

# Hot Tearing in Aluminum Cast Alloys: Measures and Effect of Process Variables

## Research Team:

Shimin Li

Diran Apelian

## Introduction

Hot tearing is a common and severe defect encountered in castings. It is affected by alloy composition as well as processing conditions and variables. Hot tearing is a complex phenomenon in that it lies at the intersection of heat flow, fluid flow and mass flow. Over the years many theories and models have been proposed and accordingly many tests have been developed. Unfortunately many of the tests that have been proposed are qualitative in nature; meanwhile, many of the prediction models are not completely satisfactory as they lack quantitative data. The need exists for a reliable, robust and repeatable quantitative test to evaluate/characterize hot tearing in Al cast alloys.

## Objectives

This project is focused on the study of hot tearing in cast aluminum alloys. The objectives were to:

- Develop a reliable experimental methodology/ apparatus to quantitatively measure and characterize hot tearing.
- Quantify the mechanistic contributions of process variables; investigate the effects of the variables on hot tearing tendency.

## Methodology

In order to achieve the above objectives, the following methodology and strategies were pursued:

- An extensive literature review was carried out; established the mechanisms and identified major factors that control the formation of hot tears.
- **Phase I** – Developed a reliable experimental methodology/apparatus to quantitatively characterize hot tearing tendency of aluminum alloys.

Conducted hot tearing tests using available modern measurement apparatuses/ techniques to evaluate their reliability.

- Select model alloys
  - Hot tearing measurement using N-Tec mold on model alloys: 206, 319, A356, 390, 518 and 713 (qualitative)
  - Constrained rod mold measurement on 206 and A356 (quantitative)
- **Phase II** – Investigated the effects of process variables on hot tearing.
 

Performed systematic experiments with the H13 constrained rod mold to fully characterize the effect of various variables on the formation of hot tears in A356 and 206.

  - Effect of mold temperature on A356;
  - Effect of mold temperature on 206;
  - Effect of pouring temperature on 206;
  - Effect of grain refinement on 206.
- **Phase III** – Simulation of Hot Tearing
  - Computer simulation on filling and solidification processes;
  - Simulation on strain and hot tearing.

## Outcomes / Deliverables

- An extensive literature review on hot tearing has been carried out. The critical issues and areas for improvement in the hot tearing field are discussed.

### Publication:

*S. Li and D. Apelian, Hot Tearing of Aluminum Alloys – A Critical Literature Review, to be submitted (International Journal of Metalcasting)*

- In **Phase I**,

CANMET and WPI- both members of the Light Metal Alliance joined forces to address the need for a reliable quantitative test. A reliable quantitative hot tearing test was developed (Figure 1). The following are the accomplishments.

- Constrained rod mold with load cell/LVDT was developed and used to characterize and quantify the contraction behavior of cast aluminum alloys during solidification. The mold temperature is controlled precisely with heater plates. Different castings dimensions can be obtained by replacing the inserts. The test piece has two arms. One test arm is constrained at one end with threads to keep the bar from contraction; this causes tension to be developed and hence cracking is induced during solidification. The other arm is for temperature and load/displacement measurement with one end connected to a load cell or linear variable differential transformer (LVDT). The casting rod

was designed with a slight taper to reduce friction between the mold and casting.

