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Collaborative Research: Contacting and Solidification in Casting-by-Design

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Abstract: A technology to enable continuous casting of molten metals, in a single step, to the specifications of the designer is being developed. To cast aluminum foil, e.g., in a single step, would reduce CO_2 emissions to the atmosphere by 250,000 tons per year, in the US alone. Every kilogram of aluminum saved in reducing manufacturing waste translates into electricity saved at the energy-hungry smelter. The technology is based on controlling length scales previously uncontrolled. Tunable casting uses substrate modification to manipulate product quality.

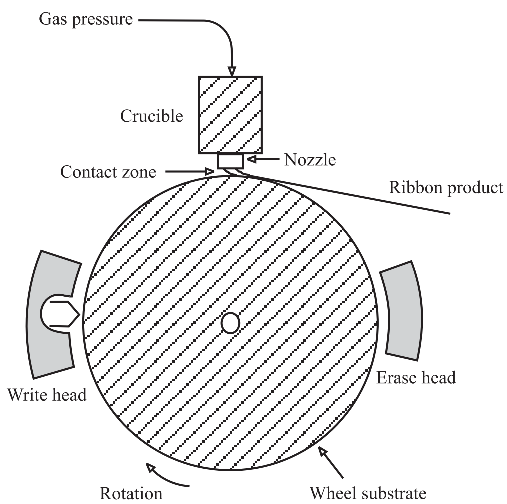


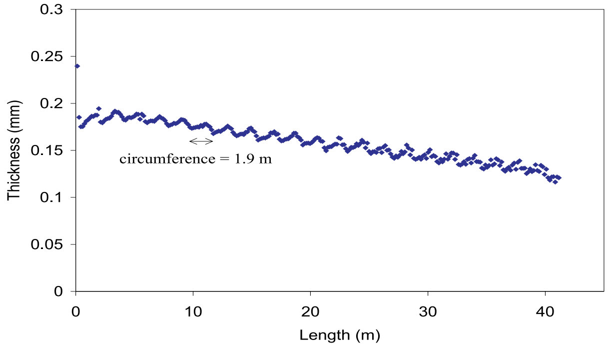
Fig.1 Single roll casting schematic with 'write' and 'erase' head concept.

1. Overview: Single roll casting is a favored technique to produce foil or ribbon, a technique limited, however, by the ability to influence the contacting and solidification event within the contact zone. Molten metal is forced through a nozzle onto the substrate where it forms a puddle. The rotating substrate causes a solidification front to grow from it as it translates and eventually a ribbon product is spun off. Casting rates of 10 *m/s* (tangential velocity) are achievable with our apparatus that uses a wheel of 3 *m* circumference. In the zone between nozzle and wheel, there is contact under pressure, phase-change, and large concentration (for alloys), velocity and thermal gradients. The complicated interplay between contacting, wetting and solidification physics is not well understood. Features of the ribbon product range in length scale over 6 orders of magnitude, from the product macroscale (50 *m* long) to the grain size (10^{-5} *m*). Interest is in influencing the smaller scales ($<10^{-2}$ *m*) since these lead to surface irregularities, unacceptable product and waste.

The goal is to condition the substrate by imposing either thermal or compositional gradients before the contact zone. Gray-scales in ink-jet printing are produced by the spacing and arrangements of ink dots of the same size. In much the same way, the proposed gradients will be established with arrangements and spacing of spots, hot spots and material spots of thin solid film. Laser heating will induce the hot spots and drop-on-demand devices will deposit the compositional spots.

A pre-processor ('erase head') is introduced to clean the wheel surface (un-condition it) and a processor ('write head') to condition the surface. To influence scales down to microstructure, a spot size of 10 microns and a spacing between spots (spatial resolution) of 100 microns are the goals. Recent advances in laser and drop-on-demand technology make the concept with these goals, 'just realizable'.

2. Project Questions: The figure below shows thickness variations of product for Al cast on a 1.9 m circumference wheel. Peaks and valleys of the wheel during a similar cast on the 3 m wheel are seen to have a similar variation but with the oscillations decreasing periodically in amplitude. The initial variation is due to cold wheel eccentricities. Then the wheel deforms during the cast, changing shape in a way that is nonuniform. This is due to the heat-loading of the cast metal.



Surprisingly, wheel irregularities become smoothed after about 3 seconds or so. What is the mechanism for the deformation? What makes the peaks and valleys grow again? Can this be modeled quantitatively?

The cross-stream oscillation defects are regular marks with characteristic wavelength. They are actually variations in thickness of the ribbon. What ultimately causes the oscillation marks? Can they be controlled?

Laser modifications of the surface can generate roughness or can just add heat to the cold substrate. The scale of these laser spots is on order of 100 micron. Better laser focusing can narrow the spots somewhat but defocusing due to wheel (or meniscus) motion makes the precise size difficult to control. Insulation strip modifications (BN thin film) can reduce the heat-transfer and, if thick enough, provide a mechanical disturbance. These modifications can be laid down in a variety of patterns or as single disturbances. What is the response of the product to these disturbances? How does the roughness couple to the heat-transfer and ultimately influence solidification?

It has been argued by some that roughness primarily aids in nucleation, by others that its primary role is to hinder heat-transfer through trapped air while others say it has primarily a wetting influence. Which of these explanations holds true for the parameter regimes of interest to SRSC?

Can we model and explain the pit formed in the strip due to laser interaction? To what extent can we control the cooling rate in the product using the laser and BN `printing'? How are mechanical properties influenced by the substrate modifications?

Finally, in a successful cast, the product sticks to the substrate near 12 o'clock on the wheel and then parts from it before 3 o'clock. What is the nature of this bond? We have observed that Al sticks to a much greater extent on our steel wheel relative to the copper wheel. Can the adhesion be influenced by the laser or BN spots? Product with cracks often occur. How are adhesion and cracking related? Can cracking be controlled?

3. Acknowledgments: This project starts on 1 October 2004. This paper is submitted in September 2004. The questions to be answered by this project are expected to have major contributions from Eric Theisen, Cormac Byrne (Graduate Students) and Dr. Mike Vogel (Postdoctoral Fellow). Work will be supported by National Science Foundation grant # DMI-0423791.

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