Granulation for Submerged Arc Welding (SAW)

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Goal: Develop material and process understanding leading to increased process yield and granule strength for a Submersible Arc Welding (SAW) flux composition.

Approach:

1) Investigate relevant microscale parameters including milling of raw materials, wetting of same with various silicate binders, and evaluation of granular structure using compaction analysis.
2) Development and construction of a prototype mixer-granulator; process studies now in progress.

This work is sponsored by Lincoln Electric, Cleveland, OH

Project Background

Submerged arc welding (SAW) is a joining process commonly used for applications requiring long welds; it uses an electric arc to weld two metals. A ceramic, granular flux is used to cover and protect the molten metal formed by the electric arc. This flux is fed in front of the arc and forms a protective heap over the weld zone. SAW flux comprises a blend of alumina, silicate, and other elemental powders bonded with aqueous silicates to form granules.

Lincoln Electric (LE) is considering upgrading the granulation process used to produce SAW flux, with a goal of improving process yield, granule structure, and facilitating changes between fluxes in use.

This project is in its second year and builds on previous work. This year's work focuses on structural effects of SAW granules and implications for processing.

Experimental Methods

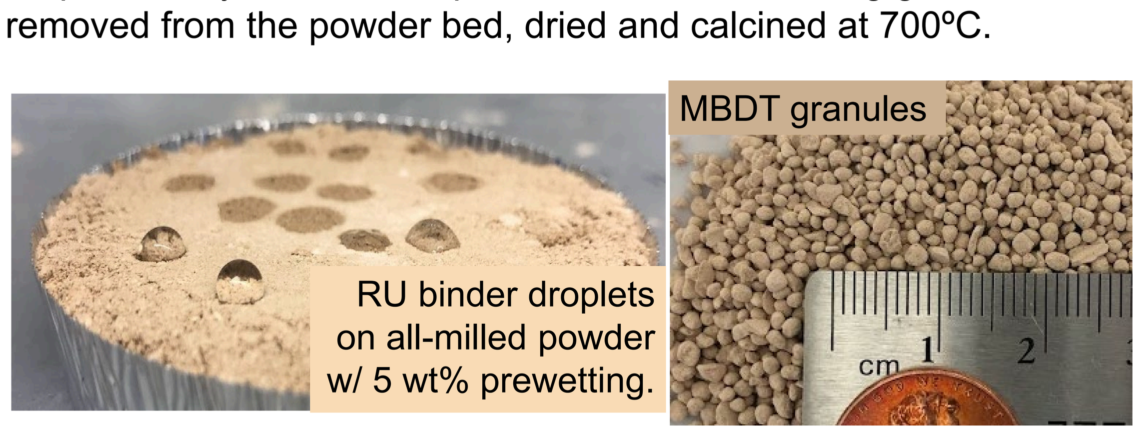
Milling & Particle Size Distribution (PSD)

Raw material powders were milled in a planetary ball mill (right), using ceramic media for 2 hours at 400 rpm. The reduction in particle size distribution was analyzed using the Malvern Mastersizer 3000.

The use of milled powder is especially relevant for capping, i.e., the addition of fine powder at the end of the granulation step, and is exemplified for fluorspar.

Granulation and Droplet Penetration Time (DPT)

Drop-templated granulation was performed on static powder beds. This enabled direct observation of binder-powder interaction, and comparison based on drop penetration time. Test variables included pre-milling of raw powders, pre-wetting of same, preparation of the powder bed (tapping vs. compaction), and binder-droplet composition (aqueous sodium silicate grades RU and K, and potassium silicate). The DPT is the time required for a binder droplet to fully infiltrate the powder surface. Resulting granules were removed from the powder bed, dried and calcined at 700ºC.



As a variant of DPT, a moving-bed drop-templated process (MBDT) was developed, using a food processor to create a moving bed of powder with a pulse of impinging droplets provided by a syringe pump.

