

The Use of Bottom Ash in the Manufacture of Clay Face Brick

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ABSTRACT

The clay brick face industry has utilized bottom ash as a body additive for many decades in the US. Bottom ash has properties that provide many favorable benefits to the clay brick maker.

Brick making clays that are plastic in nature form a dense mass when subjected to the extreme pressures of the extrusion process used in the brick manufacturing process. The denser the extruded product, the more sensitive it is to drying. These materials also tend to be high in drying and firing shrinkage. These characteristics can result in high process losses due to the formation of cracking of the brick during the drying and firing process.

There is therefore a need to improve the properties of clays such as these by the inclusion of a suitable non-plastic body additive, designed to reduce the shrinkage and stabilize the body's drying and firing properties, to enable it to be processed successfully. It has been found that these plastic brick clays can be improved a great deal by the inclusion of a non-plastic material such as bottom ash into the manufacturing formulae.

The paper examines the characteristics of bottom ash as well as the beneficial effects that bottom ash provides to a brick making raw material and the brick making process. An example of a body composition enhancement, processing improvements and the resultant overall production improvement is given.

The technical and economic advantages of using a waste material such as bottom ash for the manufacture of durable structural clay products, is discussed.

INTRODUCTION

Furnace bottom ash has been used in the brick industry in the US for many decades, in many applications and with a variety of different clay and shale types. Many benefits have been derived from its use as an inexpensive non-plastic component in the brick body, designed primarily to reduce and stabilize the shrinkage properties of the body in the drying and firing processes (1). The use of bottom ash is particularly advantageous with brick making clays that are extremely plastic in nature and fine in particle size. Such a material exists at the Acme Brick San Filipe plant in southeast Texas. The main clay component of the body is unique in that it is high in montmorillinite content. Montmorillinite is an extremely fine plastic material, which has very high shrinkage properties. The brick manufacturer often avoids the use of this type of clay due to the extreme difficulty experienced when attempting to process it. In the case of the San Filipe facility, this clay type was the predominant clay reserve available in the particular area that was chosen for the plant construction. The decision to build the facility in this location was market driven. It was therefore left to the technical group to develop a suitable brick body that would make production of quality products possible.

Many brick plant operations that need a non-plastic component in the body formulation make use of a suitable fine graded sand component with great success. This was the original approach taken when the San Filipe plant was first commissioned. However, it was soon found out that this formula would not work. The extremely fine montmorillinitic clay type at San Filipe required an additional component to stabilize the body. Bottom ash was found to be the most suitable material.

Experience has shown in the operation of the plant over the past twenty five years that the use of bottom ash in combination with the San Filipe materials has been essential. The elimination or variation of the bottom ash component in the body results in high production losses and poor product quality. Work was done to at the Acme Technical Center in Denton, Texas to investigate the technicalities behind the influence of the bottom ash component on the San Filipe body. It was important to gain an understanding of the mechanisms at work and thereby determine the critical process control areas in order to sustain the success of the plant.

CHARACTERIZATION OF RAW MATERIALS AND BRICK BODY

The current San Filipe brick body composition consists of the following components:

Chew clay	53%	(range 52 - 54%)
Abel sand	32%	(range 31 - 33%)
Bottom ash	15%	(range 14 - 16%)

Chew clay

Characterized as a soft phyllosilicate mineral, of the Smectite Group. The San Filipe formation is montmorillinitic clay and is extremely fine and plastic (2). The water content of these clays is typically variable. Increases in moisture cause swelling and extremely high and variable shrinkage. The drying sensitivity is therefore high due to high shrinkage properties. Lime content is relatively high and quartz content low.

Abel sandy clay

The Abel material is a sandy kaolinitic clay mineral. It has a high in free quartz content and is poor in plasticity. It contains no Smectite minerals.

Bottom ash

Typical PRB coal bottom ash received at approximately 12% moisture. QA/QC controlled by the supplier not to exceed 2% LOI. The ash also contains high concentrations of soluble sulfates and some pyrite.

Table 1 illustrates the approximate chemical and mineralogical analysis of the three San Filipe body components.

Major chemistry	Chew clay %	Abel sand %	Bottom ash %
SiO ₂	46.1	83.7	42.8
Al ₂ O ₃	15.6	13.0	16.8
Fe ₂ O ₃	5.70	3.31	7.52
Na ₂ O	0.29	0.05	1.09
K ₂ O	2.24	0.26	0.38
CaO	10.9	0.05	22.0
MgO	3.08	0.25	4.27
TiO ₂	0.66	0.32	1.29
S	<0.05	<0.05	0.34
Mineralogy			
Quartz	16	65	5
K-feldspar	5	-	<5
Plagioclase-fsp	-	-	10
Mica/illite	12	-	-
Smectite	42	-	-
Kaolinite	-	32	-
Calcite	17	-	-
Clinopyroxene	-	-	15
Gehlenite	-	-	20
"Amorphous"	-	-	<40

Table 1: Approximate chemistry and mineralogy of the SFP components.

