Ilkogretim Online - Elementary Education Online, 2021; Vol 20 (Issue 6): pp. 1016-1025
http://ilkogretim-online.org
doi: 10.17051/ilkonline.2021.06.109

Borax frit: testing leadless fluxes for glazing earthenware ceramics in educational institution

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Abstract: In this laboratory research, the suitability of increasing the percentage of fluxes in glaze recipes for earthenware ceramics was investigated. The aim was to develop glazes appropriate for low-temperature ceramics by using as much Borax frit as possible in each glaze recipe to avoid complicated recipes in both educational and professional contexts. Using as few chemical items as possible in ceramic glaze recipes is important for a wide range of scientific and industrial processes in the field of ceramics to reduce financial costs. Specifically, the experiments in this research mainly assessed the possibility of using Borax frit in different glazing recipes in quantities of 50% and above in each glaze recipe. To achieve this purpose, Borax frit, code P2953/ Potterycrafts, was used in all experiments in this research.

Keywords: Borax frit, glazes, ceramics

Received:	Accepted:	Published:

INTRODUCTION

According to Taylor and Bull (1986), frits are the essential ingredients in most ceramics glazes developed at temperatures 1150°C and below. Compared to raw glazes, fritted glazes play an important role in decreasing melting temperatures; therefore, the glaze maturing time can be shorter, and the surfaces of ceramics pots can be smooth and bright effortlessly.

Most low-temperature earthenware glazes require fluxes to reduce their melting temperature point and reach their maturing point. But unfortunately, most fluxes are either poisonous because they include lead or water soluble because they include sodium and potassium. Usually, these materials are used raw, but this is not satisfactory for contemporary ceramicists. In fact, raw lead is considered the most poisonous material in ceramic glazing labs. Furthermore, and especially when raw Borax is used, the glazes cannot be stored for a long time because the Borax will form crystals and the final results will not be satisfactory to ceramicists (Norsker&Danisch, 1993).

The following table from Norsker and Danisch (1993) shows raw materials used by ceramicists to compose frits:

Table 1 : **Frits General Raw Materials**

Raw Material	Chemical Formula
Silica sand	SiO_2
Rice husk ash	SiO_2

Sodium borate	$Na_2B_4O_7\ 10H_2O$
Boric acid	H_3BO_3
Limestone	$CaCO_3$
Soda Feldspar	K_2O
Potash Feldspar	Na_2O
Clay	$Al_2O_3\ 2SiO_2$
Zinc oxide	ZnO
Zircon	$ZrSiO_4$
Red lead oxide	Pb_3O_4

One of the most widely used frits in glazing ceramics, Borax frit is a compound containing an elementary substance called boron, combined with oxygen and soda. It is readily found in deposits produced by the evaporation of seasonal lakes. Borax is also called tincal, from the Sanskrit word for the first deposits revealed in Tibet in dry lakes. In the eighth century, Borax was transported along trade routes to Arabia. The first evidence of the use of Borax was by Arabian goldsmiths and silversmiths in the Middle East.

In the tenth century, Borax was used by the Chinese in ceramic glazes as a melting agent. And we still use this material in modern ceramics to guarantee a perfect fit between a glaze and the clay body. Borax also increases durability and shine. Furthermore, for the purpose of reducing energy use in the ceramic firing process, Borax has lately also been added to clay bodies during production (Material World, 2004).

According to 20 Mule Team, Borax, one of the most popular producers of Borax frits, stated

> Borates are also incorporated into frits to render them insoluble. The resulting material is then mixed with other materials, including water, and finely ground to make a suspension that can be applied to the surface of the desired substrate. After application, the substrate is dried and fired to fuse the glaze or enamel onto the surface. Frits also basically 'premelt' the ceramic glaze before the firing process, helping to obtain a high-glaze gloss even when using very short firing cycles. (2021)

In this project, Borax frit (P2953) will be used in all ceramics glazing experiments. This frit is a leadless frit with medium thermal expansion, which makes it ideal as the main ingredient in earthenware glazes (Potterycrafts, 2021). And according to the producer and supplier, the firing range for this frit to be melted is between 900 to 1100 °C. The table below shows its specific chemical formula:

Table 2: Technical Information for Borax Frit

Chemical formula	Raw materials	Percentage
SiO_2	Silica	49.6%
B2O3	Boron Trioxide	18.0%
MgO	Magnesium oxide	0.1%
Al2O3	Aluminum oxide	7.5%
Na2O	Sodium oxide	8.8%
K2O	Potassium oxide	1.7%
CaO	Calcium oxide	14.1%

METHODS

1. **Laboratory Experiments (Stage 1): Testing Glaze Recipes**

Data on Borax frit and its impact on glaze recipes were gathered from multiple sources during a literature review. To ensure accurate documentation for the slip recipes and their percentages, the researcher made a waterproof label for each glaze recipe and placed it on the container(Almamari, 2019). To begin this process, glaze recipes with a Borax frit content of 50% and above were identified, and their calculations completed. This research began with the following recipe from Glazes for the Self-Reliant Potter by Norsker and Danisch (1993, p. 151):

Table 3: Test (1) Recipe from Glazes for the Self-Reliant Potter

Test (1)	
Item	**Percentage**
Borax	**50%**
Red earthenware clay	**5%**
Silica	**30%**
Whiting	**5%**
Yellow ochre	**10%**
Total	**100%**
Firing temperature	**1020°C**

Figure1: Test (1) with a temperature of 1020°C (right) and test (1) with a temperature of 1280°C (left)

Test (1) - 1020 °C   Test (1) - 1280 °C

For test (2), the recipe consisted of Borax at a concentration of 50%, Silica became 35%, and whiting was increased to 15%. Also, 4 g of a red stain, coded P 4187.5, from Potterycrafts was added. After grinding the powder for 1 min using a coffee grinding machine to reach a sieve 120 mesh level of fineness, 100 ml of clean water was added to the powder recipe. The mixture was left for one night and was then used to paint two bisque fire earthenware test tiles. One of them was fired in an oxidation atmosphere to reach 1020 °C as the low-temperature test, and the second test was conducted in a similar atmosphere but at a higher temperature of 1280 °C.

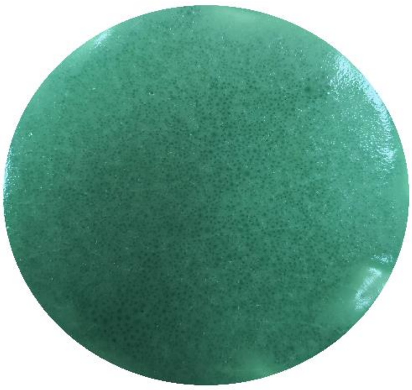
Figure2: Test (2) with a temperature of 1020 °C (right), and test (2) with a temperature of 1280 °C (left)

Test (2) - 1020 °C

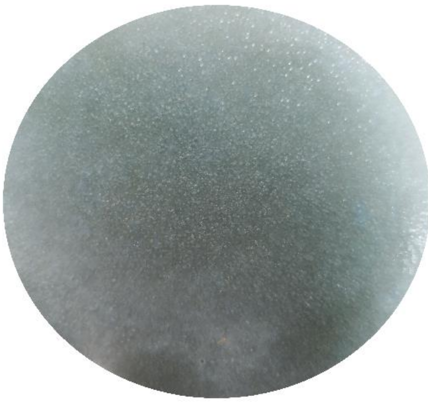
Test (2) - 1280 °C

For test (3), the recipe consisted of Borax at 50%, Silica became 45%, and whiting was decreased to (5%). Also, 4 g of a green stain from Potterycrafts, coded P 4108.5, was added. After grinding the powder for 1 min using a coffee grinding machine to reach a sieve 120 mesh level of fineness, 100 ml of clean water was added to the powder recipe. The mixture was again left for one night, and then used to paint two bisque fire earthenware test tiles. One of them was fired in an oxidation atmosphere at 1020 °C as a low-temperature test, and the second was fired in similar atmosphere but at a higher temperature of 1280 °C.

