THE QUALITY OF OMANI DAMS' CLAYS FOR CERAMICS INDUSTRIES: EXAMINING THE QUALITY OF WADI AL JIZI AND WADI MISTAL CLAYS FOR GLAZING CERAMICS

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Abstract:

Most wadi dams in Oman reservoirs have become a major storage source for sediments, including clays, over the last 30 years. According to statistics, wadi dams have clay fractions that sometimes range from 50% to 70% of the sediments located in these dams. Ceramic clays are known to be natural and easily engineered porous-structured materials. The ways dams gather these huge quantities of clays are similar to the original natural ways rivers create clays in other parts of the world. Until now, far too little attention has been paid to the importance of these dams' clay sediments for industries in general and the ceramics industry in particular. Therefore, the aim of this research project was to evaluate the clays of Wadi Al jizi and Wadi Mistal for ceramics industry applications, especially when used with frits to develop glazes.

Keywords: clays, dams, ceramics, glazes.

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1. Introduction

Clays are used as raw materials in various manufacturing fields, including the ceramics, paper, paint, and petroleum industries (Celik, 2010). Mentioned in ancient Greece as "keramikos," ceramic clay is recognized as man's earliest utilitarian raw material (Burst, 1991). The composition property of clays that is significant to the ceramics industry is their plasticity, which helps shape the body, chemistry, mineral structure, thermal properties, color, and mechanical strength after the firing process in special kilns (El Idrissi et al., 2018). Clays are the main materials for the cores of earthfill dams (Gokalp, 2009). Deposits are natural materials that gather in harbors, canals, river lagoons, and dams. They are a relatively mixed product and demonstrate a broad composition distribution, combined with the presence of organic materials and a significant amount of water (Goure-Doubi et al., 2015). Goure-Doubi et al. (2015) added that because of the extraordinary content of clay reserves, the combination of dam sediments in the sector of traditional ceramics, including ceramic tiles and clay bricks, is a very promising industry. In fact, the appropriateness of different clays in different uses is intensely reliant on their mineralogical and chemical compositions, physical assets, structure, plastic, and thermal behavior (Gualtieri et al., 2010). According to Murray (1991), significant physical characteristics relating to applications of clay are particle dimension, surface chemistry, particle form, surface region, "and other physical and chemical properties specific to a particular application such as viscosity; color; plasticity; green, dry, and fired strength; absorption and adsorption; abrasion; and others." In this project, samples of dam clays from Wadi Al jizi and Wadi Mistal will be used to develop ceramic glazes associated with ceramic frits.

Clay Samples: Clays from Wadi Al jizi and Wadi Mistal

This research experiment used two clay samples collected from the dams, as follows:

The Wadi Al-Jizi's Dam Sample:

The Wadi Al-Jizi Dam area was selected as the study area (located between 24°18'22.7"N and 56°31'03.0"E) and was covered in a topographic map (Akhtar, 2021). It is a coastal plain located in the Al-Batinah region of northwestern Oman (Shibli, 2002). The study area is located between the Sea of Oman (on the north), and the Al Hajer Al Gharbi mountains (on the south). Rainfall in the Al-Batinah region's coastal usually occurs between October and April. Because of thunderstorms in the foothills and hills during the month of July, which gather in the dam each year (MAF & ICBA, 2012). According to Young et al. (1998), the Wadi Al-Jizi catchment, with approximately 100 mm of average annual rainfall, is classified as arid. At higher altitudes in the catchment (1000 m and above) adjacent to mountains, the average annual rainfall is approximately 300 mm, contributing to the coastal aquifer recharge. A total of 30 kg of dam clay was collected to conduct the research experiments.

The Wadi Mistal's Dam Sample:

Wadi Mistal (Wādī Misţāl) is a wadi (class H–hydrographic) in Oman. It is located at an elevation of 339 meters above sea level.

Wādī Misţāl is also known as Wadi Mistal. Its coordinates are 23°21'34"N and 57°39'3"E in degrees minutes seconds (DMS), or 23.3594 and 57.6508 in decimal degrees. Its UTM position is EL68, and its Joint Operation Graphics reference is NF40-03.