EXPERIMENTAL

In order to study the influence of the bottom ash, the following two body mixes were compared:

Non – bottom ash body (SFP-17)		Current SFP bottom ash body (SFP-18)	
Chew clay	60%	Chew clay	53%
Abel sand	40%	Abel sand	32%
		Bottom ash	15%

The two sample batches were prepared in the lab by grinding to an 8-mesh particle size. The mixes were tempered to the correct moisture content and extruded through a lab scale extruder into 50 x 20mm extruded bars. Influence of the bottom ash was analyzed from the data obtained from various measurement techniques used on the dried and fired samples. The comparison of the dry samples and the fired samples at the plant firing temperature was made. The reactions through heating and the resultant shrinkage and water absorption values over a range of temperatures were examined for each body.

The following analyses were carried out on the two bodies:

- Analysis of dry and fired physical properties (including Chew clay)
- Particle Size Equivalent analysis (PSE)
- Pore size distribution analysis of dry and fired samples
- Simultaneous Thermal Analysis (STA)(DTA/TGA/SDA)
- XRF chemical analysis
- XRD analysis; quantitative mineralogical analysis
- Microscopic analysis

RESULTS AND DISCUSSION

Shrinkage and fired strength comparisons

The examination of the two bodies in the dry state provided a clear picture of the importance of reducing the wet to dry shrinkage. The comparison with the pure Chew clay in Figure 1 illustrates the effective reduction of shrinkage when using high proportions of sandy clay (sample SFP-17) as well as the sandy clay/bottom ash combination (sample SFP-18). It can be seen that the wet to dry shrinkage of the Chew clay is 8.4% and fired shrinkage some 0.4%. The sandy clay body (SFP 17) and sandy clay/bottom ash combination body (SFP 18) are used the two bodies are virtually

identical, with wet to dry shrinkage reduced to 6.8% and firing shrinkage increased to 0.9% and 1.3% respectively. Furthermore, a 46% increase in the fired Modulus of Rupture was seen when comparing the non-ash body with the ash body. These changes are significant and will be discussed later in the text. Both test bodies were seen to have uniform and acceptable drying properties.

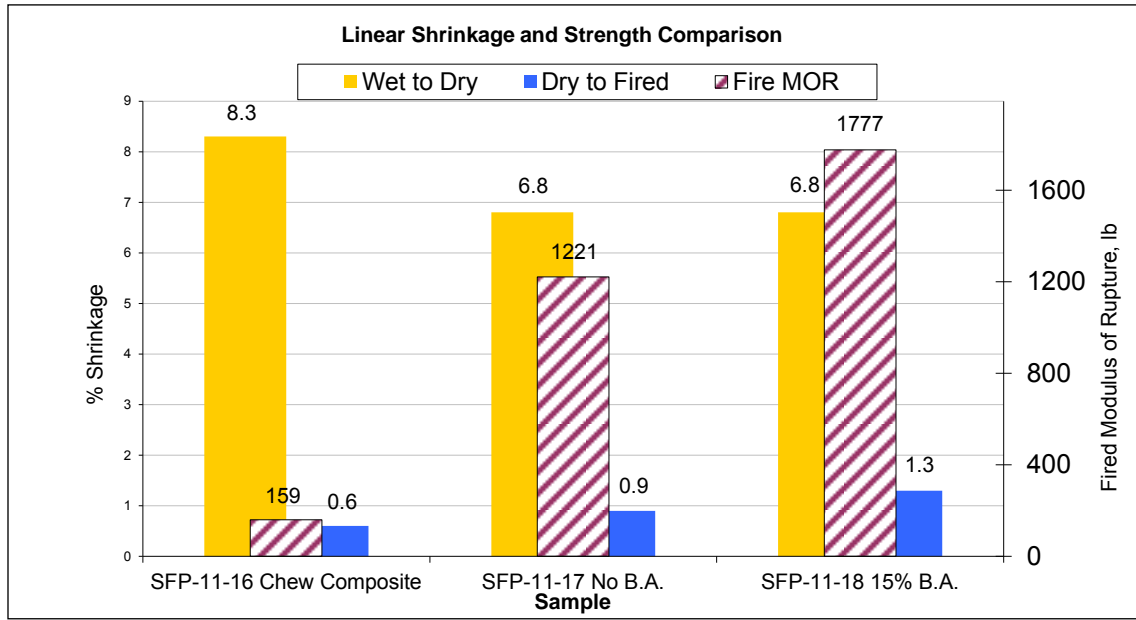


Figure 1: Wet-Dry and Dry-Fired shrinkage and MOR of the Chew clay and test bodies

