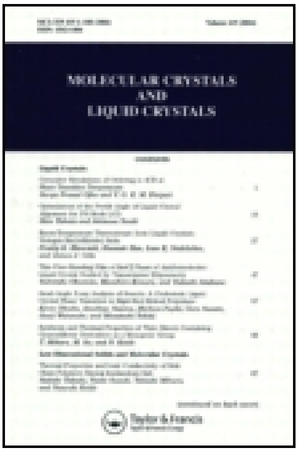

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C. Madivate [a], R. Manjate [b], H. Filimone [b], H. Muiambo [a] & A. Manhique [a]
[a] Universidade Eduardo Mondlane, Maputo, Moçambique
[b] Laboratório de Engenharia de Moçambique, Maputo, Moçambique

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Reutilization of Solid Waste from Ornamental Rocks Processing

C. MADIVATE,[1,*] R. MANJATE,[2] H. FILIMONE,[2]
H. MUIAMBO,[1] AND A. MANHIQUE[1]

[1]Universidade Eduardo Mondlane, Faculdade de Ciências, Maputo, Moçambique
[2]Laboratório de Engenharia de Moçambique, Maputo, Moçambique

The effect of marbles and granites on the plasticity and bending stress of two Mozambican clays (OUA and CIMOC) was studied. For that purpose, clay masses with addition of marble and granite rejects have been prepared, their plasticity and mechanical strength determined. While CIMOC clay results showed a non-regular behaviour, OUA clay, clay with high plasticity, exhibited a regular decrease of plasticity with increasing amounts of additives on one side, improving processability. Bending stress results obtained with OUA clay showed no significant differences for the various additives used on the other side. The results obtained with OUA clay are desirable since residues processed on each day at the respective factory represent a mixture of different marbles and granites with varying (unknown) compositions. This difference in composition has apparently no additional effect on the bending stress of fired samples of OUA clay masses.

Keywords Bricks; industrial waste; granite; marble; mechanical properties; rejects

Introduction

Industrial activity of a country contributes for the improvement of the quality of life of its citizens. On the other hand, it has a negative impact on the environment. These opposite aspects present a challenge to modern societies, which have to manage this delicate balance of the positive and negative aspects of the industrialization process. One example of this is the processing of marbles and granites in Maputo. This activity generates residual powders which are deposited in inadequate areas, where they are partially dissolved causing soil pollution with negative consequences on plants and the quality of water [1].

As a consequence of the growing interest on environmental issues, studies are being carried out to promote a sustainable processing of such materials, normally through recycling or reutilization of the generated residues. Recycling or reutilization of secondary products has the following advantages [2–6]:

- saving on non-renewable resources through substitution of natural raw materials by generated residues;
- saving of energy in case of residues with a potential use as fuels, or residues which exhibit exothermic reactions during processing;

*Address correspondence to Carvalho Madivate, Department of Chemistry, University Eduardo Mondlane, Maputo – Mozambique, PO Box 257. E-mail: cmadivate@uem.mz, cmadivate@yahoo.com

– elimination of the costs for treatment and removal of these residues;
– inertness of toxic residues without the emission of vapours as occurs in incinerators.

Reutilization of residues finds a wide application in the glass [7] and in the ceramic industry [8]. Depending on the colour of produced glass, the glass industry can incorporate more than 50% of glass cullet [7]. Contrary to the glass industry, the ceramic industry, especially red clay production, can incorporate heterogeneous residues from different origins and compositions without a significant depreciation of its quality. The residues generated from processing of ornamental rocks are rich in silicon and aluminium oxides, carbonates, metal oxides and other impurities; components similar to the ones present in the traditional ceramic raw materials. For that reason masses used for red clay production tolerate incorporation of various types of residues, even in significant amounts [8–10].

In the present work results of the effect of addition of marbles and granites residues on technological properties of clays are presented. Marbles are materials composed mainly of $CaCO_3$ and/or $CaMg(CO_3)_2$, while granite contains basically feldspar, quartz and micas [8]. These components are non-plastic and can reduce significantly the plasticity of masses where they are incorporated.

