# Development of High Temperature ODS Alloys for Additive Manufacturing of Aerospace Structural Components

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PURDUE MATERIALS ENGINEERING

Powder processing parameters were explored to incorporate yttria particles into NiCrAl powder for use as an oxide dispersion-strengthened (ODS) alloy in additive manufacturing. Orbital and attritor milling were used. Particle size analysis, SEM, and specific surface area measurements showed that many cycles of particle welding followed by fracture occurred during orbital milling. Compared to orbital milling, attritor milling resulted in faster welding and fracture cycles. EDS revealed that yttria powder was evenly dispersed onto NiCrAl particle surfaces during milling.

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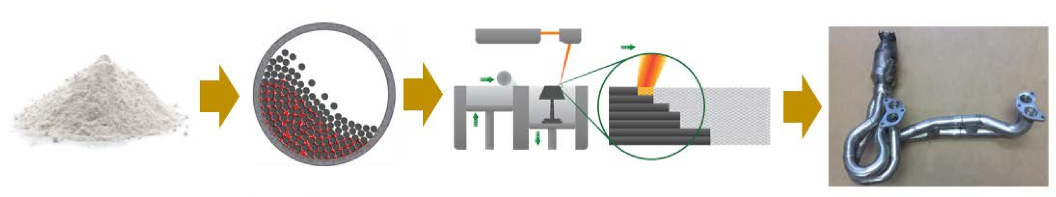
## Project Background

- Additively manufactured MCrAl(Y) powders are being explored for high temperature, corrosion resistant parts with complex geometries



Powder Milling SLM Part

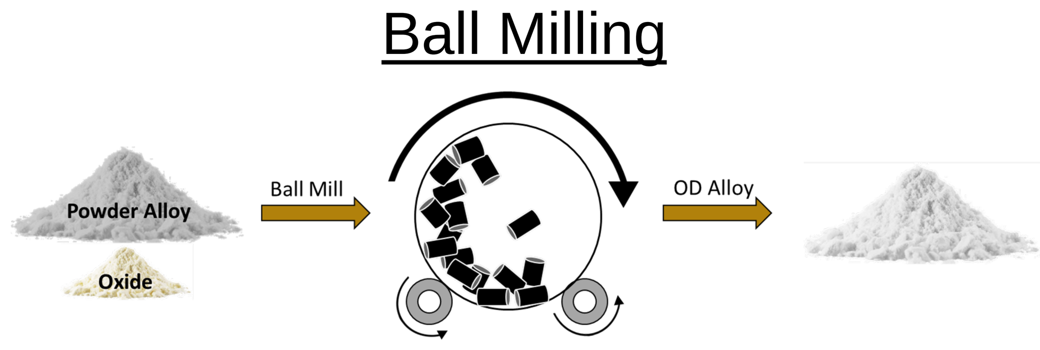
- The MCrAl powders are currently used in thermal spray for their high temperature and corrosion properties. Adding yttria to NiCrAl powders strengthens the alloy by the forced bowing of dislocations through Orowan strengthening.

- Ball milling refines particle size and incorporates the yttria into the powders through a cycle of welding particles together and fracturing these agglomerates. Controlling milling parameters like speed, loading and time allows for particle size control. Two milling types were used:
  - Planetary Milling – powders and media are put in containers which are rotated around a central point.
  - Attritor Milling – powders and media are put in one container which rotates in place.

- Selective Laser Melting (SLM) melts powder spread on a lowering stage according to a computer file layer by layer to create parts with complex shapes.

## Experimental Procedure

### Ball Milling




NiCrAl and 0.6 wt% yttria powder are milled via two milling methods: Planetary ball milling at a low RPM with ¼" stainless steel spheres & attritor ball milling at a high RPM with ¼" WC spheres. Powders were sieved post-milling using 325 and 635 mesh.

