A Study of Granulation Methods for Lincoln Electric

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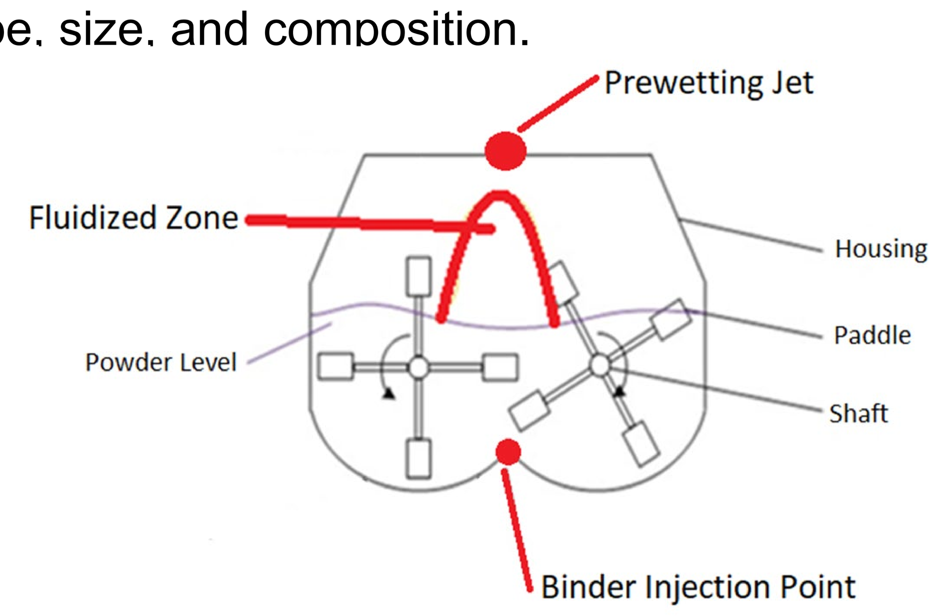
The senior design team working on the Lincoln Electric project is seeking to assist Lincoln Electric in developing improvements to the granulation processes of SAW granular fluxes to increase efficiency in production, specifically to reduce the mass fraction of particles that are too small (fines) or too large (overs), and thus fail to meet strict sizing criteria. Granulation processes such as high-shear mixing, Forberg paddle mixing, and fluidized bed granulation were tested to determine which process would result in prototype granules best matching the samples produced by Lincoln Electric.

This work is sponsored by Lincoln Electric, Cleveland, OH.

Project Background

Lincoln Electric is considering an upgrade to its manufacturing process for its product family of bonded Submerged Arc Welding (SAW) fluxes and is seeking an analysis and prototype demonstration using various granulation methods available at Purdue's Center for Particulate Products and Processes (CP3). Bonded SAW fluxes are typically a blend of powders (alumina, silicates, fluorspar, magnesia, and other minerals), bonded together with aqueous silicates in a granulation process.

The goal of this project is to determine the best granulation method to reduce out of size granules while maintaining current product properties, such as shape, size, and composition.

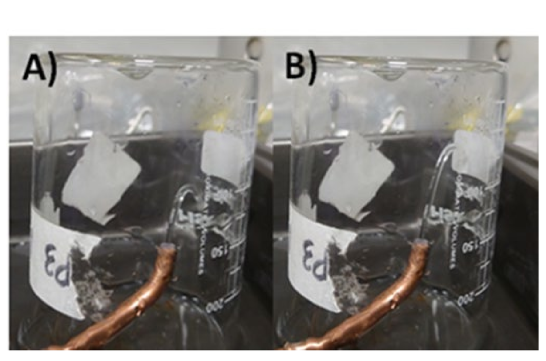


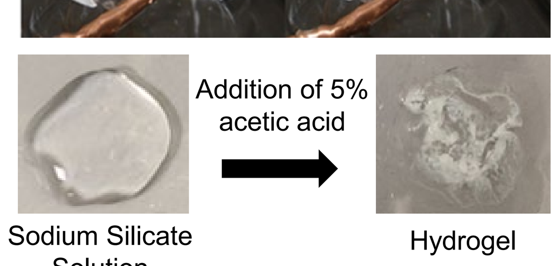
The Forberg mixer (above) was chosen for testing granulation processes due to its fluidization zone where binder could be injected, and the ease of installation in Lincoln Electric's current facility.

