



Incorporation of Granitic Wastes and Malha Formation Clays in the Sewage Pipes Industry: Insights on Industrial Using and Environmental Impact

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ABSTRACT

One of the most common industrial byproducts created by the construction industry is granite waste. Despite having a special chemical composition, granite waste is nevertheless wasted in large quantities without being recycled, which could have a negative influence on the environment. For this reason, the current study offers a workable strategy for recovering and using granite waste as a flux to create a value-added with prominent physical-mechanical properties. The granitic wastes are additives for the purpose of improving natural clay. A batch composition including 20% of granite waste is then created, dried, and fired at various sintering temperatures (1100, 1150, and 1200°C). The chemical and mineralogical components of the raw materials are characterized, whereas the mechanical, chemical, and mineralogical characteristics of the fired samples are accomplished. The results of the fired samples' tests at 1200°C revealed that the samples treated with 20% granite waste had enhanced bulk density from 1.86 to 1.96 g/cm³, apparent porosity from 19.23 to 9.22 %, modulus of rupture from 24.26 to 37.14 N/mm², water absorption from 13.82 to 3.74 %, and chemical resistance from 0.28 to 0.19 % to fulfill EN 295: 2013 criteria. The final research approach demonstrated that there is potential to manufacture environmentally friendly pipes with improved physical-mechanical characteristics and a reduction of harmful environmental hazards.

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دمج نفايات الجرانيت والطين لتكوين المألحة للاستخدام فى صناعة أنابيب الصرف الصحي: رؤى حول الاستخدام الصناعى والآثار البيئية

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ملخص	معلومات الارشفة
تعتبر نفايات الجرانيت واحدة من أكثر المنتجات الثانوية الصناعية شيوعاً التي أنشأتها صناعة البناء. على الرغم من وجود تركيبة كيميائية خاصة، إلا أن نفايات الجرانيت تُهدر بكميات كبيرة دون إعادة تدويرها، مما قد يكون له تأثير سلبي على البيئة. لهذا السبب، تقدم الدراسة الحالية استراتيجية عملية لاستعادة واستخدام نفايات الجرانيت كتدفق لخلق قيمة مضافة بخصائص فيزيائية ميكانيكية بارزة عن طريق استبدال الطين الطبيعي بمسحوق الجرانيت. تم بعد ذلك تكوين دفعة تشتمل على 20% من نفايات الجرانيت وتجفيفها وحرقتها في درجات حرارة تليد مختلفة، بما في ذلك 1100 و 1150 و 1200 درجة مئوية. تم تمييز المكونات الكيميائية والمعدنية للمواد الخام، بينما تم تمييز الخصائص الميكانيكية والكيميائية والمعدنية للعينات المحروقة. أظهرت نتائج اختبارات العينات المحروقة عند 1200 درجة مئوية أن العينات التي عولجت بمخلفات جرانيتية 20% عززت الكثافة الظاهرية من 1.86 إلى 1.96، والمسامية الظاهرة من 19.23 إلى 9.22 %، ومعامل الاختطاف من 24.26 إلى 37.14 N/mm ² ، ماء امتصاص من 13.82 إلى 3.74 %، ومقاومة كيميائية من 0.28 إلى 0.19 % لتلبية معايير EN 295: 2013. أظهر نهج البحث النهائي أن هناك إمكانية لتصنيع أنابيب صديقة للبيئة ذات خصائص فيزيائية ميكانيكية محسنة وتقليل المخاطر البيئية الضارة.	تاريخ الاستلام: 16- أغسطس 2022 تاريخ المراجعة: 28- يناير 2023 تاريخ القبول: 01- فبراير 2023 تاريخ النشر الإلكتروني: 30- يونيو 2023 الكلمات المفتاحية: نفايات جرانيتية تكوين مألحة خواص تكنولوجية خواص حرارية خط المراسلة: الاسم: أحمد وحيد Email: awahid_84@sweillem.net

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Introduction

The cutting and polishing of granitic stones generate massive amounts of waste, which litter the environment and pollute the air, soil, and water. The collection of huge amounts of granitic wastes in the landfill creates necrotic conditions for flora and fauna, while after drying, the fine particles can damage the lungs of mammals during the process (Torres et al., 2003). The wastes of such industrial activities can reach even 20 to 25 % of the raw materials (Fernandes et al., 2003). A viable alternative approach to reducing waste output and, thus, the potential environmental effects has been thought of as solid waste management outside the mining and processing industries (Ngayakamo et al., 2021). The approach known as industrial ecology considers industrial wastes as byproducts and potential raw resources for other industries (O'Rourke et al., 1996). Recycling of wastes has unambiguously beneficial environmental and economic impacts, while high-temperature firing can turn wastes, which contain hazardous components, into inert and safe for health products (Ferreira 2003). The use of Malha clay and granite waste is suggested in this study as a potential method for

converting an unwanted byproduct that is typically disposed of close to factories. Cutting and polishing are used as raw materials for manufacturing clay pipes with high mechanical characteristics adding significant value to the final products. In the traditional ceramic industry, such as floor tiles and sewage pipes, the used materials have a high heterogeneity due to the wide range of chemical and mineralogical composition of the clays. So, there is a good chance for incorporating huge amounts of suitable wastes as raw materials (Ribeiro et al., 2003). Generally, the ceramic industry was classified as a heavy industry that consumes huge amounts of natural resources (Martins, 1996 and Moura, 2001), and recycling of these wastes in ceramics has unambiguously beneficial economic and environmental impact (Boccaccini et al., 2000).

