INFLUENCE OF THE CASTING AND COOLING PARAMETERS ON THE GEOMETRY OF RAPIDLY SOLIDIFIED METAL RIBBONS

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Abstract
During the rapid solidification the conditions necessary for the production of new materials with improved properties were established. The following results of the rapid solidification were present during our investigations: small grain size, the appearance of a fine dispersed precipitated phases (nano-materials), supersaturated solid solution, and the appearance of meta-stable phases having a crystalline structure. During the rapid solidification, the quasi-crystalline phases can form in the melt, which could be classified according to their structure between crystalline and amorphous states.

The rate of solidification depends to a certain degree on the geometry of the rapidly solidified ribbons. This geometry depends on the velocity of the wheel, the jetting pressure, temperature of the melt or rather the overheating of the melt, diameter of the orifice, the distance between the orifice and the wheel, the angle of jetting, etc.. Within the framework, their influence on the final dimensions of the ribbons created from rapidly solidified aluminium and copper alloys has been investigated.

1. INTRODUCTION
The basic principle of rapid solidification on a rotating wheel is to eject the melt from the orifice onto the rotating surface of a wheel. When the melt comes into contact with the wheel, a small melt puddle, which plays an important role in the formation of ribbons, forms. This melt puddle is in direct contact with the surface of the wheel thereby forming a link between the jetting melt and the wheel, enabling heat transfer to occur and solidification to begin. The solidified layer accelerates to the speed of the rotating wheel and separates from the melt puddle. The heat transfer which occurs on the surface of the wheel is presented in Figure 1. The cooling rate on the free surface of the ribbon is negligible and we can therefore say that cooling occurs only in one direction.

Figure 1. The formation of the melt puddle, formed when the melt comes into contact with the surface of the rotating wheel (a) and the transfer of heat on the cooling wheel (b).
2. RIBBONS FORMATION

The key parameter in the production of ribbons is rapid cooling, which depends on the creation of the ribbons. The melt puddle, from which the ribbons are created, appears at the moment when the jet of melt hits the surface of the wheel. The thickness and width of the ribbons depend on the dimensions of the melt puddle. Analysis of experimental results show that the thickness of the ribbon depends on the length of the melt puddle, which, consequently, depends on rotating speed of the wheel. The mechanism by which these ribbons are created is mirrored in the relation between the thickness of the ribbon and the time \( t = \frac{L}{V} \), where \( L \) is the length of the melt puddle and \( V \) is the rotating speed of the wheel. This relation between the thickness and time is given with the following equation: \( d = C t^m \), where \( C \) and \( m \) are empirical parameters [1]. The value of the exponent \( m \) coincides with the mechanism through which the resultant ribbons are created.

The speed and temperature of the melt within the hell change and are dependent on the position with respect to the surface of the wheel. This field is known as the temperature and hydrodynamic boundary field.

Depending on the effectiveness of transport of the melt and heat transfer, three mechanisms can be distinguished in the creation of ribbons [2]:

1. Mechanism which is heat transfer controlled (HTC),
2. Mechanism which is moment transfer controlled (MTC), and
3. Mechanism which is controlled by the rate of heat transfer and the transfer of liquid particles.

3. MICROSTRUCTURE OF RAPIDLY SOLIDIFIED RIBBONS

The microstructure of rapidly solidified ribbons depends on the process of solidification. For the analysis of the process of rapid solidification during the casting of ribbons, various modeling methods and analytical calculations can be used. Using experimental results, it has been determined that the thickness of the ribbon depends primarily on the rotating speed of the wheel, the viscosity of the melt, the jetting speed of the melt and the position of contact between the melt and the surface of the wheel. The most important technological parameter in the production of rapidly solidified ribbons is the rotating speed of the wheel. Whether solidification begins in the melt puddle or at some distance from the melt puddle when the melt is transported in the form of a thin layer depends on the rotating speed of the wheel. Using theoretical analysis, it has also been determined that the temperature gradient within the melt, the released heat of solidification and the temperature difference between the melt and the solid state at the solidification front influence the process of solidification.

