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# The effect of small amounts of chrome ore on dry press diaspore refractories

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# - T H E S I S -

# THE EFFECT OF SMALL AMOUNTS OF CHROME ORE ON DRY PRESS DIASPORE REFRACTORIES.

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# - I N D E X -

# THE EFFECT OF SMALL AMOUNTS OF CHROME ORE ON DRY PRESS DIASPORE REFRACTORIES.

## - INTRODUCTION -

Diaspore:

The term "Diaspore" as used in this paper will be used to mean the diaspore clay from which refractory bodies are made. The pure mineral Diaspore ($Al_2O_3 \cdot H_2O$ ) has an $Al_2O_3$ content of 85%, while the best grades of diaspore clay run from 76% to 79% diaspore. Diaspore clay consists of a varying percentage of diaspore, ranging from 60% to 79%, and the remaining percentage as clay. The most objectionable impurities which occure in diaspore clay are alkalies.

The chief source of diaspore is the central part of Missouri. It occurs in pot hole formations accompanied by "flint" and "burley" clays, which are nothing more than clays of lower $Al_2O_3$ content.

The high refractoriness of diaspore products, along with its resistance to spalling and slag action makes it a very valuable material to the refractories industry. The one big disadvantage which must be contended with in the use of diaspore refractories is their tendency to continue to shrink in service.

The P.C.E. value for commercial diaspore products is from cone 36 to 39. They show no subsidence under 40 pounds per square inch load at cone 33 ( 1350°C.), and are very resistive to abrasive action. These properties, along with a low coeficient of thermal conductivity, make them very suitable for rotary cement kiln liners, which is chiefly the use to which they are put.

Chrome Ore:

Chrome refractories are made from the igneous mineral Chromite ($FeCr_2O_4$). The chemical composition of the pure mineral is 32% FeO and 68% $Cr_2O_3$. The common impurities are magnesium, alumina and silica. For use as a refractory the chromium content must be at least 40% and not over 60%. Chromium ores containing over 60% chromium are too valuable to the chemical industry to be used in refractories. The general properties for commercial chromite are; black, massive, granular, compact; hardness - 5.5; specific gravety - 4.3 to 4.6; luster - sub-metalic; streak - dark brown; tenacity - brittle; magnetism - slight; melting point - 2180 degrees C.; It is a neutral material, neither reactive to bases or acids, which makes it quite valuable as a refractory.

Chrome refractories will not stand up under load at high temperatures, have a poor resistance to spalling, and will not confine heat at high temperatures. They have a high mechanical strength at room temperature, but very low strength at high temperatures. Chrome is neither reactive to basic or acid slag under nearly all conditions.

Some common forms of chrome refractory products are:- brick, metal case brick, parts and bulkheads of metallurgical furnaces, cements for laying brick and patching, etc.

Most of the chromite used in this country is imported. The most important deposits are found in Cuba, Rhodesia (Africa), and Greede. Other deposits are found in, Russia, Norway, Quebec, Wyoming, and Oregon.

## - ABSTRACTS -

A carefull survey of all the available literature, which might contain publication pretaining to the subject, was made and the following abstract is the only article which delt with the mixing of diaspore and chrome in any manner.

### - Abstract -

A STUDY OF CHROME AND DIASPORE MIXES.

By Harlow G. Jones. J.A.C.S. Nov. 1929.

Plan of Investigation.

1. Softening point of various mixtures.
2. Workability of the mixtures by soft mud, stiff mud, and dry press, operations.
3. Determination of porosity, shrinkage on firing, shrinkage on reheat, slag action, and spalling.

Results:

1. Fusion: All the mixes of chrome and diaspore stood cone 33 - 34 without any signs of failing. This puts all of them in the class of super-refractories.
2. Workability; Bars of chrome and diaspore mixes were made of soft mud and dry press methods. Was impossible to make bars by the stiff mud process due to extremely low plasticity of the material.

Soft mud bars were very hard to make and very weak in the green state.

No trouble experienced with making of stiff mud bars. Were of high enough strength in green state to be feasable as manufacturing process.

Bars fired in frit furnace. Unfavorable conditions. Cone 16 down at end of six hours firing at 1400°C. 1400° C. held for at least one hour at end of firing.

Bars were well sintered and strong enough for use as superrefractory. Bars were fired at rapid rate and cooled in eight hours, yet no cracks or checks appeared. This makes it appear that manufacturing would not be a delicate job.

The chrome used was gound up chrome brick.

3. Absorption and Shrinkage:

The chrome and diaspore were ground to pass 20 mesh, proportioned, thoroughly mixed, and dry pressed into bars 1" x 1" x 8".

Were fired in oil furnace; firing increase of gradual rate. Shrinkage and absorption were taken after the initial fire and again after a reheat run of 1400° C. for 5 hours. Bars made in this firing were well sintered and in good shape.

The absorption is highest in a 75% diaspore bar and lowest in a solid chrome bar. However, there is no great change throughout the mixtures. The absorption of 90% diaspore and 10%, 100 mesh chrome is low, as expected, due to the finer ground chrome addition.

4. Percent Linear Shrinkage:

The percent linear shrinkage curves show;- The greater percentage of diaspore the greater the shrinkage. The change is much more rapid on diaspore end of curve, or above 50% diaspore. Showing that chrome ore can be used to cut down diaspore products shrinkage. A 50% combination of each would give about the maximum effect. A more thorough study would give a definite mix which would undoubtedly be nearer the diaspore end.

5. Slag Action:

Three types of slag were used. 1. Blast furnace, 2 acid open hearth, and 3 basic open hearth. The slag was crushed to pass 20 mesh and placed in caveties in the test pieses.

6. Blast Furnace Slag:

All the slag had melted at 1340° C. All bars containing over 25% chrome had absorbed the entire sample. No effect on these pieces except it made them denser on the slag exposed surface.

The test pieces containing 90%, 20 mesh diaspore, and 10%, 100 mesh chrome had less penetration with about one half inch of slag on the surface. A fluxing action had broken down a small amount of the body.

The 100% diaspore trial had the least penetration, but fluxing action had taken place to some extent.

The commercial diaspore sample, made up of 40% raw diaspore, 50% calcined diaspore and 10% plastic fire clay, had the most vigorous fluxing action.

Basic Open Hearth Slag:

This slag was more finely ground than 20 mesh. This slag penetrated into the bars in varying degrees, greatest in the 100% chrome bar and least in the 100% diaspore bar.

The more diaspore in the body the less was the penetration but the greater was the decomposition of the body itself.

The trial made up of 90%, 20 mesh diaspore and 10%, 100 mesh chrome showed the least penetration of any mix. This was, no doubt due to the denser mixture of the specimen.

Most vigorous slag action in the case of the commercial mix. This may be accounted for by; 1. the addition of the plastic fire clay which may be more easily fluxed; 2. the more porous nature of the body due to the 50% of calcined diaspore which acts much the same as grog in an ordinary fire brick.

Open Hearth Slag:

This slag was more refractory and consequently did not melt thoroughly at the temperature fired to, (1400° C.). The slag seemed to attack the 100% diaspore more vigorously than it did the 100% chrome, yet there was no breaking down of any of the intermediate series.

The most important point brought out by the slag test was that small percentages of finely ground chrome cut down the slag action considerably.

6. Spalling:

Bars 1" x 1" x 8" were used for the test. The dipping time was reduced to two minutes and the steam interval was reduced to three minutes. The bars were heated in a Hoskins Electric Furnace to 850° C.

The addition of diaspore to the chrome in every case increased the resistance to spalling action.

A point of interest is brought out in the special mix 90%, 20 mesh diaspore and 10%. 100 mesh chrome. This group of four bars. averaged 31 dips, which is more than the average for straight 100%

diaspore. This indicates that a small amount of chrome ore does not decrease the spalling action of the diaspore.

The commercial mix, 50% calcined diaspore, 40% raw diaspore, and 10% fire clay, did not spall over 10% in any case on 35 dips. At this point the test was discontinued since all the other bars had failed.

## 7. Conclusions:

1. No combinations of diaspore and chrome were found having a cone fusion below cone 34. It may be several cones above this.

2. The dry press method of forming ware made from this mixture of chrome and diaspore is apparently the best.

3. The use of 50% chrome ore cuts the shrinkage down one third of that of 100% diaspore.

4. Chrome and diaspore have very nearly the same absorption and when mixed this figure does not change materially.

5. The addition of small amounts of finely ground chrome cuts down the action of slag on diaspore.

6. The addition of diaspore to chrome increases its resistance to spalling action. The addition of finely ground chrome to diaspore also increases its resistance to spalling action.

## 8. Acknowledgments:

Indebtedness is acknowledged to the various manufacturing companies for supplying the slags and praticularly to Dr. M.E. Holmes for his helpfull suggestions and advice during the course of the research.

## - OUTLINE OF INVESTIGATION -

In making an investigation on the mixing of chrome ore and diaspore it is necessary, due to the broadness of the subject, to confine the work to one specific problem, as a general investigation would be far too large a problem to complete in the limited time available for research work. With this in mind the following outline of investigation was drawn up and will be strictly followed throughout the research procedure.

First; two conclusions drawn by Harlow G. Jones in his paper on, "A Study of Chrome and Diaspore Mixes",[1] were accepted as true and were used as a basis on which to start further research. These conclusions are:-

1. No combinations of diaspore and chrome could be found which have a cone fusion point below cone 34.
2. The dry press method of forming ware made from mixtures of chrome and diaspore is apparently the best.

A high grade Missouri diaspore, ground to pass 20 mesh, will be used in every mix. A series of three grades of chrome ore will be ground to 60 mesh and added to the diaspore mixes in quantities of ten percent. Special mixes can be made in which the size of grinding of the chrome may be varied but the 10% addition will be constant. One lot of pure diaspore will be made up.

