The Effect of Increasing Tramp Elements on Weldability of Alloy 718

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Abstract: Inconel 718 is a nickel-based superalloy that is utilized in the aerospace industry due to its high strength properties, high corrosion resistance and good weldability. Inconel 718 has a very specific composition with many tramp elements that affect the mechanical properties. The tramp elements of interest are Phosphorous, Manganese, Silicon, Copper and Vanadium. The purpose of this study is to evaluate if the listed tramp elements affect the mechanical properties of Inconel 718.

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HOWMET AEROSPACE

Background

Motivation

•Virgin 718 is becoming scarce, leading to rising costs and the consumption of revert material, increasing the presence of tramp elements.
•AMS 5383 has specified limits for tramp elemen
•Their effect on base 718 and its weldability is or partly understood.

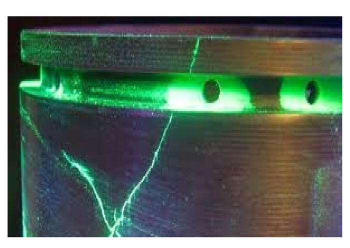
Gas turbine engine nozzle guide vane

Inconel 718

Nickel-based aerospace superalloy that possesses high corrosion, heat, creep resistance and good **weldability** properties. AMS 5383 specifies homogenization, solution, and precipitation heat treatments.

Weldability: The relative ease with which a metal can be welded using conventional practice.

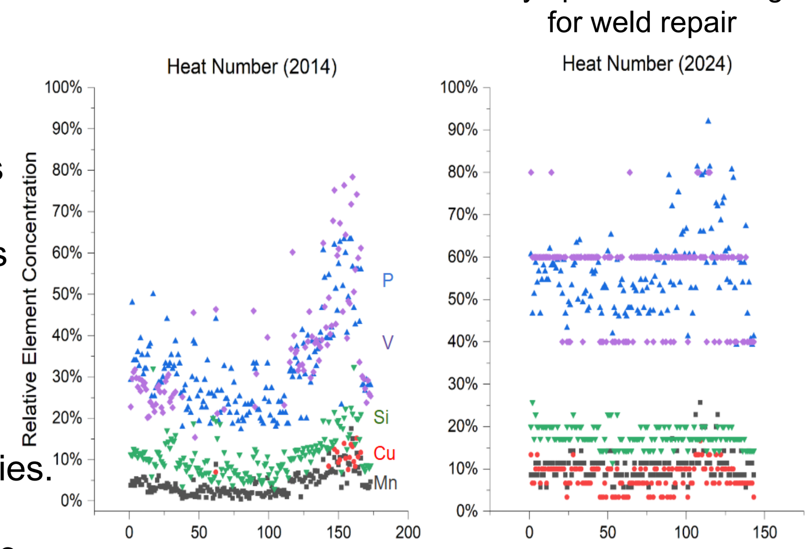
- Weld repair is essential in delivering structural aerospace parts.



Dye penetrant testing for weld repair

Tramp Elements

- Tramp element presence increases with time.
- Literature suggests that certain tramp elements have concerns about decreasing 718's mechanical properties.
- **How do tramp elements affect the weldability of 718?**



Tramp element concentration (wt. %) for different heats from 2014 and 2024

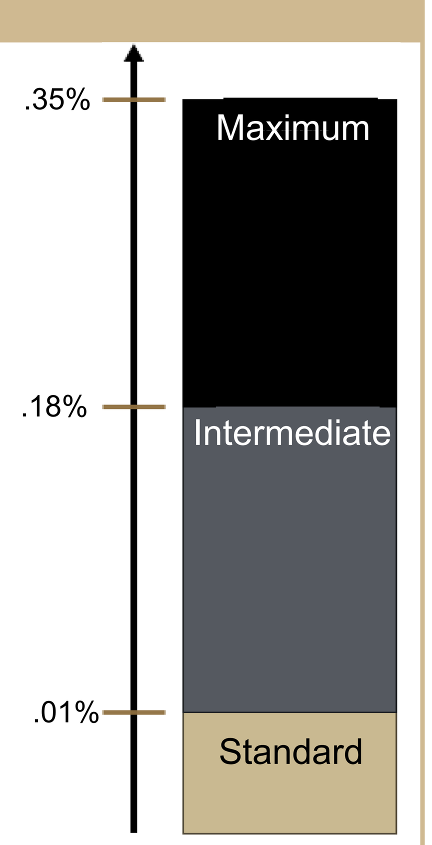
Experimental Procedures

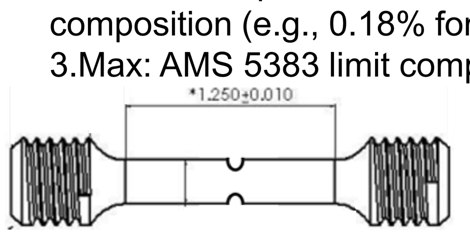
Sample Matrix

Composition:

Three dopant levels of tramp elements with 10 sample groups in total:

1. Standard: Heat composition, provided by Howmet
2. Intermediate: average between the standard composition and the max composition (e.g., 0.18% for Mn and Si)
3. Max: AMS 5383 limit composition



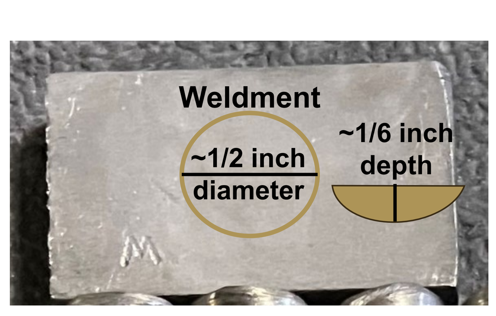


Groove size: 0.3 x 0.0625-in.

Machined tensile bar

All tensile bars undergo heat treatment via AMS 5383.

Weldability: Tensile bars were machined (above), then the groove was "repaired" with welded material to test mechanical properties. 1-inch chem pads were machined and welded (right) for pre-failure weldment microstructure.



Mechanical Testing: Welded and unwelded test bars of each alloy composition were tensile tested at room temperature and compared with UTS, YS, %EL, and %RA of the AMS 5383 specification.

Element	Min	Max
Carbon	–	0.08
Manganese	–	0.35
Silicon	–	0.35
Phosphorus	–	0.015
Sulfur	–	0.015
Chromium	17.00	21.00
Nickel	50.00	55.00
Molybdenum	2.80	3.30
Columbium (Niobium)	4.75	5.50
Titanium	0.65	1.15
Aluminum	0.40	0.80
Titanium + Aluminum	–	1.75
Cobalt	–	1.00
Boron	–	0.006
Copper	–	0.30
Iron	remainder	

Metallography: Conducted standard metallographic preparation. Utilized Kalling's etchant.

Grain Size: average grain intercept (AGI) allows for rapid, repeatable quantification of grain size. Five parallel lines laid over each micrograph, with intercepts counted manually. AGI values allow for direct comparison of grain size between groups.

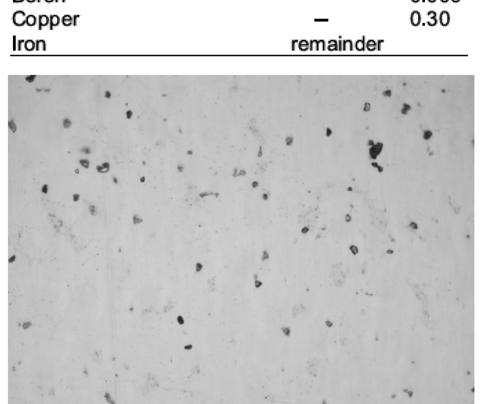
$AGI = \frac{N_i}{L}$ (N_i = number of intercepts, L = length of line)

Porosity Fraction: Threshold images to verify the black areas are pores.

Calculated by $Porosity\ Fraction = \frac{A_{pores}}{A_{Total}} \times 100\%$

Carbide Fraction: Measured the area of the carbides as they appear as a secondary formation.

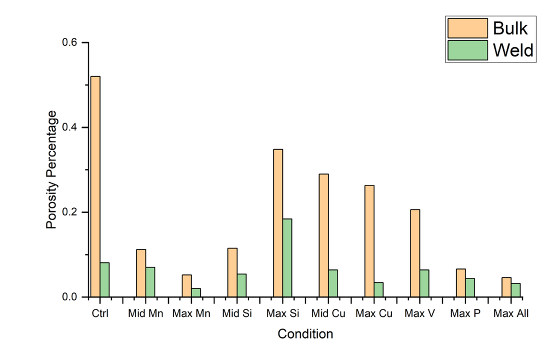
Calculated by $Carbide\ Fraction = \frac{A_{carbides}}{A_{Total}} \times 100\%$