Materials and Methods

Samples of marbles and granites processed in different companies in Maputo - Mozambique were collected. These companies work basically with marbles and granites imported from Brazil, Portugal, South Africa, Namibia and Sweden, as well as a white and a gray marble from Cabo Delgado, in the North of Mozambique.

Collected samples were dried, grinded and submitted to XRF and XRD analysis for determination of the chemical and mineralogical composition of samples respectively.

After the XRD and XRF experiments, clay masses with contents of marbles and granites between 0 and 40% were prepared and submitted to

– plasticity experiments to see the effect of marbles and granites on the plasticity of clays;
– thermal analysis (Netzsch STA 409 PC/PG) to identify the thermal effects associated to the presence of the marble or granite in the clay mass;
– and finally to firing experiments and determination of the bending stress of fired specimens, for determination of the effect of the additives on the mechanical strength of fired clays.

The obtained results were tested (5% significance level) to see if the differences in the results were statistically significant. These experiments were carried out with the CIMOC and OUA clays. Both clays are used in the industrial production of bricks. The OUA clay is an excessively plastic clay, which is industrially processed only after addition of low plasticity clay to reduce its plasticity.

Results and Discussion

Mineralogical Composition

The results of the mineralogical compositions are presented in Table 1. Marbles are basically composed of calcite (1–96%) and dolomite (4–90%), which are present in variable

Table 1. Mineral composition of marble and granite samples used in this study

Mineral	Granite P. São Gabriel	Granite Prata	Granite Preto	Granite Green Sea	Granite Castanho	Granite Vermelho Brasil	Marble Estremoz	Marble Branco	Marble Imp Marron	Marble Cinzento
Calcite	1.38	1.29	0.0	0.94	2.04	1.45	96.33	3.29	5.29	9.34
Dolomite	0.0	0.0	0.0	0.0	0.0	0.0	3.67	92.27	91.09	74.81
Biotite	60.23	21.53	0.0	10.61	10.37	18.0	0.0	0.0	0.0	0.0
Chlorite	0.0	2.03	0.0	0.0	0.0	2.29	0.0	0.0	0.0	0.0
Diopside	3.21	3.07	8.26	3.81	6.8	5.5	0.0	0.0	0.0	0.0
Entstatite	0.0	0.0	14.31	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hornblende	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.85
Magnetite	0.0	0.0	1.85	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Microcline	11.21	31.33	4.08	3.43	17.7	13.57	0.0	0.0	0.0	0.0
Muscovite	0.0	0.0	2.24	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Plagioclase	18.73	17.42	67.69	11.17	31.47	22.1	0.0	4.45	3.62	3.0
Quartz	5.24	23.33	1.58	70.03	31.63	37.09	0.0	0.0	0.0	0.0

quantities, resulting in marbles rich in calcite and others rich in dolomite. They show additionally components like plagioclase (in contents varying from 0–6%) and hornblende (only in gray marble).

Granites present as main components biotite, with contents varying from 0-9%; microcline (3–32%), plagioclase (10-67%) and quartz (2-70%). The two clays used in this work are typically composed by silica (%) and alumina (%). Ca, Mg, Ti, K and Na oxides are present as minor components.

Thermal Analysis

Thermal behaviour of OUA clay before and after granite and marble residues inclusion is shown in Fig. 1(a). TG curve of parent clay shows a small mass loss between 20 and 100°C which can be attributed to absorbed water. The intense mass loss (8%) observed above 100°C is assigned to volatiles in the clay sample. Addition of granites as resulted in reduction of volatiles content therefore reduced mass loss. Marble addition as resulted in increased mass loss due to carbonates decomposition, with maximum at 680°C. DTA curve, not shown here, depicted an exothermic transformation consistent with mullite formation [8,10].

Plasticity Experiments

The results of the effect of marbles and granites on the plasticity of the CIMOC and OUA clays are presented in Figs. 2 and 3 respectively. In Fig. 3 amount of additive goes up to 40%, because OUA clay is more plastic and is normally processed with an additive to reduce its plasticity. While results obtained from experiments carried out with the CIMOC clay show no regular decrease of plasticity with higher contents of additives, OUA clay show a decrease of plasticity with increasing amounts of additives.