Figure3: Test (3) with a temperature 1020 °C (right), and test (3) with a temperature of 1280 °C (left)



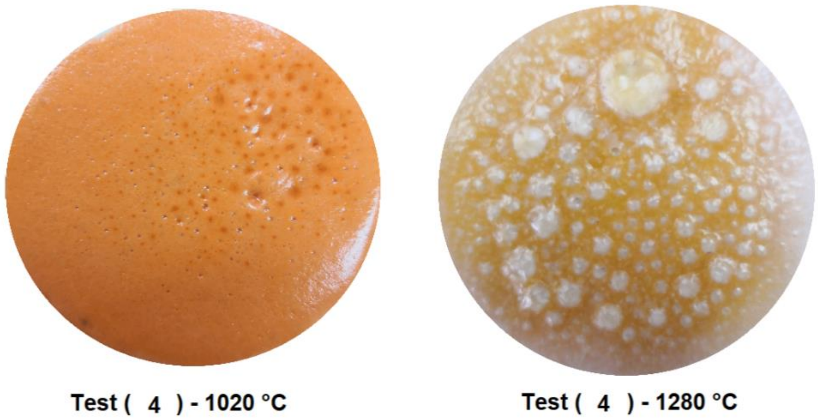
Test (3) - 1020 °C



Test (3) - 1280 °C

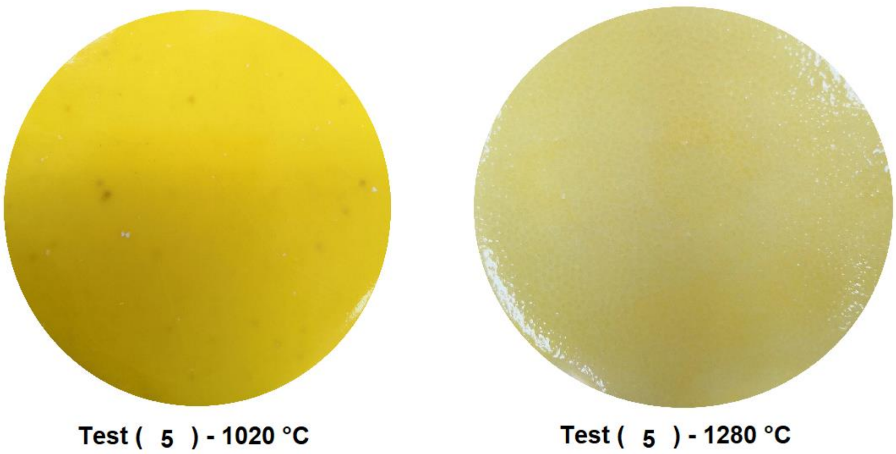
For test (4), the recipe consisted of Borax at a concentration of 50%, quartz substituted silica at 40%, and dolomite substituted whiting at 10%. Also, 4 g of an orange stain from Potterycrafts, coded P 4188.5, was added. After grinding the powder for 1 min using a coffee grinding machine to reach a sieve 120 mesh level of fineness, 100ml of clean water was added to the powder recipe. The mixture was left for one night, and then used to paint two bisque fire earthenware test tiles. One of them was fired in an oxidation atmosphere at 1020 °C as a low-temperature test, and the second was fired in a similar atmosphere but at a higher temperature of 1280 °C.

Figure4: Test (4) with a temperature of 1020 °C (right), and test (4) with a temperature of 1280 °C (left)



For test (5), the recipe consisted of Borax at a concentration of 50%, silica was reduced to 30%, and potash feldspar was added at 20%. Also, 3 g of a yellow stain from Potterycrafts, coded P 4189.5, was added. After grinding the powder for 1 min using a coffee grinding machine to reach a sieve 120 mesh level of fineness, 100 ml of clean water was added to the powder recipe. The mixture was left for one night, and then used to paint two bisque fire earthenware test tiles. One of them was fired in an oxidation atmosphere at 1020 °C as a low-temperature test, and the second was fired in a similar atmosphere but at a higher temperature of 1280 °C.

