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Research Article

Characteristics of environmentally-friendly cement and lime mortar containing recycled granite waste as a partial replacement of fine aggregate

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Abstract

The increasing consumption of Portland cement and natural aggregates is depleting natural resources and increasing environmental impact, particularly carbon dioxide emissions from cement manufacturing. This research aims to promote environmental sustainability by reusing construction waste and conserving natural resources for future generations. Limestone dust was used as a partial substitute for cement and granite waste as a partial substitute for fine aggregate in cement mortar. Seven mixes were cast in this study in addition to the reference mix. In the first three mixes, Portland cement was replaced at three weight ratios (5, 10, and 15%) with limestone dust, and the optimum mix was extracted. The other four mixes replaced the fine aggregate of the optimum mix of the three above with recycled granite waste at replacement ratios of 10, 30, 50, and 70% by weight. To demonstrate the effect of these materials on the cement mortar, the consistency (flow), compressive strength, tensile strength, flexural strength, and absorption were tested. The results obtained from this work demonstrated the possibility of obtaining a sustainable and environmentally friendly cement mortar made from replacing 10% of the weight of Portland cement with limestone dust and 50% of the weight of natural fine aggregate with recycled granite waste.

1. Introduction

Ordinary Portland cement is one of the most widely used construction materials in the world, as it is the basic material used in the manufacture and formulation of cement mortar and concrete [1]. Its production process has a significant negative impact on the environment due to carbon dioxide emissions during its manufacture, The amount of carbon dioxide emitted by the cement industry is estimated to account for approximately 7% of global emissions [2,3], as well as the high consumption of fuel and energy, the depletion of natural resources and the failure to preserve them for future generations [4, 5]. With the growing global push for environmental conservation and the use of sustainable materials to reduce carbon dioxide emissions, there is an urgent need to use and develop alternatives to cement, both partially and fully, using synthetic or natural materials with a lower environmental impact. The added materials should not lower the strength of concrete which is essential for sufficient performance [6]. It is worth noting that the cost of cement is estimated to constitute 20% of the total cost of concrete [7]. The total annual global consumption of aggregates in the concrete industry has reached more than 40 billion tons [8]. Therefore, the search for alternatives to concrete components, especially cement, is important from an economic and

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environmental perspective to obtain concrete that meets sustainability requirements [9-12]. In recent years, researchers have studied the possibility of completely replacing cement with other more economical and environmentally friendly materials, such as fly ash, ground blast furnace slag (GGBS), metakaolin [13], and rice husk ash [14].

Numerous studies on producing concrete from solid waste by using granite dust as a partial substitute for sand and cement to improve some of the properties of concrete and reduce environmental pollution from this waste [15, 16]. Valeria et al. prove that the substitution10% of sand by marble powder gave maximum compressive strength at 28 days compared to the reference mix [17]. Ali and Hashemi found an increase in the splitting tensile strength when replacing marble powder with 10% of cement, while the strength decreased if this percentage was increased [18]. The frost resistance and permeability of concrete were also improved by using granite powder in concrete, Zhang et al. [19].

Limestone is extensively utilized in building, resulting in significant waste that is detrimental to the environment. Some previous studies have shown that the additions of limestone waste powder as a fine aggregate replacement at 15% level cannot significantly influence concrete strength [20]. Other researchers have demonstrated that the properties of concrete and cement mortar are not influenced when sand is replaced with powdered limestone waste in 12-18% proportion [21]. Many studies have been carried out on the effects of different replacement ratios of limestone powder to fine aggregate on the properties of both concrete and cement mortar. The results showed that it is possible to replace 10–15% of lime shaped particles in the crushed sand without compromising physical and mechanical properties of concrete [22]. It has big influence on the compressive strength of concrete when using limestone powder to produce fine aggregate. Using up to 15% fine limestone dust as a partial replacement for fine aggregate was found to increase the compressive strength of concrete [23]. Celik and Marar studied the effect of varying dust content on workability and mechanical properties of concrete. It was observed that the compressive and tensile strengths of concrete were enhanced by adding 10% dust content in concrete. However, when this ratio was exceeded the compressive and tensile strength decreased [24]. The addition of 10 % quarry limestone powder also increases the compressive strength of the cement pastes [25,26].

