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PROCESSING PROBLEMS AT STANDARD CLAY PRODUCTS, LIMITED, NEW GLASGOW, NOVA SCOTIA

by

K. E. BELL

MINERAL PROCESSING DIVISION

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- - -

SUMMARY OF RESULTS

The materials and mixtures slake slowly and are of moderate plasticity, with dilatant tendencies, accounting for their poor forming and drying characteristics. The Red Clay is the most plastic and the Blue Shale the least; the standard mixture (1 Red Clay: 2 Blue Shale) shows an optimum consistency and is recommended for continued use. The Blue Shale is the more difficult to oxidize during firing, but shows the lower maturing temperatures and the longer firing range. Again, the standard 1:2 mixture shows near-optimum properties.

The forming characteristics were markedly improved by vacuum extrusion and by minor additions of deflocculants. The greatest improvement was shown by deaired bodies containing about 0.15 per cent Calgon, followed closely by deaired bodies with addition of 0.25 per cent Lignosol TSD. The denser bodies produced by deairing increased the time required for oxidation but lowered the maturing temperatures and broadened the firing range. The Calgon addition had similar effects on both the non-deaired and deaired body. The Lignosol addition decreased the time required for oxidation of the non-deaired body, but increased maturing temperatures and shortened the firing range; deaired bodies containing Lignosol showed no change in rate of oxidation, but increased firing range. Thus, Calgon is probably the preferred additive in non-deaired ware, Lignosol TSD in deaired bodies.

The addition of grog reduced the plasticity and is suitable only in deaired, deflocculated bodies. Such bodies could be grogged at the 20 to 25 per cent level to increase oxidation rates.

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INTRODUCTION

Mr. Eric L. Hartley, President, Standard Clay Products, Limited, Mount Royal, P. Q., requested technical assistance in overcoming several problems occurring at the company's plant at New Glasgow, Nova Scotia. Heavy losses incurred during the forming, drying and firing processes were reported to be largely responsible for a sustained financial loss over several years. As a result, the company made a Proposal under the Bankruptcy Act in December, 1963, and is currently being operated by the creditors.

The plant uses local raw materials to manufacture vitrified sewer pipe (4-inch to 24-inch diameters) and flue lining. Although, by present-day standards of efficiency, the plant equipment and design is outmoded to the point of obsolescence, the losses reported are much above normal, even for this type of plant. Thus, the basic cause of the processing difficulties was considered to be the raw materials themselves, and an investigation was undertaken to determine the characteristics of these materials and to devise methods of improving their properties.

The company provided full details of the nature and extent of the losses, all the required information regarding processing (mixtures, firing schedules, etc.), and samples of the raw materials. The "Red Clay" was assigned Lab. No. 1519 and the "Blue Shale" was designated Lab. No. 1520.

Analysis of the losses indicated two distinct serious problem areas. Firstly, the high forming and drying losses indicate poor plastic properties of the raw materials--the green strength of the extruded body seems too low to resist the stresses of deformation during extrusion and of unequal shrinkages during drying. Laminations and variations in density over the cross-section of the pipe probably contribute to cracking and warping during drying and firing. The second problem arises during firing and is concerned with the difficulty of oxidizing the large amounts of carbon and sulphides present in the raw materials--poorly oxidized ware may bloat or blister, causing cracking or deformation, or the body (although of good mechanical appearance) may be of low strength or too permeable for acceptance under the existing specifications.

FORMING AND DRYING

Plasticity of the Raw Materials

A preliminary evaluation of the plastic properties of the raw materials and the plant mixtures was made, using the Brabender Plastograph. The Plastograph curves are shown in Figure 1. The Blue Shale is the least plastic, and mixtures containing too much are known to cause extrusion difficulties. The mixture of half Red Clay and half Blue Shale shows a median consistency and is used for the largest sizes of pipe because of its better oxidation characteristics. The mixture of one part Red Clay and two parts Blue Shale shows an unexpected higher consistency, probably due to better particle size distribution. The latter is the standard mixture used at the plant.

The indicated minimum consistency of about 900 metre-grams of torque would normally be considered adequate for successful extrusion of sewer pipe using modern machinery. In the Plastograph, mixing is intensive and the rate of water addition is regulated to develop maximum consistency. The materials were observed to wet and slake rather slowly, and under plant conditions maximum consistency is probably not developed--deairing and/or the use of hot water would doubtless be beneficial. Further Plastograph tests to confirm these points were deferred in favour of laboratory extrusions, which more closely duplicate plant conditions.

Both raw materials were shown, by the Plastograph, to be dilatant, that is, resistance to shear increased with increased rate of shear. Dilatancy is characteristic of granular, non-plastic materials (e. g., beach sands), thus is often encountered in hard, non-slaking shales that produce a minimum of fine particles on grinding, and in heavily flocculated or over-flocculated clays. These materials, flowing differentially in dies, form slip-planes at right-angles to the flow which are manifest in materials of low cohesive strength as dog-ears or feathered edges (circumferential cracks in pipe). Where such materials are successfully extruded, slow rates of flow are used and rates of deformation are restrained through the use of long, flat-tapered dies, usually lubricated with oil or steam.

