The Effect of Removing Dust from Backup Stuccos on Shell Properties

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ABSTRACT

A recent trial using Virginia Mullite showed a higher than desired amount of nuisance dust in the 20x50 stucco. In response, Kyanite Mining Corporation implemented changes in the existing screening production process to remove the minus 65 mesh mullite and smaller particles. The following paper examines the effect of the removal of the minus 65 mesh particles in the new standard 20x50 product compared to the original 20x50 material. Testing and comparable data was derived which contrasts the two stuccos in both a rotary drum sander and fluidized bed.

INTRODUCTION

Virginia Mullite™ has been used in the investment casting industry as flour and stucco for many decades. A recent trial of the 20x50 stucco product generated a customer comment on the amount of dust coming out of the rainfall tower. This dust was a nuisance to the operators, it was reported. Kyanite Mining Corporation (KMC) was asked if it could investigate this issue and if changes to the material were possible to limit the employee's exposure to these fines. Historical data showed that KMC's 20x50 mullite stucco commonly contained between 20-30% in the pan (-50 mesh) and was at the bottom end of the specification for particle size. It was decided that this is too many fines in the product and the specification needed to be tighter.

The task to reduce fines was given to the plant. The plant first tried to vary the screen size to adjust the number of fines (defined as able to fall through a 50 mesh screen). They were able to produce material that had less fines, but they had to greatly reduce the feed rate to achieve the desired screening. Multiple attempts at changing screen size and feed rates resulted in limited success. Virginia Mullite™ is made by calcining Virginia Kyanite™, which is a blade shaped mineral. The mullite created after the conversion process keeps this blade shape, creating individual crystals that have a high aspect ratio. This caused difficulties as the blades may be able to pass through a screen when turned up on end that are much too large in any other orientation. Reducing the feed rate caused higher amounts of vibration on the screen, leading to an increase of particles passing through endwise.

After some internal work, KMC reached out to two screen suppliers for advice. Trials were done at both supplier's facilities to find the right solution. In the end, three things were changed:

1. Changed the size of the bottom screen to allow the fines to pass more easily
2. Added an additional screen in the middle of the screen stack. This helped to reduce the load on the final screen and improve screening efficiency
3. Adjusted the position of counterbalance weights to control the bounce of the product and retention time on top of the screen

With these changes, the plant was able to create a product with less than 6% in the pan while also retaining less than 1% on the top screen (20 mesh). The new setup also allowed the plant to produce this material at only a slightly reduced rate as compared to the old, "dustier" product. After the successes proved repeatable, changes to the 20x50 specification were suggested, shown in **Table 1**.

Table 1: Particle Size Specifications for the old and new 20x50 stucco

	Retained on Screen (%)			
	20m	40m	50m	pan
Old	1	27-42	30-50	30 max
De-Dusted	<1	93 min		<6

KMC wanted to make sure that removing these fines would not have a negative effect on the performance of the product. A literature review showed many studies examining how changes in particle size distribution of flour effects slurry rheology,[1,2,3] but less work has been done on the influence of particle size on stucco. Studies show that increasing particle size tends to lead to thicker shells, weaker post-fired Modulus of Rupture (MOR), and increased permeability.[4,5] Most of this work was done on fused silica stuccos and there was little data on the effects of changing the particle size distribution of aluminosilicate stuccos. It was decided that this needed to be tested in the R&D lab at KMC to evaluate the old vs de-dusted material before another trial.

TEST SETUP

The primary goal of the study was to determine the effects of fine particles on a 20x50 stucco. KMC wanted to verify that removing the -50 mesh particles did not have a drastic negative effect on the performance of the stucco. To test this, two stuccos were used. The first the stucco that had been the standard product for KMC for many years. The second is the new standard product with the dust removed. For clarity, the old material is labeled “Old” and the new material “DD” in the graphs and tables. The stucco was applied using either a rotary drum sander (RD) or a fluidized bed (FB), as both are common in the industry. This created four unique conditions: Old material applied by rotary drum, old material applied by fluid bed, de-dusted applied by rotary drum, and lastly, de-dusted applied by fluid bed. The 20x50 stuccos were used in all layers. Dust collection systems were turned on for both application methods.

Each of the stuccos was screened on a Ro-Tap before dipping began and in between each coat. Screening was done after each coat was applied to check for loss of fines to the surroundings (nuisance dust).