Materials and methods

Seven granitic samples were collected from Shaq El-Thoban industrial area in Helwan City. They mixed well to form a homogeneous mixture, and then mixed with clay materials by 20 % (the same percentage of feldspars was used as fluxing materials with other clays). Five representative samples were collected from the studied section of the Malha Formation at Abu Darag; 29°21'4.00" N - 32°32'56.00" E. Samples were collected carefully, and stored in suitable sample bags to avoid contamination by other materials. The clay samples were typically whitish to reddish with a soft touch of clay rocks. The studied clay samples were subjected to mineralogical, chemical, and thermal analyses, while the fired samples were subjected to mineralogical analysis. The mineralogical composition is conducted by XRD using X'Pert PRO PW3040/60 (PANalytical) diffractometer equipped with a monochromatic Cu K α radiation source. The test was run at 40 kV and 30 mA. The acquired data were identified using X'Pert high source software works with a PDF-2 database at Housing and Building National Research Center (HBRC), Cairo, Egypt. The clay fraction (with particle size less than 2 microns) is separated from the bulk sample for clay-mineral identification by decantation and then mounted on a substrate of glass slides (Hume and Nelson, 1982). The clay fraction is analyzed in three conditions: a) air-dried condition, b) heated condition (at 550° C in a controlled furnace for 2 h), and c) glycerol-solvated condition. The chemical data of major oxides were analyzed by X-ray fluorescence (Philips PW 1404 WD-XRF) at Das ceramic institute, Germany. Four representative samples were thermally analyzed using a computerized DT.-50 thermal analyzer (Shimadzu Co., Kyoto, Japan). The heating rate was 20 (°C/min). The heating temperature increased up to 1000°C for DTA and TGA under a nitrogen atmosphere (30 ml/min) at the Housing and Building National Research Center, Cairo, Egypt. The studied samples are glazed by the dipping method. The firing of the studied samples is done by using a lab kiln (Sacmi – Italy) at a temperature of 1100, 1150, and 1200° C with a rate of firing of about 10° C/min, and soaked for 2 hours at Sweillem Company, Cairo, Egypt.

The modulus of rupture (MOR) was carried out according to ASTM C1161 – 13, 2014 using Netzsch Geratebau 401, Germany. The water absorption and chemical corrosion are carried out according to EN 295-3, 2013. The linear shrinkage is determined according to ASTM C531, 2012. The bulk density and apparent porosity are carried out according to ASTM C20 – 00, 2015 at Sweillem Company, Cairo, Egypt.

Geologic setting

The studied area is located on the western side of the Gulf of Suez in the northern Galala Plateau at Abu Darag area. Tectonically, it occurs in the unstable shelf area and is represented by an asymmetric anticlinal fold due to the effects of the Syrian Arc System affecting the late Carboniferous, Permo-Triassic, and Cretaceous rocks (Farouk, 2016). The studied area includes different rock units ranging in age from Carboniferous to Eocene and capped with quaternary deposits as shown in the geological map (Fig. 1). The most important rock unit including kaolinitic clays is the Malha Formation.

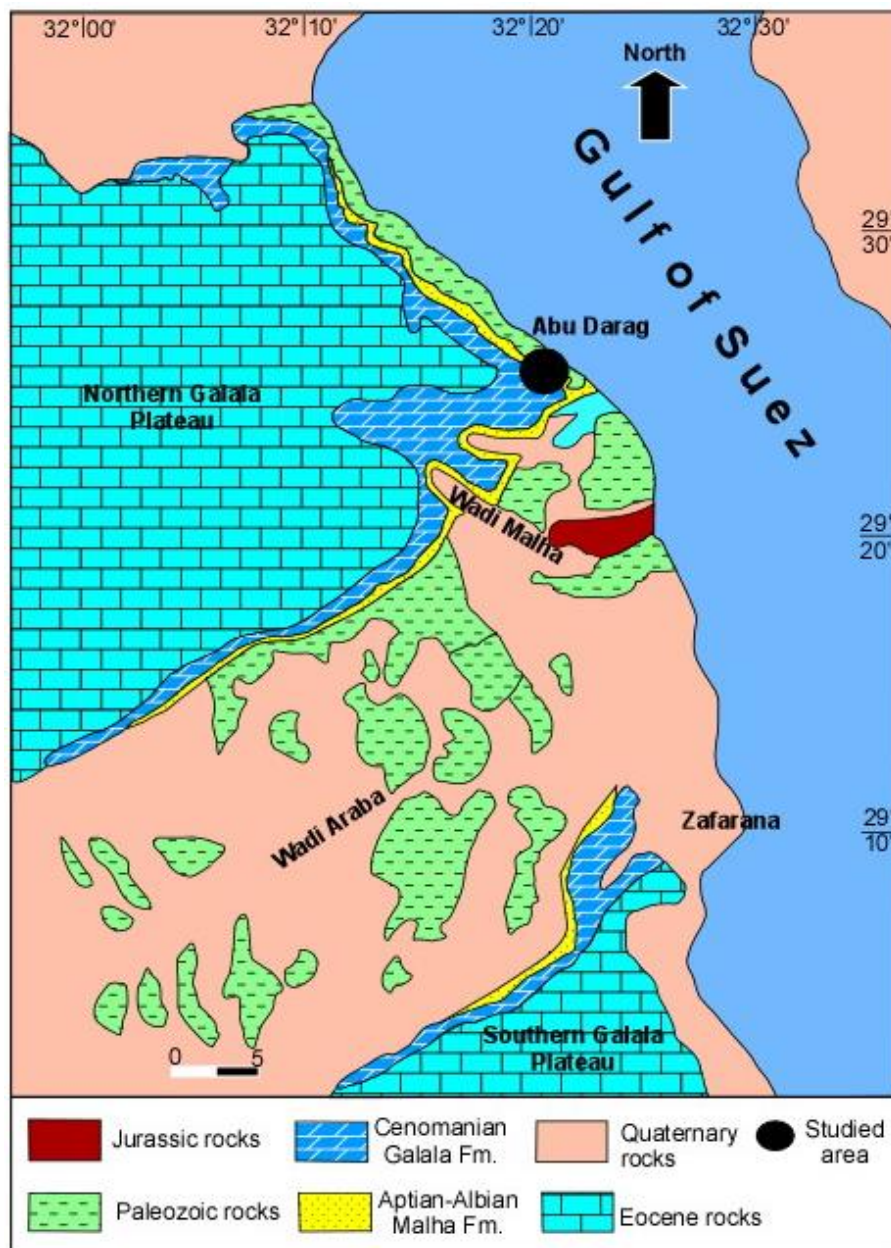


Fig. 1. Simplified geologic map of the area around Abu Darag, Egypt (Modified after Baioumy, 2014)