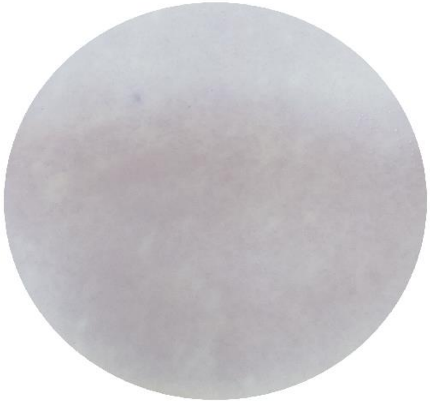
Figure5: Test (5) with temperature 1020 °C (right), and test (5) with temperature 1280 °C (left)



For test (6), the recipe consisted of Borax at a concentration of 50%, quartz at 40%, and magnesium carbonite at 10%. Also, 4 g of a purple stain from Potterycrafts, coded P 4182.5, was added. After grinding the powder for 1 min using a coffee grinding machine to reach a sieve 120 mesh level of fineness, 100 ml of clean water was added to the powder recipe. The mixture was left for one night, and then used to paint two bisque fire earthenware test tiles. One of them was fired in an oxidation atmosphere at 1020 °C as a low-temperature test, and the second was fired in a similar atmosphere but at a higher temperature of 1280 °C.

Figure6: Test (6) with a temperature of 1020 °C (right), and test (6) with a temperature of 1280 °C (left)

Test (6) - 1020 °C



Test (6) - 1280 °C

In order to assess the role of Borax frit in developing glazes, laboratory experiments were conducted. Taken together, the results are promising, as common defects such as crawling, pinholes, crazing, and shivering did not appear in any of the six glazes tested. Comparing the six results, it is clear that test (5) was the best for several reasons. First, the test tile had a perfectly smooth texture and color in both the low-temperature test (1020 °C) and high-temperature test (1280 °C). Second, the test did not show any defects, including crawling, pinholes, crazing, and shivering. Finally, the test recipe included only three components, which would make it more accessible in the field of ceramic art and ceramics industries. This test was therefore selected for the second stage of the research experiments for more intensive testing. Table 4 shows the basic recipe for this test:

Table 4 : Test (5) Glaze Recipe

Test (5)	
Item	**Percentage**
Borax	50%
Silica	30%
Potash Feldspar	20%
Total	**100%**

2. Laboratory Experiments (Stage 2): Intensive Tests for Selective Recipe (Test 5):

The purpose of the experiments in the second stage was to examine the functionality of the selected test, test 5, with different colors, component percentages, and firing ranges. This reduced the cost of the experiment, including the cost of kiln firing and the expensive materials, by reducing the materials used in the recipe. To achieve this, the basic recipe of test 5 was applied with different stains. Table 5 shows the stain used with each test:

Table 5: Stage (2) tests glaze recipes and the stains used with each test

Test No.	Stain code & color According to PotteryCrafts	Quantity (g)
Test 7	P 4179.5 (Orange Egg Yellow)	8 g
Test 8	P 4108.5 (Cossack Green)	8 g
Test 9	P 4188.5 (Orange)	8 g
Test 10	P 4148.5 (Mandarin Yellow)	8 g
Test 11	P 4142.5 (Golden Brown)	8 g
Test 12	P 4129.5 (Sky/Jay Blue)	8 g

Test 13	P 4132.5 (Mazarine Blue)	8 g
Test 14	P 4187.5 (Deep Red)	8 g

At this stage, each test was conducted on two samples, one of them fired at 1020 °C, and the other fired at 1280 °C. The following figures show the final results of the tests:

Figure7: Tests (7, 8, & 9) at a temperature of 1020 °C (right), and tests (7, 8, & 9) at a temperature of 1280 °C (left)

