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Production of artificial stone slabs using waste granite and marble stone sludge samples

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Abstract

In this work, the waste stone sludge obtained from the granite and marble stone processing factories was used for the manufacture of artificial stones using vibratory compaction in a vacuum environment. The results obtained showed that water absorption and density increased, and the flexure, compressive, and tensile strengths decreased with increase in the content of the waste stone sludge. These results also demonstrated that by combining 50% of stone sludge, 12% of ground quartz, 25% of waste glass, and 13% of resin at a compaction pressure of 12 MPa, a vibration frequency of 30 Hz, and vacuum conditions at 50 mm Hg, artificial stone slabs with a water absorption less than 0.64, a density less than 2.68, a flexure strength more than 45 MPa, a compressive strength more than 90 MPa, and a tensile strength more than 35 MPa can be obtained. The artificial stone slabs obtained in this research work had good density and water absorption, and flexure, compressive, and tensile strengths compared to the natural stones, and thus they can be regarded as the ideal construction materials for covering walls or paving floors.

Keywords: *Waste Stone Sludge, Artificial Stone, Resource Recycling*.

1. Introduction

Iran has huge reserves of dimension stones, and is one of the major producers of dimensional stones in the world. Based on the statistics, nearly 5500 factories in Iran are active in the field of stone processing, which annually produce 5 million tons of wastes as stone fragments and stone-cutting sludge [1].

The stone-cutting sludge has fine particles (< 100 μm in diameter), and has an extremely good water permeability of less than 10^{-7} cm/s and a low dehydration rate. The fine particles of waste stone sludge can be easily dispersed by wind and settle down by rain and snow. Without treatment or recycling, the waste stone sludge would cause environmental pollution [2].

Recycling and reusing the waste stone fragments and sludge in different applications such as manufacturing concrete [3-5], brick [6-8], ceramic [9, 10], artificial aggregates [11-15], and asphalt [16-18] as well as stabilizing agriculture soils [19] and water treatment [20, 21] have been studied by many researchers.

The production of lightweight artificial aggregates from sintered sludge has been studied by many researchers [12-14]. The results obtained have shown that variations in the chemical composition of the waste sludge cause problems in the quality control. Moreover, a large amount of energy is required for drying and sintering the waste sludge. These drawbacks undermine the possibility of commercial recycling of sludge for the production of lightweight aggregates.

Lee et al. (2008) have recycled waste glass and stone fragments from stone slab processing as raw materials to make artificial stone slabs using vibratory compaction in a vacuum environment. Waste glass powder (40%) and fine granite aggregates (60%) were mixed with unsaturated polymer resins (8%) as binders. Under a compaction pressure of 14.7 MPa, a vibration frequency of 33.3 Hz, and vacuum conditions at

50 mm Hg, artificial stone slabs with a high compressive strength of 148.8 MPa, a water absorption of less than 0.02%, a density of 2.445, and a flexure strength of 51.1 MPa were obtained after 2 minutes of compaction [14].

Chang et al. (2010) have studied manufacturing artificial aggregates by the waste stone sludge obtained from slab stone processing and waste silt from the aggregate washing plants. Fine-powdered stone sludge was mixed with the waste silt of larger particle size; vibratory compaction was applied for good water permeability, which resulted in the use of a smaller amount of solidifying agent. The results obtained showed that by combining 35% of stone sludge with 50% of waste silt and 15% of dried solidifying agents, a compact structure artificial aggregate with a water absorption rate of less than 0.1% was produced. This research work showed that the ratio of the compacted packing is one of the influential factors for the compressive strength, and that compaction pressure is the main factor contributing to the compacted structure, which differs from the theory of cement concrete [15].

In this work, the waste stone sludge samples obtained from the granite and marble stone processing factories were recycled to be used as raw materials for manufacturing artificial quartz stone. This type of stone (engineered quartz stone) is a mixture of about 93% natural ground quartz powder, 7% color pigments, and polymer resin by weight (66% quartz and 34% resin by volume). This mixture is pressed into slabs (or larger blocks) using vibratory compaction in a vacuum environment.

