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Suitability of Egyptian ornamental stone calcite wastes as non-conventional aggregates in concrete

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Abstract

The objective of this study is to investigate how the use of ornamental stone calcitic wastes as aggregate affects the mechanical properties and durability of concrete when exposed to high temperatures up to 600ºC. The concrete compositions consisted of different types of coarse aggregates: dolomite (control), calcite, and granite. A super plasticizer (SP)-type (F) was employed to lower the water/cement ratio. The physical and mechanical properties of the raw aggregates were determined, and the same properties were analyzed for the various concrete types. The impact of fire exposure up to 600ºC on the mechanical properties and microstructures of the concrete was also investigated .The results indicated that concrete mixes composed of 50% dolomite and 50% calcite, as well as 75% dolomite and 25% granite aggregate, satisfy the compressive strength requirements for normal concrete after a 28-day. When compared to the control concrete (D100), the chloride ion migration coefficient and water penetration depth slightly increased in concrete containing granite and calcite waste aggregates. Subsequently, at exposure temperatures of 300ºC, 400ºC, and 600ºC, the compressive strength values of concrete mixes incorporating granite and calcite waste aggregates exhibited a slight decrease in comparison to the control concrete (D100).

Keywords: calcitic wastes, fire resistance, granite aggregate, calcite aggregate, compressive strength, microstructure.

1. Introduction

The ornamental stone industry plays a crucial role in the Egyptian economy and is also significant for the most developed countries worldwide. Egypt annually produces approximately 3.2 million tons of ornamental stone and exports around 1.5 million tons of raw materials [1]. This industry relies on population growth and the construction of new urban cities, which leads to an increase in the variety and quantity of building materials. Consequently, there is a significant amount of solid waste generated, resulting in notable environmental impacts on the surrounding areas.

During the extraction, sizing, and polishing processes of ornamental rocks, approximately 20% to 30% of waste materials are produced relative to the overall production volume [2]. The ornamental solid waste materials from the Shaq Al-Thoaban area consist mainly of calcitic and granitic compositions. Two types of solid waste are generated in the Shaq Al-Thoaban industrial area: rock cutting powders (Sahala wastes) and reject crushed slabs (Solid Slab wastes). Unfortunately, these waste materials are often indiscriminately dumped near the industrial area due to the lack of a viable disposal alternative.

The long-term dumping of these waste materials creates adverse environmental impacts and poses significant hazards to human health. Additionally, it contradicts the sustainable development plans of developed countries. Therefore, it is essential to propose valuable solutions to transform these wastes into by-products and restore their economic value [3].

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Nowadays, recycling of these waste materials has a global concern, and many research studies explore the new applications with using auspicious technologies for conservation of resources, sustainable development and environment management. One such application involves recycling ornamental waste materials in the construction industry, particularly as fine and coarse aggregates to replace traditional aggregates like sand and gravel in concrete, as well as in the cement industry. Binici et al. [4] concluded that incorporating coarse marble aggregate in concrete improves its workability, chemical resistance (higher resistance to chloride and sulfate attack), and mechanical strength compared to conventional concrete mixtures. From an economic and environmental perspective, these recycled aggregates can be used to produce more durable concrete mixtures. Furthermore, Hebhoub et al. [5] investigated the potential use of coarse marble waste material as a coarse aggregate in concrete, specifically examining its impact on concrete durability and workability. They found that replacing conventional coarse aggregate with coarse marble aggregate enhances compressive and tensile strengths, reduces water absorption, and improves workability, thus making this waste material suitable as a concrete aggregate. Belachia and Hebhoub [6] utilized coarse waste marble as aggregate in concrete at various ratios (0%, 25%, 50%, 75%, and 100%) and evaluated the rheological properties of fresh concrete as well as the mechanical strength of hardened concrete. They discovered that the highest strength concretes were achieved with a 25% replacement rate, while the maximum concrete density was obtained with a 50% replacement rate. Therefore, marble waste aggregates can be used as alternative concrete aggregates due to their economic aspect. Shaheen and Aziz [7] assessed the recycling of waste concrete and limestone slabs resulting from the extraction and sizing of ornamental raw limestone blocks as aggregates in concrete production. They evaluated the characteristics of fresh and hardened concrete, such as slump, compressive strength, flexural and splitting strengths, and modulus of elasticity. Recycled aggregate concrete exhibited higher absorption values compared to natural aggregate concrete, making it suitable for use in lightweight building structures. However, the recycled aggregate concrete had lower mechanical strengths, elastic modulus, slump, and density. André et al. [8] assessed the influence of replacing primary aggregate with marble aggregate (at ratios of 20%, 50%, and 100% of the total volume of aggregates in concrete mixture) on the workability, density, compression strength, water absorption, carbonation, and chloride penetration characteristics of concrete. They concluded that there were no significant differences in durability between conventional concrete mixtures and concrete mixtures containing coarse marble aggregate, demonstrating that using coarse marble waste aggregate as a concrete aggregate is feasible. Uygunoğlu et al. [9] evaluated the use of coarse marble waste aggregate instead of limestone aggregate in self-consolidating concrete. They reported that the workability properties of self-compacting concrete, such as flowability, blocking resistance, and segregation resistance, improved when pieces of coarse marble waste aggregate were used instead of limestone aggregate. Therefore, marble waste aggregate can be employed in the production of self-consolidating concrete, promoting the sustainability of buildings and the environment. Alyamac and Tugrul [10] observed that by utilizing marble waste materials (dust and broken fragments) as alternatives to conventional fine and coarse aggregates in concrete production, it is possible to obtain durable, aesthetically pleasing, and eco-friendly concrete. Gameiro et al. [11] evaluated the workability characteristics of concrete when normal concrete aggregates were replaced with waste materials obtained from marble quarries at different ratios (0%, 20%, 50%, and 100%). They found that the addition of marble aggregate reduced water absorption, and concrete with marble aggregates exhibited better performance compared to concrete with normal fine sand aggregates, particularly in the range of 50-100%. Ahmed et al. [12] investigated the possibility of recycling quarrying marble and granite rock fragments in concrete production as a full replacement for natural gravel in concrete mix. They evaluated the physical, mechanical, and chemical properties of the new concrete mixes and found that the compressive strengths after 28 days of curing were 262 Kg/cm2 and 272 Kg/cm^2 for marble and granite aggregates, respectively. They concluded that these recycled coarse aggregates can be used in concrete production instead of natural gravel and are suitable for constructing ordinary buildings. Elçi et al. [13] assessed the suitability of using limestone waste aggregate as a complete substitute for conventional aggregate in normal strength concrete production. They suggested that this limestone waste aggregate can be effectively used in the production of normal concrete with compressive strength less than 42 MPa.

