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

Spring 2019 Semi-Annual Meeting

Iowa State University, Ames IA

April 3-5, 2019

Students: Undergraduate students TBD (Mines)
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Industrial Mentor: Paul Brancaleon (NADCA)

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

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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

- Reviewed published information on die materials for high melting temperature alloys
- Identified a study where refractory metals were successfully used as die materials for steel die casting
- Looking at three approaches to fabricate a die that will meet project targets

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	15%	●
3. Casting trials to evaluate die materials	0%	●
4. Provide a coated tool for the demonstration of on-demand melting	0%	●

Industrial Relevance

Needs

- The supply chain for net-shape titanium components can be expanded by the development of high volume die casting methods

Benefits

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





Project Outline

- **Three Universities**
  - CSM, Purdue, University of Alabama at Birmingham
- **Technology:**
  - Develop an on-demand die casting system for titanium alloys
  - Develop advanced die materials for casting titanium
  - Ensure castability through modifications of titanium alloy composition
  - Optimize metal quality

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

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

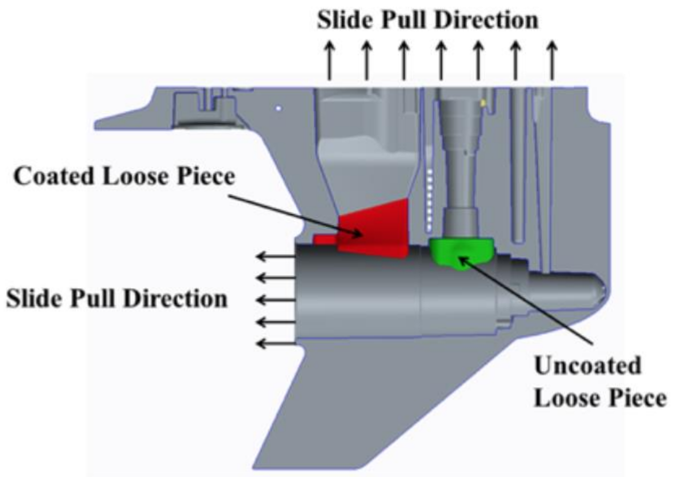
Tooling Concepts

