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

Fall 2018 Semi-Annual Meeting
Colorado School of Mines, Golden, CO
October 2-4, 2018

Student: Undergraduate student TBD (Mines)
Faculty: Steve Midson (Mines)
Industrial Mentors: Paul Brancaleon (NADCA)

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

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Center for ADVANCED NON-FERROUS STRUCTURAL ALLOYS

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

Project Duration
UG August 2018 to July 2023

- 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 the literature on the castability of titanium alloys
- Performed calculations to determine the best approach for the fabrication of a permanent die that can withstand the high temperatures associated with molten titanium alloys.

Metrics

Description	% Complete	Status
1. Review of castability of conventional titanium alloys	5%	●
2. Identification of titanium alloy with improved castability (if necessary)	0%	●
3. Identification of candidate high temperature resistant die casting die materials & coatings for titanium die casting	10%	●
4. Provide a coated tool for the demonstration of on-demand melting	0%	●

Project Outline

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- **Three Universities**
  - CSM, Purdue, University of Alabama at Birmingham
- **Technology:**
  - Improve an on-demand melting system for casting of titanium.
  - 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. Provide an improved titanium alloy composition for die castability and high performance properties
2. Identify candidate high temperature resistant die casting die materials and coatings for titanium casting
3. Provide a coated tool for the demonstration of on-demand casting of titanium

Coated Tool

Melting Temperatures

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Alloy	Melting Temperatures	
	(°C)	(°F)
Aluminum die casting alloys	~600	~1,110
Pure copper	1,083	1,981
Titanium alloys	~1,650	~3,000

- Titanium's melting temperature is significantly higher than either aluminum alloys or pure copper

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Die Surface Temperature

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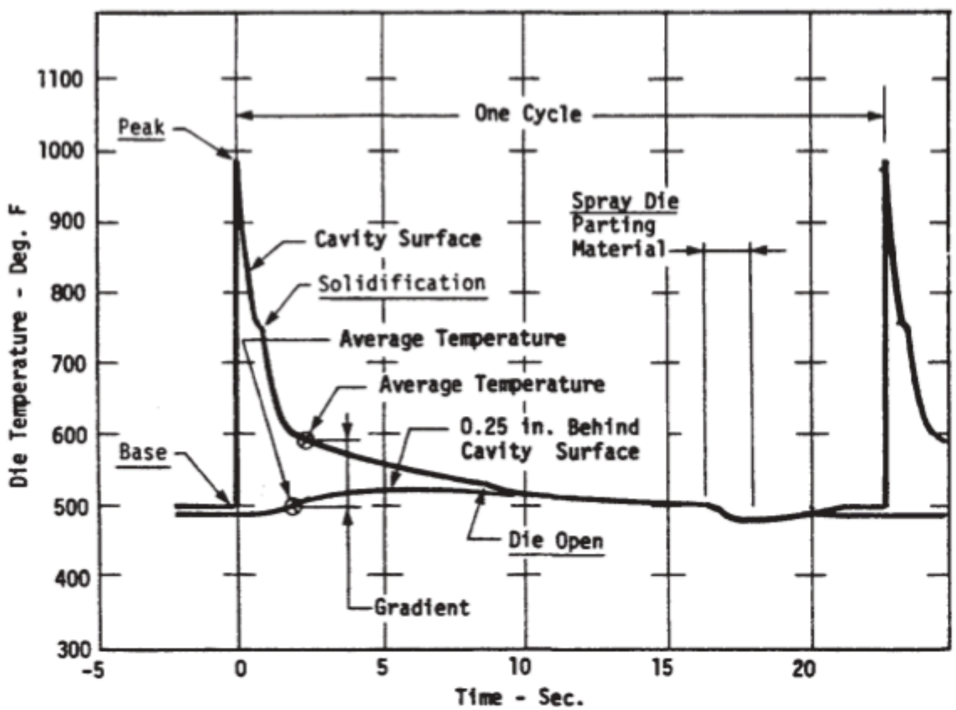

Source: NADCA's *Die Casting Process Control*

- Surface of the die reaches close to the temperature of the liquid metal
- For aluminum die casting
  - Die surface reaches ~ 1000°F (537°C)
- So for die casting pure copper
  - Surface of the die reached ~1850°F (1000°C)
- For die casting titanium
  - Die surface might be expected to reach about 2900°F (1600°C)
  - Higher than the melting temperature of H13 steel which is 2482-2680°F

