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DEVELOPMENT OF SEWER PIPE BODIES FROM ST. JOHNS CLAY AND NEW JERSEY FIRECLAYS

by

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INTRODUCTION

The Standard Clay Products, Limited at St. Johns, Que. requested assistance in an investigation to determine mixtures of local clay and New Jersey fireclay which would be suitable for the production of sewer pipe. Up to the present, mixtures used at the plant have frequently produced pipe which had large losses, particularly after drying. The company has been combining 65% local clay with 35% New Jersey fireclay as a standard body. Either Crossman or Kelloss fireclays were used. Occasionally ground scrap ware was added as grog. The company forwarded 100 pounds of each of the clays and 100 pounds of grog for the investigation. It was decided to determine the fired and unfired characteristics of various proportions of local clay, fireclay, grog and chemicals. In this manner it was anticipated that suitable combinations might be arrived at in which as much local clay and as little grog and fireclay as possible could be used.

PROCEDURE

The clay as received was ground to pass a 16 mesh Tyler screen. A screen analysis was made on the grog as received. Trial briquettes, ¼" by 1½" by 1½", were prepared from the various clays and from appropriate mixtures of the clays, grog, and chemical additives. In most cases the plant ratio of approximately 65% St. Johns clay to approximately 35% fireclay was adhered to. All mixtures were formed into a plastic mass and briquettes were hand molded in steel molds.

The water of plasticity was calculated. One briquette from each body composition was placed in a drier at 185°F and any tendency to crack with rapid drying was observed. The remainder of the samples in each batch were air dried for 24 hours and finally dried at 212°F for 24 hours. The drying shrinkage was measured. The briquettes were fired in an electric laboratory kiln in an oxidizing atmosphere. The kiln was brought up slowly to approximately 1500°F overnight and finished at the appropriate cone in approximately 4 hours the next day. The fired colour, hardness, shrinkage, and water absorption after a 24 hour soak in cold water were noted. The briquettes of many of the bodies which showed a considerable tendency to crack in rapid drying were not fired because they were mainly considered unsuitable for plant production. The pyrometric cone equivalents (PCEs) of the pure clays only were obtained.

No combinations of the two fireclays plus the St. Johns clay were investigated. Common salt (NaCl), ammonium chloride (NH_4Cl) and hydrated lime - $Ca(OH)_2$ - were used as chemical additives in an attempt to improve drying.

RESULTS

The composition of all the bodies and their unfired characteristics are shown in Table I. The chemical percentages are by weight and the clay and grog percentages are by volume.

Table I - Unfired Characteristics of Clays and Bodies

Lab. No.	Body Composition	Unfired Characteristics
89	100% Mellose fireclay	Good plasticity, works well, water of plasticity 26.4%, safe drying, drying shrinkage 6.3%
90	100% Crossman fireclay	Good plasticity, works well, water of plasticity 26.7%, safe drying drying shrinkage 5.7%.
91	100% St. John common clay	Works fairly well, tendency to be sticky, water of plasticity 27.8%, cracks with rapid drying, drying shrinkage 6.7%
91-1	65% #91 35% #89	Good plasticity, works well, water of plasticity 27.6%, cracks with rapid drying, drying shrinkage 6.7%.
91-2	65% #91 35% #90	Good plasticity, works well, water of plasticity 27.8%, cracks with rapid drying, drying shrinkage 6.7%
91-3	56% #91 28% #89 16% grog	Good plasticity, works well, water of plasticity 24.1%, slight tendency to crack in rapid drying, drying shrinkage 5.3%
91-4	53% #91 27% #89 20% grog	Good plasticity, works well, water of plasticity 22.3%, slight tendency to crack with rapid drying, drying shrinkage 5.2%.
91-5	49% #91 26% #89 25% grog	Less plasticity than 91-3 or 91-4, water of plasticity 21.6%, slight tendency to crack with rapid drying, drying shrinkage 5.1%.
91-20	40% #91 60% #89	Good plasticity, works well, water of plasticity 25.9%, very slight tendency to crack with rapid drying.

