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Center for Advanced Non-Ferrous Structural Alloys
An Industry/University Cooperative Research Center

Project 38-L: On-Demand Casting of Net-Shape Titanium Components for Improved Weapon System Reliability

Fall 2019 Semi-Annual Meeting
Colorado School of Mines, Golden, CO
October 9 - 11, 2019

Student: TBD (Mines)

Faculty: Steve Midson (Mines)

Industrial Mentors: Paul Brancaleon (NADCA)

NSF

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IOWA STATE UNIVERSITY

Industrial Relevance

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Objective

- Develop die casting of titanium alloys

Benefits

- Expanded supply chain for net-shape titanium components
- Production of lower cost titanium components
- Replace heavier components with lightweight titanium castings





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- Undergraduate student: TBD
- Advisor: S. Midson (Mines)

Project Details
UG August 2018 to July 2023
Funded by DLA

- Problem: The supply chain for low-cost, lightweight net-shape titanium components needs to be expanded.
- Objective: Extend the die casting process for the casting of titanium alloys. Identify a permanent die + coating system for titanium die casting.
- Benefit: Die casting is a low-cost approach for producing components, and so the extension of die casting to Ti-alloys could have a significant impact on the titanium marketplace.

Recent Progress

- Looking at three approaches to fabricate a die that will meet project targets
- Performed an initial trial using graphite inserts
- Identified a supplier that can provide thermally sprayed coatings

Metrics		
Description	**% Complete**	**Status**
1. Identification of titanium alloy with improved castability (if necessary)	5%	●
2. Identification of candidate high temperature resistant die casting die materials & coatings for titanium die casting	22%	●
3. Casting trials to evaluate die materials	5%	●
4. Provide a coated tool for the demonstration of on-demand melting	0%	●

Project Tasks - CSM

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1. Die casting dies
   - Identify high temperature resistant die materials and coatings for titanium die casting
   - Test die concepts in the laboratory
   - Provide a coated tool for the demonstration of on-demand die casting of titanium
2. Alloys
   - Identify a titanium alloy that can be produced by high pressure die casting
     - Fluidity
     - Hot tearing resistance
     - Melting temperature

