The usage of different sludge wastes in the manufacture of ceramic tiles

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Abstract— Sludge wastes produced from different sectors such as construction, industries and urban. About 1.3 billion tons of different sludge wastes produced per year in Europe. Disposal and landfilling of these wastes become unuseful to the environment. The strict conditions and requirements of environmental protection in different countries prompted the necessity to find a safe alternative to dispose of these sludge wastes, from an environmental point of view and also to use it as an alternative to the much more expensive raw materials that serve sustainable development and saves limited resources for future generations. Recycling of these materials could be a good disposal solution. Sludge wastes can be used as secondary raw material in the manufacturing of ceramics such as wall, floor and roof tiles. This paper aims to review the effect of utilizing different types of sludge waste materials in the manufacturing of ceramic tiles on their properties.

Keywords: Sludge wastes, Recycling, Ceramic, Tiles, Environmental

1 Introduction

Nowadays different types of sludge wastes (construction, industries, urban. etc.) have been increased due to the growth and the variety of the industries, Despite the management regulations of waste internationally and nationally that have been carried out and adopted. To realize the problem, Europe only for example produces about 1.3 billion tons of a variety of different sludge wastes per year, which comes mainly from the manufacturing industries and mineral processing. This quantity shows that it has a significant severe impact on the environment.

The dumping, landfilling and usual waste disposal methods of different sludge wastes have become not useful for the surrounding environment, as its negative impact pollution arises in many ways like soil, water and air pollutions besides the cost of disposal is very high so the suitable solution must take into consideration to manage the sludge wastes properly.

The idea of dealing with the sludge wastes as a raw material for other industries shows up with saving natural resources. The incorporation of different sludge wastes into red ceramic is nowadays an environmental precise solution. This approach has been already attempted with different degrees of success in the manufacture of several types of building ceramic products. Various efforts were exerted to utilize various waste sludges in ceramic tiles production such as sewage sludge, marble sludge waste, ceramic sludge waste, perlite, paper sludge waste, petroleum oily sludge waste, fine steel sludge waste and sludge waste from the natural rubber manufacturing process. This review highlights the effects of various sludge waste materials on the building ceramic materials' property like mechanical and physical properties. sludge waste materials on the building ceramic materials' property like mechanical and physical properties.

2 Review of Literature Works

2.1 Development of Ceramic Tiles from Sewage Sludge Waste

Jordan et al. (2005) investigated a comparative study to produce ceramic tiles using different percentage of sewage sludge ranging from 0 to 10% produced from different sources of a wastewater treatment plant. They found that due to partial replacement of sludge, the soluble salts (Cl^- and SO_4^{-2}) slightly increased due to the low percentage of replacement. They also found that increasing the waste percentage increase water percentage and decrease the bending strength due to oxidation of organic matter present in sewage sludge during firing which leads to increase the presence of the open pores in the ceramic bodies. [1]

Cusido et al. (2003) studied the emissions produced from the utilization of urban sewage sludge in the production of ceramics without any treatment as a raw material. They monitored the volatile organic compound (VOC) using a bench-scale furnace. The produced emissions from firing the sewage sludge were compared with those produced from firing the conventional clay using gas chromatography. The results showed that acetic acid, carbon disulfide, benzene, toluene and 2-2 dimethyl pentane produced during firing are much lower than the legal limit. On the other hand, the emissions produced from the heavy metals are higher than those produced from the conventional firing of ceramics. They also found that HCl is most significant in the production of ceramics due to the presence of chlorine in the sludge accompanied with the treatment of wastewater. [2]

Cermades et al. (2018) examinated the possibility of using spray-dried sludge producing from drinking water treatment plants in the production of ceramic tiles. Clay and spray dried sludge were mixed in presence of 5% wt. of water as a binding agent with different percentages of sludge ranging from 0 to 70% wt. to produce rectangular specimens with cross-sectional area 70 x 10 mm^2. The specimens were fired at temperature 980°C at soaking time 3 hours. They found that increasing the percentage of sludge increasing the presence of the open pores in the ceramic samples. They also found that using drinking sludge doesn't cause any pollution problems which verified using leaching test NEN-7345 and accelerated degassing test PSS-01-702 and PSS-01-729 according to the standards of the

