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Effect of Waste Marble and Granite Dust on Compressive Strength of Concrete

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ABSTRACT: *The purpose of this study is evaluating the effect of cement replacement with marble dust (MD) and granite dust (GD) on the on the compressive strength of concrete. Portland cement was individually replaced by different percentages (2, 4, 6, 8 and 10 wt%) of MD and GD. The compressive strength and X-Ray Diffraction (XRD) were carried on the MD and GD mixtures in addition to control mix.* ***All the specimens of the experimental work were casted and strengthened at Concrete Research and Material Properties Laboratory, "Faculty of Engineering, Fayoum University".*** *The results showed an improvement in the compressive strength at all curing ages of concrete with individual MD and GD content up to a replacement ratio of 6%, then strength decreased with increasing the replacement content of MD and GD. The compressive strength of concrete with 6% MD at 7, 28 and 90 days increased by 7%, 8.2% and 5.4% of control value, respectively. Whereas the strength of concrete with 6% GD at 7, 28 and 90 days increased by 18%, 17.1% and 18.5% of reference value, respectively. The results of the XRD analysis agreed with the compressive strength results as insignificant changes in hydration products due to using MD were observed, whereas a higher C-S-H content due to the use of GD was detected, compared to the control mix.*

KEYWORDS *-Marble dust, Granite dust, Concrete Compressive strength, XRD analysis*

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I. INTRODUCTION

Cement production is considered one of the main sources of carbon dioxide, which represents around 5-7% of the total man-made emissions [1]. The significant increase in the consumption of natural raw materials on the one hand and the massive expansion of building and construction projects on the other hand led to the need to widely search for alternatives and effective solutions to achieve a balance between non-renewable natural resources and continuous construction. Waste recycling was the perfect solution to solve this problem, as it is one of the methods of sustainability that most developed countries are currently applying. Waste recycling includes the recycling of industrial waste such as waste from the manufacture of ornamental stones that accumulate in large quantities without economic values [2].

Recycled waste is used in the concrete industry, and many studies have partially or fully replaced one of the components of concrete with this waste. Recycling and reuse of waste in the concrete industry has become an appropriate technology for two reasons: eliminating waste and improving concrete properties. Since the concrete industry is always expanding, it is necessary to evaluate concrete with waste from all aspects to determine its capacity [3]. Shaq El- Thu'ban industrial cluster, located in the east of Cairo, and it is the largest industrial agglomeration for marble and granite in Egypt in addition to being ranked fifth in the world in the manufacture of marble and granite [4]. The use of granite and marble waste in various industrial sectors, especially the construction industry, can help protect the environment and conserve natural resources [5].

Many researchers studied the use of marble powder as a partial replacement of sand and cement. Valeria et al. [6] reported that 10% replacement of sand by marble powder provided maximum compressive strength after 28 days of curing, compared to control mix. Taji et al. [7] studied the effect of replacing cement with marble and granite powder separately according to the mechanical properties of concrete, and found that the optimal replacement of marble and granite is 5% and 10%, respectively. Arshad et al. [8] reported 15% increase in the compressive strength when 15% replacement of cement by marble powder. Rashwan et al. [2] concluded that marble and granite dust can be used separately up to 20% as a substitute for cement in the manufacture of concrete without negatively affecting the mechanical performance or durability. Ergün [9] found that the strength of concrete with 5% and 7.5% replacement of cement by marble improved for 0.5 w/b ratio, whereas the strength decreased in case of concrete with 15% replacement of cement. However, for concrete with 0.40 w/b ratio; slight improvement in compressive strength was observed for 10% replacement of cement by marble powder, with comparing to control mix. Soliman [10] reported increasing in compressive strength, indirect tensile strength and modulus of elasticity for concrete with replacement cement of 7.5% marble waste.

