**Research and Education Activities:**

The continuous casting of thin aluminum strip with a single-wheel melt spinning process offers great potential for low-cost production of finished products with unique surface textures. To perfect this process requires fundamental understanding of the phenomena which control solidification shape, including flow oscillations in the melt pool, meniscus interaction with the wheel surface, intermittent solidification against the moving wheel, and thermal distortion. This was done through a three-step process as given below:

1) Development of a quantitative, computational model of heat transfer and solidification coupled with the transient flow of molten aluminum during the melt spinning of aluminum.
2) Validation of the model through extensive comparison with experiments performed at Cornell University under the direction of PH Steen.
3) Application of this model to improve understanding of the heat transfer during the process thereby develops a fundamental mechanism governing the relationship between various process parameters.

Melt-spinning process can be used to cast amorphous metallic glass ribbons or thin metal strips with fine microstructure and properties. The strip produced during this process has several different types of observable surface defects. These include cracks, holes, hot tears, segregation and surface depressions. If the surface depressions can be controlled, this process could be an economical way to produce strip product with textured surfaces embossed with text and images.

Different techniques can be used to produce strips with textured surfaces. These include laser interaction with the melt-pool, meniscus fluctuations from vibrations of the melt pool, and treating the wheel surface either thermally (such as via laser scanning) or physically, such as via coating deposits. For example, imprinting a layer of low-conductivity BN onto the wheel can act as an interface surface depression that transfers a 'negative' template from the substrate to the product during solidification. Surface depressions include longitudinal depressions along the casting direction and transverse depressions across the width of the strip. A depression on the substrate surface causes a local increase in thermal resistance at the interface between the strip and the wheel (wheel side surface) and thus slows the heat transfer and local solidification rate. This produces a corresponding deeper depression on the opposite upper surface of the strip (liquid side surface) which translates into discernible thickness variations. In order to quantify the effect of these interfacial depressions, a thorough understanding of the heat transfer phenomena occurring during this process is essential.

Previous work to investigate the strip-casting process includes heat transfer-solidification models of melt spinning, estimating the effects of process condition on heat transfer in strip casting processes, and understanding the surface defects occurring in different continuous casting processes. It is clear from previous research that fluid flow is responsible for observable surface depressions on the strip surface. It is not clear, however, if the waves caused by the time-dependent flow freeze to form surface depressions directly, or act indirectly by affecting the upstream meniscus. Despite many previous studies of surface defects in melt spinning, there has been very little effort to quantify them. This research aims to develop multi-dimensional heat-transfer models of the process and use them to quantify the effect of wheel-side surface depressions and other casting parameters on heat transfer and upper-surface depressions and thereby confirm the mechanism of their occurrence.

As a first step towards quantitative understanding of heat transfer during melt spinning, a mathematical model of the process called STRIP1D has been. STRIP1D is a transient one-dimensional heat-transfer model of the planar-flow melt-spinning process used to cast Al-7% Si strips on a Cu-Be wheel. The STRIP1D model has been used to validate two- and three-dimensional heat transfer models of the process. The models are then applied to investigate the effect of casting conditions and interfacial depressions on heat transfer and solidification during melt spinning, including thickness variations and surface depressions. In particular, the longitudinal depressions caused by a continuous ridge of BN deposits and transverse depressions caused by rows of small, closely-spaced air pockets are investigated.

As a part of this project, a mechanism for solidification and the formation of transverse wavy depressions on the strip surface in the melt-spinning process has been developed. These steps are consistent with, and build upon the mechanism proposed by Steen and coworkers.

- The gap height and pressure head exerted by the melt in the crucible determine the flow rate of the liquid entering the melt pool. The flow rate increases with gap height due to the drop in flow resistance and with pressure head from the Bernoulli relations.
- Time-varying flow in the melt pool causes periodic oscillations of the meniscus, which continuously moves the upstream meniscus upstream and downstream along the wheel surface.
- The oscillation frequency increases with decreasing melt pool volume, so decreasing gap size causes more oscillations.
- The upstream movement of the upstream meniscus captures air pockets at the wheel-meniscus contact interface. If capture occurs at the same instant during the meniscus oscillation, the gas pockets will form a discontinuous wavy line with the same shape as the melt pool meniscus at that instant.
- As metal solidifies around these pockets, they form wheel-side surface depressions that move with the strip through the melt pool at the wheel speed.
- The gas pockets retard heat transfer locally, which causes an equivalent liquid-side surface depression with the same shape. The depth of the liquid-side depressions grows with time, according to conduction within the strip. If the gas pockets are they aligned, the depressions they can merge into continuous lines, such as the cross-stream pattern.
- The pitch of the resulting defects naturally has the same frequency as the meniscus oscillation.
- With increasing time, thermal expansion of the heating wheel causes the gap height between the nozzle and the wheel surface to gradually decrease throughout the cast. Superimposed within each wheel rotation cycle, local variations in gap are caused by the slightly oblong shape of the wheel.
- Superimposed on these variations are the meniscus oscillations that are responsible for the third time scale of thickness variations.
- The decreasing gap height, and its accompanying higher frequency of menisci oscillations, and increased number of air pockets captured, causes a decrease in the average contact area between the liquid and wheel surface. This decreases the interfacial heat transfer coefficient. The decrease in gap height is also responsible for a decrease in flow rate which decreases the strip thickness to satisfy mass balance. Increasing casting speed would cause the same effects.

Liquid in the melt pool remains until the strip thickness has solidified, which dictates the end of the puddle.