2. Materials and method

2.1. Waste stone sludge

The sludge samples from slab stone processing were obtained from granite and a marble processing factory in the number 2 industrial zone of Khorram-Abad, Iran. Table 1 shows the chemical compositions of the granite and marble stone sludge samples, determined by the XRF analysis. As it can be seen in this table, the granite sludge was mainly composed of SiO_2, Al_2O_3, CaO, K_2O, Na_2O, and Fe_2O_3, and most of the marble sludge was composed of CaO.

Figures 1 and 2 shown the particle size distributions (volume percentages) in the granite and marble sludge cakes, determined by a laser diffraction particle size analyzer. As it can be observed in these figures, both materials were very fine, and had similar size distributions. For both waste sludge samples, D75 (75% passing size), D50, and D25 were about 40, 15, and 5 µm, respectively. The XRD analyses of the waste sludge samples showed that quartz, albeit, and muscovite were the main minerals present in the granite sludge, and calcite was the main mineral present in the marble sludge.

Table1. Chemical composition of marble and granite sludge.

Content (%)	Sio_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	K_2O	Na_2O	SO_3	SrO	L.O.I
Granite sludge	67.25	13.52	2.88	4.37	1.12	0.37	3.07	3.89	-	-	3.46
Marble sludge	0.95	0.24	-	54.86	0.42	-	-	-	0.09	0.11	43.33

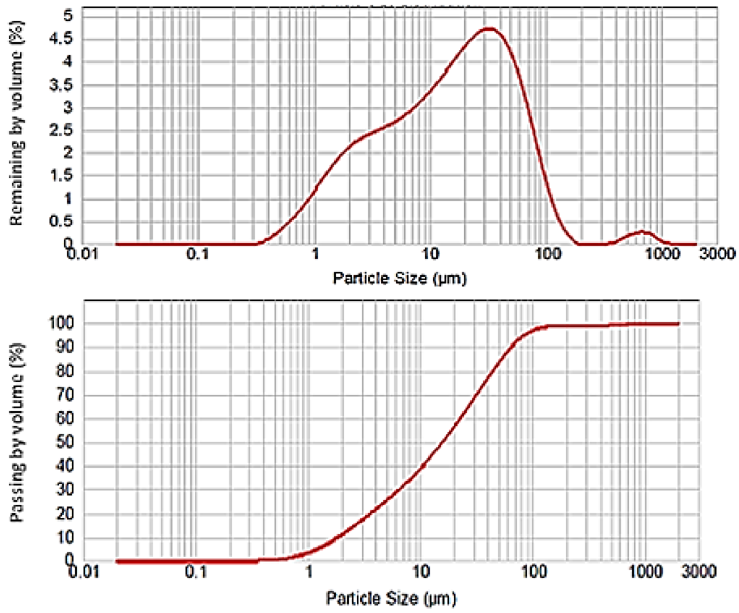

Figure 1. Size distribution of granite sludge.

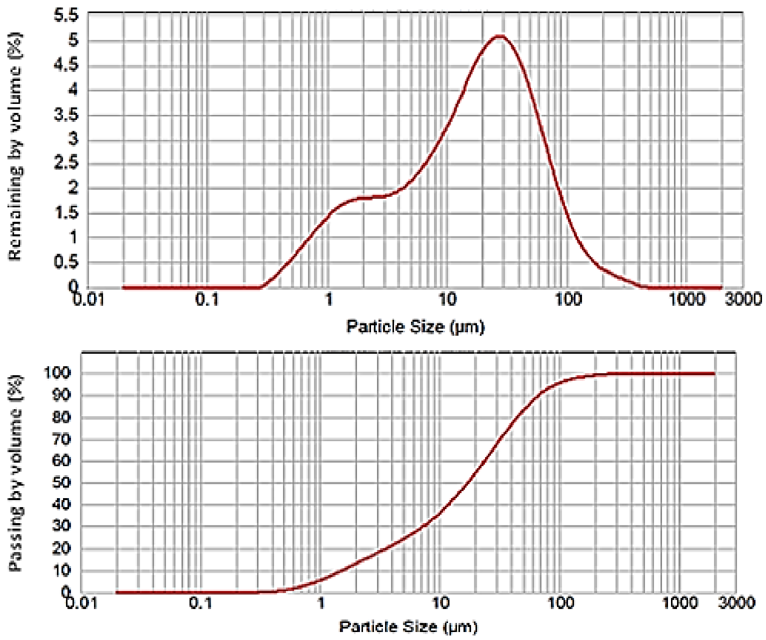

Figure 2. Size distribution of marble sludge.

