A Novel Prime Coat Slurry Mineral for Aluminum Investment Castings

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Presentation Outline

Introduction to the idea

- Findings from a Department of Energy (DOE) study

Lab Testing at Kyanite Mining Corporation (KMC)

- Initial cup tests
- More complex shapes

Foundry trials at O'Fallon Casting

- 1st trial
- 2nd trial

Introduction

The DOE funded a study to improve the energy efficiency of molten metal handling with a focus on aluminum alloys

Refractories were a main area of focus

- Heat loss due to degradation results in increased energy consumption

Degradation primarily due to attack by the molten aluminum on refractories

- Typically, non-wetting agents are added to the refractory to hinder the aluminum attack
  - $BaSO_4$, CaF_2, etc.

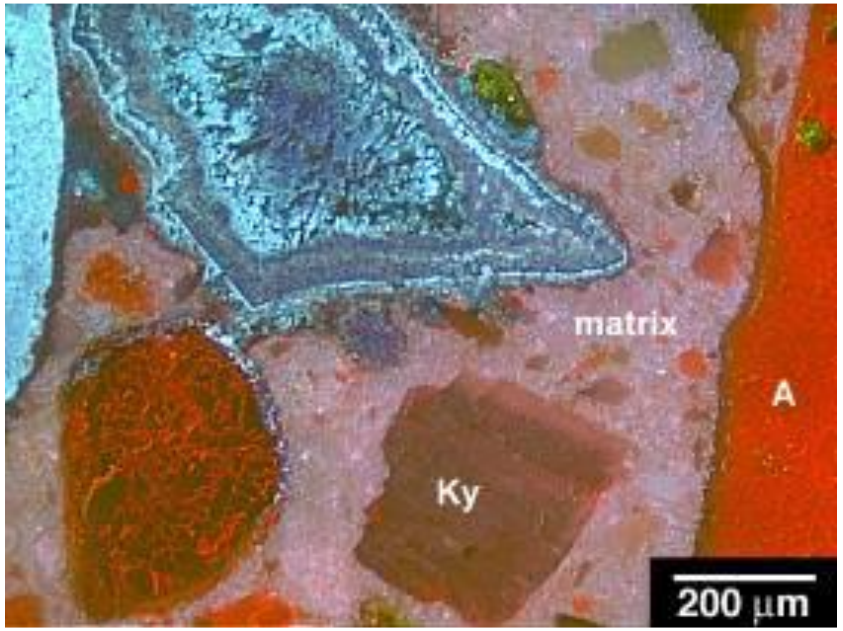
Introduction

SEM showed most of the aggregates were attacked by the molten aluminum

- Kyanite blades appeared to be unaffected

Several other studies have verified that kyanite is more resistant to aluminum attack than other common refractory aggregates

- Bauxite, mullite, and silica



Introduction

Zircon is the primary mineral used in prime coat slurries when investment casting most metals, including stainless, super alloy, aluminum, and copper

- **Very high melting point (2190°C)**
- **Non-reactive with the metal at pour temperatures**

Zircon is great for metals poured at hot temperature, but is this high temperature resistance really needed for lower melting temperature metals?

- **One prime slurry pot is common in most shops**

Purpose of this Study

What we know:

1. Kyanite naturally resists molten aluminum attack
2. Aluminum is cast at much lower temperatures than super alloys
   - High refractoriness of zircon may not be needed
   - Casting temperature is well below the kyanite to mullite conversion temperature
   - Kyanite will not expand at these lower temperatures

What we are trying to answer:

- Can kyanite be used in the prime coat slurry instead of zircon to produce castings of same or similar quality?