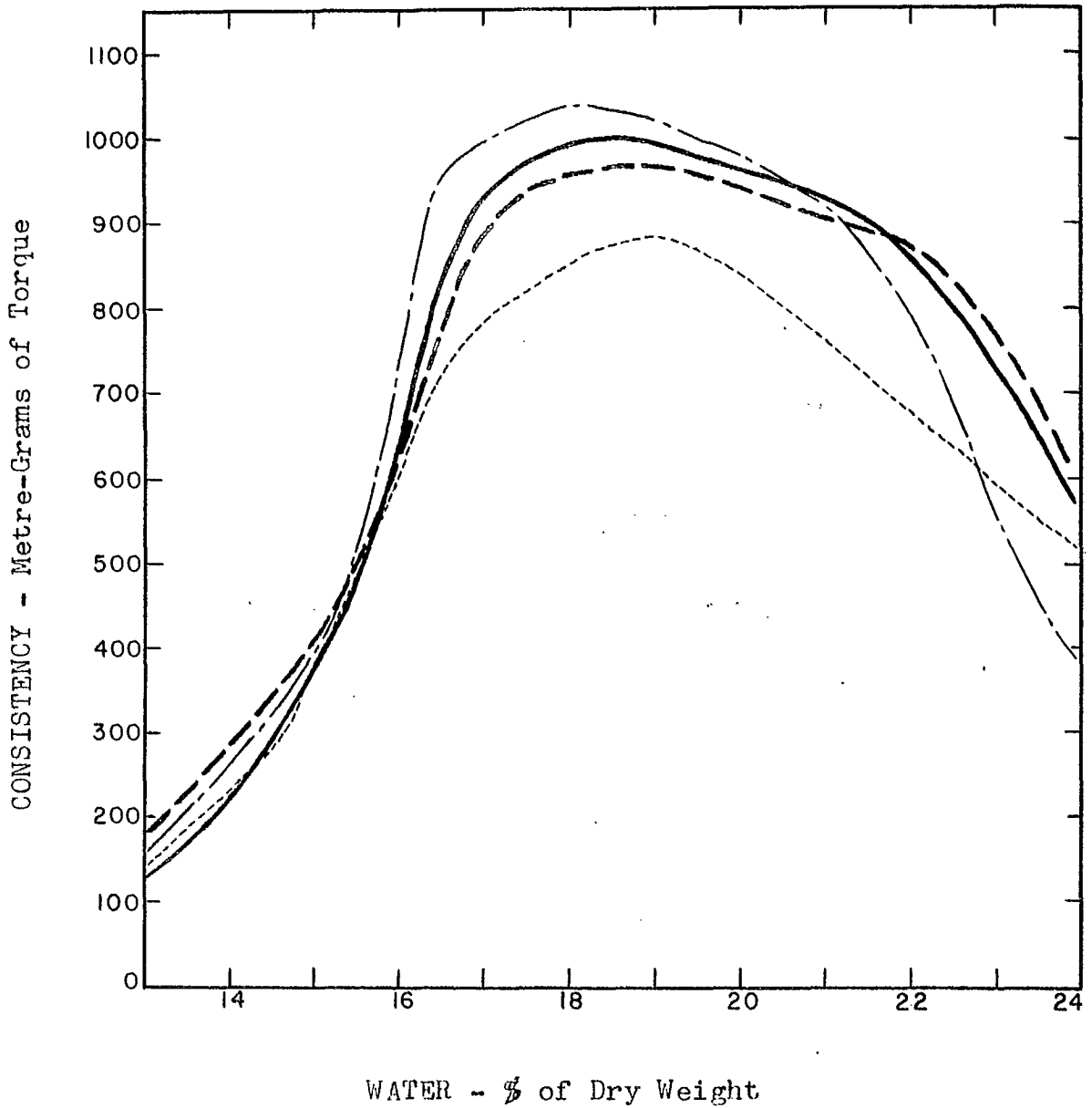


Figure 1. Plastograph Curves of Raw Materials and Plant Mixtures:

- Red Clay (—)
- Blue Shale (---)
- 1 Red Clay: 1 Blue Shale ... (— · —)
- 1 Red Clay: 2 Blue Shale ... (— — —)

Test Procedures

Extrusion trials were conducted using the raw materials individually and in mixtures, and with additions of various types intended to improve the plastic properties. Deflocculants, such as sodium hexametaphosphate* and soda ash, act to improve extrusion by increasing particle mobility and dispersion, thus easing the resistance to flow and reducing power requirements. Deflocculated systems require less water of plasticity, resulting in denser, stronger bodies of reduced drying shrinkage. (In this instance, a denser body could be expected to aggravate the oxidation problem). Flocculants, such as hydrated lime and the chlorides and sulphates, increase the consistency of clays, providing for greater deformability without rupture, although power requirements may be higher. The green and dry strengths are thus higher, although densities are less and drying shrinkage may be increased. The more-open pore structure should aid oxidation. Ammonium chloride was selected for trial because ammonium compounds have been reported to aid oxidation. Sodium chloride is known to improve the drying characteristics of many clays. Sulphates were not tested because of their propensity to cause scum, which would interfere with the salt glaze used at the plant. In addition, tests were conducted featuring additions of lignosulphonate, with combined deflocculant and binder properties (again, the ammonia salt** was selected from considerations of oxidation), and of a wetting agent, Teepol***, which functions primarily as an internal lubricant.

When it became apparent that the dense, deflocculated bodies showed the most promise, additions of grog were incorporated to open up the structure and provide for easier oxidation, as well as to reduce drying shrinkage. The grog, minus 10 mesh (Tyler), was prepared by heating a pre-ground mixture of two parts Red Clay to one part Blue Shale at 1400° F for 30 to 35 minutes--the coarser particles of Blue Shale still showed vestigial carbon cores, the Red Clay appeared to be completely oxidized. Thus, the drying shrinkage was probably almost completely eliminated, but the pore structure probably remained open, allowing free passage of gases.

Suitably sized test batches of each mixture were made up. Where chemical additives were used they were added in solution or suspension in the pugging water. Each batch was extruded, using an auger-type machine, the first half of the batch with no deairing, the second half under full vacuum. The extrusion behaviour and power requirements for each batch were noted. Each column, 1 x 1 inch in cross-section, was cut into 8-inch lengths, each numbered and marked for identification.

* Calgon

** Lignosol TSD, Lignosol Chemicals Limited, Quebec, P. Q.

*** Teepol 410, G. H. Wood and Company Limited.

One specimen of each test batch, deaired and non-deaired, was immediately placed in a laboratory oven maintained at 185° F to determine the drying behaviour under severe conditions. The remainder were allowed to air-dry for 24 hours and then were oven-dried at 220° F. Shrinkages were measured and calculated in per cent of wet length.

At least five specimens of each batch, deaired and non-deaired, were broken in flexure (3 point suspension) and the average Modulus of Rupture was calculated.

Results

The results of the extrusion and drying tests are given in Table 1.

TABLE I
Summary of Extrusion and Drying Properties

Sample No.	Composition	Water (% of Dry Wt)	Vacuum (in. Hg)	Power (amp)	Comments on Extrusion	Drying Behaviour	Drying Shrinkage (% of Wet Length)	Dry Modulus of Rupture (psi)
1519	Red Clay	18	Nil	-	Not satisfactory, no specimens, Corners torn (featheredged).	-	-	-
			27.5	4.4-4.6	Slightly featheredged; a longer, lubricated die required.	No cracks (safe) during rapid drying.	4.3	538
1520	Blue Shale	18	Nil	-	No flow at corners, no specimens, Corners feathered.	-	-	-
			27.5	5.6-5.8	Good, slightly featheredged.	Safe	4.6	668
1519/20 "A"	50% No. 1519 50% No. 1520	18	Nil	4.5-4.6	Featheredged, requires more back-pressure (longer die).	Safe	4.1	328
			27.5	4.6-4.8	Good, slightly featheredged.	Safe	4.6	446
1519/20 "B"	33.3% No. 1519 66.7% No. 1520	18	Nil	5.2-5.4	More feathering than mixture "A".	Safe	4.3	440
			27.5	5.4-5.6	Good, slight feathering, slight separation of water (bleeding) indicative of dilatancy.	Safe	4.7	566
1519/20 "F"	Mix "B" plus 0.15% Calgon	17.5	Nil	5.2-5.4	Slightly longer die required to prevent feathering.	Safe	4.2	598
			28	5.4-5.6	Good, smooth column through short die.	Safe	4.8	732
1519/20 "Q"	Mix "B" plus 0.45% Soda Ash	17.5	Nil	4.2-4.4	A little soft, sticky but short (low strength), slight feathering.	Cracked during rapid drying.	4.2	486
			28	4.4-4.6	Tough column, good plasticity, perhaps a little soft.	Safe	4.8	681
1519/20 "D"	Mix "B" plus 0.25% Lignosol TSD	18	Nil	5.2-5.4	Longer die required to prevent feathering.	Safe	4.0	828
			18	5.6-5.8	Very slightly feathered through short die.	Safe	4.9	718
1519/20 "E"	Mix "B" plus 0.25% Ca(OH) ₂	19	Nil	5.2-5.4	Little, if any, change from mix "B" with no additive.	Safe	3.7	440
			28	5.4-5.6		Safe	5.1	596
1519/20 "G"	Mix "B" plus 0.25% NH ₄ Cl	18.5	Nil	4.4-4.6	Severe feathering, stiff, but short column.	Safe	3.0	375
			28	5.8 increasing to 6.2	Very stiff, tough column. Column heating caused increased power consumption, but no visible bleeding.	Safe	4.1	522
1519/20 "R"	Mix "B" plus 0.50% NaCl	18	Nil	4.2-4.4	A little soft, sticky but short, slight feathering.	Safe	3.8	273
			28	4.4-4.6	Fairly stiff column. Moderate plasticity.	Safe	5.0	363
1519/20 "S"	Mix "B" plus 0.25% Teepol	17.5	Nil	5.2-5.4	A little soft; sticky, yet short, moderate feathering.	Safe	3.6	312
			28	5.3-5.5	Good plasticity. Fairly stiff column.	Safe	4.7	475
1519/20 "C"	90% Mix "B", 10% Grog	18.5	Nil	4.0	Badly feathered.	Safe	4.5	257
			27.5	4.5	Good, slight feathering.	Safe	4.1	585
1519/20 "P"	70% Mix "B" 30% Grog, plus 0.10% Calgon	16	Nil	5.8	Very stiff, short column, badly feathered, some column heating.	Safe	2.7	464
		18	28	5.2-5.4	Stiff, tough column, fairly plastic, slight heating, slight feathering.	Safe	4.0	596