The studied succession is composed mainly of massive clays. It occurs mainly as non-fossiliferous beds, free from any calcareous matter. The claystone is grey to reddish grey. The lower bed is composed of fine, medium, and coarse-grained sandstones and has displayed many primary structures of cross-bedding and fine-lamination, intercalated occasionally with grey-yellow to reddish kaolinitic clays. The clayey layers are represented by a thick laminated red-colored sequence. The red color most probably resulted from weathering of iron silicate-

bearing minerals under oxidizing conditions (Cai et al., 2012). The studied area is close to the basement rocks which contain feldspar minerals. Kolkila et al., 1989 suggested that these basement rocks are the source rock of the Malha Formation. Commonly, the investigated section end is towards the top by the appearance of a weathered layer of Galala limestone. The Malha Formation extends greatly in the Abu Darag area; the targeted layer has a thickness of 3 meters and a surface area of 1000*270 meters, with an estimated reserve of roughly 2 million tons. Due to the thin overburden and low transportation costs for 200 km distance from Cairo, the mining costs are lower than those of the Aswan clays (1000 km to Cairo).

Results

The mineralogical and chemical composition

The mineralogical composition of the studied samples (No.1,3,5) of the Malha Formation (Fig. 2) shows that they are composed mainly of kaolinite and quartz with hematite and illite as accessory minerals.

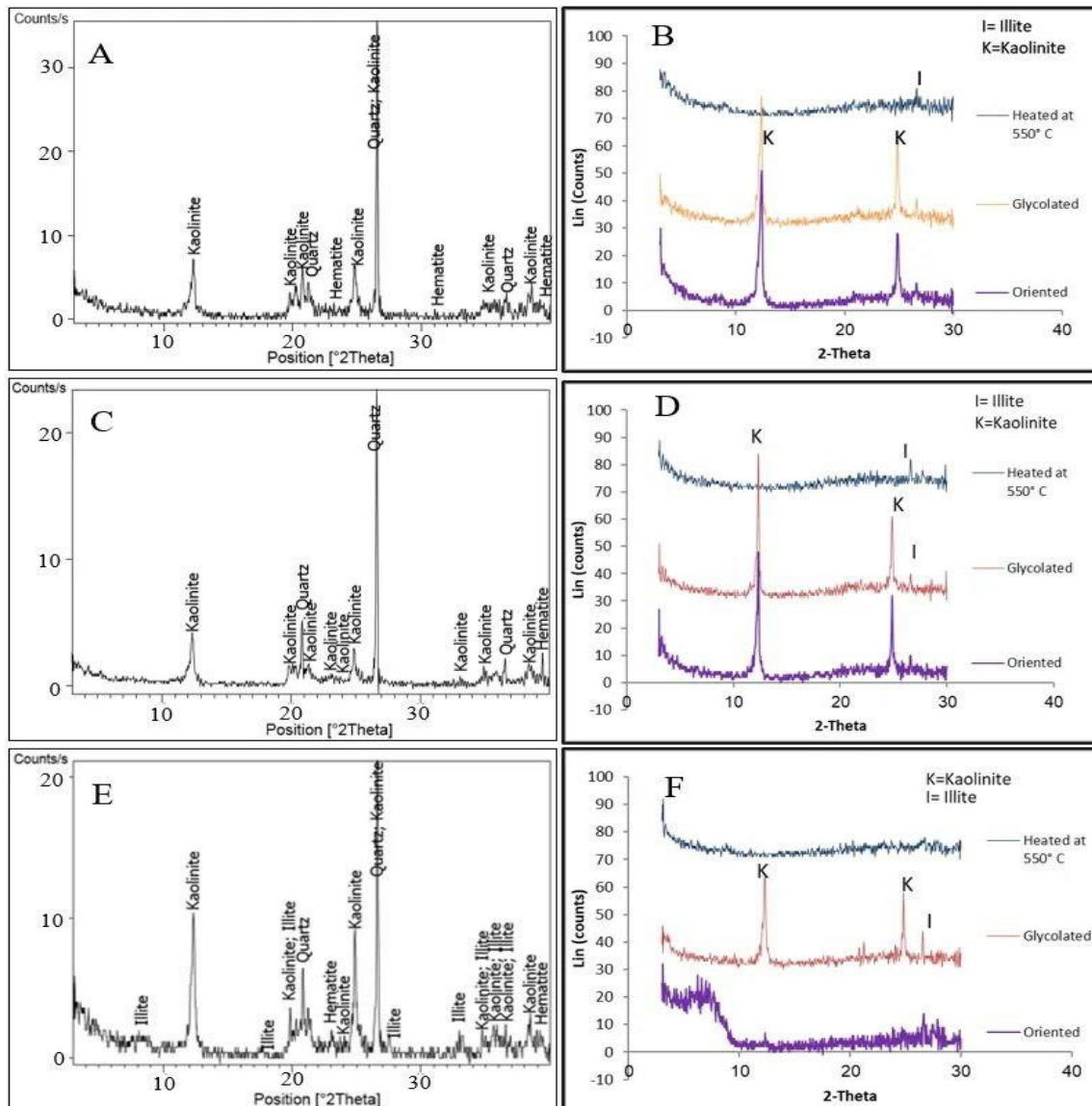


Fig. 2. XRD patterns of the Malha Formation samples. (A-B) bulk sample and clay fraction after the treatments of sample no. 1, (C-D) bulk sample and clay fraction after the treatments of sample no. 3, (E-F) bulk sample and clay fraction after the treatments of sample No. 5.

Table 1 shows the chemical composition of the studied samples. The data of major oxides show that the studied samples are composed mainly of SiO_2 and Al_2O_3 as major constituents with lower percentages of Fe_2O_3 , K_2O , Na_2O , TiO_2 , CaO , and MgO .