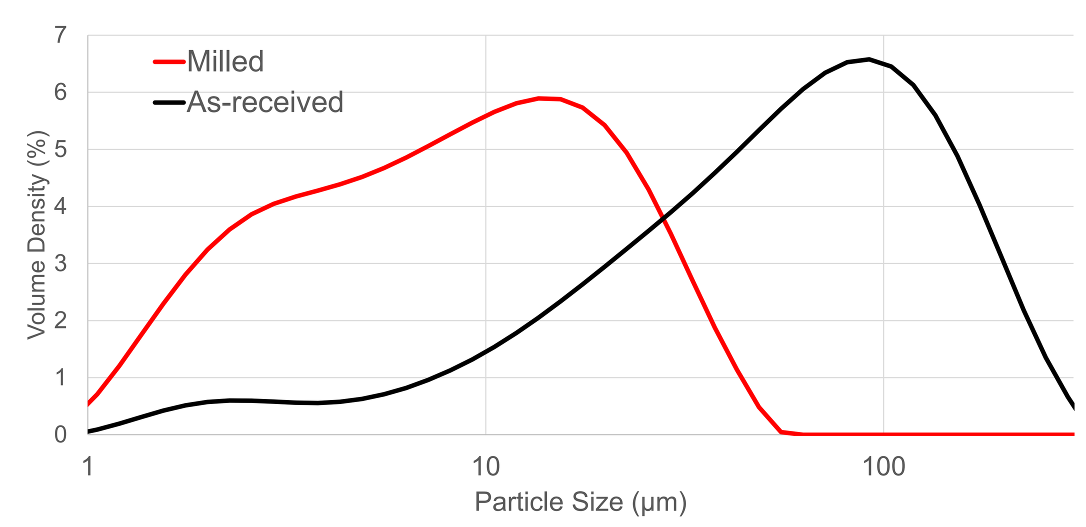
Compaction

Calcined MBDT granules were compacted in a tablet die, using an MTS load frame to collect force-displacement data, and converted to compaction curves using a python code developed by Dr. Paul Mort. Compaction curve analysis shows structural features including deformation yield stress of granules. MBDT granules were compared to LE flux samples to determine how different processing methods affect granule strength and density.

Results & Discussion

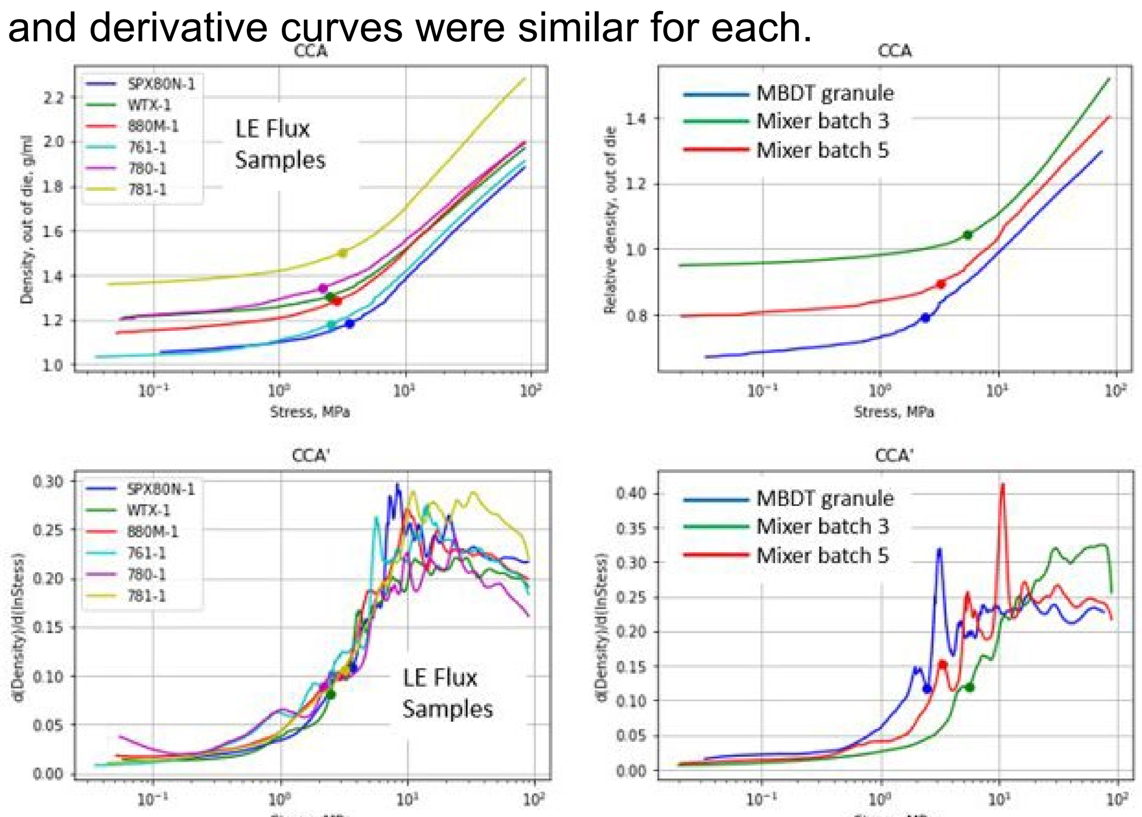
Milling & Particle Size Distribution (PSD)

