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Waste Minimisation of Ceramic Wall Tiles

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Many wastes are commonly produced during the ceramic tiles manufacturing process such as: Roller kiln grinding waste, cyclone dust waste, and ceramic sludge. Those wastes are landfilled because they have been predictable to be less conducive to recycling. In this study, the recyclability of the mentioned wastes is enhanced to minimize natural resource consumption, save energy, reduce cost and decrease hazards to the surrounding environment. Three types of collected wastes were added in different ratios to a standard wall tile mix and factorial 2^3 design techniques was used to investigate the effect of adding these wastes in different ratios on the properties of unfired and fired bodies. Suggested recipes were shaped in standard tile form, dried and fired at 1,160 °C for 15 min. Tests performed on these tiles revealed that they abide by standard requirements for ceramic wall tiles.

1. Introduction

Construction and demolition waste are in continuous increase in parallel with the economic growth especially in the emerging and developing countries (Mah et al, 2017). Waste minimization is a very important topic from the public health, the environmental and industrial perspectives. In fact, the reutilizing of waste produced from a given industry as raw materials for the same product is the supreme beneficial waste management method, which is the trend of this work.

Generally, ceramic tiles production has shown a great rate of growth in recent years. In Egypt, tile production was 20 M m^2 in 1996, while it reached 83 M m^2 in 2004 with a growth of more than four folds (> 400 %) (Giacomini, 2005). Egypt manufacturing output reached 200 M m^2 in 2009. Egypt produces, Consumes, and exports more tiles than any other African country (El Nouhy, 2013)

As early as 1991, Manfredini et al (1991) has suggested minimizing the pollution due to ceramic sludge by rationalizing the addition of waste waters and sludge in tile production processes. The analytical and rheological results, obtained on the body slips used for "white gres" tile production in waste purified waters demonstrated that the addition of dried sludge up to 5 % by weight makes the slip completely compatible with industrial requirements.

The possibility of addition of roller kiln waste has been studied by Roushdy et al. (2014) who successfully used the fine waste obtained from grinding of rollers of the firing kiln as an addition to wall tiles bodies. They concluded that adding of 1 to 2 % of that waste to a standard wall tiles mix produced tiles abiding by Standards and helps eliminating a hazardous waste.

Waste minimization in the ceramic industry in the preparation of ceramic floor tiles in the same factory was studied by García-Ten et al (2016), where green scrap, fired scrap, dust from kiln cleaning filters, polishing sludge, glaze sludge and frit residues were added to the base body. Characterization of the composition indicated that it displays appropriate behaviour in the different production process stages and exhibits the required properties for use as urban flooring.

This research aims at investigating the possibility of substituting part of the main body mix of wall ceramic tiles by some wastes produced during manufacturing. The chosen wastes are: Roller kiln grinding waste, Cyclone dust waste, and ceramic sludge waste obtained from the water treatment unit.

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2. Methods

2.1 Raw materials characteristics

Four types of material were used; all of them kindly supplied by Ceramica Venus factory, 10th of Ramadan City, a Cairo industrial suburb. Those materials are Ceramic wall tiles basic mixture, the composition of which is displayed in Table 1, Cyclones dust waste, Sludge waste obtained from the water treatment unit of the factory and Roller kiln grinding waste.

Table 1: Raw Mix Tiles Body Composition

Percent	Aswan clay	Kaolin clay	Ball clay	Bentonite	Feldspars	Sand	Lime stone
Wall tile mix	36	9	10	1.5	25	9.5	9

The mineralogical composition of the four materials used was assessed using X-ray diffraction (Brukur D8advanced computerized X-ray diffractometer apparatus with mono-chromatized Cu Kα radiation, operated at 40 kV and 40 mA).
On the other hand, their chemical composition was determined using X-ray fluorescence technique type. The used machine was Axios, Panalytical 2005, wavelength dispersive (WD–XRF) sequential spectrometer.
The grain size distribution was determined according to the standard sieving procedure described by ASTM D 422 (ASTM D 422, 2016)
Finally, the powder densities of basic mixture of floor tiles (raw mix) and the selected wastes were measured using the standard Pycnometer method (density flask). This method is a very precise procedure for determining the density of powders, granules and dispersions that have poor flowability characteristic (ASTM D 311, 2016).