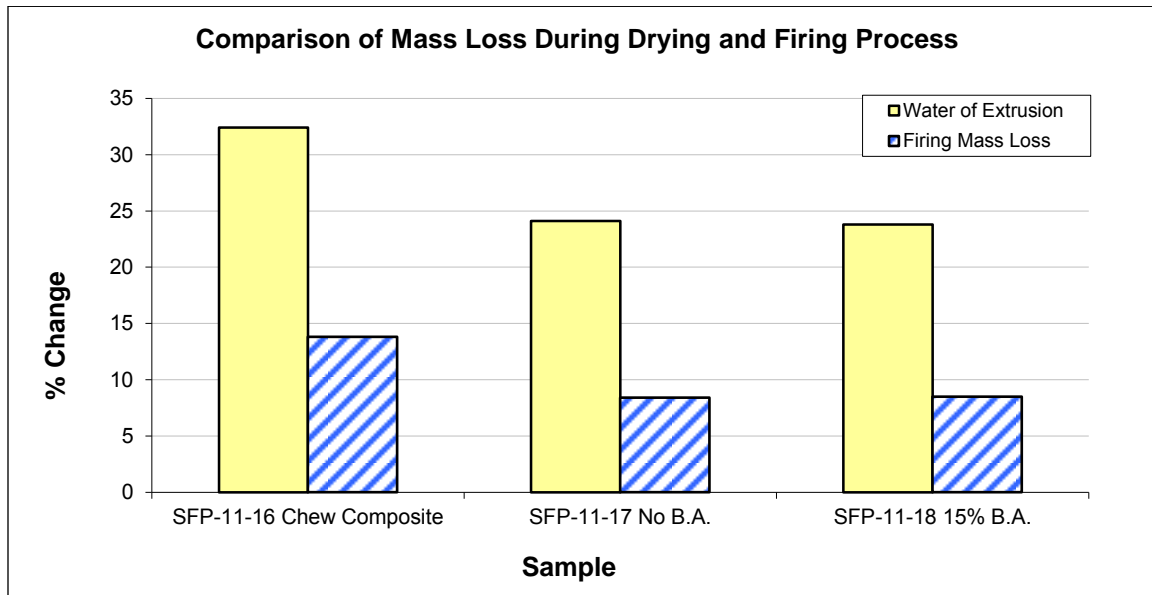


Figure 2: Comparison of mass loss during drying and firing process

Figure 2, illustrates the reduction in the water of extrusion and dry to fired mass loss. Beneficial reductions of these parameters are seen in the brick body with Abel sand (SFP 17) and the body with the bottom ash component (SFP 18), resulting in improved drying characteristics.

Particle Size Equivalent Analysis (PSE)

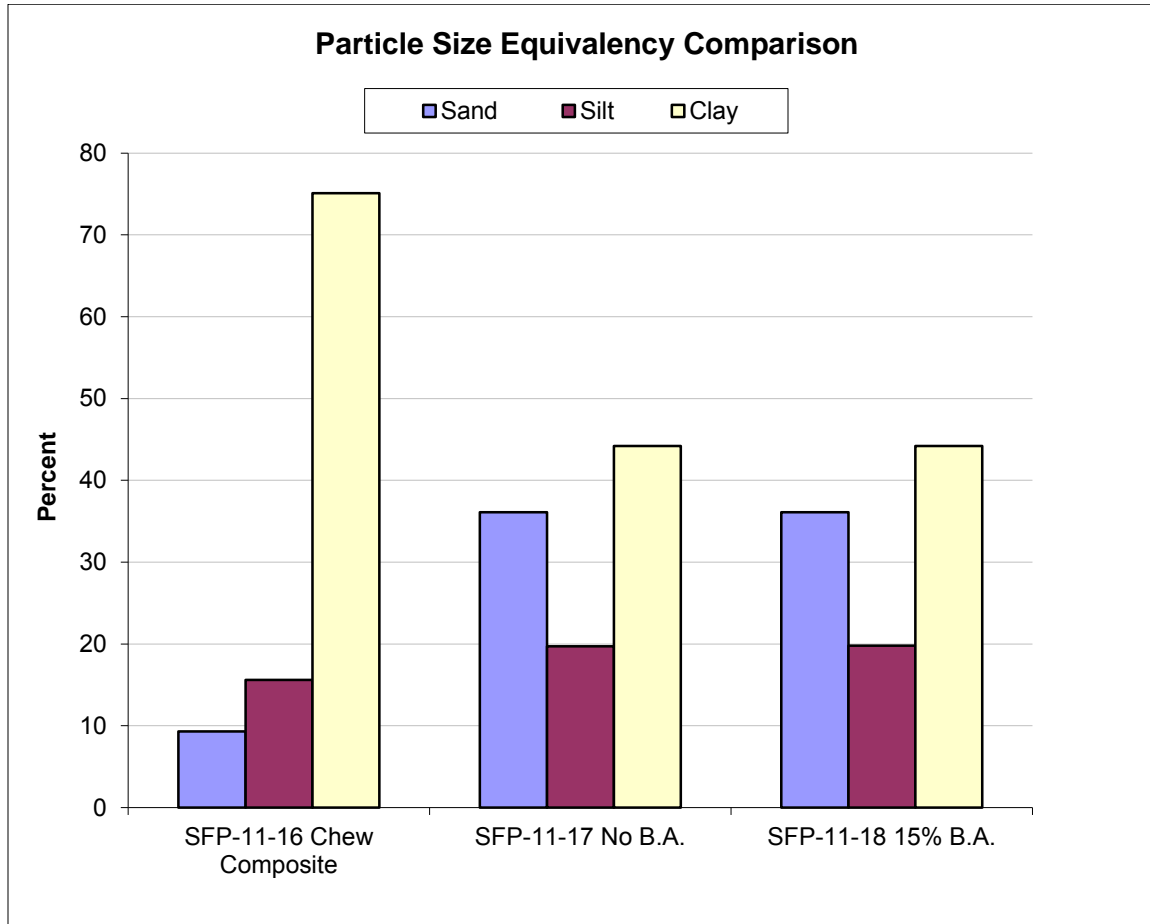


Figure 3: Particle size equivalent (PSE) of the pure Chew clay and the two test bodies.

The addition of the Abel sandy clay in SFP 17, as well as the sandy/bottom ash combination in SFP 18, reduced the clay content to workable levels. It can be seen how similar the two test bodies were when using of the Abel sandy clay (SFP 17) as well as the sandy clay/bottom ash combination (SFP 18).