Discussion

Neither the Red Clay nor the Blue Shale, individually, showed good forming properties; their dilatant natures and slow-slaking characteristics were evident in their behaviour, and in the low strength of the non-deaired columns. Deairing markedly improved their extrusion properties. The Blue Shale showed the poorer extrusion and consumed more power, but produced a denser, stronger product. The mixtures showed better flow properties than either individual material. The mixture containing the largest amount of Blue Shale showed the poorer flow characteristics, but the greater strength. Probably each of these materials and mixtures would extrude more satisfactorily through a longer die, causing more back-pressure on the columns. Conversely, softer columns (more water) would probably be of better appearance, but drying shrinkages would be higher, and the history of the plant suggests that cracking during drying might become a problem.

The most effective additives were the deflocculants. Sodium hexametaphosphate (Calgon) was the best; an addition of 0.15 per cent resulted in an acceptable extruded column of good strength that dried safely with moderate shrinkage. About four times this amount of soda ash would probably be required for equivalent results. Further, the non-deaired specimens containing soda ash cracked under severe drying conditions. This could probably be remedied by substitution of sodium silicate for a portion of the soda ash, but further work in this direction was not undertaken in view of the success achieved with addition of Calgon and of ammonium lignosulphonate. Additions of 0.25 per cent of the latter (Lignosol TSD) resulted in improvement of all the properties studied, second only to that with Calgon.

Additions of flocculants, hydrated lime and chlorides, were either ineffective or had adverse effects on the extrusion properties and strength. It is assumed that the materials are naturally flocculated by soluble salts, probably sulphates since pyrite is known to be present.

The one wetting agent tested (the detergent, Teepol) did improve the flow properties, probably through increased slaking rates, but the strength was considerably reduced.

An addition of 10 per cent grog did not have any great effect on the forming properties, nor did it decrease the drying shrinkages. Additions of about 30 per cent grog were required before there was a significant reduction in drying shrinkage. Such a mixture would probably produce an adverse effect on flow and thus was supplemented with an addition of 0.10 per cent Calgon. The results were roughly equivalent to those with no additions. Finer grinding of the grog would probably be

beneficial. Additions of about 10 to 15 per cent grog could apparently be tolerated in the deflocculated, non-deaired body, should such additions be useful in improving the oxidation characteristics.

In every case, extrusion under vacuum resulted in markedly improved forming properties and increased strengths. The smoother flow no doubt resulted in decreased residual forming stresses in the body, and the greater strengths offered more resistance to the stresses set up during drying. Hence, the non-deaired specimens containing soda ash cracked during drying, but the deaired specimens did not. In those mixtures that laminated, the extent of the laminations was visibly reduced by deairing. Thus, deairing could be expected to reduce or eliminate blistering and slabbing.

FIRING BEHAVIOUR AND FIRED PROPERTIES

Firing Behaviour of the Raw Materials

The firing characteristics of the Red Clay and Blue Shale were investigated by differential thermal analysis (DTA) and by thermogravimetric analysis (TGA).

The thermograms (DTA curves) are shown in Figure 2. The large exothermic peaks centered about 750°F are the result of heat liberated by the combustion of carbon and sulphides in the raw materials. The upper-temperature area is obscured by an overriding endothermic reaction (dehydroxylation of the clay minerals). The probable course of the burn-out in the Blue Shale is indicated by the dotted line. In both cases, oxidation is doubtless complete (in normal air atmospheres) by about 1150°F, which is about the median temperature of the oxidation stage of the plant firing schedule.

The actual weight loss due to removal of combustibles is very small, and not clearly delineated on the thermogravimetric curves. Further, the weight loss due to oxidation is obscured in the higher temperature area by the much larger loss of weight associated with the breakdown of the clay mineral structure. Thus, the TGA curves are not shown.