Table 1. The chemical composition of the studied Formation and the granitic wastes

Oxides	Granitic waste samples (%)								Average	Malha clay samples (%)					Average	clay with 20% granite
SiO ₂	73.32	69.00	65.73	67.70	72.20	74.62	74.77	71.05	71.05	52.71	49.52	51.51	54.74	48.69	51.43	55.35
Al ₂ O ₃	14.42	14.84	17.65	14.28	13.79	12.16	12.82	14.28	14.28	26.85	25.19	26.14	27.38	26.61	26.43	24.00
Fe ₂ O ₃	0.85	3.12	2.02	4.41	2.27	2.87	1.19	2.39	2.39	6.21	7.89	8.79	2.90	4.92	6.14	5.39
CaO	1.35	1.85	0.79	0.86	1.49	0.62	0.98	1.13	1.13	0.61	1.42	0.77	0.49	1.09	0.88	0.93
MgO	0.23	0.43	0.29	0.33	0.31	0.12	0.50	0.32	0.32	0.25	0.28	0.66	0.18	0.22	0.32	0.32
SO ₃	0.05	0.08	0.05	0.06	0.08	0.05	0.11	0.07	0.07	0.08	0.08	0.10	0.40	0.10	0.15	0.13
K ₂ O	4.74	5.84	6.76	4.72	5.38	4.11	4.59	5.16	5.16	1.24	1.66	1.08	0.59	1.14	1.14	1.94
Na ₂ O	4.03	3.34	5.64	6.22	3.44	4.52	3.92	4.44	4.44	0.32	0.42	0.28	0.10	0.58	0.34	1.16
TiO ₂	0.14	0.49	0.56	0.50	0.29	0.23	0.11	0.33	0.33	1.78	1.92	1.77	2.05	1.90	1.88	1.57
MnO	0.02	0.05	0.07	0.14	0.04	0.05	0.03	0.06	0.06	0.09	0.10	0.08	0.08	0.09	0.09	0.08
P ₂ O ₅	0.04	0.15	0.03	0.08	0.11	0.02	0.01	0.06	0.06	0.11	0.14	0.07	0.09	0.10	0.10	0.09
LOI	0.71	0.73	0.30	0.57	0.53	0.50	0.89	0.60	0.60	9.75	11.38	8.75	11.00	14.56	11.09	8.99
Total	99.90	99.92	99.89	99.87	99.93	99.87	99.92	99.90	99.90	100.00	100.00	100.00	100.00	100.00	100.00	99.98

The content of SiO_2 ranges from 48.7 - 54.7 % with an average of 51.4 %. The content of Al_2O_3 ranges from 25.1-27.4 % with an average of 26.4 %. The total iron (Fe_2O_3) content of the studied samples is relatively high, it ranges from 2.9-8.8 % with an average of 4.1 %. The alkalis content ($\text{K}_2\text{O} + \text{Na}_2\text{O}$) is relatively low with an average of 1.5 %. The content of MgO and CaO is very low with an average of 1.2 %. The average content of TiO_2 is 1.9 % (Table 1). The chemical composition of the granitic wastes is shown in Table (1), where all contain a high value of SiO_2 with an average of 71 %. The average of Al_2O_3 is 14.28%. The average of alkalis (K_2O and Na_2O) is recorded at 9.5 %.

Figure (3, A) represents the XRD patterns of granite wastes containing quartz, albite, and biotite. Figure (3, B-C) shows the XRD patterns of two representative samples without additives fired at 1200°C , where XRD patterns of those samples incorporated with 20 % granite waste were shown in Figure (3, D-E). As appeared in all the XRD patterns, the detected crystalline phases are mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$), quartz (SiO_2), cristoballite (SiO_2), and hematite (Fe_2O_3).

Thermal properties

The studied samples are characterized by three endothermic reaction peaks, the first one ranges from 45.9 to 56.3°C and appears as a low symmetric peak. The second ranges from 338.3 to 348.2°C and appears as a small peak in all studied samples. Meanwhile, the third one ranges from 551.7 to 565.9°C and exhibits a large symmetric peak. On the other hand, the studied samples have only exothermic reaction peaks that take place at about 1000°C without any weight loss. The dehydration curves for the studied samples show a humidity loss ranges from 1.1 to 1.7 % below 300°C , while the dehydroxylation of clay minerals ranges from 500 to 600°C and the loss weight percent varies from 7.4 to 8.8 % (Fig. 4).