1. Tooling

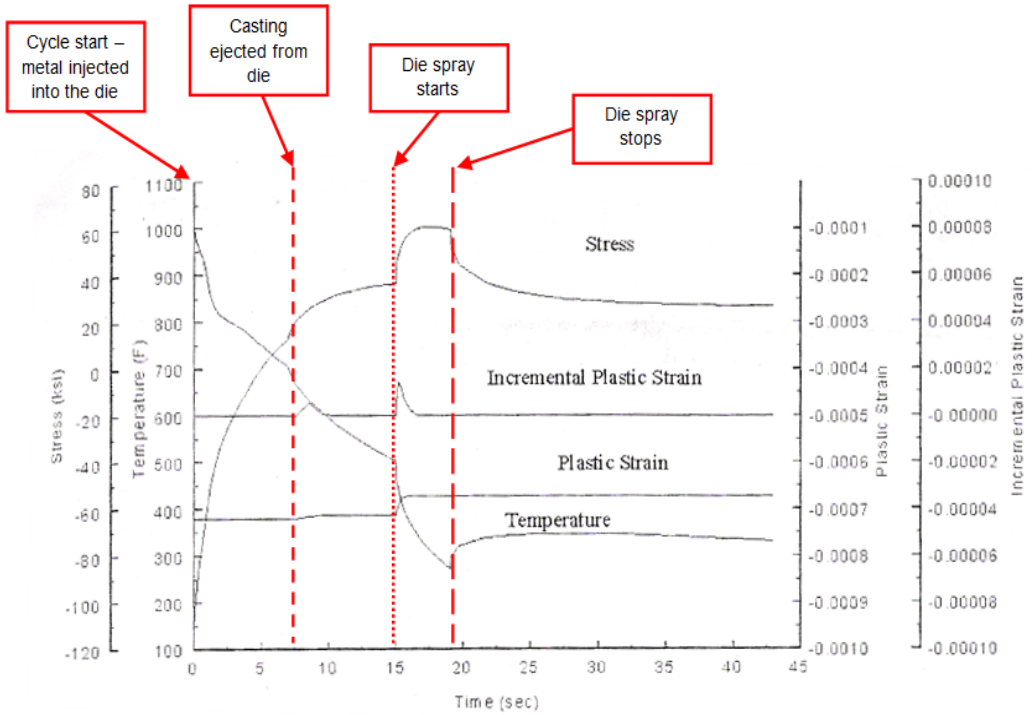
Potential Tooling Issues

- Heat checking
  - Cracking of die surface due to cyclical thermal fatigue
- Gross cracking
  - From high levels of thermal and mechanical stresses
- Oxidation of die
  - Due to high melting temperature of the titanium
- Reaction between liquid titanium and mold material

Heat checking of an H13 steel die

Die Surface Temperature During One Casting Cycle

- Die surface is heated by injection of liquid metal
  - Die surface is in compression
- Die surface cools after casting is ejected and sprayed with lubricant
  - Die surface is in tension
- Need to minimize magnitude of tensile-compressive stresses



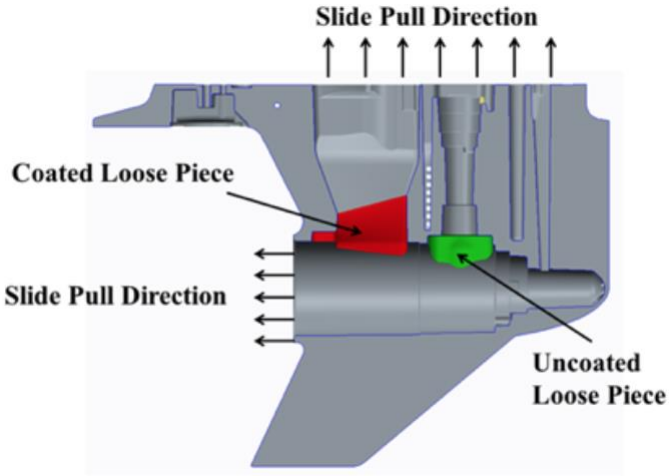
Source: NADCA's book on Extending Die Life

Tooling Concepts

- Examining three approaches
  1. Metallic tool with graphite liners
  2. Metallic tool with ceramic coatings
  3. Refractory metal tools

Graphite Liners

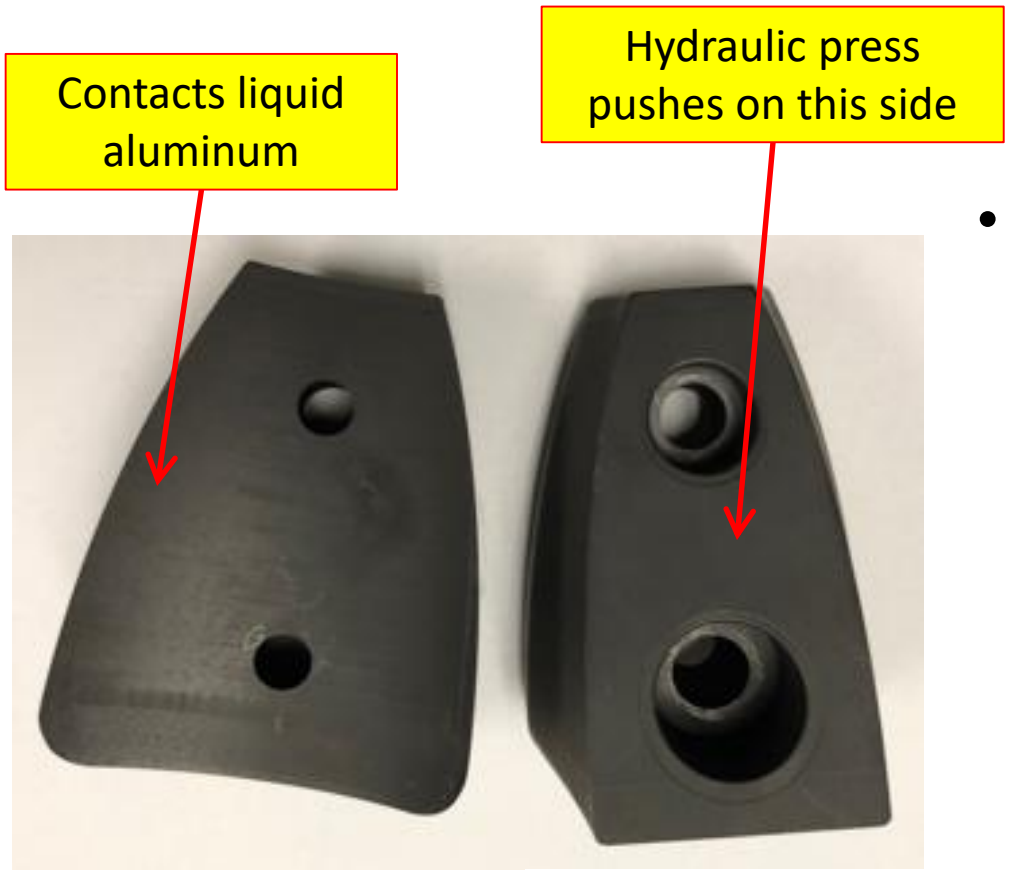
- Would a relatively soft graphite liner survive aggressive die casting process?
  - High injection speeds
    - 25 m/sec
  - High injection pressures
    - 6,000 psi
- Fabricate an insert from graphite
  - For an aluminum die casting die
- Perform a test at Mercury Castings