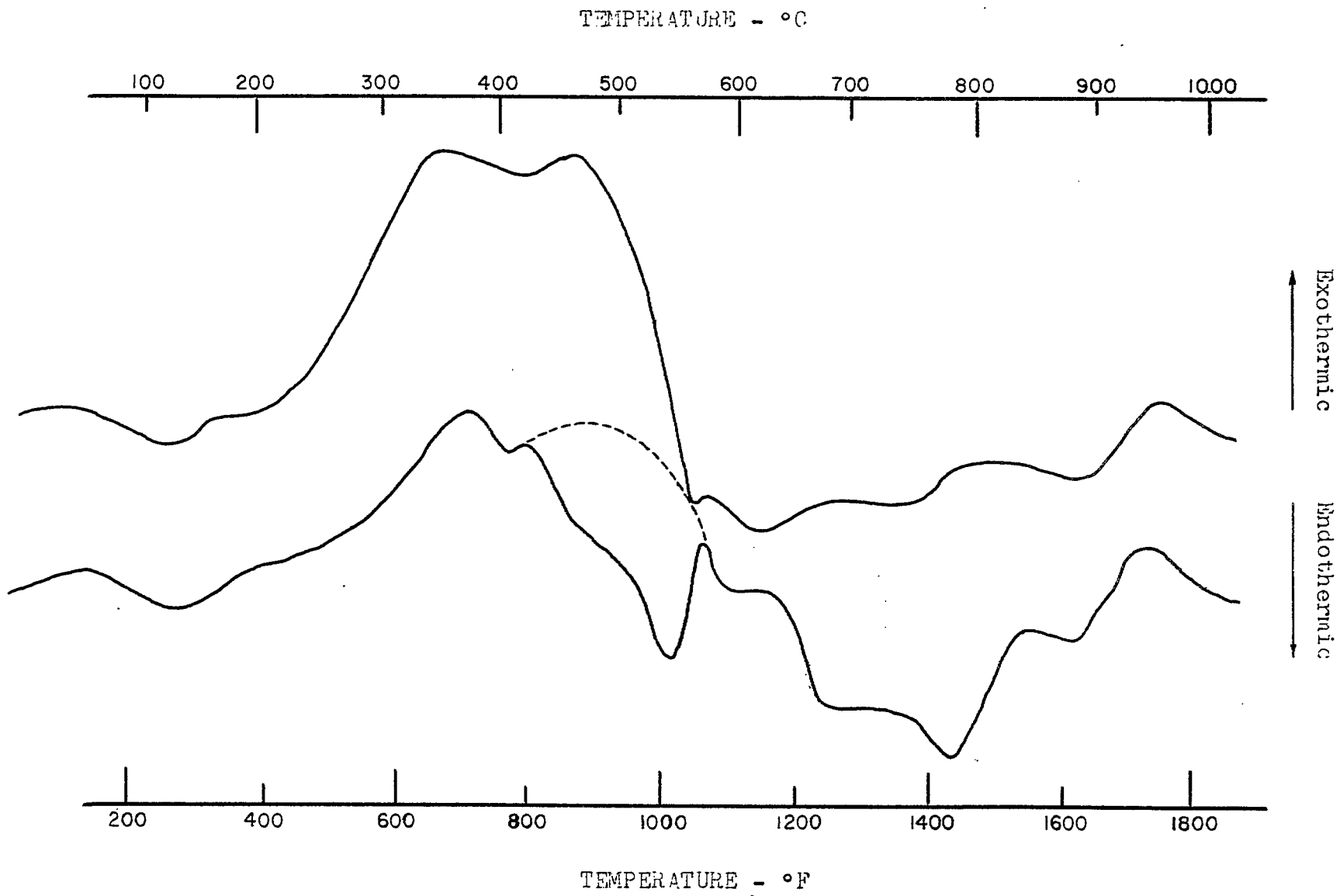


Figure 2. Thermograms of Red Clay (upper curve) and Blue Shale (lower curve).

Oxidation Studies

Multiple specimens (1 x 1 x 4 inches, from the dry modulus of rupture tests) of each extruded mixture, deaired and non-deaired, were placed on end, spaced, in an electrically heated furnace (oxidizing atmosphere - air) and brought to 1160°F. After 15 minutes, when the furnace was under full control at this temperature, one specimen of each series was withdrawn and broken open to reveal the black carbon core. At hourly intervals thereafter, further specimens were withdrawn and broken open, the diminution of the black core being indicative of the degree of oxidation that had taken place. As a result of opening and closing the furnace door, temperatures varied between 1145 and 1165°F, but the atmosphere of the furnace was thus periodically replenished with fresh air.

The results are illustrated pictorially in Figure 3. Specimens containing soda ash, the flocculants, and Teepol, all of which had detrimental effects on extrusion or drying, are not shown.

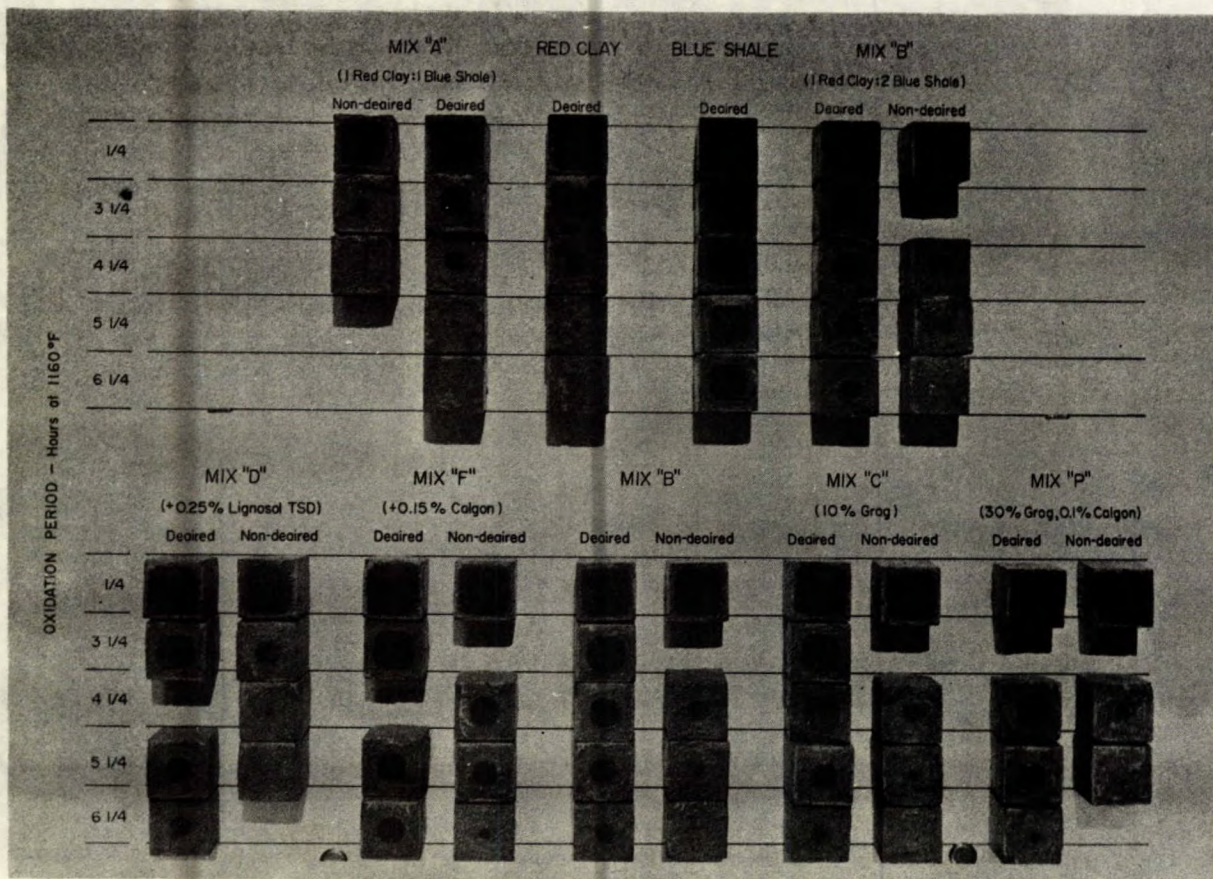


Figure 3. Oxidation Studies, Raw Materials and Selected Mixtures.

Fired Properties

Duplicate specimens (about 1 x 1 x 4 inches, from the dry modulus of rupture test) of each mixture, deaired and non-deaired, were fired in electrically heated kilns to various appropriate temperatures, as indicated both by thermocouples and pyrometric cones. Fired shrinkages were determined, calculated in per cent of green (wet) length, i. e., the same basis as drying shrinkages. Water absorptions of the fired specimens, as a percentage of dry, fired weight, were determined on the basis of 5-hour immersion in boiling water. These properties, and their variation with heat treatment, are illustrated in the curves of Figures 4 to 9, for the mixtures of interest. Again, the curves for mixtures containing soda ash, the flocculants, and Teepol are omitted, since these substances had adverse effects on the extrusion or drying characteristics.