Table 1 - (Cont'd)

Lab. No.	Body Composition	Unfired Characteristics
91-6	56% #91 29% #90 15% grog	Works well, less plasticity than 91-3, water of plasticity 23.3%, slight tendency to crack with rapid drying, drying shrinkage 5.0%.
91-7	53% #91 27% #90 20% grog	Plasticity and workability similar to 91-6, water of plasticity 22.8%, slight tendency to crack in rapid drying, drying shrinkage 5.6%.
91-8	49% #91 26% #90 25% grog	Plasticity and workability similar to 91-6, water of plasticity 22.1%, slight tendency to crack with rapid drying, drying shrinkage 5.0%.
91-9	40% #91 60% #90	Good plasticity, works well, water of plasticity 25%, very slight tendency to crack in rapid drying, drying shrinkage 5.2%.
91-10	37.5% #91 37.5% #90 25% grog	Fair workability and plasticity, water of plasticity 20.2%, very slight tendency to crack in rapid drying, drying shrinkage 4.6%.
91-12	36% #91 44% #90 20% grog	Fair plasticity and workability, water of plasticity 21.1%, very slight tendency to crack in rapid drying, drying shrinkage 4.7%.
91-11	65% #91 35% #90 2% NaCl	Good plasticity, works well, water of plasticity 27.5%, tendency to crack with rapid drying, drying shrinkage 6.8%.
91-13	37.5% #91 37.5% #90 25% grog 0.5% NH_4Cl	Same plasticity and workability as 91-10 water of plasticity 20.6%, slight tendency to crack in rapid drying, drying shrinkage 4.3%.
91-14	100% #91 2% $Ca(OH)_2$	Poor plasticity, very short and weak, water of plasticity 34.6%, safe drying, drying shrinkage 5.0%.

Table 1 - (Cont'd)

Lab. No.	Composition	Unfired Characteristics
91-15	100% #91 1% $Ca(OH)_2$	Inclined to be short, works fairly well, water of plasticity 34.7%, safe drying, drying shrinkage 8.1%.
91-16	65% #91 35% #90 0.5% $Ca(OH)_2$	Good plasticity, works well, water of plasticity 27.1%, safe drying, drying shrinkage 6.6%.
91-17	65% #91 35% #90 0.3% $Ca(OH)_2$	Good plasticity, works well, water of plasticity 29.9%, slight tendency to crack with rapid drying, drying shrinkage 8.5%.
91-18	75% #91 25% #90 0.5% $Ca(OH)_2$	Good plasticity, works well, water of plasticity 31.1%, slight tendency to crack with rapid drying, drying shrinkage 8.7%.
91-19	53% #91 27% #90 20% grog 0.5% $Ca(OH)_2$	Slightly shorter than 91-18, water of plasticity 26.4%, safe drying, drying shrinkage 6.6%
91-26	65% #91 35% #89 0.25% $Ca(OH)_2$	Good plasticity, works well, water of plasticity 30.2%, slight tendency to crack in drying, drying shrinkage 9.2%.
91-20	65% #91 35% #89 0.5% $Ca(OH)_2$	Good plasticity, works well, water of plasticity 31.3%, very slight tendency to crack with rapid drying.
91-22	65% #91 35% #89 0.75% $Ca(OH)_2$	Slightly shorter than 91-20 but works fairly well, water of plasticity 31.0%, very slight tendency to crack with rapid drying, drying shrinkage 8.5%.
91-27	65% #91 35% #89 1% $Ca(OH)_2$	Fair plasticity, works fairly well, water of plasticity 33.7%, very slight tendency to crack with rapid drying, drying shrinkage 9.3%

Table 1 - (Cont'd)

Lab. No.	Composition	Unfired Characteristics
91-21	56% #91 29% #89 15% grog 0.5% $Ca(OH)_2$	Slightly shorter than 91-20 but still works well, water of plasticity 27.2%, very slight tendency to crack in rapid drying, drying shrinkage 7.0%.
91-23	56% #91 29% #89 15% grog 0.75% $Ca(OH)_2$	Inclined to be short, water of plasticity 27.7%, safe drying, drying shrinkage 7.3%.
91-24	50% #91 50% #89 0.5% $Ca(OH)_2$	Good plasticity, works well, water of plasticity 29.1%, very slight tendency to crack with rapid drying, drying shrinkage 8.0%.
91-25	42½% #91 42½% #89 15% grog 0.5% $Ca(OH)_2$	Good plasticity, works well, water of plasticity 26.3%, safe drying, drying shrinkage 7.1%.

Note See 91-28 in this table following 91-5

The size of the grog which was forwarded from the plant and used in all experiments was as follows (Tyler mesh):

	+ 8 mesh	- 1.05%
-8	+20 mesh	- 27.55%
-20	+65 mesh	- 34.40%
-65	mesh	- 37.00%

The test results of the bodies which were fired are shown in Table 2.