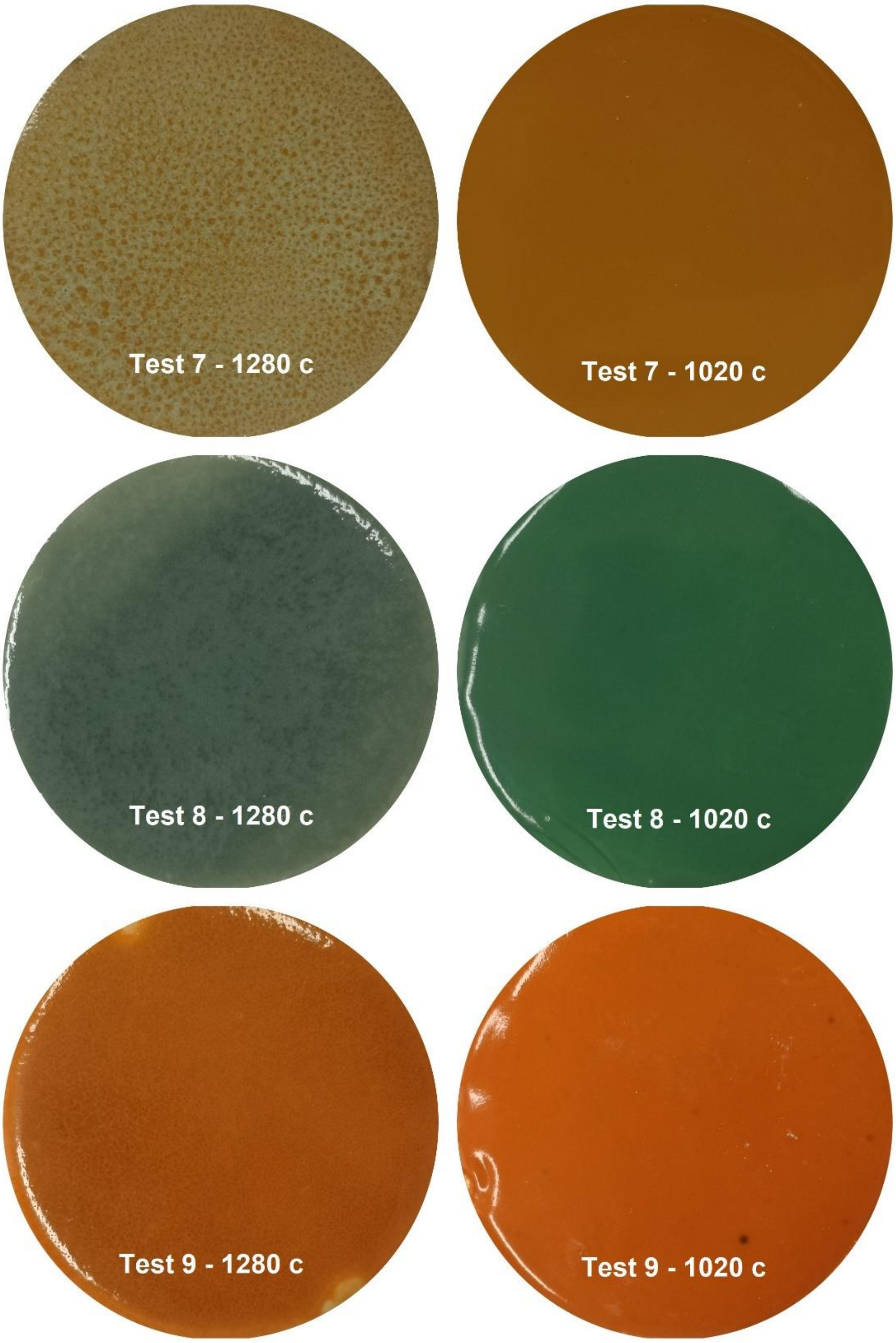


Figure8: Tests (10, 11 & 12) at a temperature of 1020 °C (right), and tests (10, 11, & 12) at a temperature of 1280 °C (left)

