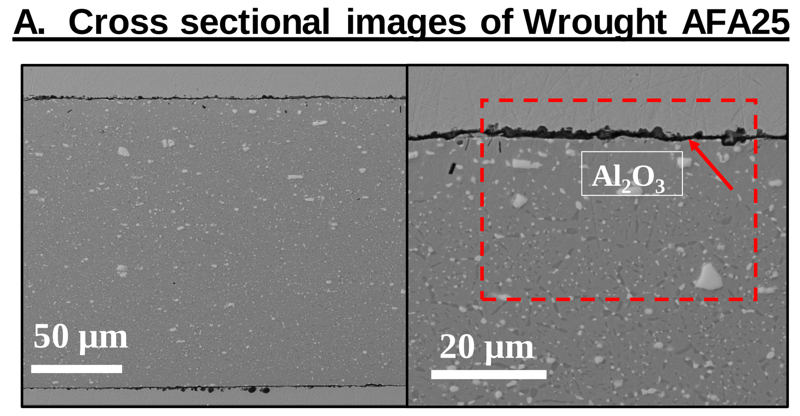
B. Oxidation kinetics

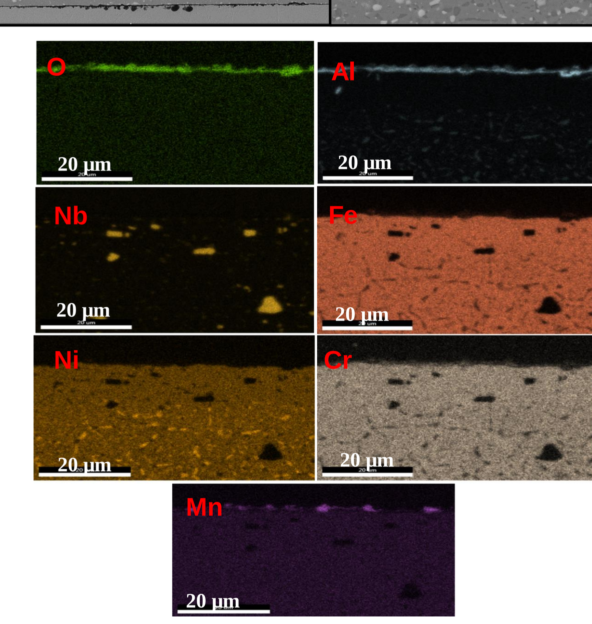


Alloys	Kp (mg/cm²s$^{1/2}$)
Wrought AFA	3.00E-05
HIP AFA	6.00E-05
AM1- AFA	6.00E-05
AM16-AFA	3.00E-05