TABLE 2 - Fired Characteristics

Lab. No. & Composition	Cone No.	Fired Shkge. %	Water Abs^{n}. %	Colour	Hardness	Remarks
89	02	0.8	19.0	pink-buff	soft	PCE Cone 29. This is an open firing fireclay with good plasticity, workability and drying characteristics. Scums slightly and there is some vanadium efflorescence.
100% McKose	1	1.5	18.1	pink-cream	soft	
fireclay	10	3.5	13.3	light buff	fairly hard	
90	02	1.0	20.5	light pink	soft	PCE Cone 23; scums slightly. This is an open firing fireclay with good plasticity, workability and drying characteristics.
100% Crossman	1	2.0	19.2	light pink	soft	
fireclay	10	5.0	13.7	pink-buff	fairly hard	
91	06	1.7	15.8	salmon	fairly hard	PCE cone 2½. This is a red burning common clay with good workability and plasticity It is difficult to dry. The firing range is short for production of a hard dense product. Scums.
100% St. Johns	04	5.0	9.4	light red	hard	
Common clay	02	10.3	1.3	dark red	steel hard	
91-1						The fired shrinkage is high in the range in which a dense product is produced. The plasticity and workability are good but the mixture is hard to dry. Scums.
65% #91	04	3.8	10.9	salmon	hard	
35% #89	02	7.5	4.0	light red	very hard	
91-2						
65% #91	04	4.5	11.5	salmon	fairly hard	
35% # 90	02	7.6	5.3	red	hard	Same comments as 91-1.
91-3						The grog tends to reduce the shrinkage and increase the absorption at a given temperature. The mixture cracks in drying but not as severely as #91-1. The plasticity and workability are good. Scums.
56% #91	06	0.8	15.5	salmon	fairly hard	
29% #89	04	2.7	11.1	salmon	fairly hard	
15% grog	02	4.5	7.2	light red	hard	

Table 2 (Cont'd)

Lab. No. & Composition	Cone No.	Fired Shkge. %	Water Abs. %	Colour	Hardness	Remarks
91-4 53% #91 27% #89 20% grog	06 04 02	0.8 2.1 4.0	14.7 12.0 8.2	Salmon Salmon red	fairly soft fairly hard hard	Same comments as 91-3. This mixture still has a slight tendency to crack in rapid drying.
91-5 49% #91 26% #89 25% grog	06 04 02	0.7 2.1 3.8	13.9 12.0 8.1	salmon salmon red	fairly soft fairly hard hard	Same comments as 91-1. The mixture has a very slight tendency to crack with rapid drying.
91-6 56% #91 29% #90 15% grog	06 04 02	1.0 2.5 4.8	15.7 12.1 8.4	salmon light red red	fairly soft fairly hard hard	The addition of grog tends to reduce shrinkage and increase absorption at a given temperature. The mixture has less tendency to crack in drying than 91-2. Scums.
91-7 53% #91 27% #90 20% grog	06 04 02	1.0 2.0 4.1	14.3 11.4 6.8	salmon light red red	fairly soft fairly hard hard	Same comments as 91-6. This mixture has a very slight tendency to crack with rapid drying.
91-8 49% #91 26% #90 25% grog	06 04 02	1.0 1.5 4.0	14.0 11.5 7.6	salmon light red red	fairly soft fairly hard hard	Same comments as 91-7.
91-9 40% #91 60% #90	06 04 02	0.8 1.8 4.8	18.3 16.6 9.8	salmon salmon light red	fairly soft fairly soft fairly hard	This mixture requires a slightly higher temperature than cone 02 to produce a hard dense body. There was a very slight tendency to crack in rapid drying.
91-10 37.5% #91 37.5% #90 25% grog	06 04 02	0.5 1.7 3.1	14.6 12.7 9.7	salmon light red red	soft fairly soft fairly hard	same comments as 91-9

TABLE 2 (Cont'd)