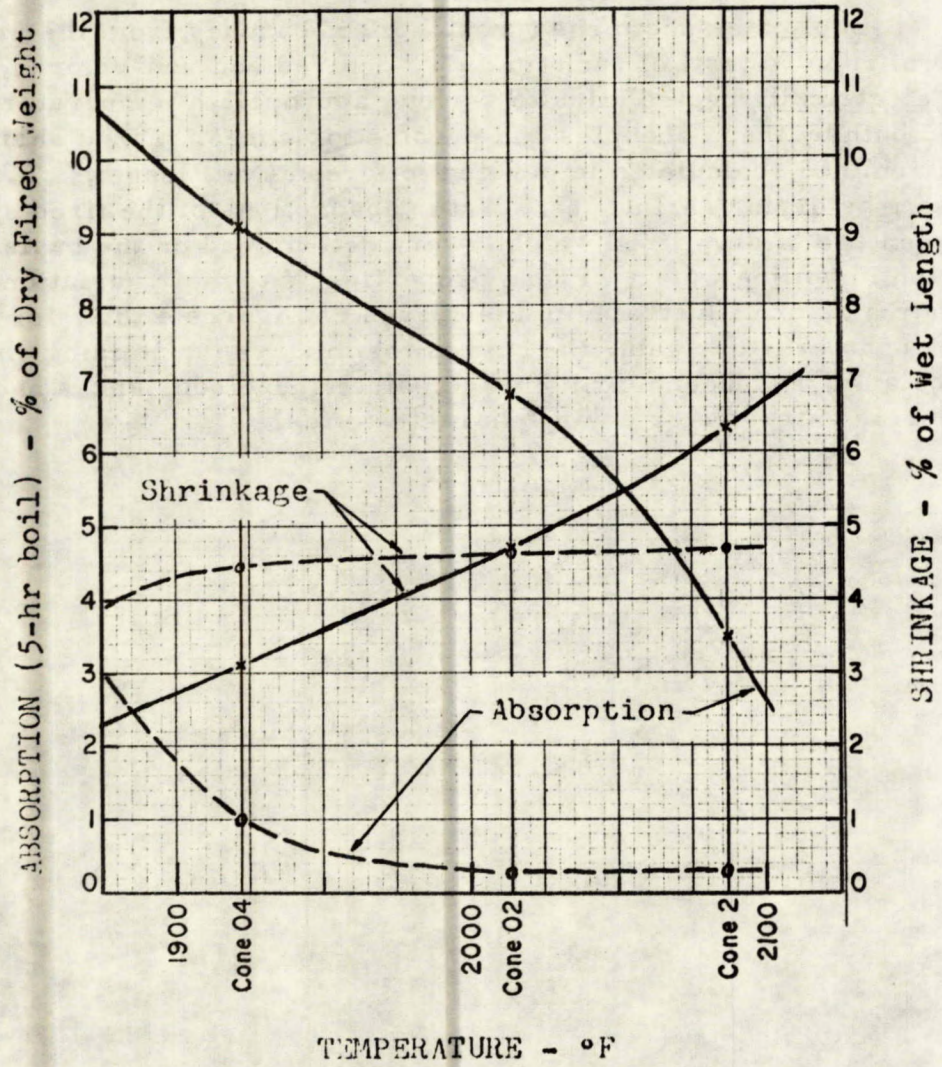


Figure 4. Fired Properties of the Raw Materials:

Red Clay, deaired (—)
Blue Shale, deaired (---)

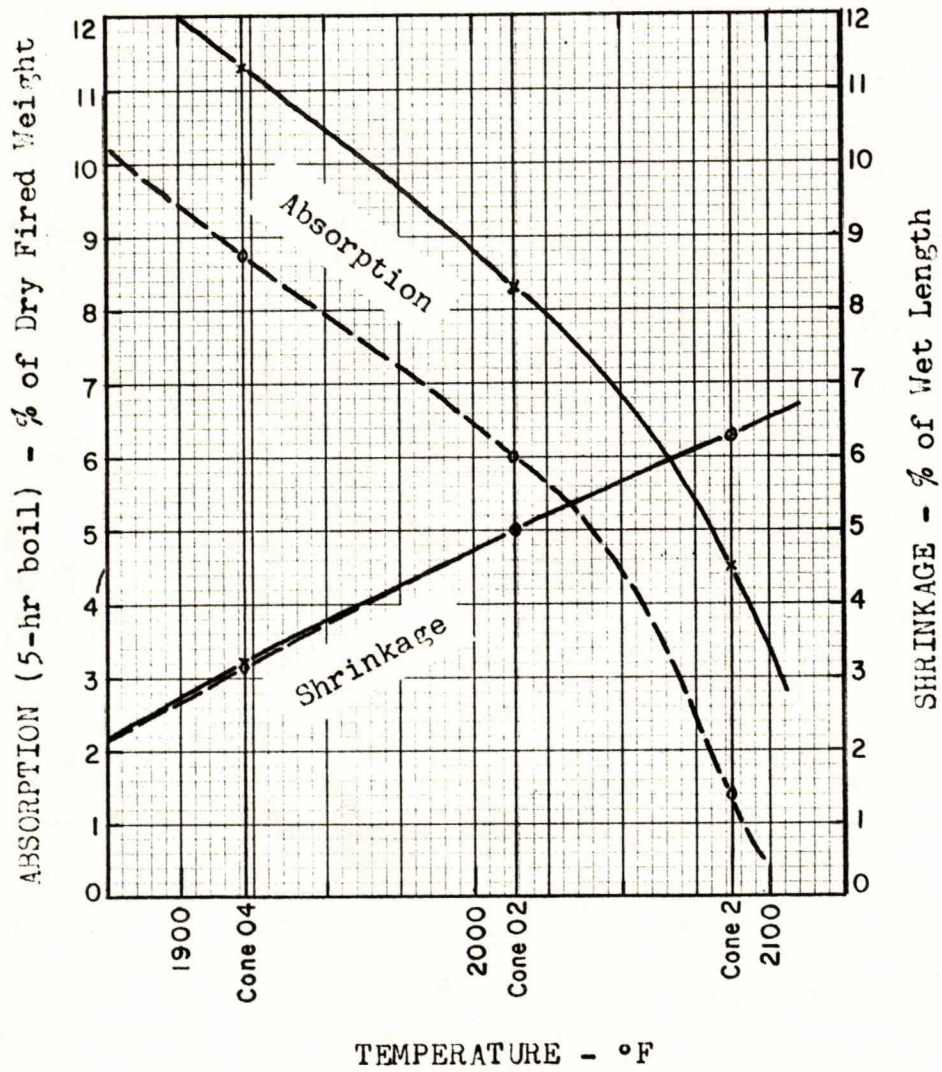


Figure 5. Fired Properties of Mix "A" (1 Red Clay: 1 Blue Shale); non-deaired (—), deaired (---).