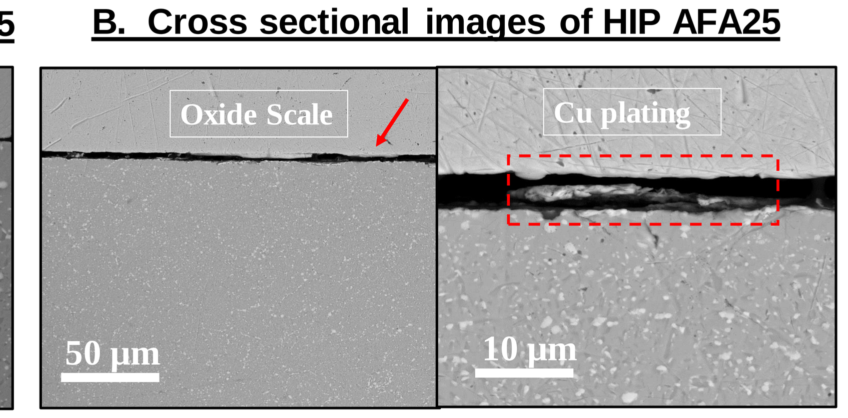
3. SEM Characterization After Oxidation

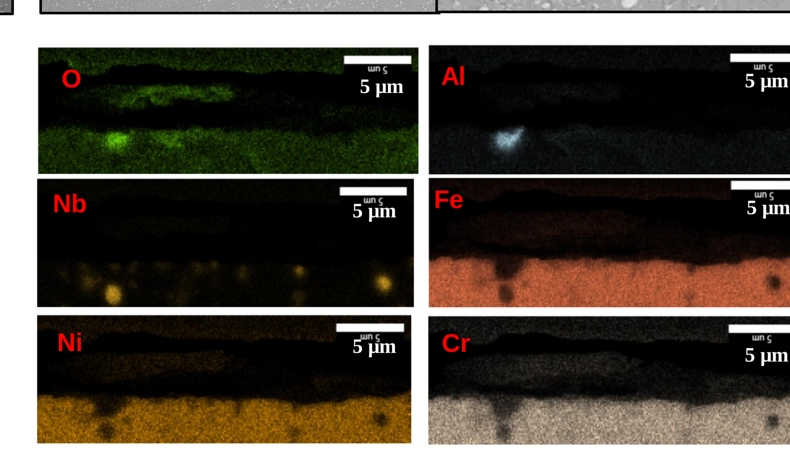
A. Cross sectional images of Wrought AFA25





B. Cross sectional images of HIP AFA25

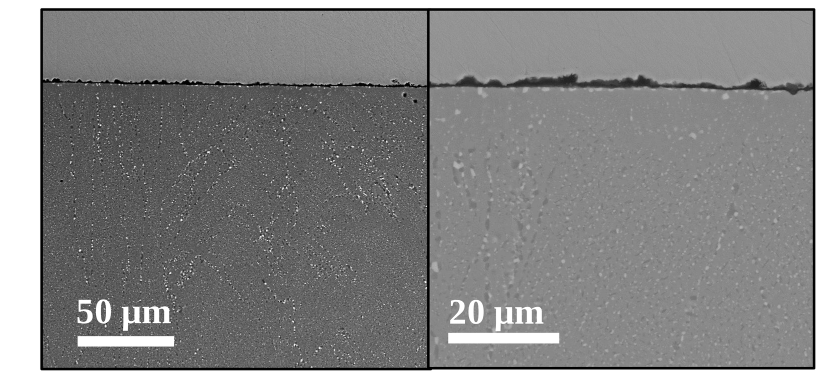


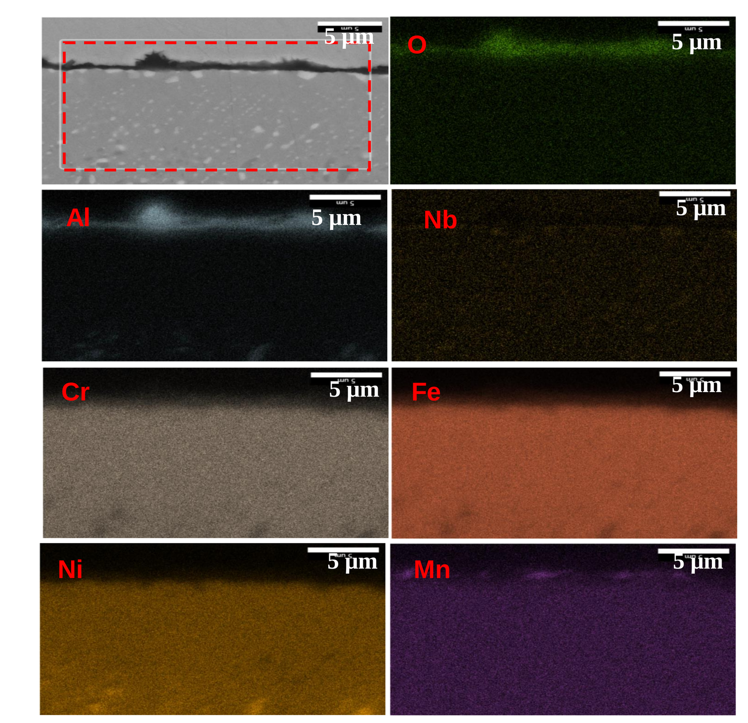


- Formation of an external alumina scale.
- precipitation of bright Mo-Nb rich phases during oxidation.