European Space Agency. It was proved that the addition of sludge up to 40% can be used in regions with frost cycles while 70% sludge addition can't be used on the surface exposed to the environment. [3]

On the other hand, Ferreiraa et al. (2017) investigated the possibility of using sludge from the treatment of wastewater produced from a poultry slaughterhouse in the production of ceramic tiles. They used this sludge in 2% and 4% wt. as a partial replacement of the ceramic mass. They found that the apparent density of specimens contains sludge is lower than the standard ceramic mass and increasing the firing temperature above 940°C, decreasing linear firing shrinkage and water absorption. They also found that using 2% wt. of sludge as a partial replacement will reduce the fuel consumption required in the manufacturing of ceramics as a result of the exothermic combustion of organic compounds present in the sludge at a temperature ranging from 350 to 550°C. [4]

Monterio et al. (2008) explored the possibility of using the sewage sludge produced from the water treatment plant in the production of red ceramics consists mainly of kaolinite clay. They prepared mixtures with different percentages of sludge 0,3,5 and 10% wt. incorporated in the ceramic body. Rectangular samples were pressed uniaxially at 20 MPa and then fired at different firing temperatures ranging from 700 to 1100°C. They found that increasing the waste addition increase the water absorption and decrease the mechanical strength of fired ceramics as a result of the presence of pores produced from the oxidation of organic matter in the sludge at firing stage. They also found that the waste can be recycled into red ceramic manufacturing up to 10% wt. to meet the standard specifications of ceramics. [5]

Teixerira et al. (2011) investigated the incorporation of the sludge produced from the water treatment plant into the manufacturing of the ceramic roof tiles. The samples with different percentages ranging from 0 to 20% wt. of sludge were replaced with the clay, they fired at different firing temperature ranging fro 850 to 1200°C. The results showed that 10% wt. of sludge can be used in solid bricks at firing temperature lower than 1000°C while up to 20% wt. of sludge can be incorporated in the production of roof tiles to meet the standard specification. [6]

Amin et al. (2018) utilized municipal sewage sludge that contains many dangerous of toxic heavy metals and pathogens which collected from domestic, hospitals and industrial plants in the production of floor tiles. Ceramic specimens were prepared with different percentages of sewage sludge ranging from (0 to 35% wt.) by increasing 5% to a standard basic floor mixture. The specimens were moulded and fired at a temperature ranging from 1050 to 1150°C with soaking time 15 minutes. Different properties were measured to determine the quality of the produced floor tiles. They found that the maximum waste addition of sewage sludge is 7% wt. at firing temperature 1150°C to match the standard specifications required for ceramic floor tiles. [7]

Zhoua et al. (2013) studied the effect of using municipal sewage sludge (MSS) without any treatment in the production of split tiles. The specimens were prepared with different percentages of waste ranges from 50 to 65% wt. as a partial replacement of the basic mixture which fired at different temperatures varying from 1150°C to 1230°C. They found that the optimum waste addition is 60% wt. of MSS at firing temperature 1210°C that have bending strength of 25.5 MPa and low water absorption of 1.14 %wt. to meet the standards of fine-grade split tiles according to ISO 13006:1998. [8]

Lin et al. (2007) discussed the effect of partial replacement of incinerated sewage sludge ash (ISSA) in the manufacturing of glazed tiles with four different proportions of ISSA ranging from (0 to 45% wt.). They fired the samples at 800°C then four different concentrations of colorants were applied on the biscuit tile samples, followed by sintering at 1050°C. They found that water absorption and bending increases with increasing of sludge addition. They also found that the abrasion of glazed tiles reduced from 0.001 to 0.002g which enhance the abrasion resistance of tiles. [9]

