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Thanh-Trung Vo, Saeid Nezamabadi, Jean-Yves Delenne, Farhang Radjai. Agglomeration Process of Wet Granular Material: Effects of Size Distribution and Froude Number. 28th ALERT Workshop, Oct 2017, Aussois, France. 2017. hal-01772410

HAL Id: hal-01772410

<https://hal.science/hal-01772410v1>

Submitted on 20 Apr 2018

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Agglomeration Process of Wet Granular Material: Effects of Size Distribution and Froude Number

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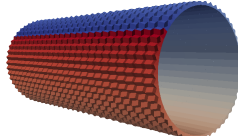
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OBJECTIVES & METHODOLOGY

We investigate the agglomeration process of solid particles in the presence of a viscous liquid. We are mostly interested in application to iron ore granulation in a horizontal rotating drum. In this work, we use Molecular Dynamics (MD) method to simulate the agglomeration process during the dense granular flows in the rotary drum. In which particles are distributed by a uniform distribution of particle volume fractions.

INDUSTRIAL PROCESS



Granulation (balling) Drum

Agglomeration is the process of particles size enlargement and most commonly refers to the upgrading of material fines into larger particles, such as pellets or granules. Iron ore granulation is an important stage in the steel making.

MOLECULAR DYNAMICS METHOD

$$m_i \frac{d^2 \mathbf{s}_i}{dt^2} = \sum_{(j)} ((f_{jn} + f_c + f_{vis}) \mathbf{n} + f_t \mathbf{t}) + m_i \mathbf{g}$$

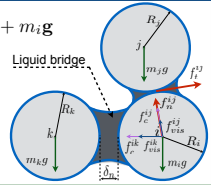
\mathbf{s}_i position vector of particle i

\mathbf{g} vector gravity

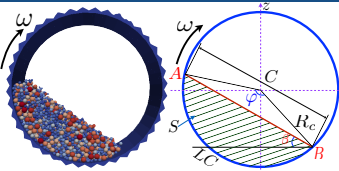
\mathbf{n} normal unit vector

\mathbf{t} tangential unit vector

m_i mass of particle i (kg)



ROLLING - CASCADING MODEL



$$C = AB = 2R_c \sin \frac{\omega}{2} \sin \beta$$

$$S = \frac{R_c^2}{2} (\varphi - \sin \varphi)$$

$$LC = AB = \varphi R_c$$

ω Rotational speed (rad/s)

β Free surface angle

φ Filling angle (degree)

Packing fraction:

$$\Phi = \frac{V_s}{S * L} = \frac{\sum (\frac{4}{3} \pi R_i^3)}{S * L}$$

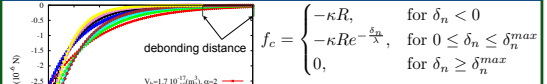
Filling level:

$$f = \frac{S}{\pi R_c^2} = \frac{\varphi - \sin \varphi}{2\pi}$$

Froude number:

$$Fr = \frac{\omega^2 R_c}{g}$$

CAPILLARY COHESION & VISCOUS FORCE



$$f_c = \begin{cases} -\kappa R, & \text{for } \delta_n < 0 \\ -\kappa R e^{-\frac{\delta_n}{\lambda}}, & \text{for } 0 \leq \delta_n \leq \delta_n^{max} \\ 0, & \text{for } \delta_n \geq \delta_n^{max} \end{cases}$$

$$f_{vis} = \frac{3}{2} \pi R^2 \eta \frac{1}{\delta_n} \frac{d\delta_n}{dt}$$

$$\kappa = 2\pi \gamma_s \cos \theta$$

$$\delta_n^{max} = (1 + \frac{1}{2}\theta) V_b^{1/3}$$

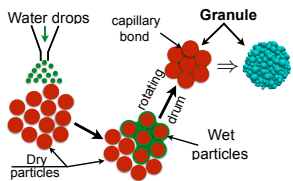
$$\alpha = \frac{R_{max}}{R_{min}}$$

$$\lambda = c h(\alpha) (\frac{V_b}{R'})^{\frac{1}{2}}$$

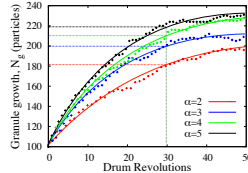
$$R = \sqrt{R_i R_j}$$

Diagram of capillary bridge

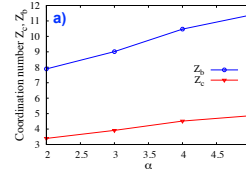
AGGLOMERATION RESULTS



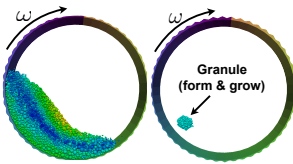
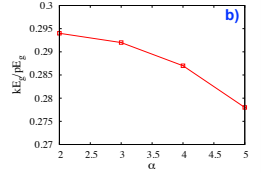
Mechanism of granule formation



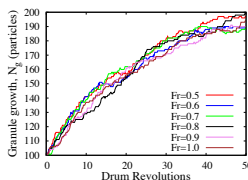
Exponential increase of granule for different size ratios



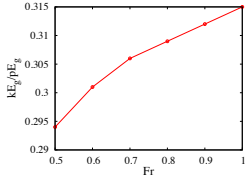
Exponential increases of wet & contact coordination numbers (a) and decrease of kinetic energy normalized by potential energy of granule (b), as functions of size ratio α .



Granular material flow & granule growth in the cascading regime



Exponential increase of granule for different Froude numbers.



Exponential increase of kinetic energy normalized by potential energy of granule as function of Fr .

Conclusions

- 1) The effect of size ratio on the granule growth is more crucial than that of rotational speed.
- 2) Granule growth is an exponential function of size ratio and rotational speed of drum.
- 3) Kinetic energy normalized by potential energy increases proportional to the rotational speed, but inversely proportional to the size ratio.
- 4) The wet and contact coordination numbers of agglomerate grains are proportional to size ratio.

FURTHER RESEARCHES

- Investigation the agglomeration process of a huge number of particles.
- Comparison between experiment and simulation of agglomeration processes in rotating drum.

