NOTES ON SAGGER CLAYS AND MIXTURES.

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Introduction.

The sagger problem, although an old one, does not appear any nearer its solution than it was several years ago. The sagger losses in our potteries and other ceramic industries is a serious one and the life of the saggars is an important item in the profit and loss columns in most of the plants. It is true that there is considerable variation in the length of life of the saggars used in the different plants, but there appears to be no generally accepted practice particularly as to the kinds of clays used in the sagger mixtures. Frequently, a change in the composition of the sagger mixture is necessitated by inability to secure the clays formerly used and the consequent substitution of new and untried materials in the sagger batches.

In a great many plants, the composition of the sagger mixture is governed for the most part by the cost of the clays—the quality of the clays and their suitability for this purpose being secondary to the price per ton. However, very often, a so-called low-grade or cheap clay will produce a sagger having longer life than some of the so-called high-grade clays sold at fancy prices.

Character of Sagger Failures.

The character of sagger failures may be briefly classified as follows:

1. Breakage due to the rough handling of the unburned saggars in placing in the kiln.
2. Breakage due to the too rapid heating of the saggars during the first burning.
3. Breakage during the cooling in the kilns.
4. Breakage due to rough handling of the saggars in drawing from the kiln and emptying and in again placing in the kiln.

5. Failures due to the deformation of the loaded saggers at the maximum kiln temperatures.

Taking up in order the above types of failures:

1. Breaking in Handling.—The breakage in the green state during placing may obviously be reduced by more careful supervision of the placing of the unburned saggers in the kiln. This breakage is, however, governed to a large extent by the strength of the sagger clays in the dried condition and clays having good strength should be used—all other properties being satisfactory. The strength in the dry condition is also governed by the size and proportioning of the grog particles and the percentage of grog used.

2. Breakage in Heating-up.—Some of the breakage of saggers may be ascribed to their being too rapidly heated during the first burning. This is especially true if the saggers have not been thoroughly dried before placing in the kiln. It is also governed to a certain extent by the amount of rapid heating which the clays used in the sagger mixture will withstand. The writer has observed instances in which the facilities for drying the saggers were entirely inadequate and, when placed in the kiln, they still contained an appreciable percentage of the water used in tempering the sagger mixture. In starting up the fires in the kiln, this water may be too suddenly converted into steam and cracking of the saggers results.

We must not lose sight of the fact that sagger clays contain chemically combined water, as do all other clays, and that this combined water is only driven off as the kiln reaches a visible red-heat. If the temperature is raised too rapidly during this period the chemically combined water is converted too suddenly into steam, a strain in the sagger is set up, and cracking and breakage result.

3. Breaking in Cooling.—From the observations we have made, we are inclined to believe that most of the breakage of saggers takes place during the cooling down of the kilns. Any clay product will crack if cooled rapidly enough. Some, of course, will crack or break more readily than others. Of the many ceramic wares, fused quartz has perhaps the greatest resistance

to temperature changes—this being due to its very low coefficient of expansion and its very regular and uniform expansion and contraction when heated or cooled. A piece of fused silica ware will crack, however, if cooled quickly enough. We find the same to be true of all ceramic wares which must necessarily withstand unusual temperature changes in use. We might mention chemical porcelain, Marquart porcelain, gas mantle rings, spark plugs, etc. Turning to the heavier and cruder clay products, manufactured from fire clays, we find the same to be the case. It is well known that silica brick are very sensitive to temperature changes and crack very readily. It is generally accepted that a fire brick having a high content of quartz or silica will crack and spall more readily than the so-called high-clay fire brick. We also know that some high-clay fire brick are more sensitive to temperature changes than others. Therefore, under the same conditions of cooling, saggers made from one fire clay mixture will crack more readily than saggers made from another mixture. We will discuss the reasons for this later on in the paper.