Milling tests were done for all raw powders except for Wollastonite (which was already a fine powder). While significant size reduction effects were seen with Dead Burnt Magnesite and Leucoxene, we chose to focus on milling Fluorspar in conjunction with its potential use as a capping agent. Capping powder sticks to the outside of wet granules, stabilizing the structure, and providing a thin shell layer in the calcined product.

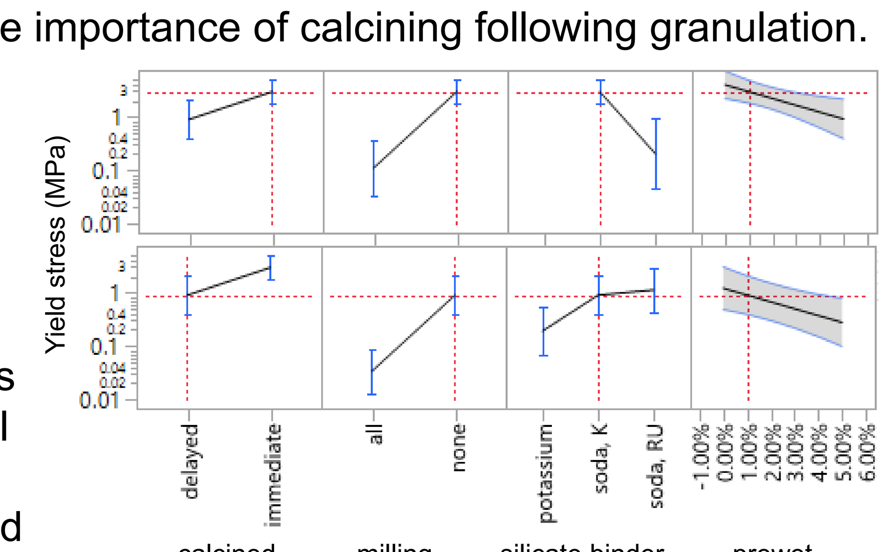


Compaction

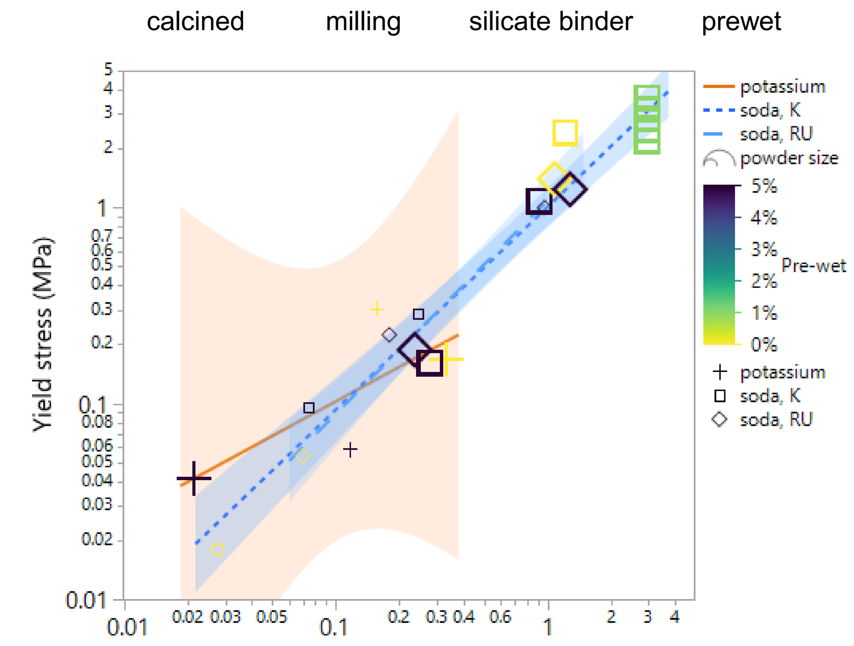
Flux samples made in the lab were compared to six flux samples sent by Lincoln Electric. The most similar MBDT sample had a similar process profile: no powder milling, 0% prewetting, and K grade silicate binder. Similar samples were also made in the lab using the mixer prototype; each with 0% prewetting and K grade silicate binder, Batch 3 with milled fluorspar and Batch 5 with no powder milling. Compaction and derivative curves were similar for each.