In seeking for an environmentally friendly and sustainable cement mortar, this study intends to investigate the influence of the replacement of different rates (weight) of Portland cement by limestone waste dust on the fresh and hardened properties of ordinary Portland cement lime stone waste recycled-cement mortar, finding out a compatible ratio from which to decrease the volume fraction of cement in such composite without having any adverse effect on its average properties. Following the consideration of the percentage of limestone dust as an addition to mortar mixes, an attempt is made in this study to investigate the potential of utilizing waste granite as a fine aggregate substitution at different replacement rates, and its effects on fresh and hardened properties for cement mortars.

The application of limestone waste dust as a partial replacement for Portland cement and the use of recycled granite waste as a partial replacement for fine aggregate in cement mortar are innovative trends in the context of sustainable construction material. It can help to decrease the demand for Portland cement with its corresponding high CO_2 emissions and avoid depletion of natural resources. It also helps in treating industrial and quarry waste, to be reutilized instead of being illegally thrown away. Economically, this partial replacement leads to lower production costs and adds value to materials that were previously considered waste. Therefore, this study aims to optimize the use of waste materials to minimize both environmental impact and economic cost, thereby promoting sustainability principles without significantly affecting the engineering properties of the mortar when using carefully considered replacement ratios.

2. Experimental program

2.1. Materials

2.1.1 Cement

Ordinary Portland cement (OPC) produced by Badosh cement factory (Mosul city, Iraq). It conforms to the Iraqi specification IQS 5/2019 [27]. The chemical analysis of OPC is given in Table 1.

Table 1. Chemical analysis of cement

Compound Composition	Contained	Specification IQS, No5,2019
SiO_2	20.9	17.0-25.0
Al_2O_3	3.36	3.0-8.0
Fe_2O_3	2.10	0.5-6.0
Cao	64.7	60.0-67.0
MgO	4.10	≤ 5
SO_3	0.93	≤ 2.8
Free lime	2.10	------
Loss in ignition (Lio)	0.11	≤ 4
Insoluble residue (InR)	0.40	≤ 1.5
Total	98.7	------

2.1.2 Fine Aggregate

Rounded natural sand from (Khazer, Mosul, Iraq) was used as a fine aggregate. It's fully passing through the sieve 4.75 mm. Specific gravity, absorption and material finer than sieve No.200 (75 µm) were (2.66, 1.7 and 0.8%) respectively. The sand was used in a saturated surface dry (SSD) condition; the sieve analysis is shown in Table 2.

2.1.3 Recycled Granite Aggregate

To obtain fine aggregate from granite waste, a quantity of the waste was brought to the laboratory and manually crushed into small pieces, then screened. To achieve a gradation similar to that of natural sand, sieves with diameters ranging from 4.75 to 0.15 were used, and the remaining aggregate on each sieve was separated. Then, quantities of the remaining granite waste on these sieves were taken in proportions that matched the gradation of the natural sand used (see Table 2). Finally, the results of the water absorption test for granite showed that the absorption was 0.09%. This decrease is attributed to the mineral nature of granite, as it is mainly composed of high-hardness minerals such as quartz and feldspar, as well as its cohesive and dense crystalline structure, which limits the permeability of water to the internal pores of the stone.

Table 2. Sieve analysis of fine aggregate and recycled granite fine aggregate

Sieve size (mm)	Accumulated percentage passing (%)		Limits of B.S882:1992 (Fine F) specification
	Natural fine aggregate	Recycled granite fine aggregate	
4.75	100	100	-
2.36	89.0	89	80-100
1.18	74.5	74	70-100
0.6	55.5	56	55-100
0.3	21.5	22	5-70
0.015	35	35	-

2.1.4 Recycled Limestone Dust

In this study, construction waste (limestone) was used to study its effect on the properties of cement mortar. To use it as a partial cement substitute, the wastes were brought to the laboratory, crushed into small pieces, and then ground into dust (powder) as shown in Figure 1. The specific gravity of recycled limestone powder was 2.67. The recycled limestone powder, which was passed through a 150-µm sieve, was used as a cement replacement [28]. The chemical composition of these materials is illustrated in Table 3.

2.1.5 Tap Water

In this investigation, Ordinary tap water was used.

2.1.6 Super plasticizer

To reduce the water content of the mixture while maintaining good consistency, Conplast SP 2000 was used as a high-water-reducing admixture in the mortar preparation. This admixture complies with the requirements of ASTM C494 [29].

