Experimental investigation of High-Speed Melt Spinning by Means of Digital Image Analysis

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Abstract: We carry out an experimental characterization via high-speed camera of Chill-Block Melt Spinning process by means of digital optical flow for melt ejection velocity calculation and temperature measurement.

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1. Introduction

Chill block melt spinning (CBMS) process is widely used especially for the production of permanent magnets and metallic glasses. It is a rapid solidification process whereby a melt is ejected via a nozzle onto a rotating wheel solidifying in the form of a ribbon. It is empirically known that the cooling rate increases with decreasing ribbon thickness and therefore the material properties are dramatically improved [1].

The production of amorphous materials with this technique is of current industrial interest for the construction of electrical transformer nuclei for the benefits in energy efficiency which can reach up to 80%. Scaling from a scientific scale to an industrial one, requires validation by experiments [2], the support of materials characterization techniques and numerical simulation [3]. This work is a step toward the experimental characterization of the melt spinning technique for adequate numerical simulation.

2. Experimental details

The CBMS equipment for producing the ribbons of amorphous material [4, 5] is depicted in Fig. 1. An ingot is milled to a size of about 5 mm, and then placed inside a quartz tube of 10 mm diameter and 1.5 mm thick. This tube works as a crucible to obtain the ribbon. This crucible has a Boron Nitride nozzle attached with a circular ($z = 0.8$mm) orifice in its center, through which the molten alloy flows. The copper wheel works as a heat sink to obtain a cooling rate of about 10^6K/s), necessary to achieve the glassy phase. In our experiments the small gap (G) between the ribbon and the casting wheel was placed at 2 mm. The temperature profile is monitored by an external optical pyrometer to verify that it reaches a stabilization temperature zone for free jet ejection. [5]

The High-speed camera (Visionresearch Phantom-HD camera) was placed perpendicularly from the the wheel and the crucible at a distance of 20 cm. Image acquisition was carried out at 5602 fps, 20 μs exposure time and resolution 200×320. All images were processed using MATLAB.

3. Image Analysis and Measurements

3.1. Ejection Velocity Measurement

We measure the ejection speed by using optical flow [6]. Optical flow is a technique for estimating 2D image velocity. We can compute the two components (u, v) of velocity per pixel. However, often such high resolution optical flow is not needed. The optical flow estimation uses median filtering and a binary mask that was computed to avoid changes in brightness or reflections on the wheel taken as motion.

In Fig. 2 we show the successive images starting just when the molten alloy starts to flow until it comes into contact with the wheel. From this data we can calculate many parameters related to the ejection. We show the maximum speed per frame. The melt takes about 14 frames to be ejected (@5602 fps) and come into contact with the rotating wheel.

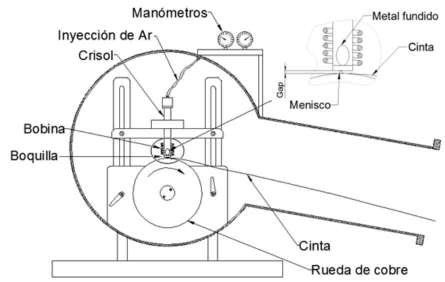


Fig. 1. CBMS equipment.

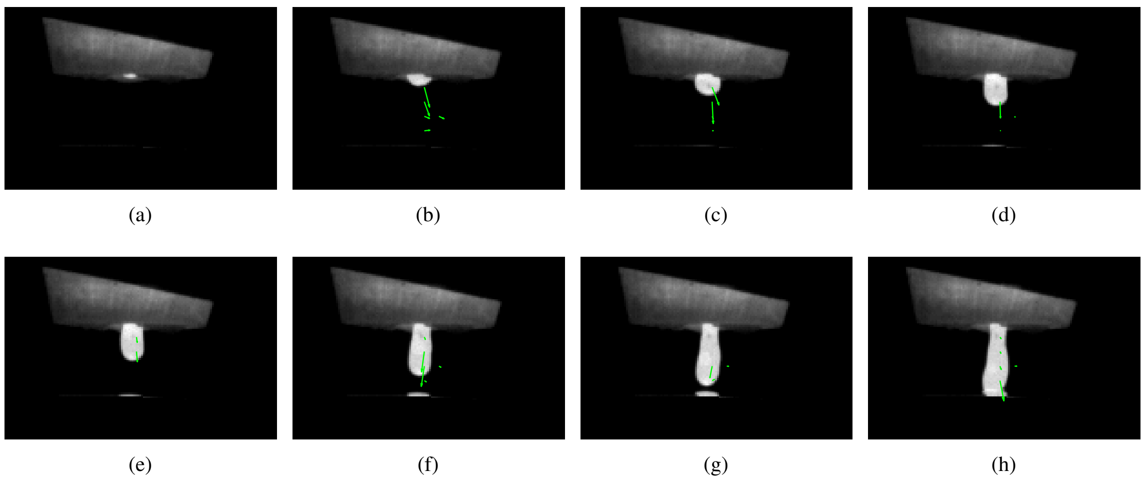


Fig. 2. Velocity measurement of melt ejection by optical flow. The arrows indicate the most significant velocity. Maximum speed: (a) 0.008 m/s, (b) 0.087 m/s, (c) 0.408 m/s, (d) 1.227 m/s, (e) 1.354 m/s, (f) 1.193 m/s, (g) 0.745 m/s, (h) 0.806 m/s