4. Breakage from Handling.—Some of the sagger breakage is undoubtedly due to the more or less rough handling which the saggers receive in placing in and drawing from the kiln. This breakage may be aggravated by the use of a vitrifying wad-clay and the consequent necessity of pounding the sagger in order to loosen it from the one underneath. It may also take place in setting the sagger on the floor or on the bench. A sagger may not be actually broken by the handling but it may be so weakened that it will crack and break the next time it is fired. Obviously, the reduction of breakage from this source is a question of using the right kind of wad-clay and of supervision of the drawing from and placing in the kiln.

5. Deformation.—Failures through the deformation of saggers—due either to heavy loading or firing to high temperatures—are not so common as those due to cracking or breaking. This type of failure, of course, is more prevalent in those plants firing large and heavy wares and in those plants employing the higher firing temperatures. Our American pottery practice differs markedly from that of Continental Europe in the firing tem-

peratures employed—which are uniformly lower in our ceramic plants. We might say that the average firing temperatures of our kilns is not above cone 10 or 11 and very rarely in this country do we encounter firing temperatures above cone 13 as against cones 16, 17, and 18 reached in Europe. Our sagger problem is, therefore, not analogous to theirs. We must repeat, therefore, that deformation is not the most general type of failure of saggars.

Requisite Properties of Saggars.

Having discussed the character of sagger failures we take up the question of the properties requisite in saggars in order to reduce the failures due to the above. The requisite properties of a sagger may be outlined as follows:

1. Refractoriness.
2. Mechanical strength.
3. Resistance to deformation.
4. Resistance to temperature changes.

1. **Refractoriness.**—The refractoriness of the clays used in a sagger mixture should receive first consideration. Refractoriness has come to mean more than a high melting or softening point.

The investigations on fire clays during the past ten years have led to a very definite classification of our fire clays, not only in accordance with their so-called melting points, but also on the basis of their vitrification or burning behavior at the temperatures at which they are to be used. The fact that one fire clay has a softening point two or three cones higher than that of another fire clay does not necessarily mean that the former will give better service in a sagger mixture. If a kiln of ware is being fired to cone 12, it is immaterial whether the saggars used have a melting or softening point of cone 29 or cone 32. In this case the behavior of the sagger at cone 13 and below is of infinitely more importance than is its behavior at cone 26.

Sagger clays, and all fire clays used as a bond in the manufacture of clay products, may be roughly divided into two classes, insofar as their burning behavior is concerned, *i. e.*, they may be classified as *vitrifying* and *open-burning*. A vitrifying clay is, of course, one which vitrifies at a comparatively low temperature.

FIG. 1.

and retains its vitrified structure and low porosity over a wide temperature range without swelling or over-burning. In Fig. 1 is shown the burning behavior of a clay of this type. It will be noted that the shrinkage of this clay although high is quite uniform and that the trend of the shrinkage curve conforms quite closely with that of the porosity curve.

In Fig. 2 is shown the burning behavior of an open-burning clay—one which retains a porous structure and high absorption at a comparatively high temperature. The burning shrinkage of this type of clay is usually low and shows little change in firing over a wide temperature range.

In Fig. 3 is shown the burning behavior of a clay which does not fall under the above classification. It will be noted that the porosity of this clay decreases quite regularly with the firing

FIG. 2.

temperature until a vitrified structure is attained at a high temperature. The firing shrinkage increases quite regularly with the firing temperature and the shrinkage curve conforms with the porosity curve, *i. e.*, as the porosity decreases, the shrinkage increases. A clay of this type is obviously not well suited to the manufacture of many of our clay products as with each increase in temperature the clay undergoes further shrinkage and consequently does not reach a condition of equilibrium until a high temperature is reached.

In Fig. 4 is illustrated the burning behavior of a clay which is obviously unsuited to the manufacture of saggers or other clay products which are burned to high temperatures. It will be noted that the porosity of this clay decreases somewhat uniformly with the increase in temperature until it reaches the

FIG. 3.

minimum porosity, after which the porosity increases rapidly, indicating the development of a vesicular structure.