- 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

Grade of Graphite	Compressive Strength (ksi)	Tensile Strength (ksi)
IPG24	24	7



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

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

Metallic Tool with Ceramic Coating

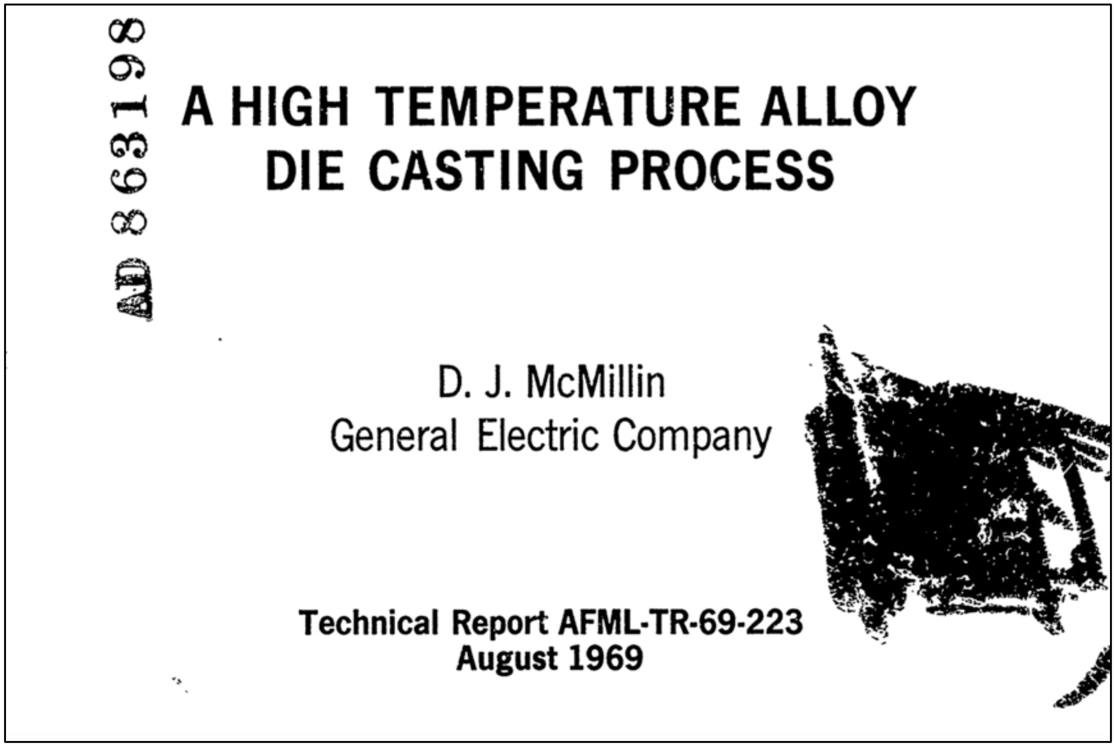
- Metallic tool would support loads from die casting process
  - Ceramic coating would protect the metallic tool from the high temperatures associated with titanium die casting
- Utilize similar ceramics as thermal barrier coatings
  - Partially or fully stabilized zirconia
  - Yttria
  - Coating would need to be fully dense
- Current deposition process of EB-PVD would provide poor adhesion to the metallic substrate
- Alternative deposition processes
  - Sputtering
  - Pulsed laser deposition
  - Thermal spray + post-deposition grinding

Metallic Tool with Ceramic Coating

- What are the potential failure modes?
  - Spalling of coating
  - Thermal shock of coating
- Test by fabricating simple coated tool for evaluation in CSM foundry
- Pour liquid metals into the mold
  - Liquid aluminum
  - Liquid copper
  - Liquid steels
- Evaluate integrity of ceramic coatings after testing

Refractory Metal Dies

- GE examined ferrous die casting in the 1960s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A HIGH TEMPERATURE ALLOY
DIE CASTING PROCESS

D. J. McMillin
General Electric Company

Technical Report AFML-TR-69-223
August 1969

- Produced an extensive 450 page report in 1969
  - 80 pages involves a die material study

GE's Die Life Study

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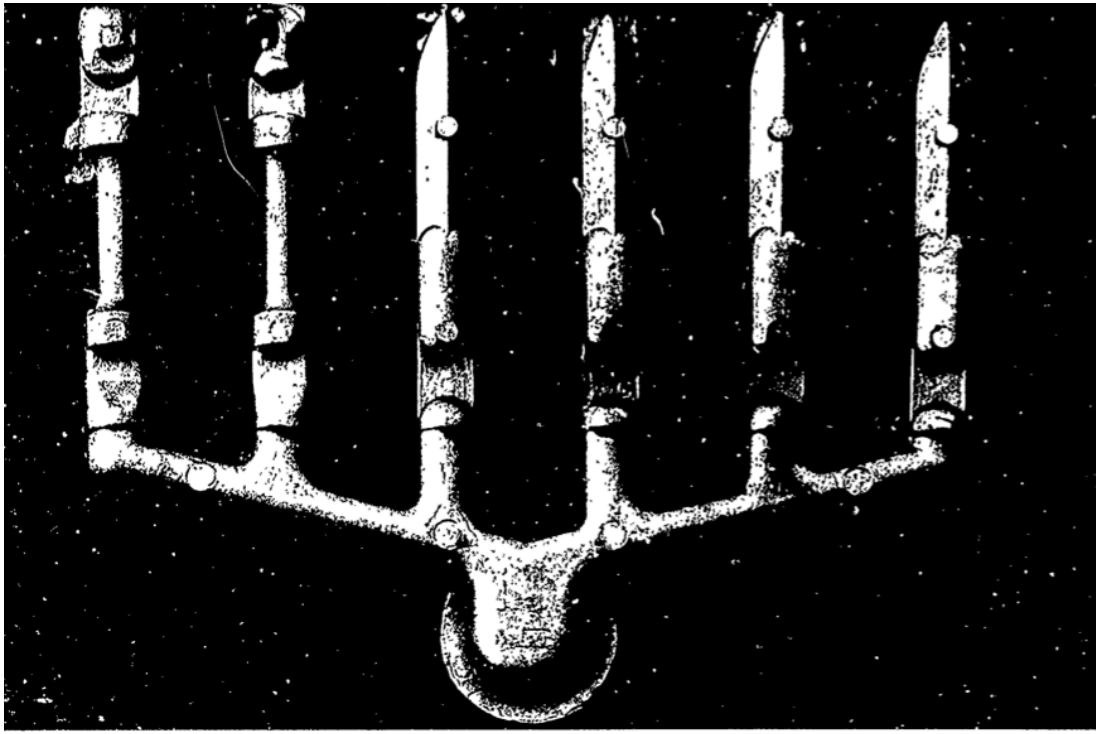