Wadi Mistal, which is about 15 kilometers south of Nakhal, opens out into the vast Ghubra Bowl over which the Wakkan village gazes from 1400 meters; in turn, the village is overlooked by the southwestern escarpment of Al Jabal Al Akhdar. The drive through the wadi entrance is below sections of the Kahmah formation of limestone rocks from about 120 million years ago. The white streaks through the rocks are calcite, a relatively common crystaline calcium carbonate. About 5 kilometers west of Ghubra village is one of Oman's oldest deposits of debris from a glacier. The ascent to Wakkan village by 4WD will give an excellent view of the escarpments and massive erosion that created the Ghubra bow. A total of 20 kg of dam clay was collected from this dam to conduct the research experiments.

Figure 1: Clay section from Wadi Mistal Dam (Photo: Ahmed Almusalami)

2. Methodology: Ceramic Laboratory Experiments

In this research project, the research team proposed laboratory experiments as a productive methodological addition to existing published data regarding the use of selected dam clays when mixed with glazing materials. The laboratory experiments were accomplished under highly controlled conditions, including the glaze firing process and chemical safety procedures in which accurate measurements could be taken to evaluate the created glazing tests. Usually, after the clay is extracted from the mines, it is brought directly to the pottery studio for further treatment. This is because some raw clays contain so much sand that the true clay content found in primary clay deposits may be only 15% or less (Norsker, 1990). Selecting suitable test sieves with the correct openings ensures accurate particle sizing. Both samples of clay were prepared in the laboratory by grinding and sieving them through 180 sieve degrees (Figure 2).

Figure 2: Preparation of clay samples before composing glaze recipes.

In fact, the test sieves were constructed with full-height frames, which offer more space for agitation of larger particles, whereas half-height frames allow more sieves to be used at the same stack height when using a sieve shaker. This is vital in preparing glazes because the size of the particles plays an important role in creating smooth glaze recipes.

To evaluate the quality of dam clays for developing glazes, four tests were conducted with different types of frits, including Borax Frit, Frit 3110, High Alkail Frit, Lead Basilicate Frit, Frit 3195, and Frit 3124. In fact, four tests were conducted with each of the abovementioned frits, so at the end of the laboratory experiments of this project, 24 tests were developed and applied to ceramic bodies (Figure 3). The percentage of selected dam clays was between 50% and 70% in each recipe, and the added colorant was 8 g in each recipe. All glazed tiles were matured in a low temperature range (Cone 06/1000˚C) in an oxidation firing environment using an electric kiln.

