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Center for ADVANCED NON-FERROUS STRUCTURAL ALLOYS

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

Project 37-L: Advanced Engineered Coatings with Extended Die Life for Tooling

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

Student: Nelson Delfino de Campos Neto (Mines)

Faculty: Steve Midson, Andy Korenyi-Both, Michael Kaufman (Mines)

Industrial Mentors: Paul Brancaleon (NADCA)

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Project 37-L: Advanced Engineered Coatings with Extended Die Life for Tooling

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Center for ADVANCED NON-FERROUS STRUCTURAL ALLOYS

- Student: Nelson Delfino de Campos Neto (Mines)
- Advisor(s): S. Midson; A. Korenyi-Both, M. Kaufman (Mines)

Project Duration
PhD: August 2018 to July 2023

- Problem: Molten aluminum tends to solder to die faces in die casting process and is used a large amount of lubricant in the attempt to reduce the adhesion but reduces the parts quality.
- Objective: Identify PVD coatings to be applied to die casting dies to avoid the molten aluminum soldering and understand the adhesion mechanisms involved.
- Benefit: Increase die casting parts quality, eliminate the use of lubricants, extend the dies life and reduce cost-per-parts.

Recent Progress

- Bo Wang, "An Investigation of the Adhesion Behavior of Aluminum on Various PVD Coatings Applied to H13 Tool Steel to Minimize or Eliminate Lubrication During High Pressure Die Casting", PhD thesis, CSM, 2016.
- Literature review to: (1) Develop an improved adhesion test; (2) Identify the mechanisms involved in the adhesion behavior; (3) Identify the best PVD coatings and coating architectures.

Metrics		
Description	**% Complete**	**Status**
1. Literature review and development of an improved adhesion test that simulates the die casting process by incorporating a mechanism to pressurize/quick fill the liquid aluminum against the coating.	10%	●
2. Identification of the mechanisms that rules the adhesion behavior.	5%	●
3. Identification of a working layer coating that is free of molten aluminum adhesion by laboratory tests	0%	●
4. Development of a coating architecture (single or multi-layer) that will add sufficient durability to the die coatings to allow them to survive for as long as the die casting die itself (≥100,000 shots)	0%	●
5. Guidelines for depositing the coating system on die components/die tooling and in-plant trials.	0%	●

Introduction / Problem

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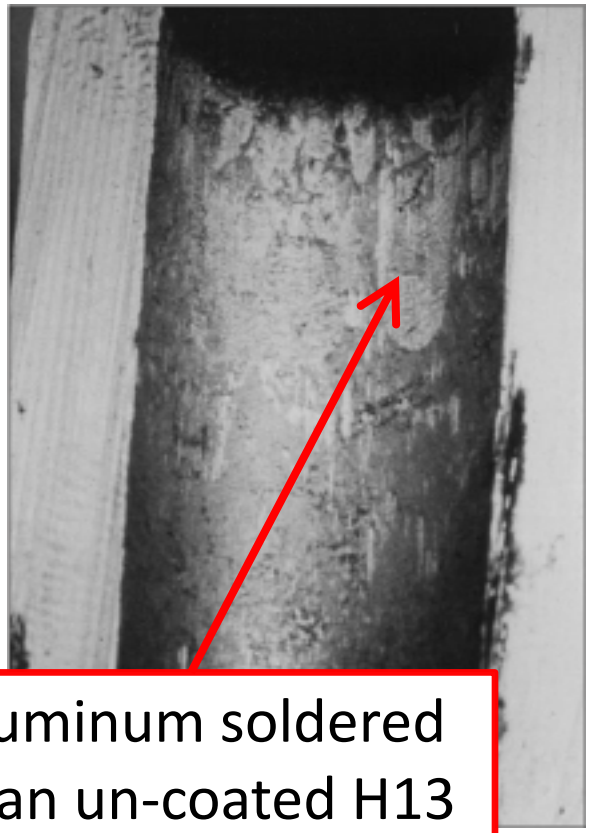