### Characterization and Preparation Sites

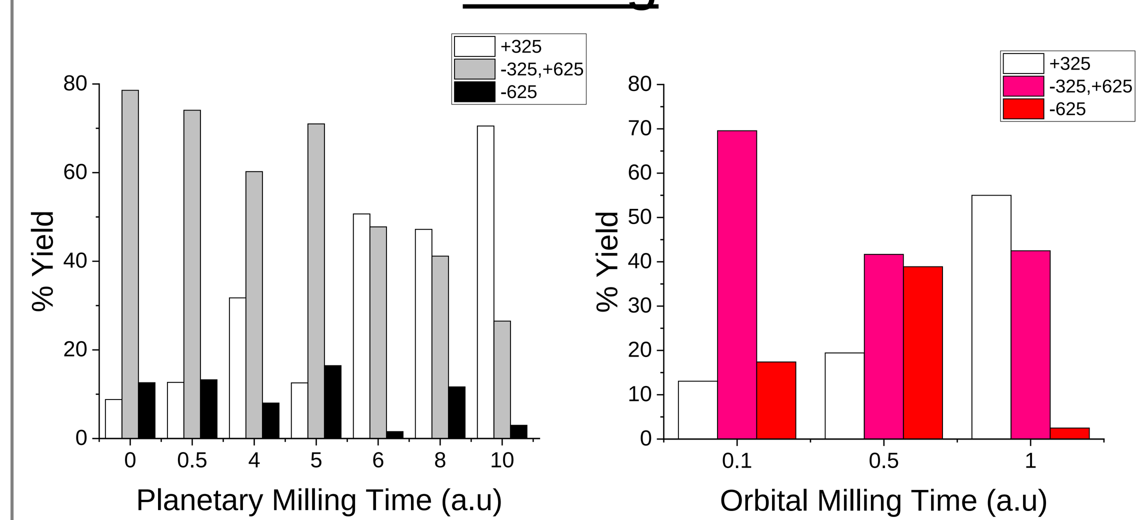
| NASA Glenn | Purdue University |
|---|---|
| Powder milling | BET Surface Area |
| Separation from media | SEM |
| Initial sieving | Morphologi analysis |
| Morphologi gathering | |

BET Procedure:
- Degassed 12 hours, 250˚C

Morphologi Procedure:
- Sample dispersed over slide
- Automated optical microscope images powders
- Diameter, circularity, intensity, etc. gathered

