Modeling of Oxide Bifilms in Aluminum Castings

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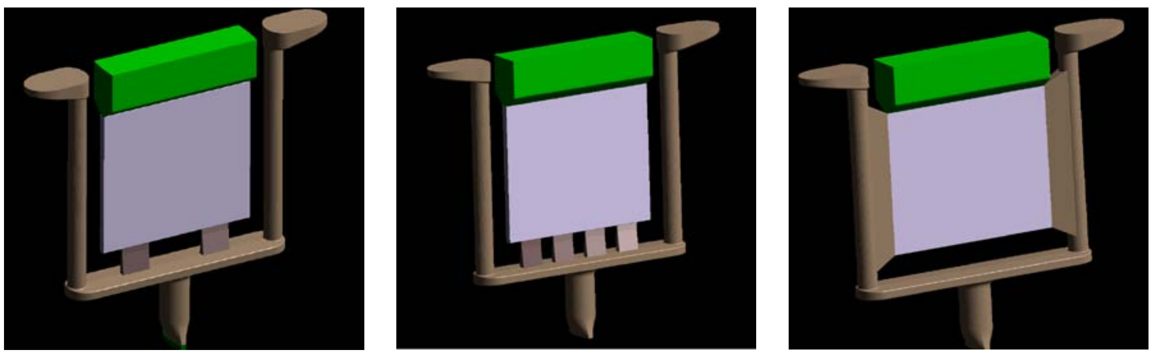
ABSTRACT: This work describes the collaboration research carried out during this IREE experience, which deals with the formation of defects during solidification of cast alloys, particularly those known as confluence welds in Aluminum A356 alloys. During the casting process, the separation of metal fronts can produce cracks upon rejoining of the fronts due to the interaction of oxide films. This phenomenon is evident in the case of multiple gating systems, which can lead to the confluence of several flow fronts causing possible regions of failure. The casting of thin plates for three gating configurations have been modeled for this project as a means of comparing the simulation results with the castings made in the foreign counterpart's foundry. From each of the cast plates, microstructural data will be obtained in order to determine the differences in characteristics of each casting using various input parameters. Currently, research has been started on one of the three gating designs and on selected castings which had apparent confluence welds on the surface. As this research continues and microstructural information is collected from all the cast parts, they will be tested and analyzed to detect possible failure regions resulting from the prescribed defects. From this collaboration, it is anticipated that the analysis of the experimental data and modeling results will provide information about the effect of process parameters on confluence welds, thus improving gating design.

INTRODUCTION

The current National Science Foundation grant (CTS-0553570, PI: Sergio Felicelli, Mississippi State University) has provided an opportunity for the initiation of in depth research of defects during solidification processes, specifically in Aluminum A356 cast alloys. In the casting process, the molten metal is often taken through a rigorous process which can leave the final state of the material with numerous defects that can lead to premature failure of the product[1-3]. Since aluminum is highly reactive with the atmosphere, a concern in aluminum castings is the development of a thin solid oxide layer on the surface of the molten metal. If the design of the casting requires that gating systems be used to deliver the metal to the mold cavity, then these oxide layers can cause the metallic fronts to not to adhere successfully when the streams rejoin. In the event that this should occur, the mechanical properties of the casting at these metallic interfaces can be significantly affected and could develop into a region prone to crack initiation. In this work we will focus on developing and modeling, using MAGMAsoft applications, multiple gating systems for three different bottom fill configurations.