Ali and Hashmi [11] reported an increase in splitting tensile strength with replacement of marble powder up to 10% of cement, whereas the strength decreases in the case of addition of marble powder to concrete. Azunna and Okolo [12] reported increase in compressive strength for concrete with addition 10% granite powder as weight of cement. Mashaly et al. [13] observed that using 20% of marble sludge as a cement replacement improved the mechanical and physical properties of concrete. Sharma et al. [14] observed improvement in workability, durability, and modulus of elasticity of concrete with granite slurry as a partial replacement of cement. Singh et al. [15] reported an improvement in physical strength and durability of concrete when marble powder slurry replaced with cement up to 15%. Aliabado et al. [4] found that the porosity of concrete decreases with the increase in the content of marble powder as a partial replacement for both cement and sand for w/b ratios 0.50 and 0.40. Also, Demirel [16] reported decrease in the sorpivity coefficient of the concrete with the increase in marble powder content. Zhang et al. [17] revealed that using granite powder improves frost resistance, and permeability of concrete.

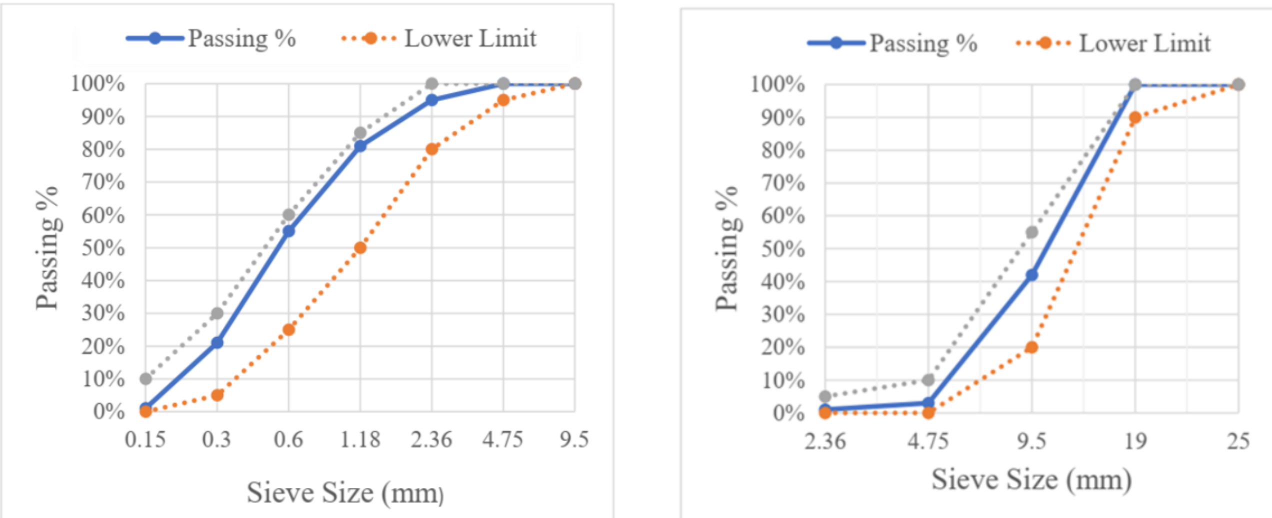
II. Materials and experiments

2.1 Cement

Ordinary Portland cement (OPC), CEM I 52.5 N produced by Misr Beni Suef company (Beni Suef city, Egypt) complies with the ASTM C 150 was used in the study. Table 1 illustrates the chemical composition of OPC. The properties of the used OPC are as the following; Specific gravity, surface area, initial setting time, final setting time, compression strength after 7 days, compression strength after 28 days, and soundness are, respectively, equal to 3.15, 3500 cm^2/gm, 90 min, 185 min, 38 MPa, 54 MPa, and 1 mm.

2.2 Aggregate

Crushed dolomite and natural sand were used as coarse and fine aggregates, respectively. The physical properties of dolomite and sand are as the following; specific gravity is 2.64 and 2.56, bulk density is 1662 and 1714 kg/m^3, void ratio is 37 and 32.7, and percentage of absorption is 0.5 and 0.9%. Crushing value of dolomite is 23%. Sieve analysis have been conducted on aggregate and meet the grading requirements of concrete aggregates according to (ASTM C 33-2003) as shown in Fig.1.



a) Fine Aggregate. b) Coarse Aggregate.

Fig. 1: Grading curve of fine and coarse aggregate with regard to ASTM C33-03 limits.

2.3 Water

Clean and free of impurities tap water is used in casting and curing.

2.4 Chemical admixture

In this work, the superplasticizer Sikament® -NN is used as a high range water reducer of modified polycarboxylates, to improve the workability of the fresh concrete.

