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REGULAR CONTRIBUTIONS

THE RELATION OF COLOR AND STRENGTH OF PORCELAIN TO THE ACTUAL BAKING TEMPERATURE.*

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The most difficult and trying part of porcelain work to-day is, and always has been, to produce with exactness just the shades desired and to produce uniform effects with the same materials. Since these difficulties are due almost entirely to the variations in shade produced by a difference of only a few degrees of temperature in baking, the problem has been exceedingly difficult. However, I believe I am able to offer a solution, and which I trust the results and tests we will here present will satisfactorily demonstrate. First, let us understand that the fault is not in the materials used, but in the inability to manipulate it uniformly. We do not produce the same results with the same shades because we do not bake them at exactly the same temperature, and we do not produce a maximum or uniform strength because of the difference in the quality of the porcelain as well as shade produced by relatively a small difference in baking temperature.

I have made very extended tests of the difference in both the color and strength of a number of different makes of porcelains and of different shades of the same make, and find these variations in both strength and color running through them all and fortunately also find that both the color and strength are practically uniform for bakes made at exactly the same temperature.

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*Read before the Odontographic Society, Western Pennsylvania, at Pittsburg, Pa

We will now take these results up in the order of different makes starting with Brewster enamel body. The buttons were all made in the same mold with as nearly as possible the same manipulation, and the shape of the mold was meant to produce such a surface and form as would somewhat represent a large contour inlay. The crushing strengths were tested very carefully with the testing machines at Case School of Applied Science. Using the glaze and color and strength produced by the temperature indicated on our pyrometer as a standard, and calling the crushing strength of that as one hundred per cent we find that Brewster enamel body (shade G), baking at fifty degrees Centigrade has less than the standard of one thousand one hundred and forty degrees Centigrade or two thousand and fifty degrees Fahrenheit (the pyrometer having both scales), is considerably darker and has only eighty-six per cent as much strength, as at the proper temperature, and when baked at one hundred degrees less is still darker and had only seventy-three per cent the strength. When baking at fifty degrees above the standard temperature, the color was nearly baked out and the strength was only seventy-three per cent, and when baked at one hundred degrees above the standard temperature, the color was completely gone and the strength reduced to fifty-six per cent. In all of these cases not less than two crushing tests were made and their average taken.

This card I will pass around has all these buttons baked on to it and the temperature of baking and strength beside them. You will notice the shade varies from very dark to no color or white, the color all being baked out.

With shade N of Brewster enamel body, dark brown, the color changes were still more extreme, as you will see from this card. The tests of Brewster's foundation body show much the same changes of shade, though not so extreme, but the crushing strength varied even more when baked at fifty degrees too low the strength was sixty per cent, and at one hundred degrees too low was only fifty per cent. At fifty degrees too high the strength was ninety per cent and at one hundred degrees too high the strength was eighty-six per cent.

You will see from either of these two cards that all the shades of brown, from the darkest to pure white, may be produced with just one bottle by sacrificing some of the strength.

Kindly notice also that the shrinkage is nearly in proportion to the temperature throughout.

The tests with White's inlay porcelain show these same very marked changes in color, over-baking rapidly takes out the color which is practically all baked out before one hundred degrees too high is reached. The crushing strengths were at fifty degrees too low ninety per cent; at one hundred degrees too low, eighty per cent; at fifty degrees too high, ninety-two per cent, and at one hundred degrees too high, seventy-three per cent.

With Close's body the variations were even more marked as you will see. At fifty degrees too high the color is nearly all gone, and at one hundred degrees too high is entirely gone and the button has fallen like a griddle-cake, showing this body even more exacting regarding temperature than the preceding ones. The crushing strength of the buttons of this body baked at fifty degrees too low was ninety-three per cent, and at one hundred degrees too low, seventy-seven per cent. At fifty too high, seventy-eight per cent, and at one hundred too high only thirty-four per cent..