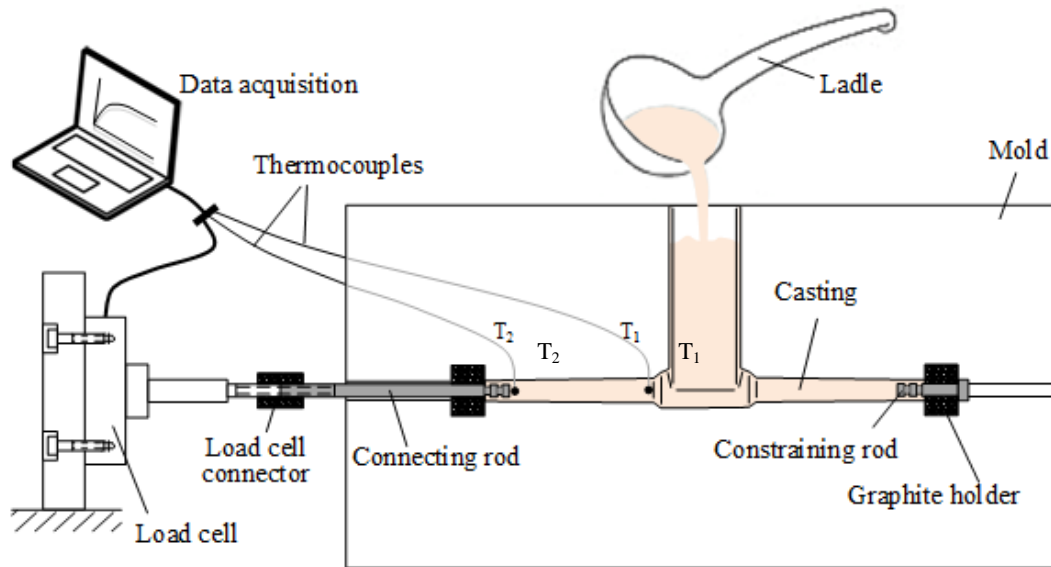


Figure 1: Diagram of Experiment Set-up

- Onset of hot tearing can be determined from load curve, its first derivative and cooling curve. (Figure 2 and Table 1). The amount of shrinkage/contraction can be quantitatively measured. The correlation between the extent of hot tearing and the disruption of the tension load measured during solidification is consistent with the hot tearing susceptibility evaluated by the fully restrained test rod. Test results are reliable and repeatable.
- The test is a discriminating one, and shows the different behavior of different alloys. The measurement results are reliable and repeatable.

Table 1: Contraction force (load) measurement data

Alloy	Onset Temp. (°C) / $f_s$	Maximum loading rate (N/s)	Load and temp. @ maximum loading rate (N) / (°C)	Cracking initiation temp. (°C) / $f_s$	Major crack temp. (°C) / $f_s$	Load @ $T_{nes}$ (N)
A356	561/0.89	51	125/531	No crack	No crack	578
M206	618/0.72	36	26.5/561	561/0.887	544/0.90	360