Aluminum soldered to an un-coated H13 steel core pin

Introduction / Problem

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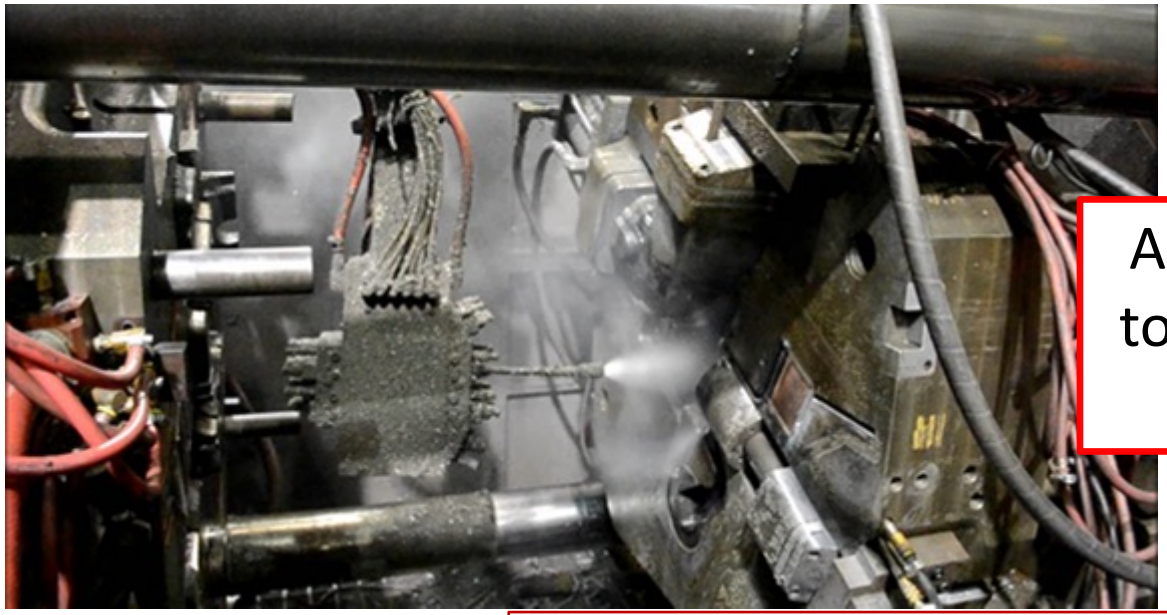
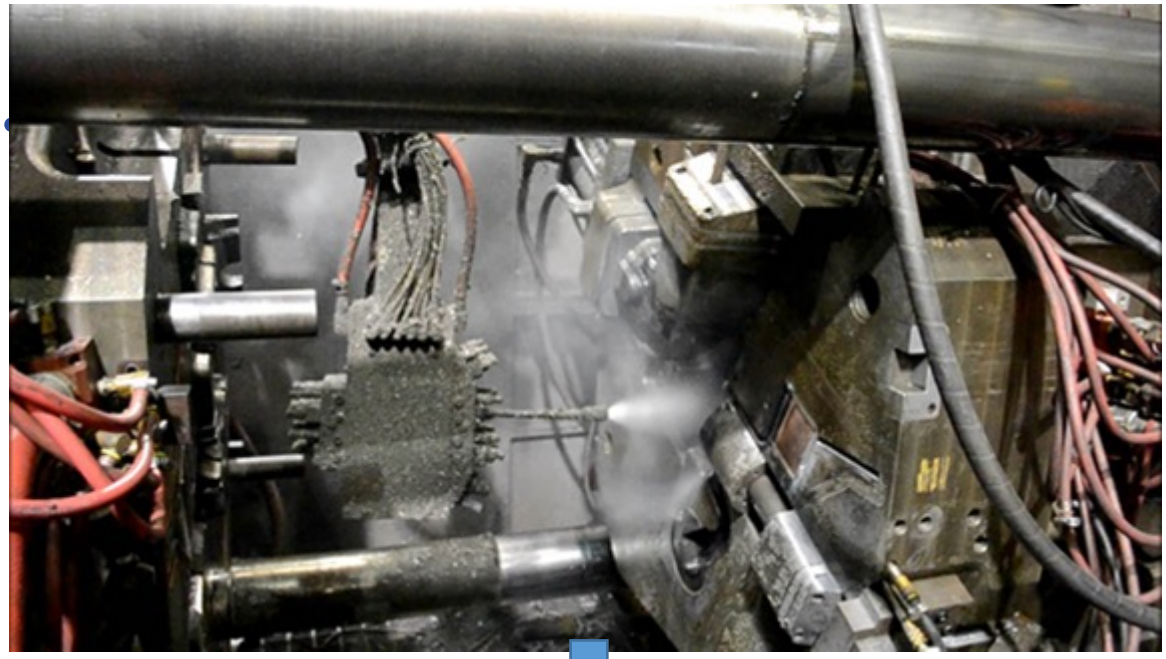
- Lubricants are used in die casting to prevent liquid metal from sticking to the die
  - Increases costs
  - Reduces quality of castings
  - Causes environmental issues