Experimental Procedure

The five raw material powders used are weighed and added to the mixer. The materials are dry-mixed to ensure even distribution. A select fraction of the fifth raw material is left out and is used later to cap the granules due to its high surface area.

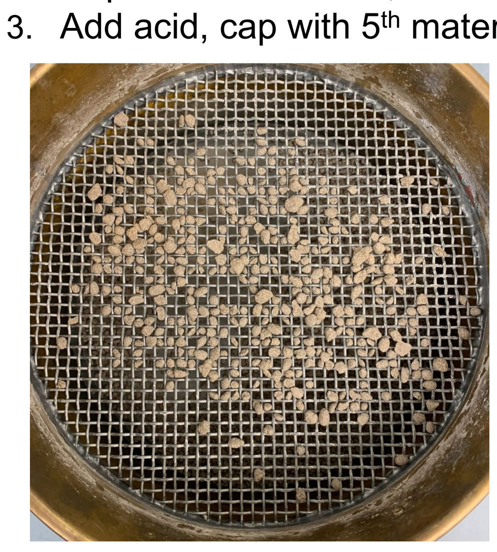
After dry-mixing, the sodium silicate binder is injected into the fluidization zone in the center of the mixer. The gel produced by the sodium silicate solution can be "set" with the addition of a weak acid. Acid is not a typical component and is mainly used in our prototype batches to expedite their preparation for characterization.





After the addition of the binder, several capping methods are tested by the addition of the fifth raw material powder and the acid.

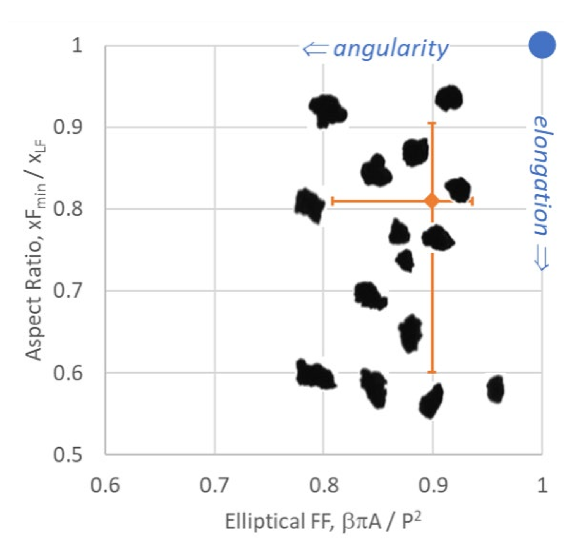
1. Cap with 5th material, no acid
2. Cap with 5th material, add acid
3. Add acid, cap with 5th material



Once the granulation process is finished, the granules are dried and sieved to remove any granules larger than 1700μm which are considered "overs" and cannot be used for welding. These are typically recycled and reworked in production. Granules smaller than 1700μm are termed "accepts."

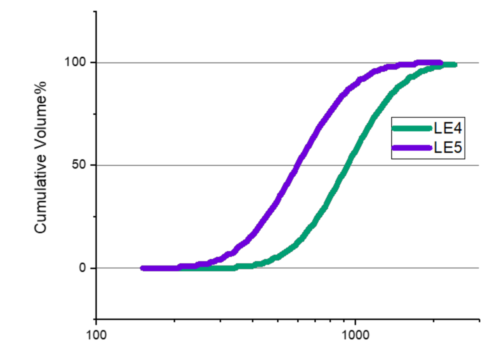
Results and Discussion

A Canty SolidSizer was used to collect size and shape data on the granules through image analysis, and a Flowdex was used to determine the angle of repose.