$f_s$ : fraction of solid,  $T_{nes}$ : non-equilibrium solidus

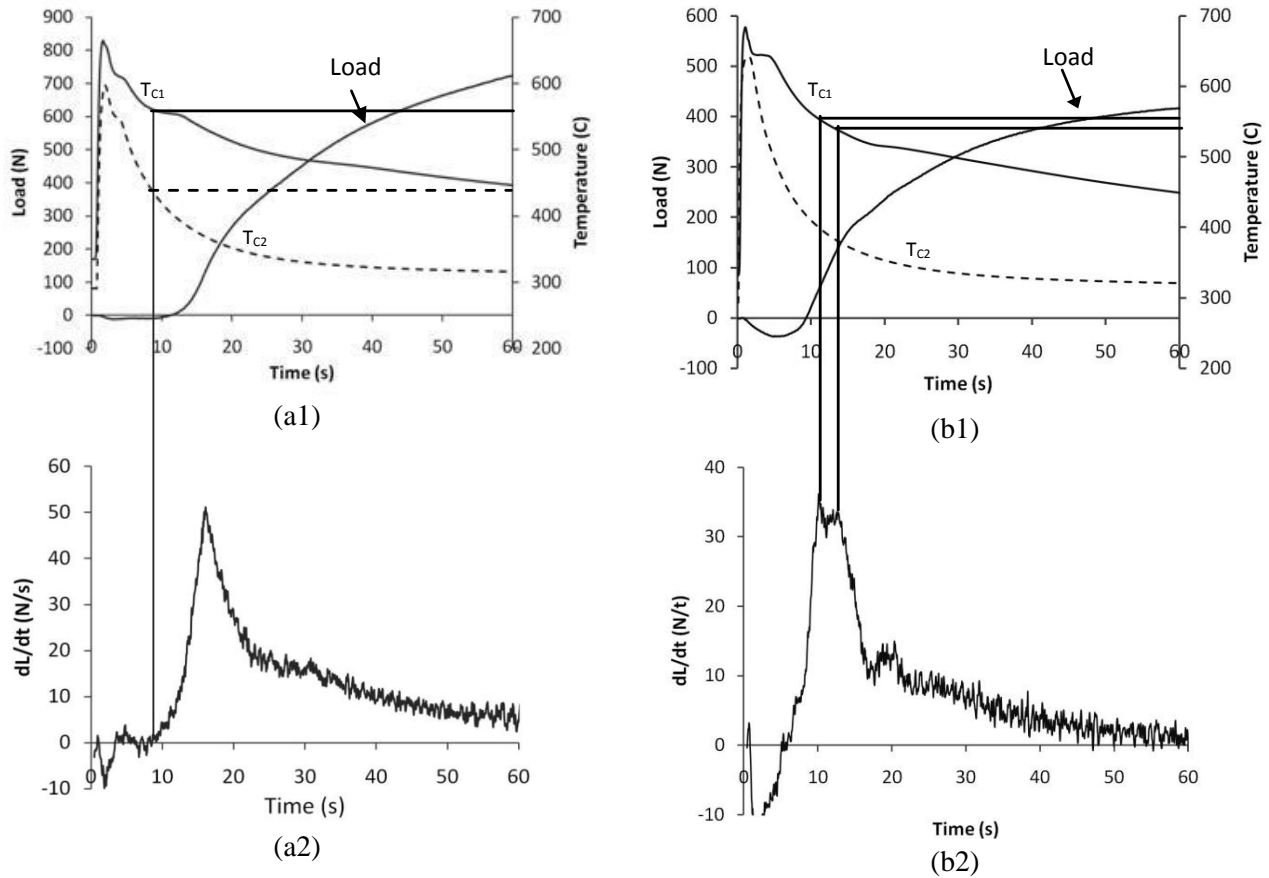


Figure 2: (a1) Temperatures and load development as a function of time of A356,  $T_{C1}$  and  $T_{C2}$  are thermocouples located at centerline of the rod defined in Figure 1; (a2) Derivative of load vs. time curves of A356; (b1) Temperatures and load development as a function of time of 206; (b2) Derivative of load vs. time curves of 206.

### Publications:

*S. Li, D. Apelian, K. Sadayappan. Quantitative Investigation of Hot Tearing of Al-Cu Alloy (206) Cast in a Constrained Bar Permanent Mold, Materials Science Forum, Vols. 618-619 (2009): 57-62*

*S. Li, K. Sadayappan and D. Apelian, Characterization of Hot Tearing in Al Cast Alloys: Methodology and Procedures, submitted to Cast Metals Research.*

- In **Phase II**, systematic investigation of the process variables on hot tearing was completed.

- Mold temperature has a significant effect on hot tearing. Elevated mold temperature (low cooling rate) reduced hot tearing tendency in 206 significantly by promoting uniform casting contraction and therefore alleviating stress concentration (Figure 3).
- Hot tearing was not significantly affected by varying pouring temperature in 206 in this test within the temperature range between 700-750C (50-150C superheat) - Figure 3.
- Grain size and grain morphology are important to reduce hot tearing susceptibility in alloy 206. It was found that a fine globular structure is necessary to prevent the formation of hot tearing during solidification of alloy 206 (Figure 4).