2.2. Binder

The binder used in this research work was an unsaturated polymer resin (orthophtalic resin) with the characteristics of intermediate viscosity and low exothermic temperature. It had 35-40% styrene, and its viscosity ranged between 450 and 550 cps when spindle at 60 rpm at 25 °C.

2.3. Sample preparation

Figure 3 summarizes the manufacturing process of the artificial stone slabs studied in this work. The ground quartz powder, glass powder, and waste stone sludge (granite or marble) along with the unsaturated polymer resins added as the binder were mixed at different mix contents using a mixer for 3 min. Tables 2 and 3 show the plan of the experiments carried out on the granite and marble sludge samples, respectively.

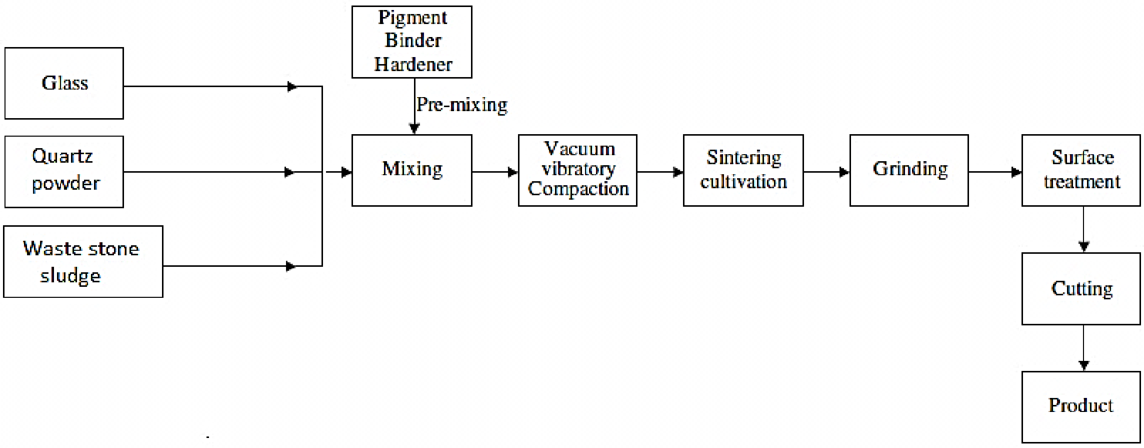

Figure 3. Manufacturing procedure of artificial stone slabs.

Table 2. Plan of experiments for making artificial stone from granite sludge.

Test number	Granite sludge (%)	Quartz (%)	Glass (%)	Resin (%)
1	30	32	25	13
2	40	21	25	14
3	50	9	25	16
4	60	8	14	18

Table 3. Plan of experiments for making artificial stone from marble sludge.

Test number	Granite sludge (%)	Quartz (%)	Glass (%)	Resin (%)
1	30	35	25	10
2	40	24	25	11
3	50	12	25	13
4	60	11	14	15

As it can be seen in these two tables, the content of the stone sludge ranged within 30-60%, increasing by 10% intervals. The test samples were prepared as follow. First, a 50 × 800 × 800 mm compaction mold was filled with thoroughly mixed materials, and sealed. The materials were then compacted using a vibratory compactor at a frequency of 30.0 Hz for 3 min. After compacting, the samples were retrieved, and immediately enclosed in plastic wraps to prevent dehydration. These samples were subsequently dried in an oven at a constant temperature of 90 ℃ for 60 min.

The density and water absorption of the artificial stone slabs were analyzed according to ASTM C97. ASTM C880 and ASTM C170 were adopted to determine the flexure strength and compressive strength, respectively. The tensile strength was determined by the Brazilian test proposed by ISRM.

3. Results and discussion

3.1. Density and water absorption

Tables 4 and 5 show the physical properties of the samples made from granite and marble sludge, respectively.