Arel [14] studied the recycling of ornamental marble waste in concrete, replacing both cement and aggregate. It was assumed that replacing conventional aggregates in concrete with ornamental marble waste increases compression strength and improves concrete workability. Additionally, using marble waste materials in concrete production resulted in a 12% reduction in CO2 emissions and a decrease in concrete cost from 40$/m^3 to 33$/m^3.

Kore and Vyas (15) examined the potential use of coarse marble waste as a substitute for conventional coarse aggregate in concrete production. They conducted various experimental tests, including compaction factor, compressive strength, permeability, acid resistance, and microstructure analysis through X-ray diffraction. The findings indicated that the workability of concrete incorporating marble aggregate increased by approximately 14% compared to conventional concrete. Moreover, the average compressive strength values exhibited a significant improvement of 40% and 18% at 7 and 28 days, respectively. From an economic and environmental standpoint, the utilization of coarse marble aggregate was deemed beneficial in enhancing the mechanical properties of traditional concrete mixes. Rana et al. (16) conducted a review on the feasibility of utilizing waste from dimensional stones such as marble and granite in concrete. They investigated various parameters related to workability, strength, and durability, including permeability, chloride migration, porosity, water absorption, carbonation, acid resistance, and sulfate resistance. Their study suggested that the conventional aggregates in concrete mixes could be entirely substituted with coarse marble and granite waste aggregates to produce durable concrete with satisfactory strength. Tunc (17) examined the impact of ornamental marble waste on the compressive and splitting tensile strengths of concrete. The study revealed that incorporating waste marble materials in specific proportions, instead of coarse/fine aggregates, cement, and admixture materials, resulted in the production of high-strength concrete. Gonçalves et al. (18) examined the physical and mechanical characteristics of concrete by replacing coarse aggregate with residues from the cutting process of marble and granite. Replacement rates of 40% and 60% were tested. The results indicated that substituting conventional coarse aggregate with marble and granite aggregates of size 9.5 mm led to a 9.68% and 11.42% increase in compressive strength, as well as a 6.20% and 7.02% increase in tensile strength for the respective replacement rates. Although a slight rise in water absorption was observed, the authors suggested that these recycled aggregates could be effectively utilized in concrete production. Hashmi et al. (19) investigated the incorporation of marble waste aggregates and stone dust as replacements for coarse and fine aggregates in concrete production, respectively. The study assessed various aspects such as physical properties (workability and absorption), durability (acid resistance), and strength properties (compressive, flexural, and tensile strengths) of concrete mixes containing 10-30% coarse marble aggregate. The results indicated that an increase in the substitution of coarse marble aggregate led to improved workability, reduced absorption, decreased resistance to acid attacks, and lower strength characteristics (compressive, flexural, and tensile strengths) compared to the controlled conventional concrete.

Wu et al [20] studied the effect of the coarse aggregate type on the compressive strength, splitting tensile strength, fracture energy, characteristic length, and elastic modulus of concrete produced at different strength levels with 28-day target compressive strengths of 30, 60, and 90 MPa, respectively. Concretes considered in this paper were produced using crushed quartzite, crushed granite, limestone, and marble coarse aggregate. The results show that the strength, stiffness, and fracture energy of concrete for a given water/cement ratio (W/C) depend on the type of aggregate, especially for high-strength concrete. It is suggested that high-strength concrete with lower brittleness can be made by selecting high-strength aggregate with low brittleness.

Willam et al., [21] examined the interaction of thermal and mechanical damage processes in heterogeneous materials such as concrete. After a brief introduction of high temperature effects in concrete, we address two topics: (a) the interaction of thermal and mechanical damage at the micromechanical level of observations, when volumetric and deviatoric degradation take place simultaneously; (b) the effect of thermal expansion and shrinkage in the two-phase concrete material when thermal softening of the elastic properties leads to massive degradation of the load resistance.

The primary objective of this study is to assess the impact of substituting conventional concrete aggregates with coarse solid ornamental waste materials (Solid Slab wastes), and studies the physical and mechanical properties on concrete containing ornamental stone calcite as well as it applied in some applications such as fire resistance and water, chloride penetration, and water.

2- Materials and Methods

Shaq Al-Thoaban area is the main industrial zone for processing the ornamental stones in Egypt. The rock blocks are cut into slabs by using water-cooled industrial saws in more than 500 enterprises in the area (Figs. 1a, b). During the cutting and polishing processes, the rock dust is mixed with the saws cooling water then drained through artificial pathways into storing tanks. The dust-water sludge is collectively termed as "Sahala" that stored in tanks until pumped-out and even filter pressed (Fig. 1c) or drained-off into the surrounding landfills, natural water resources, subways and sewage networks causing hazardous environmental problems. The "Sahala" powder sludge is termed by the local workers as "Sahala Beyda" and "Sahala Sowda" when being white and black, respectively. In most of the enterprises, these two waste samples are gathered in two separated tanks, while in others, they are collectively gathered in the same tank and called then "Sahala Mix".