As this is a test of stucco, the slurry used for each coat was kept constant. This slurry was a 200 mesh Virginia Mullite™ based slurry that utilized large particle colloidal silica and a latex polymer. Surfactant was added to aid in wetting the wax and antifoam was used to combat bubbles. This slurry was used on all coats throughout the shell build. The viscosity was held constant at 20 seconds on a Zahn EZ #5 cup. The bars were made of 8 layers of slurry and stucco followed by a seal coat.

Metal bars approximately 12x1x0.125 inches were dipped in a non-filled wax to create the substrate for the MOR samples. The same was done on larger bars measuring 12x2x0.125 inches for the permeability samples. Bars were placed in a temperature and humidity-controlled cabinet before dipping began and after each dip. Bars remained in the cabinet until dry and for a minimum of 4 hours. Loose stucco was brushed off with a paint brush before each dip.

MOR was done according to ASTM C133-97 (2015) in three-point bend on both green and post-fired bars. The post-fired bars were fired in a box furnace at 2400°F (1315°C) with a two-hour hold. The test was conducted with the flat wax surface facing downwards and in tension. 10 bars were tested for each condition, both green and fired.

Permeability testing was done at the Buntrock Industries Inc. Technology Lab using a permeability testing method presented at the 52nd ICI Technical Conference and Expo.[6] This test was chosen to avoid any issues with inadequate burnout of the ping pong ball.

RESULTS AND DISCUSSION

Screening

Screening samples were taken before each coat of slurry was applied. **Table 2** shows a comparison between the old and the de-dusted material that was used. The de-dusted stucco material was much coarser than the old stucco. The two samples of the old 20x50 show a much higher amount of -50 mesh particles, as was expected. The de-dusted material also has a significant amount of +30 mesh material that is not present in the older material. This coarser size stucco should help improve shell building. Evidence of this is seen in the thickness of the MOR bars, discussed further below.

Table 2: Particle size distribution of the starting stuccos for all four conditions

	Mesh Size							
	20	**30**	**40**	**50**	**70**	**100**	**140**	**pan**
Old RD	0.00	0.38	25.13	47.98	25.18	0.99	0.16	0.19
Old FB	0.00	0.16	26.71	46.15	25.60	1.06	0.12	0.20
DD RD	0.00	9.56	41.16	43.67	5.15	0.19	0.13	0.15
DD FB	0.00	8.03	45.33	41.21	5.12	0.17	0.05	0.09

As the dipping began, screening samples were taken to observe any changes in particle size distribution. **Figure 1** shows how the stucco changed for all four conditions. In general, the number of fines (defined as -50m) in the fluid bed stuccos did not drastically change. There were some inconsistencies in the intermediate coat data, but the material saw less than 1% change from the first to last coat in both cases.

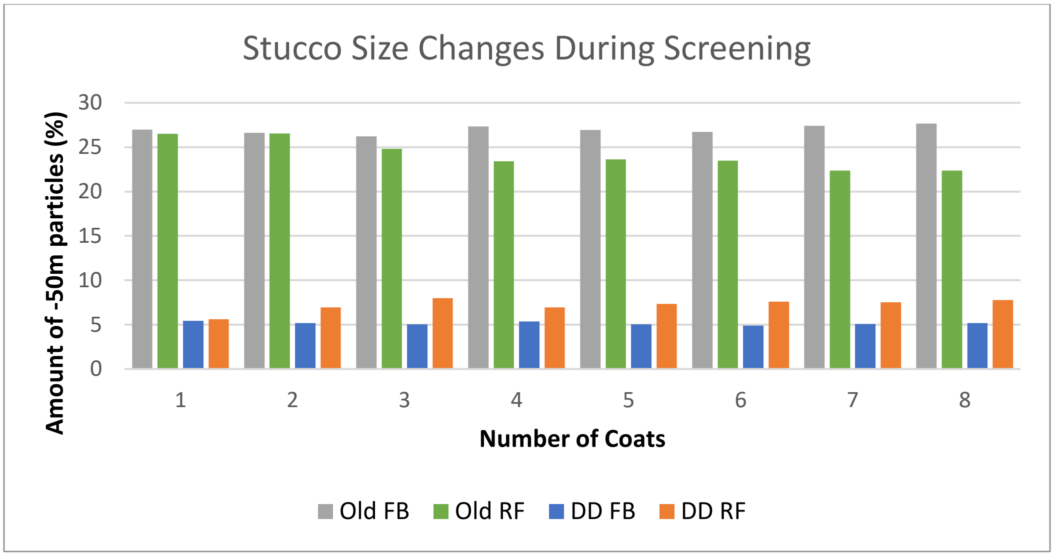

Figure 1: The change in particle size of each stucco was observed before each coat was applied