Figure 4 demonstrates the density of the artificial slabs made from the waste sludge stone. As it can be seen in this figure, this density increased with increase in the content of the waste stone sludge. The average density of natural granite was between 2.65 and 2.75 g/cm^3, and the average density of natural marble was between 2.4 and 2.7 g/cm^3. The results obtained showed that, except for 60% of the sludge samples, the densities of the other samples were within these ranges.

Figure 5 shows water absorption by the artificial slabs made from the waste sludge stones. As it can be seen in this figure, this water absorption increased with increase in the content of the waste stone sludge. The average water absorption of natural granite was between 0.1 and 0.6%, and that for natural marble was less than 0.5% (except for rainforest green/brown with 2-3%). The results obtained showed that, except for 60% of the sludge samples, densities of the other samples were less than 0.6%. Figures 4 and 5 demonstrate that the stone sludge content had the same effect on the density and water absorption of the granite and marble samples.

Table 4. Physical properties of samples made from granite sludge.

Test number	Granite sludge (%)	Density (g/cm3)	Water absorption (%)	Flexural strength (MPa)	Compressive strength (MPa)	Tensile strength (MPa)
1	30	2.36	0.06	64.26	115.69	45.46
2	40	2.52	0.52	55.11	105.76	40.85
3	50	2.68	0.63	50.46	100.38	38.43
4	60	2.83	1	40.32	90.29	35.78

Table 5. Physical properties of samples made from marble sludge.

Test number	Granite sludge (%)	Density (g/cm3)	Water absorption (%)	Flexural strength (MPa)	Compressive strength (MPa)	Tensile strength (MPa)
1	30	2.35	0.09	60.52	105.69	40.91
2	40	2.5	0.55	53.92	100.70	38.14
3	50	2.67	0.64	45.73	89.91	35.32
4	60	2.81	1	40.52	75.61	30.70

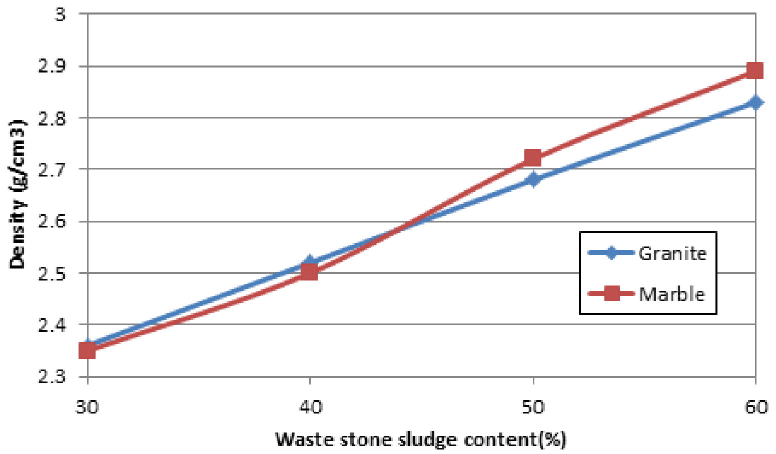

Figure 4. Effect of sludge content on density.

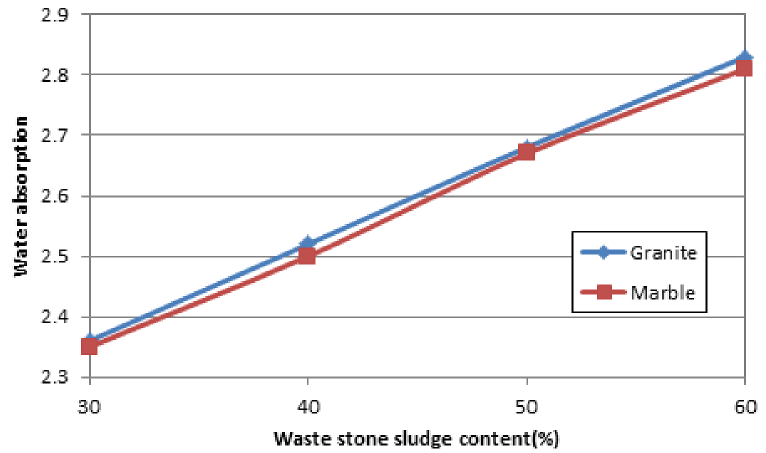

Figure 5. Effect of sludge content on water absorption.