Table 3. Limestone construction waste chemical composition

Oxides	Granite	Limestone
CaO	2.07	89.4%
SiO_2	79.8	1.75%
Al_2O_3	8.94	0.7
Fe_2O_3	2.05	0.9
MgO	0.32	0.4
SO_3	0.05	0.26%
Na_2O	3.08	0.06
K_2O	4.63	0.03

2.2. Mix Proportion

The work was divided into two phases. The first phase used recycled limestone dust (L) to produce an adhesive mortar as a partial substitute for cement. Four cement mortar mixers were produced, in which a portion of the cement was replaced with recycled limestone dust at ratios of (5, 10, and 15) %, as shown in Table 4 below. The optimal mix was then selected in terms of the properties claimed for the study, and considered the optimal mix for the next phase. In the second phase, the mix selected from the first phase was considered the reference mix.

Table 4. Reference mixture quantities

Mixture	Cement (kg/m^3)	Natural Sand (kg/m^3)	Water (kg/m^3)	Super plasticizer (kg/m^3)
CM	521	1432.7	239.6	3.12

Table 5. Specifications for the mortar mix proportions

Mixes	Cement %	Limestone Dust %	Natural Sand (%)	Recycled Granite Sand (%)	w/c Ratio	Super plasticizer (%)
CM	100	0	100	0	0.46	0.6
5LCM	95	5	100	0	0.46	0.6
10LCM	90	10	100	0	0.46	0.6
15LCM	85	15	100	0	0.46	0.6
RCM	90	10	100	0	0.46	0.6
CMG10%	90	10	90	10	0.46	0.6
CMG30%	90	10	70	30	0.46	0.6
CMG50%	90	10	50	50	0.46	0.6
CMG70%	90	10	30	70	0.46	0.6

**RCM: is identical to the optimum mixture with 10% limestone powder replacement (10LCM) and was used as the control group in the granite replacement studies in Phase 2 of this study.*

To demonstrate the effect of sand recycled from granite waste (G), five mixes were prepared in which natural sand was replaced at ratios of (10, 30, 50, and 70) % with recycled granite sand to demonstrate its impact and the possibility of using it as an alternative to natural sand in producing a sustainable and environmentally friendly mixture (See Table 5). All of the mixes were made using the proportion of binder to sand that was determined to be 1:2.75 as shown in Table 4. For the purpose of observing the impact that the materials that were utilized had on the flow of fresh mortar, the ratio of water to cementitious materials and the super plasticizer were both fixed at 0.46% (by weight of cement) and 0.6, respectively, for all of the mixes.

Fig. 1. Materials used and preparation process

2.3. Casting and Curing

To ensure the samples were lifted from the molds, the molds were greased with oil after cleaning and before pouring. After the mixing process was completed, the mortar was poured into standard molds (50*50*50) mm for compression testing, prismatic molds (40*40*160) mm for flexural testing, and special molds (briquettes molds) for tensile testing (see Figure 2) . To ensure good compaction, an electric vibrator was used for all samples. The compaction process was carried out systematically until the air bubbles stopped escaping, thus obtaining a homogeneous and well-compacted mortar free of air voids, ensuring accurate results and improving the mortar's mechanical properties. After a full day (24 hours), the samples were removed from the molds and deposited in curing tanks at a standard water temperature of $(23 \pm 2)^{o}$C until testing.

Fig. 2. Casting, remolding, and curing of specimens

2.4. Test Procedures

2.4.1 Testing of Fresh Mortar

To estimate the amount of water required to achieve a good consistency for cementitious mortar in its fresh state, a flow table was used (see Figure 3). Testing was carried out for all mixes according to the requirements of ASTM C1437 [30]. A conical mold with dimensions of (100, 70 and 50) mm for bottom diameter, top diameter and height, respectively, was used. The mold was filled with fresh mortar in two layers, with each layer being compacted 20 times. The mold was then removed from the mortar, and the table was dropped 25 times per 15-second interval from a height of 12.5 mm, and the spread diameters of the mortar were then measured.

2.4.2 Testing of Hardened Mortar

To demonstrate and clarify the effect of the materials used on the hardened properties of cement mortar, mechanical and absorption tests were conducted on hardened specimens. Compressive strength tests were performed on hardened mortar cubes for each mix with standard dimensions of (50*50*50) mm at test ages of 7 and 28 days. Flexural tests were performed on prisms (40*40*160) mm at test ages of 7 and 28 days. According to BS EN 196-1, in the compressive strength test, the load is applied at a constant loading rate of (2400 ± 200) N/s until failure, while in the flexural strength test, the load is applied at a rate of (50 ± 10) N/s to the specimen until fracture is achieved [31]. The flexural strength of the specimens was calculated by using the following equation:

Fig. 3. Flow table test

$$F_{1X} = (1.5 \times P \times L)/b^3 \quad (1)$$

Where: F =flexural strength (MPa), P =load (N), L =distance between supports (mm), b = cross-section dimension of the prism.