As part of the international collaboration between Mississippi State University (MSU) and the Foundation for the Research and Development in Transport in Energy (CIDAUT) in Spain, Ratessiea Lett, a Mechanical Engineering undergraduate at MSU performed research at the host instituion during May-August 2008. The relation between MSU and CIDAUT had been initiated by Dr. John Berry (Professor, MSU) and Rafael Cuesta (CIDAUT) during a visit trip in the previous year. In late May 2008, Dr. Sergio Felicelli (Associate Professor, MSU) and Rogelio Luck (Associate Professor, MSU) visited the CIDAUT facilities, to outline a schedule of tasks and discuss desired outcomes for the summer time period. The group with which Ratessiea conducted research with was Aleaciones Ligeras (Light Alloys), where she was supervised and trained by Rafael Cuesta and David Losua. CIDAUT is comprised of several research teams that focus on the behavior of materials and metals from experimental stages to final product testing. In the area of cast alloys CIDAUT works directly with Aleaciones Ligeras Aplicadas (Applied Light Alloys - ALA), which is a commerical foundry that fabricates various nonferrous components and is also the site where a new and innovative casting process developed by CIDAUT has recently been employed. This process is known as the EPGS casting process in which a DISAMATIC linked to an electromagnetic pump produces high speed green sand molds. As CIDAUT has had much experience with aluminum alloys and constantly strives to provide methods to produce high integrity parts for its customers and the ALA foundry, a collaboration would prove beneficial to both research teams in the area of casting defects.

The preliminary procedures of the research project were carried out at both CIDAUT and MSU, with constant correspondence through email. The first major accomplishment was the design of three gating configurations, in order to determine an optimal system for the flow of metal into the plate cavity. These designs are shown in Figure 1.



(a) ***(b)*** ***(c)***

Figure 1. Gating Designs (a) A1 Configuration (b) A2 Configuration (c) B Configuration

The A1 and A2 configurations have tapered ingates at the bottom center of the plate area and the B configuration has side tapered ingates. All three of the bottom fed configurations have a runner that connects to the two side surge tanks, which eliminate the possibility of the entrance of contaminated first metal into the plate cavity. Of the three configurations, only results from the B design will be discussed in this work, as there were scheduling conflicts during travel at the foreign counterpart which prevented casting of many A1 and A2 plates. These castings will be performed shortly, as the collaboration between both groups is still ongoing.

RESEARCH ACTIVITIES AND ACCOMPLISHMENTS OF THE INTERNATIONAL COOPERATION

While on site at the host laboratory, additional casting simulations with altered parameters were created with the MAGMAsoft program. Several models had been already been produced prior to travel. By ensuring the researcher had become familiar with the program, work could begin immediately upon arrival at CIDAUT. Interaction with experienced modellers at CIDAUT could offer direction on how to better interpret results and what parameter alterations would provide more accurate simulations. For the preliminary research results, four simulations were created using fill times of 6, 9, 12, and 15 seconds. The main objective of these models were to monitor the velocity at the ingates in order to obtain an approximate fill time that would produce a velocity of approximately 25cm/s for the B-configuration and 50cm/s for the A1 and A2 configurations. These values were determined from research on the principle of critical velocity[4-6], which is an important factor in design to ensure the liquid metal will not be damaged due to entrance splashing as a result of high velocities. The following figures illustrate the velocities in the B-configuration at the ingates for a fill time of 15 seconds. The scale shown to the right in the figures shows corresponding velocities in cm/s.

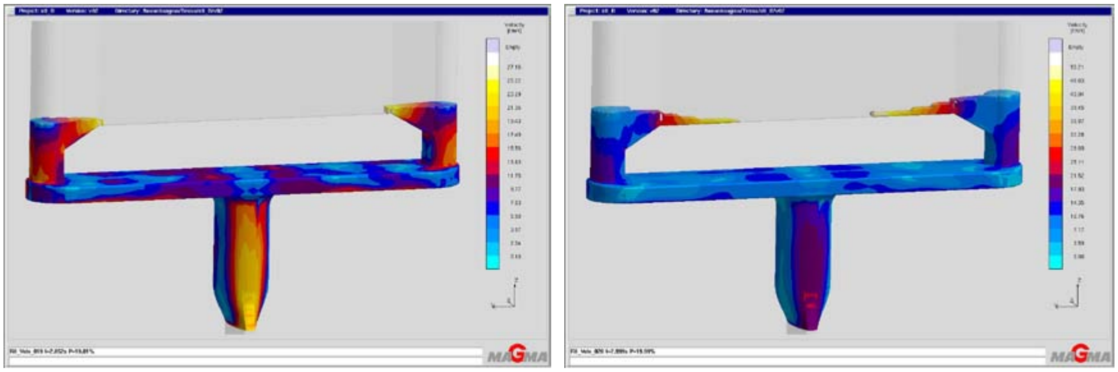


Figure 2. Velocity at Ingates for B configuration at Different Times into the Filling

Additional results used from each of the MAGMA simulations were the fill time (for location of possible air entrapment), porosity, temperature, and Dendrite Arm Spacing (DAS).