Aluminum soldered to an un-coated H13 steel core pin

Source: B. Wang, Ph.D. thesis, Colorado School of Mines, 2016.

Introduction / Problem



Aluminum soldered to an un-coated H13 steel core pin

- Permanent Physical Vapor Deposition (PVD) coatings
  - Can prevent aluminum die castings from soldering to die
  - Reduce or eliminate the amount of organic lubricants used

Source: B. Wang, Ph.D. thesis, Colorado School of Mines, 2016.

Industrial Relevance

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- Reducing or eliminating lubricant spray will:
  - Significantly **improve the quality** of the die castings
    - Reduce gas porosity and scrap
    - Used in higher performance applications
  - **Reduce costs**
    - Eliminate purchase costs for lubricants
    - Reduce effluent clean-up costs
    - Significantly extend die life
  - **Improve productivity**
    - Faster cycle rates

Justification

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- Factors that prevent the die castings from sticking to the coatings
  - Still not fully understood
  - Optimum coating compositions
    - Not yet been identified
- Die coating architectures need to be identified
  - Allow the coatings to last as long as the dies
  - ~100,000 shots

Objectives

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1. Develop die coatings that are truly non-wetted by molten aluminum

2. Improve the die coatings so they can survive as long as the life of the die

3. Understand the mechanism that controls the adhesion of molten aluminum to dies/coatings

Project Tasks

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1. Develop improved adhesion test
2. Define mechanism controlling wetting and adhesion of molten aluminum to coating
3. Develop a coating architecture to provide long life
4. Conduct in-plant trials
5. Create guidelines for depositing the coating on tooling