After splitting the prisms in half for flexural testing, a water absorption test was conducted according to ASTM C642 [32]. The specimens for each mix were placed in an oven at 100-110°C for 24 hours or until the weight stabilized. Their dry weight was then calculated. After cooling, the specimen was immersed in water to saturate all pores of the specimen for 24 hours or until the weight stabilized. The water absorption was then calculated according to the equation shown below:

$$Absorption\ (\%) = [(A - B)/B] \times 100 \quad (2)$$

Where: A = weight after immersion, B = weight of specification oven dry.

The tensile strength of the cement mortar was tested according to ASTM C190 [33] (see Figure 4). The tensile strength was obtained by dividing the load at failure by the cross-sectional area of the specimen.

$$Tensile\ Strength = P\ (N)/A\ (mm^2) \quad (3)$$

Where, A: It area of failure for two parts after testing, A= (A1 + A2)/2

All of the above tests were performed using an average of three specimens for each mixture under the same conditions.

(a) Compressive test (b) Tensile test (c) Flexural test

Fig. 4. Testing of hardened mortar

3. Results and Discussion

3.1. Consistency (Flow Test Results)

The results obtained from the mortar flow test showed that replacing cement with dust of recycled limestone waste decreased the flow by percentages consistent with the replacement percentages, as shown in Table 6. The results showed that the flow of the mortar decreased compared to the reference mix CM by (1, 3, and 8) % for mixes 5LCM, 10LCM, and 15LCM, respectively. This is due to the high fineness of the material and the increased surface area consumed by water for the fine materials. While the flow results for mixes containing granite waste sand showed a very slight decrease at low replacement percentages, at high replacement percentages, the decrease was clear and obvious. The results showed that the flow rate of the mortar decreased in a consistent manner with the replacement ratio of natural sand with recycled granite sand, as observed in Figure 5.

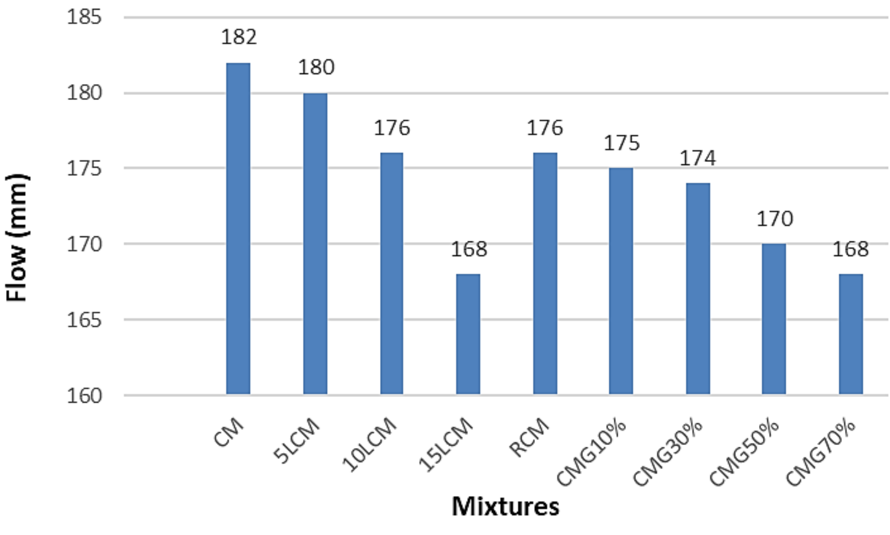

Fig. 5. Flow test results for every mixture

For example, the flow rate decreased by (0.5, 3.4, 4.5, and 7.9) % for the CMG10%, CMG30%, CMG50% and CMG70 mixes, respectively, compared to the reference mix RCM. This may be due to the irregular shape of the granite grains, which hindered the diffusion compared to the round-shaped natural sand grains with a somewhat smooth surface. The bridging caused by the angular shape and rough surface of the recycled fine aggregate (granite) leads to restriction of mortar movement during flow testing, which is reflected in a decrease in measured flow values and an increase in internal flow resistance, thus affecting workability and the consistency of laboratory results.