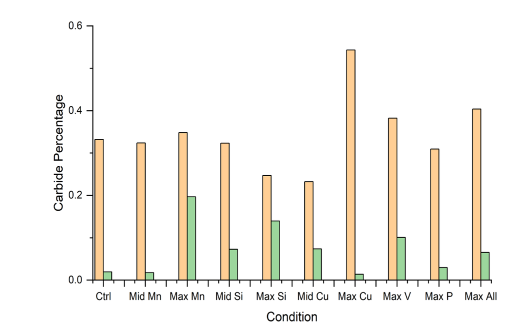
Max Si group polished to 6 micron

Results & Discussion

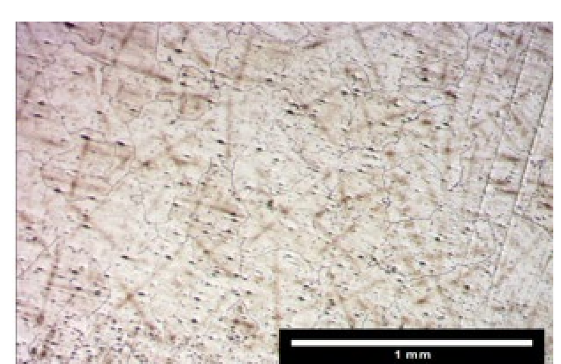
Metallography



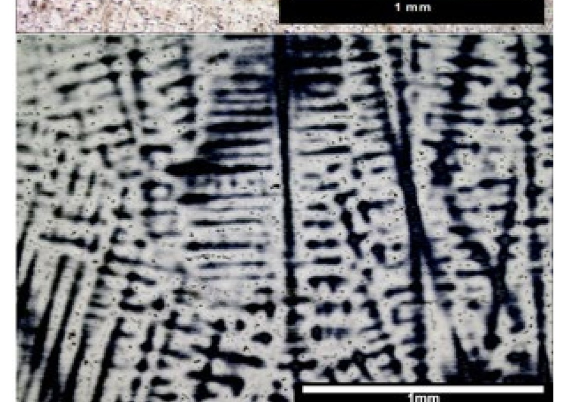
Porosity: Welded areas exhibit lower porosity than non-welded areas, most likely due to faster cooling rates compared to casting



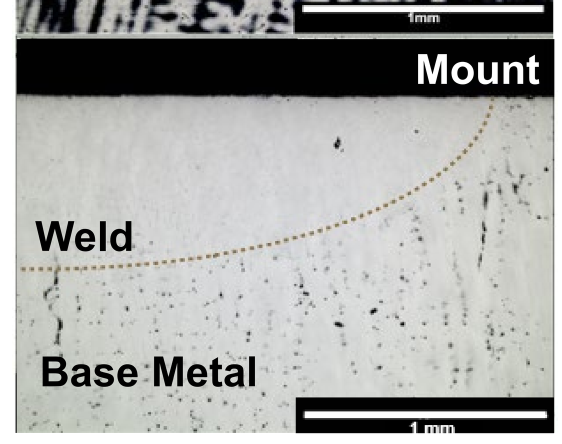
Primary Carbides: Welded areas exhibit lower carbide fractions than non-welded areas. Likely due to lower carbon wt. % in weld wire.



Micrograph of **etched Max All** tramp elements tensile bar sample. Grain boundaries are visible with smaller dendrites. Etched condition used for grain size analysis.



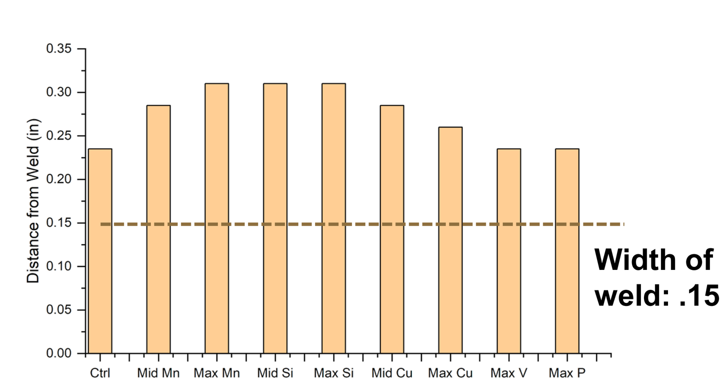
Micrograph of **etched Mid Mn** chem pad sample. Dendrites are fully visible. Etched condition used for grain size analysis, dendrite arm spacing and dendrite length measurements.



Unetched micrograph of the HAZ sample with the Max of all tramp elements.

- Dendrite-like formation is visible beyond the HAZ.
- Small transition zone between the base metal and weld.

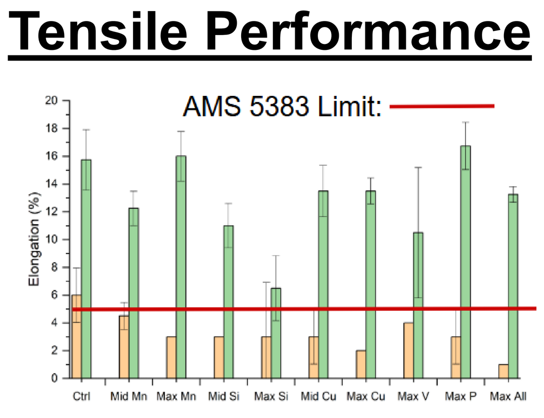
Takeaways: The weld area is not as responsive to Kalling's etchant, suggesting corrosion resistance. No visual difference in dendrite spacing for each condition. Tensile bars consistently failed outside of the weld area:

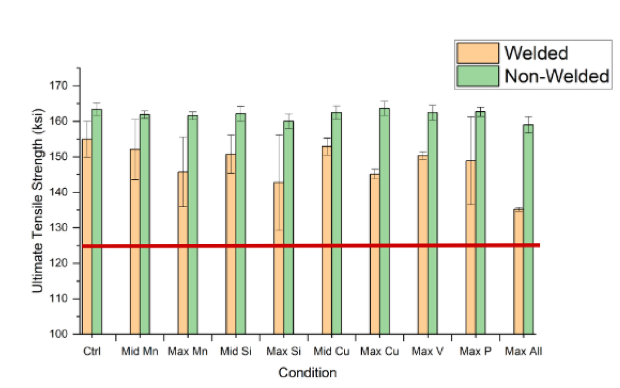


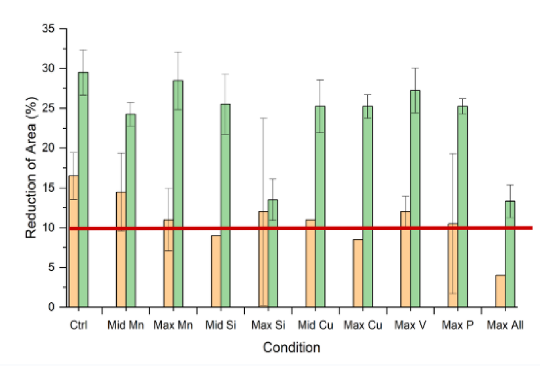
Distance From Weld

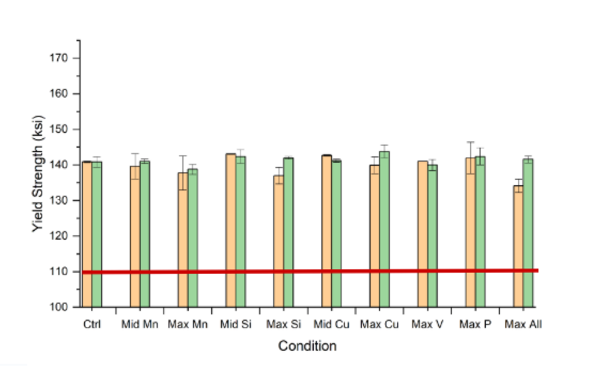
None of the welded samples failed in the welded area. However, welding still compromised the ductility of samples, as shown below.

Tensile Performance









Ductility: Non-welded outperforms welded counterparts. Control is only welded group above specification. Cu/Si are the most detrimental individuals. Max All performs the worst. Welding with tramp elements decreases ductility.

Strength: Non-welded samples outperform but to a lesser extent. Max All performs worst in both cases. Still, all groups perform above the AMS 5383 specification. Welding does not affect strength as much as ductility.

Conclusions

The investigated tramp elements (V, P, Si, Cu, and P) demonstrated varied but detrimental effects on the performance of welded 718.

Microstructurally, welding demonstrated:

- Lower porosity via optical microscopy when compared to unwelded counterparts
- Carbide formation was lower in weldments via optical microscopy and visual examination
- Grain size was smaller in weldments, mostly likely due to rapid cooling

Mechanically, welding demonstrated:

- Decreased performance for tramp elements in reduction of area and elongation, falling below AMS 5383 standards.
- With strength, weldments demonstrated no major deviation and were above AMS 5383 standards.
- The discrepancy between the effect on strength performance and ductility suggests an embrittlement mechanism, although the welded specimens all failed outside the weld region.

Conclusively, tramp elements act to decrease the ductility of 718. However, more work is needed to determine the mechanism behind the discrepancy between the effect of welding on ductility and strength performance with tramp elements.

Future Work

For a more complete understanding on the effect of tramp elements, specifically embrittlement, the investigators recommend the following:

- Increased number of welded samples
  - Allows for more accurate statistical analysis
  - More samples allow for larger variety of mechanical tests
- Stress rupture, creep life, and hot tensile tests
  - Embrittlement of welded samples suggests decreased creep life
  - Not specified in AMS 5383, still vital in aerospace applications.
- Examination of reduced ductility in welded samples
  - Samples failed outside of weld, but showed reduced ductility
- Investigating the effect strain has on 718's corrosion resistance.
  - Tensile bar gauge sections took longer to etch and had a worse quality etch than chem pads
  - Increased dislocation density from strain could provide resistance to acids and other corroding substances
- Investigation of tramp elements in pairs
  - Observe if there are compounding effects on weldability, mechanical performance, and microstructure with only two elements at high compositions
- Observe the effects of other tramp elements
  - The five analyzed in this report were of highest concern, however other elements such as boron may have additional detrimental effects.

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