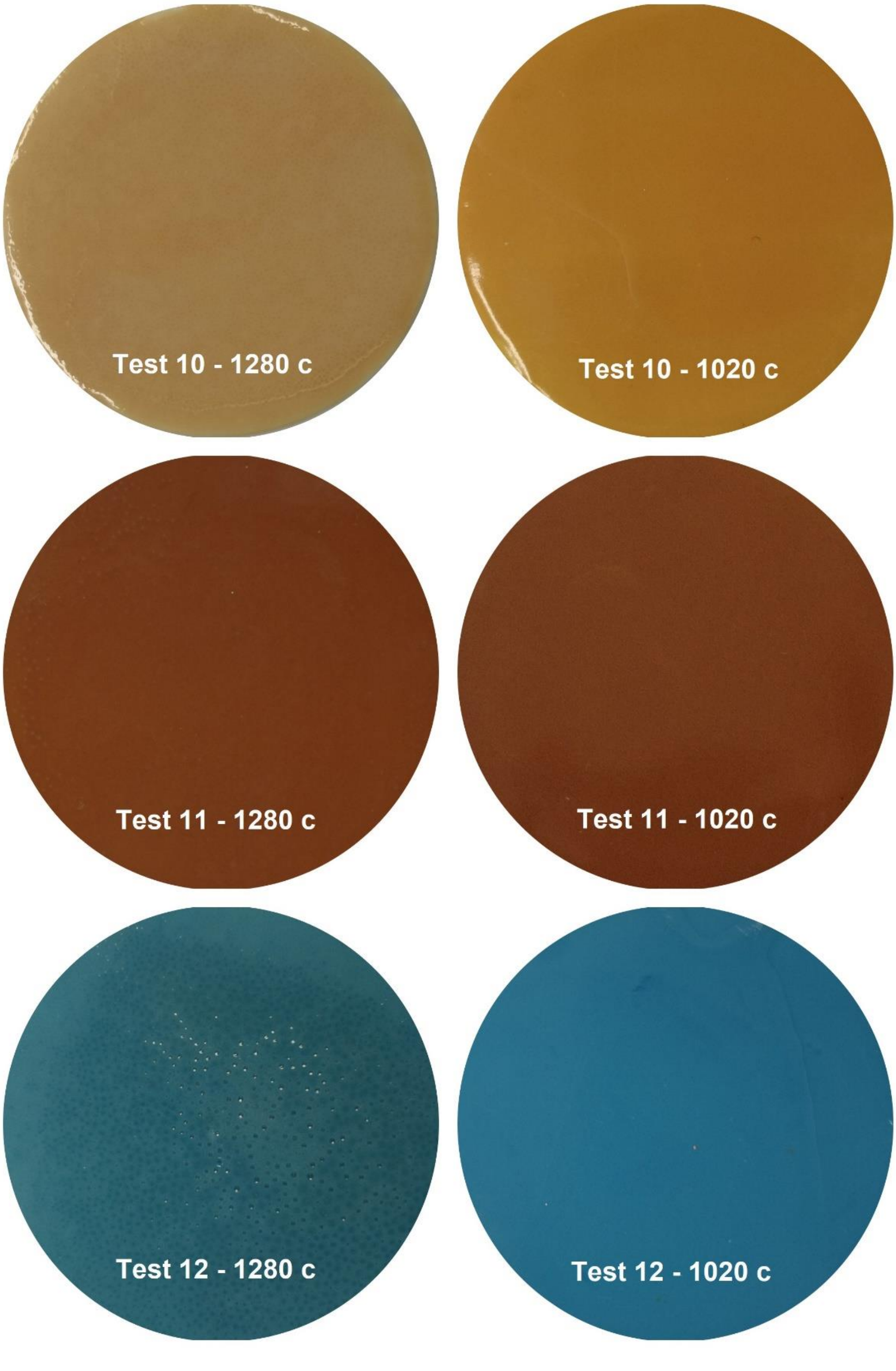
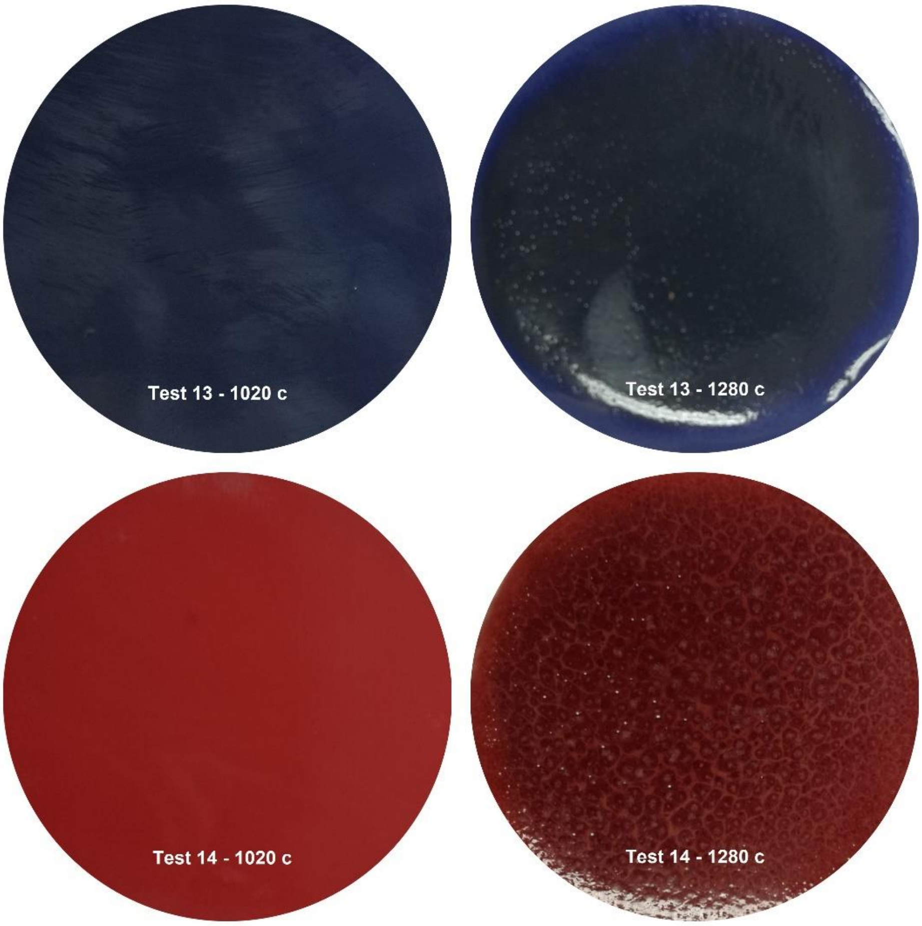