Both bodies performed well in the drying process, but the non-ash body (SFP 17) failed to produce acceptable quality brick due to extrusion lamination difficulties and inferior fired properties.

Pore Size Distribution Analyses

Further, examination of the pore size distribution was carried out using Mercury Intrusion Porosimetry (3). Figures 4 and 5 illustrate the influence bottom ash has on the dry and fired micro-structure of the brick body.

The bottom ash increased the median pore diameter by some 86%. The dry permeability and resultant drying rate and hence drying sensitivity of the body is influenced by this parameter. Production experience has shown that the bottom ash body produces the best performance through the drying process.

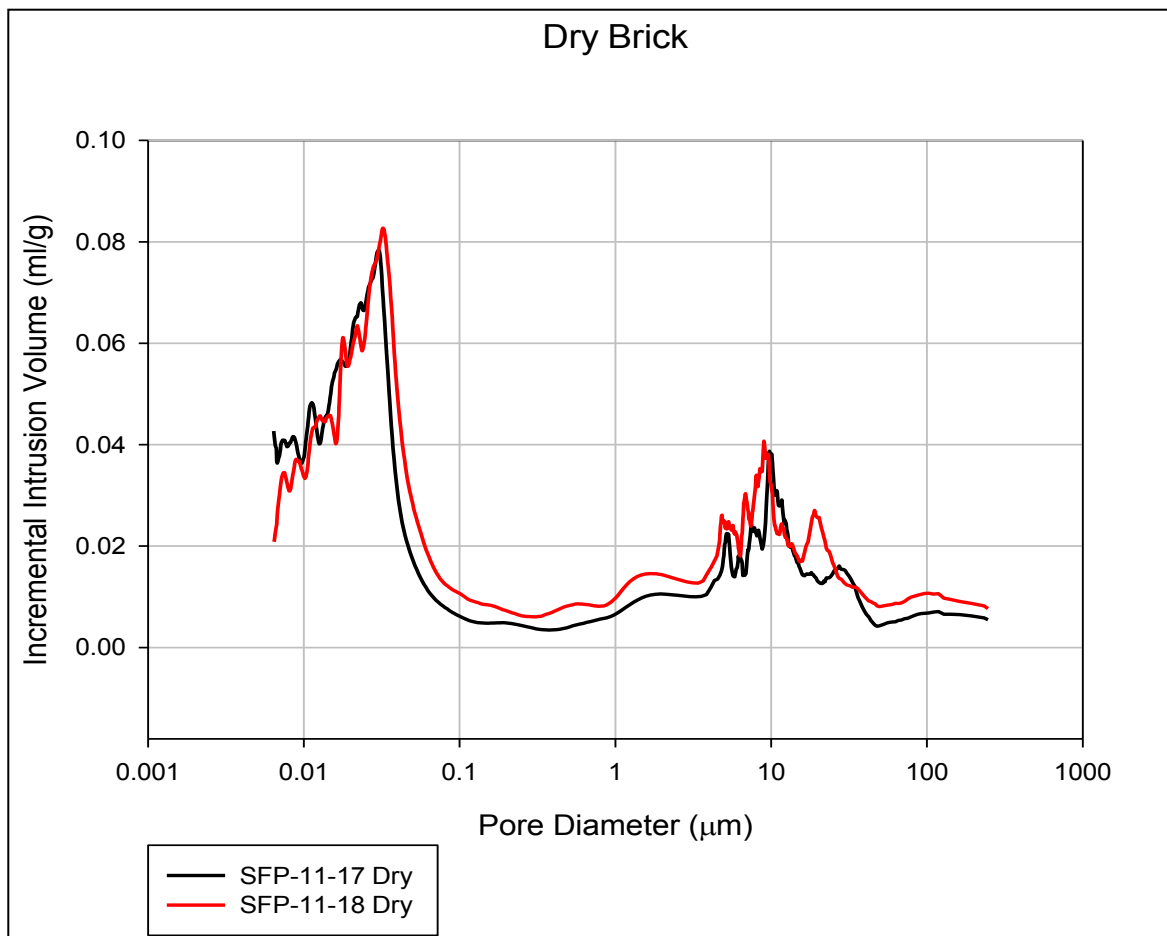


Figure 4: Pore size distribution comparison dry samples SFP 17 and SFP 18.

It can be seen from the pore size distribution analysis that there is very little difference in the distribution pattern however; the bottom ash body has a median pore diameter that is some 86% higher than the non-bottom ash sample.