Task 1:
Improved Adhesion Test

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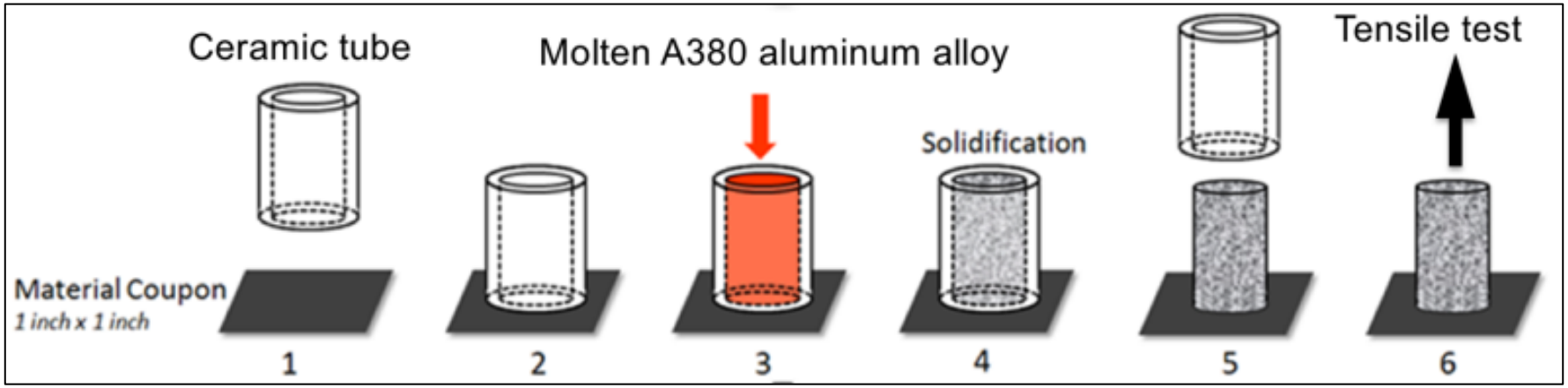
- Previous project developed a laboratory test
  - To measure adhesion of aluminum to coating



- Develop an improved test
  - Pressurize/fast fill the molten aluminum against the coated substrate

Source: B. Wang, Ph.D. thesis, Colorado School of Mines, 2016

Task 2:
Define Adhesion Mechanism

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- Evaluate the technical literature on related subjects:
  - PVD coatings used in die casting
  - Chemical interactions between liquid metals and ceramics
  - Wetting of ceramics by liquid metals
  - Brazing
    - Chemical interactions between liquid filler metal and solid work piece

Task 2:
Define Adhesion Mechanism

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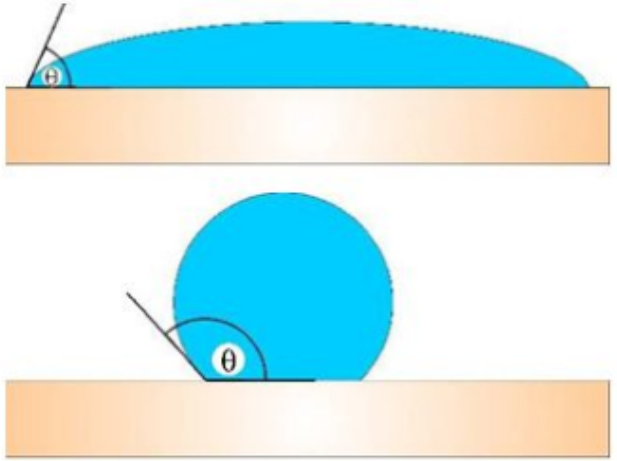
- Relevant paper by Eustathopoulos:
- Wetting of a non-reactive liquid on a flat, smooth and chemically homogeneous solid surface
  - Quantified by the value of Young's contact angle θ_Y

- Wetting (θ_Y <90°)



- Non-wetting (θ_Y >90°)

Source: Eustathopoulos, Metals 5, 2015, 350-370

Task 2:
Define Adhesion Mechanism

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- Wetting Characteristics:
- Liquid metals wet ceramics such as carbides, nitrides and borides of transition metals
  - These are the types of ceramic coatings currently used for die casting dies
- Solids that are not wetted by *non-reactive* liquid metals include
  - Different forms of carbon
  - Ionocovalent oxides
  - Predominantly covalent ceramics with a high band gap like BN