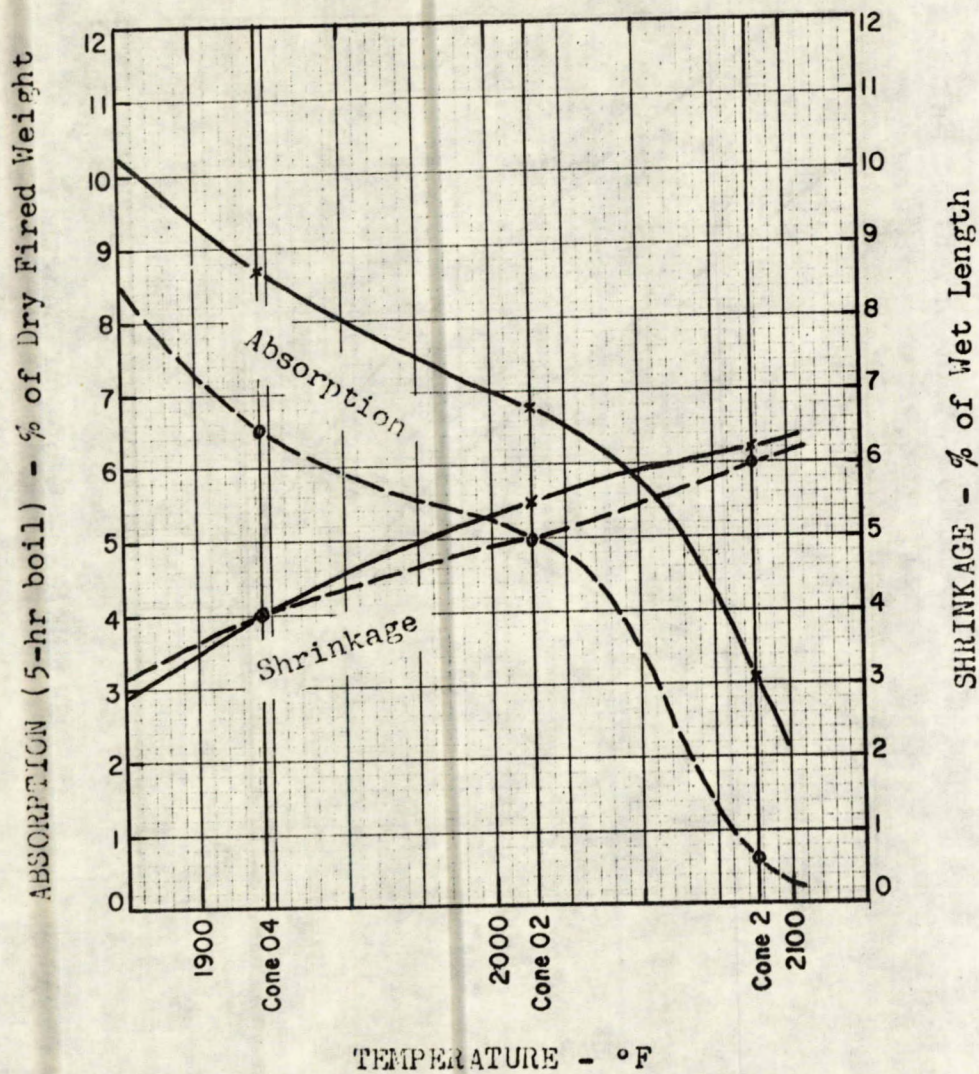


Figure 6. Fired Properties of Mix "B" (1 Red Clay: 2 Blue Shale); non-deaired (—), deaired (---).

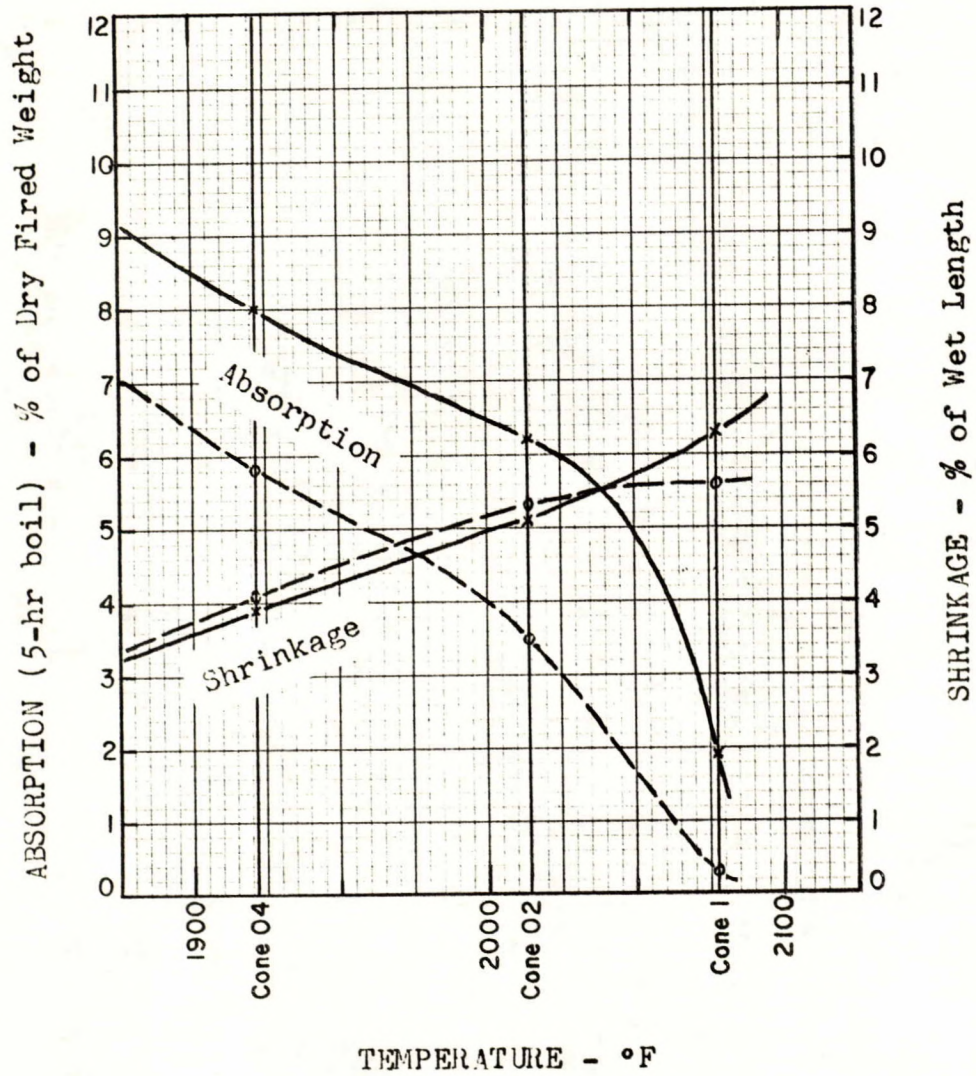


Figure 7. Fired Properties of Mix "F" (Mix "B" + 0.15% Calgon); non-deaired (—), deaired (---).