After reviewing the MAGMA results from the preliminary simulations, six cast plates were fabricated at the ALA foundry. However, these molds were filled using mass flow rate versus time values; therefore comparisons to the MAGMA simulations could only be made based on the final fill time of the actual castings. These fill times are referred to as fast and slow fills, which are closest related to the 15s and 6s MAGMA simulations, respectively.

The next phase of research consisted of obtaining information about the microstructure of the plates, which will be used for later comparison when samples are prepared for all three configurations. For each of the cast plates the following are to be completed:

- Cut samples (nine per plate) in 20x20x10mm sizes from specified plate locations for density measurements
- Measure Dendrite Arm Spacing (DAS)
- Attain values for pore area distribution, equivalent pore diameter, and aspect ratio of porosity using optical microscope program created by CIDAUT personnel
- SEM/EDX analysis to locate possible oxides

The objective of the tasks listed above is to obtain results that provide insight on locations of possible porous regions in the plates, how the pores develop (by characterizing their shape and orientation), and the cooling rate of the casting for model validation.

In two of the six cast plates, there were apparent confluence welds created on the outer surface of the plates, which are shown in Figure 3.

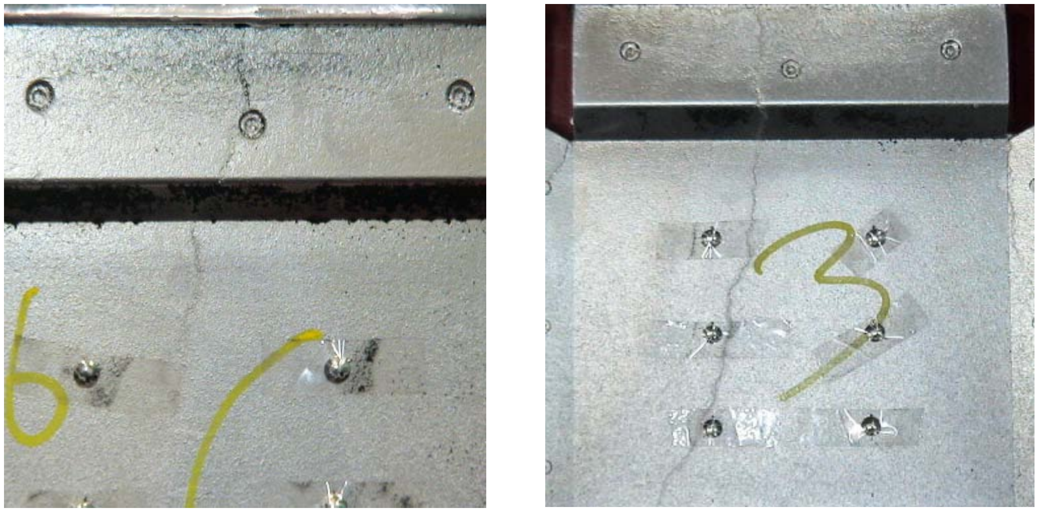


Figure 3. Confluence Welds in B-Configuration Plates

In the castings above, only the confluence weld area was examined on the optical microscope, no microstructural data from the previous list was attained from these plates. For the confluence weld samples, the top surface and cross section of the defective area were examined to determine if the weld had extended into the depth of the plate. After preparing the top surface samples, the outline of the weld (as is seen in Figure 3) had diminished, but there were areas of porosity which still existed along this area.
Some of the results from this IREE project have already been presented in the ASEE conference[7] and a journal article was recently submitted to the Transactions of the AFS[8].