Source: Eustathopoulos, Metals 5, 2015, 350-370

Task 2:
Define Adhesion Mechanism

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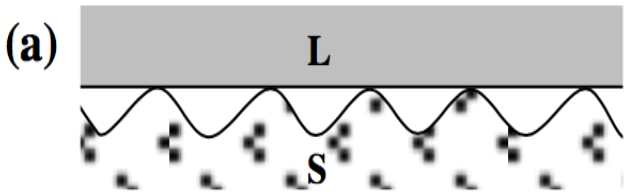
- The impact of roughness on wetting:
- When $\theta_Y >> 90°$
  - Wetting on high-roughness solids leads to the formation of "composite interfaces"
  - Partly solid–liquid and partly solid–vapor
    - Stress during cooling leads to detachment of the solidified metal from the substrate by a purely adhesive rupture



Non-wetting
$\theta_Y >> 90°$

Wetting
$\theta_Y < 90°$

Source: Eustathopoulos, Metals 5, 2015, 350-370

Task 2: Define Adhesion Mechanism

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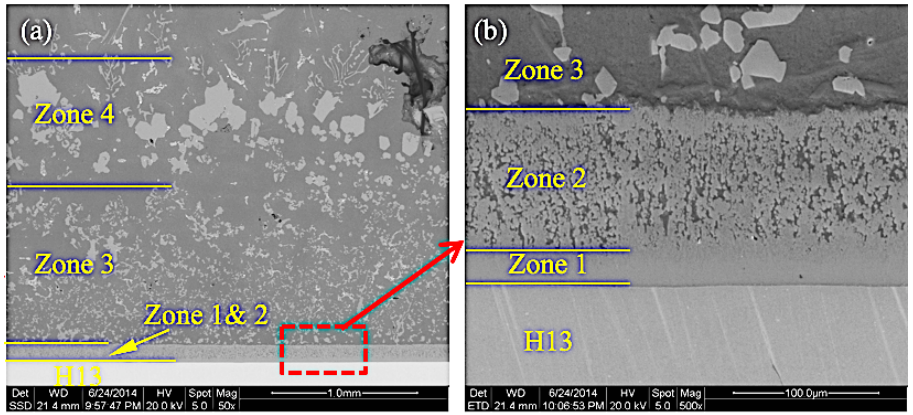
- Reactive Wetting:
- Wetting in metal/metal and metal/ceramic
  - Often accompanied by reactions at the solid–liquid interface
- For many liquid metal–solid systems
  - Formation of a new compound is preceded by the dissolution of the solid in the liquid



- Behavior exhibited between liquid aluminum and un-coated H13 die steel:
- Zone 1: Dense Al-Fe-Si intermetallic layer
- Zone 2: Columnar grains of Al-Fe-Si intermetallic + A380 alloy
- Zone 3: Contains small, dispersed Al-Fe-Si particles
- Zone 4: Smaller number of larger Al-Fe-Si particles

Source: Eustathopoulos, Metals 5, 2015, 350-370

Source: B. Wang, Ph.D. thesis, Colorado School of Mines, 2016

Future Work

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- Literature review
- Development of an improved adhesion test
- Initial testing

Progress (Gantt chart)