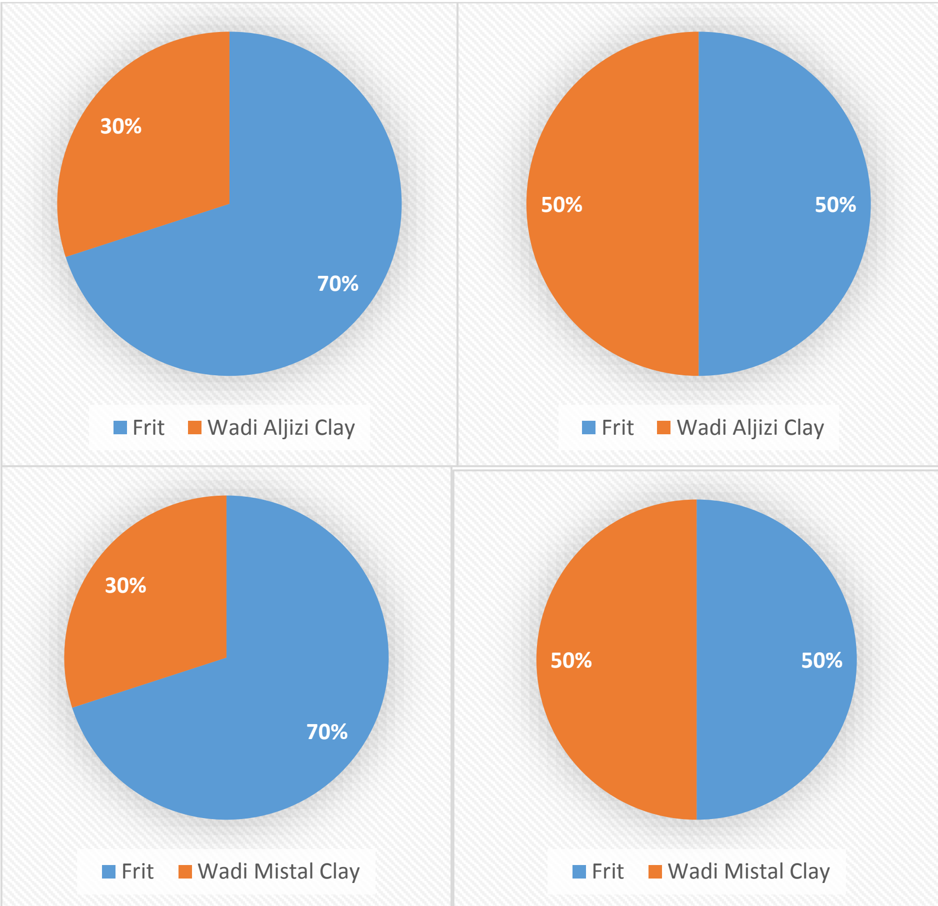

Figure 3: Diagrams showing standard glaze recipes for each frit used in the experimental tests.

Developing Glaze Recipes

Experiments in this project were divided into 6 groups beside the number of frits that mixed with selected clay samples. Consequently, the project's tests were as follows:

Group (1) Borax Frit E: For test group (1), which used Borax Frit (E), Recipe 1 consisted of Borax Frit (E) at a concentration of 70%, and Wadi Aljizi clay at 30%. Recipe 2 was composed by dividing the recipe equally between the frit and the clay sample, so the percentages were 50% Wadi Aljizi clay and 50% Borax Frit (E). The researchers followed similar recipe components with Wadi Mistal clay, where Recipe 3 consisted of Borax Frit (E) at a concentration of 70%, and Wadi Mistal clay at 30%. Finally, Recipe 4 was composed by dividing the recipe equally between the frit and the clay sample, so the percentages were 50% Wadi Mistal clay and 50% Borax Frit (E) (Appendix 1, Group 1).

Group (2) Frit 3110: For test group (2), which used Frit 3110, Recipe 5 consisted of Frit 3110 at a concentration of 70%, and Wadi Aljizi clays at 30%. Recipe 6 was composed by dividing the recipe equally between the frit and the clay sample, so the percentages were 50% Wadi Aljizi clay and 50% Frit 3110. The researchers followed similar recipe components with Wadi Mistal clay, where Recipe 7 consisted of Frit 3110 at a concentration of 70%, and Wadi Mistal clay at 30%. Finally, Recipe 8 was composed by dividing the recipe equally between the frit and the clay sample, so the percentages were 50% Wadi Mistal clay and 50% Frit 3110 (Appendix 1, Group 2).

Group (3) High Alkail Frit: For tests group (3), which used High Alkail Frit, Recipe 9 consisted of High Alkail Frit at a concentration of 70%, and Wadi Aljizi clay at 30%. Recipe 10 was composed by dividing the recipe equally between the frit and the clay sample, so the percentages were 50% Wadi Aljizi clay and 50% High Alkail Frit. The researchers followed similar recipe components with Wadi Mistal clay, where Recipe 11 consisted of High Alkail Frit at a concentration of 70%, and Wadi Mistal clay at 30%. Finally, Recipe 12 was composed by dividing the recipe equally between the frit and the clay sample, so the percentages were 50% Wadi Mistal clay and 50% High Alkail Frit (Appendix 1, Group 3).