Then for a comparison of the two extremes of chrome addition, a lot of each chrome ore will be made up in which 90%, 20 mesh chrome will be mixed with 10%, 60 mesh diaspore.

1. See abstract, page 3, "A Study of Chrome and Diaspore Mixes", Jones, J.A.C.S. - Nov. 1929.

N.B. Jones

No softening point tests will be run on these materials as the work of Jones proves that any mixture of chrome and diaspore has a cone fusion point above cone 34, and no eutectics are developed.

All test pieces will be made up by the dry press method as this method is proven by Jones to be the best. A determination of the correct amount of moisture required for pressing of the mixes will be made.

The following physical tests will be made on the standard number of test pieces and the average values taken:- Drying shrinkage, Firing Shrinkage, Reheat Linear Change, Percent Porosity on Fired Trial Pieces, Percent Porosity on Reheat, Green Modulus of Rupture, and Fired Modulus of Rupture. In addition a comparative test on the spalling and slagging characteristics will be run.

If the time permits, after the above procedure has been completed, the chrome ore giving the best properties to the diaspore refractory body will be mixed, in varying small amounts, with the diaspore and a more complete series of tests will be run on it. This will include a complete series of tests on commercially fired nine inch straights. This will include standard tests for, hot load, spalling, and slagging.

## - LABORATORY PROCEDURE -

Materials:

The diaspore used in this investigation was a high grade Missouri diaspore, the $Al_2O_3$ content of which is approximately 76% to 79%. The chemical composition was not determined.

The chrome ores used were furnished by the Research Department of General Refractories Company, Philadelphia, Pa. The typical chemical analyses of these materials were furnished with the ores, and are tabulated below.

| | Chrome A. Cuban | Chrome B. Grecian | Chrome C. African |
|---|---|---|---|
| Ignition Loss | 1.11% | 1.18% | 1.06% |
| Silica | 3.72 | 6.82 | 3.42 |
| Ferric Oxide | 15.73 | 15.95 | 17.75 |
| Alumina | 27.39 | 18.95 | 10.16 |
| Calcium Oxide | Trace | 0.81 | Trace |
| Magnesia | 17.95 | 17.27 | 15.66 |
| Chromic Oxide | 34.10 | 39.62 | 51.95 |

A small amount of calcined diaspore was required for use in a special commercial mix. This material was furnished in lump form by the A. P. Green Fire Brick Company, Mexico Mo. This material was ground to through 6 mesh and used as grog in the above mentioned commercial mix.

All of the raw diaspore and chrome ores were ground to pass 20 mesh, except the amount used for the 10% additions which was ground to pass 60 mesh.

Forming of Test Pieces:

All test pieces were made up into bars 1" x 1" x 8" on a hand operated dry press machine. This machine is manufactured by the Patterson Foundry and Machinery Company, East Liverpool, Ohio.

This press is capable of three thousand pounds per square inch pressure. It would be hard to estimate the pressure applied in making the test bars but as uniform a pressure was applied to each bar as possible.

Ten percent moisture was found to be the required amount in dry pressing the 10% chrome - 90% diaspore bars, and 6% moisture was required by the 90% chrome - 10% diaspore bars.

A series of bars of each lot were marked to determine the drying and firing shrinkage. These bars were also used in determining the volume reheat shrinkage and the fired and reheat porosity.

A series of bars were made up with a cavity in the top at each end of the bar, to be used in the slag test. These cavities were made by placing semi-cylindrical lugs of wood along the surface of the bar before pressing.

A series of bars were made up for the determination of green and fired modulus of rupture.

In pressing the low percentage chrome bars no bonding a agent was necessary and the bars had sufficient strength to withstand fairly rough handling without chipping. However the high percentage chrome bars would not bond without the addition of a bonding agent. The bonding agent used in this case was dextrine. Even with the bonding agent, care in handling the bars was required until they had dried for several minutes. Upon drying slightly they were quite strong and gave no trouble from chipping or breaking upon handling.

**Firing:**

The test bars were all fired at once in a small, rectangular, down draft, oil fired, kiln to cone 20 down. Pyrometeric cones were placed at the front and back of the setting and the fact that cone 20 on each plaque was just down when the firing ceased is a good indication that the heat distribution throughout the kiln was fairly even. The rate of temperature increased rather fast up to 1050° C. due to the fact that the bars were very dry when placed in the kiln, there was no dehydration period to slow up for, and there was very little oxidizable material in the body. From 1050° until the end of the firing schedule the temperature increase was slowed down quite a bit. The firing diagram on page 13 shows the exact rate of temperature increase, and the time required to complete the firing. A Leeds and Northrup thermocouple pyrometer was used to control the temperature.

The fired pieces were well burned and in a very good shape, excepting a small amount of warping due to the unevenness of the kiln floor which allowed the setting to sag slightly under its own weight during the heavy firing. It was noticed that the bars containing 90% chrome showed a tendency to subside at the points where the setting rested upon them.

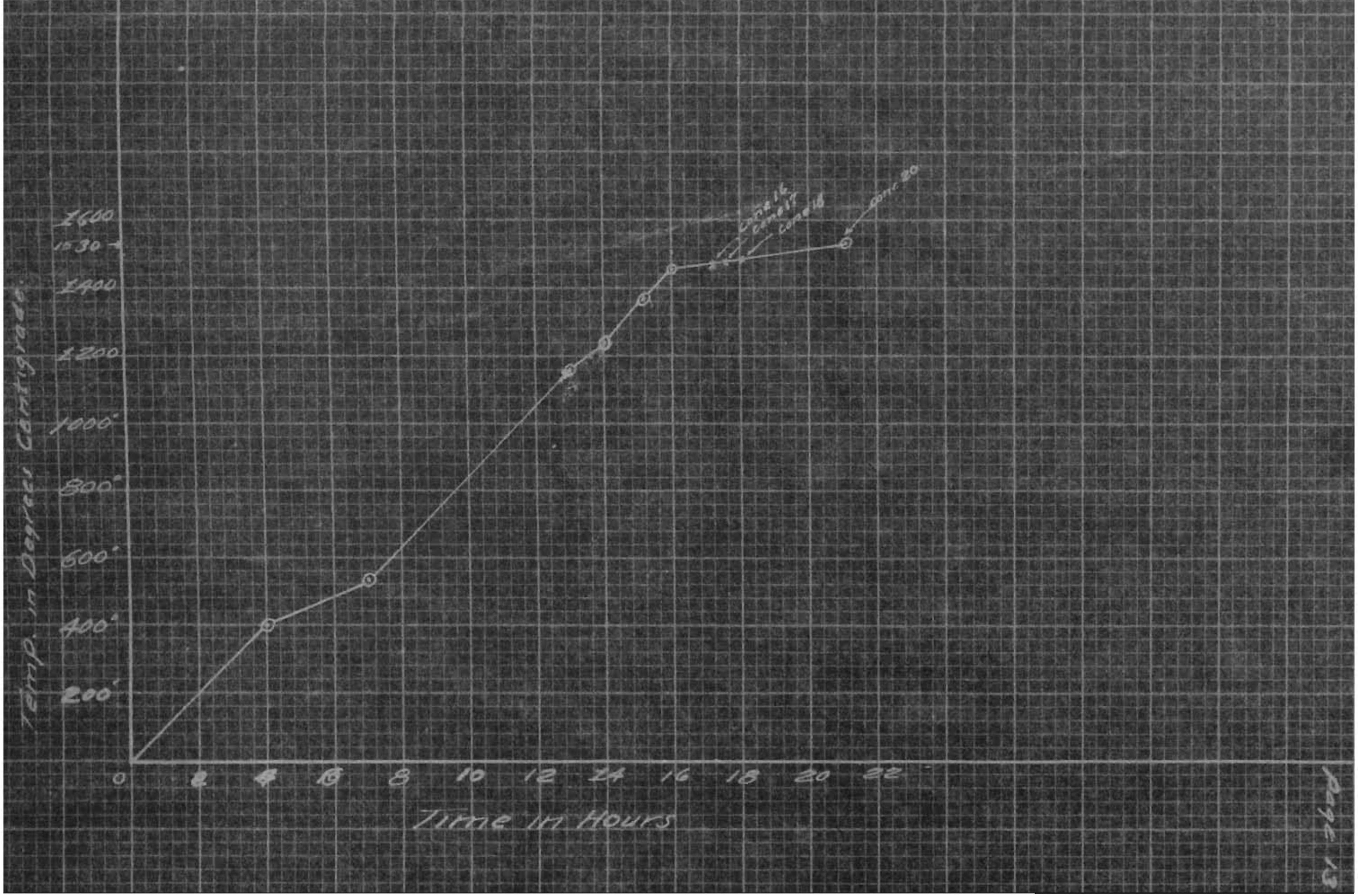
There was very little loss from breakage but several of the bars developed some small cracks. These cracks were probably due to the warping.

Reheat Firing:

After the fired shrinkage and porosity data was taken, the trial pieces were subjected to a reheat firing in which they were heated at 1500° C. for a period of five hours. This firing was done in the same kiln in which the test pieces were first fired.

# Plate I

## Firing Data.



The temperature was increased as fact as possible, approximately 100 degrees an hour, until 1400° C. was reached. A Leeds and Northrup Thermocouple Pyrometer was used to regulate the temperature. The kiln was closed up tightly at the end of the firing and allowed to cool. The cooling time was a day and a half. No signs of cracking or warping were developed in this firing.

Slag Test:

The method of forming the test pieces for this test is discussed under "Forming of Test Pieces".

The slags used were, acid open hearth slag, from the American Steel Foundries, Indiana Harbor, Indiana, and a blast furnace slag from the St.Louis Coke and Gas Company, Granit City Ill. Both slags were ground to pass 20 mesh. Three trial pieces from each lot for each slag were used for the test.

