SURFACE TENSION STUDIES OF MOLTEN $CaO\text{-}Al_2O_3$ JETS – OSCILLATING JET METHOD

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Introduction

Blast furnace slag currently is being used as an additive in cement owing to its chemical and phase compatibility with the latter[1]. However, during actual processing, the slag is water-cooled using atomisation technique prior to its usage in cement. This not only consumes a tremendous amount of water (roughly 10 times the weight of slag) but also the slag temperature of approximately 1500°C goes unutilised. To tap into this energy potential, researchers have been working on various techniques for waste heat recovery from slags. This technique involves shearing the slag surface using an external force, predominantly centrifugal in nature viz: rotating disc or drum method[2-4]. The shearing force decides the size and shape of the droplets generated. On a fundamental viewpoint thermophysical property like surface tension, viscosity and density play a key role in deciding the shape of the jet and its break up into drops.

The jet emanating from the rotating disc or drum can be physically equated to a jet generated from a nozzle tip. In order to understand the dynamics of the molten slag jet formation and break up, an experimental set up was designed and fabricated. Molten oxide jets were observed and the profile of the jet followed in detail. The surface tension of the oxide mixture can be obtained from the first three dip and swells of the liquid. The current work discusses on molten $CaO\text{-}Al_2O_3$ slag jets emanating from a graphite nozzle.

Materials and Experimental set up

High purity alumina and calcium carbonate were used as the starting materials for the experiments. The calcium carbonate was reduced to CaO by keeping the former in a muffle furnace maintained at 1373 K for 12 hours. Based on the calcia-alumina phase diagram, the composition was fixed to be close to the eutectic (51% Al_2O_3 -49% CaO) composition. The composition and melting point was verified chemically and optically using XRF and a horizontal furnace- camera assembly. Bulk quantity of the slag was prepared by repetitive melting and pouring of the slag – ensuring chemical homogeneity.

The slag was then loaded in a closed crucible with a nozzle-plunger assembly which was controlled using an actuator. The specially designed crucible was made of high purity graphite which demands the reaction tube to flushed with argon. The crucible arrangement was then loaded in 3 zone – cross tube furnace coupled with a high-speed camera set up. The latter ensured capturing the jet formation and breakup in the order of milliseconds. A both elliptical as well as circular jet was created by using nozzles of respective shape. Further details on the set up and crucible design can be had from earlier publications[5,6].

Oscillating jet technique

Circular Jets

A jet was initiated with the help of plunger movement as well as argon pressure above the molten slag inside the crucible. This jet exits from the tip of a circular nozzle and instabilities are formed which then grow in the axial direction as a function of time and space creating necks and swells along the vertical axis. Images are then captured at high frame rate hence then contour change of the jet is recorded and later analysed using Image Pro software. The camera position was set up such that the jet disintegration point was also captured. The generalised equation for the jet radius as a function of time and distance is given as:

$$r(z,t) = R_0 + \epsilon_0\, e^{\alpha t}\cos(kz) \qquad (1)$$

R_0 is the initial radius of the jet, ε_0 is the amplitude of the initial disturbance, α is the growth factor and k is the wave number. Figure 1 (top) shows the profile of the jet with and without the cosine term, the variation in the jet profile is shown in the middle figure. Figure 1 (bottom) shows the logarithmic difference between the maximum radius minus the initial radius of the jet divided by the initial disturbance. The growth factor α is obtained from the slope of this graph. Obtaining this and using the relation between surface tension, viscosity, growth rate and wave length as shown below we can find the surface tension[7]

$$\sigma = 2\rho R_0^3 \frac{\alpha^2 + \alpha \frac{3\mu}{\rho R_0^2}(kR_0)^2}{(kR_0)^2 - (kR_0)^4} \qquad (2)$$

The density was calculated from in house experiments using the drop volume method by noting the weight against a fixed number of drops collected. The viscosity was calculated from the Urbain model for the slag composition[8]. Substituting these values in the above equation the surface tension was calculated as a function of time.