Group (4) Frit 3195: For test group (4), which used Frit 3195, Recipe 13 consisted of Frit 3195 at a concentration of 70%, and Wadi Aljizi clay at 30%. Recipe 14 was composed by dividing the recipe equally between the frit and the clay sample, so the percentages were 50% Wadi Aljizi clay and 50% Frit 3195. The researchers followed similar recipe components with Wadi Mistal clay, where Recipe 15 consisted of Frit 3195 at a concentration of 70%, and Wadi Mistal clay at 30%. Finally, Recipe 16 was composed by dividing the recipe equally between the frit and the clay sample, so the percentages were 50% Wadi Mistal clay and 50% Frit 3195 (Appendix 1, Group 4).

Group (5) Lead Bisilicate Frit: For test group (5), which used Lead Bisilicate Frit, Recipe 17 consisted of Frit 3195 at a concentration of 70%, and Wadi Aljizi clay at 30%. Recipe 18 was composed by dividing the recipe equally between the frit and the clay sample, so the percentages were 50% Wadi Aljizi clay and 50% Lead Bisilicate Frit. The researchers followed similar recipe components with Wadi Mistal clay, where Recipe 19 consisted of Lead Bisilicate Frit at a concentration of 70%, and Wadi Mistal clay at 30%. Finally, Recipe 20 was composed by dividing the recipe equally between the frit and the clay sample, so the percentages were 50% Wadi Mistal clay and 50% Lead Bisilicate Frit (Appendix 1, Group 5).

Group (6) Frit 3124: For test group (6), which used Frit 3124, Recipe 21 consisted of Frit 3124 at a concentration of 70%, and Wadi Aljizi clay at 30%. Recipe 22 was composed by dividing the recipe equally between the frit and the clay sample, so the percentages were 50% Wadi Aljizi clay and 50% Frit 3124. The researchers followed similar recipe components with Wadi Mistal clay, where Recipe 23 consisted of Frit 3124 at a concentration of 70%, and Wadi Mistal clay at 30%. Finally, Recipe 24 was composed by dividing the recipe equally between the frit and the clay sample, so the percentages were 50% Wadi Mistal clay and 50% Frit 3124 (Appendix 1, Group 6).

Documenting Technical Results:
The purpose of this study was to assess the quality of clays extracted from Omani dams to be used in ceramic glazes by composing recipes of ceramic colors, including frits and selective clays from Wadi Aljizi and Wadi Mistal dam clays. The initial objective of the project was to identify whether selected clays and inorganic frits fit locally manufactured ceramics and pottery. Besides using the art practice-based evaluation approach, in consideration of the desired effects mentioned above, a specific rubric was designed to assess the final results. Table 1 shows the research team's rubric and reporting results of the experimental test tiles after firing in the electric kiln within a range of temperatures between 1020°C and 1100°C.

Table 1: Rubric of the evaluation of glaze tests.

Group	Test No.	Fit with clay body	Glaze Defects		
			No	No Crawling	No Blisters

			Shivering		
1	**1**	✓	✓	✓	✓
	2	✓	✓	✓	✓
	3	✓	✓	✓	✓
	4	✓	✓	✓	✓
2	**5**	✓	✓	✓	✓
	6	✓	✓	✓	✓
	7	✓	✓	✓	✓
	8	✓	✓	✓	✓
3	**9**	✓	✓	✓	✓
	10	✓	✓	✓	✓
	11	✓	✓	✓	✓
	12	✓	✓	✓	✓
4	**13**	✓	✓	✓	✓
	14	✓	✓	✓	✓
	15	✓	✓	✓	✓
	16	✓	✓	✓	✓
5	**17**	✓	✓	✓	✓
	18	✓	✓	✓	✓
	19	✓	✓	✓	✓
	20	✓	✓	✓	✓
6	**21**	✓	✓	✓	✓
	22	✓	✓	✓	✓
	23	✓	✓	✓	✓
	24	✓	✓	✓	✓

All recipes were applied to ceramic fired bodies, and after collection from the kiln, all tests were documented visually, as shown in Appendix 2.