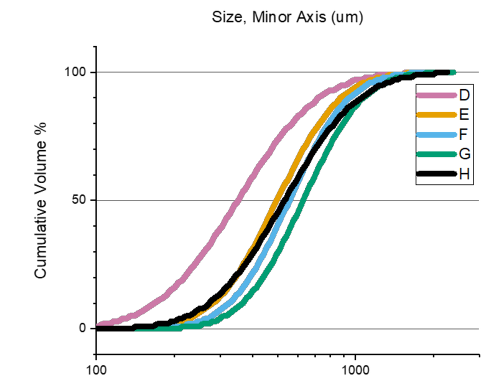


This plot is an example of the images collected by the SolidSizer. Here, the particles are plotted by their elliptical form factor and aspect ratio. The closer both variables are to 1, the more spherical and smooth the granules are; leading to increased flowability.

Lincoln Electric provided samples to use as a baseline to work towards.



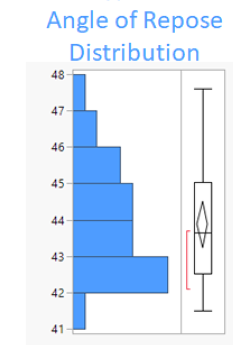
As samples were created, they were characterized in a similar manner.



Since the granules need to be able to flow well and pile up over a weld joint, the drained angle of repose (φ_d) needs to be between 40-45 degrees. This target was achieved in most prototype batches.

Sample/Prototype Batch	Average Drained Angle of Repose (degrees)
LE Sample 4	44.5
LE Sample 5	42.2
Prototype - Maximum	47.6
Prototype - Q3	45.025
Prototype - Median	43.65
Prototype - Q1	42.525
Prototype - Minimum	41.5

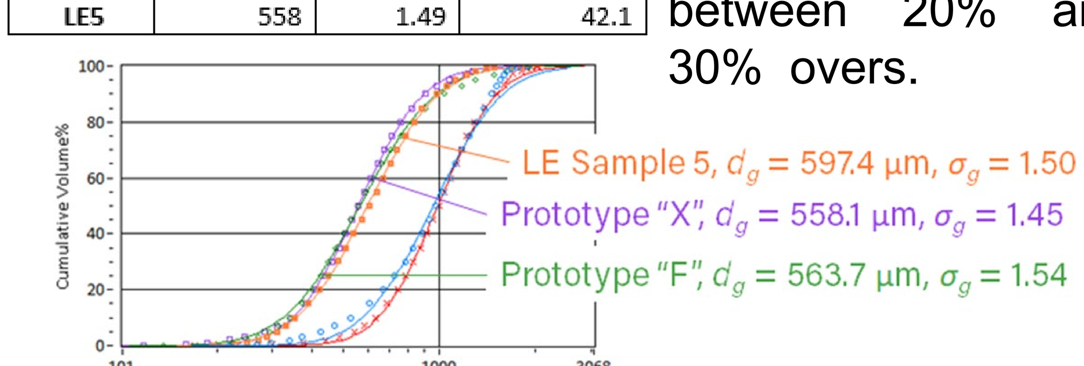
Prototype Drained Angle of Repose Distribution