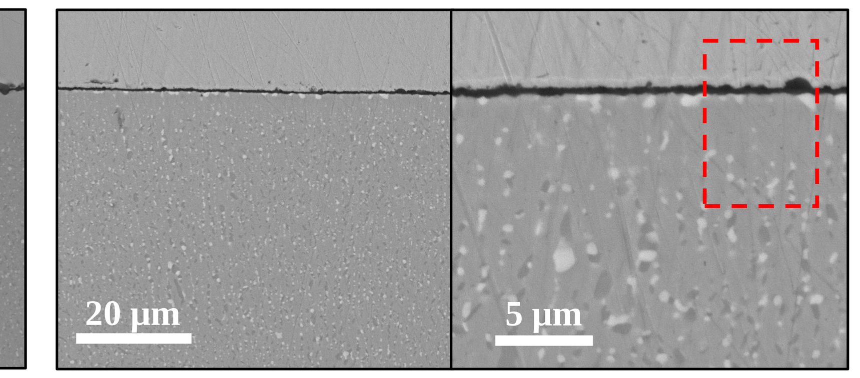
Results and Discussion

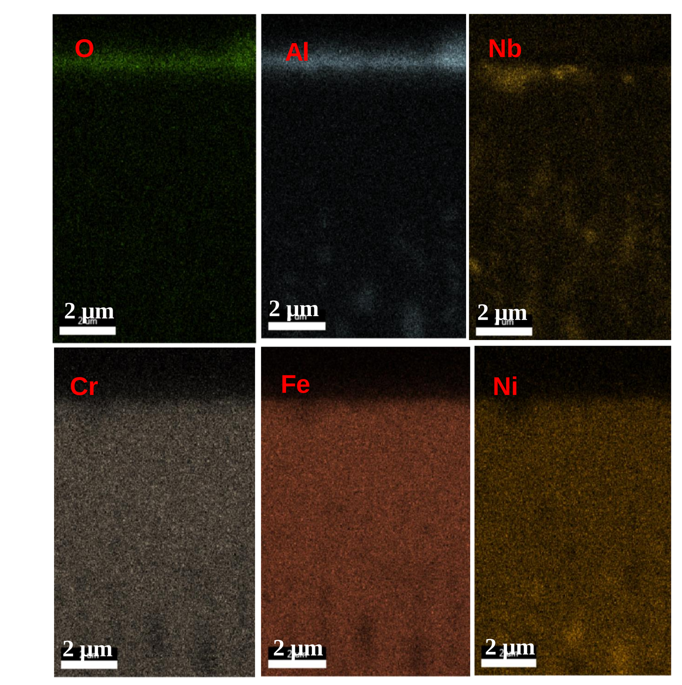
C. Cross sectional images of AM AFA (1)





D. Cross sectional images of AM AFA (16)





- The AM AFA 25 alloys showed good oxidation resistance which was comparable with that of the wrought and HIP AM alloys.
- The high temperature oxidation resistance of AM alloys was dependent upon the AM parameters.

Conclusions

- Well adherent, protective, external alumina layer formed on AFA25 alloys at 850 °C.
- AM AFA25 processed by different parameters showed similar oxidation behavior like wrought and HIP alloys.
- **AM can be used to produce AFA25 alloy without compromising the high temperature oxidation behavior.**

Future Works

- Future work will focus on the in-depth characterization by using TEM, FIB.
- The oxidation test will run for longer time (1000 hrs)

Acknowledgements

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References

- 1. M. P. Brady *et al.*, "*The development of alumina-forming austenitic stainless steels for high-temperature structural use*," *JOM*, vol. 60, no. 7, pp. 12–18, Jul. 2008.
- 2. M. P. Brady, Y. Yamamoto, M. L. Santella, H. Bei, and P. J. Maziasz, "*Development of Alumina-Forming Austenitic (AFA) Stainless Steels*," 23rd Annual Conference on Fossil Energy Materials", Pittsburg, 2009.
- 3. L. Yang *et al.*, "*Additive manufacturing of metals : the technology, materials, design and production"*, Springer, Switzerland, 2017.