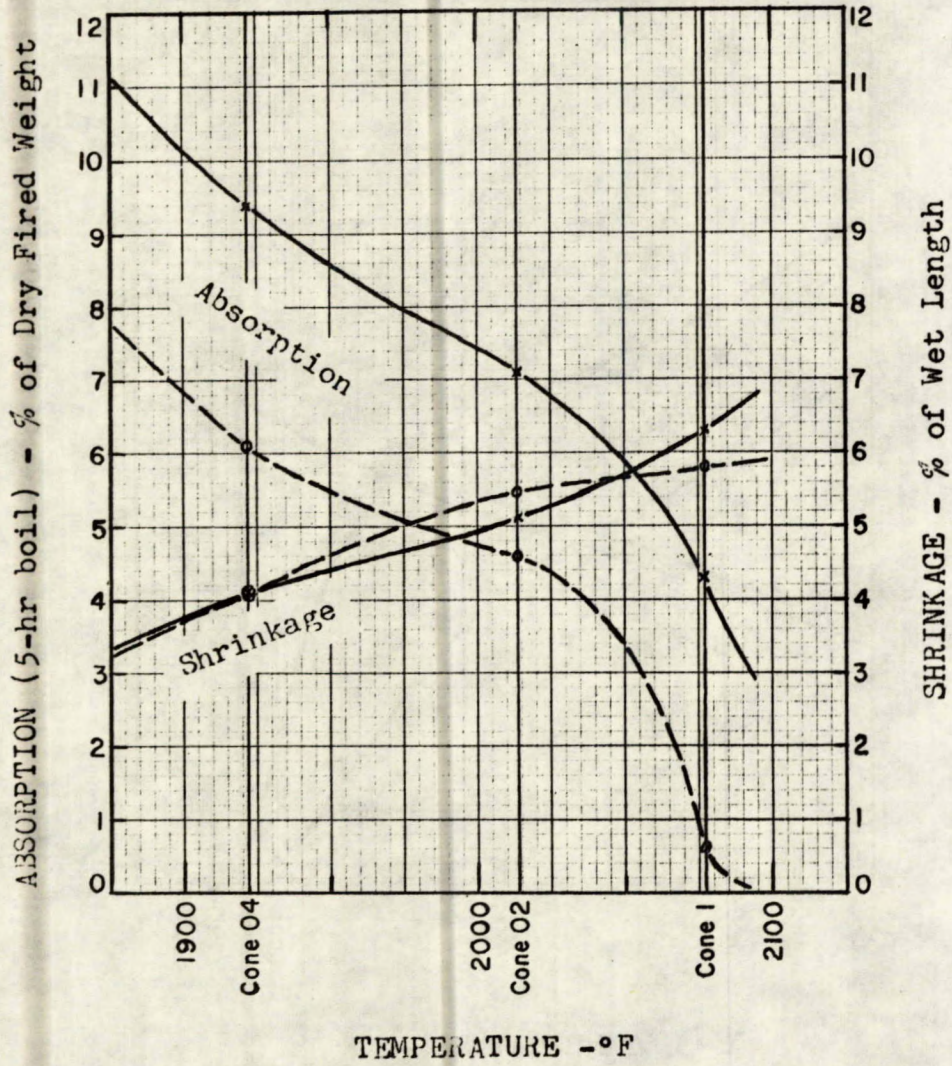


Figure 8. Fired Properties of Mix "D" (Mix "B" + 0.25% Lignosol TSD); non-deaired (—), deaired (---).

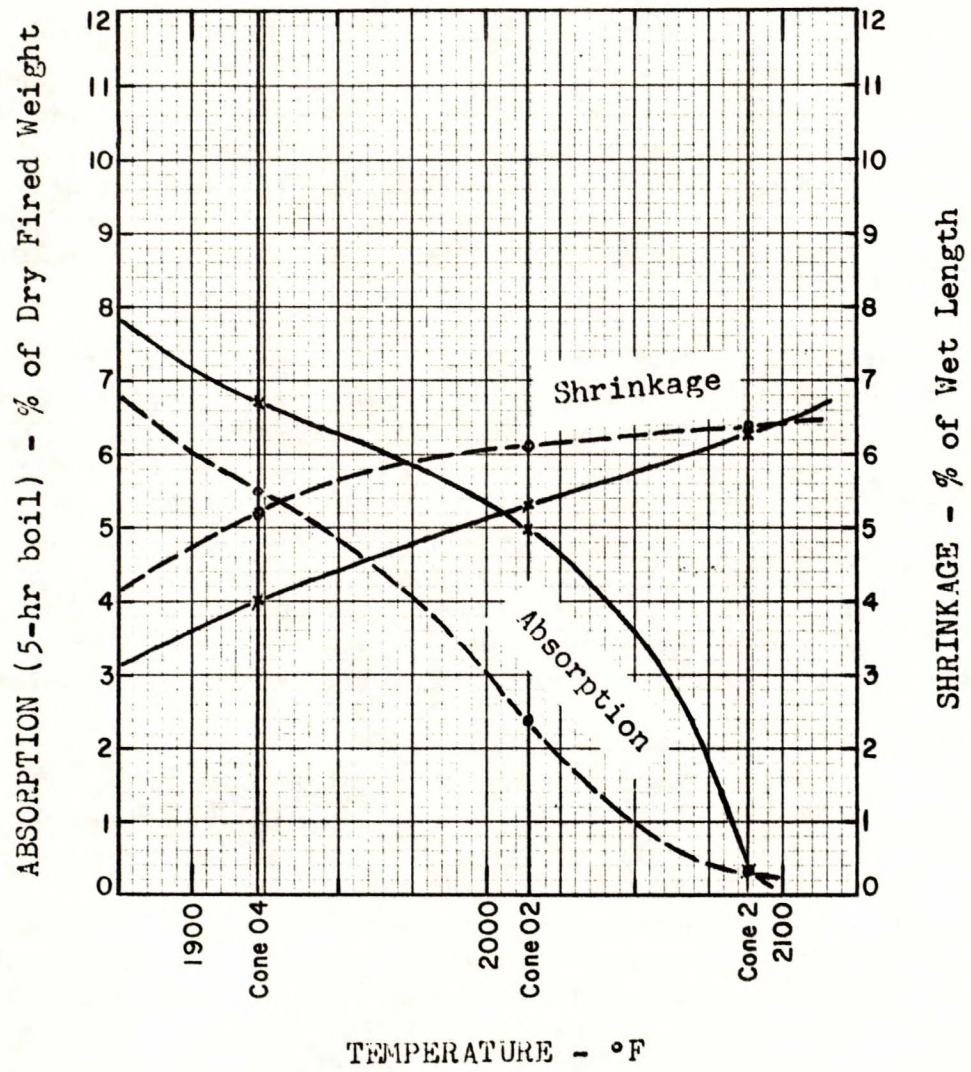


Figure 9. Fired Properties of Grogged Mixtures; Mix "C" (10% grog), deaired (—), Mix "P" (30% grog), deaired (---).

Discussion

From the results of the oxidation studies (Figure 3) it is apparent that the problem is primarily caused by the Blue Shale, and the difficulty encountered is largely a function of the proportion of this material in the mixture--mix "B", containing two-thirds Blue Shale required 2 to 3 hours longer for complete oxidation than did mix "A", one-half Blue Shale. These results confirm the validity of the plant practice of using a 50-50 mixture for heavy-section ware to equalize the oxidation rates in kilns of mixed sizes of ware.

However, the curves of Figure 4* demonstrated that the Blue Shale makes the greatest contribution to low absorption and to uniformity of the fired ware (very little change in properties between cone 04 and cone 2). For equal firing temperatures, mix "B", containing the greater proportion of Blue Shale (Figure 6), shows lower overall absorptions than mix "A" (Figure 5), and also shows a longer firing range at the desirable absorption levels below 8 per cent. For example, ware ranging in absorption from 3 to 7 per cent would result from firing mix "A" (non-deaired) at temperatures between about 2045 and 2105°F (60 Fahrenheit degree range), from mix "B" between 2000 and 2090°F (90 Fahrenheit degree range).