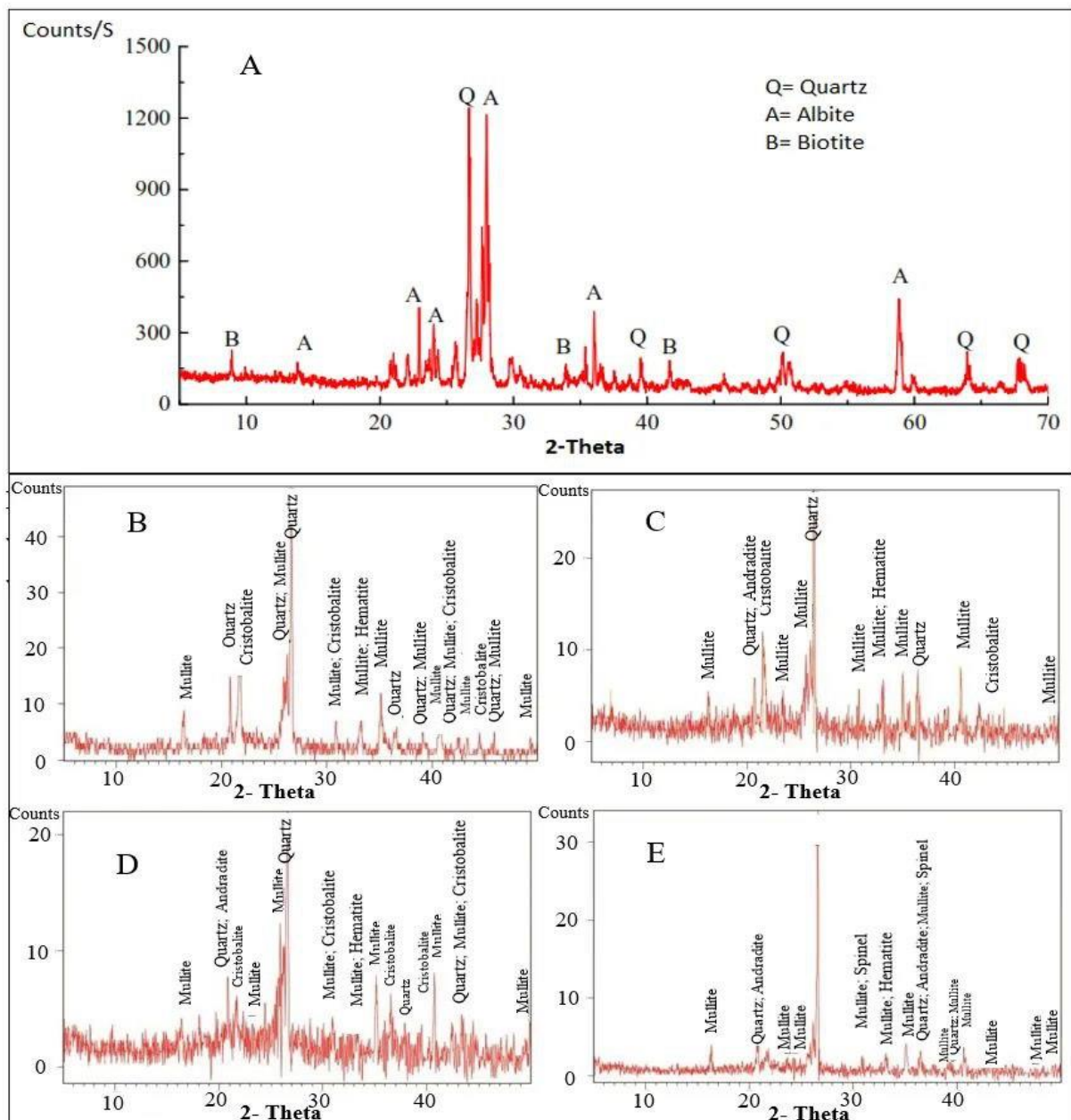


Fig. 3. XRD (A) XRD pattern of granite wastes; (B-C) patterns of the fired clay samples 1 and 3 without additives at 1200° C; (D-E) patterns of the clay samples 1 and 3 mixed by 20% granite waste and fired at 1200° C.

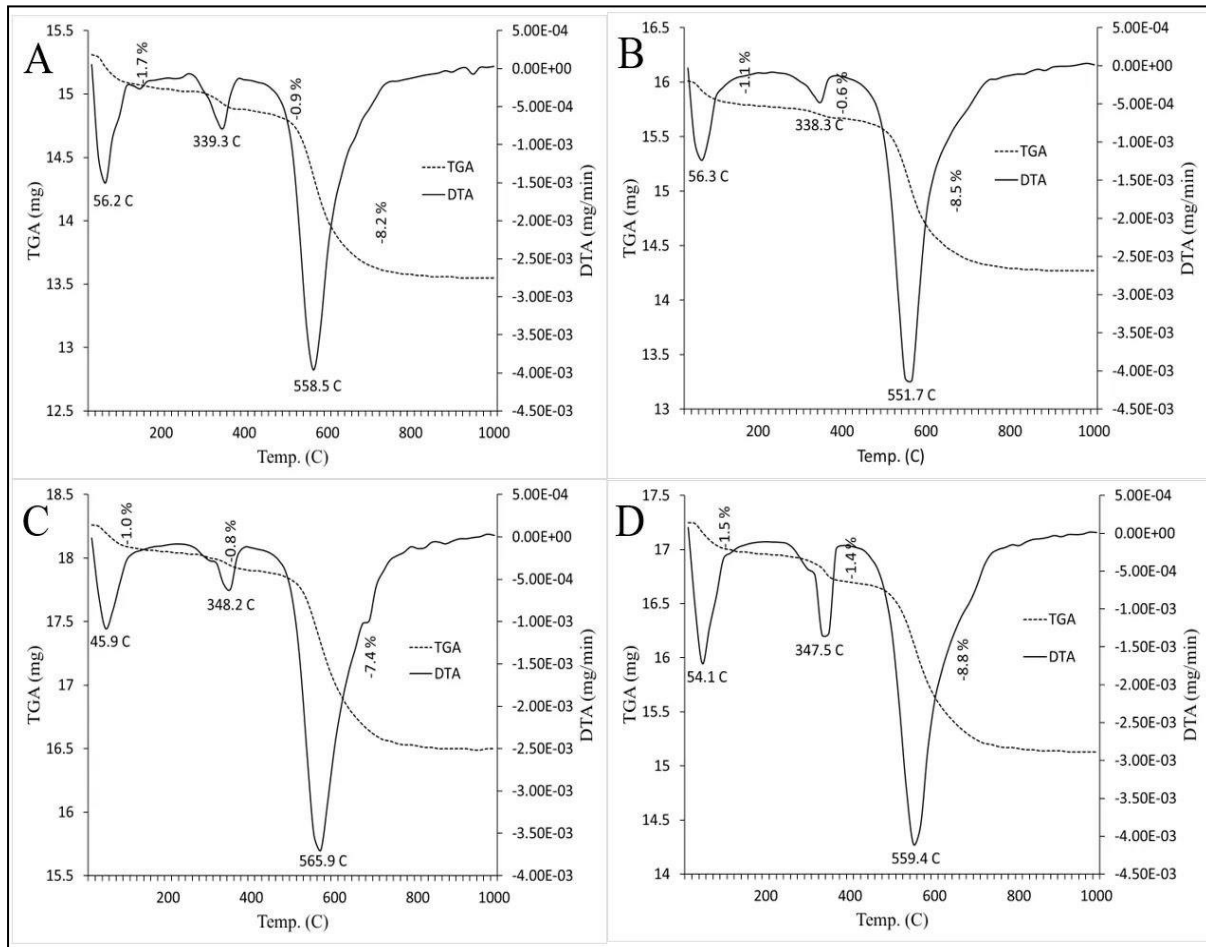


Fig. 4. DTA and TGA thermograms of Malha samples represented by A) sample no. 1, B) sample no. 2, C) sample no. 4, and D) sample no. 5.