Lab Testing-Slurry Recipe

Multiple slurries were created with varying properties to optimize rheology

- **Changes to PSD of flour**
- **Altering % solids, %SiO_2, polymer level, and viscosity**

% Total Solids	% SiO_2	% Polymer	Viscosity (EZ Zahn 5)
80.8	25	8	20 seconds

Lab Testing-Cup Tests

Wax coated paper cups were dipped into kyanite prime slurry

- 1 prime, 6 back up coats, seal coat
- All coats used the same kyanite slurry

Special 70x100 kyanite stucco created for lab testing

Virginia Mullite 20x50 used as the backup stucco

- Stuccos applied via rainfall sander

Cups were made in a similar fashion with a zircon prime slurry

- Zircon prime stucco
- Kyanite slurry backups

Lab Testing-Cup Tests

A356 aluminum was poured at 1450°F

- **Cups were buried in sand to insulate and simulate a longer hold time**
- **Allowed to cool to room temperature**

No distinguishable difference in surface finish between cast metal slugs made with zircon and kyanite prime slurries were observed

Lab Testing-Cup Tests

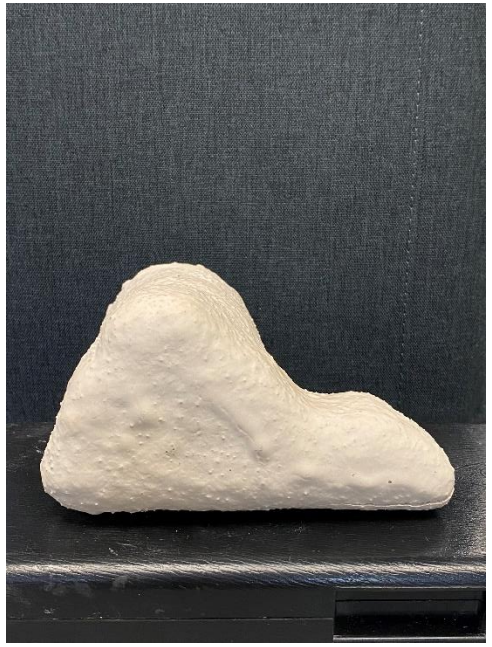
Lab Testing-More Complex Shapes

After initial successes, KMC wanted to test more complex shapes

- Metal molds were used to create wax patterns in the shape of the state of Virginia
- Dipped and cast in a similar manner to the cup tests, with both zircon and kyanite prime slurries
- Dewaxed with a blow torch

Again, no notable surface finish differences were observed

Lab Testing-More Complex Shapes



Lab Testing-More Complex Shapes

KMC next needed to test a shape with corners and internal passages

- Wanted to observe knock-out characteristics

Dipped numerically shaped wax birthday candles

- Dipped and cast in the same manner as the previous lab tests

Difficulties dewaxing

- Flash fired in the mullite calcination kilns at KMC

Again, no differences noticed between parts with kyanite vs zircon prime slurry

Lab Testing-More Complex Shapes

Results of Lab Testing

1. KMC successfully made a slurry utilizing kyanite that had good slurry rheology
2. This slurry was used as the prime coat for several small castings
3. There were no surface finish differences between aluminum castings made with kyanite vs zircon prime slurries

Testing at KMC indicated that kyanite could be used in a prime slurry for aluminum castings

The next step was to perform a foundry trial at O'Fallon Casting (OFC)

Foundry Trial-Batch 1-Slurry

First foundry trial made with the same formula as the lab slurry

- All materials were added, and slurry was mixed for 5 hours

Issues with scale up

- 3 gal slurry in the lab vs 120 gal trial tank
- Difficulty mixing in all the flour - multiple increases to mixing speed were needed
- Burped the slurry several times

Slurry was then pumped to a working tank from the mix tank

- Some material buildup remained on the edges
- Indicated longer mix time was needed

Foundry Trial-Batch 1-Slurry

The slurry properties were tested the following day:

- Viscosity (EZ Zahn 4), specific gravity, plate weight

Slurry control with Zahn cup daily

- Water additions when needed

Evaporated quicker than expected resulting in more frequent water additions than typical OFC prime

- Slurry never gelled and was able to be recovered after getting thick
- The slurry remained stable for 3 months before being thrown out