The firing temperature was intended to be 1400° C. for two hours but due to the looseness of the setting the temperature could not be increased above 1330° C. This temperature was held for approximately two hours but the blast furnace slag failed to completely melt. Enough melt was obtained, however, to get a fairly representative set of data on the penetration.

Spall Test:

Due to the lack of material with which to make standard nine inch straights, bars 1" x 1" x 4" were used for this test. The ends of the bars were placed in the door of a Hoskins Electric Muffle Furnace and were heated to 850° C. The dips were made in running water and the cooling time was two minutes. The steaming interval was five minutes.

The data obtained from this test is not recommended as being comparable to the standard 850 degree spall test due to the fact that it was necessary to place the greater part of the bars inside the furnace in order to maintain a temperature of 850° C., which resulted in the bars becoming quite hot throughout their length and thus reducing the thermal shock to some extent. However, it serves the required purpose in that it gives a comparative figure on the spalling characteristics on each lot.

A series of three bars were run for each lot and the averages were taken.

It was not possible to get all the bars in the door of the furnace at once and lots 7 , 8 and 9 were held out until there was room for them due to failure of other lots. This accounts for the fact that complete spalling data was not obtained on lot 8, as it was not considered worth while to continue the test after all the other lots had failed.

TABLE NO. 1.

SHRINKAGE CHARACTERISTICS OF EACH LOT.

| LOT | MIXTURE | %Lin. Drying Shrinkage. | %Lin. Firing Shrinkage. | % Change on Reheat [1] Linear | % Change on Reheat [1] Volume | |
|---|---|---|---|---|---|---|
| 1. | A. Chrome - 90%, Dia.-10%. | .68 | .56 | .40 | 1.27 | |
| 2. | B. Chrome - 90%, Dia.-10%. | .48 | .26 | (.61) | (.95) | - Expansion. |
| 3. | C. Chrome - 90%, Dia.-10%. | .48 | .18 | (.20) | (.50) | - Expansion. |
| 4. | A. Chrome - 10%, Dia.-90%. | .51 | 6.86 | 5.20 | 16.12 | |
| 5. | B. Chrome - 10%, Dia.-90%. | .57 | 6.46 | 4.30 | 13.42 | |
| 6. | C. Chrome - 10%, Dia.-90%. | .00 | 8.23 | 4.60 | 14.70 | |
| 7. | B. Chrome - 10%, Dia.-90%.[2] | .00 | 7.83 | 5.50 | 16.42 | |
| 8. | B. Chrome - 10%, Dia.-40%,[3] Calcined Diaspore - 50%. | .00 | 4.00 | 4.50 | 14.53 | |
| 9. | Raw Diaspore 100%, - 20 mesh. | .20 | 8.56 | 3.80 | 11.35 | |

Note:- All 90% additions are ground to pass 20 mesh.
All 10% additions are ground to pass 60 mesh, excepting lot 7. which contains 10% B Chrome through 100 mesh.

1. The figures for Volume Change on Reheat were obtained in the lab. and the Linear Change values were calculated from them.
2. The Chrome addition in this mix was ground to, through 100 mesh.
3. The Calcined Diaspore was ground to, through 6 mesh.

TABLE NO. 2.

SPALL TEST? POROSITY? AND MODULUS OF RUPTURE DATA OF EACH LOT.

| | | PERCENT POROSITY | | MODULUS OF RUPTURE | | SPALL TEST |
|---|---|---|---|---|---|---|
| LOT | MIXTURE | FIRED | REHEAT | GREEN | FIRED | NO. DIPS, 20% loss. |
| 1. | A. Chrome - 90%, Dia.-10%. | 23.49 | 20.95 | ----- | 2,408 | 21 |
| 2. | B. Chrome - 90%, Dia.-10%. | 24.11 | 21.29 | ----- | 2,503 | 19 |
| 3. | C. Chrome - 90%, Dia.-10%. | 26.37 | 23.39 | ----- | 1,706 | 32 |
| 4. | A. Chrome - 10%, Dia.-90%. | 23.04 | 10.15 | 112 | 4,498 | 35 |
| 5. | B. Chrome - 10%, Dia.-90%. | 28.99 | 12.76 | 110 | 3,509 | 31 |
| 6. | C. Chrome - 10%, Dia.-90%. | 27.33 | 13.27 | 143 | 4,088 | 32 |
| 7. | B. Chrome - 10%, Dia.-90%.[1] | 27.09 | 9.28 | ----- | 5,229 | 9 |
| 8. | B. Chrome - 10%, Dia.-40%, Calcined Diaspore - 50%. | 41.81 | 35.99 | ----- | 934 | 20 -No sign of failure. |
| 9. | Raw Diaspore - 100%,20 mesh. | 33.85 | 19.48 | ----- | 2,885 | 22 |

1. See foot note 2 on Table 1.

2. See foot note 3 on Table 1.

## - DISCUSSION OF DATA -

### SHRINKAGE.

Linear Drying Shrinkage:

The bars which were marked for shrinkage, in each lot, were measured upon drying and the average values taken. As the shrinkage curves on Plates 2, 3, and 4, show, this figure was quite low in every case, if not zero.

Linear Firing Shrinkage:

After the bars were fired to cone 20 (1530° C.), the shrinkage marks were measured again and the averages taken. From this figure the firing shrinkage was calculated. The curves for these values, Plates 1 and 2, show rather interesting results. Lot 1, which the low percentage chrome ore (Cuban), gives the highest value for shrinkage. Lot 3, which contains the highest percentage chrome ore (African), gives a slightly lower shrinkage figure than lot 2, and much lower figure than lot 1. This is probably due to the higher refractoriness of the material.

Lot 9, 100%, 20 mesh diaspore, gives the highest firing shrinkage figure of all, which would indicate that the addition of 10% chrome ore reduces the shrinkage considerably.

Lot 8, 50% grog mixture, has a much lower firing shrinkage than any other body, which is to be expected.

The 10% B. chrome addition in Lot 5 produces a body with the lowest shrinkage when compared with the 10% additions of A. and B. chrome to Lots 4 and 6 respectively. This indicates that small amounts of B. chrome added to a diaspore mix would reduce the shrinkage to a greater extent than either the A. or C. chrome. The C. chrome addition in lot 6 gives a figure so slightly under that of pure diaspore that it would be of very little use commercially.

Linear Change on Reheat:

The linear change on reheat was so small, in some cases, that it was necessary to determine the volume change and calculate the linear change from it.

This set of data is extremely interesting due to the fact that Lots 2 and 3, 90% B. and C. chrome bodies, gave a slight expansion figure instead of a shrinkage. The expansion was the greatest in Lot 2 and Lot 1 gave a slight shrinkage figure. Slight expansion expansion of refractory brick, on reheating, is a very desirable quality as it tightens the joints between the brick and increases the strength of the setting.

Of Lots 4,5, and 6, the 10% chrome additions of chromes A, B, and C, respectively; Lot 5 again gives the lowest shrinkage figure. Lot 6 compares favorably with it but Lot 4 is considerably higher than both of them.

It is surprising at first to note that the 100% diaspore mix, Lot 9, gives the lowest reheat shrinkage figure of all but when the absence of a 10% addition of 60 mesh material is taken into consideration this condition is probably to be expected.

The fact that the shrinkage will increase with the fineness of grind is proven by the shrinkage figure of Lot 7. Lot 7 is of the same composition as Lot 5 excepting that the 10% B. chrome addition is ground to 100 mesh instead of 60 mesh.