The technological properties of the studied specimens

All samples from the studied Formation were dried, ground, mixed with water, shaped in a prismatic steel mold of 130* 28* 15 mm, and then carefully dried at 120° C (Fig. 5A). The same samples were mixed with 20% granite wastes and the same drying profile was applied (Fig. 5C). The same samples, were mixed with 20% granitic wastes, and the same conditions were applied. The prepared samples were glazed before being fired at 1200° C for 2 hours at a firing rate of 10° C/min in a controlled lab furnace (Fig. 5B). The same samples were mixed with 20% granite wastes, and the same firing profile was applied (Fig. 5D). The vitrified specimens were tested for determination of their technological properties according to the relevant European and American standards.

To assess the quality of the vitrified specimens that were fabricated from the clay samples and the clay mixed with granitic wastes to be used as pipes for sewages purposes, different physical, mechanical, and chemical tests are determined, and their results are examined to decide their suitability for the industrial application. The vitrification parameters are determined and evaluated according to the standard specifications of EN-295, 2013, ES-56, 2005, and ZP WN 295, 2016. The results of water absorption, bulk density, and apparent porosity of the tested specimens at different firing temperatures were given in Table (2).

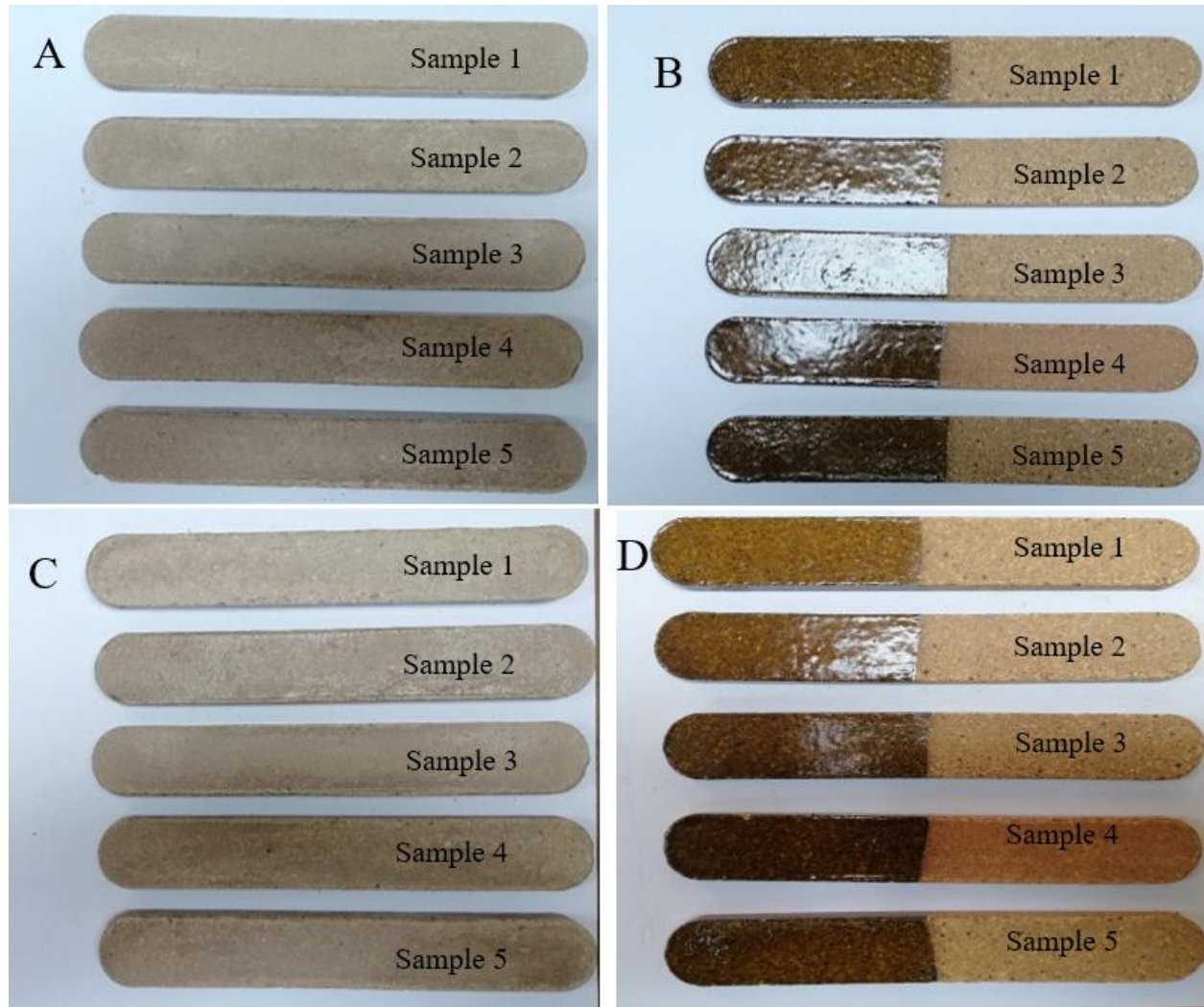


Fig. 5. (A) Dried samples without additives. (B) Fired samples without additives at 1200° C. (C) Dried samples with 20% granite wastes. (D) Fired samples with 20% granite wastes at 1200° C.

Table 2. The physical, mechanical, and chemical characteristics of the studied specimens