The materials in the rotary drum sander did change over time. The old material lost some of its fines (4.16%) to the environment from first to last application. This loss of fines was a linear change and can likely be attributed to nuisance dust being lost to the environment or pulled out by the dust collection system. In contrast, the number of fines slightly increased in the de-dusted material as the testing progressed. There was a 2% gain in the number of fines when comparing the first to last application. The fines reached their highest amount on the third coat and remained steady throughout the rest of the test. This can be explained by the friable nature and shape of the mullite. When kyanite converts to mullite, there is expansion of the crystal, making it a more friable material. When the stucco falls on the screen inside the rotary drum sander, sharp corners are knocked off and weak particles break. By the third stucco application, these weaker particles appear to have already been broken, causing a plateau in the data. The same likely happens in the old dustier stucco, but the phenomenon is not noticed due to nuisance dust being lost.

Videos were taken during each dip of all four conditions to observe the amount of nuisance dust floating in the air. As expected, the videos showed a higher amount of dust escaping both application methods when using the old stucco. There was as noticeable amount of fine mesh material coating the lip of the drum sander that was not observed using the de-dusted material.

The results of the screening tests indicate that the de-dusted material will not cause a lot of issues with nuisance dust for the operator. Another benefit is less dust will end up in the dust collection system and more of the product shipped in the bag will go directly on the castings and not be lost to the dust collector. This also means less cleaning out the bag house which saves time and money.

The dust loss data on the old stucco suggests that dustier stuccos should be run for a while in the rotary drum sander before the operator has to be in the area for an extended period when new material is introduced to the sander. This would allow the dust collection system to extract some of the fines from the stucco and reduce the operator's exposure to dust. The extra amount of time to perform this step would have to be evaluated on a per case basis.

MOR

The Modulus of Rupture (MOR) was tested to investigate the effect of dust on the strength of the shell. This data is shown in **Figure 2**. All four green conditions had similar MOR except for the de-dusted stucco applied with the fluid bed. That sample had a 16% lower MOR value than the old stucco applied the same way. This large difference was not expected as the rotary drum sander produced bars with similar green strength using both stuccos. Further testing needs to be done to confirm or update this result.

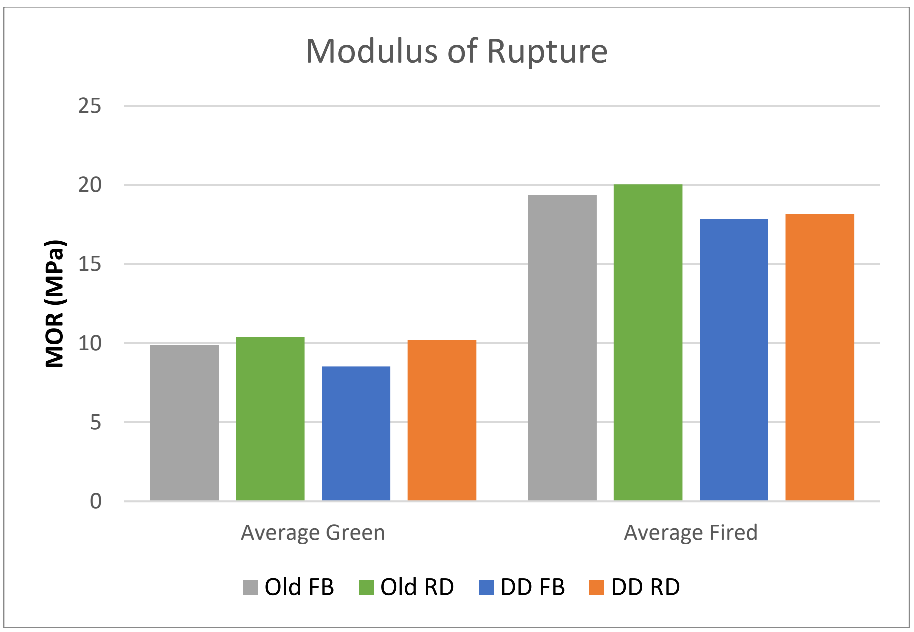

Figure 2: Modulus of Rupture was used to examine the effects of removing dust on the strength of the shell in both the green and post-fired condition.