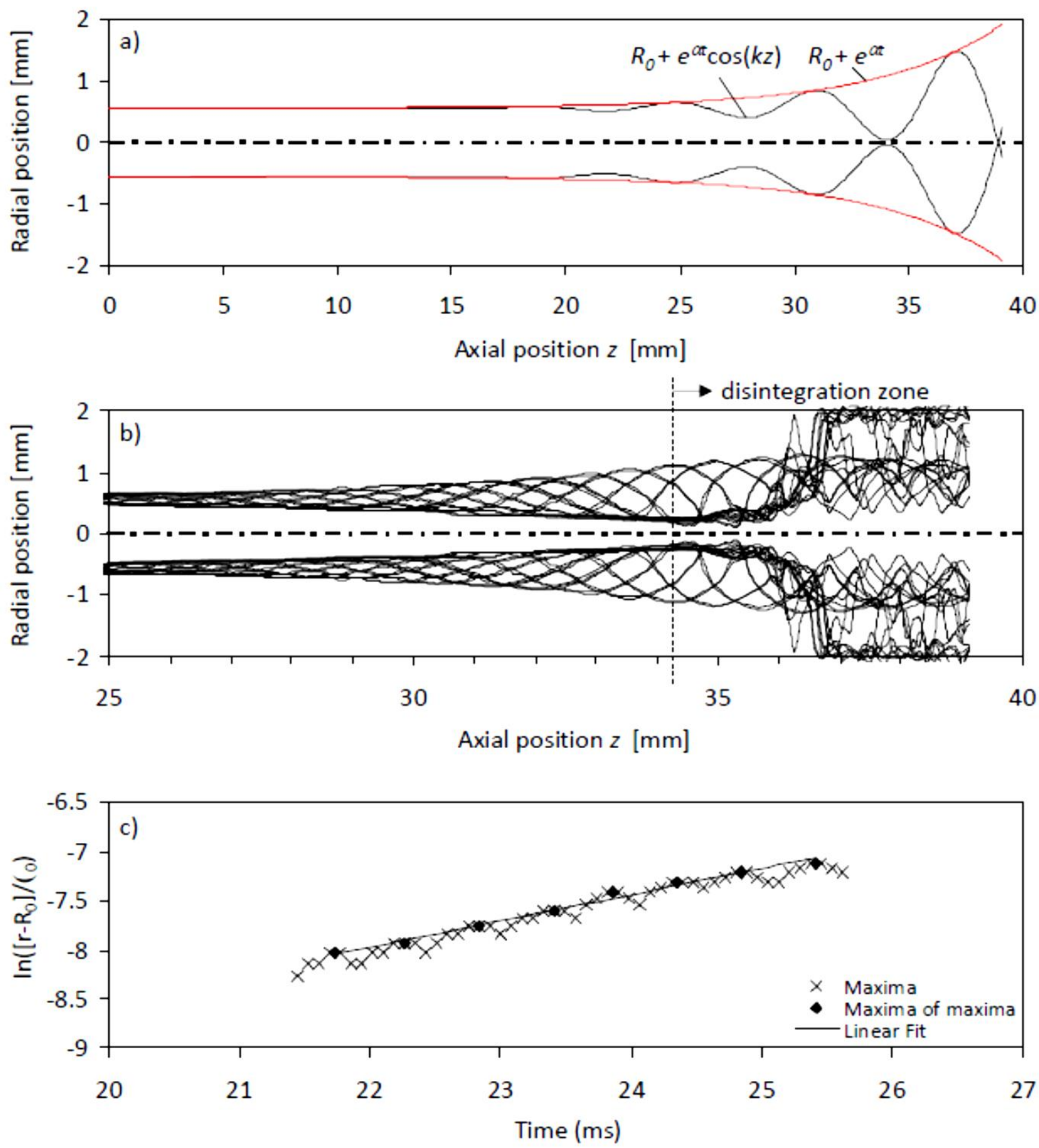

Figure 3: Jet profile according to Equation (1) (top). Actual jet profile extracted from recorded images (middle). Determination of instability growth rate and initial disturbance of the jet. The slope of the line through the maxima gives the growth rate[6]

Results

The surface tension of the binary slag was measured as 624 mN/m. This value is quite close to the works of Ershov and Popova (624 mN/m at 1933 K) and Sokolov *et al.* (626 mN/m at 2000 K) mentioned in the Slag Atlas[9]. A limitation worth mentioning is that there is very limited possibility for measuring the surface tension of slags at lower temperatures. This was due to the fact that the procedure demands the formation of at least three consecutive necks and swells. At lower temperatures, the viscosity was too high to form the oscillating profile.

Conclusions

The surface tension of molten slags is possible to be measured using dynamic techniques like the oscillating jet method. However, the limitation with the process is with the formation of jets with suitable profiles. A minimum operating temperature above the liquidus of the slag is required for accurate measurements.

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