Lab. No. & Composition	Cone No.	Fired Shkge. %	Water Abs. %	Colour	Hardness	Remarks
91-14 100% #91 2% $Ca(OH)_2$	06 04 02	1.0 2.3 7.1	25.3 21.7 7.1	scummed " "	very soft very soft hard	Safe drying: the addition of $Ca(OH)_2$ increases the absorption and decreases the plasticity, workability, shrinkage and hardness. Scumming is objectionable.
91-15 100% #91 1% $Ca(OH)_2$	06 04 02	1.5 2.8 9.3	20.2 16.9 4.2	scummed " "	soft soft very hard	Same comments as 91-14. 1% $Ca(OH)_2$ is greatly in excess. The clay (#91) dries safely.
91-16 65% #91 35% #90 0.5% $Ca(OH)_2$	06 04 02	1.5 3.5 6.6	17.6 14.5 6.9	salmon salmon red	fairly soft fairly hard hard	There is a few white spots from the $Ca(OH)_2$. The mixture dried safely and had good workability. The fired shrinkage is decreased and the absorption increased when compared with 91-2.
91-19 53% #91 27% #90 20% grog 0.5% $Ca(OH)_2$	06 04 02	0.7 2.0 4.3	15.7 13.9 8.3	salmon salmon red	fairly hard fairly hard hard	There is considerable white scum from the $Ca(OH)_2$. The mixture dries safely and the fired properties are favourable.
91-20 66% #91 33% #89 0.5% $Ca(OH)_2$	06 04 02	2.1 3.6 7.5	14.5 11.0 3.7	salmon salmon red	fairly hard ~~fairly~~ hard very hard	The fired properties are similar to 91-1. There is a very slight tendency to crack with rapid drying. There is a very little white scum from the $Ca(OH)_2$
91-21 56% #91 29% #89 15% grog 0.5% $Ca(OH)_2$	The fired properties are similar to sample 91-23. This sample was fired at cone 02 only.					There are a few white spots at cone 02 from the $Ca(OH)_2$. The workability and plasticity are good. There is a very slight tendency to crack in in rapid drying.

TABLE 2 (Cont'd)

Lab. No. & Composition	Cone No.	Fired Shkge. %	Water Abs. %	Colour	Hardness	Remarks
91-23 56% #91 29% #89 15% grog 0.75% $Ca(OH)_2$	06 04 02	1.0 2.1 4.3	16.5 14.9 10.1	scummed " "	fairly soft fairly soft fairly hard	This mixture is safe drying. The quantity of $Ca(OH)_2$ is excessive and scumming is very severe. The plasticity and workability are reduced.
91-24 50% #91 50% #89 0.5% $Ca(OH)_2$	The fired results are similar to 91-25. This sample was fired at Cone 02 only					Same remarks as 91-21
91-25 42½% #91 42½% #89 15% grog 0.5% $Ca(OH)_2$	06 04 02	1.0 2.0 3.7	15.5 14.3 10.6	salmon salmon red	fairly hard fairly hard hard	This mixture scums slightly. It is safe drying and the workability and plasticity are good. To produce a hard dense body a slightly higher firing temperature than cone 02 may be required.

The temperature equivalents of the various cones used in the investigation are as follows:

Cone	Temperature Equivalent °F
06	1816
04	1922
02	2014
1	2077
2	2088
3	2106
10	2345
23	2921
29	3018

DISCUSSION OF RESULTS

The St. Johns clay (#91) is a common, low grade, heterogeneous clay which cracks under rapid drying conditions. It has a drying shrinkage of approximately 7% which is slightly high for the manufacture of clay products. This material has a very short firing range in which a hard dense product can be obtained. This is shown by the fired shrinkage which increases from approximately 5% at cone 04 to approximately 10% at cone 02. With the same temperature change, the absorption decreases from approximately 9% to approximately 1%. These rapid changes indicate that the clay is a difficult one to fire to a uniform size. This clay cannot be considered suitable for the manufacture of sewer pipe unless a more refractory clay with a long firing range and low shrinkage is added to improve the fired properties.

The McMose and Crossman fireclays (#89 and #90) from New Jersey, U.S.A. have unfired and fired characteristics which are similar to each other. They are safe drying and have drying shrinkages of approximately 6%. They are both open firing clays with long firing ranges. Their absorption decreases from approximately 20% at cone 02 to approximately 14% at cone 10. During that same large temperature interval the shrinkage increases from approximately 1% to approximately 4 to 5%.

Mixtures 91-1 and 91-2 which are similar to the bodies commonly used at the plant are made up of 65% St. Johns clay and 35% fireclay. These mixtures do not dry satisfactorily under rapid drying conditions. In each case the fireclay increases the firing range of the St. Johns Clay. However, at cone 02 where a hard dense body is produced the fired shrinkage is approximately 7.5% which is undesirably high. The test results on these two mixtures indicate that extreme care would be required in drying, and close and uniform temperature control during firing would be necessary to produce a dense, uniformly sized sewer pipe.