Table 6. Results of all tests

Mixes	Flow (mm)	Compressive Strength (MPa)		Tensile Strength (MPa)		Flexural Strength (MPa)		Water Absorption (%)
		At 7 days	At 28 days	At 7 days	At 28 days	At 7 days	At 28 days	
CM	182	31.00	42.78	3.16	3.84	8.50	9.27	11.86
5LCM	180	30.40	41.76	3.10	3.68	8.42	9.18	12.16
10LCM	176	29.74	40.80	3.04	3.66	8.26	8.94	12.32
15LCM	168	26.20	35.37	2.68	3.30	7.62	8.26	12.68
RCM	176	29.74	40.80	3.04	3.66	8.26	8.94	12.32
CMG10%	175	30.20	41.30	3.07	3.68	8.41	9.13	12.26
CMG30%	170	31.46	42.14	3.10	3.76	8.61	9.27	12.17
CMG50%	168	32.60	45.85	3.17	3.80	8.90	9.36	11.86
CMG70%	162	28.40	37.94	2.71	3.32	6.84	7.82	12.30

3.2. Compressive Strength Results

Table 6 shows the compressive strength results for all mixes in this study. The results generally showed that using construction waste as a replacement (for cement or fine aggregate) in cement mortars resulted in a decrease in compressive strength. For the first part of the study, the results showed that replacing cement with limestone dust resulted in a decrease in compressive strength, and the amount of decrease was consistent with the replacement ratios. The compressive strength at 7 days decreased from 31% for the reference mix (CM) without mortar to 30.4%, 29.7%, and 26.2% for mixtures containing limestone dust at cement replacement ratios of 5, 10, and 15%, respectively. The compressive strength results at 28 days also showed that replacing cement with limestone dust at ratios of 5, 10, and 15% resulted in a decrease in compressive strength of 2.3%, 4.6%, and 17.3%, respectively. As shown in Figure 6. This decrease is due to the fact that this material is considered a weak filler, and the decrease in cement components in the mix led to this decrease in compressive strength. The (10LCM) mix, which contained 10% limestone dust, was considered the optimum mix due to the reduction in cement consumption without significantly affecting the compressive strength. To study the effect of using waste of granite as a partial replacement for fine aggregate, the 10LCM mix was used as the reference mix (RCM). The results in Table 5 clearly show that replacing fine aggregate with recycled waste granite by 10%,30%,50% resulted in a slight increase in compressive strength at both ages compared with the mixture without recycled granite aggregate (RCM). The increase in compressive strength of the mortar, may result from the partial replacement of the fine aggregate with recycled granite waste aggregate, can be explained by a combination of physical factors. The angular and coarse nature of the aggregate particles, along with their inclusion of fine particles, improved particle size distribution, filling efficiency, and reduced porosity. The rough surface of the recycled aggregate also enhanced mechanical bonding and the interfacial zone between the paste and the aggregate, thus limiting micro-crack formation. Furthermore, the fine particles acted as a filler, filling micropores and promoting internal structure density. They also provided additional sites for hydration product growth and improved microstructure development at later ages. The 50% replacement ratio is optimal, balancing the properties of natural and recycled aggregates without negatively impacting workability or increasing water demand, thus explaining the increased compressive strength compared to the reference mortar.

On the other hand, Compressive strength decreased by (4.5%), (7%) at 70% replacement ratio (CMG70 mix) for ages 7 and 28 days, respectively. The reduction in the compressive strength of granite aggregate is elucidated by Jin et al. [34], who demonstrated that substituting fine aggregate with over 60% granite powder diminishes the compressive strength of concrete due to heightened porosity, consequently impairing the pore-filling effect.