Statistical treatment of CIMOC results shows that the effect of marbles and granites cannot be easily grouped in each of the two types of additives. Some marbles differ from other marbles but do not differ necessarily from the granites. This behaviour is found also

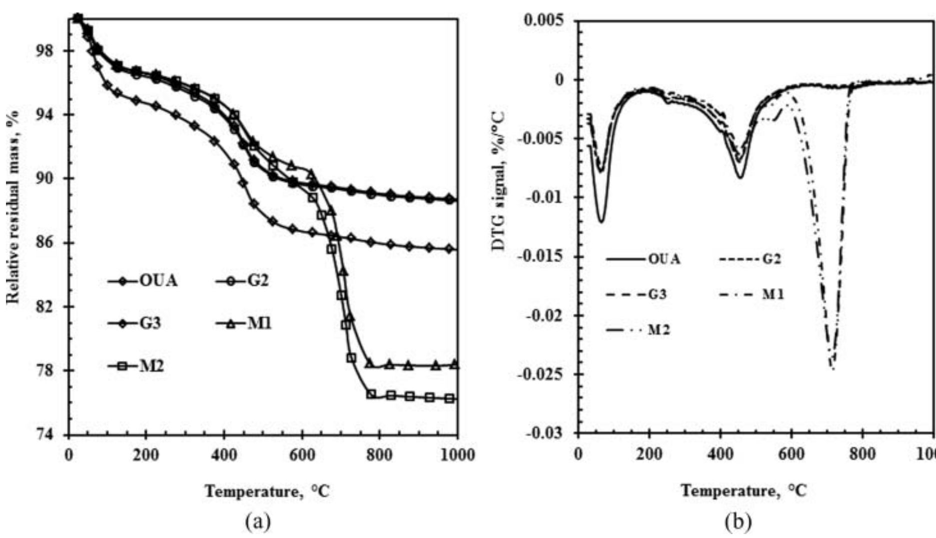

Figure 1. Thermal behaviour of OUA clay. (a) TG, and (b) DTG.

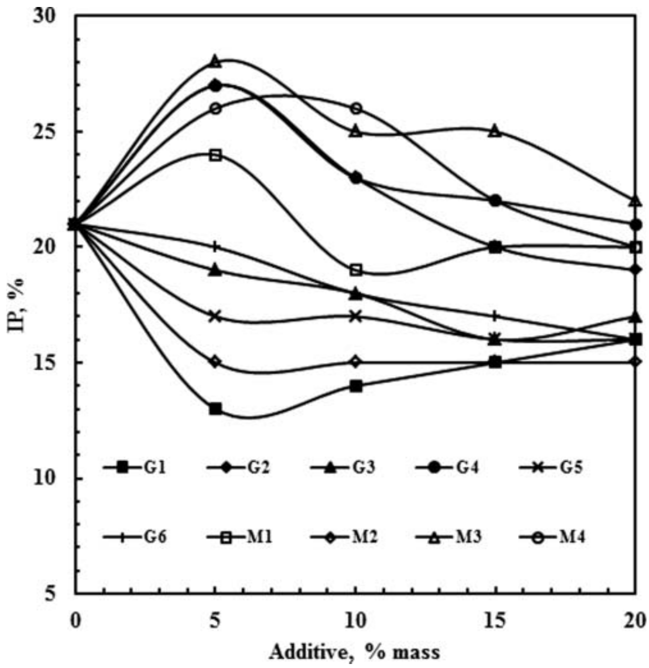

Figure 2. Effect of additives on the plasticity of the CIMOC clay.