Ciarán et al. (2016) studied the usage of sewage sludge ash (SSA) in the production of ceramic tiles. They found that the SSA has a similar chemical structure of ceramic materials such as (SiO_2, Al_2O_3 and CaO) and also after sintering vitrification takes place. As a resulting of the fluxing properties of SSA, it reduces the firing temperature of ceramic production and also reduces the plasticity of the mixtures which leads to an increase in the amount of water required for forming. They also found that SSA can be used for glazed and unglazed tiles up to 50% wt. which decrease the water absorption. The abrasion resistance was satisfied for all percentages of waste addition, while ageing resistance and firing shrinkage was not affected by waste addition. Due to the thermal treatment and the nature of ceramic product leads to decrease the heavy metals leaching to the lowest level. [10]

2.2 Development of Ceramic Tiles from Marble and Granite Sludge Waste

Al-Hamaiedh, (2010) studied the changes in the physical and mechanical properties of ceramic tiles formed from raw materials containing marble sludge slime resulted from the decorative stone processing industry in Jordan. The results demonstrated that the partial replacement for kaolin, $CaCO_3$ and feldspar by the marble sludge slime produced a deformation of the plane for the formed tiles. Though, the replacement of the bentonite using sludge slime keeps the mechanical strength for the formed tiles unchanged and decreased their shrinkage values from 1.66% to 0.5 %. The results existing in this paper reveals that all the produced sludge slime could be consumed effectively in ceramic manufacture, that would reduce the expensive managing of the deposits with landfill and reserve an equivalent quantity of natural resources (bentonite); thus, environmental sustainability will be improved. [11]

Hojamberdiev et al. (2010) examined the effect of muscovite granite waste on the physio-mechanical properties for ceramic tiles to prove its fitness for industrial production. A set of facing - and flooring tiles were formed by the addition of 20, 25, and 30 wt% muscovite granite waste to the compositions. Degrees of densification together with the sintering performance of two classes of ceramic tiles were estimated by characterizing them and determining their physio-mechanical properties using X-ray diffraction and scanning electron microscopy, respectively. Unsurprisingly, it has been found that facing ceramic tile sample, having wollastonite, quartz, cristobalite, hematite, and anorthite, with 20 wt% muscovite granite waste displayed lesser physio-mechanical properties than the sample, containing cristobalite, mullite, quartz and calcium aluminosilicate, with 30 wt% muscovite granite waste. To discuss this result, the low firing temperatures were found to be the main cause as it could not fast-track a complete blend of granite waste that behaves as an inactive non-plastic material like quartz. These results demonstrate the projections of using muscovite granite waste in ceramic tile manufacture. [12]

Torres et al. (2009) studied the incorporation of sludge from ordinary rock polishing and cutting to prepare roof tiles. The sintered products including the sludge were embattled to have comparable or even improved properties in comparison to tiles made from a standard reference dough industrially used to manufacture concurrent products presented in the marketplace. The raw materials, including the used sludge, were characterized for their X-ray diffraction (XRD), thermal properties, particle size distribution, loss on ignition and density. Different preparations were formed to evaluate the influence of each constituent on firing processes, drying, plasticity of pastes, and on the ultimate properties of the tiles. At last, the most promising preparations were formed and characterized for water absorption, flexural bending strength, and sintered density. The obtained results made it conceivable to accomplish the possibility of manufacturing roof tiles by utilizing10% of granite wastes having superior properties (bending strength values of about 14 MPa, water absorption <6%, 38 MPa for the green and sintered products, and lower pyroclastic deformation index). Thus, the sludge resulted from the granite cutting and polishing processes can be categorized as a by-product appropriate to substitute natural non-plastic raw material used in the traditional ceramic preparations. This will contribute in the preservation of non-renewable resources; thus, it allows minimizing the negative environmental influence due to its discarding. [13]