3.2. Flexure, compressive and tensile strengths

Figure 6 represents the effect of the sludge content on the flexure, compressive, and tensile strengths of the samples made from the granite sludge. It can be seen that all of these three strengths decreased with increase in the sludge content. By increasing the sludge content from 30 to 60%, the flexure strength decreased from 64.26 to 40.32 MPa (37% relative reduction), the compressive strength decreased from 115.69 to 90.29 MPa (22% relative reduction), and the tensile strength decreased from 45.46 to 35.78 MPa (21% relative reduction). This means that the sludge content has more effects on the flexure, compressive, and tensile strengths.

Figure 7 shows the effect of the sludge content on the flexure, compressive, and tensile strengths of the samples made from the marble sludge. It can be seen that all the three strengths decreased with increase in the sludge content. By increasing the sludge content from 30 to 60%, the flexure strength decreased from 60.50 to 40.52 MPa (33% relative reduction), the compressive strength decreased from 105.69 to 75.61 MPa (28% reduction), and the tensile strength decreased from 40.91 to 30.7 MPa (25% reduction). This means that, like the granite samples, the sludge content has more effect on the flexure, compressive, and tensile strengths.

Lee et al. (2008) have made an artificial stone with a highly compressive strength of 148.8 MPa, a water absorption of less than 0.02%, a density of 2.445, and a flexure strength of 51.1 MPa from waste glass (40%), stone fragments (60%), and unsaturated resin (8%) [14]. They used the crushed granite fragments in three categories (4, 2, and 0.6 mm in diameter) and a very high compaction pressure of 14.7 MPa, while a very fine stone sludge (100% passing 100 µm) and a low compaction pressure of 12 MPa were used in the present work.

Chang et al. (2010) have made an artificial stone with a low compressive strength of 29.4 MPa and a water absorption of less than 0.1% from the waste stone sludge (35%), waste silt (50%), and pozzolanic cement, as the binder (15%) [15]. Similar to the present work, they used fine materials (100 passing 600 µm) and a low compaction pressure of 49 MPa. However, they used the pozzolanic cement as the binder.

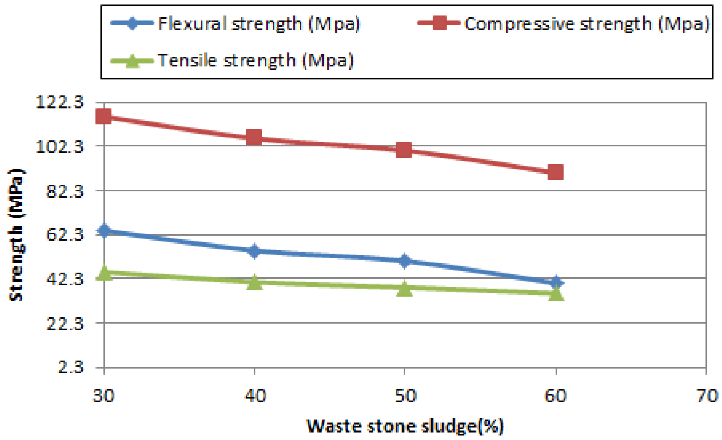

Figure 6. Effect of sludge content on flexural, compressive, and tensile strengths of granite samples.

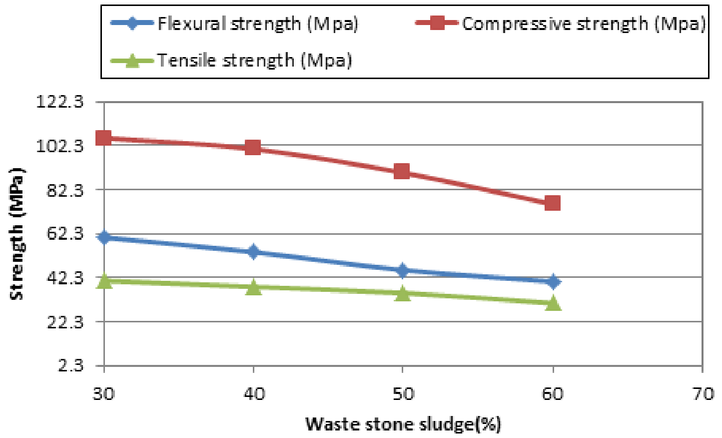

Figure 7. Effect of sludge content on flexural, compressive, and tensile strengths of marble samples.