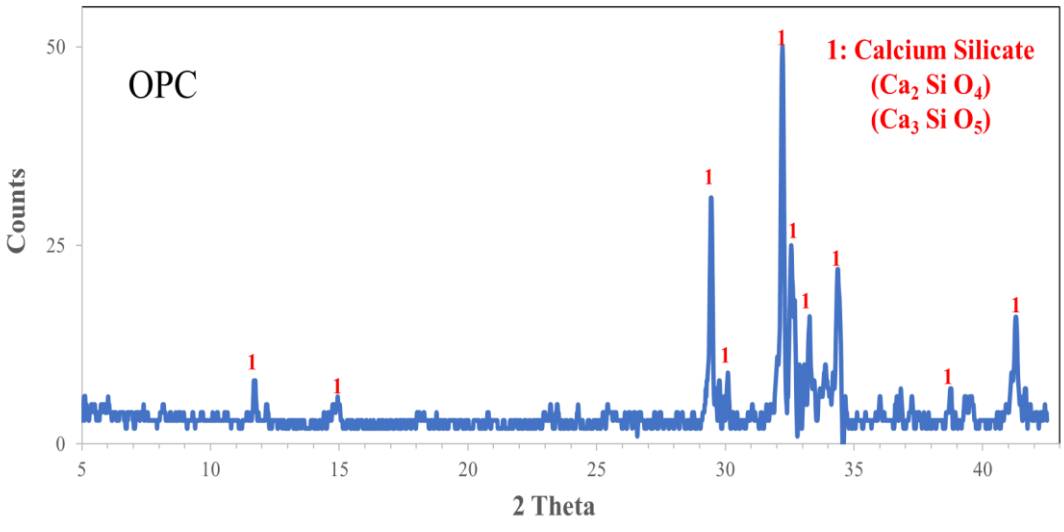
2.5 Marble and granite dust

Marble and granite dust were obtained from the factories waste located at Shaq El- Thu'ban area in Egypt, as a by-product of marble and granite stones, then dried in an oven in the laboratory at 100 ◦C for 2 h to remove the moisture, after that ground in ball mill for 10 min to remove any agglomeration then sieved throughout sieve No. 200 to get particles less than 75 micron to be ready for replace cement. Specific gravity and surface area of MD and GD were found equal to (2.64, 2.73) and (7600 and 14650 cm^2/g) respectively. Chemical composition of MD and GD resulted of XRF test is represented in Table 1. The mineralogical composition, crystal structure and microstructure of MD and GD were investigated by XRD, and SEM as illustrated in Figs. 2 and 3.

Table 1. Chemical composition of Cement (OPC), Marble dust (MD) and Granite dust (GD)

Composition (%)	Cement (OPC)	Marble dust (MD)	Granite dust (GD)
SiO_2	19.64	0.47	68.6
Al_2O_3	4.4	0.12	13.7
Fe_2O_3	3.34	0.05	3.22
CaO	63.23	55.4	2.64
MgO	1.24	0.26	0.6
SO_3	3.07	0.02	0.08
Na_2O	0.2	0.05	2.93
K_2O	0.17	0.02	6.01
P_2O_5	0.13	----	0.2
Cl	0.09	0.02	0.04
TiO_2	0.34	---	0.39
LOI*	4.05	43.5	1.18

* LOI: Loss on Ignition at 1000 ◦C.