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Thermal Expansion of the Die Surface

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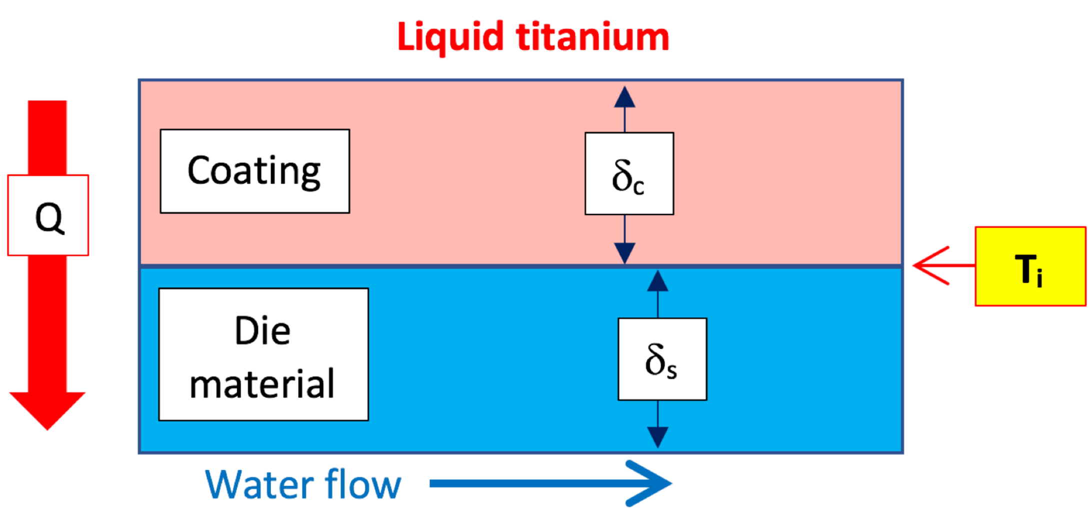
- If the die surface is heated to a very high temperature
  - The thermal expansion of the die surface will be very large
  - Plastic deformation of the die surface will occur on each shot
    - Excessive heat checking will occur very quickly
- So along with conventional H13 steel dies
  - Other coated die concepts will be considered

Die Casting Titanium

- Proposed approach is to use a coating on the surface of the die
  - To protect the die surface from reaction with titanium
  - To reduce the temperature of the die surface



- Calculate the impact of various coatings on the maximum temperature of the die surface
  - Temperature T_i

Impact of Die Coatings on Die Surface Temperature

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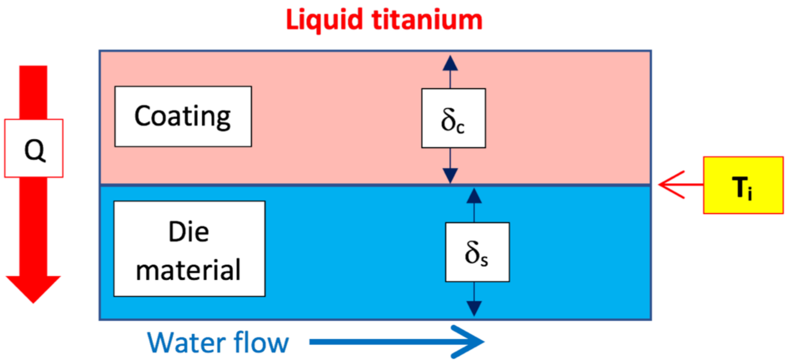

$$k_c \frac{T_M - T_i}{\delta_c} = k_s \frac{T_i - T_w}{\delta_s} \Rightarrow$$

$$\frac{k_c}{\delta_c} T_M + \frac{k_s}{\delta_s} T_w = \left(\frac{k_s}{\delta_s} + \frac{k_c}{\delta_c} \right) T_i$$

- At equilibrium, heat flux through coating and die must be equal

Constant titanium temperature: T_m

Constant water temperature: T_w

Coating thickness: δ_c

Thickness of die material (distance to water line): δ_s

Thermal conductivity of coating: k_c

Thermal conductivity of die material: k_s

- Examine the impact of different coatings and die materials on T_i

Calculated Die Temperatures - Graphite Liner

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- Machine a thick (12 mm) graphite liner for the die
  - Rammed graphite molds are commonly used for casting of titanium alloys

Sleeve		Die Material		Temperature at Interface	
Material	**Thickness**	**Material**	**Thickness**	**Deg-C**	**Deg-F**
Graphite	12 mm	H13 steel	12 mm	845	1553
Graphite	12 mm	Anviloy	12 mm	459	858
Graphite	12 mm	Cu-Be	12 mm	337	639

- Will a graphite liner survive the die casting process?