Another prominent wastes in Shaq Al-Thoaban area are the cuttings and shreds of the rock slabs that result during the cutting process (Fig. 1d). There are two local names given to these cutting wastes: "Calcitic Cuttings" (CC) and "Granitic Cuttings" when being white and rose black, respectively. Eighteen single calcitic cutting samples (C1- C18), about 150kg each, have been collected representing all the "white" shreds all over the area. These single samples were mixed to be represented by one technological sample will be referred as (CS). To determine the detailed mineral content of the samples, X-ray diffraction (XRD) analysis was conducted. Prior to analysis, each sample underwent grinding using a planetary ball mill (Pulverisette 6, Fritsch, Germany) and was then sieved to ensure a particle size of ≤63 µm. The X-ray diffraction measurements were carried out using. A Cu-Kα source with a post sample Kα filter was used for XRD analysis using a Philips PW1050/70 Diffractometer. From 0° to 50° 2θ (step size 0.02° 2θ and speed 0.4° θ/min), XRD patterns were obtained. As an internal standard, silica was used. The XRD software was used to identify the data (pdf-2: database on CD-Release 2005). A laser scattering particle size distribution analyzer was used for particle size analysis (Horiba LA-950, Kyoto, Japan). The thermal behavior of the calcitic cutting samples was investigated through thermal analysis using the TGA (Thermogravimetric Analysis) method. Thermogravimetric Analysis (TGA) on a dried sample in a nitrogen atmosphere (TGA-50 (Schimadzu Co. Tokyo, Japan)) was performed on a sample of roughly 15 mg with a heating rate of 20oC/min. FTIR (Fourier Transform Infrared) spectra of the samples were obtained using an FTIR Bruker Vertex 70 spectrometer, at a weight ratio of KBr: specimen = 200:1, the test sample was pulverized and uniformly mixed with KBr. The 0.20 gmixture was squashed into a 13 mm diameter disc for examination at 8 t/cm2. The wave number varied between 400 and 4000 cm−1.

X-ray fluorescence (XRF) was employed for the chemical analysis of the collected samples. Table (1) Chemical composition of selected calcitic cutting samples. The size distribution of the crushed calcitic cutting samples were achieved applying ASTM D5444 – 15 using dry sieving as well as laser particle sizer ANALYSETTE 22 NeXT Nano - Fritsch. The microstructure of the collected calcitic cutting samples have been achieved through identifying thin section using polarizing research microscope equipped with camera (Nikon, United states). These investigations were determined under polarized and analyzed light (Ppl and Xpl). Un-covered thin sections were microstructurally studied by SEM attached with Energy Dispersion X-ray (EDX) module and PC terminal to analyze the elemental compositions and digitalize the image of sample microstructure.

Concrete mixes were mixed using a 180 kg pan mixer (2a). The mixing procedure of cement and aggregates used can be described as follows: (a) before adding the cement and aggregates, the paddles and pan of the mixer were moistened using a damp cloth. (b) The procedure involved adding approximately half of the coarse aggregates, followed by the entire fine aggregate, and finally the remaining coarse aggregate into the pan. (c) The coarse and fine aggregates were mixed together for approximately two minutes. (d) Within the next 15 seconds, half of the total volume of water was added. (e) The aggregates were then mixed in the mixer pan for three minutes. (f) The ordinary Portland cement (OPC) as the binder material and the superplasticizer were evenly added over the aggregates in the pan while continuous mixing occurred for 30 seconds. The mixer was briefly stopped to scrape off any material adhering to the paddles, after which mixing resumed. The remaining water was added within the next 30 seconds. Mixing continued for an additional 3 minutes after all the materials were added. Once the mixing was complete, the concrete was turned over several times in the pan mixer using a trowel to ensure uniformity.

The fresh mixes underwent workability testing through the slump test, following the guidelines of ASTM C143-010 (Fig. 2b). To assess the workability of the concrete in its fresh state, the slump test was conducted in accordance with BS EN 12350-2, 2009. To prevent the leakage of bleed water and cement paste, the joints of the steel molds were sealed with a thin layer of silicone sealant before casting. Additionally, a light coat of mold release agent was applied to the molds. The fresh concrete mixes were then poured into cubic steel molds measuring 10 cm × 10 cm × 10 cm (Fig. 2c). Following demolding, the cubes were submerged in tap water at 7, 28 and 90 28 days, and compressive strength tests were taken. The crushed samples at each hydration period were ground first, then stopped the hydration process using a 1:1 by volume combination of acetone and methanol, followed by drying at 80 ºC for 24 hours to avoid extra hydration, and then the samples were retained in desiccators for future investigation. The curing procedure outlined in ASTM C511-09.

The measurements of compressive strength were performed using a 2000 KN compression testing machine, applying a loading rate of 0.60 MPa/s (Fig. 2d), in accordance with the guidelines of BS EN 12390-3, (2001). The compressive strength of all specimens was determined at the ages of 7, 28, and 90 days, following the specifications outlined in ASTM C109/C109 M-16a [22]. The split tensile test is an indirect way of evaluating the tensile test of concrete. In this test, a standard cylindrical specimens is laid horizontally, and the force is applied on the cylinder on the surface which causes the formation of a vertical crack in the specimen along its diameter. Tensile strength=2p/πdl, Where, P= Crushing load (Newton – N) L= length (mm), d=diameter (mm).