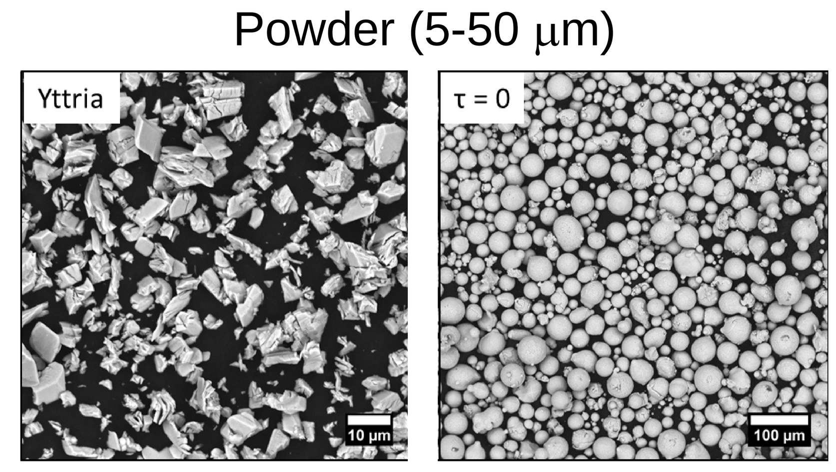
## Results & Discussion

### Sieving

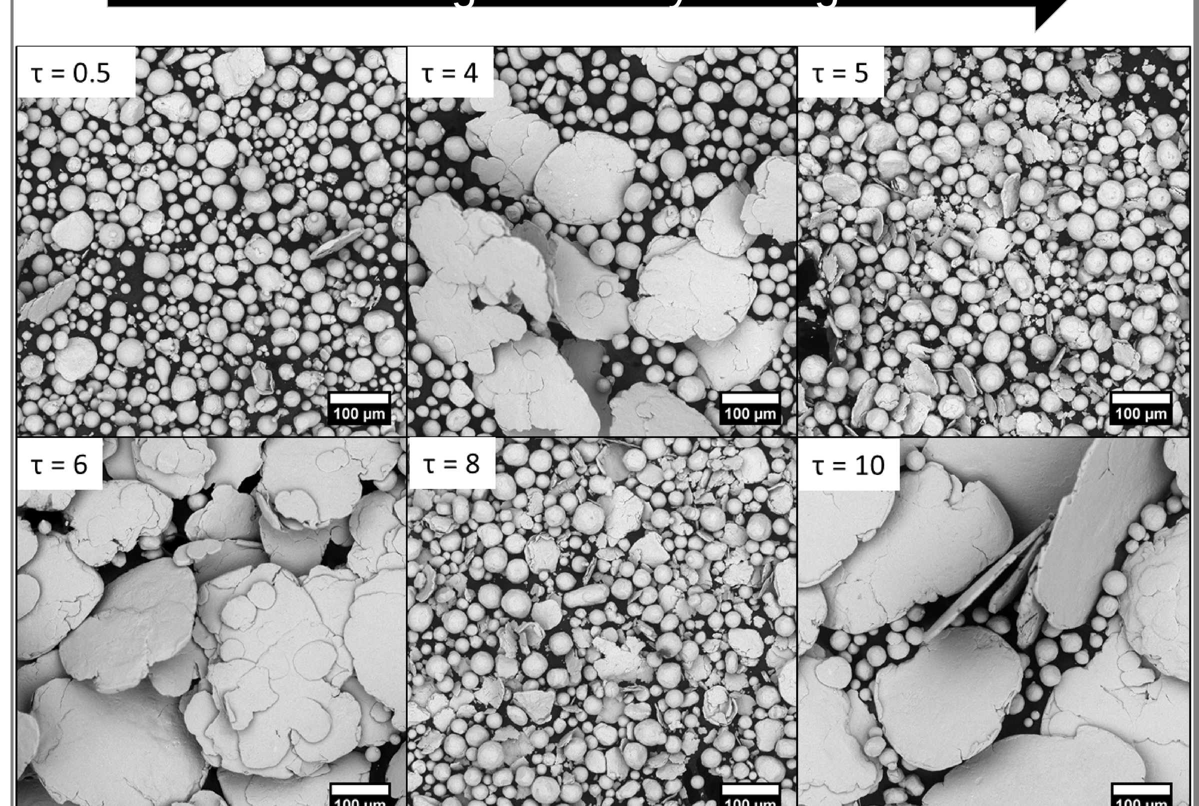



### Scanning Electron Microscopy

Starting Materials: Yttria Powder (<10 $\mu$m) and NiCrAl Powder (5-50 $\mu$m)

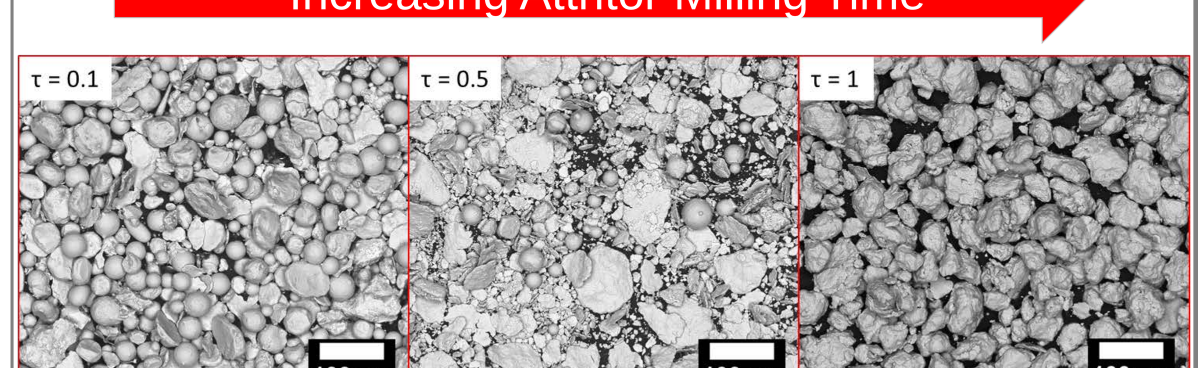



Increasing Planetary Milling Time



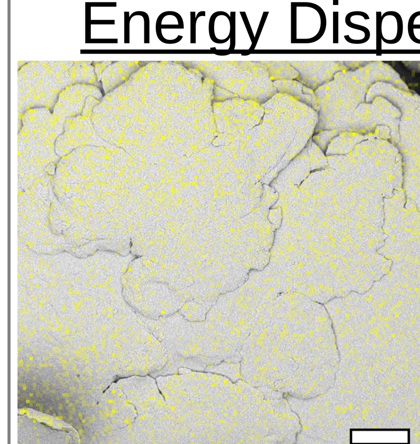

Cycles of welding and fracture occur as milling time is increased from $\tau = 0$ to 10 a.u.

Increasing Attritor Milling Time




Welding and fracture occur faster for attritor milling compared to orbital milling