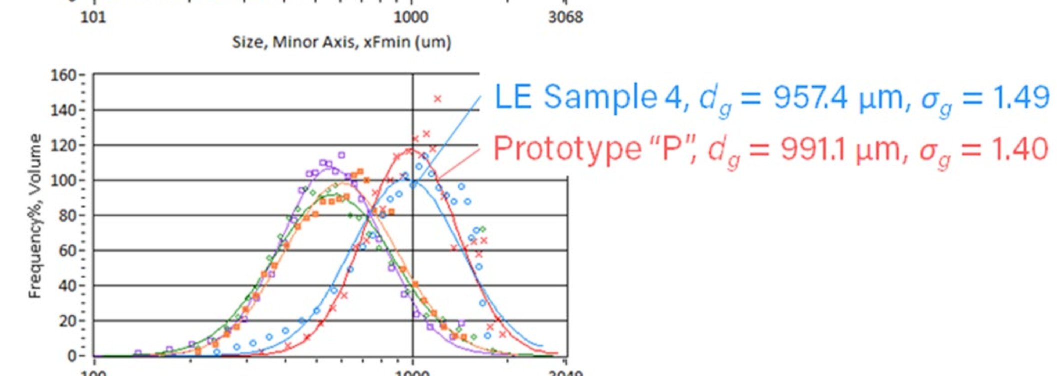


Granulations with φ_d > 45° are capped with concentrated acid and have lower FF* values

Sample	Geometric Mean (dg)	Standard Deviation	Avg Drained Angle of Repose
D	351	1.76	46.0
E	498.1	1.56	44.9
F	554.5	1.52	42.8
G	627	1.52	44.0
H	531.6	1.69	43.8
LE4	889.9	1.6	44.5
LE5	558	1.49	42.1

Early samples were very promising and within the acceptable ranges, except for the number of overs as each batch contained between 20% and 30% overs.