The water penetration depth and rapid chloride permeability (RCPT) of the concrete cubes was determined (Fig. 2e). The depth of penetration of water under pressure on hardened concrete in accordance with BS EN 12390-8. The test is performed on cylindrical samples with surface dimension 150 mm. To assess the resistance of concrete prepared with chloride binders to chloride ingress, RCPT was performed on triplicate specimens from each mixture cured for 28 days as per ASTM C 1202-2019. Specimens were 100×50 mm disks placed between two compartments (one cathodic with 0.5M NaOH solution and the other is anodic with 3% NaCl solution) and subjected to a voltage of 60 V for 6 h. At the end of testing, the calculated total passing charge provides an indication on the ease of fluid ingress through specimens as indicated in Table 2 with lower values implying higher resistance to penetration. The valuate of the alkali-silicate reaction (ASR) according to ASTM C1260-14; (Fig. 2f) [23, 24, 25].To investigate the impact of various temperatures on the properties of hardened concrete, concrete cubes were prepared. Following a curing period of 28 days in tap water, the specimens were subsequently dried at a temperature of 105 ± 5ºC for 24 hours. The samples of hardened concrete were exposed to different temperatures at 200, 300, 400 and 600ºC in a muffle furnace having maximum temperature of 1200ºC. The samples were placed unloaded in the furnace chamber and the temperature was increased with a rate of 5ºC/min., till reaching the target temperature.

After being maintained at the target temperature for 2h, the hardened concrete specimens and the furnace were allowed to cool down to room temperature. Subsequently, the specimens were subjected to various tests.

Figure 1: Ornamental stone blocks are transported from the store house to be processed (a); the blocks are cut by industrial saws (b); ("Sahala" after pressing by filter press (c) and Cuttings and shreds in the work environment (d) in Shaq Al-Teaban industrial zone.

Figure (2): Concrete pan mixer and casting molds (a), slump test (b), cast concrete cubes (c), compressive strength machine (d), rapid chloride permeability testing (RCPT) (e) and alkali-aggregate reaction testing setup (f).

Table (1): Chemical composition of selected calcitic cutting samples

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	SO_3	P_2O_5	Cl^-	LOI
C4	0.68	0.25	0.09	55.90	0.30	0.06	0.07	0.00	0.06	0.03	0.03	42.40
C5	0.70	0.23	2.75	54.00	0.31	0.06	0.08	0.00	0.08	0.06	0.03	41.60
C6	0.15	0.05	0.00	56.00	0.17	0.00	0.04	0.00	0.03	0.04	0.02	43.00
C7	0.33	0.17	0.00	55.00	0.69	0.05	0.05	0.00	0.03	0.01	0.02	43.29
C8	0.24	0.07	0.02	56.00	0.32	0.00	0.06	0.00	0.20	0.00	0.02	42.90
C9	0.40	0.10	0.05	56.00	0.23	0.02	0.05	0.00	0.04	0.02	0.01	42.61
C10	2.17	0.66	0.23	54.00	0.94	0.19	0.10	0.06	0.02	0.04	0.02	41.40
C11	0.59	0.20	0.19	56.08	0.51	0.07	0.05	0.00	0.05	0.02	0.00	42.10
C14	4.04	1.35	0.91	54.10	0.42	0.53	0.14	0.17	0.04	0.02	0.00	38.20
CS	1.03	0.34	0.47	55.23	0.43	0.11	0.07	0.03	0.06	0.03	0.02	41.94

Table 2 Chloride ion penetrability based on charge passed (ASTM C1202, 2019).

Charge passed (Coulombs)	Chloride ion penetrability
> 4000	High
2000-4000	Moderate
1000-2000	Low
100 – 1000	Very low
< 100	Negligible

3. Results and Discussion

3.1. Raw material characterization

3.1.a. XRD analysis

The XRD diffractograms show the identified minerals of the collected (CC) waste samples. Calcite is the main mineral (Pdf 96-702-2028) (72.20-100.00 wt. %) with minor dolomite (Pdf 96-900-4930) (1.70-95.70 wt. %) in most samples except for C12 sample where dolomite is the main mineral (Fig. 3). The thermal analysis of the samples confirms the detailed mineral contents determined by XRD (Fig. 4). The CC wastes begin to thermally decompose beginning from 650°C with the maximum decomposition at 850°C (Fig. 4). The average mass loss is ranged between (32.02-39.85wt.%) that occurring at a temperature range from 840 to 877°C is due to the calcite and dolomite decomposition.

3.1.b. Optical and chemical analyses

The IR analysis of the CC waste samples confirms the existence of the $(CO_3)^{-2}$ function group in both the calcite and dolomite minerals with the absence of any organic function group (Fig. 5). The calcitic wastes are dominated by CaO (54-56wt.%) and LOI

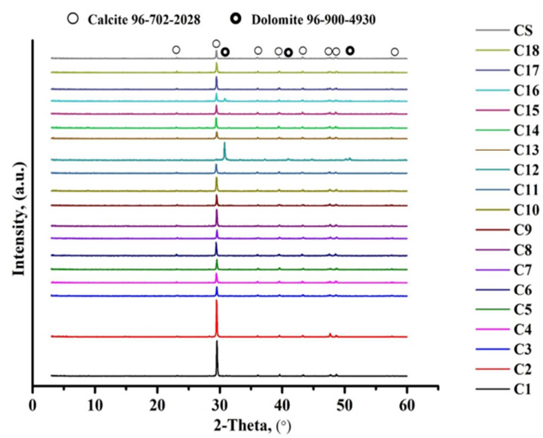

Figure (3): XRD of the CC waste samples along the main and sub-roads in Shaq Al-Teaban industrial zone.

(35.40-43.29wt.%). The minor contents of MgO (0.17-0.94), SiO_2 (0.15-4.04), Al_2O_3 (0.05-1.35), Fe_2O_3 (0.00-2.75), alkalis (0.00-0.53), TiO_2 (0.00-0.17), SO_3 (0.03-0.20), P_2O_5 (0.00-0.06) and Cl (0.00-0.03wt.%) would refer to inclusion of Mg in the calcite lattice and the existence of least content of free silica, i.e., quartz, clays as well as iron oxides in the CC samples. Figure (6) shows the grading curves for sand and dolomite aggregates as well as calcite samples after their crushing in jaw crusher (Pulverisette 1, Fritsch, Germany) where 50 wt. % of the grain size is 9 mm. The crushed material will be used as grain aggregates in concrete application.