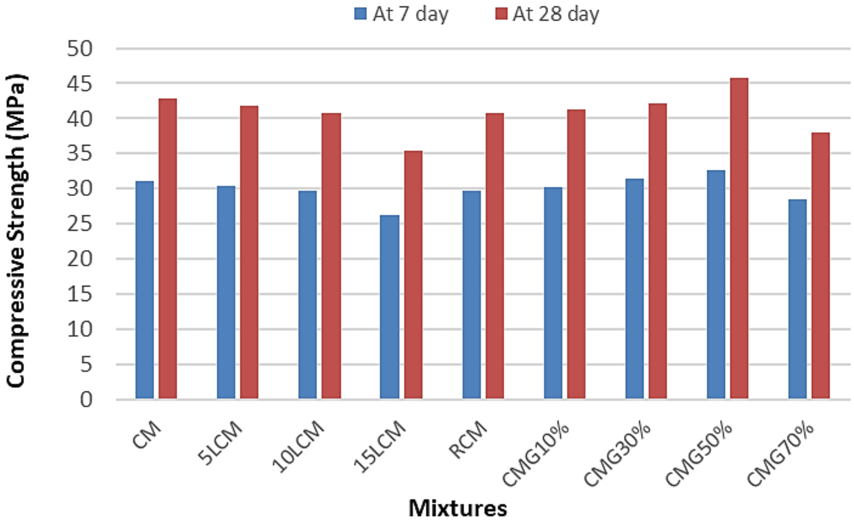

Fig. 6. Results of compressive strength test for all mixtures

3.3. Tensile Strength Results

The tensile strength results for all mixtures are presented in Table 6 and illustrated in Figure 7. The findings indicate that substituting cement with mortar dust resulted in a reduction of the tensile strength of the mortar, as evidenced by the compressive strength measurements. With an increase in the replacement ratio, there is a corresponding decrease in tensile strength. The findings indicated a reduction in tensile strength at 7 days of (1.8, 3.7, and 15.1)% for 5%, 10%, and 15% cement replacement ratios with limestone dust, respectively, in comparison to the reference mix CM. The results at 28 days indicated that substituting cement with limestone dust at 5%, 10%, and 15% reduced the tensile strength of the cement mortar by 4.1%, 4.6%, and 14%, respectively, in comparison to the reference mix without limestone dust (CM). This results from a deficiency in the bonding zone (interfacial transition zone) between the aggregate and the cement-lime stone dust paste (ITZ) [35]. The 15LCM mix, which included 15% limestone dust, experienced the most significant percentage decrease at 15.1%.

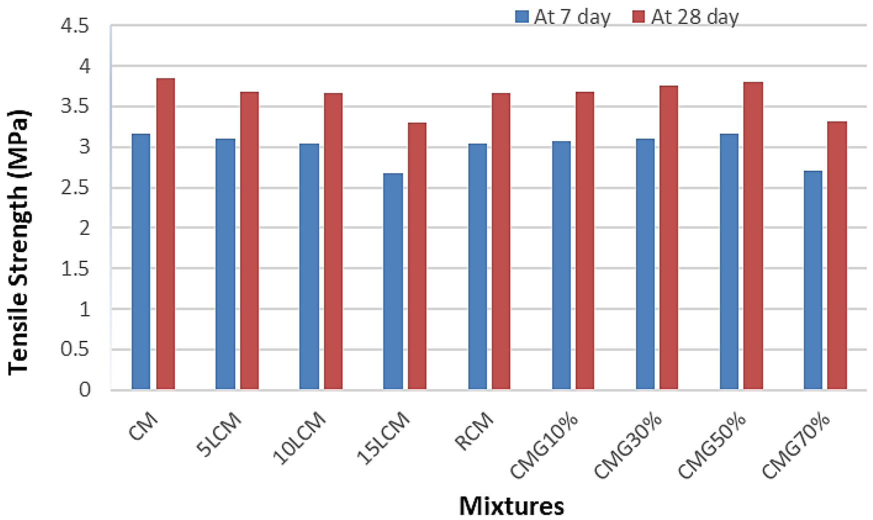

Fig. 7. Tensile strength test results for every mixture

The minimal percentage decrease of 4.1% occurred at a 5% replacement ratio for the 5LCM mix. The 10LCM mix served as the reference mix (RCM) to investigate the impact of granite waste as fine aggregate. The findings indicated that the tensile strength at 28 days improved by 0.5%, 2.7%, and 3.8% at replacement ratios of 10%, 30%, and 50%, respectively, in comparison to the reference mix (RCM). This increase in tensile strength in the second stage may be related to the stronger mechanical bonding provided by the mortar matrix as a result of the irregular/angular grain shape of the recycled granite aggregate compared to rounded natural sand. The tensile strength for the mix CMG70% decreased by 9.2% at 28 days. This enhancement of mechanical properties for the cement mortar when natural sand is substituted by recycled granite waste fine aggregate, in a substitution ratio up to 50%, is related to an association of mechanical-microscopic interrelated mechanisms. The uniform particle size distribution of granite aggregate (mimicking natural sand) facilitates an enhanced packing density and minimum interstitial spaces in the mortar, leading to its lower overall porosity and improved stress transfer across the matrix.