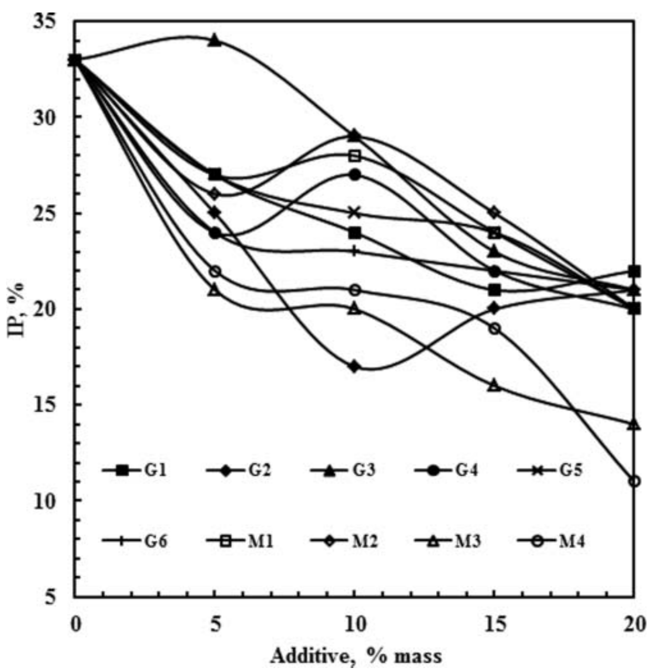

Figure 3. Effect of additives on the plasticity of the OUA clay.

within the granites, showing that no simple or linear relation can be derived hereby. CIMOC clay shows no significant differences between the different amounts of additives tested with this clay.

OUA clay gives a different picture: It shows no significant differences between the different additives tested, but statistically significant differences between the different amounts of additives added to the clay. This result is more desirable since it shows that a mixture of a residue composed of different marbles and granites with varying compositions would give results which are statistically not different from each other.

Mechanical Strength of Fired Specimens

Mechanical strength of fired specimens was tested on specimens fired at temperatures between 850 and 1050°C. On these experiments two marbles (Branco and Estremoz) and three granites (Preto São Gabriel, Prata and Preto) were used as additives.

Bending strength of fired CIMOC clay masses with increasing amounts of additives does not show regular increases or decreases. The typical behaviour of CIMOC clay masses with different additives is represented in Fig. 4.

The statistical treatment of obtained data shows that in general a) marbles differ from granites but do not differ from other marbles, while b) granites differ from marbles but do not differ from other granites. Granite Preto São Gabriel represents here an exception since its effect does not differ from that of any other samples used in these experiments (see Table 2).

Fired OUA clay masses show a nearly linear increase on the bending stress with increasing amounts of additives (Fig. 5). Data in Fig. 5 start from 10% additive and do not include pure OUA clay (0% additive) because wet moulded OUA develops easily cracks.

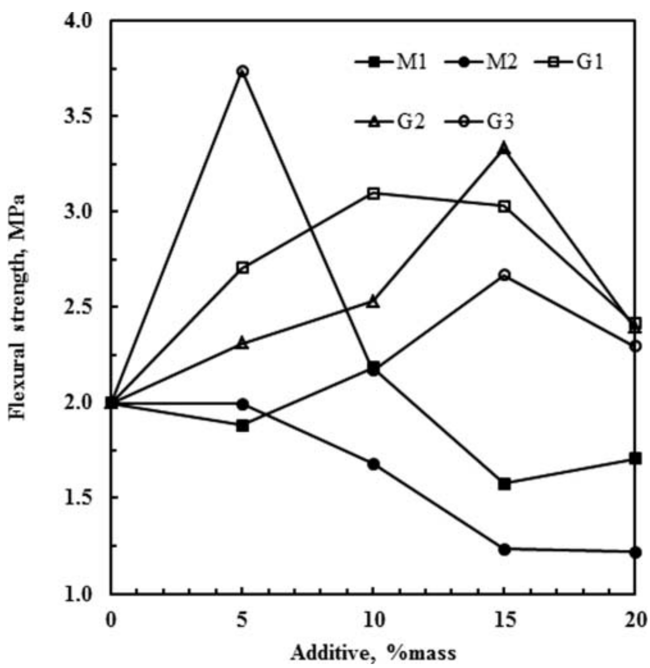

Figure 4. Bending stress of CIMOC clay masses, fired at 1000°C, with increasing amounts of additives.