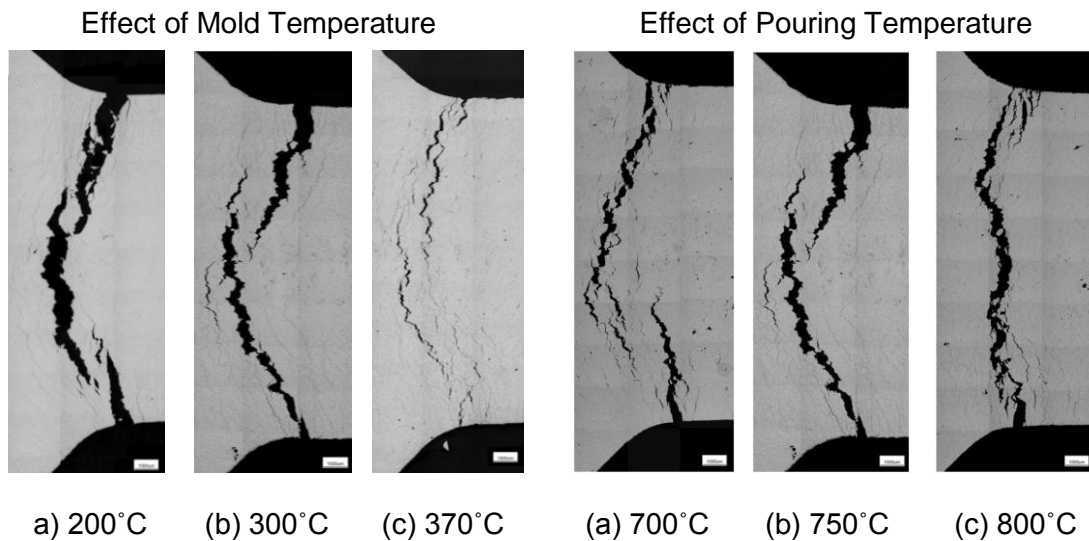


Figure 3: Effect of Process Parameters

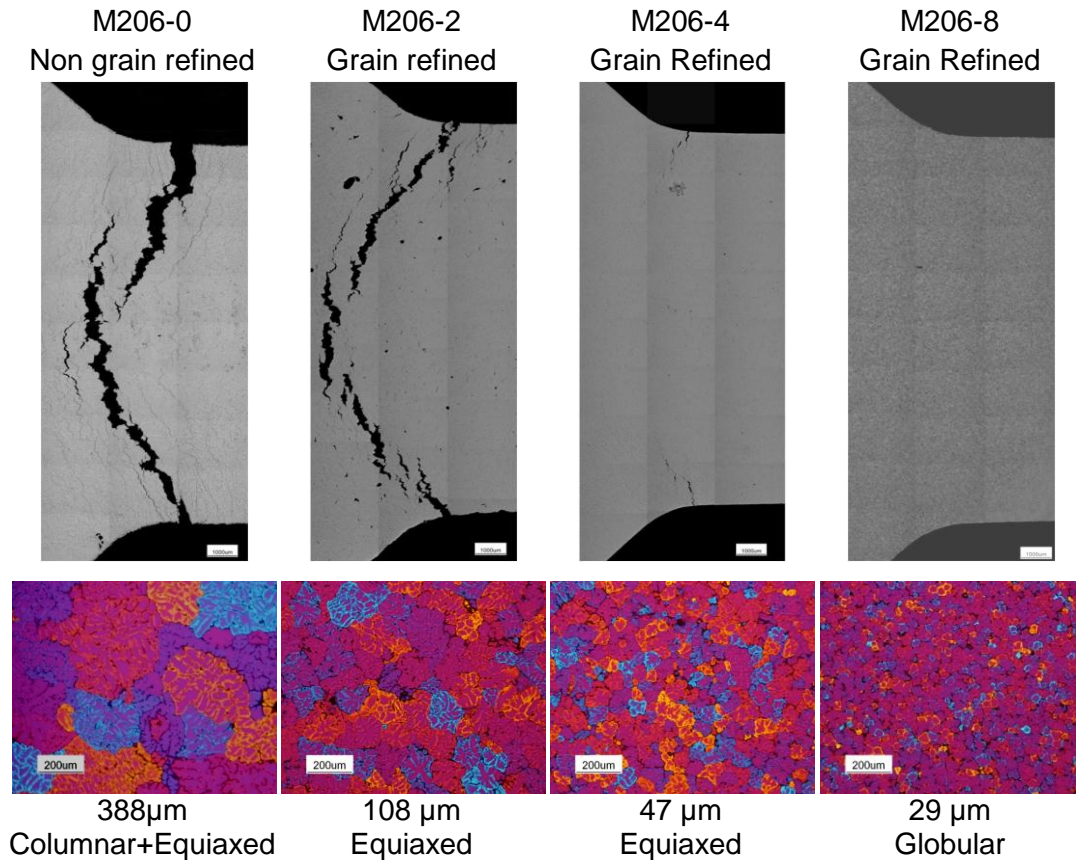


Figure 4: Effect of Grain Refinement

### Publications:

*S. Li, K. Sadayappan and D. Apelian, Why Some Al Alloys Hot Tear and others do not? – Part I: Effect of process parameter, submitted to Mat and Met Trans B.*

*S. Li, K. Sadayappan and D. Apelian, Why Some Al Alloys Hot Tear and others do not? – Part II: Effect of alloy parameters and the role of grain refinement, submitted to Mat and Met Trans B.*

- **Phase III:**

- Simulation results of effect of mold temperature on hot tearing by ProCast were compared with hot tearing tendencies measured experimentally for alloy 206. The simulation results are consistent with experimental results.
- The effective plastic strains accumulated during solidification have been calculated for different mold temperatures. The strain in critical area is much lower at higher mold temperature. The lower hot tearing tendency in higher temperature mold is associated with the reduced strain during solidification.

## **Acknowledgments**

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