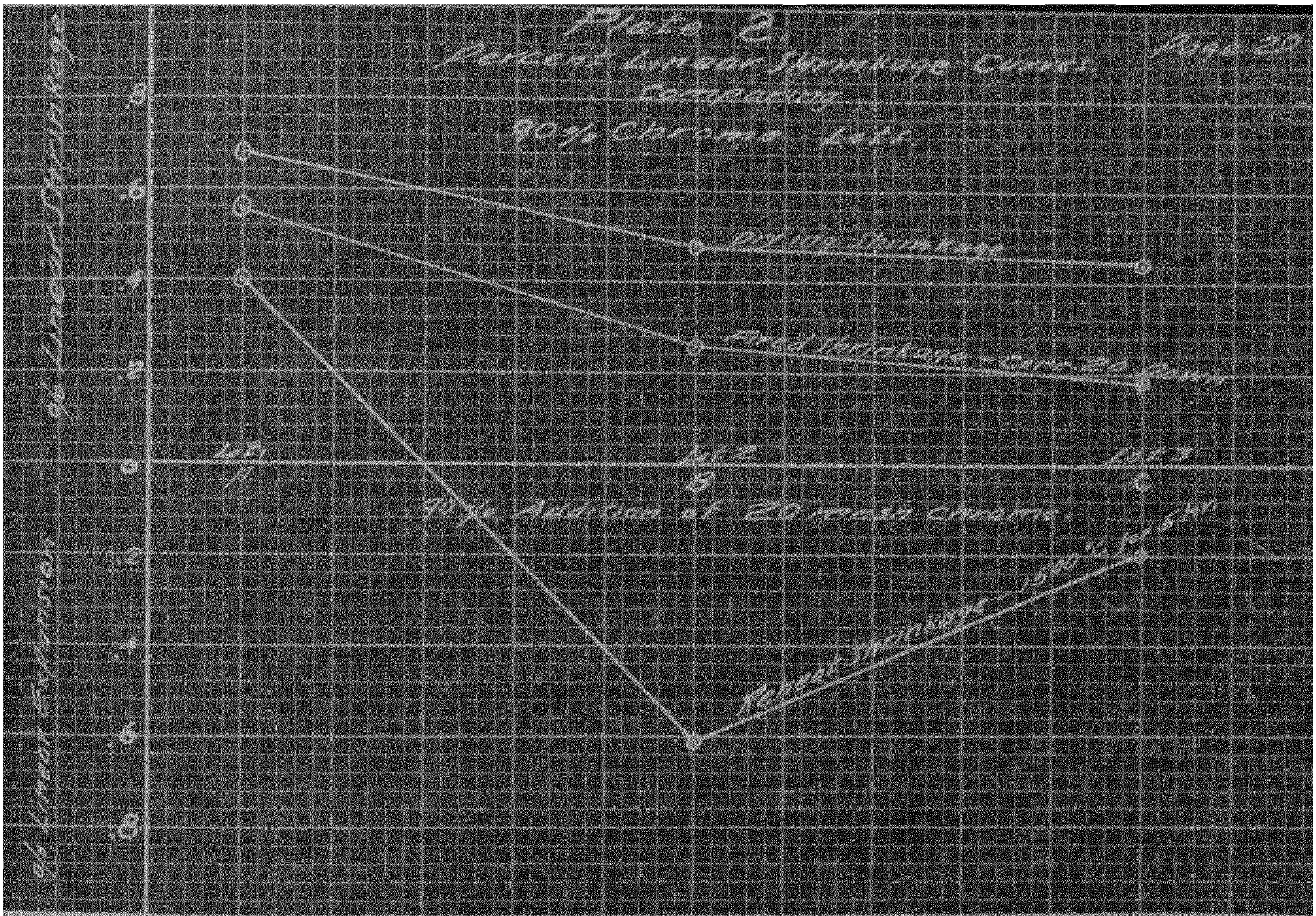


Plate 2
Percent Linear Shrinkage Curves
Comparing
90% Chrome Lots.
Page 20
% Linear Shrinkage
% Linear Expansion
.8
.6
.4
.2
0
.2
.4
.6
.8
Drying Shrinkage
Fired Shrinkage - Cone 20 Down
Reheat Shrinkage - 1500°C for 5 Hr.
Lot 1
A
Lot 2
B
Lot 3
C
90% Addition of 20 mesh Chrome.

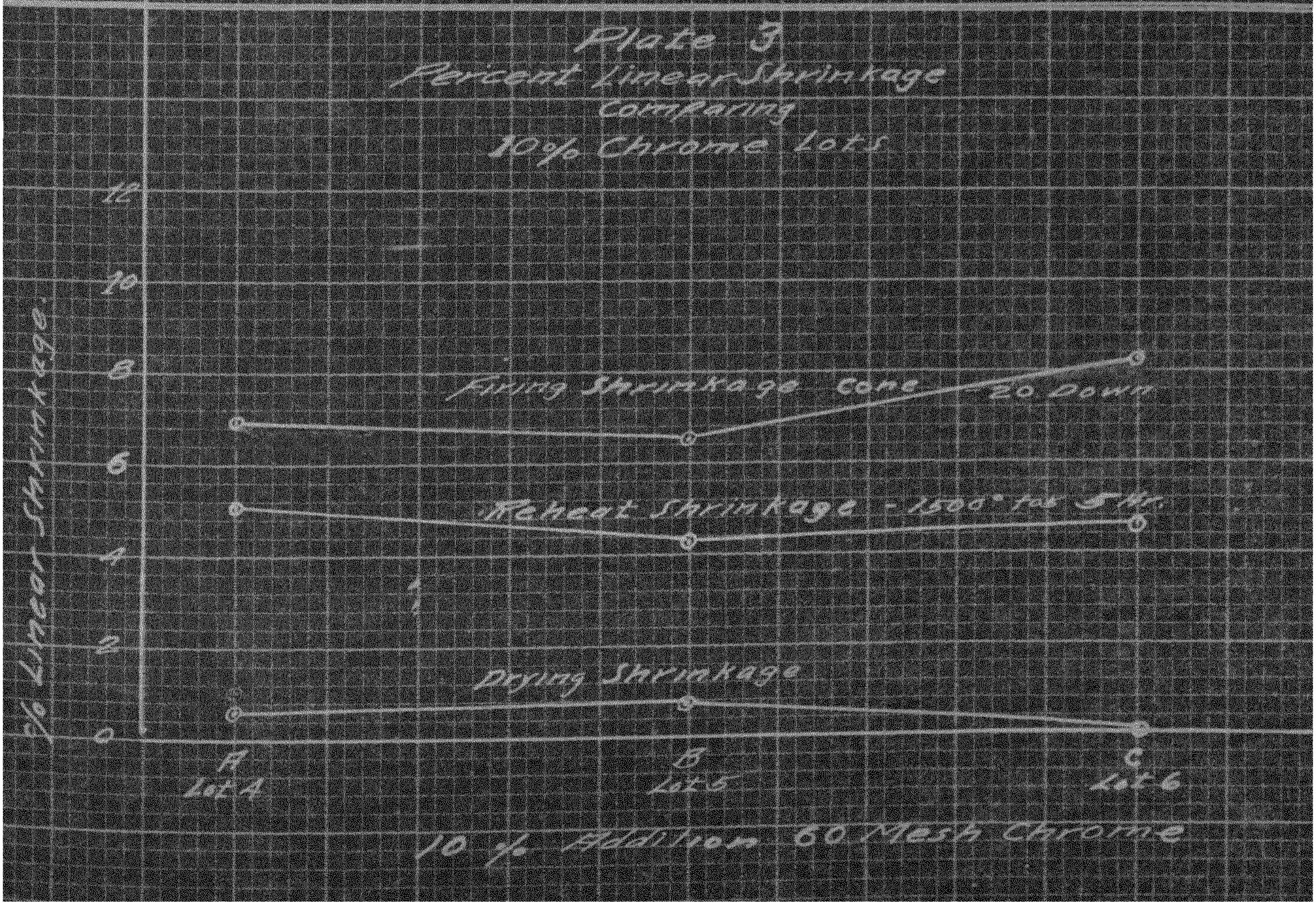
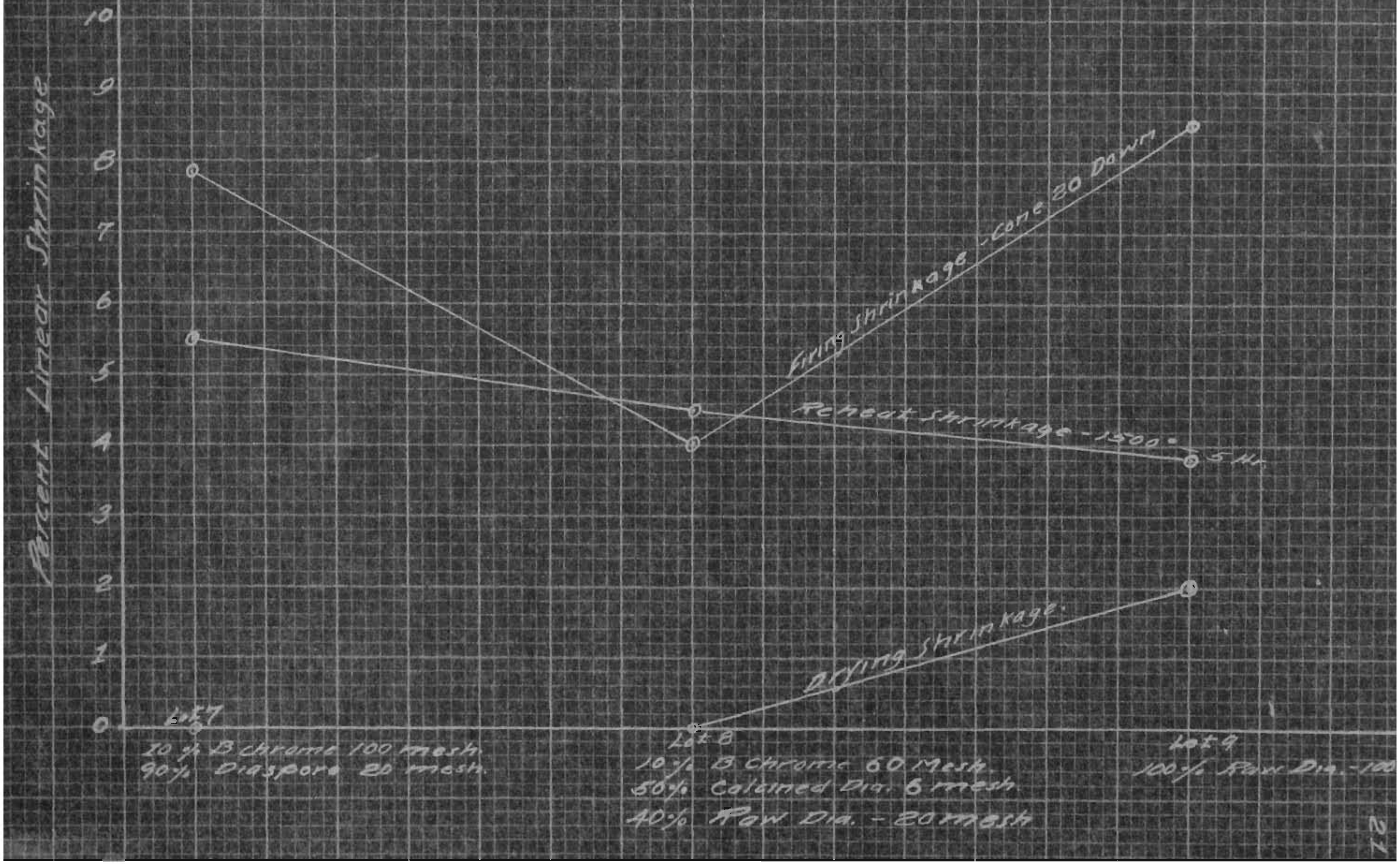



Plate 3
Percent Linear Shrinkage
Comparing
10% Chrome Lots.
% Linear Shrinkage.
12
10
8
6
4
2
0
Firing Shrinkage Cone 20 Down
Reheat Shrinkage - 1500° for 5 Hr.
Drying Shrinkage
A
Lot 4
B
Lot 5
C
Lot 6
10% Addition 60 Mesh Chrome

Plate 4.