3.1.c. Petrographical analysis

Compositionally, sample 1 is dominated by allochems (50%) relative to orthochems (45%) (Figs. 7a-c). Micrite is the main orthochem (80%) while neomorphic sparite is recorded in lower concentration

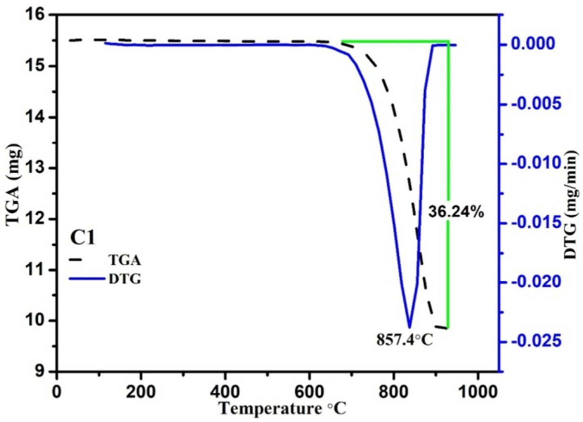

Figure (4): TGA-DTG of C1 sample.

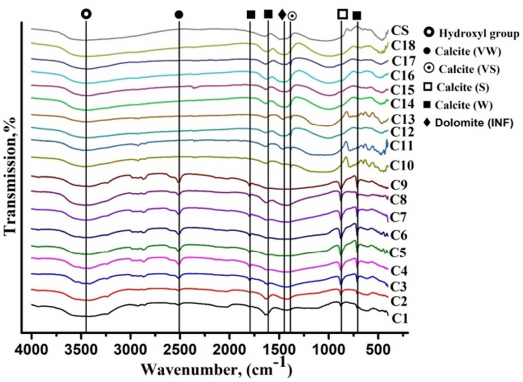

Figure (5): IR curves of selected CC waste samples.

(20%) (Fig. 7d) than micrite. On the other hand, allochems are represented mainly by skeletal grains, most of which are small and large forams, echinoid, bryozoan and pelecypod fragments, algae, carbonate clasts and other skeletal debris (Figs. 7a-c). The non-skeletal allochems are not recorded. The noncarbonate components (5%) are made up mainly of argillaceous materials, iron oxides and quartz grains (Figs. 10-13). Texturally, most of the allochems are re-crystallized, gravely sized (20%) as well as very coarse (40%), coarse (10%) and medium (30%) sand-sized (Figs. 7a-c). The allochem roundness belongs to different categories, these are: without roundness (Class I), i.e., angular, (20%); moderately-rounded (30%) (Class II) and rounded (50%) (Class III). In addition, most allochems display no contacts (Figs. 7a-c), however, point and tangential contact packing appear in places (Figs. 7a-c). The dominant pore shapes are intraparticle fabric-selective pores (Fig. 7e) as well as micro-fractures as not fabricselective pores (Figs. 7f). Based on the above detailed petrographic description, the average petrographic composition domains the calcitic cuttings samples could be biomicrite – wackestone. Mineralogically, the average sample mineral composition is composed mainly of calcite with scattered iron oxides and quartz grains in places.

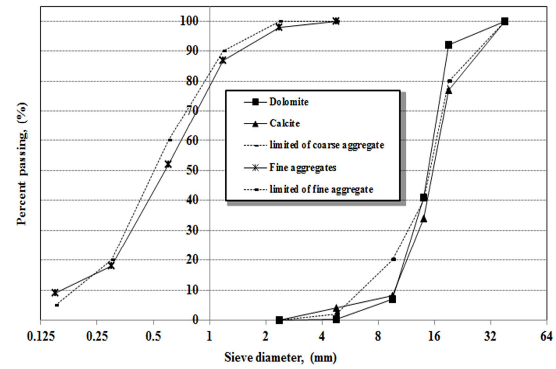

Figure (6): Sieve analysis of coarse and fine aggregates.

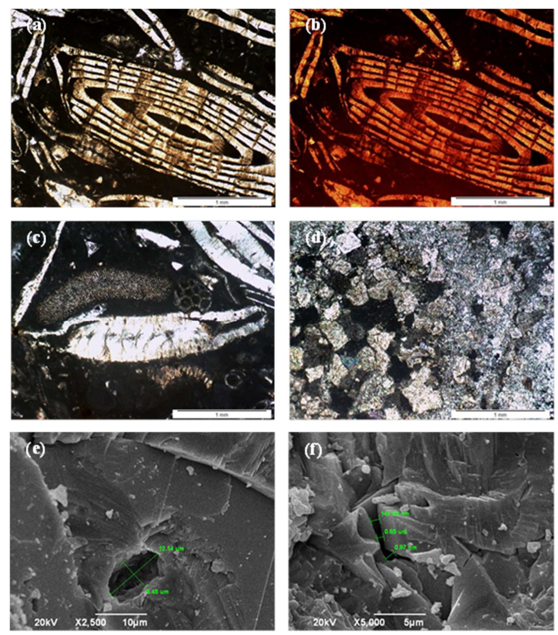

Figure (7): Photomicrographs showing the bio-micrite (wackestone) in TLM (XN) (a) and CL (b); the mud-supported limestone in TLM (XN) with echinoid plates and bryozoan fragments floating in micritic groundmass (c); the pore filling recrystallized sparite in places (d); intra-particle (e) and microfracture pores (f) in the allochems and groundmass, respectively

3.2. Physico-mechanical properties of concrete mixes containing calcite aggregate

3.2.1. Mechanical properties

The concrete design includes crushed CC aggregates, ordinary Portland cement (OPC - CEM1-42.5 N) as the binding material. Its particle size analysis and median size were ~ 34.565 µm and ~ 27.262 µm, respectively. The crushed dolomite as control coarse aggregates sourced from Suez Cement Company and Attaqa quarry area respectively. Manual sieving was employed to separate the coarse aggregates into different fractions (5-20 mm) following ESS 1109 and ASTM C637 standards. The fine aggregate used in the mixture is local sand, which was washed at the site to eliminate harmful substances and chloride contamination. Table (3) presents the physical and mechanical properties of the coarse aggregates and their fine portion, evaluated in accordance with the specifications outlined by ESS 1109 and ASTM C637.