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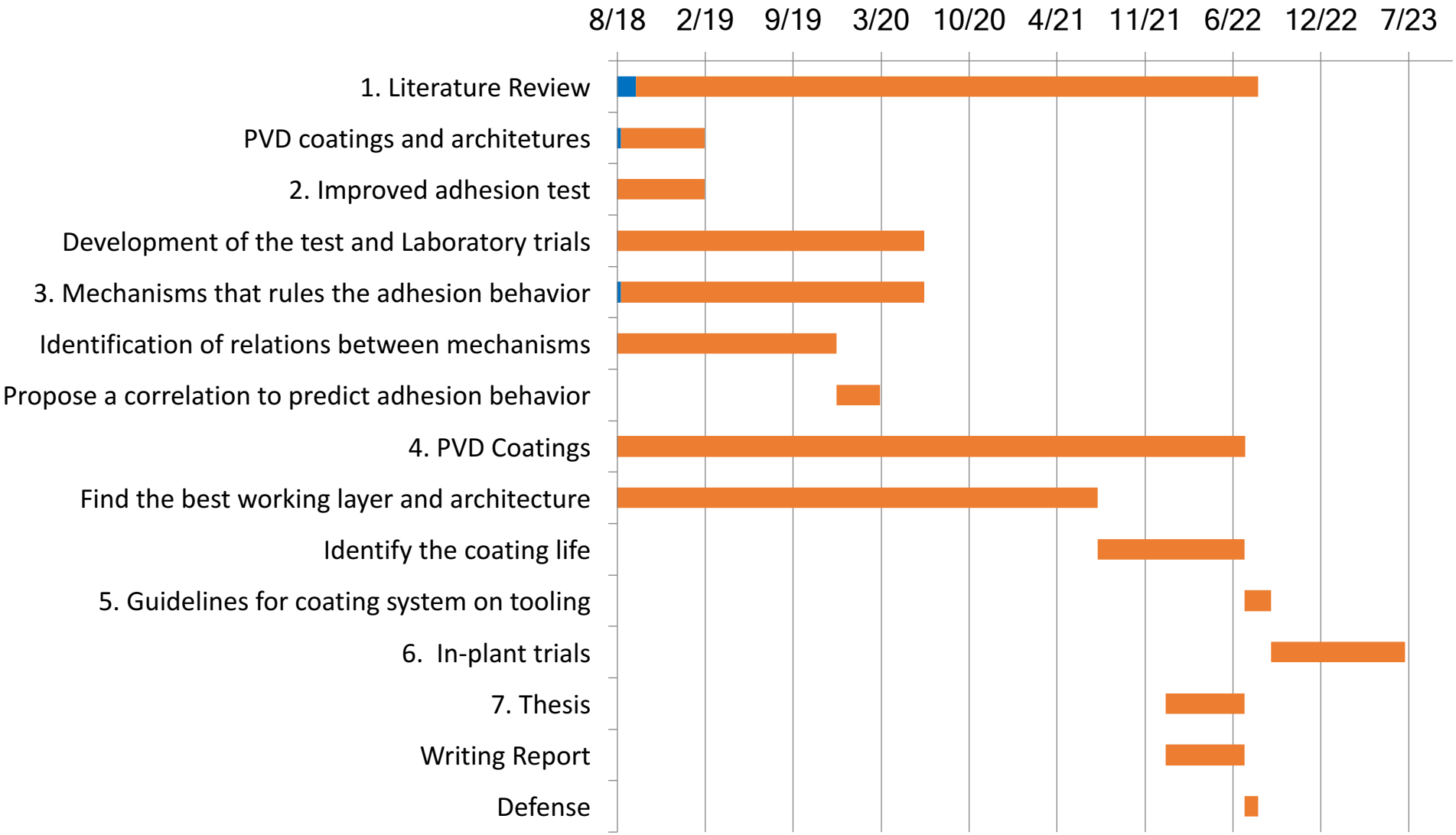

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Thank you very much!

Nelson Delfino de Campos Neto

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Student: *Nelson Delfino de Campos Neto*

Faculty: *Steve Midson; Michael Kaufman*

Industrial Partners: *Paul Bracaleon (NADCA)*

Project Duration: *Aug. 2018 – July 2023*

Achievement

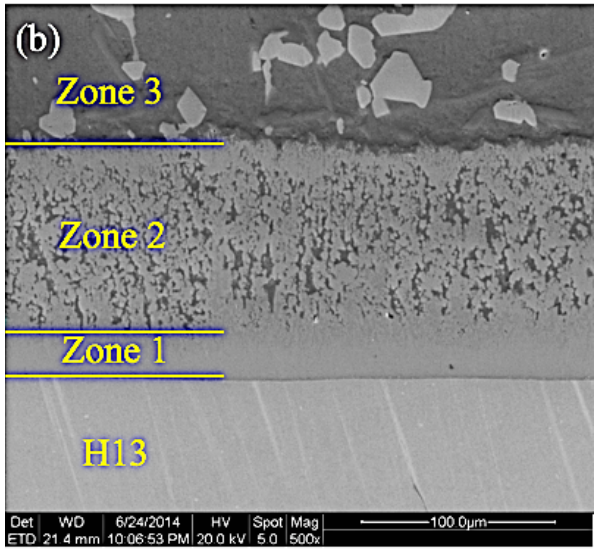
- Identify PVD coatings to be applied to die casting dies to avoid the molten aluminum soldering and understand the adhesion mechanisms involved.