Percent Linear Shrinkage Curves
comparing
Lots 7, 8 and 9.



Graphic comparisons of these shrinkage values may be seen on Plates 2, 3, and 4.

## - PERCENT POROSITY -

Percent Fired Porosity:

The commercial mix, Lot 8, gives by far the highest porosity. The raw diaspore mix, Lot 9, gave the next highest figure which is considerably above all the other mixes. The rest compare fairly closely, showing that the porosities of chrome and diaspore are practically the same.

The difference between the pure diaspore porosity and that of the diaspore mixtures is explained by the addition of 10%, 60 mesh material to the latter. This, of course, tends to increase shrinkage and decrease the porosity.

Percent Porosity on Reheat:

By referring to Plate 3, it will be noticed that Lots 1, 2, and 3, have approximately a 2.5% decrease in porosity on reheat. This small decrease is to be expected in bodies containing 90% chrome. However, it is rather interesting to note that Lots 2, and 3, both expanded slightly on reheating, and at the same time they had a decrease in porosity. If a True Specific Gravity determination were made on these materials, before and after reheating, it would probably be found that the total closed pore space had increased.

In comparing Lots 4,5, and 6, the 10% additions of 60 mesh A, B, and C, chrome respectively; Lot 4 gives the greatest reduction

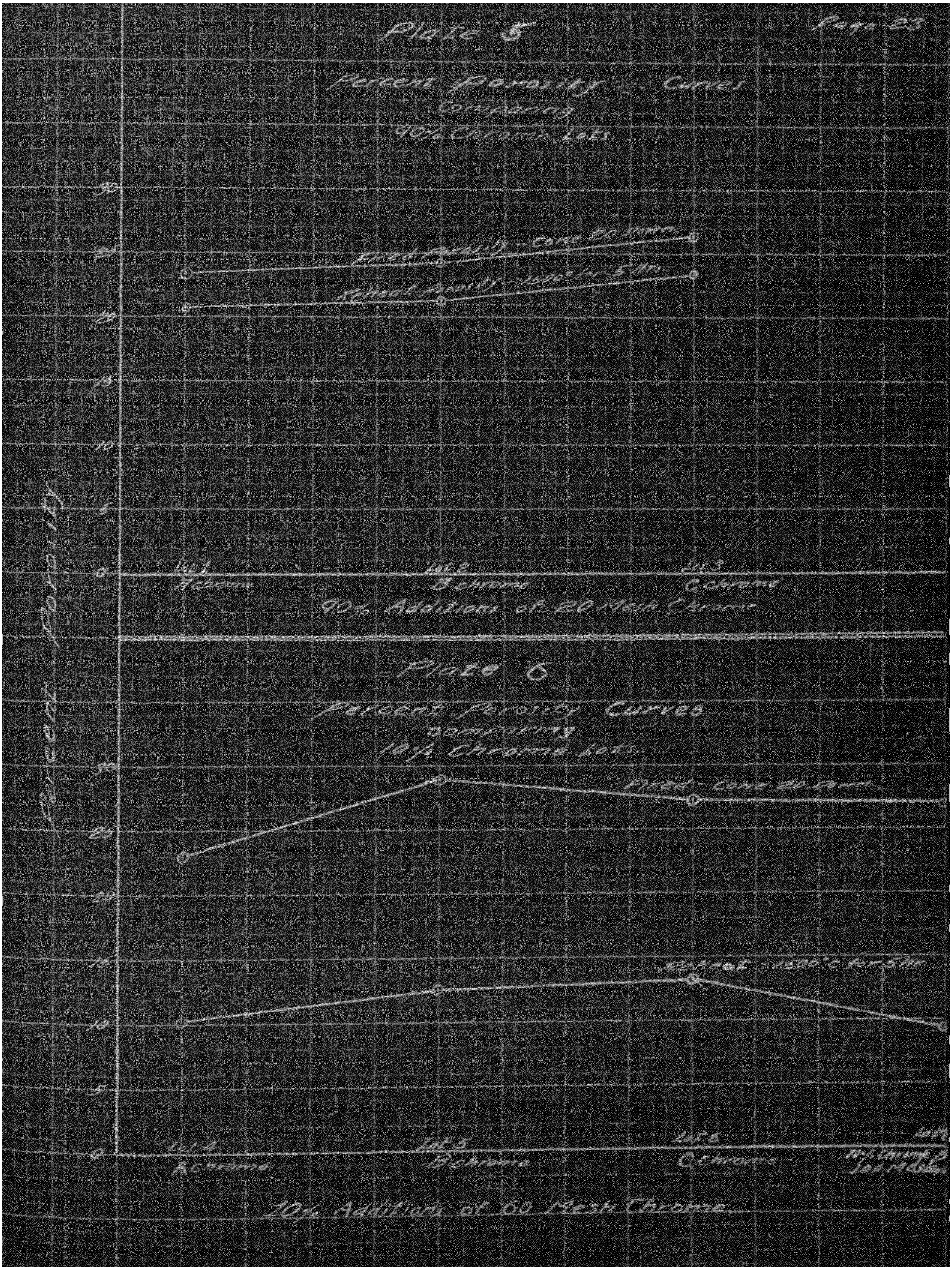


Plate 5
Page 23
Percent Porosity Curves
Comparing
90% Chrome Lots.
Fired Porosity - Cone 20 Down.
Reheat Porosity - 1500° for 5 Hrs.
30
25
20
15
10
5
0
Lot 1
A chrome
Lot 2
B chrome
Lot 3
C chrome
90% Additions of 20 Mesh Chrome
Percent Porosity
Plate 6
Percent Porosity Curves
comparing
10% Chrome Lots.
Fired - Cone 20 Down.
Reheat - 1500°c for 5 hr.
30
25
20
15
10
5
0
Lot 4
A chrome
Lot 5
B chrome
Lot 6
C chrome
10% Additions of 60 Mesh Chrome.

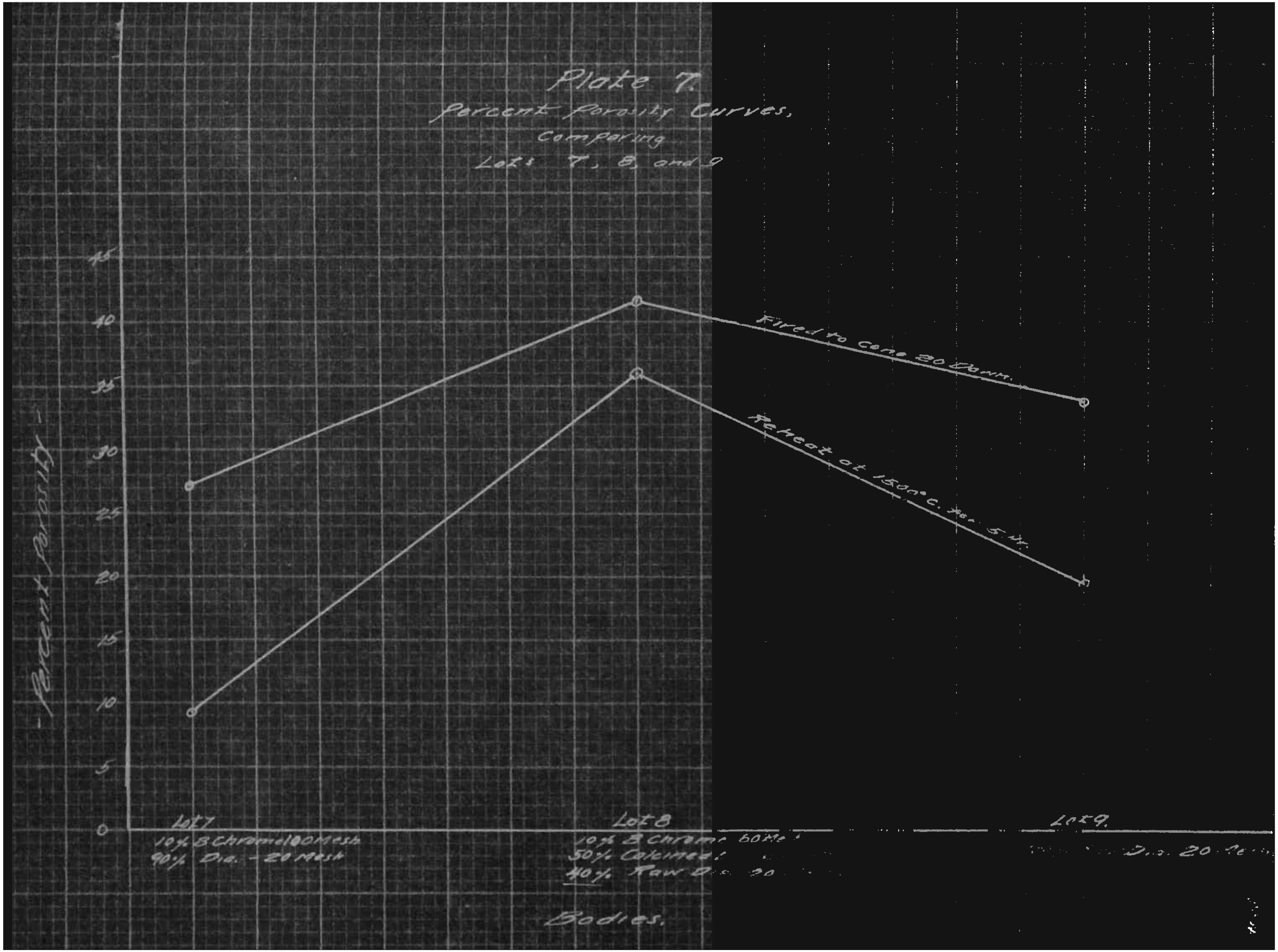


Plate 7.
Percent Porosity Curves,
Comparing
Lots 7, 8, and 9
Fired to Cone 20 Down.
Reheat at 1500°C. for 5 Hr.
- Percent Porosity -
45
40
35
30
25
20
15
10
5
0
Lot 7
10% B Chrome 80 Mesh
90% Dia. - 20 Mesh
Lot 8
Lot 9.
Bodies.

in porosity which compares with the greatest shrinkage on reheat. Lots 5 and 6 compare very closely in both respects.