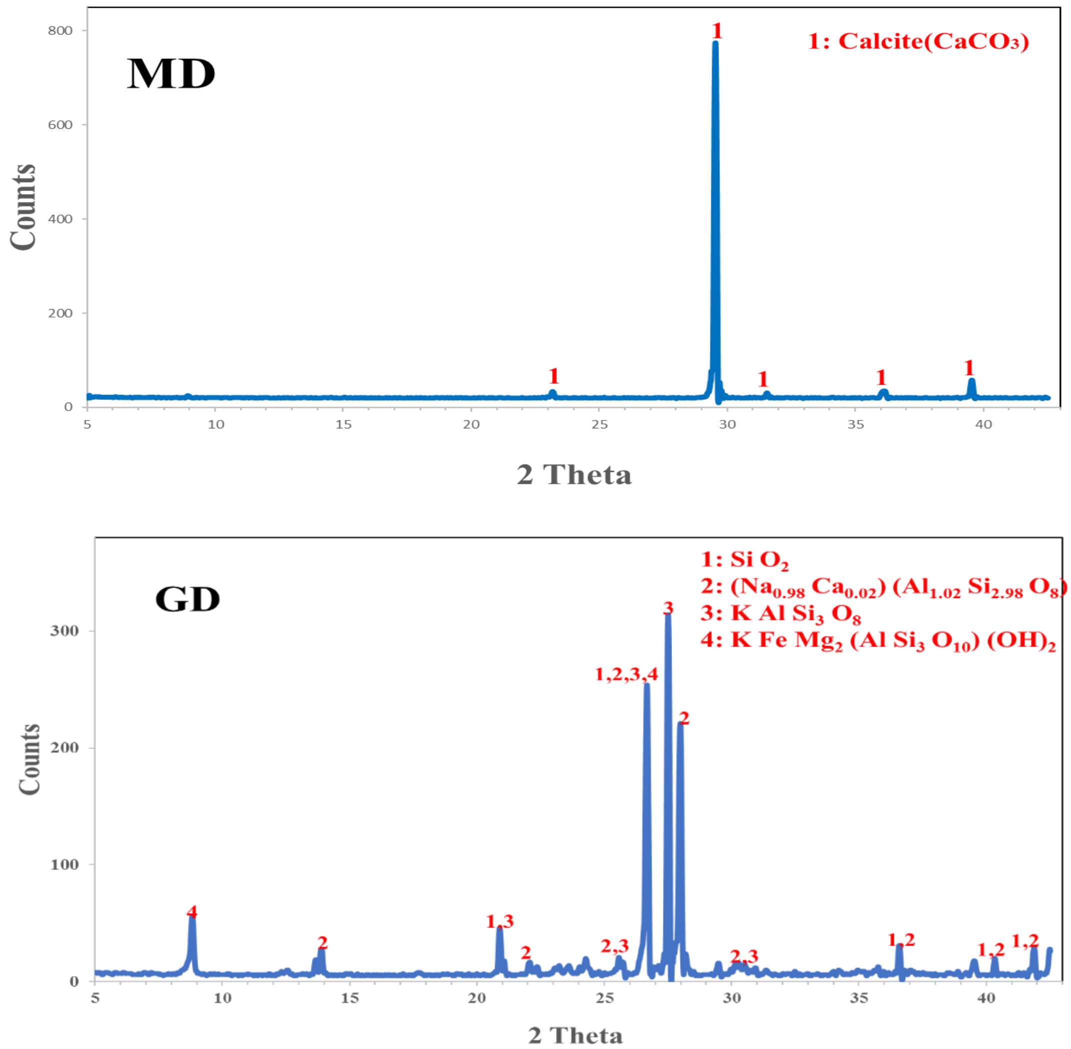
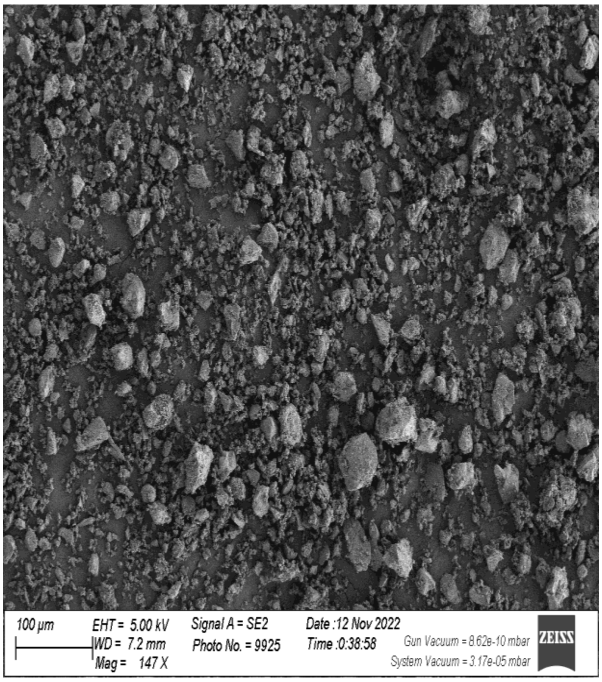
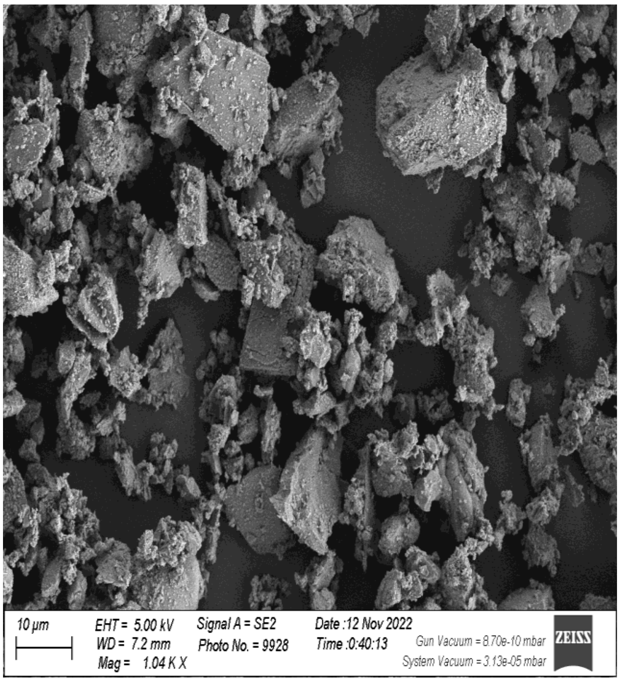