2.2 Preparation of samples

Samples were prepared by grinding the sludge waste using a laboratory ball mill fitted with alumina balls. Fine waste powder of cyclone dust and roller kiln waste was then added in predetermined levels. This mix was used to replace part of the basic mixture for wall tiles. A 2^3 factorial design matrix was established to determine the proportions of wastes to be added. Eight mixtures were thus prepared besides three at the central of design were prepared (Lazic, 2004). These mixtures were mixed on dry basis for 10 min for each sample after which 5 – 7 % by weight water was added. The plasticity of the different blends was determined using the Pfefferkorn method (De-Andrade, 2010)
Rectangular tile specimens of approximate dimensions 111 × 57 × 7 mm^3 were molded by using an automatic laboratory hydraulic press, under uniaxial pressure of 25MPa. The samples were then dried in a muffle dryer for 5 h at a temperature of 145°C.
Samples were subsequently fired in a laboratory muffle furnace following a programmed schedule that takes into account the evolution water from the dehydroxylation of kaolinite by fixing the temperature at 750° C for 30 min. The maximum temperature attained was 1,160°C with a soaking time of 15 min to simulate fast firing conditions.
The following tests were performed to determine the characteristics of fired samples: Percent linear firing shrinkage (ASTM C 326, 2016), percent water absorption and apparent porosity (ASTM C 373, 2016) and breaking strength and modulus of rupture (ISO 10545 – 4 / 2014).

3. Result and discussion

3.1 Raw materials analyses

Chemical composition

XRF results for all raw materials are shown in Table 2.
As can be seen from that table, roller kiln waste contains a relatively high proportion of alumina. This is expected in view of the refractory nature of the rollers required to withstand temperatures exceeding 1,150 °C.

Mineralogical analysis of raw materials

The wall tile raw mix XRD pattern has been studied by Amin et al. (2012) who found that the mix is mainly composed of the following phases: Quartz, albite, calcite and kaolinite. On the other hand, the phases constituting wall dust main are quartz and albite (Nagy, 2016). As investigated by El Mahgary et al. (2017), waste sludge is composed of a mixture of all ingredients constituting the raw mixes for wall and floor tiles namely, kaolinite ($Al_2O_3.2SiO_2.2H_2O$), quartz, microcline ($K_2O.Al_2O_3.6SiO_2$), calcite ($CaCO_3$) and albite

($Na_2O.Al_2O_3.6SiO_2$). As for mineralogical analysis of the roller grind waste has been previously investigated by Ibrahim (2009) who found that the waste is solely constituted from alumina and mullite.

Table 2: Chemical analysis of raw materials (Weight %)

Main constituents	Sludge waste	Wall Dust waste	Roller kiln waste	Wall mix
SiO_2	67.38	61.29	23.55	55.51
TiO_2	0.65	0.74	0.33	0.91
AlO_3	15.35	14.67	63.86	19.73
Fe_2O_3tot.	4.25	2.8	1.16	5.10
MgO	0.79	0.32	1.96	0.40
CaO	2.57	8.26	3.51	5.15
Na2O	2.75	1.6	0.8	1.43
K_2O	1.43	2.1448	0.	1.17
ZrO_2	0	0.044	3.45	0
ZnO	0	0.025	0.22	0
CuO	0	0.007	0.22	0
P_2O_5	0.19	0.14	0.17	0.23
SO_3	0.14	0.44	0	0.31
Cl	0.03	0.07	0	0.09
Minor oxides	0.276	0	0.18	0.284
LOI	4.18	7.37	-	9.68
TOTAL	99.986	99.916	99.89	99.994

Screen analysis of raw materials

Following screen analyses performed on the dry raw materials, the median (D_{50}) values were obtained, as indicated in Table 3.

Table 3): Median particle size of the raw materials

Powder	Wall mix	Wall dust	Roller waste	Sludge
D50 μm	425	13.72	225	75

This table demonstration that cyclone wall dust is by far the finest fraction of the raw materials used whereas the wall mix is the coarsest.

Powder density

The powder densities of sludge waste, roller kiln waste, wall dust waste, and wall tiles mix were found to equal 2.35, 2.92, 2.57 and 2.28 $g.cm^{-3}$. The elevated value of density of roller kiln waste is due to its high alumina content.

3.2 Properties of unfired wall tiles samples

Composition of chosen samples

Following the 2^3 factorial design procedure, the following mixes were selected including as previously mentioned three identical mixes at centre of design.

Effect of wastes addition on drying shrinkage

On adding the three wastes to the basic wall mixture, it was found that the drying shrinkage did not take place uniformly in the three dimensions. That is why it was thought preferable to substitute the volume shrinkage (VDS) for the linear one. The results attained are summarized in Table (5). The correlation table (Table 6) shows that addition of roller waste is the most influential factor affecting drying shrinkage. This is due to its high alumina content. On the other hand, the effect of dust is generally low to moderate while sludge hardly affects it at all.