Graphic comparisions of these porosity values may be seen on Plates 5, 6, and 7. (Pages 23 and 24)

## - MODULUS OF RUPTURE -

### Green Modulus of Rupture:

Green modulus of rupture was determined only on Lots 4, 5, and 6, the 10% additions of A, B, and C, chrome respectively. An organic bond was necessary in the case of the high percentage chrome mixes and such data would be of no value.

Lot 6 had the greatest strength and Lot B had the lowest strength with Lot A. slightly above it.

These values are plotted on Plate 8.

### Fired Modulus of Rupture:

In comparing the three high percentage chrome mixes, Lots 1 and 2 compare very closely in strength, Lot 2 being slightly stronger. The modulus of rupture figure for Lot 3 is approximately one half as great as that for Lots 1 and 2. This indicates that the firing temperature was not high enough to develop a strong bond in this body. The fact that the porosity of this body is somewhat higher than the other two bears this fact out. Another evidence which indicates that little melt had been formed between the grains of this body is the fact that the test bars, when briken on the testing machine, did not break in a brittle manner, as did Lots 1 and 2, but gradually failed and did not break apart.

Lots 4, 5, and 6, all show high enough strength to indicate that they had received the necessary heat treatment to develop a good bond. Lot 4 has the highest modulus of rupture figure.

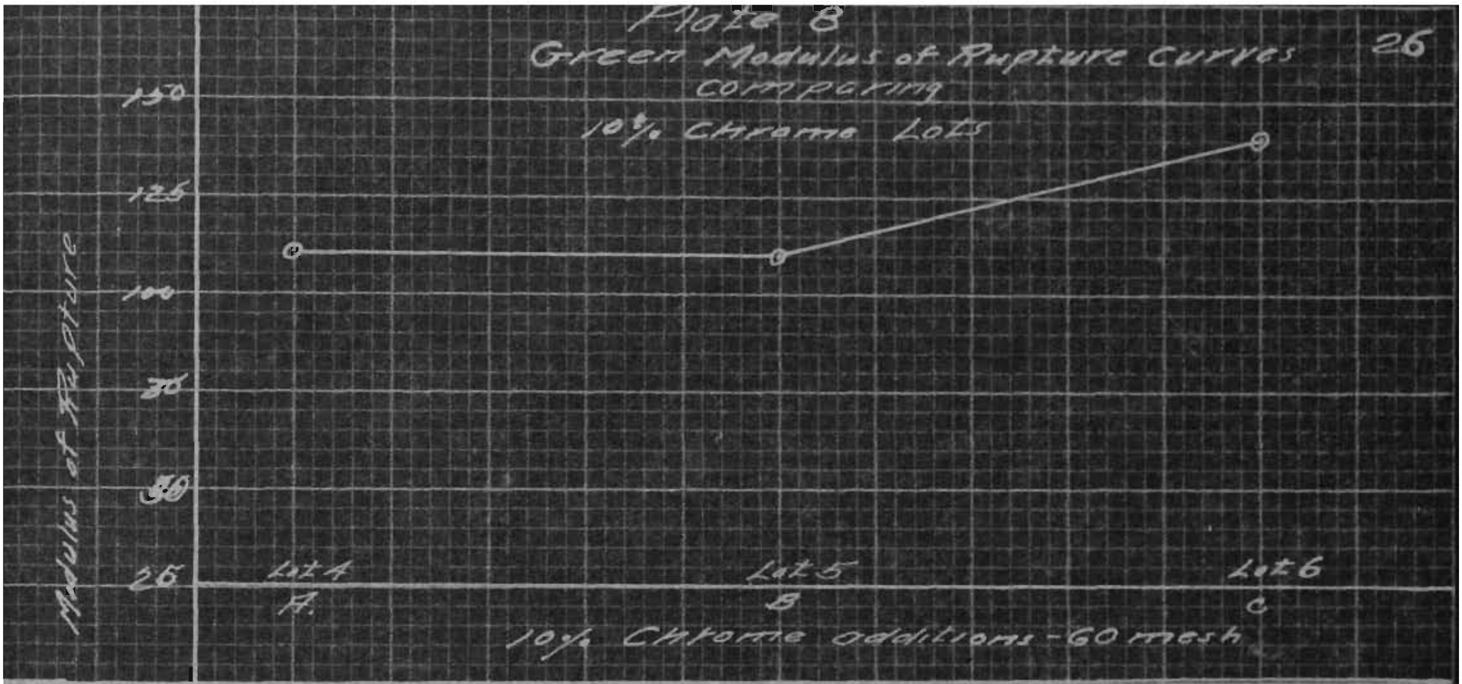


Plate 8
Green Modulus of Rupture Curves
comparing
10% Chrome Lots
Modulus of Rupture
150
125
100
25
Lot 4
A.
Lot 5
B
Lot 6
C
10% Chrome additions - 60 mesh

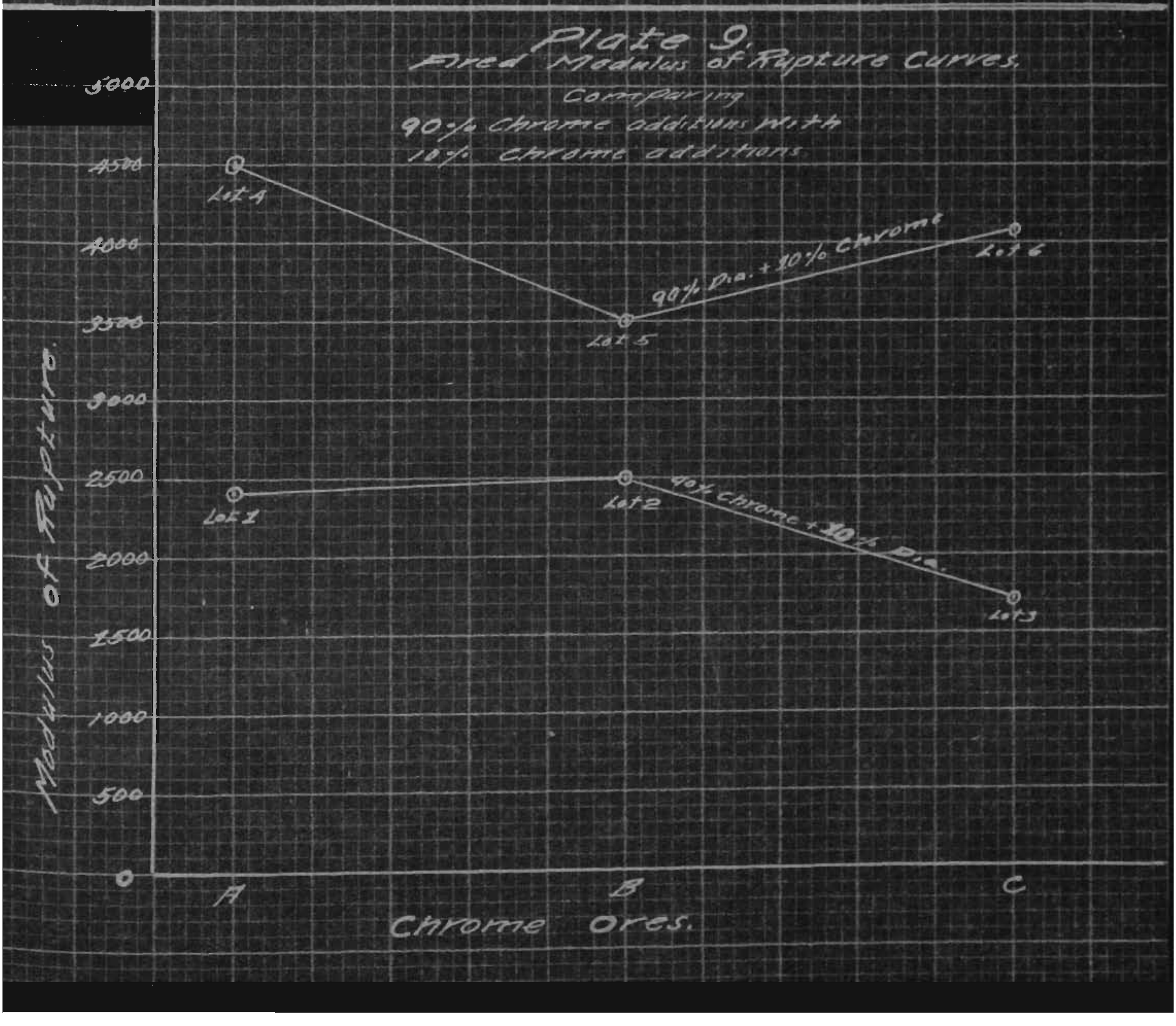
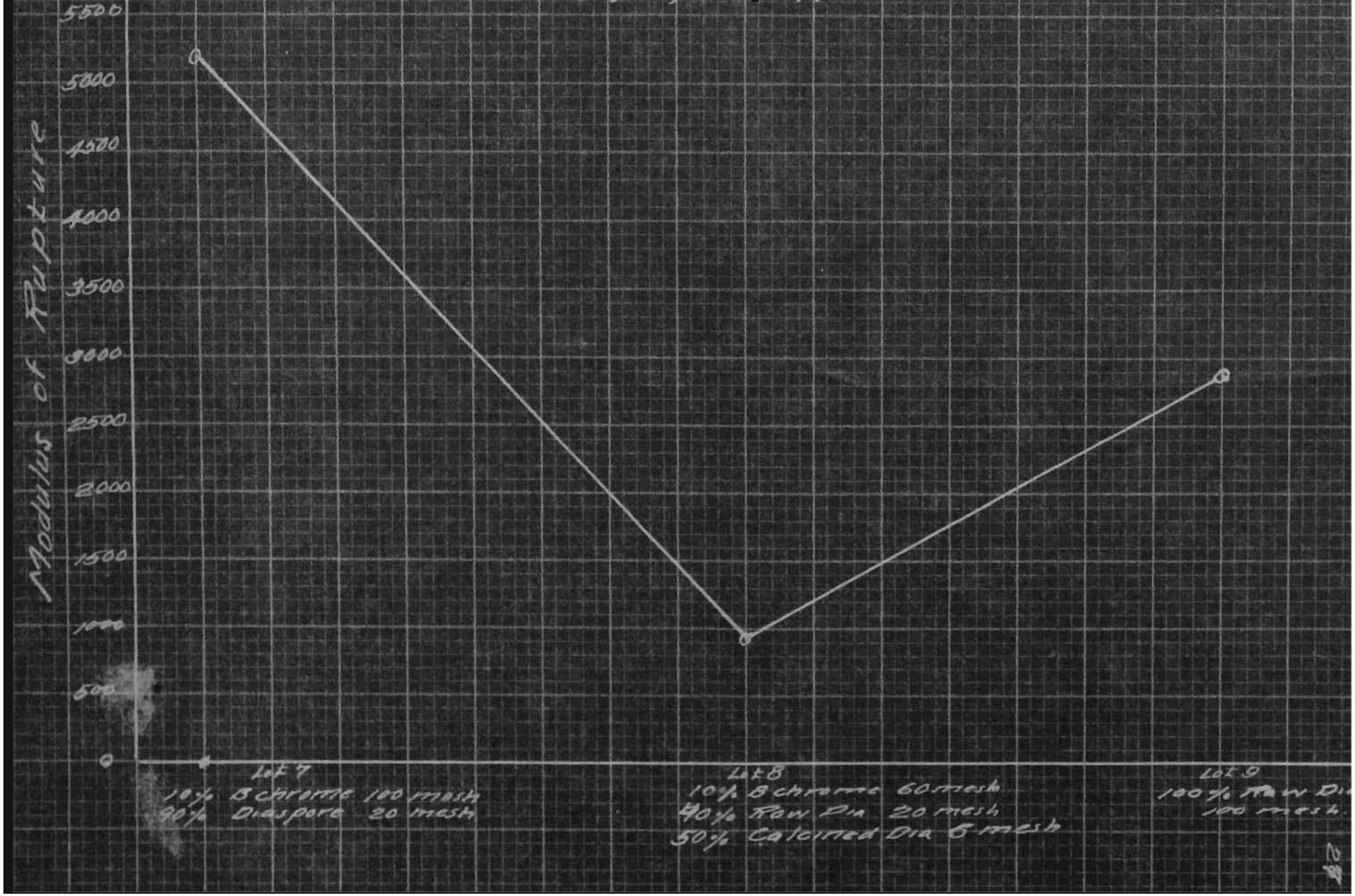