The concrete mixes were assessed to have a free water content equivalent to approximately 35% of the total binder, in addition to the water absorbed by the coarse and fine aggregates. Achieving a high level of workability and significantly reducing the amount of mixing water is only possible through the application of a superplasticizer. The specific compositions of the designed concrete mixes can be found in table (4).

The workability of the concrete mixes can be evaluated by measuring their slump. Table (5) provides the slump values and unit weight of the fresh concrete mixes, namely D100, C100, D50-C50, and D75-C25. The results indicate that the mixes containing dolomite aggregate (D50-C50 and D75-C25) exhibit higher workability, with slump values of 17cm and 18cm, respectively, compared to the mix comprised solely of CC aggregates (16cm) (Table 5). Consequently, increasing the content ratios of dolomite aggregate enhances the workability, with the D100 mix demonstrating optimal workability at 19cm (Table 5). The enhancement of the mixes workability is attributed to the fact that dolomite aggregates have lower water absorption (0.79) while the CC aggregates are more porous (Figs. 7e and f) and have higher water absorption (1.30%) (Table 3). The mixes containing dolomite aggregates give the higher unit weight (2.32-2.34) more than the concrete mixes containing CC aggregates (2.30), consequently D100 mix is of the maximum unit weight (2.38ton/m^3). This is due to the higher density of the dolomite (2.71) compared with the CC aggregates (1.46 ton/m^3) (Table 3). Table (5) presents the physico-mechanical properties of the concrete cubes that were cured in tap water for 7, 28, and 90 days. The compressive (CS) and tensile strength (TS) of the cubes increase with curing time in the sequence D100> D75-C25> D50-C50> C100 (Table 5 and Fig. 9). The latter physical characteristics of D100 cubes increase by (23.40, 14.89, 10.64); (18.60, 15.10, 9.30) and (3.00, 1.50, 0.75%) when compared with the concrete cubes of C100, D50-C50 and D75-C25 at the curing age of 28 days. The obtained results indicate that latter characteristics of the concrete cubes of D100 decrease by (35.25, 16.39, 4.92) and (21.56, 37.16, 24.54) when compared with those of C100, D50- C50, D75-C25 at the curing age of 28 days. This consequently refers to the decrease of the CS and TS are diluted with the CC aggregates. However, all these characteristics are in the acceptable ranges for concrete applications (Table 5). The changes observed in the physico-mechanical properties of the concrete cubes over time can be primarily attributed to the progression of cement hydration. As the curing time increases, there is a greater accumulation of hydration binding phases, which fill up the available pores within the concrete matrix. Consequently, this leads to an increase in compressive strength (CS), tensile strength (TS) (Fig. 8). The microstructure of the CC aggregates would interpret the physico-mechanical characteristics of the cubes containing the CC aggregates. The micrite content as calcite mud groundmass in the CC (80%) would work as a natural filler for the aggregate pores resulting in lower pores in the CC aggregate groundmass (Fig. 7a-d). In addition to micrite, the aggregates internal textural characteristics refer to the content of angular allochems (20%) (Figs. 7a-d). These angular grains would increase the surface area between the allochems and the infiltrated cement inside the CC aggregates leading consequently to increase the intra-aggregates hydration binding phases. In addition, the clays content of the CC aggregates (2.80wt.%, Table 3) would as well increase the intraaggregates hydration binding phases due to their possible dissolution in the alkaline medium of the cement (pH>7) resulting in extra hydration binding phases.

3.2.2. Water penetration depth under pressure

Water permeability in concrete, which indirectly indicates the depth of water penetration under pressure, is influenced by the type of concrete used. Figure 9 illustrates the impact of different concrete types on water absorption. It has been observed that incorporating waste materials such as granite and calcite into the aggregate concrete mixtures results in a slight increase in water permeability compared to control concrete mixes. Specifically, at 28 days of age, the concrete mixes containing granite (D75-G25) and calcite waste aggregates (D50-C50) exhibited increases in water permeability of 9% and 4% respectively, in comparison to the control concrete mix (D100).

Table (3): Physical properties of the fine and coarse aggregates used in the concrete mix design

Physical & mechanical properties	Sand	Dolomite	Limestone	Limits of coarse aggregates
Specific Gravity, (g/cm^3)	2.65	2.60	2.71	-
Unit Weight, (ton/m^3)	1.62	2.71	1.46	-
Clay and fine materials, (%)	1.40	0.38	2.80	≤ 4 (1) ≤ 10 (3)
Water absorption, (%)	-	0.79	1.3	≤ 2.5 (1)
Flakiness Index, (%)	-	40.21	17.69	≤ 25 (2)
Elongation Index, (%)	-	20.38	19.80	≤ 25 (2)
Crushing value, (%)	-	-	19.19	≤ 30 (2)
Impact value, (%)	-	12.01	30.88	≤ 45 (1)

(1) According to (Egyptian Standard Specification No. 1109 2002).
(2) According to (Egyptian Code of Practice for Reinforced Concrete No. 203 2017).
(3) According to (ASTM C637 2009).