In view of the wide variations in the burning behavior of the different fire clays, the softening or fusion point is therefore not a safe criterion in the selection of a clay to be used in a sagger mixture.

2. Mechanical Strength.—Under mechanical strength we will consider the resistance of the sagers to breakage during placing and drawing after the first firing. The mechanical strength of a burned sagger in the cold is dependent upon several factors:

1. The extent to which the bond clays vitrify at the finishing temperature of the kiln.
2. The mesh of the sieve through which the grog is sieved and the proportioning of the grog particles.

FIG. 4.

3. To the presence or absence of hair cracks—small cracks so often developed by sagger mixtures in drying and burning.

4. The proportion of grog to raw-clay used and the uniformity of mixing and tempering.

1. *Bonding Clays*.—A certain amount of vitrifying bond clay is necessary to the production of a sagger of good mechanical strength in the cold. By the sole use of an open-burning bond clay the particles of grog are held loosely together and weak sagers result. By the use of a vitrifying bond-clay the grog particles are held firmly together. The use of a certain amount of a vitrifying bond-clay having a burning behavior similar to that shown in Fig. 1, is desirable in order to secure a sagger of the desired strength. The greater the amount of vitrifying bond clay used the greater will be the strength of the resultant sagers.

It is not desirable to use too much of the vitrifying clay. In order to secure a sagger of the desired openness a certain amount of open-burning clay, having a burning behavior similar to that shown in Fig. 2, must also be used. By confining our mixture to grog, a vitrifying clay and an open-burning clay, and by varying the proportions of the two clays, we can secure a sagger of any desired mechanical strength in the cold. A good proportion is, say 50 per cent grog, 20 per cent vitrifying clay and 30 per cent open-burning clay.

2. *Sagger Grog*.—It has been our experience that too little attention has been paid to the screening of grog for sagger mixes and that our knowledge of the best practice is limited. The work of F. A. Kirkpatrick¹ on the effect of the size of grog in fire clay bodies has thrown considerable light on this subject. In a sagger mixture in which there is a preponderance of large sized grog particles, the spaces between the grains are filled with the bond clay which, in vitrifying, allows the particles of grog to slide upon each other. Instead of having a skeleton of grog particles touching at many points and held together by the bond clay we have a matrix of bond-clay in which are imbedded the grog particles and the bond-clay becomes the predominating factor in the behavior of the mixture.

The proportions of the sizes of grog particles secured by screening through a single sieve are very irregular—this being especially true if a sieve of large mesh is used. As an illustration, a grog which was prepared by passing through a $\frac{3}{8}$ mesh sieve had the following proportions of different sized grains:

3/8 - 1/4 mesh	36 per cent
4 - 8 mesh	30 per cent
8 - 12 mesh	10 per cent
12 - 20 mesh	9 per cent
20 - 40 mesh	8 per cent
Through a 40 mesh . . .	7 per cent

It will be noted that in this grog the larger particles predominated and very little shaking caused the finer particles to settle out leaving a skeleton of coarse grains.

¹ *Trans. Am. Ceram. Soc.*, 19, 268-300 (1917).

3. *Hair Cracks*.—We have often observed the small hair cracks in saggars, sometimes present in the green sagger before burning but more often observed in the burned saggars. These hair cracks may be caused by the use of a too large-mesh screen in sieving the grog, to improper proportioning of the grog particles, to the use of a bond clay which has an excessive drying and burning shrinkage, or to a combination of the above causes. If there is a preponderance of large sized grog particles there will be an excess of bond clay between the grog grains, and the bond clay, having a greater shrinkage than the grog, decreases in volume and pulls away from the grog particles causing a strain and producing the small cracks which are bound to decrease the mechanical strength of the sagger. The qualities imparted by coarsely ground grog in the sagger mixture may be more than offset by improper proportioning of the grog grains and the resultant unsound structure produced by the small hair cracks.