3.1. Characterization of ribbons from Cu – X

The directional transfer of heat is responsible for directional solidification which causes the formation of columnar crystals. Trans-crystallographic solidification results in anisotropic growth from the cooling surface of the wheel to the melt with heat transfer occurring in the opposite direction. The primary axis of dendrites is parallel to the direction of heat transfer, while the solidification front runs parallel to the isotherms. The directional growth deviates a few degrees from the normal at the surface of the wheel in the direction of rotation (Figure 2). Reasons for this deviation can be either the temperature gradient and/or the speed of the melt in the direction of the rotating wheel. The angle of deviation increases with increasing speed of the wheel.
Figure 2: Rapid solidification of ribbons on a rotating wheel of alloy Cu-Nb. a) The microstructure of ribbons solidified on a rotating wheel with a velocity of 35 m/s and b) 23 m/s. The microstructure of the ribbons in an axial cross-section shows the trans-crystalline zone of columnar grains, which reach to the upper free surface of the ribbon.

3.2. Characterization of ribbons from Al-Ni-Mn alloy and Al-Fe

The achieved solidification speeds enabled the process of solidification to occur with or without micro or nanoscale particles homogeneously distributed throughout the Al matrix (Figure 3a).

Figure 3: Microstructure of the axial cross-section of rapidly solidified ribbons of Al-Ni-Mn alloy: a) SEM image of a ribbon of 15 µm thickness (rotating velocity 35m/s) and b) thickness 45 µm (rotating velocity of 23 m/s).

Electron microscopy of ribbons having a thickness of 45µm shows the presence of two zones. The surface of the ribbon which was in contact with the wheel has a nano-cellular microstructure which gradually becomes a micro-cellular microstructure. The transition between the two microstructures can be seen in Figure 3b. During rapid solidification on the rotating wheel, the speed of the solidification front was lower than boundary speed of absolute stability, at which solidification occurs without micro-precipitation. The size of the cells changes with the speed of the solidification front. With a decrease in the temperature gradient, at a certain distance from the lower edge of the ribbon, the velocity of the solidification front decreases and the cells are therefore larger. During solidification latent heat of the undercooled melt is released and transferred into the melt and the cooling wheel through additional resistance present due to the solidified layer of alloy. The external and internal heat transfer results in decreasing the undercooling of the melt as well as a smaller temperature gradient.
Figure 4: Typical OM-image (a, b) and TEM image (c) of the cellular microstructure of Al-Fe alloy.

Rapidly solidified Al-Fe alloys have a cellular microstructure with regions where the boundaries between cells form a continual network of the Al-Fe phase. The microstructure which was seen using both the light and electron microscopes shows the presence of two zones (Figure 4). Both zones have the same qualitative chemical composition. OM and TEM images show the transition from the nano-cellular (A) microstructure to the micro-cellular (B) microstructure. The size of the cells depends on the diffusion of the solute atom and with faster solidification fronts, the cell sizes decreases.

4. CONCLUSIONS
In this work, we experimentally determined and assessed that the thickness of the ribbons depends primarily on the rotating speed of the wheel, the viscosity of the melt, the jet speed of the melt and the position of contact between the melt and the wheel. The most important technological parameter in the production of rapidly solidified ribbons is the rotating speed of the wheel and the angle of jetting at a constant velocity of the melt through the orifice. Both of these parameters influence the shape of the melt puddle, which plays a definitive role in the formation of ribbons and thereby, on the development of the microstructure of the rapidly solidified alloy. The structure of the surface of the wheel also plays an important role, as it influences the formation of precipitates and the growth of crystalline grains. The significance of individual technological parameters depends on the type of metal and alloy being used.

5. BIBLIOGRAPHY