BROADER IMPACTS OF THE INTERNATIONAL COOPERATION

Through this collaboration, the Light Alloys research group hosted one of their first American students. This gave both the researcher and the personnel at CIDAUT the opportunity for a continual cultural exchange. The fact that there were not many Americans in the surrounding areas (as Valladolid is not a popular tourist locale), provided an opportunity to network and interact with only native speakers. Prior to travelling, the student had taken basic classes in the Spanish language, but had not been immersed in a surrounding to use the knowledge attained in the classroom for conversational skills. The personnel at CIDAUT spoke English as well as Spanish, so in order for the researcher to improve foreign language skills each week a devoted amount of time was taken to learn the native language. It can be extremely challenging to travel to a non-English speaking country and have to maneuver around the city alone, but it helps the individual to become more independent, sociable, and to develop a new perspective about diverse cultures.

Several of the CIDAUT personnel volunteered to show the student different historical villages and activities that are typical of the country. Visits to Madrid, Salamanca, Uruena, Medina del Campo, a bull fight in Segovia, and running of the bulls in Arevalo added to the depth of knowledge about the history of Spain and its people. In each of these experiences the history of the area, or tradition was discussed and compared to that of America.

To further expand the international scope of this project, a visit to the University of Birmingham in England was arranged with Prof. William Griffiths. The visit to the campus provided an opportunity to learn about related projects on oxides in metal alloys which are beneficial for the discussion of current research methods and results that have already been obtained. In addition to these research-related benefits, since the awardee university is currently working on a larger scale foundry, by visiting Birmingham's well established foundry, where students have the opportunity to work on a variety of different casting projects, ideas can be exchanged for suggested equipment for MSU. One objective of this visit was to open doors for future collaboration between Mississippi State and the University of Birmingham. As research persists on this project, it is important to have sources of previously completed related research.

DISCUSSION AND SUMMARY

Provided in this work are some of preliminary results obtained from the international collaboration between MSU and CIDAUT to study the problem of defects relating to solidification in multiple-gated systems. For the initial phases of the project, MAGMAsoft simulations were created based on fill times only. After castings were fabricated at the ALA foundry, information is available for mass flow as a function of time, which will be used for future more accurate simulations. Valuable microstructural information was obtained using optical microscopy, but additional SEM analysis is needed in order to better characterize the microstructure in this region. In future work, samples will be examined from A1 and A2 plates in order to obtain a better understanding of the roles of gating design, fill rates, and other process parameters in the fabrication of castings. The IREE NSF grant has provided support for the development of international relationships with both CIDAUT and the University of Birmingham for research in an area which may enhance the field of metal casting.

Recommendations for future first visits to a foreign institute include that the student enrolls in a class of foreign language for at least 2 semesters or a conversational class before travelling to the foreign counterpart. If at all possible, enrolling in a class of the foreign language upon arrival in the foreign country would be even more beneficial because it would give the student an opportunity to learn the language from native speakers and interact with peers in a classroom setting. Also, the foreign institute or host lab should try at best to ensure that personnel responsible for training will be available once the student arrives to eliminate loss time on the project and to maximize the results of the time spent in the foreign institution. It is also advantageous if the researcher is knowledgeable of the programs and equipment to be used at the host institution, work can commence immediately upon arrival with minimal supervision. Most of these provisions were properly taken care of in our project, which led to a successful and rewarding experience for student and researchers.

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BRIEF BIOGRAPHY OF RESEARCHERS

Ratessiea Lett received the Associates Degree in Arts and Sciences from Jefferson Davis Community College in 2005 and the B.S. degree in Mechanical Engineering from Mississippi State University in 2008. She has recently begun graduate studies as a doctoral student at MSU in the field of Mechanical Engineering and will also complete requirements for the Materials Science Certificate while pursing the PhD.

Sergio D. Felicelli received a Nuclear Engineer degree from Instituto Balseiro (Argentina) in 1985 and a Ph.D. degree in Mechanical Engineering from the University of Arizona in 1991. He is currently an Associate Professor of Mechanical Engineering at Mississippi State University and has held positions at the Argentine Atomic Energy Commission and Saint-Gobain Ceramics and Plastics. His research areas are modeling of solidification processes, computational mechanics and transport phenomena.