Shear test before dipping to ensure an even coat

Foundry Trial-Batch 1-Parts for Testing

Several different parts were chosen for testing

- Various alloys
  - A356, A357, C874, and a Metal Matrix Composite (MMC)
- Different part geometries
  - Thin walls, flat faces, and tube passages
- Different temperatures tested
  - Aluminum: Metal=1300°F; Mold=800-1000°F
  - Copper: Metal=1900°F; Mold=1450°F

Foundry Trial-Batch 1-Procedure

Parts were dipped by hand – alumino-silicate stucco applied via rainfall sander

- Standard OFC prime stucco was used

Kyanite slurry only used in prime

- Shells went through the rest of the standard dip sequence (3 intermediate, 3 backup, and dip seal)

Foundry Trial-Batch 1-Casting

Parts went through dewax and burnout without issues such as cracking

A356 and A357 poured with conventional ladle pour

C874 and MMC used counter gravity casting

None of the parts ran into issues during pouring

Foundry Trial-Batch 1-Results

A356 and A357 parts

- No difference in surface finish
- Operators reported no difference during water wash

Foundry Trial-Batch 1-Results

MMC

- Slight issues with metal penetration in tight corners
- Increased time in water wash reported

Foundry Trial-Batch 1-Results

C874

- No issues with water wash
- Sprue stick and some runners showed increased oxidation compared to a similar sprue with OFC prime layer
  - Did not lead to any scrapped parts
  - Surface confirmed via fluorescent penetrant inspection (FPI)

Foundry Trial-Batch 2-Slurry

Goal was to further prove the success of the slurry while making it easier to mix and pump

Slurry properties altered to more closely match OFC's standard prime slurry

- Lower percent solids
- Lower %SiO_2
- Slightly lower viscosity

Biocide added to more closely mimic OFC's standard prime

Foundry Trial-Batch 2-Slurry

2nd batch was smaller than the 1st

- 90 gal vs 120 gal

Significant improvement in mixing observed

- Easier wet-in of the flour
- Lower mixing RPM maintained

Slurry pumped after 5 hours, like the first batch. Did not have pumping issues from 1st trial

Foundry Trial-Batch 2-Parts for Testing

A356 and MMC parts were chosen

- Test different part geometries with A356
- MMC parts: Would they be similar or better in water wash with the new slurry?
- Shell build, dewax, burnout, foundry temperatures all the same as first trial

Foundry Trial-Batch 2-Slurry Issue

Issue with slurry sticking to the wax parts

- Slurry would dip fine by the plow
- Slurry wouldn’t stick on other side of tank
- It appeared the slurry somehow separated or wasn’t mixed properly

Mixed further with a small electric drill; problem resolved

- Problem did not reappear

Let the slurry age 2 weeks while wax parts were being prepared

- With mixing fixed and good shear test results, the parts were dipped like in Batch 1

Foundry Trial-Batch 2-Results

A356

- All parts poured well
- Water wash was the same as first trial (similar to the standard OFC prime)
- Clean cast surface finish

Foundry Trial-Batch 2-Results

MMC

- **Similar results as the first trial**
- **Some metal penetration in tight corners**
- **Slightly longer time required to remove parts of the shell**

Foundry Trial Conclusions

The surface finish and wash ability are comparable to the normal OFC process

Only parts that suffered a slightly longer wash time was the MMC alloy parts

Mixing of the slurry improved significantly after alterations to the recipe for the 2nd batch

- Showed that mixing and rheology issues in the first batch were due to issues with scale up and batch size

After testing parts across multiple alloys and complexities, the Kyanite slurry can be considered a success for aluminum and copper alloys

Acknowledgements

KMC would like to thank O'Fallon Casting for the use of their facility for this test

The presenters of this presentation would like to thank their co-author, Austin Scheer, for his work during both the lab and foundry trial phases

Thank you for your time and attention!

Are there any questions?

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