In the fired state, the old stucco had higher MOR than the de-dusted material in both application methods. The old stucco was 10.3% stronger than the de-dusted stucco using the rotary drum sander and 8.3% stronger using the fluid bed. It is understood that wider particle size distributions create a ceramic body with better particle packing.[7] Having more variance in particle size allows small particles to fill gaps between larger ones, reducing the pore sizing between the ceramic particles. The presence of a higher number of fines also increases the overall surface area of the mullite stucco. The decreased pore space in combination with higher surface area would lead to a greater amount of sintering during firing than a coarser stucco with a narrower particle size distribution. This would create a stronger structure and produce higher MOR values. With a lower post-fired MOR, the de-dusted stucco would create a shell that is easier to knock off than the old material.

Lastly, the MOR of the bars made via the fluid bed had lower MOR values than those made with the rotary drum sander using both stuccos. This can be attributed to the depth of stucco penetration into the slurry layer. The rotary drum application method allows the stucco to fall and gain kinetic energy before contacting the wet slurry. This allows the stucco particle to penetrate the slurry level deeper, coating more of the particle in slurry and creating a stronger bond.[8] This result is in line with others who have examined MOR differences between shells created using fluid bed vs rainfall sanders. [8,9,10]

Shell Thickness

Thickness measurements from the MOR bars show that the de-dusted stucco created a thicker shell with the same number of coats. On average, the coarser de-dusted stucco shell was around 6% thicker than the shell with the old stucco. This was expected as similar results were seen in the literature.[5] The higher amount of+30 mesh material in the de-dusted stucco would tend to create a larger coat by itself, but the removal of dust also aids in shell build. There was a noticeably higher amount of airborne dust when using the old stucco in both application methods. This dust started to coat the wet bar as soon as it was introduced to the sander and reduced the ability of the larger particles to properly adhere, resulting in a thinner shell.

The bars using the de-dusted stucco applied by the fluid bed were the thickest, as expected. Research has shown that fluid beds produce thicker shells than rainfall sanding methods.[9] As mentioned previously, the increased kinetic energy gained by falling in a rainfall situation allows the stucco to imbed itself further into the slurry layer. This reduces the height of the stucco sticking out and creates a thinner shell.

Permeability

Unfortunately, due to issues in the lab at KMC, permeability data was not available at the time of publication. This data will be presented at the technical conference.

However, it has been shown in the literature that increasing the particle size increases permeability of the shell. It was also shown by Whitehouse/Snyder that additions of 50x100 stucco had a negative effect on the shell's permeability.[5] It is therefore hypothesized that the coarser size of the de-dusted stucco will create a shell with higher permeability than one made with the old stucco.

A review of the literature also indicates that using a rainfall sander to apply the stucco will create a shell with less permeability than one created with a fluidized bed.[8] This is due to the increased kinetic energy at impact due to falling from an elevated height. Data from the thickness testing has already shown one effect of the increased kinetic energy at contact. It is hypothesized that the samples make the in rotary drum will have a lower permeability than samples made in the fluid bed for this same reason.

CONCLUSIONS

The main goal of reducing nuisance dust was achieved by tightening the specification on the -50 mesh particles. The number of fines in the de-dusted material changed very little over the course of the dipping sequence in either the rotary drum or fluid bed while dust was lost to the environment when using the old stucco. There was a slight increase of smaller particles when using the dedusted material in the rotary drum that reached a plateau on the 3rd application. This can be attributed to the friability of the mullite. This phenomenon would be seen in the old stucco as well if the evidence were not being washed out by the loss of fines to the environment.

MOR testing showed that removing the fine particles from the stucco had a negative effect on the fired strength of the cast bars. This could be a good outcome as knockout would be made easier. The green strength remained mostly unchanged, except for the de-dusted stucco when using the fluid bed. Further testing will be done to confirm or update this result. Differences in shell thickness were also observed on the MOR samples. The bars made using the de-dusted stucco were thicker, indicating a faster shell build with this new material.

In conclusion, it is likely that the de-dusted stucco did meet the goal of less nuisance dust without any drastic negative impacts on the final product. By reducing the amount of dust lost, the operators will be able to work in a cleaner environment and the dust collection system will need cleaning less frequently, saving time and money. Further investigation will be performed to make sure that permeability has not been negatively affected.

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