In addition, the geometry of surface features on RGA with rough and sharp edges obtained purposefully during crushing and finishing operations enhances the interfacial transition zone (ITZ) between cement paste and aggregate. This results in a stronger mechanical bond and a thinner, weaker ITZ as compared to natural sand-based mortar, so that the formation and spread of micro-cracks under loading is confined. The general mechanical behavior of the cement mortar, particularly as regards compressive, tensile, and flexural strength, improved with moderate replacement rates, where proportions over 50% caused deterioration in this response due to an increase in heterogeneity and a greater likelihood of residual porosity.

3.4. Flexural Strength Results

From Figure 8, which presents the flexural strength at 7 and 28 days of age on cement mortar mixes, it can be seen that the effect of replacing cement with limestone dust had a different influence according to its percentage replacement and the curing time. After 7 days, if cement is replaced with 5%, flexural strength slightly decreased compared to the reference mix (CM) by around 0.94%. This reduction rose to around 2.82% at a 10% level of replacement, and peaked at around 10.35% under the condition of 15%. Also, results show the mixes with 5% and 10% limestone dust at 28 days showed comparable or lower flexural strength than the control. However, the 15% replacement revealed a remarkable improvement than that of 7 days while it was strength lower than reference mix. This means that the depression effect of limestone dust was intensified with higher substitution percentage, particularly at young ages—all results related are shown in table 6 and Figure 8.

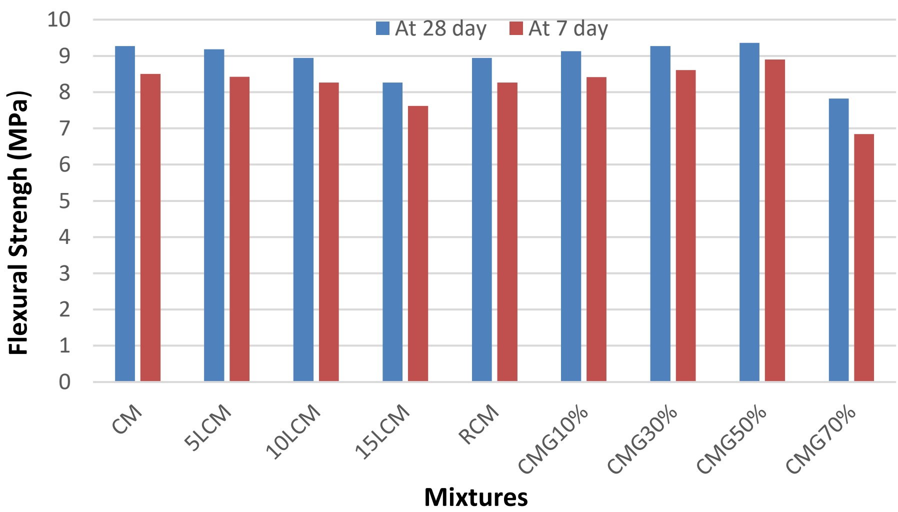

Fig. 8. Results of the flexural strength test for all mixtures

As well as for the influence of using recycled fine aggregate from granite waste in 10% limestone dust mixes, it was observed a slight enhancement in flexural strength at 7 days when the percentage of recycled granite sand increased reaching up to 50%, with an expected increase of about 7.74% versus the control mix which included only limestone dust (10LCM). As the percentages of recycled aggregate used were increased to 70%, there was a decrease in flexural strength to 17.19% at 7 days. At 28 days, the mortar mixes with 50% recycled granite aggregate had the highest flexural strength value of around 4.7% more compared to control mix. These findings show that the partial substitution of cement by limestone dust could be deemed acceptable, at a low content, while the replacement of granite wastes recycled fine aggregate can enhance flexural strength when used at moderate (up to 50%) content and especially in advanced hardening times promoting sustainable use of these secondary materials with minor negative impact on cement mortar's mechanical behavior.

3.5. Water Absorption Results

Table 6 shows the absorption results, which show that absorption rates increased with increasing limestone percentage. For example, the water absorption increased by 2.5%, 3.8%, and 7% for the mixes 5LCM, 10LCM, and 15LCM, respectively as a compared with the reference mix (CM). This is due to the high absorption capacity of limestone. However, we note that the absorption rate began to decrease in the mixtures in which granite was substituted for sand. This is attributed to the lower absorption capacity of granite compared to sand. Finally, the absorption value increased at a replacement rate of 70% of granite instead of fine aggregate, as shown in Figure 9. The reason is possibly due to the increase in the percentage of voids in the mortar as a result of the irregular granite particles not filling the voids as well as the rounded sand grains. For example, the results shown in Table 5 and Figure 9 showed that the water absorption rate decreased from 12.32% for the RCM mix that did not contain granite waste to 12.26, 12.17, 11.86, and 12.3 for the mixes CMG10%, CMG30%, CMG50% and CMG70%, respectively.