In bodies 91-3, 91-4, and 91-5, 15,20 and 25% grog respectively is added to a St. Johns clay - McMose fireclay mixture in which the ratio of local clay to fireclay is approximately 65 to 35. The drying characteristics are improved by the grog but the tendency to crack with rapid drying is not eliminated. The drying and fired shrinkage is reduced and the absorption decreased. Thus the grog enables a hard dense body to be obtained in which the fired shrinkage of approximately 4 to 4.5% at cone 02 is considerably less than the 7.5% of body 91-1.

Similar results are observed with bodies 91-6, 91-7, and 91-8 in which 15, 20 and 25% grog respectively is added to a mixture of St. John and Crossman clay in the approximate ratio of 65 to 35. The briquettes have a slight tendency to crack with rapid drying. The grog reduces the drying and fired shrinkage and increases the absorption of these bodies when they are compared to body 91-2.

Body 91-28 consisting of 40% St. Johns clay and 60% Mellose clay and body 91-9 consisting of 40% St. Johns clay and 60% Crossman clay have a very slight tendency to crack with rapid drying. There are very faint cracks on the top of the test briquettes indicating that with the St. Johns clay reduced to 40% there might still be a tendency to crack under severe drying conditions. The fired characteristics of 91-9 are suitable for sewer pipe production. No fired results of 91-28 were obtained but they would likely be similar to 91-9. No further work was carried out on mixtures having a high fireclay content because of the cost of laying down the fireclay at the plant.

Bodies 91-10 and 91-12 containing 25% and 20% grog respectively and having a ratio of St. Johns clay to fireclay of 50 - 50 and 45-55 respectively crack very slightly in rapid drying. Thus it is possible a little drying difficulty might be experienced under hot and dry conditions. The fired characteristics of body 91-10 are satisfactory and it is likely that body 91-12 would have similar fired properties.

Body 91-11 in which 2% sodium chloride was added to the plant mix of 65% St. John clay and 35% Crossman clay cracked in drying. Sodium chloride was not considered to be a suitable chemical additive and no further work was carried out along this line.

Ammonium chloride (0.5%) was added to body composition 91-10 to form body 91-13. There was no apparent improvement in drying from this chemical and so its use was discontinued.

Hydrated lime - $Ca(OH)_2$ - which is commonly used for agricultural purposes proves to have a marked effect on St. Johns clay. Bodies 91-14 and 91-15 which are made up of St. Johns clay plus additions of 2% and 1% $Ca(OH)_2$ respectively dry safely. The plasticity and workability of the clay are greatly reduced. The fired shrinkage and hardness are reduced, and the absorption is increased. After firing, all briquettes of these two bodies are covered with a white scum. It is apparent that hydrated lime improves the drying qualities of the St. Johns clay. However, from the results it is evident that approximately 1% is considerably in excess of the amount needed to provide proper workability, good plasticity and a fired product free of scum.

Body 91-16 containing 65% St. Johns clay 35% Crossman clay and 0.5% $Ca(OH)_2$ dries safely. Body 91-17 containing the same proportions of the same clays and 0.3% $Ca(OH)_2$ has a very slight tendency to crack in drying. The workability and plasticity of each one are good. There are a few white scum specks on the 91-16 briquettes indicating that 0.5% $Ca(OH)_2$ is slightly in excess of the proper requirements. Thus, indications are that a body containing 65% St. Johns clay, 35% Crossman clay and approximately 0.4% $Ca(OH)_2$ should dry satisfactorily, extrude properly, and produce a satisfactory fired product.

Body 91-18 containing 75% St. Johns clay, 25% Crossman clay and 0.5% $Ca(OH)_2$ has a slight tendency to crack in drying. Accordingly, to achieve a safe drying body when the St. Johns clay is 75% or greater the percentage $Ca(OH)_2$ should be slightly greater than 0.5% but probably not exceeding 0.7%.

Body 91-19 containing 20% grog, 0.5% $Ca(OH)_2$ and a St. John - Crossman clay ratio of 65-35 dries safely under sever conditions.. There is a great deal of excess white scum on the fired briquettes. Thus when clay is replaced by grog then the $Ca(OH)_2$ requirement is reduced. Indications are that for the above body approximately 0.3% $Ca(OH)_2$ would produce a safe drying body with little visible white scum on the fired product.