Compaction results from the DOE and LE flux samples were compiled into a statistical model, predicting yield stress as a function of material and process parameters. In addition to effects of raw powder milling and pre-wetting, the silicate binder had a strong correlation with calcining schedule, suggesting the importance of calcining following granulation.

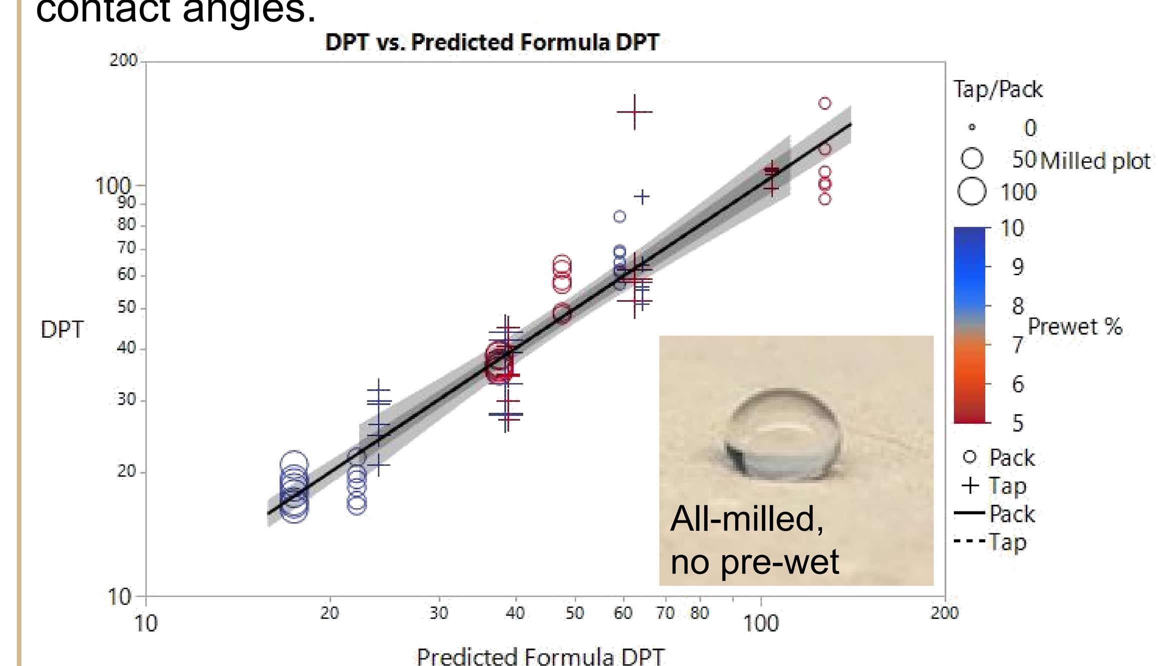


While no significant improvements in mechanical properties were achieved in the DPT study, the DPT method was shown to be a good proxy method for lab-scale formulation screening.