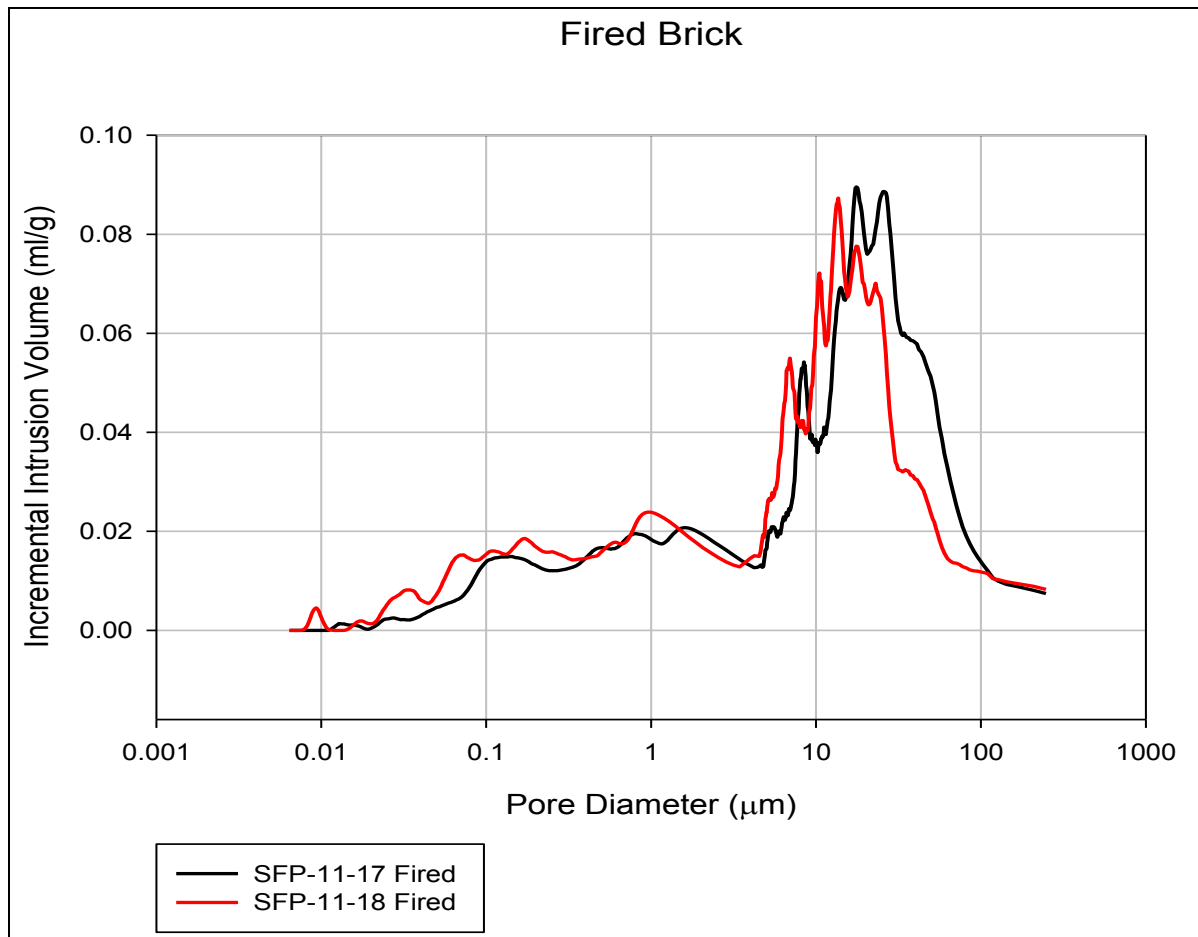


Figure 5: Pore size distribution of fired samples SFP 17 and SFP 18.

It can be seen that the pore size distribution has shifted to a larger size range between 10 and 100µm. The overall pore volume and porosity were very similar for both fired samples. The bottom ash sample had slightly more fine pores and lower median pores, producing a slightly higher water absorption and saturation coefficient. Both test bodies had acceptable saturation coefficients and would have acceptable durability in application.

STA Thermal Analyses (DTA/TGA)

The two test bodies were analyzed using a NETZSCH STA 409 Thermal analyzer at The National Brick Research Center in Clemson, NC (4). DTA, TGA, DSC, CO₂ and H₂O traces were performed in order to observe the differences between the non-ash and the bottom ash bodies. The STA analyses indicated that the presence of the bottom ash in the body composition resulted in a significant reduction in the release of moisture at dehydroxilation at 513°C. Figure 6 shows the H₂O trace for the two samples.

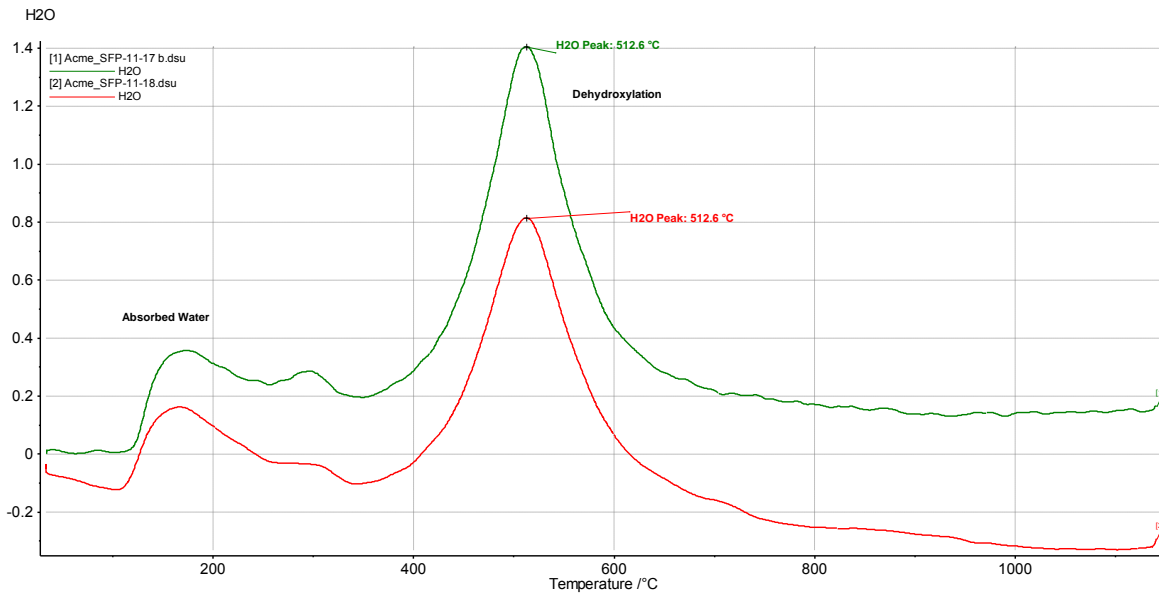


Figure 6: H₂O trace from the STA Analysis illustrating decreased dehydroxylation with the bottom ash body.