Torres et al. (2004) incorporated granite residue in the form of sludge, resulted from granite cutting manufacturing in the batch preparations of porcelain tiles. The extreme possible replacement of sludge for feldspar was studied. Samples of various formulations, in the form of spherule, were prepared at both laboratory and pilot-plant scales and assessed along with all the phases of the manufacturing process. The optimal percentage for the used raw materials and firing temperature about 1180°C, the produced porcelain items comply with the nearby ISO standard (13006, Group B-I), also can display much better properties when comparing to mercantile porcelains, according to flexural strength, widening of sintering range and water absorption. The experimental results in addition to their theoretical explanation show that appropriate incorporation for granite sludge can yield porcelain tiles with characteristics, in terms of water absorption (0.07%) & bending strength (>50 MPa). Sludge utilization had an insignificant effect on, shrinkage, plasticity and density during all phases of the tile-manufacturing process, expecting no variations in the industrial manufacture line. [14]

Torres et al. (2007) investigated the industrial sludges resulted from cutting and polishing stones (quartzite and granite) with respect to particles size distribution, mineralogical and chemical composition together with thermal behaviour and their potential to be utilized as a main component in red-clay-based tiles was assessed. High levels of utilization about (60–70 wt.%) were tried aiming at manipulating new formulations proposed to be cost-effective and possess better ultimate properties (lesser water absorption and better flexural strength) when it is compared to a manufacturing reference body practice in the manufacturing of rustic tiles through extrusion, with characterization, 8–9% water absorption and flexural strength of 17–18 MPa. Extruded bars of various formulations were shaped and fired at 1100°C, 1125°C, 1150°C and 1200°C. The experimental results presented all the formulations accomplished better with the greatest significant improvements as it is obtained with the utilization of granite sludge. Flexural strength values higher than triplicate and water absorption reduced by more than 1 order of magnitude if it is compared to the reference paste. Formed products satisfy the requirements of the ISO 13006 standard. [15]

2.3 Development of Ceramic Tiles from Ceramic Sludge Waste

Kizinievic et al. (2013) analyzed the effect of the addition of water treatment sludge (WTS) on the mechanical and physical properties, structural parameters in addition to the mineralogical composition of the ceramic products. It was specified that the main water treatment sludge component is amorphous Fe2O3. The magnitude of the water treatment sludge particles reaches 138 μm. Specimens were prepared by blending from 5% to 40% of water treatment sludge additive and firing temperature from 1000 0C to 1050 0C. Examination showed that the mechanical and physical properties of the ceramic products vary contingent upon the incorporation of the amount of the water treatment sludge: compressive strength, density and the relative wall thickness of the pores and capillaries decreases while the water impregnation and the effective porosity increase. It was found that water treatment sludge incorporation, generally composed from colorific Fe2O3, can be utilized as a pigment that dyes the ceramic product in darker, more concentrated red color. [16]

Amin et al. (2019) incorporated waste sludge, the deposit of ceramic manufacturing processes washed down particles, constitutes about 2 weight % of the ultimate products. The sludge comprises a water suspension of coarse particles (ground fired tiles, quartz and feldspar), fine particles (clay mineral deposits such as kaolinite) and glaze residue. The sludge was filtered off and then dumped or used in wet grinding of raw materials. In this research, the sludge was re-used in the production of wall and floor tiles. Ground and dried sludge waste were added in different percentages, from 5 % up to 50 % to standard floor and wall tile mixes, shaped, pressed at 30 MPa, dried and then fired at temperatures of 1180 °C for floor tiles and of 1160 °C for wall tiles with soaking time of 15 min. The green and fired tiles properties were studied as a function of the per- cent of the waste added. The vitrification parameters (apparent porosity, water absorption and linear firing shrinkage) in addition to the mechanical properties were specified and compared to ISO standards. The tile samples having the composition of the suggested mixtures were fired in a roller kiln and their properties were studied. Microstructure investigation of some fired sample was determined by scanning electron microscopy (SEM). The obtained tiles satisfied the ISO standards for sludge addition up to 20 % for the floor tiles and up to 10 % for the wall tiles. [17]