Table (4): Mix proportions for concrete per (1m^3)

Composition	Concrete ingredients, (kg/m^3)					
	OPC	Water	Fine aggregates	Coarse aggregates		SP
			Sand	Dolomite	Calcite	
D100	450	157.5	623	1246	-	8.1
C100	450	157.5	623	-	1246	9.5
D50-C50	450	157.5	623	623	623	9.2
D75-C25	450	157.5	623	935	312	8.9

Table (5): Physico-mechanical characteristics of concrete cubes

Mixes	Physical properties		Compressive strength, (MPa)			Tensile strength, (MPa)			Bulk density, (ton/m^3)			Water absorption, (%)			Apparent porosity, (%)		
	Slump, (cm)	Unit Weight, (ton/m^3)	7 days	28 days	90 days	7 days	28 days	90 days	7 days	28 days	90 days	7 days	28 days	90 days	7 days	28 days	90 days
D100	19.00	2.38	35.00	47.00	58.00	6.90	8.60	9.60	2.62	2.67	2.69	1.76	1.22	0.91	6.23	4.36	2.05
C100	16.00	2.30	28.00	36.00	41.00	4.90	7.00	7.60	2.52	2.59	2.60	2.11	1.65	1.38	7.91	5.30	2.72
D50-C50	17.00	2.32	31.00	40.00	49.00	5.30	7.30	8.10	2.55	2.63	2.64	1.87	1.42	1.13	6.78	5.98	2.55
D75-C25	18.00	2.34	32.00	42.00	53.00	5.70	7.80	8.80	2.59	2.65	2.67	1.81	1.28	1.02	6.48	5.43	2.32

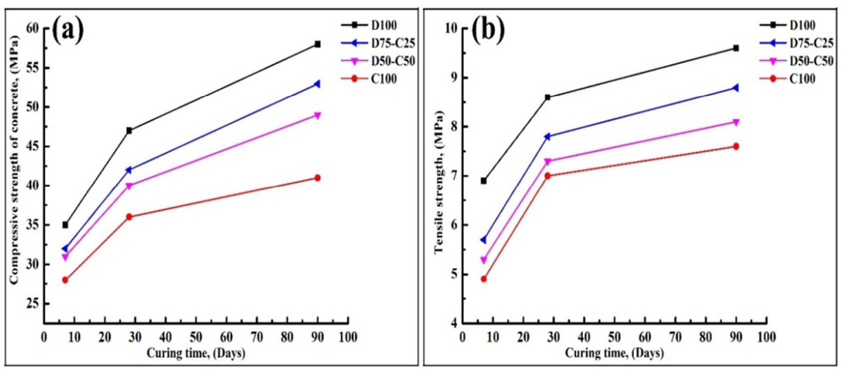

Figure 8: Compressive strength of the concrete cubes with the curing time (a); Tensile strength of the concrete cubes with the curing time (b).

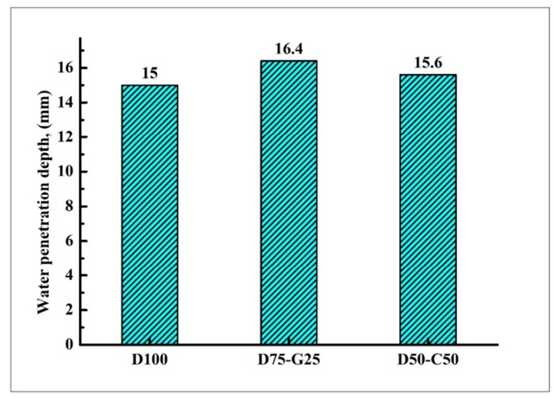

Figure (9): Effects of concrete mixes on water penetration depth

3.2.3. Chloride ion permeability

Accordance with, the cylinder specimens were subjected to the Rapid Chloride Permeability Test (RCPT). After applying 60 volts for 6 hours, the total charge passed, measured in Coulombs, was recorded. Figure (10) presents the measured values along with their corresponding standard deviations. At 28 days of age, the control concrete (D100) and the concrete mixes containing aggregates (D75-G25 and D50-C50) exhibited total charges of 2431, 2541, and 2492 Coulombs, respectively. These values categorize the concrete as having "moderate chloride permeability." The results indicated a slight increase in the chloride ion migration coefficient at 28 days for the concrete mixes incorporating granite and calcite waste aggregates compared to the control concrete (D100). The findings suggested a reduction in the total charge transmitted with the inclusion of dolomite, granite, and calcite waste aggregates. This improvement may be attributed to the enhanced microstructure of the interfacial transition zone (ITZ) and the strengthened bond between the cement and aggregates, resulting in a relatively dense and compact microstructure.

3.2.4. ASR test for the concrete cubes applying the standard test procedure.

It was important to determine the alkali-reactivity of the coarse aggregates before using them in the production of the concrete. Accordingly, the (ASTM C 1260, 2014) has been applied to the coarse aggregates, furnishing information upon their alkali-reactivity. The linear expansion reached due to the reaction between each type of coarse aggregate (dolomite and calcite) and the alkali (OH^-) formed upon cement hydration is shown in Figure (11). The test duration has been extended for 16 days to confirm the reached expansion values. It is evident that the expansion achieved while using any of the coarse aggregates, D100, D75-G25 and D50-G50 is less than the expansion limit stated by the standard specification (i. e. not exceeding 0.1 %).

3.3. Effect of temperature on concrete ageing:

The concrete cubes were heated for 2 hours at temperatures of 200, 300, 400, and 600ºC at a rate of 5°C/min. The burnt cubes' compressive strength and weight variations have been determined.

3.3.1. Residual Compressive strength

Figure (12) shows the results comparing the residual compressive strength values of concrete samples made with D100, D75-G25, and D50-C50 after being subjected to elevated temperatures up to 600^{o}C, in relation to their initial compressive strength values before heating. The findings indicate that the compressive strength values of all concrete mixtures exhibit an increase after exposure to elevated temperatures up to 300^{o}C, in comparison to their original compressive strength before heating. This can be primarily attributed to the shrinkage of specimens and the increasing of surface forces between gel particles as the absorbed moisture is driven out. However, at exposure temperatures of 400^{o}C and 600^{o}C, the compressive strength values of all concrete mixtures gradually decrease when compared to their original values before heating. This decrease in compressive strength is a result of the thermal decomposition of cement hydration products, the generation of internal thermal stresses around pores leading to micro-cracks, and subsequent thermal expansion of the specimens [21, 26].