Calculated Die Temperatures - Yttria Coating

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- Thin (1.5 mm) surface layer of yttria (Y_2O_3)
  - Yttria is a coating commonly used for investment casting of titanium alloys

Coating		Die Material		Temperature at Interface	
Material	**Thickness**	**Material**	**Thickness**	**Deg-C**	**Deg-F**
Yttria	1.5 mm	H13 steel	12 mm	1045	1913
Yttria	1.5 mm	Anviloy	12 mm	632	1170
Yttria	1.5 mm	Cu-Be	12 mm	447	837

- Will a thin layer of yttria survive the die casting process?

Summary – Coated Tool

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- If we utilize this approach, several questions need to be answered
  - Will this approach of coating + die material work for the die casting of titanium?
  - How would the coatings be fabricated?
    - Graphite lining would be fabricated by CNC machining
    - Yttria coating would have to be applied to the die face
  - Can the graphite liner or yttria coating survive the die casting process?
    - For this project, target die life is 1,000 shots

Future Work

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- Further evaluate the application of coated dies
  - Optimize coating/liner thickness based on thermal expansion
    - i.e., what coating thickness generates the same expansion for the coating/liner and for the die?
  - How can a yttria coating be applied?
    - Examine coatings used on turbine blades for airplane engines
- Explore previous work
  - What die materials were used for previous attempts to die cast titanium
    - Talk with people involved with these projects

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Student: *TBD (Undergraduate)*

Faculty: *Stephen Midson (Mines)*

Industrial Partners: *NADCA*

Project Duration: *August 2018 – July 2023*

Achievement

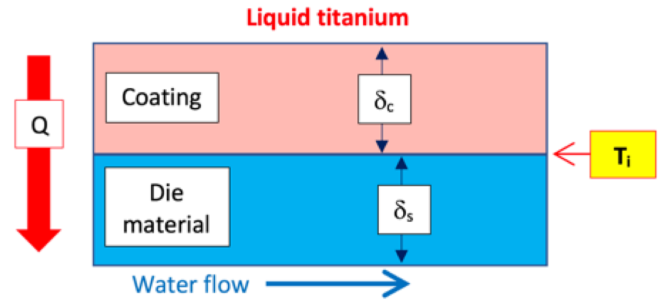
- Starting to examine the best approach for fabricating a die casting die that will withstand molten titanium temperatures.

Significance and Impact

- Die casting is a low cost manufacturing process, and so the extension of die casting to titanium alloys could have a significant impact on the titanium marketplace.

Research Details

- Part of a three-university project to evaluate the feasibility of titanium die casting.



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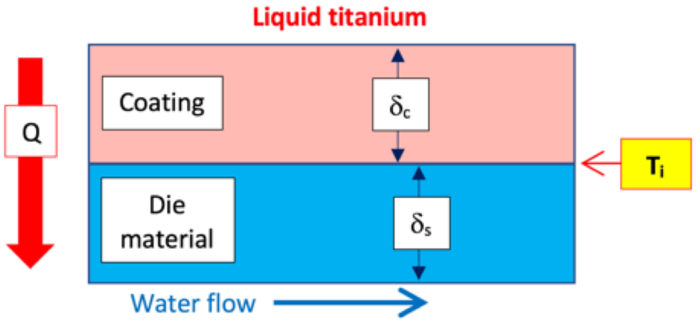

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Industrial Partners:

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Program Goal

- Extend the die casting process to high melting temperature metals such as titanium alloys.

Approach

- Develop an approach for fabricating die casting dies that will withstand temperatures associated with molten titanium alloys.

Benefits

- Die casting is a very low cost manufacturing process, and so the extension of die casting to titanium alloys could have a significant impact on the titanium marketplace.