The general practice in Europe—employed to a limited extent in this country—of grading the particles of sagger grog into different sizes and then adding definite proportions of each size to the sagger mixture is an excellent one. In this way the voids between the larger sized grog particles are filled with smaller sized grog particles and so on until we have a skeleton of grog particles held together by the bonding clays. A mixture of this kind will have a smaller drying and burning shrinkage and greater mechanical strength when burned than a similar sagger mixture in which there is a preponderance of the larger sized grog particles.

3. **Resistance to Deformation**.—As we have previously stated, failures due to deformation of the saggars appear to be fewer than the losses due to breakage.

The causes of the deformation of fire clay bodies in general and in particular of fire brick have been very thoroughly studied—especially by the Bureau of Standards.¹ We are all more or less familiar with the load test as applied to fire brick when heated to high temperatures. The behavior of a fire brick when weighted down or loaded is analogous to the behavior of a sagger when filled with ware. In the case of the fire brick it has been found that the deformation under a load is largely due to the softening

¹ Bur. Standards, *Tech. Paper 7*.

of the bonding clay used in holding together the particles of grog. A vitrifying clay softens and deforms more readily than an open-burning clay and hence, if our saggers are failing through bending or deformation, the remedy is to use a smaller percentage of vitrifying clay, or to substitute a refractory open-burning clay for some or all of the tight-burning clay used in the sagger mixture.

4. Resistance to Temperature Changes.—A large proportion of sagger breakage appears to take place during the cooling down of the saggers in the kiln. It has been well established that a very dense vitrified fire clay body has less resistance to temperature changes than a fire clay body retaining an open structure after burning. A sagger mix prepared from a dense grog and excessive quantities of vitrifying bond clay is bound to be very sensitive to changes in temperature. The structure of the sagger should be as open and porous as possible without sacrificing its mechanical strength in the cold. This, of course, is governed by a proper proportioning of the contents of open-burning and vitrifying bond clay used in the mixtures.

The cracking and breaking of saggers is undoubtedly in many instances due to the use of open-burning bond clays, having a high content of sand. The practice of adding sand to a sagger mixture is not a sound one from the information which is available. The sensitiveness to cracking of all clay products containing a high percentage of silica is well known.

Silica brick, which contain from 93 to 98 per cent silica, are particularly sensitive to changes in temperature and for this reason are not used in a great many furnaces which are heated up and cooled down intermittently. We have encountered a greater tendency in the so-called quartzite or siliceous refractories to crack and spall than is observed in the so-called high clay refractories. We know that red-burning clays, containing a high percentage of sand, used in some localities in the manufacture of common building brick, are very sensitive to cracking if cooled down quickly in the kilns. By the introduction into a sagger mix of an open burning bond clay having an excess of free sand, we are inviting cracking and breaking of the saggers—through the inability of the sagger as a whole to withstand the volume changes of the particles of sand introduced in the bonding clay.

The irregular thermal expansion and contraction of the different forms of silica is the source of trouble in the manufacture of a great many of our ceramic wares. It has given trouble through the cracking and "dunting" of terra cotta, of vitreous and porcelain sanitary ware, fire brick, and in every clay product in which there is an excess of silica, either in the form of sandy fire-clays or in the form of flint as in our white burning pottery products.

We would, therefore, expect that the introduction of an excessive amount of sandy clay into a sagger mixture is very liable to cause cracking—followed by breaking of the sagger either in the same or in the succeeding burn.

Raw Materials and Composition.

In view of the above, therefore, it is not sufficient that we know the burning behavior of our sagger clays—whether vitrifying or open-burning. We must also know something of their composition, especially as regards their content of coarse or even very fine grained sand or silica. Obviously, the sagger should be as free from iron as possible and from all granular materials which are liable to cause popping or spitting-out.