4. Conclusions

In this work, we successfully manufactured artificial stones from waste granite and marble stone sludge, ground quartz powder, ground waste glass, and an unsaturated polymer resin by the vibratory compaction method. Under a compaction pressure of 12 MPa, a vibration frequency of 30 Hz and vacuum conditions at 50 mm Hg, the artificial stone slabs of densified structures were obtained.

The results obtained showed that, for both stone sludge samples, water absorption and density decreased with increase in the content of waste stone sludge, and the flexure, compressive, and tensile strengths decreased with increase in the content of the waste stone sludge.

By combining 50% of stone sludge, 12% of ground quartz, 25% of waste glass, and 13% of resin under a compaction pressure of 12 MPa, a vibration frequency of 30 Hz, and vacuum conditions at 50 mm Hg, the artificial stone slabs with a water absorption of less than 0.64, a density less than 2.68, a flexure strength ofmore than 45 MPa, a compressive strength ofmore than 90 MPa, and a tensile strength ofmore than 35 MPa can be obtained.

The artificial stone slabs obtained in this research work had a good density, water absorption, and flexure, compressive, and tensile strengths compared to the natural stones, making them ideal construction materials for covering walls or paving floors.

The artificial stone slabs obtained in this research work had a good density, water absorption, and flexure, compressive, and tensile strengths compared to the natural stones, making them ideal construction materials for covering walls or paving floors. Recycling waste stone sludge into construction materials not only creates brand-new products for use but also offers an ecological and economic alternative for waste treatment.

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تولید سنگ مصنوعی با استفاده از پودر لجن سنگ‌های گرانیتی و مرمریتی

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چکیده:

در این تحقیق با استفاده از پودر لجن به‌دست‌آمده از فرآیند برش سنگ‌های گرانیتی و مرمریتی در کارخانه‌های سنگ‌بری، اسلب‌های سنگ مصنوعی تولید شده است. پودر لجن به همراه پودر کوارتز، خرده‌شیشه، رزین و رنگ‌دانه به نسبت‌های مختلف ترکیب و سپس تحت شرایط ارتعاش، فشار، خلأ و عملیات حرارتی اسلب‌های سنگ تولید شده است. نتایج این تحقیق نشان می‌دهد که با افزایش مقدار پودر لجن در ترکیب سنگ، میزان جذب آب و دانسیته سنگ افزایش و مقاومت خمشی، برشی و فشاری کاهش می‌یابد. نتایج همچنین نشان می‌دهد که با ترکیب شامل ۵۰ درصد پودر لجن، ۲۰ درصد پودر کوارتز، ۲۵ درصد خرده‌شیشه ضایعاتی و ۱۳ درصد رزین چسباننده در فشار ۱۲ مگا پاسکال، فرکانس ارتعاشی ۳۰ هرتز، فشار خلأ ۵۰ میلی‌متر جیوه، می‌توان اسلب‌های سنگ مصنوعی با میزان جذب آب کمتر از ۰/۶۴، دانسیته کمتر از ۲/۶۸، مقاومت خمشی بیشتر از ۴۵ مگا پاسکال، مقاومت فشاری بیشتر از ۹۰ مگا پاسکال و مقاومت کششی بیشتر از ۳۵ مگا پاسکال تولید کرد. به‌طورکلی اسلب‌های سنگ مصنوعی به دست آمده در این تحقیق در مقایسه با سنگ‌های طبیعی دارای شرایط فیزیکی و مکانیکی مناسب‌تری هستند و می‌توان از آن‌ها به‌عنوان مصالح ساختمانی جهت پوشش دیوارها و کف ساختمان استفاده کرد.

کلمات کلیدی: پودر لجن سنگ، سنگ مصنوعی، بازیافت باطله.