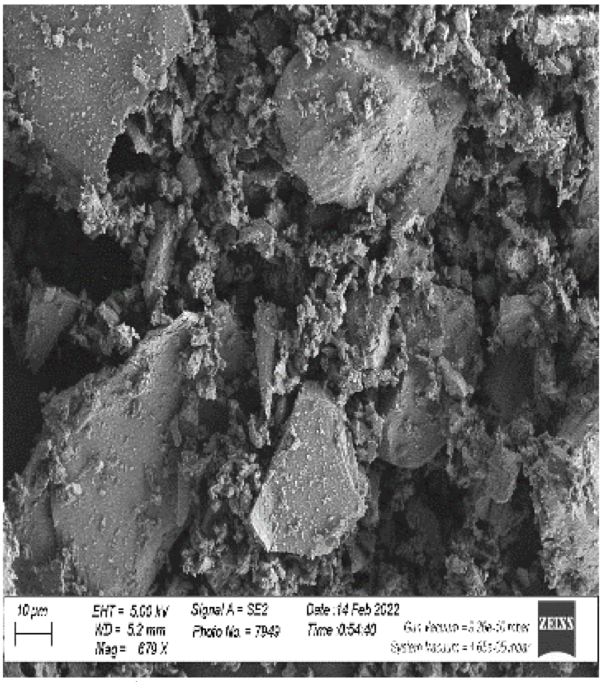
Fig. 2. XRD Patterns of OPC, MD and GD.



a) OPC.



b) MD.



c) GD.

Fig. 3. SEM images for a) OPC, b) MD, c) GD.

2.6 Mix Design

Ten mixes in addition to the control mix were designed according to the method of ACI 318-2019 recommendations. The mix proportions used for experimental program 1 m^3 of concrete mixture were 400, 635, 1080 and 160 Kg for cement, fine aggregate, coarse aggregate and water content, respectively as shown in Table 2. A superplasticizer dosage was used with dosage 1.5% of the cement weight for all mixes.

2.7 Mixing Procedures

Mixing procedures of the different mixtures can be briefed in the following steps:

- Fine and coarse aggregate were mixed together for 30 seconds.
- Required powder materials (cement/MD/GD) were incorporated as designed and mixed for 2 minutes.

• 80% of estimated mixing water required and the determined superplasticizer quantity were added during mixing gradually and continued for five minutes.
• The remaining 20 % of water added and mixed for 2 minutes.