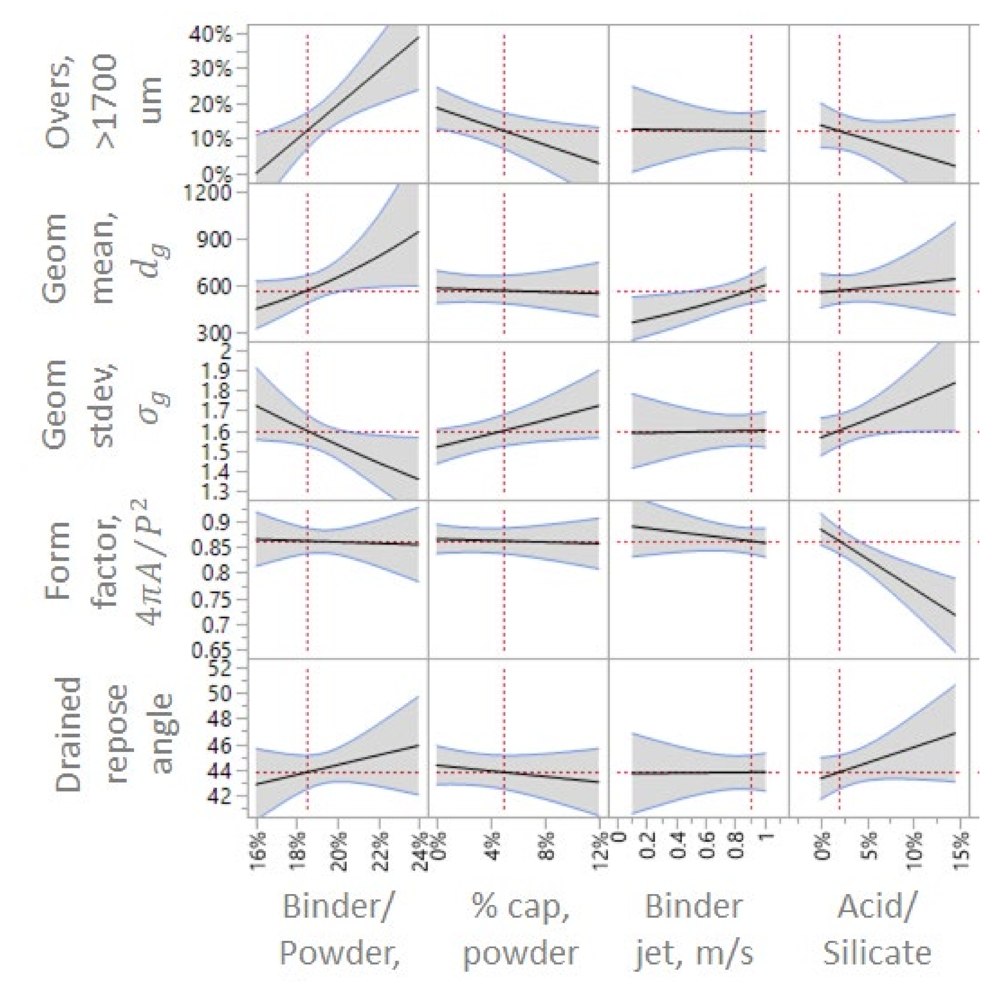




Of the many granulation processes we tested with different parameters, prototype "X" had the most similar size distribution of accepts to our target with 13% overs and φ_d of 45.0°. "X" was made with 18% "Binder / Powder, pre-cap" ratio, 1% "cap - powder", 3% "Acid/Silicate" ratio added before powder cap.

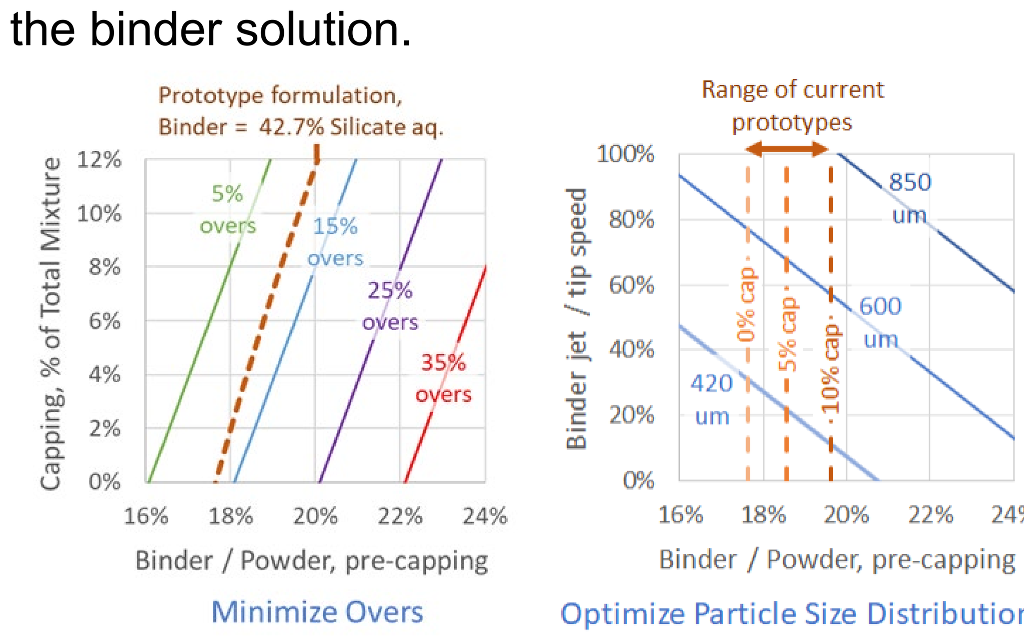
Summary of Effects

Compiling the processing parameters with the associated changes in particle characteristics, we created a linear multivariate least squares fit regression model with JMP analytical software. With the JMP Prediction Profiler, general trends in effects on granule characteristics created by changes in the processing factors independent of each other are observed.



The goal of this analysis is to determine which processing parameters will yield granulations with reduced overs without creating accepts that have too wide variations and too low average sizes.

Contour plots derived from the model show the processing parameter values interacting with overs and geometric mean particle size. Reducing the "Binder / Powder, pre-capping" ratio can reduce the number of overs but is also correlated with a decrease in d_g of accepts. Increasing the "Capping, % of Total Mixture" allows for an increased "Binder / Powder, pre-capping" ratio without increasing overs while also increasing the d_g of accepts. An increased "Binder jet / tip speed" ratio correlates with increased d_g of accepts with little effect on overs. Overs could also be reduced by increased concentration of silicate in the binder solution.



Recommendations

Based on these findings, Lincoln Electric should seriously consider a modified Forberg mixer as a feasible candidate to replace their current granulation mixer. We believe this will increase production efficiency, reduce cost, and produce a product that falls within their ideal design criteria.