More difficultyis experienced with producing safe drying briquettes made up from mixtures of St. Johns clay and McHose fireclay. Initially various percentages of $Ca(OH)_2$ were added to the plant mixture of 65% St. Johns clay and 35% McHose clay. These bodies are 91-26, 91-20, 91-22, and 91-27, containing 0.25, 0.5, 0.75, and 1.0% $Ca(OH)_2$ respectively. Body 91-26 has a slight tendoney to crack in rapid drying and the balance have a very slight tendency to crack. Thus there is little apparent advantage of adding $Ca(OH)_2$ in excess of 0.5%. It is likely that body 91-20 containing 0.5% $Ca(OH)_2$ would dry safely if care was exercised in drying. The fired briquettes are similar in properties to those of 91-1 except that they have a few white spots from the $Ca(OH)_2$. The unfired briquettes of bodies 91-22 and 91-27 show evidence of having a scum and although they were not fired it is apparent they would be discoloured by a white surface scum.

Bodies 91-21 and 91-23 are similar to 91-3 (56% St. Johns clay, 29% McHose clay, 15% grog) with the exception that 91-21 contains 0.5% $Ca(OH)_2$ and 91-23 contains 0.75% $Ca(OH)_2$. The drying characteristics are improved by the $Ca(OH)_2$ although a very slight tendency to crack remains in 91-21. Body 91-23 is safe drying but is inclined to be short and the fired briquettes are covered with a white scum which indicates that the percent $Ca(OH)_2$ is too high. A few white specks from the $Ca(OH)_2$ were observed on 91-21. Indications are that a mixture similar to 91-21 could probably be processed satisfactorily in the plant provided care is exercised in drying. This mixture contains 15% grog whereas 91-22 contains no grog. Their drying characteristics are somewhat similar and in each case some care is required in drying.

Body 91-24 has a very slight tendnecy to crack with rapid drying and again care would be needed in drying. This mixture contains 50% St. Johns clay, 50% McHose fireclay, 0.5% $Ca(OH)_2$, and no grog. There are a few white specks from the $Ca(OH)_2$ on the fired briquettes.

Mixture 91-25 has a 50-50 ratio of St. Johns clay to McHose fireclay plus 15% grog and 0.5% $Ca(OH)_2$. This mixture is safe drying under severe conditions. The fired briquettes contain a few white specks from the $Ca(OH)_2$. It is likely that approximately 0.4 to 0.5% $Ca(OH)_2$ would be a large enough addition for this combination.

It should be noted that all briquettes were hand molded into a plastic mass which would contain more moisture than the stiff mud consistency used in sewer pipe manufacture. As a result the drying shrinkages and waters of plasticity reported here would be higher than on the plant.

SUMMARY AND RECOMMENDATIONS

The St. Johns local clay is a difficult material to dry satisfactorily and it has an extremely short firing range. In order to make use of this material in the production of sewer pipe, additions must be made to aid drying and to lengthen the firing range. McHose and Crossman fireclays which are used at the plant are safe drying and tend to lengthen the firing range of the St. Johns material when added in percentages of 35% or greater. Combinations of 65% St. Johns clay and 35% fireclay which are the usual plant mixtures are difficult to dry due to the large quantity of the former material. Additions of grog prepared from scrap ware and small percentages of hydrated lime - $Ca(OH)_2$ - aid the drying characteristics and in many cases improve the fired properties of the test briquettes. Indications from the mixtures investigated are that bodies containing McHose clay are more difficult to dry under sever conditions than bodies containing Crossman clay.

Preliminary tests using ammonium chlorice (NH_4Cl) and sodium chloride ($NaCl$) indicate that these chemicals will not improve drying.

Additions of grog from 15 to 25% to St. Johns clay - fireclay mixtures having an approximate ratio of 65 - 35 improve the drying characteristics but do not entirely eliminate cracking under severe drying conditions. Mixtures containing up to 44% fire-clay and 20 to 25% grog also tend to crack very slightly with rapid drying conditions. The grog in all the above cases reduces

the drying and fired shrinkage and increases the absorption slightly. Thus the grog has a beneficial effect although it does not entirely eliminate the drying troubles. It is likely that 15% will be the maximum quantity that can be used successfully at the plant. It will probably be difficult to obtain sufficient scrap for the use of a larger percentage and in addition too great a percentage often causes trouble at the cutter.