The Jenkins body on this card shares this same marked tendency to flow as the Close, and much more contraction though but little change in the color for this amount of over-fusing. Its greatest variation is in its strength, being one of the strongest we have when baked at its proper temperature, and the weakest with the same variation of over and under-baking. As you will see, this body requires a very accurate baking temperature, as so many of you have found from sad experience. At fifty degrees too low the strength was twenty-five per cent and at one hundred degrees too low was only eight per cent. These two were scarcely biscuited. At fifty degrees too high crushed at eighty-nine per cent and at one hundred degrees too high at thirty-nine per cent. You will notice that at only fifty degrees too high it shows a marked tendency to spheroid, and at one hundred degrees to high the cone has taken a shape as round as a split pea. No furnace, gas or electric, can fuse this body to compare with the pyrometer furnace for definiteness of result.

In all these cases the buttons that were crushed were baked with these, which I have exhibited on the cards.

To show you the difference in shade that only a few degrees will make, I have baked a series in steps of ten degrees too high and too low, which shows the gradual but constant change in color produced by such small variations.

Doubtless some will say "but I think I do not have such variations of strength and color." To test this I sent buttons of the same Brewster's enamel body to a number of porcelain workers, telling them the color and kind, and which all of them were using. I stated that I wanted a glaze finish retaining the color and was very much surprised to see the very wide variety in results which you will observe on this card. It is as great almost as any of the sets I have shown you. One could scarcely believe that they were all made from the same bottle, which they certainly were.

This much is certain, that to get even relatively uniform color we must bake within a few degrees of the same temperature. How closely can we work by any of the methods heretofore available?

First, let us consider the time method of waiting a certain time on each post. The basis of this method is that a certain amount of heat will raise the temperature of a given mass a certain amount in a given time. This is true provided the mass is at the same temperature each time to start with and the conditions of radiation remain the same. But this is just where the trouble comes in, for every time a furnace is heated, if it does not have time to cool back to the temperature of the room, it will contain throughout its mass more or less total heat units as compared with every other time it is heated, depending upon the time between the heats, which determines the amount of this heat lost by radiation. Many operators have told me that by turning the switch on just to a certain button for five or ten minutes and then go to a certain other button for say two minutes and a certain other for two minutes they got the exact temperature. There is only one condition under which they can, and that is to wait each time not only until the muffle has cooled down to that temperature from which that given series of time on buttons would come to the proper temperature but also the material about the muffle which radiates the heat from the muffle in proportion not to the temperature of the muffle but the difference in its and their temperature. When the mass about a muffle has its average temperature raised say one hundred degrees, the muffle will come to a given temperature in less time than before and with each succeeding heat of the furnace, without allowing it to entirely cool down, the average temperature of the mass around the muffle is increased and does not change rapidly, requiring an hour or more to cool to relatively a constant relation to the muffle. Hence, for bakes made within short periods of varying duration the temperature of the muffle with a given time on each step will not have a constant temperature and certainly not within so short a range as is required to produce exactly a certain shade. For example, see the following reading of the exact temperature of the muffle with successive heatings of varying duration between them. And since in the furnace used the mass of material producing the heat, viz: the platinum wire, is relatively large in proportion to the surrounding mass as compared with most furnaces, this can be taken as a fair example of what any furnace will do with these same ratios of time. The lever of the rheostat was put on the first step for five minutes to let the furnace heat up, then it was put on the fourth step for two minutes and then on the first step for two minutes, then on the fourth step two minutes and fifty seconds to heat the furnace up thoroughly as we would suppose. The temperature went to two thousand two hundred and ten degrees Fahrenheit, the fusing point of Brewster's foundation body. Note that it took one minute and fifty seconds on the ninth step to go to the fusing point of Brewster's enamel, two thousand and eighty degrees, and one minute more to go to Brewster's body. For the second heat the lever was put on the first step for two minutes, then on the fourth step two minutes, on the eighth step one minute and on the ninth one minute, at which time it just reached the proper baking point for Brewster's enamel as shown both by the pyrometer and by the bake on this card. You would think that after heating the furnace up first very hot, away above the temperature required, that the temperature for successive bakes would not vary much from this second heat, provided we use at least relatively even time between bakes. For the third heat and second bake the lever was put on the fourth step for two minutes, on the eighth step one minute, and on the ninth step one minute, the same as before, and this button marked "second bake" shows that the temperature was too high. The pyrometer showed that the temperature was sixty degrees Fahrenheit too high and that the muffle reached the proper temperature in forty-five seconds on the ninth step, instead of one minute as before. For the fourth heat and third bake the heat was turned down to fourth step again and for two and one-half minutes, and then on each the eighth and ninth steps for each one minute again, and the bake was away over as shown by this sample. The pyrometer showed that the temperature was one hundred and thirty degrees too high and that the proper time on the ninth step should have been thirty seconds. The next time we waited still longer back on the fourth step, three and one-half minutes, then proceeded as before on the eighth and ninth, each one minute, and the button was still more over-baked as you see by the button marked fourth bake, the temperature being one hundred and sixty degrees Fahrenheit too high and the proper time in the ninth step should have been twenty-five seconds instead of one minute. To abbreviate, remember that the time on the eighth and ninth steps remained the same, viz. one minute, and the time between bakes on the fourth step was varied, but note that as the furnace got more and more heated through the waits or fourth step effected it relatively less. For the sixth heat and fifth bake, waited on fourth step three and one-half minutes; over-bake, two hundred degrees Fahrenheit; proper time on ninth step would have been seventeen seconds. Seventh heat and sixth bake, waited on fourth seven minutes; over-bake two hundred and ten degrees too high, and correct time on ninth step fifteen seconds. Eighth heat and seventh bake, waited on fourth step nine minutes. You see much longer and over-bake was reduced to one hundred and seventy degrees and the correct time on the ninth step should have been thirty-five seconds. For the ninth heat and eighth bake we waited on the fourth step only two minutes and the over-bake was two hundred and seventy degrees and the correct time on ninth step should have been only eleven seconds. and for the tenth heat and ninth bake, waiting on the fourth step thirteen and one-half minutes and the overbake was only one hundred degrees, and the correct time on the ninth should have been thirty-five seconds. Notice that the result depends very much upon the length of time between bakes and that even this relation changes continually as the number of heats is increased. I am very sure that all that is necessary to demonstrate this point conclusively to any one is to try it with an accurate temperature-recording device like this. The increasing difference in the color and shape of these buttons, all made from the same bottle of