2.8 Casting and curing
All the specimens were casted in **the Faculty of Engineering, Fayoum University's Concrete Research and Material Properties Laboratory**. After mixing the concrete in the mixer, the slump cone test of each mix was performed immediately. The slump cone test of each mix was performed immediately after mixing. The slump test is a good indication for workability and fresh properties of concrete. It is clear that the particles of marble dust, which have almost twice the surface area of cement, slightly decreased the slump when replaced with cement as reported by Rana et al. [18]. Granite dust particles, which have almost four times the surface area of cement, decreased the slump when replaced with cement as reported by Bacarji et al. [19]. After the slump cone procedure, concrete was casted into moulds with dimensions 100 × 100 × 100 mm cubes. Immediately after casting, the concrete was compacted and the surface samples were smoothed. After 24 hours of casting, specimens were demoulded then immersed in a water tank until the indicated testing times.

Table 2. Concrete mix design (kg/m^3).

Mix	Cement	MD	GD	Water	Aggregate		SP	Slump (cm)
					Fine	Coarse		
C0	400	0	0	160	635	1080	6	7.5
2%MD	392	8	0	160	635	1080	6	7.4
4%MD	384	16	0	160	635	1080	6	7.2
6%MD	376	24	0	160	635	1080	6	7.1
8%MD	368	32	0	160	635	1080	6	6.8
10%MD	360	40	0	160	635	1080	6	6.6
2%GD	392	0	8	160	635	1080	6	7.1
4%GD	384	0	16	160	635	1080	6	6.4
6%GD	376	0	24	160	635	1080	6	5.9
8%GD	368	0	32	160	635	1080	6	5.5
10%GD	360	0	40	160	635	1080	6	5.0

2.9 Test methods
2.9.1 Compressive strength

Cubic concrete samples with a size of 100 × 100 × 100 mm were used to conduct the compressive strength test of concrete samples. For each mixture, three cubic samples were tested to determine compressive strength at 7, 28, and 90 days of curing. The compressive strength value was the average of the three tested samples under the same conditions.

2.9.2 XRD analysis

Microstructural characteristics for concrete samples were analysed by X-Ray Diffraction analysis (XRD) technique to analysis and explain the characteristics and the microstructure of cement paste samples. Samples were prepared for XRD analysis by crushing the concrete samples to obtain a uniform powder size passing from 200-micron sieve to be ready for analysis.

III. Results and Discussion

3.1 Compressive Strength

Table 3 and Fig. 4 illustrate the effect of using separately MD and GD as cement replacement on concrete compressive strength after 7, 28 and 90 days of curing. From the results, it is clear that the effect of using up to 6% MD as cement replacement slightly improved the concrete compressive strength compared to control mix at all ages. The improvement in strength for concrete with 6% MD at 7, 28 and 90 days is 7%, 8.2% and 5.4% of control mix value, respectively. This increase in compressive strength may be due to the filling effect of high fineness MD, which can densify the microstructure and fill the pores in concrete.

The usage of marble dust of content more than 6% cement replacement has a negative effect on concrete compressive strength at all ages where the compressive strength decreased for concrete mixes with 8% and 10% MD as cement replacement compared to control mix. The strength at 7, 28, and 90 days with replacing 10% MD decreased by -10.7%, -11.6% and -8.1%; respectively, compared to control mix. The decrease in concrete strength of containing more than 6% MD as cement replacement may be attributed to the reduction in cement content, which is primarily responsible for the hydration process.

Similarly, the results of GD showed that the compressive strength significantly improved in the case of partial replacement of cement up to 6% GD at all ages of curing. The compressive strength of concrete with 6% GD at 7, 28 and 90 days increased by 18%, 17.1% and 18.5% of reference value, respectively. This remarkable improvement in strength is attributed to the physical and chemical role of GD. The physical role lies in the filling effect of using high fineness GD, which densify the microstructure and fill the cracks and micro and macro pores. The chemical role lies in the fact that granite is a pozzolanic material, which contain more than 80% amorphous silicate and aluminate in its chemical composition, as shown in Table 1. Silicate and aluminate have the ability to participate in a pozzolanic reaction by reacting with CH resulting in the hydration process to produce more additional C-S-H and C-A-H which improves the early and later ages compressive strength. The results show the possibility of using GD up to 8% without any negative impact on the strength, where the strength of 8% GD at 7, 28 and 90 days slightly increased by 0.9%, 2.4% and 6.2%; respectively, compared to control mix. On the other hand, replacing cement with 10% GD had a small negative impact on the compressive strength, where the strength at 7, 28 and 90 days decreased by -6.7%, -5.6% and -2.9%; respectively, compared to control mix. This reduction in compressive strength may be due to the reduction in cement content and may be attributed to the increase in the surface area of the aggregate mix that could require an excess amount of cement to bind between them.