2.4 Development of Ceramic Tiles from Paper Sludge Waste

Nandi et al. (2014) valorized two wastes, classified as Class I on the word of the Brazilian Standard ABNT NBR 10004:2004 to have a ceramic engobe for the manufacturing of single-fire ceramic tiles. Ceramic sludge resulted from a wastewater treatment plant of a ceramic tile producer and recycled glass were used to get a frit to make the glass and sludge inactive in a vitreous matrix. Therefore, a representative quantity of the ceramic sludge was gathered, dried, and assessed by chemical analysis, X-ray diffraction, and thermal analyses (thermogravimetric, differential thermal, and dilatometric analysis). Moreover, the ceramic sludge was characterized along with the ABNT NBR 10004:2004. Seven preparations containing ceramic sludge content varied from 20 to 80 wt% and recycled glass content varied from 12 to 48 wt% and using dolomite, calcite, ulexite, and saltpetre as raw materials were settled. Each preparation was melted in a laboratory kiln at 1420 0C for 1 hr, and was discharged into the water at room temperature to yield frits. Each frit was crushed, and the coefficient of thermal expansion was measured using dilatometry. The results reveal that the studied ceramic sludge offered high contents of fluoride and barium. The main recognized crystalline phases were elite, zircon, a-quartz, and barium silicate. The coefficient of thermal expansion after thermal treatment was 5.6 * 10-6 0C-1. After it has been characterized, the probability of using these wastes as raw materials for the manufacturing of ceramic frits was assessed. The results of the glaze fluidity flow test, dilatometric analysis and visual analysis presented that the utilization of these wastes would result in the obtainment of ceramic frits for preparing ceramic engobes. Therefore, three preparations of engobe were made and heat-treated at 1150, 1165, and 1175°C. The engobes were assessed (XRD, microstructural analysis by optical microscopy, colourimetry, and determination of brightness) also showed appropriate properties for use in the manufacturing of ceramic tiles. Engobe E3, that presented the supreme ceramic sludge content, was carefully chosen for an industrial test. The results of the water spot test and visual analysis exhibited the investigated engobe, compared to a commercial engobe (engobe reference), could be used in the manufacturing of glazed ceramic tiles. [18]

Maschio et al. (2009) describes results attained in the progress of preceding research. The firing was studied together with the sintering performance and some properties of tiles comprised of a mixture of 40 wt% of glass cullet and 60 wt% of paper mill sludge were measured. The performance of this material is then compared to those shown by materials prepared using the same mix added with 10, 20 and 30 wt% of a normal red clay. Separately, the same properties are also measured on a reference mixture, which is currently used to yield commercial tiles. It has shown that these powders containing 40 wt% of glass cullet together with 60 wt% of paper sludge to which 30 wt% of clay is added give rise to materials that show a stable sintering procedure and have respectable strength and hardness and thus could be used for the industrial manufacture of tiles. [19]

Asquini et al. (2008) characterized the sintered ceramics produced from paper mill sludge and glass cullet. Three different sources of paper sludge were incinerated and then abrasion milled separately or mixed with glass cullet in different proportions to obtain powders of various compositions, dried, sieved, uniaxially pressed into specimens and sintered. The samples were characterized after being fired by strength, density, shrinkage on firing, fracture toughness measurements, water absorption and hardness; X-ray diffractions and SEM were made to investigate phase composition and microstructure. Some sintered samples showed reasonably good mechanical and physical properties as a result of their little residual porosity and fine microstructure. [20]

2.5 Development of Ceramic Tiles from another Sludge Wastes

Junkes et al. (2011) studied the effect of using different industrial sludge waste produced from the varvite cutting and polishing process, gneiss crushing, clarification of potable water and clay in the manufacturing of ceramic tiles. The produced sludge was dried, ground using a ball mill, and characterized using thermal analysis, x-ray fluorescence, and x-ray diffraction to identify the possibility of using these materials in the ceramic tiles. Specimens with different percentages of wastes were prepared and moulded using extrusion to be fired at two different firing temperatures 1100°C and 1150°C respectively with a soaking time of 40 minutes. The results showed that the forming of specimens using the extrusion process is feasible for these materials due to the higher index of the plasticity that doesn't need any additives. The mechanical strength of the produced specimens was found to be in the range from 21 to 58 MPa to meet the specification requirements of ISO 13006 and the best firing cycle at temperature 1100°C. [21]