Plate 9.
Fired Modulus of Rupture Curves.
Comparing
90% Chrome additions with
10% Chrome additions.
Modulus of Rupture.
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Lot 4
Lot 5
Lot 6
90% Dia. + 10% Chrome
Lot 1
Lot 2
Lot 3
90% Chrome + 10% Dia.
A
B
C
Chrome Ores.

Plate 10

Fired Modulus of Rupture Curves
comparing
Lots 7, 8, and 9.



Lot 6 has the lowest, and Lot 5 is about an average of the two.

Lot 7, shows quite an increase in strength over Lot 5 which is due to the addition of 100 mesh chrome instead of 60 mesh. The commercial mix, Lot 8, shows by far the lowest strength due to the 50% addition of 6 mesh calcined diaspore.

Lot 9, the raw diaspore mix, shows a low strength as compared with the other mixes. This is due to the fact that there was no addition of fine grained material to the mix and consequently a weaker bond was formed.

The modulus of rupture figures for these mixes are plotted on Plates 9 and 10, Pages 26 and 27.

## - SLAG TEST -

Acid Open Hearth:

This slag melted at about 1300° centigrade and due to the fact that this temperature was held for about four hours in the attempt to increase the temperature to 1400°, all the slag had been absorbed by the test pieces, and considerable fluxing action had taken place.

Lots 1, 2 and 3, had been penetrated deeper than Lots 4, 5, and 6, due to the more open texture of the chromium. Lot 2 showed the least penetration of the three, Lot 1 showed slightly more and Lot 3 showed the most. A clearly defined outline of the slag penetration could be seen as it showed up as a very dense vitreous body. Although the high percentage chrome mixes readily absorbed the slag there was no evidence of any corrosive action having taken place.

Lots 4, 5 and 6, showed much less penetration than the first three lots and they compare very closely with each other. Lot 5 showed slightly less penetration than Lots 4 and 6, and 4 and 6 showed the same penetration. All three lots showed a considerable amount of corrosive action. Lot 4 showed the least amount, Lot 5 showed the next, and Lot 6 showed the most. However, there was not much difference in penetration. It may be said that Lot 4 is more resistant to slag action than the other high percentage diaspore mixes, however this is not true to any great degree.

Blast Furnace Slag:

The melting point of this slag was some place close to 1350$^{\circ}$ centigrade as this was approximately the highest temperature that was held for any length of time, and at this temperature the slag had only partially melted.

All lots showed virtually the same amount of penetration which indicates that there was not enough liquid slag formed to give a true value of the slagging characteristics. It is assumed that the penetration in the high chrome mixes, Lots 1, 2, and 3, was greater than was recorded as the depth of penetration was not clearly defined and the figures recorded were therefore nothing more than estimates.

The black slag gave a very clearly defined line of penetration against the brown body of the high percentage diaspore mixes, but the depth of penetration was the same in every case. Thus, no valuable information was obtained in regards to the depth of penetration.

The high chrome mixes showed no sign of fluxing action or decomposition of the body. However, in the case of the high diaspore mixes, there were slight signs of fluxing reaction. This was greatest in the bars of Lot 5 and was hardly noticeable in Lot 6. Thus it might be said that a 10% addition of C. chrome to a diaspore body produces a body more resistant to slag action than the same addition of the A. and B. chrome ores.

## - SPALL TEST -

The data obtained from this test is very interesting. In the first three Lots, which are the 90%, 20 mesh chrome bodies, Lots 1 and 2 withstood 21 and 19 dips before loosing 20%. However the C. chrome, Lot 3, withstood 32 dips for a 20% loss, which compares very favorably with the high diaspore content mixes. This high spalling resistance quality is explained in the following manner. The modulus of rupture figure on this lot was approximately one half as great as that of Lots 1 and 2. The bars broke in a sodden manner indicating that a small amount of melt had formed to bond the grains together, thus the body was of a less brittle nature and less subject to thermal shock. The porosity of this body was greater than that of either of the other two high chrome content bodies, which tends to increase the resistance to spalling. When subjected to the spall test, this body did not shatter and crack off in large pieces, as did the other bodies, but became friable. This indicates that the bond was being broken down and that there was not enough of it present to cause cracking and spalling when subjected to repeated thermal shocks.

Lots 4, 5, and 6, all gave comparative figures for spalling resistance which were considerably greater than the results obtained from the pure diaspore body, Lot 9. A direct comparison of these Lots and the diaspore, Lot 9, cannot be made as there was not a 10% addition of 60 mesh material in Lot 9 as was the case in the others. However it is safe to say that, additions of small amounts of 60 mesh chrome to a diaspore body will increase its spalling resistance. There is a limit to the fineness of grind of this chrome addition and the increase in spalling resistance still maintained. This fact is proven by the spalling figure obtained on Lot 7. The composition of this body is the same as that of Lot 5, excepting that the 10% chrome addition is ground to 100 mesh instead of 60 mesh. There is quite a contrast in the spalling characteristics of these two bodies. Lot 5 gives a figure of 31 dips for a 20% loss as compared with 9 dips for 20% loss for Lot 7. The explanation of this being that a much greater quantity of glassy melt is formed in the case of the 100 mesh addition and thus the resistance to thermal shock is much less than in the case of the 60 mesh addition.

Lot 8 proves that the addition of grog to the body greatly increases the resistance to spalling. This lot is of the same composition as Lot 5 excepting that a 50% calcined diaspore (6 mesh) addition takes the place of part of the raw diaspore. This body showed no loss on 20 dips and there was no sign of failure. There was no sigh of the slightest breaking down of the bond and no difference could be noticed between the strength of these bars and bars of the same lot which had not been subjected to the spall test. After all the other bars had failed it was not considered worth while to continue the test for Lot 8 as it gave promise of lasting for a great many more dips.