Brewster's enamel and formed in the same moulds, should convince most any one that unless very long waits are made between heats, and these waits always of the same duration, there cannot be a certain time on each step that would produce the same temperature in the muffle. We took the second heat in this case as a standard. What heat of all of those would have been accurate for them all or even any three of them? Not any; they are all different.

The next best method is a definite time from pure gold. While this method is not nearly accurate, it is better than the former, because it shortens the field of error which comes from the same source as in the last method In this series of heats the furnace was cooled down each time to eleven hundred degrees Fahrenheit, six hundred degrees Centigrade, by blowing into it. For the first heat the time required between the melting point of gold and the proper fusing point of Brewster's enamel body was forty seconds, and between gold and Brewster's foundation body one minute and forty seconds.

2nd heat, time to Brewster's enamel, 20 seconds, to Brewster's foundation body. 60 seconds

3rd heat, time to Brewster's enamel, 18 seconds, to Brewster's foundation body, 54 seconds.

4th heat, time to Brewster's enamel 15 seconds, to Brewster's foundation body, 44 seconds.

5th heat. time to Brewster's enamel, 18 seconds, to Brewster's foundation body, 55 seconds.

6th heat, time to Brewster's enamel, 17 seconds, to Brewster's foundation body, 53 seconds.

7th heat, time to Brewster's enamel 15 seconds, to Brewster's foundation body, 44 seconds.

8th heat, time to Brewster's enamel, 14 seconds, to Brewster's foundation body, 40 seconds.

9th heat, time to Brewster's enamel, 10 seconds, to Brewster's foundation body. 30 seconds.

You see, no one of these durations of time above gold would have done exactly for any other bakes, in fact there is a very big difference in the buttons produced. If we had taken as the standard the second heat, the eighth heat was seventy degrees too high for Brewster's enamel body and ninety degrees too high for Brewster's foundation body. And for the ninth heat one hundred degrees too high for Brewster's enamel body and one hundred and ten degrees too high for Brewster's foundation body.

Another method that is used is to train the eye to the appearance of the glaze, which is not constant for different shapes of surfaces and colors or for different conditions of the eyes. The range of error from this method must be considerable as shown by the set of buttons made from the same bottle by nine different dentists and most of them used the glaze test. The range goes from the darkest brown to a nearly chalk white, but were supposed to be alike.