T. (C.)	Property	Clay samples without additives						Clay samples with 20 % granitic wastes						EN 295: 2013 Requirements
		1	2	3	4	5	Average	1	2	3	4	5	Average	
1100	W.A(%)	18.42	19.19	18.86	20.47	19.98	19.38	14.64	15.61	14.70	16.80	15.19	15.39	Maximum 6
	B.D (g/cm ³)	1.66	1.53	1.64	1.69	1.68	1.64	1.71	1.63	1.72	1.83	1.76	1.73	Minimum 1.5
	A.P (%)	27.36	26.85	27.76	30.60	29.79	28.47	25.11	23.98	24.81	28.00	27.33	25.85	Maximum 20
	Firing shr.(%)	1.50	1.68	1.45	1.58	1.68	1.58	1.71	1.82	2.10	1.96	2.31	1.98	Minimum 4%
	MOR (N/mm ²)	14.50	15.30	13.50	16.00	15.80	15.02	20.70	19.80	19.60	22.80	21.50	20.88	Minimum 20
	Chem.Cor. (%)	0.42	0.53	0.39	0.42	0.47	0.45	0.34	0.41	0.30	0.32	0.39	0.35	Maximum 0.25%
1150	W.A(%)	14.68	14.34	14.54	15.90	15.21	14.93	9.55	9.41	9.18	10.90	10.10	9.83	Maximum 6
	B.D (g/cm ³)	1.69	1.54	1.67	1.72	1.70	1.66	1.80	1.60	1.80	1.80	1.80	1.76	Minimum 1.5
	A.P (%)	21.19	19.05	20.71	23.24	21.97	21.23	18.00	15.80	17.30	19.10	17.90	17.62	Maximum 20
	Firing shr.(%)	3.25	3.68	4.22	3.96	3.84	3.79	4.85	4.85	5.36	5.12	4.96	5.03	Minimum 4%
	MOR (N/mm ²)	17.80	19.50	18.47	19.60	18.50	18.77	27.30	25.80	27.80	28.60	29.10	27.72	Minimum 20
	Chem.Cor. (%)	0.35	0.44	0.35	0.37	0.39	0.38	0.25	0.33	0.25	0.24	0.30	0.27	Maximum 0.25%
1200	W.A(%)	13.73	13.58	13.90	13.47	14.43	13.82	3.20	3.40	4.00	3.50	4.60	3.74	Maximum 6
	B.D (g/cm ³)	1.93	1.73	1.86	1.90	1.88	1.86	2.00	1.92	1.90	1.98	2.00	1.96	Minimum 1.5
	A.P (%)	19.91	17.41	19.33	19.21	20.31	19.23	8.10	8.90	9.20	8.70	11.20	9.22	Maximum 20
	Firing shr.(%)	5.85	5.63	5.47	5.55	4.86	5.47	6.65	6.24	7.20	7.73	6.90	6.94	Minimum 4%
	MOR (N/mm ²)	22.80	23.50	24.80	25.40	24.80	24.26	36.50	34.20	37.40	39.50	38.10	37.14	Minimum 20
	Chem.Cor. (%)	0.26	0.33	0.28	0.26	0.29	0.28	0.17	0.23	0.18	0.16	0.20	0.19	Maximum 0.25%

W.A= Water absorption B.D= Bulk density A.P= Apparent porosity Firing shr.= Firing shrinkage Chem. Cor.= Chemical corrosion

Water absorption:

The average water absorption of the studied specimens is recorded to be 19.38, 14.93, and 13.82 % at firing temperatures of 1100, 1150, and 1200° C respectively. Meanwhile, the average water absorption of the same samples after adding 20 % of granitic wastes is recorded to be 15.39, 9.83 and 3.74 % at firing temperatures of 1100, 1150, and 1200° C respectively as a result of granite melting which reduced the apparent porosity.

Bulk density:

The average results of bulk density for the studied specimens are 1.64, 1.66, and 1.86 g/cm³ at the firing temperatures of 1100, 1150, and 1200° C respectively. Meanwhile the average bulk density of the same samples after adding 20 % of granitic wastes is recorded to be 1.73, 1.76, and 1.96 g/cm³ at the firing temperatures of 1100, 1150, and 1200° C. Melting granite wastes penetrated the pore spaces and formed a denser ceramic body, increasing the density values.

Apparent porosity:

The average results of apparent porosity for the studied samples are 28.47, 21.23, and 19.23 % at the firing temperatures of 1100, 1150, and 1200° C respectively. Meanwhile, the average porosity of the same samples after adding 20 % of granitic wastes is recorded to be 25.85, 17.62, and 9.22 at the firing temperatures of 1100, 1150, and 1200° C respectively. Granite wastes were melted and used to fill the pore spaces in the ceramic texture minimizing the porosity values.

Linear shrinkage:

The average values of firing shrinkage for the studied specimens were 1.58, 3.79, and 5.47 % at firing profiles 1100, 1150, and 1200 °C, respectively. Meanwhile, the average firing shrinkage of the same specimens after adding 20 % of granitic wastes is recorded to be 1.98, 5.03, and, 6.94 % at the firing temperatures of 1100, 1150, and 1200° C respectively. The melting of the granite wastes filled the pore spaces causing a strong contraction between the filler particles, reducing volume, and increasing shrinkage values.

Modulus of rupture (MOR):

The average MOR values of the studied specimens after the firing process are recorded to be 15.02, 18.77, and 24.26 N/mm² at the firing profiles 1100, 1150, and 1200° C respectively. Meanwhile, the average MOR of the same samples after adding 20 % of granitic wastes is recorded to be 20.88, 27.72, and 37.14 N/mm² at the firing temperatures of 1100, 1150, and 1200° C respectively. The melting of granite wastes filled the pore spaces, forming a strong texture with less porosity, and thus increasing mechanical strength.

Resistance to chemical corrosion

The results of the studied samples are tested against chemical corrosion by sulfuric acid. They are recorded to be 0.45, 0.38, and 0.29 % loss of weight at firing temperatures of 1100, 1150, and, 1200° C respectively. Meanwhile, the average corrosion of the same samples after adding 20 % of granitic wastes is recorded to be 0.35m, 0.27, and 0.19 % at the firing temperatures of 1100, 1150, and, 1200° C respectively. The porosity percent is responsible for the invasion of chemical attack, and the melting of granite wastes decreased the porosity and thus increased chemical resistance.

Discussion

Mineralogical and Geochemical characterization

The studied samples are composed mainly of SiO_2 and Al_2O_3 as major constituents which reflect the mineralogy of the sediments and classify the sediments as kaolinitic clay deposits (Olusola, et al., 2014)

The high content of SiO_2 indicates that the studied samples contain a high percentage of quartz and this is revealed by XRD analysis. The SiO_2 content of the Malha Formation matches the German requirements (55-70 %) (European Commission Ceramic Manufacturing Industry, 2007).