Vichaphund et al. (2012) utilized the sludge waste produced from the manufacturing of natural rubber in the production of ceramic tiles. Different mixtures of clay and sludge waste were prepared (10-30%wt.), pressed at 24 MPa and sintered at different firing temperatures ranging from 1000 to 1200°C with soaking time 30 minutes. The results showed that sintered ceramic tiles containing 20 and 30% wt. waste addition at 1100 and 1150°C can be classified as BIa group with low water absorption according to ISO standards 13006. The flexural strength of specimens increases with increasing the firing temperatures. According to the standard specification, the sludge waste can be incorporated in ceramic tiles up to 30% wt. at sintering temperature 1150°C to produce ceramic tiles with water absorption less than 0.5% and flexural strength above 35 MPa. [22]

Pinheiro et al. (2013) utilized the petroleum oily sludge waste in the preparation of vitrified floor tiles. Floor tile preparations containing up to 5% by weight petroleum oily sludge as a replacement to kaolin. The tile preparations were granulated by the dry method, pressed, then fired at temperatures between 1200 and 1250°C by means of a fast-firing cycle. The specimens were assessed before and after firing. XRD was used to specify the crystalline phases existing during sintering and SEM was made to show how the structure varied during densification. Three parameters were used to characterize densification: flexural strength, linear shrinkage and water absorption. The results demonstrated that the petroleum oily sludge could be used as a substituent raw material in the floor tile preparations. The Intensification behaviour of the floor tiles is deeply affected by the petroleum oily sludge addition as well as the firing temperature. The prepared vitrified floor tiles met the technical properties of the porcelain floor tiles, based on petroleum oily sludge content in addition to the firing temperature. [23]

Vieira et al. (2006) evaluated the effect of utilizing fine steel sludge waste on the characteristics and microstructure of a kaolinitic clay used to fabricate roofing tiles. The steel sludge was characterization for, chemical composition, employed X-ray diffraction, scanning electron microscopy, DTA/TG analysis and particle size distribution. Specimens were prepared with the additions of 0, 5, 10 and 20 wt.% waste in a kaolinitic clay originated from Brazil. The technological properties, for instance, water absorption, flexural strength, linear shrinkage and bulk density were characterized after firing the press molded specimens were in a laboratory furnace at 900 0C. The microstructure of the fired specimens was assessed by XRD and SEM. The obtained results showed that utilizations up to 5 wt.% of fine steel sludge is valuable to the red ceramic. By contrast, utilizations above 5 wt.% yielded a negative impact on the mechanical strength of the fired specimens. [24]

3 Discussion

According to the previous studies, sludge can be used in the manufacturing of ceramic tiles which enhance its properties. The percentage of waste addition depends on the type of waste. Sludge can be classified into organic waste such as sewage sludge, paper sludge and inorganic such as marble, ceramic, steel sludge. The organic sludge could be incorporated in the production of ceramic tiles using a little amount of waste addition due to oxidation of organic matter which increases the porosity of tiles that leads of increasing water absorption and decreasing the mechanical strength. On the other hand, inorganic sludge could be utilized in ceramic manufacturing which enhances the mechanical properties of ceramic tiles.

4 Conclusions from the Review

- ✓ The optimum levels of sewage sludge replacement ranged from 2 to 10% wt. for ceramic tiles, 20% wt. for roof tiles and finally 60% wt. for split tiles at a high firing temperature.
- ✓ Sewage sludge ash could be used in ceramic tiles up to 50% wt. to meet the standard specifications.
- ✓ Ceramic sludge could be replaced with the basic mixtures of the wall and floor tiles with 10 and 20% wt. waste addition.
- ✓ The usage of marble and granite sludge in the production of ceramics decreases the water absorption and increases the mechanical strength of ceramic tiles.

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