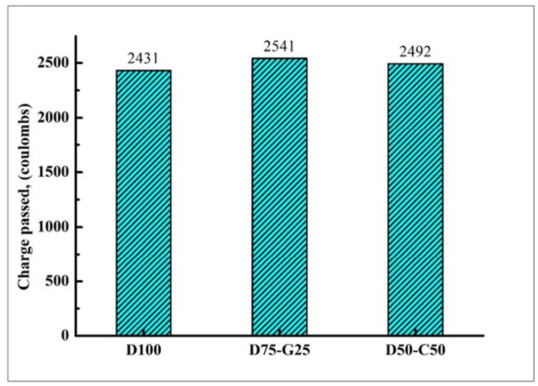

Figure (10): Chloride penetration resistance of concrete mixes at 28 days.

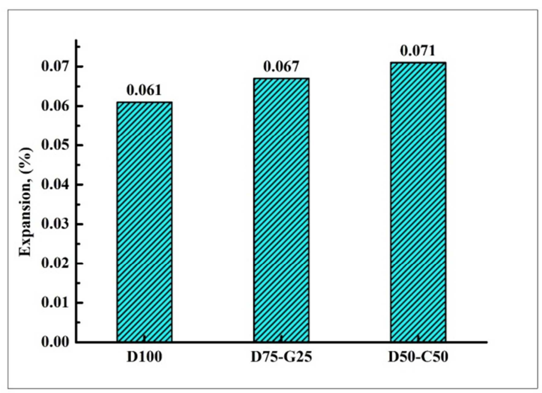

Figure (11): Linear expansion (%) of coarse aggregates after immersion in alkali for 16 days.

3.3.2. Visual inspection

Figure 13 presents the visual inspection of concrete specimens produced with D100, D75-G25, and D50-C50, which were subjected to different firing temperatures (200°C, 300°C, 400°C, and 600°C) for a duration of two hours. The findings indicate that thermal treatment of the concrete specimens up to 300°C does not result in any observable degradation. However, at 400°C, some fine micro cracks become visible on the concrete surface, accompanied by alterations in color. As the temperature exposure progresses, specifically at 600°C, extensive cracking and further deterioration become apparent in the concrete specimens**.**

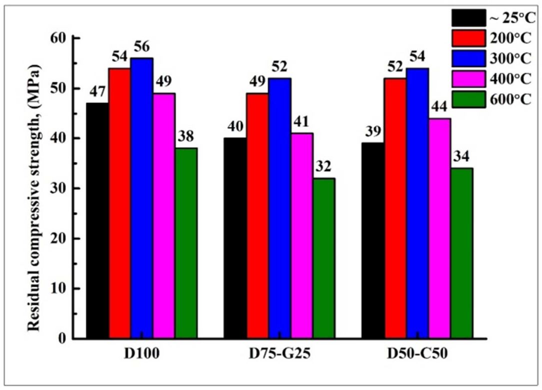

Figure (12): Residual compressive strength of concrete containing different coarse aggregates and exposed to elevated temperatures up to 600ºC.

4. Conclusion

From the experiment results, the following conclusions may be noted:

The study revealed that concrete mixes composed of 50% dolomite and 50% calcite, as well as 75% dolomite and 25% granite aggregate, met the required compressive strength standards for normal concrete after 28 days of curing. However, concrete containing granite and calcite waste aggregates exhibited a slight increase in chloride ion migration coefficient and water penetration depth compared to the control concrete (D100).

The alkali-reactivity of the coarse aggregates intended for use in the concrete fabrication was evaluated according to ASTM C 1260 (2014), and it was found that the expansion caused by any of the coarse aggregates (D100, D75-G25, and D50-G50) remained below the specified expansion limit of 0.1% outlined in the standard.

Additionally, when exposed to temperatures of 300°C, 400°C, and 600°C, the compressive strength values of concrete mixes containing granite and calcite waste aggregates experienced a slight decrease in comparison to the control concrete (D100).

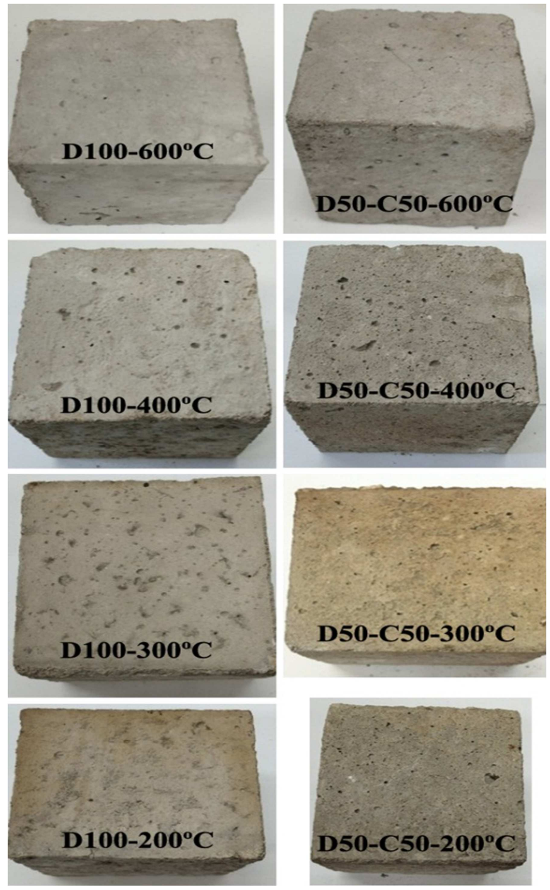

Figure (13): Visual inspection of concrete containing different coarse aggregates and exposed to different temperatures of 200, 300, 400 and 600ºC.

5. Disclosure statement

The authors did not disclose any potential conflict of interest.

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