Small additions of hydrated lime to St. Johns clay improves the drying characteristics, reduces the plasticity, workability and fired hardness, and increases the absorption. This effect is also observed in St. Johns clay - fireclay mixtures containing $Ca(OH)_2$. If the hydrated lime is slightly in excess the fired product contains a few white specks while if it is considerably in excess the fired product is covered with a white scum. In the majority of cases approximately 0.3 to 0.5% $Ca(OH)_2$ produces good results in the laboratory. With this quantity the workability and plasticity of the various mixtures are satisfactory. Consequently bodies containing 0.5% $Ca(OH)_2$ or less should extrude properly.

A body made up of 65% St. Johns clay, 35% Crossman fireclay and 0.5% $Ca(OH)_2$ dries safely under rapid drying conditions in the laboratory. It is concluded that probably 0.4% $Ca(OH)_2$ would be sufficient in the above mixture. The results indicate that a mixture made up of 53% St. Johns clay, 27% Crossman clay, 20% grog and approximately 0.3% $Ca(OH)_2$ will dry satisfactorily and be free of white discolouration after firing. From consideration of the above two mixtures it may be concluded that if the St. Johns clay-Crossman fireclay ratio is maintained at approximately

65-35 then a safe drying body should be obtained by varying the grog from 0 to 20% and the $Ca(OH)_2$ from 0.4% to 0.3%. The percent $Ca(OH)_2$ required for satisfactory results varies with the amount of St. Johns clay in the above mixtures.

The results indicate that mixtures of St. Johns clay and McHose fireclay are more difficult to dry than St. Johns clay-Crossman fireclay mixtures. With care in drying it is likely that a mixture of 65% St. Johns clay - 35% McHose clay and 0.4 to 0.5% $Ca(OH)_2$ will dry safely and extrude satisfactorily. Addition of grog to the above mixture will probably prove beneficial although when 15% grog is added there is still a very slight tendency towards cracking under severe drying conditions.

A mixture of 42½% St. Johns clay, 42½% McHose clay, 15% grog and 0.4% to 0.5% $Ca(OH)_2$ dries safely in the laboratory and is relatively free of scum. When the grog is removed from the above body and the clays maintained in the same ratio there is a very slight tendency to crack in drying.

It is recommended that trials be made at the plant of the various bodies which were found safe drying or nearly safe drying under severe drying conditions. Trials should preferably be made on St. Johns clay - fireclay mixtures having a ratio of 65-35. Up to 15% grog would be beneficial if a sufficient supply is available. Additions of 0.3% to 0.5% $Ca(OH)_2$ should reduce drier losses. The amount of $Ca(OH)_2$ required will depend mainly on the total quantity of St. Johns clay used in the mixture, on the effect on extrusion, and on the effect on the fired properties.

It is very important that the ingredients of each mixture are measured accurately and mixed thoroughly before the ware is formed. The drying should be controlled properly. Initially drying should be carried out in humid conditions so that the ware can be thoroughly heated with little evaporation taking place. As the drying progresses the temperature can be increased and the humidity decreased until drying is complete. Those conditions can exist only where there are temperature and humidity controls. All plant tests should be fired under normal plant conditions.

The severe drying conditions which were used in the laboratory investigation are probably more severe than the normal plant drying program. Consequently, as mentioned previously, mixtures which cracked very slightly in the laboratory would probably dry safely at the plant if reasonable care is employed in drying.

To summarize, the following bodies dried safely and their composition utilizes a substantial proportion of St. Johns clay so that they should be given plant trials:

1. 65% St. Johns clay
   35% Crossman fireclay
   0.4 to 0.5% $Ca(OH)_2$
2. 53% St. Johns clay
   27% Crossman fireclay
   20% grog
   0.3% $Ca(OH)_2$

(note: the percent grog may be reduced below 20%).

3. 42½% St. Johns clay

   42½% Mellose clay

   15% grog

   0.4 to 0.5% $Ca(OH)_2$

The following bodies cracked very slightly in the laboratory investigation and should be considered for plant trials provided normal care is exercised in drying:

1. 65% St. Johns clay

   35% Mellose clay

   0.4 to 0.5% $Ca(OH)_2$

2. 56% St. Johns clay

   29% Mellose clay

   15% grog

   0.4 to 0.5% $Ca(OH)_2$

JGB/LMD

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