- Used a 6-cavity die
- Examined 23 different die materials
  - Molybdenum based
  - Tungsten based

Summary of Die Life

Material	Number of Cycles Experienced	Condition	Mode of Deterioration
Cu-infiltrated W	2	Failed	Brittle failure (mechanical--not in cavity)
H-13	728	Failed	Plastic deformation (cavity)
Cu-infiltrated Mo (2% Be-Cu)*	2,745	Failed	Heat checking/erosion
Anviloy 1150	2,585	Failed	Heat checking/erosion
Cb-752	4,017	Failed	Gross cracking
GE-474*	7,017	Failed	Erosion/heat checking
P&S W-2% ThO_2+	3,470	Poor	Random brittle failure/erosion
Anviloy 1150	8,992	Failed	Heat checking/erosion
P&S W+	6,055	Fair/Poor	Random brittle failure/erosion
80-20*	8,992	Failed	Random brittle failure/heat checking
Wrought Mo	8,990	Failed	Brittle failure (delamination)
Cb-25% Zr+	8,285	Fair	Heat checking
Hi-density, P&S Mo (insert retainer plates)	8,992	Failed	Gross cracking/plastic deformation
Wrought Mo (insert retainer plates)+	6,055	Good/Fair	Gross cracking/brittle failure (delamination)
Silicided wrought Mo+	6,055	Very good	Plastic deformation (gap formation) brittle failure (delamination)
Wrought Mo+	15,047	Fair/Poor	Brittle failure (delamination)
Hi-density, P&S Mo+	8,285	Very good	Plastic deformation
Hi-density, P&S Mo	15,047	Fair/Poor	Plastic deformation (gaps and dents)/gross cracking
HOT SHOT 2920X*+	14,792	Fair	Heat checking
HOT SHOT 2920X*+ (solution annealed)	14,319	Good	Heat checking
Hi-density, P&S Mo+	15,047	Good	Plastic deformation (dents)
TZM+	15,047	Good	Brittle failure (delamination)
Mo-3*+	15,047	Good	Pitting/heat checking