3. Conclusion

This project was undertaken to evaluate the ability of Omani dam clays to create practical artistic glazes, which will elevate ceramic artwork quality by providing a variety of decorative glazing recipes. Because 24 out of 24 glaze tests meet the research objectives, artists can develop applicable glazes for artistic artwork in their studios. Taken together, these results suggest a role for all artists, craftspeople, and ceramic industries in promoting the quality of their artwork and crafts pieces. In the future, more experimental tests in making applicable ceramic glaze recipes using clays extracted from dams will help us establish a greater degree of accuracy in formulating well-manufactured ceramics. Because there are few published studies on the use of dams and clays for ceramic artists and art teachers, the issue of developing glazes is intriguing and could be explored in further research.

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4. References

1. Celik, H. (2010). Technological Characterization and industrial application of two Turkish clays for the ceramic industry. *Applied Clay Science*, *50*(2), 245–254. https://doi.org/10.1016/j.clay.2010.08.005
2. Burst, J. F. (1991). The application of Clay Minerals in Ceramics. *Applied Clay Science*, *5*(5–6), 421–443. https://doi.org/10.1016/0169-1317(91)90016-3
3. El Boudour El Idrissi, H., Daoudi, L., El Ouahabi, M., Collin, F., & Fagel, N.

(2018). The influence of clay composition and lithology on the industrial potential of earthenware. *Construction and Building Materials*, *172*, 650–659. https://doi.org/10.1016/j.conbuildmat.2018.04.019
4. Gökalp, Z. (2009). Engineering characteristics of sand-clay mixtures used for clay cores of Earth-fill dams. *Clay Minerals*, *44*(3), 319–326. https://doi.org/10.1180/claymin.2009.044.3.319
5. Goure-Doubi, H., Lecomte-Nana, G., & Thery, F. (2015). Characterization and valorization of dam sediment as ceramic materials. *International Journal of Engineering and Innovative Technology (IJEIT)*, *4*(8), 84–91.
6. Gualtieri, M. L., Gualtieri, A. F., Gagliardi, S., Ruffini, P., Ferrari, R., & Hanuskova, M. (2010). Thermal conductivity of fired clays: Effects of mineralogical and physical properties of the raw materials. *Applied Clay Science*, *49*(3), 269–275. https://doi.org/10.1016/j.clay.2010.06.002
7. Murray, H. H. (1991). Overview — clay mineral applications. *Applied Clay Science*, *5*(5–6), 379–395. https://doi.org/10.1016/0169-1317(91)90014-z
8. Akhtar, J., Sana, A., Tauseef, S. M., Chellaiah, G., Kaliyaperumal, P., Sarkar, H., & Ayyamperumal, R. (2021). *Evaluating the Groundwater Potential of Wadi Al-Jizi, Sultanate of Oman by Intergrating Remote Sensing &Amp; Gis Techniques*. https://doi.org/10.21203/rs.3.rs-761541/v1
9. Shibli.SH (2002) *Modeling of Saltwater Intrusion in Wadi Al-Jizi Aquifer*, Master's Thesis, SQU, Sultanate of Oman.
10. Ministry of Agriculture and Fisheries (MAF) and International Center for Biosaline Agriculture (ICBA) (2012) Oman Salinity Strategy - Assessment of Salinity Problem: Annex-1, Muscat. Sultanate of Oman
11. Young, M. E., de Bruijn, R. G., & Al-Ismaily, A. S. (1998). Exploration of an alluvial aquifer in Oman by time-domain electromagnetic sounding. *Hydrogeology Journal*, *6*(3), 383–393. https://doi.org/10.1007/s100400050161
12. Geology booklet - experienceoman.om. (n.d.). https://www.experienceoman.om/wp-content/uploads/2019/10/Geology-Booklet_En_EXP.pdf
13. Norsker, H. (1990). *Clay materials - for the self-reliant Potter a publication of Deutsches Zentrum Für Entwicklungstechnologien - Gate in: Deutsche Gesellschaft Für Technische Zusammenarbeit (GTZ) GmbH*. Vieweg.