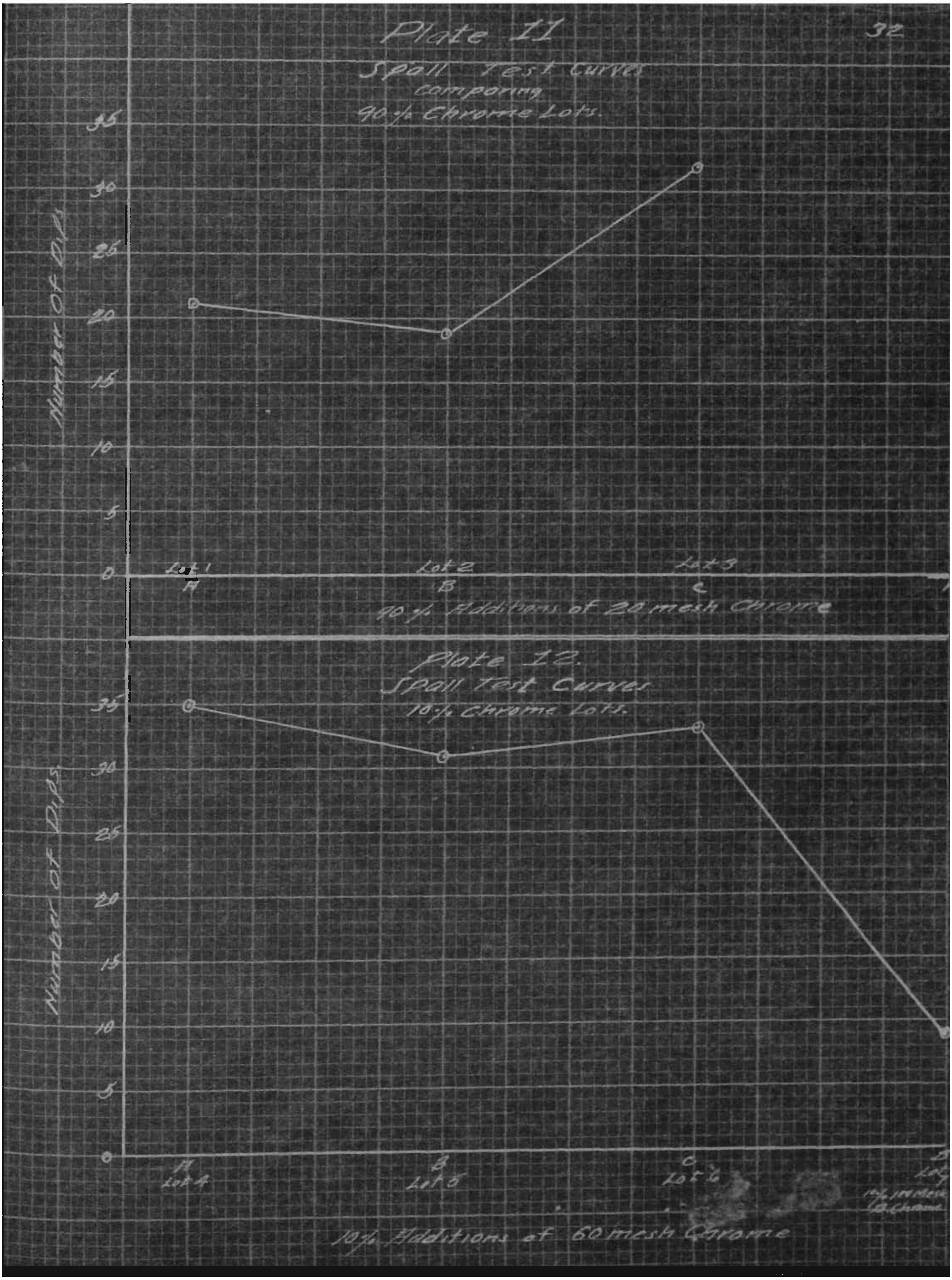


Plate 11
Spall Test Curves
comparing
90% Chrome Lots.
Number of Dips
35
30
25
20
15
10
5
0
Lot 1
A
Lot 2
B
Lot 3
C
90% Additions of 20 mesh Chrome
Plate 12.
Spall Test Curves
10% Chrome Lots.
Number of Dips
35
30
25
20
15
10
5
0
A
Lot 4
B
Lot 5
C
Lot 6
D
10% Additions of 60 mesh Chrome

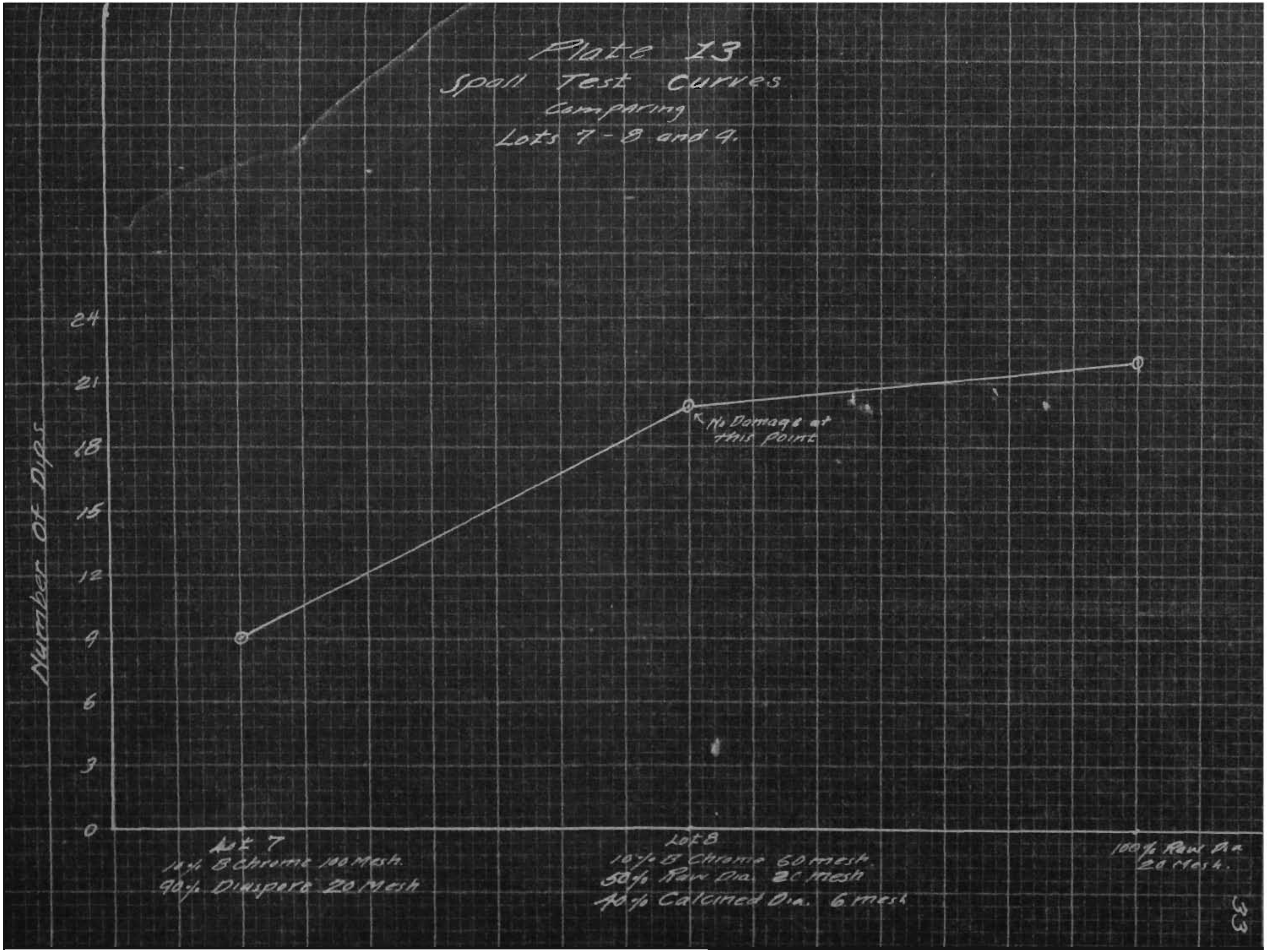


Plate 13
Spall Test Curves
Comparing
Lots 7-8 and 9.
Number of Dips
24
21
18
15
12
9
6
3
0
No Damage at this point
Lot 7
10% B Chrome 100 Mesh.
90% Diaspore 20 Mesh
Lot 8
10% B Chrome 60 mesh.
50% Raw Dia. 20 mesh
40% Calcined Dia. 6 mesh
100% Raw Dia
20 Mesh.
33

## - SUMMARY OF CONCLUSIONS -

In Regard to Selection of Most Desirable Chrome Ore:

After a thorough study of the data, the indications are that the C. chrome (African) is by far the most desirable of the three ores for small additions to a high grade diaspore refractory.

The following are the factory upon which this decision is based.

1. It has the greatest initial shrinkage, which is desired.
2. It has the lowest percentage reduction in porosity on reheat.
3. It has the property of expansion on reheat to a small degree.
4. It has the greatest strength in the green condition.
5. The low modulus of rupture figure, and other factors which were discussed in the "Discussion of Data", indicate a much higher P.C.E. value than either of the other two.
6. It compares favorably with the other ores in regard to slag action.
7. It has by far the best resistance to thermal shock.

General Conclusions:

1. Small amounts of 60 mesh chrome ore in a high grade diaspore body increases the resistance to spalling.
2. Small amounts of 60 mesh chrome ore in a high grade diaspore body appreciably decreases the shrinkage.
3. Small amounts of 60 mesh chrome ore in a high grade diaspore body increases the strength of the fired body.
4. The 50% addition of 6 mesh calcined diaspore greatly increases the resistance to spalling but reduces the mechanical strength.
5. Small amounts of 100 mesh chrome ore in a high grade diaspore body greatly lowers the resistance to spalling , increase strength, and lower the shrinkage somewhat.

## - ACKNOWLEDGMENTS -

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