Figure 7 illustrates the characteristic TGA curves of the Chew clay, bottom ash and the two test bodies. It can be seen how effectively the bottom ash in SFP 18, reduced the mass loss over the temperature range.

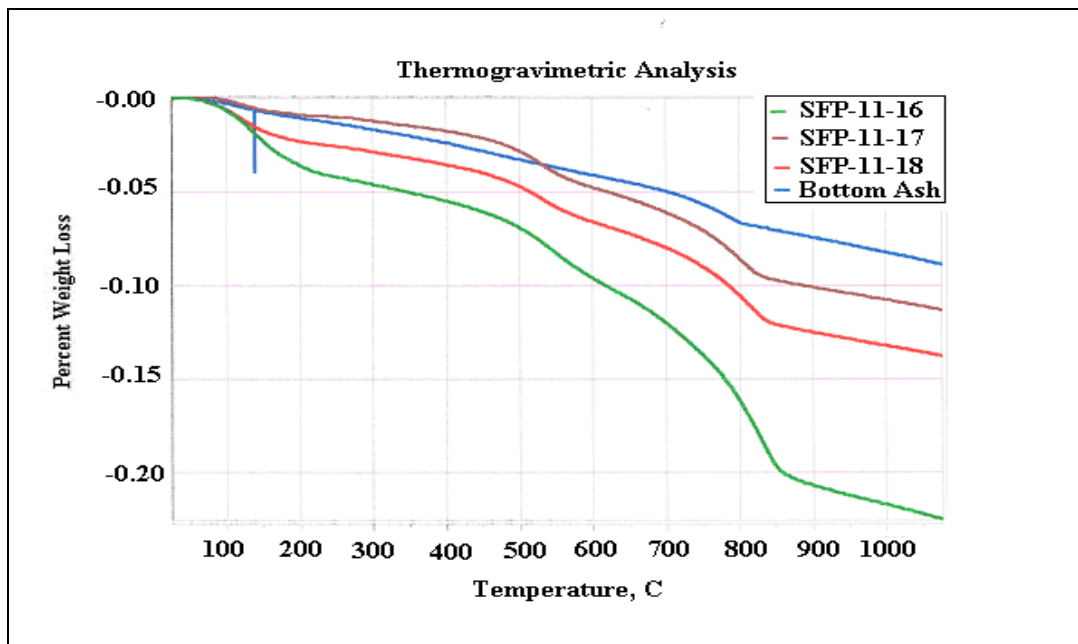


Figure 7: Thermo-gravimetric analysis of the Chew, bottom ash, SFP 17 and SFP 18.

Dilatometer Analysis (SDA)

The Dilatometer analysis of the two test bodies clearly illustrated a significant reduction in the alpha to beta expansion and contraction of the free quartz at 573°C, in the bottom ash body (SFP 18).(5).

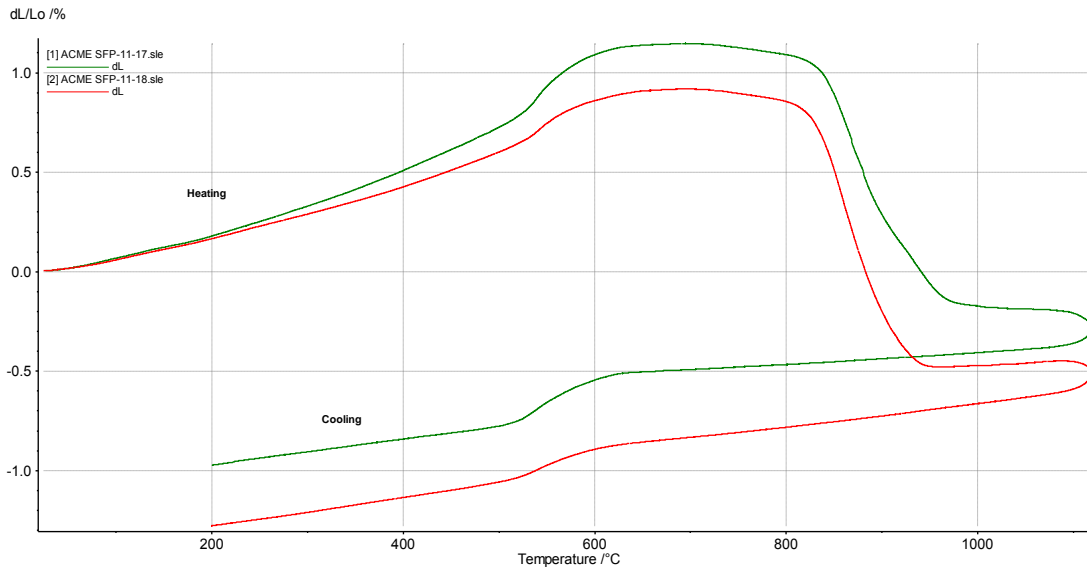


Figure 8: Dilatometer Comparison for SFP 17 and SFP 18 samples.