The studied samples contain high values of Al_2O_3 due to the extensive intensity of kaolinization, while the incomplete kaolinization process indicates a lesser amount of Al_2O_3 (Visser and Young, 1990; Sayin, 2007). Omotoyinbo and Oluwole (2008) have recorded that higher Al_2O_3 has higher refractoriness of the clay samples.

The Al_2O_3 content of the studied samples matches the German requirements (20-35 %).

TiO_2 may be disseminated within the clays as discrete minerals, e.g., rutile and anatase (Degens, 1965). However, during weathering process of kaolinite, Ti is combined with the kaolinite structure (Murray and Keller, 1993). In the studied samples, the TiO_2 is detected by chemicals, but it is not detected by XRD due to its small proportion (Fischer, 1984).

The Fe_2O_3 content is a direct measure of hematite as detected by XRD. The iron content is responsible for the reddish color of the ceramic body after the firing process. The Fe_2O_3 content matches the German requirements (1.0-10 %).

The value of K_2O in the studied samples is very low and it reflects the illite mineral with a small proportion (Akpokodje et al., 1991) as revealed by X-ray diffractograms in (Fig. 4). Commonly, the presence of alkaline in the sediments leads to reduce the vitrification temperature. The alkaline content of the studied samples conformed to the average alkaline content of German materials (2.7 %).

The low content of MgO and CaO in the studied samples reflects the low content of carbonate minerals such as dolomite and calcite. Refaat (1993) has recorded that the low content of CaO and MgO refers to non-marine deposits.

The chemical composition of the granitic wastes indicates that these materials are composed mainly of quartz and orthoclase leading to a decrease in the vitrification temperature due to their low melting point.

As appear in all XRD patterns, the detected crystalline phases are mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$), quartz (SiO_2), cristoballite (SiO_2), and hematite (Fe_2O_3). The detected phases match the results of Ekosse and Bafibiandi (2008). Mullite and cristoballite phases are formed as a result of the recrystallization of clay minerals as reported by Bennour et al. (2015). In the XRD patterns of the specimens containing 20 % granite waste, the feldspar minerals are not detected in the XRD patterns although the feldspar minerals are the main component of the granite wastes. This may be due to the complete melting of these minerals to the uncrystallized phase (glassy phase) during the firing process as reported by Torres and Puertas (2015). Also, it is noticed that the peak intensity of the mullite phase decreases by adding 20 Wt. % GPW. This may be attributed to the decrease of clay minerals (source of Al_2O_3) at the expense of granite waste replacement. The occurrence of mullite and

cristoballite is supported by Escalera (2015). At the higher temperature ($>1100^{\circ}\text{C}$), the amorphous silica or meta kaolinite is converted to mullite and cristoballite (Stevenson and Gurnick, 2016).

Physical and technical properties:

The studied specimens without additives have a high percent of porosity which leads to a high percentage of water absorption, lower values of bulk density, lower values of firing shrinkage, lower values of MOR, and low resistivity to chemical corrosion. The water absorption of the studied samples was too high ($> 6\%$) compared with the limits of the international standards (EN 295-1, 2013; ZP WN 295 2016; ES 56-1, 2005) where the maximum acceptable limit of water absorption is 6%. Also, the high values of water absorption depend on the absence of alkaline oxides ($\text{K}_2\text{O} + \text{Na}_2\text{O}$) and the high refractoriness as revealed by the chemical composition. So, the studied samples are mixed with 20 % of the granitic wastes and applied to all firing profiles ($1100, 1150, \text{ and } 1200^{\circ}\text{C}$). It is noted that the water absorption of all samples is sharply decreased and matches the standard limit of the international specifications. Other physical properties such as bulk density, modulus of rupture, apparent porosity, and linear shrinkage have a positive effect by adding 20% of granitic wastes to the studied samples (Table 2).

The obtained values of the chemical resistance of the studied samples show that the chemical resistance against the corrosion of acids is very weak. According to the international standards of sewage pipes, the maximum corrosion against acids should be less than 0.25% (EN 295; 2013). By adding 20% granite powder and applying the firing profile at 1200°C , the chemical resistance becomes very high (0.19% less than 0.25% which makes this mix more suitable for sewage pipes application).

Thermal properties:

The thermal properties of the studied samples are explained according to DTA and TGA thermograms. The endothermic peak at less than 100°C is referred to the dehydration of clay minerals and any residual humidity from the weather. The second endothermic peak between 338 and 348°C is referred to as the dehydration of goethite [$\text{FeO}(\text{OH})$] mineral associated with clay deposits. The large endothermic peak around at 550°C represents the loss of the interlayer water of clay minerals as revealed by TGA curves where the samples have lost weight in this range to 8.8 %. Todor (1976) and Smykatz-Kloss (1982) reported that the dihydroxylation of clay minerals takes place between 450 to 700°C .

The exothermic peak around 950°C represents the first step of the mullitization process (transformation of meta-kaolinite to primary mullite). Ekosse and Mulaba, (2008) reported that mullite is formed at 975°C in appreciable amounts by heating the well-crystallized kaolinite. The TGA curves show that the studied samples have losses in weight varying from 1 to 1.5 % at a temperature of less than 300°C . Also, the samples have losses of weight of 8 % at temperatures between 500 and 600°C . The ideal loss in weight of pure kaolinite is 14% (Newman, 1987) but it may be lower than 14 % since the studied samples do not only contain kaolinite but contain other clay minerals such as illite and non-clay minerals such as quartz and hematite.

Conclusion

In the context of recycling, this study investigates the environmental and economic benefits of incorporating granite wastes as raw materials in the sewage pipe industry. Granitic

wastes in the form of sludge from ornamental rock sawing are a potential raw material for ceramic incorporation and could serve as a flux source. The incorporation of granite waste into ceramic bodies for sewage pipes increased mechanical strength, bulk density, and chemical resistivity. Water absorption and porosity, on the other hand, are decreasing.

Maximizing the use of granitic waste in the manufacturing of sewage pipes would reduce both the environmental impact and the cost of sewage pipe production. The percentage of these wastes enhanced the mechanical, chemical, and physical properties of the clay materials used in this industry significantly. Recycling solid waste is the best environmental solution for saving raw materials and reducing the number of industrial waste materials, and thus the pollution of the environment.

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