Table 3. Variation of compressive strength as a function of MD and GD at 7, 28 and 90 days.

Mix	Compressive Strength (Mpa)			Increase/Reduction in Compressive Strength		
	7 days	28 days	90 days	7 days	28 days	90 days
C0	32.8	45	48.2			
MD2	34.3	46.1	49.5	+4.6%	+2.4%	+2.7%
MD4	34.1	47.3	49.7	+4.0%	+5.1%	+3.1%
MD6	35.1	48.7	50.8	+7.0%	+8.2%	+5.4%
MD8	31.2	42.5	46.9	-4.9%	-5.6%	-2.7%
MD10	29.3	39.8	44.3	-10.7%	-11.6%	-8.1%
GD2	33.7	46.3	51.3	+2.7%	+2.9%	+6.4%
GD4	35.1	49	52.9	+7.0%	+8.9%	+9.8%
GD6	38.7	52.7	57.1	+18.0%	+17.1%	+18.5%
GD8	33.1	46.1	51.2	+0.9%	+2.4%	+6.2%
GD10	30.6	42.5	46.8	-6.7%	-5.6%	-2.9%

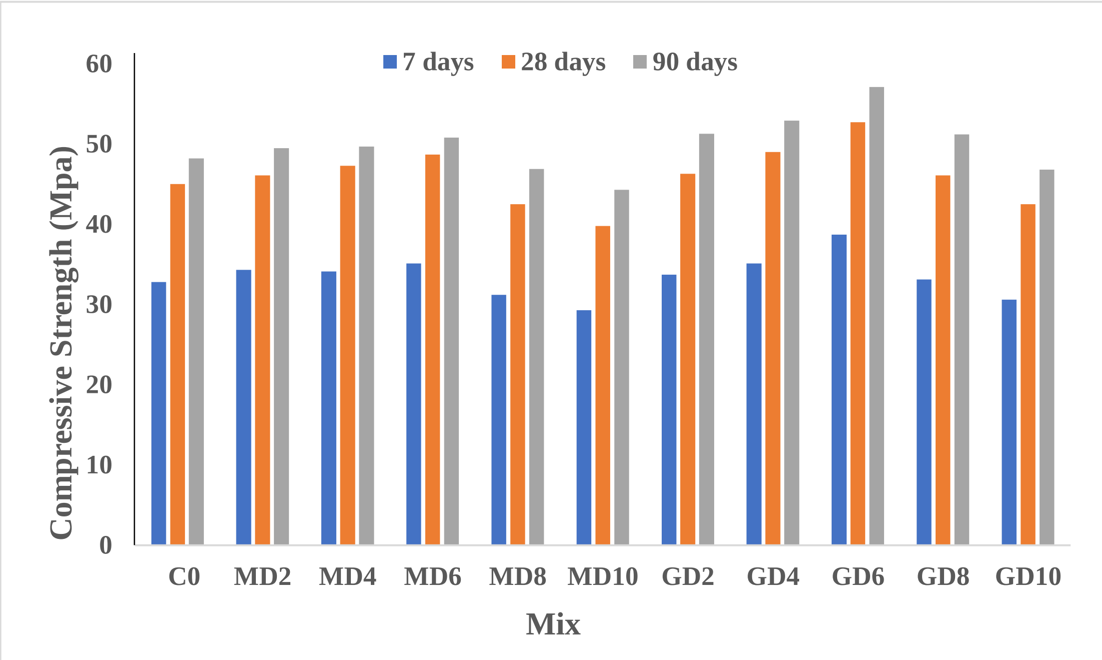


Fig. 4. Effect of marble dust content on compressive strength.

3.2. XRD analysis

Fig. 5 illustrates the XRD patterns of composite cement pastes for the optimum percentage for MD and GD compared to control paste. As shown from the figure; calcium silicate hydrate (CSH), Portlandite (CH), quartz (SiO_2), and calcite ($CaCO_3$) have been detected.