The second most apparent feature of the results of the oxidation studies concerns the use of vacuum extrusion--the deaired specimens required 2, 3 or, in some cases, probably 4 hours longer for complete oxidation than did their non-deaired counterparts. In compensation, there is a reduction in the temperature required for any given density (absorption) of the fired products. Although the extent of this reduction is variable, decreasing with increasing temperature, at a median absorption level of 5 per cent it amounts to about 40 Fahrenheit degrees for mix "A", 50 Fahrenheit degrees for mix "B", and about 90 Fahrenheit degrees for mixes "F" and "D" (Calgon and Lignosol TSD additions, respectively). Thus, the extra costs of fuel and labour expended during the oxidation stage of firing should be at least partly recouped through savings in fuel and time at the finishing temperature. Further, each mixture, when deaired, has an increased firing range, which should result in greater uniformity of the fired products, as well as greater ease of control of the firing process. Again, for a desirable product with absorptions varying between 3 and 7 per cent, the required firing temperatures for the various mixtures are as follows:

*These curves are for deaired specimens. Non-deaired specimens would be expected to show higher absorptions and shrinkages, but no essential change in the relationships between the curves.

Mixture	Minimum Temp., (7% Abs.)	Maximum Temp., (3% Abs.)	Difference, (Firing Range)
A - non-deaired	2045° F	2105° F	60
- deaired	1985	2075	90
B - non-deaired	2000	2090	90
- deaired	1910	2055	145
F - non-deaired	1970	2070	100
- deaired	1880	2025	145
D - non-deaired	2015	2095	80
- deaired	1895	2055	160

Figure 3 indicates that the addition of Calgon (mix "F") increased the oxidation period, by about one hour, over the times for the equivalent mixtures, deaired and non-deaired. Comparatively, the Lignosol TSD addition (mix "D") reduced oxidation time by one hour in the non-deaired specimens, and resulted in no change of oxidation period for deaired specimens. Mix "F" had the lowest maturing temperature whereas mix "D" had the widest firing range.

Among the mixtures tested, but not illustrated, additions of hydrated lime and sodium chloride produced little or no change in oxidation characteristics or fired properties. Ammonium chloride and Teepol additions resulted in decreased oxidation periods, high absorptions (leading to increased minimum firing temperatures) and decreased firing ranges; precisely the results expected from the weak, open-structured bodies produced by extrusion. The specimens containing soda ash, on the other hand, were very dense and the deaired specimens required the longest oxidation period of all. The fired properties of this mixture were the least changed by the application of vacuum.

The addition of 10 per cent of grog made no significant difference in rate of oxidation (Figure 3) or in fired properties (Figure 9 vs Figure 6). However, mix "P", incorporating 30 per cent grog, showed a reduction of one hour in oxidation time in spite of the fact that the body was well deflocculated with a Calgon addition. The increased oxidation rate applied to both the deaired and non-deaired specimens, although the grogged, non-deaired bodies are unlikely to be used because of their questionable extrusion characteristics. The fired properties of mix "P" were favourable, compared with those previously mentioned; the firing range was about 125 Fahrenheit degrees, between 1875 and 2000° F. Firing shrinkages, which showed no significant change for any of the other mixtures, were increased by about one per cent.

CONCLUSIONS

The mining and blending methods practiced at the plant could be much improved. Much of the forming loss has been blamed on poor mixing, but is probably partly due to variations in either or both raw materials. Preliminary sampling at the pits, coupled with laboratory tests of plasticity (extrudability), oxidation studies and determination of fired properties would enable adjustment of the mixtures to compensate for variations in the raw materials. It has been suggested that, for the present, the materials could be stockpiled in multiple layers of carefully gauged thickness, according to the desired mixture. Then a vertical face of the resulting pile could be worked, providing a mixture of good uniformity. In the long term, and when capital is available, it would seem preferable to grind the individual materials into separate storage bins fitted with proportioning feeders. Addition of deflocculants and use of vacuum-extrusion techniques would doubtless compensate for minor variations in material properties and mixtures.

The mixture of two parts Blue Shale to one part Red Clay is preferable from almost all considerations. The current practice of increasing the proportion of Red Clay in heavy-section ware does provide for equalization of the oxidation periods but must adversely affect product properties and uniformity. With deflocculant additions, and particularly once deairing procedures have been introduced, it would be preferable to open up the heavy-section ware with grog rather than with additional Red Clay. Low-fired grog of the type used in this investigation would be preferred, but grog prepared from reject ware would probably provide a useful alternative. The optimum addition appears to be 20 to 30 per cent of the total mixture.

The materials appear to be slow in slaking. Development of maximum plasticity, and most efficient distribution of additives, would probably be aided by extensive pugging and/or vacuum pugging.

The greatest improvement in forming properties was found with additions of 0.15 per cent Calgon. This is probably close to the optimum amount; larger additions could lead to over-deflocculation and a decrease in workability. Additions of Calgon do, however, have an adverse effect upon the rate of oxidation. Since the increase in oxidation period (for a one-inch thickness) was found to be only one hour, and since compensating reductions in finishing temperatures averaging about 25 Fahrenheit degrees are indicated, Calgon additions are recommended, particularly in the case of non-deaired ware.

Alternatively, additions of 0.25 per cent Lignosol TSD also markedly improved the forming properties and the green and dry strengths of the extruded ware. Further, such additions reduced the time required for oxidation by up to one hour for pieces one inch thick. The more open structure responsible for this effect (most pronounced in non-deaired ware) results in increased absorptions, or conversely, increased finishing temperatures (about 10 Fahrenheit degrees, average) and a slight (10 Fahrenheit degrees) reduction in firing range. For deaired ware, however, oxidation time is little affected, finishing temperatures reduced (about 10 Fahrenheit degrees, average) and the firing range extended by some 15 Fahrenheit degrees. Currently, with no deairing equipment available at the plant, Lignosol additions should be considered for the larger sizes of heavy section in preference to additional amounts of Red Clay. The reduction in oxidation period would perhaps be less but the finishing temperatures and firing range would more closely approximate those for Calgon-bearing small-diameter pipe, resulting in better quality and more-uniform products from mixed kiln settings.

In the long term, the advantages to be gained through deairing (improved formability, increased strengths, lower finishing temperatures and greater uniformity due to longer firing range) are considered to outweigh the disadvantage of increased oxidation period, and the adoption of vacuum extrusion is recommended. The preferred additive to deaired ware would be Lignosol TSD. Reduction and equalization of oxidation periods could then be attained through additions of grog in quantities varying with the thickness of the ware.

One further source of heavy loss reported, but not covered by this investigation, occurs during the water-smoking period of the firing cycle. The multi-floor dryer at the plant is of low efficiency, and doubtless would be even less effective when handling the denser ware formed through the use of additives and deairing. The ultimate solution lies in the construction of modern drying facilities, but until this is possible the final stages of drying will have to be accomplished in the kilns. Thus, large volumes of water vapour are present in the kilns at low temperatures. Under conditions of low draft, which prevail when stacks are cold, this steam can condense on the colder, lower courses of the setting, softening the ware and causing cracking and deformation under load. It is essential that high drafts prevail up to at least about 400° F to sweep the steam from the kiln before condensation can occur, and artificially induced draft should be provided. Since the object is to move large volumes of air at relatively low pressures, propellor-type fans have been found most efficient for water-smoking purposes. During the later stages of firing, once oxidation is complete, the requirements for draft can usually be met by the then-warm stack.

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