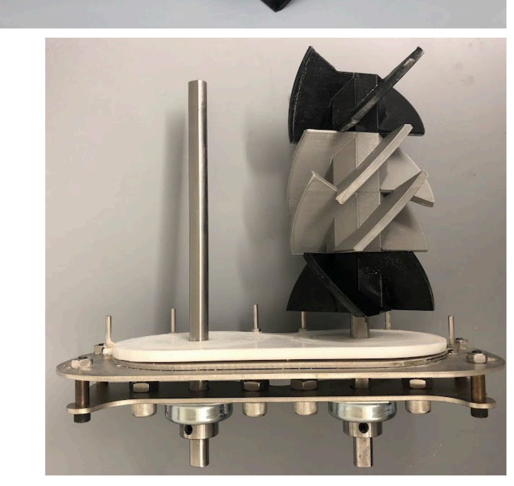
Granulation and Droplet Penetration Time (DPT)

Static DPT results were evaluated using a statistical model to better understand the impact of each variable. The model showed that milling and amount of prewetting were the two most important variables. DPT variance seems to correlate with uneven powder bed surfaces and high liquid-powder contact angles.



Mixer Prototype

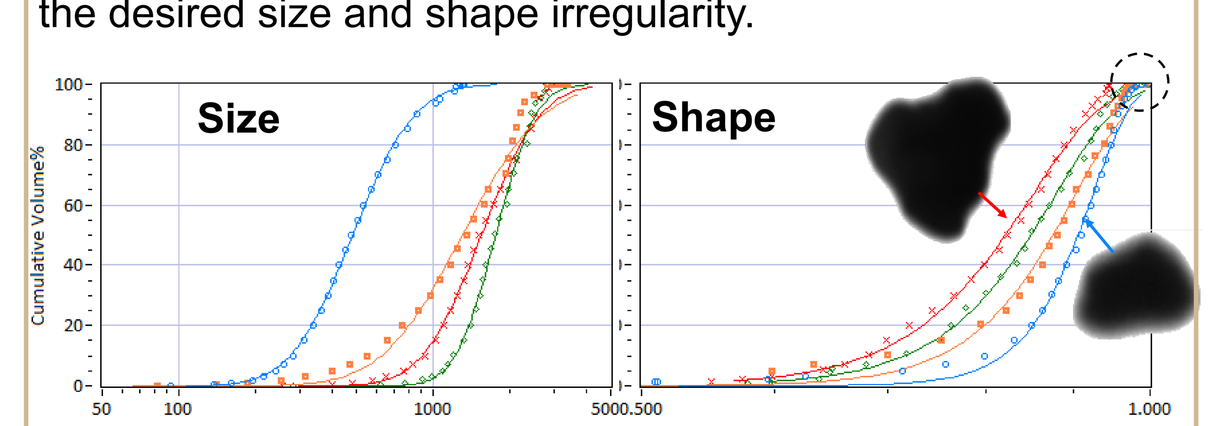
The design for a paddle mixer was provided by the previous year's LE team. The small basin size and ability to 3D print parts allowed for a high level of control over the design in addition to rapid prototyping of paddles shapes (shown right).



The mixer basin can rotate 360º to allow for swift removal of granules after granulation is complete. The drive train is easily removable from the stand and mixer body, allowing for easy cleaning of internals.

Speed is adjustable and torque is monitored. Binder can be added to the flux at a controlled rate by utilizing a syringe pump that feeds the liquid binder through a small opening in the bottom of the mixer.

Dynamic image analysis of granules made in the mixer showed the capability of the mixer to create granules with the desired size and shape irregularity.



Batch	Tip speed, m/s	Binder level, pre-cap	Binder rate	d_g	σ_g	FF*
3	1.3	~18%	~30	483	1.56	0.93
4	1.4	21%	45	1308	1.78	0.90
5	1.4	21%	30	1764	1.33	0.88
6	1.7	21%	30	1550	1.52	0.85

Conclusions

Delaying of calcining, prewetting, and milling of raw powders were found to have a negative effect on the strength of flux granules. The paddle mixer developed by the current and year previous' Senior Design teams should be able to optimize granulation parameters and outcomes including granule size distribution and granule strength. For mixer granulation, focus should be on binder addition rate and motor tip speed. Additionally, the mixer basin and paddles could be redesigned to decrease build-up over time. Fabricating mixer parts from more durable materials would also be of interest.