Significance and Impact

- Increase die casting parts quality, eliminate the use of lubricants, extend the dies life and reduce cost-per-parts.

Research Details

- Development of an advanced laboratory test to simulate the aluminum die cast process in order to find the best PVD coatings and understand the adhesion mechanisms involved.



- Liquid aluminum/un-coated H13 steel:
- Zone 1: Dense Al-Fe-Si intermetallic layer
- Zone 2: Columnar grains of Al-Fe-Si intermetallic + A380 alloy
- Zone 3: Contains small, dispersed Al-Fe-Si particles

Source: B. Wang, Ph.D. thesis, Colorado School of Mines, 2016.

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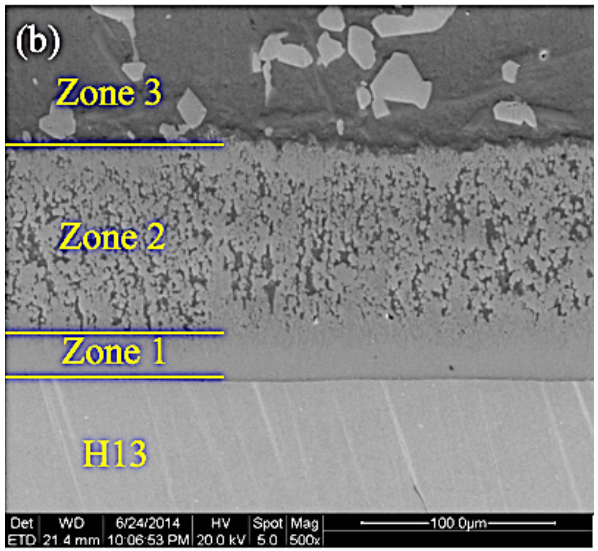

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Project Duration: *Aug. 2018 – July 2023*

Program Goal

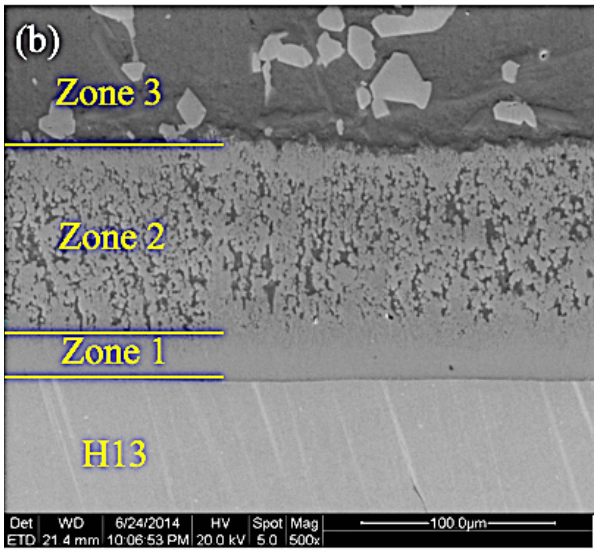
- Identify PVD coatings to be applied to die casting dies to avoid the molten aluminum soldering and understand the adhesion mechanisms involved.

Approach

- Develop an advanced laboratory test to simulate the aluminum die cast process in order to find the best PVD coatings and understand the adhesion mechanisms involved.

Benefits

- Increase die casting parts quality, eliminate the use of lubricants, extend the dies life and reduce cost-per-parts.



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