Figure9: Tests (13 & 14) at a temperature of 1020 °C (left), and tests (13 & 14)at a temperature of 1280 °C (right)



ANALYSIS

This study set out with the aim of assessing the importance of using a 50% concentration of a single frit in glaze recipes. In this case, Borax frit was used in each glaze recipe at a concentration of 50%. The majority of tests in stage 1 did not contain any glaze defects, including crazing, shivering, crawling, pin holing, or blistering. With respect to the first research question, it was found that using Borax frit as the main ingredient in each glaze recipe helped to form an appropriate glaze for ceramics and pottery. This finding has important implications for developing a simple color glaze recipe in industrial and educational ceramics fields.

Further experimental tests in a ceramics laboratory in stage two, revealed that all of the stains worked very well with the test 5 recipe. The results, as shown in figures 7, 8, and 9, indicate that all test samples were smooth, had accurate colors, and had no visible defects.

Conclusion and Recommendations

According to many students and ceramic materials suppliers, commercially imported glazes are extremely expensive for individual ceramicists or potters despite their widespread availability in Oman (Almamari, 2020). The results of this study indicate that reducing the number of chemical materials used to create coloring glazes is possible and suitable for earthenware clays. The glaze testing results are applicable to both educational and industrial contexts, particularly because the experiments were conducted in an electric oxidation environment with a low-temperature firing (1020 °C) and a mid-temperature firing (1280 °C). Further information on testing Borax frit would help us to establish a greater degree of accuracy in making coloring glazes in a wider range of clays. Further research could also be conducted to determine the effectiveness of color glaze recipes when the percentage of Borax frit is increased to more than 50% in each recipe. And if this improvement was confirmed by laboratory experiments, the findings would have a number of important implications for future practice in the field of ceramics.

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