The both bodies showed an initial stage of rapid shrinkage between 800°C and 960°. Thereafter shrinkage essentially ceased, up to the end of the heating cycle at 1100°C, with the overall contraction of the bottom ash body being slightly higher than the non-ash body. The initial rapid shrinkage beginning at 800°C was due to the decomposition of the calcium carbonate and the onset of melt formation. The higher shrinkage of the ash body produced a denser, stronger and lower water absorption product.

XRF Chemical analyses

The comparison the chemistry and mineralogy (5), of the dry and fired bodies in Table 2, reveals the changes that the bottom ash has brought about.

When comparing the chemical analyses of the unfired Chew/sandy clay body (SFP 17) with the Chew/sandy clay/bottom/ash body (SFP 18), some significant differences can be seen. The addition of bottom ash to the body increased Al_2O_3 , reduced SiO_2 thus reducing the SiO_2/Al_2O_3 ratio. The result of this, as seen in practice, is a stronger, more vitrified bottom ash body. This has been verified by a 45% increase in the fired strength of the bottom ash body.

Major chemistry	Approx unit	SFP 17 no BA unfired	SFP 17 no BA fired	SFP 18 BA unfired	SFP 18 BA fired
SiO ₂	%	65.35	73.8	57.48	66.9
Al ₂ O ₃	%	13.33	11.9	14.10	13.0
Fe ₂ O ₃	%	4.64	4.77	5.42	5.82
Na ₂ O	%	0.26	0.29	0.33	0.43
K ₂ O	%	1.52	1.42	1.65	1.49
CaO	%	6.86	6.34	10.13	9.86
MgO	%	2.03	1.71	2.49	2.23
TiO ₂	%	0.56	0.54	0.69	0.68
Mineralogy					
Quartz	%	40.5	34	30	20
Plagioclase	%	-	30	5	35
Clinopyroxene	%	-	-	-	12
Mica/illite	%	<5	-	<5	-
Hematite	%	-	<5	-	<5
Smectite	%	21	-	22	-
Calcite	%	11	-	12	-
Kaolinite	%	16	-	10	-
"Amorphous"	%	30	35	40	30

Table 2: Comparison chemical and mineralogical compositions of SFP17 and SFP18.

The chemical analysis also illustrates that the addition of bottom ash to the body increases the CaO content. These two changes in composition contribute to a more effective melt formation in the final stages of heating as can be seen from the mineralogical analyses in Table 2.

The XRD study shown in Table 2 reflects significant changes in the crystalline phases developed when bottom ash is added to the body composition. The bottom ash body shows a reduction in quartz from 30% to 20% as a result of the dissolving of some of the silica during the development of melt formation during firing. Significant phase transitions are seen in the development of increased levels Plagioclase feldspar. This would result in an increase in the degree of vitrification and would explain the improvement in the product quality and fired strength.

Microscopic study

Microscopy was performed on polished thin section specimens to compare the microstructure of the non-ash (SFP 17) and the bottom ash (SFP 18) bodies. Photomicrographs were made in reflected plane polarized light (PPL). The parallel laminar structure and the dispersed quartz granules in the non-ash body can be clearly seen in Figure 9. The photomicrograph of the bottom ash body in Figure 10, shows how the ash particles have melted into the microstructure. The presence of the angular bottom ash grains in the material effectively eliminated the laminar effect as seen in the

photomicrograph. A material with this form of microstructure could be expected to be stronger. This is borne out by the fired MOR data seen in Figure 1.

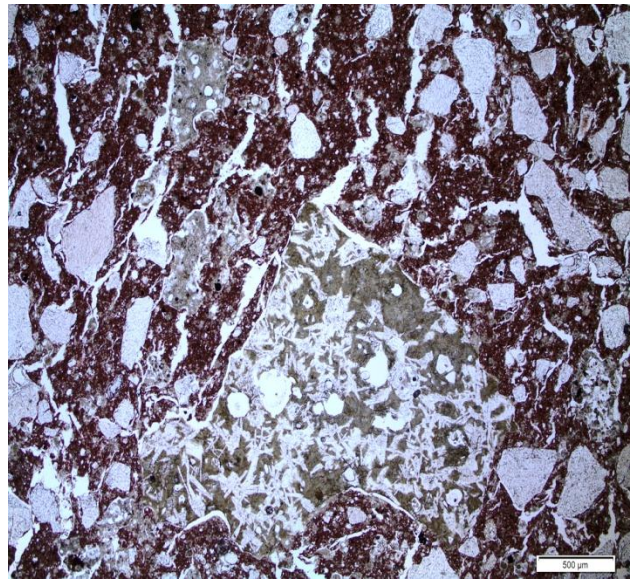
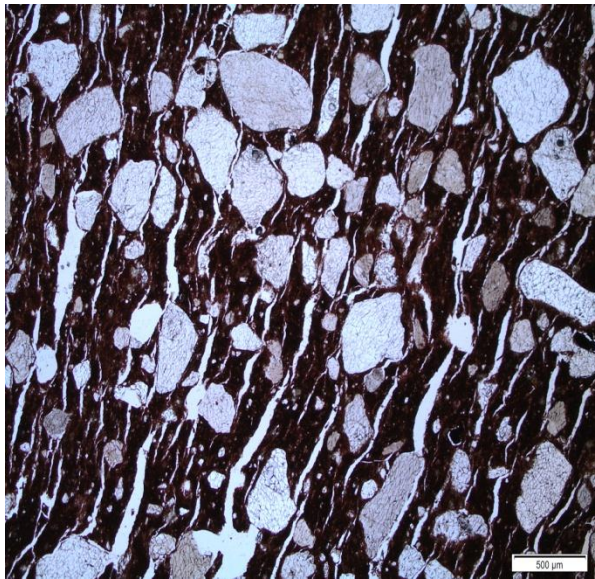