Table 2. Statistical comparison of the effect of different additives on the bending stress of CIMOC clay masses. Samples were fired at 850, 900, 950, 1000 and 1050°C

Additive	Do not differ from	Differs from
Granite Preto São Gabriel	Marbles Branco and Estremoz; Granites Prata and Preto	—
Granite Prata	Granites Preto São Gabriel and Preto	Marbles Branco and Estremoz
Granite Preto	Granites Prata and Preto São Gabriel	Marbles Branco and Estremoz
Marble Estremoz	Marble Branco and Granite P. São Gabriel	Granites Prata and Preto
Marble Branco	Marble Estremoz and Granite P. São Gabriel	Granites Prata and Preto

Statistical comparisons of data obtained for OUA clay with additives showed that the different marbles and granites gave results with no significant differences (see Table 3). The same behaviour was obtained for the different firing temperatures and the different amounts of additives.

Although CIMOC and OUA clays show different behaviours, fired specimens of both clays, with the various compositions prepared hereby, showed values of the bending stress

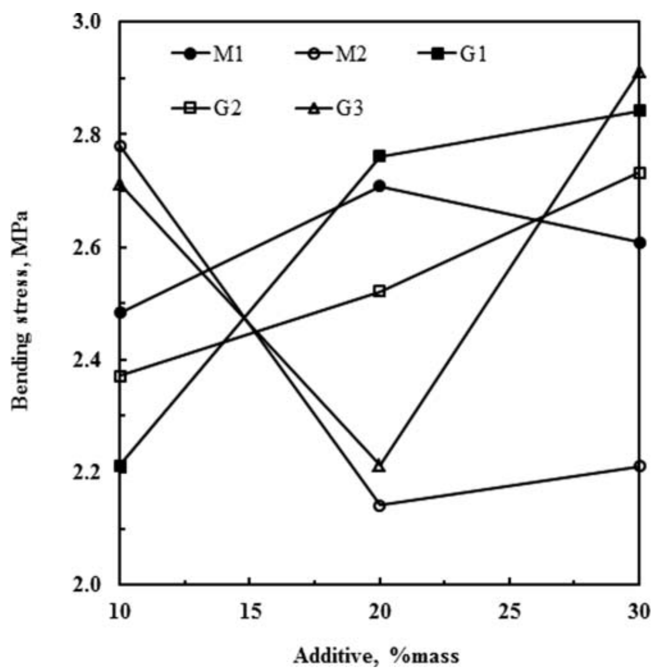

Figure 5. Bending stress of OUA clay masses, fired at 1000°C, with increasing amounts of additives.

Table 3. Statistical comparison of the effect of different additives on the bending stress of OUA clay masses. Samples were fired at 850, 950 and 1000°C

Additive	Do not differ from	Differs from
Granite Preto São Gabriel	Granite Prata, Granite Preto, Marble Estremoz, Marble Branco	—
Granite Prata	Granite Preto São Gabriel, Granite Preto, Marble Estremoz, Marble Branco	—
Granite Preto	Granite Preto São Gabriel, Granite Prata, Marble Estremoz, Marble Branco	—
Marble Estremoz	Granite Preto São Gabriel, Granite Preto, Granite Prata, Marble Branco	—
Marble Branco	Granite Preto São Gabriel, Granite Preto, Marble Estremoz, Granite Prata	—

above the minimum values prescribed in norms and testing procedures used in Mozambique for these materials [11].

Conclusions

Results presented in the previous section show that the additives used in these experiments have a more beneficial effect on OUA clay than on CIMOC clay. This is a desirable situation since OUA clay is an excessively plastic clay, which is industrially processed under addition of a low plasticity clay, to reduce its plasticity.

The statistical treatment of results from plasticity and bending stress experiments with the OUA clay shows no significant differences.

Since OUA clay is presently processed with an additive, it would be interesting to compare the effect of the additive presently used during the industrial processing of OUA clay (the low plastic clay), with that of the multi-component residues, with varying and unknown compositions, resulting from processing of the marbles and granites as described in this study.

Acknowledgments

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