Table 4: Selected Mix compositions

% Sludge	% Dust	% Roller waste	Wall mix
0	0	0	100
10	0	0	90
0	5	0	95
10	5	0	85
0	0	2	98
10	0	2	88
0	5	2	93
10	5	2	83
5	2.5	1	91.5
5	2.5	1	91.5
5	2.5	1	91.5

Effect of wastes addition on green strength

There is no recommended figure for green strength (or alternatively, modulus of rupture) although values of MOR lower than 1 MPa are commonly associated with the occurrence of minor losses on handling. Table 5 indicates that for all wastes addition the MOR is above this recommended value.
From the correlation table, table (6), sludge addition is the most influential factor on green strength as it contributes negatively to diminishing this strength. The same effect is observed on adding roller dust but to a slighter extent. This is presumably due to the presence of large amounts of non-plastic feldspar and quartz in sludge as well as the non-plastic nature of roller kiln dust. A slight positive inference is observed for fine dust because of its extreme fineness

Table 5: Properties of unfired samples

%Sludge	%Dust	%Roller waste	%wall mix	% VDS	Breaking strength, N	Green MOR, MPa
0	0	0	100	0.963	97.500	3.180
10	0	0	90	1.399	154.350	3.950
0	5	0	95	0.962	179.600	4.600
10	5	0	85	1.138	146.600	3.750
0	0	2	98	0.787	128.390	3.570
10	0	2	88	1.049	142.450	3.625
0	5	2	93	1.138	184.500	4.605
10	5	2	83	0.962	138.200	3.055
5	2.5	1	91.5	0.874	119.965	3.330
5	2.5	1	91.5	1.399	122.800	3.185
5	2.5	1	91.5	1.136	97.500	3.180

Table 6: Correlation coefficients for unfired mixes

	Sludge	Dust	Roller
% VDS	0.104	0.359	-0.600
MOR	-0.321	0.343	-0.127

3.2 Properties of fired wall tiles samples

Effect of wastes addition on linear firing shrinkage (LFS)

On simultaneously adding the three different wastes according to the present scheme, a relatively high shrinkage was observed, particularly for samples containing high amounts of sludge. On other hand, a relatively low shrinkage was observed for samples containing high levels of roller waste. The reason is associated with the presence of a high alumina which limits or decreases the formation of a liquid phase which in turns favours a low firing shrinkage. The dust has a very low effect comparing to that of sludge and roller waste (Table 9).

Effect of wastes addition on percent water absorption (WA)

The results of percent water absorption obtained for the different mixes including three replicate runs at center of design are displayed in Table (7). Except for two mixes, these can be considered to correspond to the tiles category with % WA >10.
Table (8) illustrates the correlation table between percent water absorption and each of the three wastes levels. Here also, the percent sludge plays the most important role in assessing water absorption while the role of any of the two other additions is relatively modest.

Effect of wastes addition on mechanical strength

As per standard specifications, two requirements have to be met for the mechanical properties of wall tiles: the breaking "strength" (*BS* N) and the bending strength (or Modulus of Rupture MOR MPa).
According to ISO13006/2012, the breaking strength for wall tiles of thickness less than 7.5 mm and of water absorption>10 % should exceed 200 N whereas the minimum MOR = 12 MPa. For a percent water absorption < 10%, the corresponding figures are 500 N and 16 MPa.

Table 7: Properties of fired samples

% Sludge	% Dust	% Roller waste	wall mix	% LFS	% WA	Breaking strength N	MOR MPa
0	0	0	100	0.963	10.001	473.369	16.301
10	0	0	90	1.399	9.688654	616.961	16.022
0	5	0	95	0.962	10.95512	639.292	17.048
10	5	0	85	1.138	11.17824	674.956	17.300
0	0	2	98	0.787	11.31355	637.743	17.236
10	0	2	88	1.049	10.27463	631.095	16.607
0	5	2	93	1.138	10.51651	714.488	17.616
10	5	2	83	0.962	9.546403	790.106	17.843
5	2.5	1	91.5	0.874	15.27392	646.479	17.472
5	2.5	1	91.5	1.399	13.003	646.372	17.237
5	2.5	1	91.5	1.136	12.19859	646.425	17.354

Table 8: Correlation coefficients for unfired mixes

	Sludge	Dust	Roller
% LFS	0.398	0.002	-0.300
%WA	-0.139	0.061	-0.011
B.S	0.367	0.679	0.545
MOR	-0.085	0.726	0.525

As evidenced by the results in Table 7, addition of 10 % sludge, 0 or 5 % dust and 0 or 2 % roller grinding waste result in wall tiles abiding by ISO13006/2012 for tiles with water absorption < 1 0%, while all recipes satisfy the standard requirements for wall tiles with water absorption > 10 %.

4. Conclusions

Some wastes generated in a ceramic factory such as cyclone dust, ceramic sludge, and the fine powder obtained on grinding kiln rollers were reused in the preparation of ceramic tiles at the same factory. The three selected wastes were added to standard wall mix in predetermined levels according to a factorial design 2^3 scheme. The samples were formed by dust pressing under a uniaxial pressure of 35 MPa, dried for 5 h at 145 ^oC then subsequently fired for 15 min at 1,160 ^oC to simulate industrial conditions.
Green and fired properties were determined and the steepest descent technique used to choose a mix of minimum water absorption. Mechanical properties were measured (Breaking Strength and MOR) for the selected recipes and the results in all cases satisfied the Standards.

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