Figure 9: Non-ash SFP 17 body

Figure 10: Bottom ash SFP 18 body

Economics of bottom ash

While the addition of bottom ash is an effective way of controlling shrinkage and enhancing the ceramic properties of the brick body there are some drawbacks to its use. Most bottom ash sources are high in soluble sulfates. Some sources also have high pyrite contents (6). The efficiency of the utility operation also determines the levels of residual carbon in the bottom ash and hence the loss on ignition. The San Filipe plant utilizes a bottom ash selected for its relatively low soluble salt and carbon contents. Table 3 illustrates the carbon, sulfur and soluble salt levels from the introduction of bottom ash into the body. The concentration of these contaminants will dictate the selection of the ash used.

Compound	Bottom ash	SFP 17 non BA body	SFP 18 BA body
Carbon %	0.48	1.46	1.2
Sulfur %	0.22	0.01	0.067
Soluble sulfates ppm	1840	88	212

Table 3: Comparison of carbon, sulfur and soluble salt concentrations of bottom ash and the two test bodies at San Filipe.

The soluble salts brought into the body by the ash addition needs to be offset by the addition of a suitable level of barium carbonate. The barium carbonate will react with the calcium and magnesium sulfates to precipitate insoluble barium sulfates of calcium and

magnesium. This is a common solution adopted by the brick maker, as many clay sources also contain concentrations of soluble salts. Higher barium carbonate additions are usually required when using bottom ash, which increases the manufacturing cost.

The high levels of pyrite contamination produce a greater problem. Large nodules of pyrite near the surface of the finished brick will result in surface eruptions or “pops” that detract from the quality and appearance of the product (7). The selection of the ash with low levels of pyrite is the obvious strategy to take. In addition to this, the non plastic component can be crushed and ground to a suitably fine grain size so as to minimize the visual effects of the pyrite. The San Filipe plant utilizes an ash containing low concentrations of pyrite. The ash is crushed and screened to a grain size of <1mm.

High levels of residual carbon will lead to difficulties in carbon burnout in the firing process resulting on black coring and even bloating. High carbon levels contributed by the bottom ash in the body can result in “autogenous combustion” in the preheat zones of the kiln, the ignition and combustion of the carbon takes place between 800°C and 1600°C. If the preheat zones of kiln are controlled correctly, the exothermic energy release from the autogenous combustion of the carbon can result in an improvement in overall energy efficiency of the firing process (8)(9).

Conclusions

The various analyses carried out on the individual materials, the unfired and fired body compositions, focused on the changes that the bottom ash has brought about on the physical and mineralogical properties. The following conclusions are made:

- The use of bottom ash in the San Filipe body has been very effective in reducing stabilizing the drying and firing shrinkage. The comparisons of the dry properties of the two bodies show that in the both the sandy clay body (SFP 17) and the bottom ash body (SFP 18), displayed a similar reduction in the wet to dry shrinkage. However even though the bottom ash body displayed the similar distribution, there was an 86% higher median pore diameter across the 0.05µ to 500 µ size ranges when measured with the Mercury Porosimeter. This is the likely reason for the improved drying characteristics of the ash body that has been experienced in the production plant.
- The comparative DTA analyses illustrate clearly how well the addition of bottom ash reduced the degree of moisture release through dehydroxilation. This is also reflected in the TGA analyses, where the bottom ash in combination with the sandy clay, effectively turns the Chew material a stable and usable material for brick manufacture. The sandy clay component on its own (SFP 17) rendered the body too high in free quartz, resulting in pre-heat and cooling cracking as a result

of the excessive quartz inversion volumetric changes during firing. When this body composition was used in practice, the losses were excessive.

- It can be noted that the reduction in the $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio and the increase in CaO from the bottom ash addition in the SFP 18 body is significant. Free quartz was reduced by the dilution effect of the ash included in the body composition. The XRD analysis indicates that some of the finely divided quartz was dissolved in the silicate reactions which took place during heating (9). It can be seen that after firing, the free quartz content reduced from 30% to 20% and the Plagioclase feldspar phase increased from 5% to 35% after firing. The bottom ash acted as an effective flux as well improving the body's drying characteristics.
- The need to incur the cost of using an addition of BaCO_3 to the body to off-set the soluble salts present in the bottom a disadvantage. However, the cost benefit ratio is favorable.
- The San Filipe plant continues to benefit from the use of bottom ash today. Its classification as a hazardous material as is being envisaged by the EPA would certainly bring the plant to a standstill as the alternative sources of non-plastic materials would be too costly to consider.

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