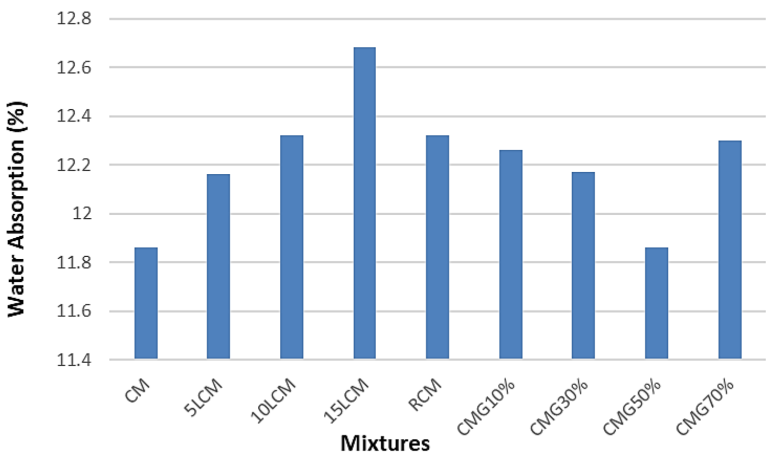

Fig. 9. Results of compressive strength test for all mixtures

4. Conclusions

Based on the results of the tests conducted in this research, the following conclusions were reached:

- The possibility of obtaining sustainable cement mortar by using 10% dust of recycled limestone waste instead of cement.
- The consistency (flow) of cement mortar is negatively affected by the partial replacement of Portland cement with limestone dust. This effect is acceptable and slight up to a 10% replacement rate. Flow values decreased by 1, 3, and 8% for mixes containing 5, 10, and 15% limestone dust as partial replacement by weight of cement, respectively. Recycled waste granite also reduces the consistency of cement mortar, and this effect increases with increasing replacement rate.
- The use of limestone dust negatively affects the mechanical properties of cement mortar, and this effect increases with increasing replacement by weight of cement. However, this effect is slight up to a 10% replacement rate and significant and unacceptable at a 15% replacement rate. The use of recycled sand from granite waste positively affects the mechanical properties of cement mortar up to a 50% replacement rate, while at a 70% replacement rate, the mechanical properties of the mortar deteriorate.
- Replacing waste of granite with natural fine aggregate improves compressive strength by 9.6% and 12.3% at a 50% replacement rate for ages 7 and 28 days, respectively. However,

compressive strength decreases at a 70% replacement rate for both ages, compared to the reference mix.

- The tensile and flexural strengths increase by 3.8% and 4.7% when using waste of granite instead of fine aggregate at 50% at the 28-day age, compared to the reference mix (RCM), which does not contain recycled granite. However, both tensile and flexural strengths decrease by 9.28% and 12.52% when the replacement rate increases to 70%.
- Using limestone dust as a partial replacement for cement at rates of 5, 10, and 15% increased the absorption of cement mortar by 2.5, 3.8, and 7%, respectively, compared to the reference mix. Meanwhile, using recycled sand from granite waste instead of fine aggregates reduced the mortar's water absorption, with the smallest percentage decrease being 3.75% for the CMG 50% mix compared to the reference mix (RCM), while the smallest water absorption being 11.86% in the mix (CM). When the replacement of recycled granite waste ratio increased to 70% for (CMG 70%), this effect decreased to almost zero.
- The study results show that it's possible to produce environmentally friendly and sustainable cement mortar without significant negative impacts on its mechanical properties. This is achieved through the carefully considered partial replacement of Portland cement with recycled limestone dust and the use of recycled fine aggregate from granite waste. The study results demonstrated an effective balance between the mechanical performance of the cement mortar and environmental requirements when partially replacing cement with 10% limestone dust and using granite waste as 50% of the natural fine aggregate.

In this study, sustainability was achieved by reducing the high carbon dioxide emissions associated with Portland cement manufacturing processes by reducing cement consumption through its partial replacement with limestone waste powder. In addition, the use of granite and limestone waste helps to reduce industrial waste and the problems associated with burying or randomly disposing of it, thus reducing environmental damage, in addition to preserving natural resources for future generations by reducing reliance on natural quarries to obtain fine aggregate.

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