Comparison between the control paste and the MD paste indicates that there is no noticeable difference between the intensities of almost peaks, except for the intensities of the portlandite and calcite peaks. There is a decrease in the portlandite peak of the MD paste, whereas there is a significant increase in the calcite peak of the MD paste compared to that of the control composite. The presence of more calcite in the MD paste was attributed primarily to the substitution of marble in the blended cement, of which calcite is the main phase, and secondarily to the partial carbonization of portlandite as reported by Kechagia et al. [20].

On the other hand, the XRD diffraction pattern of GD paste shows a significant increase in CSH peaks, while Portland peaks highly decreased, compared to control paste. Granite dust contains a high percentage of silicates that participated in the pozzolanic reaction with portlandite (CH) to produce more (C-S-H), which is reflected in a higher intensity in the C-S-H peaks and a lower intensity in the portlandite (CH) peaks. The higher content of the CSH results was reflected in the higher compressive strength of the concrete. There is a significant increase in the quartz (SiO_2) peak of the GD paste, compared to that of the control paste. The increase in the (SiO_2) peak is attributed to the higher silica content of the used granite dust as mentioned by Abdel Moaty [21].

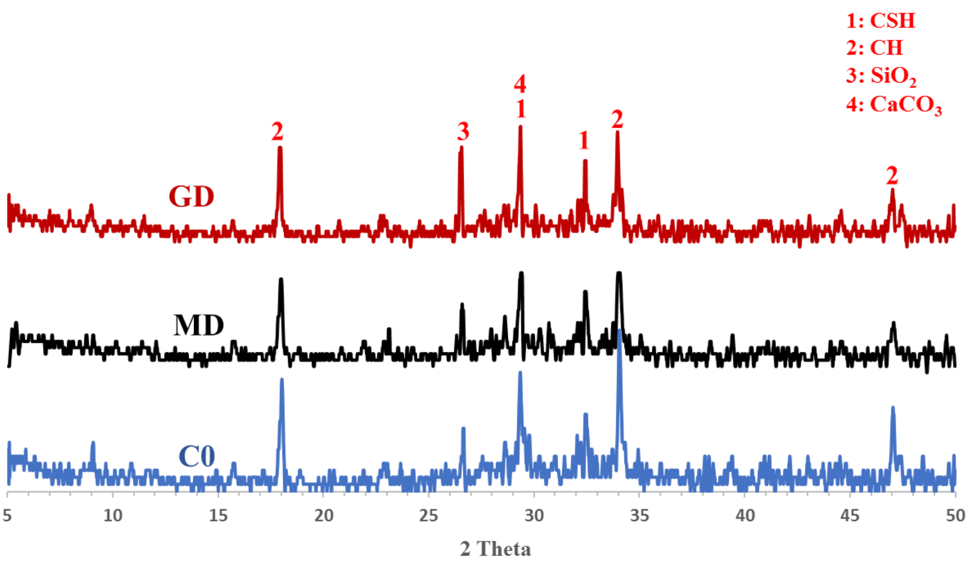


Fig. 5. XRD patterns of control and cement composites.

IV. Conclusions

Based on this experimental program study, the conclusions can be drawn as following:

- Replacing the cement with MD and GD separately up to a level of 6% improves the compressive strength of the concrete and then the strength decreases with increasing the replacement content of the cement compared to the control mix.
- The use of 6% marble dust (MD) as cement replacement slightly improves the concrete compressive strength, where the increase in strength at 7, 28 and 90 days is 7%, 8.2% and 5.4%; respectively, compared to control mix.
- The use of 6% granite dust (GD) as cement replacement improves the concrete compressive strength, where the increase in strength at 7, 28 and 90 days is 18%, 17.1% and 18.5%; respectively, compared to control mix.
- Granite dust (GD) can be used up to 8% as cement replacement without any negative effect on compressive strength, where the strength of concrete with content 8% GD increased slightly by 0.9%, 2.4% and 6.2% at 7, 28 and 90 days; respectively, compared to the control mixture.
- There is no noticeable difference in hydration products in X-ray diffraction analysis between control paste and composite paste with marble dust.
- XRD analysis confirms higher content of C-S-H in the composite paste with granite dust compared to the control paste.

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