Appendix 1: Glaze Recipes

Group (1): Borax Frit (E)

Test (1)

Item	Percentage
Borax Frit (E)	70 %
Wadi Al jizi Clay	30%
Total	100%
+ Colorant : P4129.5	8%

Test (2)

Item	Percentage
Borax Frit (E)	50%
Wadi Al jizi Clay	50%
Total	100%
+ Colorant : P4188.5	8%

Test (3)

Item	Percentage
Borax Frit (E)	70%
Wadi Mistal clay	30%
Total	100%
+ Colorant : P4185.5	8%

Test (4)

Item	Percentage
Borax Frit (E)	50%
Wadi Mistal clay	50%
Total	100%
+ Colorant : P4132.5	8%

Group (2): Frit 3110

Test (5)

Item	Percentage
Frit 3110	70 %
Wadi Al jizi Clay	30%
Total	100%
+ Colorant : P4179.5	8%

Test (6)

Item	Percentage
Frit 3110	50%
Wadi Al jizi Clay	50%
Total	100%
+ Colorant : P4187.5	8%

Test (7)

Item	Percentage
Frit 3110	70%
Wadi Mistal clay	30%
Total	100%
+ Colorant : P4108.5	8%

Test (8)

Item	Percentage
Frit 3110	50%
Wadi Mistal clay	50%
Total	100%
+ Colorant : P4140.5	8%

Group (3): High Alkail Frit

Test (9)

Item	Percentage
High Alkail Frit	70 %
Wadi Al jizi Clay	30%
Total	100%
+ Colorant : P4187.5	8%

Test (10)

Item	Percentage
High Alkail Frit	50%
Wadi Al jizi Clay	50%
Total	100%
+ Colorant : P4179.5	8%

Test (11)

Item	Percentage
High Alkail Frit	70%
Wadi Mistal clay	30%
Total	100%
+ Colorant : P4132.5	8%

Test (12)

Item	Percentage
High Alkail Frit	50%
Wadi Mistal clay	50%
Total	100%
+ Colorant : P4185.5	8%

Group (4): Frit 3195

Test (13)

Item	Percentage
Frit 3195	70 %
Wadi Al jizi Clay	30%
Total	100%
+ Colorant : P4188.5	8%

Test (14)

Item	Percentage
Frit 3195	50%
Wadi Al jizi Clay	50%
Total	100%
+ Colorant : P4185.5	8%

Test (15)

Item	Percentage
Frit 3195	70%
Wadi Mistal clay	30%
Total	100%
+ Colorant : P4132.5	8%

Test (16)

Item	Percentage
Frit 3195	50%
Wadi Mistal clay	50%
Total	100%
+ Colorant : P4179.5	8%

Group (5): Lead Bisilicate Frit

Test (17)

Item	Percentage
Lead Bisilicate Frit	70 %
Wadi Al jizi Clay	30%
Total	100%
+ Colorant : P4108.5	8%

Test (18)

Item	Percentage
Lead Bisilicate Frit	50%
Wadi Al jizi Clay	50%
Total	100%
+ Colorant : P4132.5	8%

Test (19)

Item	Percentage
Lead Bisilicate Frit	70%
Wadi Mistal clay	30%
Total	100%
+ Colorant : P4179.5	8%

Test (20)

Item	Percentage
Lead Bisilicate Frit	50%
Wadi Mistal clay	50%
Total	100%
+ Colorant : P4187.5	8%

Group (6): Frit 3124

Test (21)

Item	Percentage
Frit 3124	70 %
Wadi Al jizi Clay	30%
Total	100%
+ Colorant : P4108.5	8g

Test (22)

Item	Percentage
Frit 3124	50%
Wadi Al jizi Clay	50%
Total	100%
+ Colorant : P4140.5	8g

Test (23)

Item	Percentage
Frit 3124	70%
Wadi Mistal clay	30%
Total	100%
+ Colorant : P4182.5	8g

Test (24)

Item	Percentage
Frit 3124	50%
Wadi Mistal clay	50%
Total	100%
+ Colorant : P4138.5	8g

Appendix (2): visual documentation of glazed tests


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