### Energy Dispersive X-ray Spectroscopy



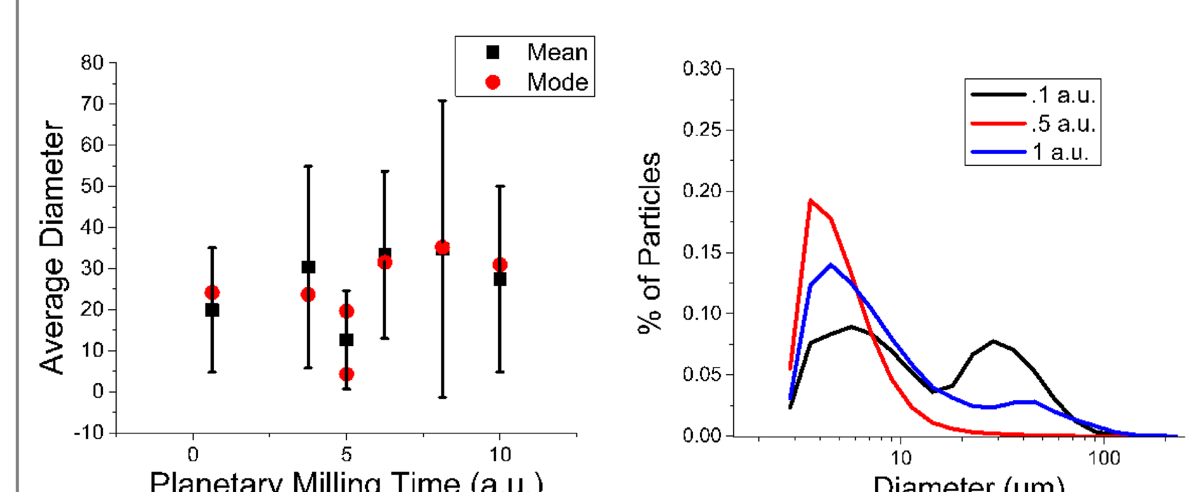
| Element | Atomic % |
|---|---|
| Ni | 55 |
| Cr | 17 |
| O | 17 |
| Al | 10 |
| Y | 1 |

Elemental analysis shows that yttria is being fractured and dispersed on the NiCrAl particle surfaces. ($\tau = 6$ a.u.)

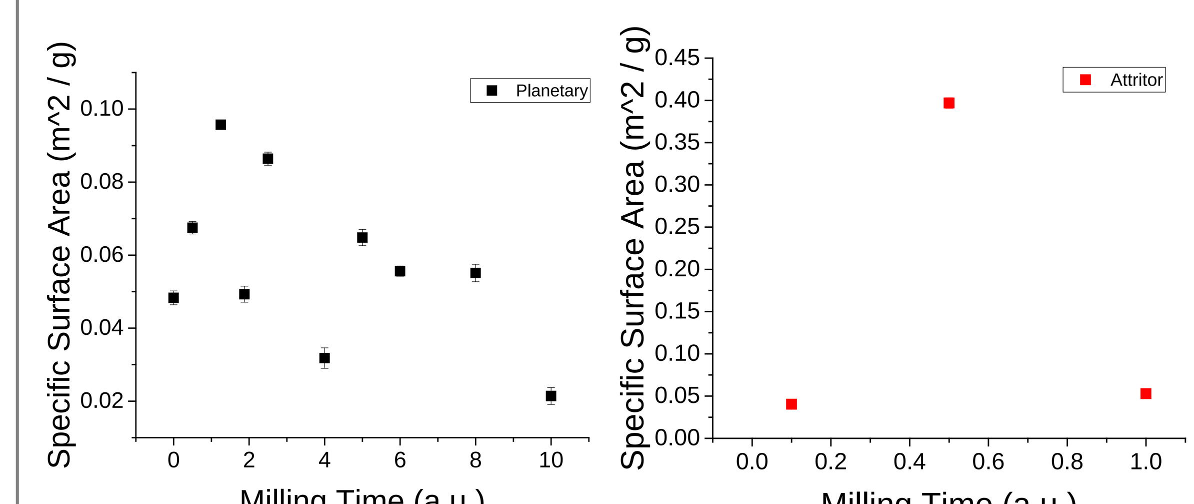
## Results & Discussion (cont.)

### Morphologi Particle Size Distributions

- Cycling through large and small average diameter in both methods
- Two sizes of particles form with attrition milling
- Attrition milling takes place over 1/10 the time




### Specific Surface Area




Attritor ball milling showed higher surface area at lower milling times compared to planetary ball milling. Welding occurred at $\tau = 0.5$ a.u. followed by fracture at $\tau = 1.0$ a.u. in the attritor. Planetary ball milling experienced cyclic welding and fracture. Planetary ball milling had less variation in surface area compared to attritor ball milling at lower hours.

## Conclusions

- Multiple cycles of welding and fracture were observed for planetary milling.
- One cycle of welding and fracture was observed for attritor milling.
- Attritor milling experienced a full cycle of welding and fracture in 80% less time than planetary milling.
- Yttria was shown to disperse evenly on the particle surface ($\tau = 6$ a.u).

## Future work

- Analysis of milling time for the planetary ball mill should be explored, to fill in intermediate times.
- Examination of an increased milling speed to further reduce time while maintaining similar trends.
- Investigate potential oxidation in milling via X-Ray Diffraction.
- Cross-sectional examination to determine yttria dispersion in the core of the particles.

## Acknowledgements

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