- 23 different die materials

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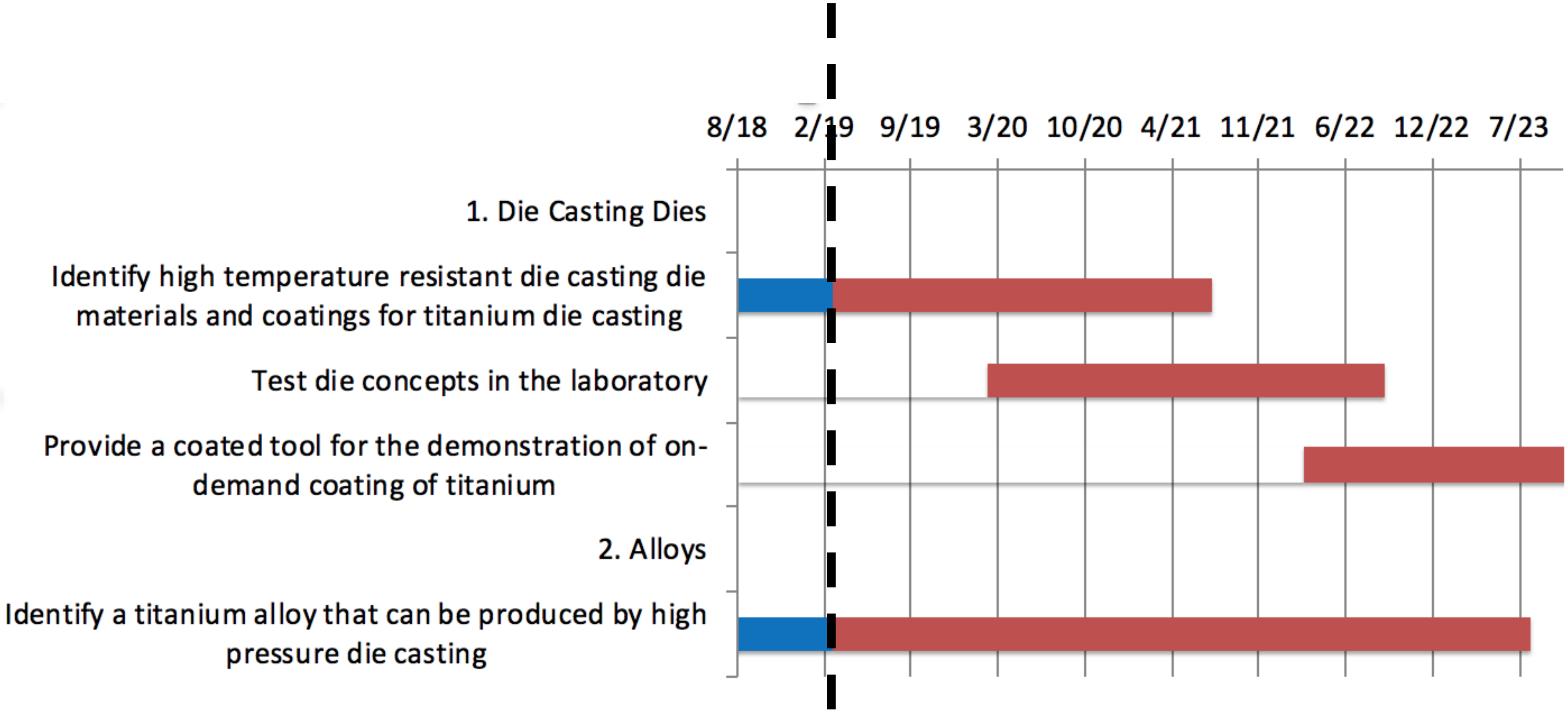
Source: GE Ferrous Die Casting Report, 1969

Future Work - Die Materials for Titanium Die Casting

- Continue to evaluate three approaches
  - Graphite liners
  - Coated metallic tools
  - Refractory metals
- Refractory metal dies
  - Use modeling to evaluate optimum configuration of die and cooling
    - Does conformal cooling extend or reduce die life
  - Cast steel alloys for testing of die materials in foundry at the Colorado School of Mines

Gantt Chart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1. Die Casting Dies
Identify high temperature resistant die casting die materials and coatings for titanium die casting
Test die concepts in the laboratory
Provide a coated tool for the demonstration of on-demand coating of titanium
2. Alloys
Identify a titanium alloy that can be produced by high pressure die casting

Acknowledgement

This research is sponsored by the DLA – Troop Support, Philadelphia, PA and the Defense Logistics Agency Information Operations, J62LB, Research & Development, Ft. Belvoir, VA

Thank you!

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