- Gearcase die casting at Mercury Castings
- Colored die inserts are ejected with casting

- Insert shown in red
- Insert is about 4-inches in size

Graphite Inserts



- Two graphite inserts were machined from IPG24 grade graphite
  - Graphite was purchased from Asbury Carbons
  - Has excellent mechanical properties

Graphite	Compressive Strength (ksi)	Tensile Strength (ksi)
Asbury IPG24	24.1	7.1

Test Summary

- The graphite inserts appeared to survive the contact with the liquid metal
  - Graphite inserts were severely chipped after production of 9 castings
  - But none of the damage observed on the graphite inserts appeared to be caused directly by the liquid aluminum
- Instead, the fracturing originated from factors unique to this operation of this die insert
- This suggests that graphite can indeed be used as a die material for the die casting of aluminum
  - And possibly for the die casting of titanium
- Further testing is planned at Mercury Castings

Thermally Sprayed Coatings

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- Cincinnati Thermal Spray has promised to provide coated samples
  - Viability of coatings will be tested in liquid metal trials
  - Aluminum, copper, steel, titanium

Bond coat	Thickness	Mid Layer	Thickness	Top Coat	Thickness	Sealer
NiCrAlY	100-150 μm (0.004-0.006"	Porous YSZ	250-300 μm (0.010-0.012")	Dense YSZ	Target 50 μm (0.002")	none
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Mo	50-100μm (0.002-0.004")	--	--	100% Yttrium Oxide	Target 50 μm (0.002")	none
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2. Alloys

Alloys

- Ti-6Al-4V is most commonly cast alloy
  - Melting temperature is high
    - ~1650°C
  - Die life is shortened as liquid metal temperature is increased
- Is it possible to use Ti-alloys with lower melting temps?

Alloy	Composition (at%)	T_l (°C)	Phases
01	$Ti_{62}Fe_{30}Mo_8$	1210	β-Ti + TiFe
02	$Ti_{63}Fe_{23}Mo_8Sn_6$	1249	β-Ti + TiFe + Ti_3Sn
03	$Ti_{60}Fe_{23}Mo_8Sn_9$	1225	β-Ti + TiFe + Ti_3Sn
04	$Ti_{64}Fe_{29}Nb_8$	1240	β-Ti + TiFe
05	$Ti_{63}Fe_{23}Nb_8Sn_6$	1230	β-Ti + TiFe + Ti_3Sn
06	$Ti_{60}Fe_{23}Nb_8Sn_9$	1215	β-Ti + TiFe + Ti_3Sn
07	c.p. Ti	1670	α-Ti

Source: M.O.A Rocha et al., Federal University of São Carlos, Brazil

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Questions?

Steve Midson
Phone: 303-868-9766
Email: Smidson@Mines.edu