It is significant that, in the manufacture of ceramic products which are particularly designed to withstand temperature changes and especially of the higher grade wares, it has been found necessary to eliminate silica in the form of flint from the body mixtures. We may mention particularly the porcelain tubes used in insulating the thermocouple wires of pyrometers. The well-known Marquarat¹ tubes are known to have a high content of alumina and little or no free silica was used in the preparation of the body. The same is true of the porcelain pyrometer tubes now being manufactured in this country. Flint has been eliminated from the body and calcined aluminous mixtures have been substituted in its place. Flint has also been found objectionable in the special porcelains which are subjected in use to temperature changes—such as gas-mantle rings, porcelain insulators, etc.

Attention should be called to the use of kaolin in sagger mixtures. In addition to being highly refractory and open burning,

¹ *Trans. Am. Ceram. Soc.*, 18, 268 (1916).

the kaolin does not contain excessive amounts of sand as do the sandy open-burning fire clays. Very satisfactory refractory bodies have been prepared from mixtures of kaolin, vitrifying fire clay and grog. The mixtures have low drying and burning shrinkage, and have great resistance to deformation at kiln temperatures. The use of kaolin, however, is not necessary providing we can secure a clay which retains a high porosity at the firing temperature. Deposits of secondary kaolin occur in this country, which, although they may not be satisfactory for use in the manufacture of high grade pottery, would be very valuable in the manufacture of saggars. We have found that the addition of kaolin in amounts as low as 10 per cent materially improves the refractoriness and other qualities of sagger or other mixes.

The composition of the grog used in a sagger mixture is governed, of course, by the composition of the raw clays used in the mixture, *i. e.*, if the grog is prepared by the crushing of old saggars the addition of a small quantity of kaolin into the mixture tends to maintain the refractoriness of the grog.

Preparation of the Mixtures.

Although most of our sagger mixtures are prepared by the soaking pit method, we would call attention to some of the advantages of using the ordinary wet-pan in mixing and tempering sagger mixtures. We have found that by the use of a wet-pan a much more uniform mixing of two or more clays is secured than by the use of a soaking-pit. The soaking-pit method depends upon the slaking down of the clays in water. If our sagger clays slake down readily in water the soaking-pit method is not so objectionable. However, we know that some fire clays will remain in water for a long time without slaking down. Clays of this kind should not be used in batches prepared by the soaking-pit method. The writer has seen saggars, made from a mixture of red and buff clay and grog mixed by this method, in which the red and yellow particles of the bond clays used could still be distinguished in the molded sagger. The use of the pug-mill in connection with the soaking pit does not always overcome the objections to the

soaking-pit method of preparation. The heavy mullers of the wet-pan crush the particles of clay and thoroughly blend the two or more clays used in the mixture.

We have also found that by the use of the wet-pan a larger percentage of grog can be introduced into the sagger-mixture without the loss of its necessary working qualities. This is accounted for by the fact that the wet-pan develops the maximum plasticity of the bond clays and hence increases their carrying capacity for grog. The advantage of the increased grog content is the lower shrinkage of the mixtures. Saggings prepared from wet-pan mixes also mold better and with smoother surfaces.

Objections have been raised to the wet-pan method on the grounds that the heavy mullers of the pan crush the larger particles of grog and make it too fine. This objection may be overcome¹ by the use of a wet-pan having mullers which are raised slightly off the bottom of the pan. By the use of a pan of this type, the particles of grog slide underneath the mullers without being crushed.

Summary.

In summarizing, we may say, therefore, that the length of life of saggings is influenced by a great many factors, not the least of these being the necessity of care in the preparation of the mixtures and in the drying and first burning of the completed saggings.

In order to produce a sagger giving maximum service, a thorough knowledge of the composition and burning behavior of the clays used in the sagger mixture is necessary.

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¹ *J. Am. Ceram. Soc.*, 1, 18 (January, 1918).