Still another method used is to judge the temperature of the furnace by its color. We all know that what appears to the eye a red heat will depend entirely upon the intensity of the light in which it is viewed and the condition of our eyes. For example, if you are annealing a piece of gold at night in a dark room in a Bunsen flame, the temperature at which it looks red is about thirteen hundred degrees Fahrenheit or seven hundred degrees Centrigrade, and doing the same in the midday in a bright light the temperature is about nineteen hundred degrees Fahrenheit or one thousand and fifty degrees Centigrade, more than half as much again as before. Now, how can any one allow for the stages of light between, occasioned by a passing cloud or a smoky day such as you have here in Pittsburg? I cannot see how it is possible and I have tried several operators who claimed they could, but the variation they made was always very large.

There is still one other method used which is to turn the current on the top notch and leave it there until you get the inlay or crown done and plunge each piece into the white-hot muffle after drying and regulate the result by the time the piece is left in the muffle. I asked an operator who used this method, how he allowed for the difference in the fusing point of Brewster's foundation body and Brewster's enamel body. He stated that he had no allowance except the time.

Gentlemen, when we consider the absolute lack of exactness in all our methods of manipulating porcelain, the wonder is, not that so much of porcelain work has been satisfactory, but that so much has been even as creditable as it has.

There are some fundamental principles underlying the fusing of porcelain that have not been recognized, and certainly not complied with, viz: to produce a definite color we must bake at a definite temperature for a definite time and that the temperature of different parts of the same piece of porcelain we are baking are not the same temperature if we are using a constantly increasing temperature, which we do by all the methods heretofore detailed. When we heat an inlay or crown, the interior of it is heated by the exterior and the more exposed parts are ten to fifty degrees hotter than the less exposed parts if the heat is constantly increasing. By this means the color is baked out more in those more exposed places like the tip of a crown or edge of a large inlay. Besides this unevenness of color we have a different degree of contraction from the different degrees of fuse which makes a much more friable piece besides tending to change its shape. We even see a blistering sometimes on exposed cusps of crowns. These defects are all entirely prevented by bringing the piece to exactly the proper temperature and holding it there until the entire mass comes to that temperature without allowing the more exposed parts to increase as is the universal custom by all the methods described. For example, here is a card with three large cones of Brewster's enamel body, each having large base like the mass of a crown, and tapering to a thin edge. In the first, the universal method of baking with a constantly increasing heat or the same thing. placing into a hot muffle as some do for a given time. It was taken out just when the exposed parts were fusing, and you see that while the top and edges are fully glazed, the base and less exposed parts are not starting to glaze.

The next cone on this card shows another cone just the same shape but left in under the same conditions until the base and less exposed part sare fused and the result is as you see that the color is not the same by several degrees at the exposed edges as at the base, because these parts were of necessity hotter and the color was baked out with this method of a constantly increasing current.

The third button is similar in size and all made from the same bottle, but in this the thin knife-edges of the exposed top and side of the cone have precisely the same color as the base in contrast with the other two.

The reason is that it was properly baked by stopping the rise of temperature by turning back the rheostat at precisely the right point by means of the pyrometer and holding the temperature of the muffle at just that point until the entire mass of the porcelain had come to that temperature. The difference is very marked and I am sure this can only be done by such an instrument as this that I have designed. A small inlay will fuse evenly through if held at the proper temperature fifteen seconds where a large crown will require forty-five seconds to one minute at that temperature. The time we will judge by the size of our piece and leaving it a little too long at just the fusing temperature will have very little effect on the color, where even ten or twenty degrees too high would. With this rheostat you can control the current with great accuracy, the error not amounting to more than two or three degrees where with the ordinary methods with the ordinary furnaces the error will average more nearly one hundred degrees. There is little danger of burning out a muffle when you can watch your temperature so accurately.

There are several other improvements in this furnace, like the proportion of the size of the steps of the rheostat to the total resistance left and the capacity for rapid heating and cooling of the muffle that I would like to have brought out the great advantage of, but I have already kept you too long and will refer you to other papers for.