Knowing the gap from the nozzle to the wheel (2 mm) we estimate an average speed of 0.80 m/s (Fig. 2). This is in line with the computed maximum speeds shown in Fig. 2.

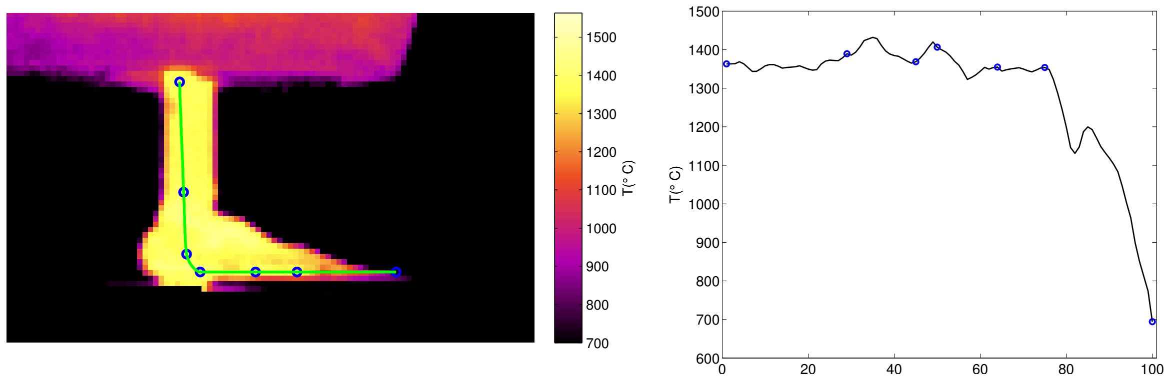
3.2. *Temperature Measurement*

To measure temperature of the molten alloy we used the method proposed by Bizjan et al. [7]. Using a high-speed, visible light digital camera we capture the intensity in 10-bit resolution. The measurement method relies on the fact that standard digital cameras are sensitive to electromagnetic radiation between 400 and 1000 nm in wavelength and the assumption that the image gray-level 0 (black) $\leq G \leq$ 1 (white), is proportional to the temperature T, provided the background illumination level is negligible.

The stabilized molten alloy ejection is shown in figure 3 alongside a green profile. From the profile note the rapid cooling rate with a drop from approximately 1300° to 400° in a space less than 1 mm.

4. Conclusions

In this work we have shown the capabilities of a 2D motion estimation technique like optical flow for calculating velocities for Chill-Block Melt Spinning. In addition, the temperature field measurements enable an increased spatial and temporal characterization of the process.



(a) (b)

Fig. 3. Temperature measurement by high-speed camera.

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References

1. K. Nagashio and K. Kuribayashi, "Experimental verification of ribbon formation process in chill-block melt spinning," Acta Materialia **54**, 2353–2360 (2006).
2. K. Nagashio and K. Kuribayashi, "Direct observation of the melt/substrate interface in melt spinning," Materials Science and Engineering: A **449-451**, 1033–1035 (2007).
3. M. Barone, M. Pagnola, and J. Useche, "Simulación con OpenFOAM® del proceso de Melt Spinning, una introducción a escala semi industrial," in "X CONGRESO COLOMBIANO DE METODOS NUMERICOS," (Cartagena, Colombia, 2015), pp. 1–10.
4. M. R. Pagnola, M. Barone, M. Malmoria, and H. Sirkin, "Influence of z/ wrelation in Chill Block Melt Spinning (CBMS) process and analysis of thickness in ribbons," Multidiscipline Modeling in Materials and Structures **11**, 23–31 (2015).
5. M. R Pagnola, M. Malmoria, M. Barone, and H. Sirkin, "Analysis of Fe 78Si 9B 13(spinning equipment," Multidiscipline Modeling in Materials and Structures **10**, 511–524 (2014).
6. D. Sun, S. Roth, and M. J. Black, "Secrets of optical flow estimation and their principles." CVPR pp. 2432–2439 (2010).
7. B. Bizjan, B. Širok, J. Drnovšek, and I. Pušnik, "Temperature measurement of mineral melt by means of a high-speed camera," Applied Optics (2015).