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Study the Effect on the Flexural Behavior of Reinforced Concrete Beams Using Waste Materials

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ABSTRACT The production of marble generates a huge amount of waste powder during its manufacturing in Egypt causing an environmental problem. The utilization of this waste in concrete is a smart solution for this environmental problem. The behavior of concrete containing waste marble powder as a replacement of cement or fine aggregate was studied previously, but the present investigation focuses on studying usage waste marble powder on large-scale reinforced concrete beams' flexure behavior. For this purpose, a numerical model using ABAQUS is developed for a series of six reinforced concrete beams. The results were validated by an experimental investigation where six specimens were casted and tested. However, the study includes its effect on the concrete mechanical properties such as compressive, split tensile, and flexure strength. Nine concrete mixtures casted using waste marble powder as a partial replacement of cement by 5%, 10%, 15%, 20% and partial replacement of fine aggregates by 10%, 30%, 40%, 50%. The results showed that the beams flexure strength increased using cement and fine aggregate partial replacement with waste marble. The investigation's optimal mixture is 10% replacement of cement content with waste marble powder, and 30% of fine aggregates replacement.
Keywords Waste marble powder, Cement replacement, Sand replacement, Mechanical properties, Flexural behavior

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I. Introduction

The production and disposal of large amounts of waste or by-product materials from industrial practices have always been an environmental issue. The most common solution for such materials is their disposal in landfills but using this waste in concrete is a solution for the environment. Marble is a metamorphic rock resulting from the transformation of pure limestone. Waste marble powder is an industrial by-product obtained during sawing, shaping, and polishing of marble and then dumped away, causing a environmental issue that is affecting public health [1].

Large quantities of marble powder are produced as by-products in Egypt [2], also it has been estimated that tons of marble powder are produced during quarrying worldwide. The utilization of marble powder has become an efficient usage in concrete for improved properties. Moreover, there is a limit on the availability of natural aggregate and minerals used for concrete production, and it is necessary to reduce energy consumption and emission of carbon dioxide resulting from cement manufacturing; a solution to this issue is through the usage of marble powder as partial replacement of Portland cement and fine aggregates [3].

The marble industry in Egypt has significantly grown during the last decades, especially in Shaq El-Thoaban area, East Cairo, which is considered the largest marble and granite industrial cluster in Egypt and the fourth world-industrial zone [4]. Shaq El-Thoaban industrial cluster shows a negative environmental impact on the surrounding and the neighboring residential communities due to large amounts of waste powder resulting during the marble production.

Many types of research are conducted to investigate the effect of using waste marble powder in concrete production. The use of waste marble powder as a partial replacement with cement and partial replacement with sand has been investigated. Research has been performed to investigate the mechanical performance of marble powder in a mortar and concluded that 10% substitution of sand by waste marble powder in the presence of super plasticizing admixtures provided maximum compressive strength comparable to that of the reference mixture after 28 days of curing [5]. Siva and Mallika [6] studied the feasibility of using marble powder in the high-strength concrete mix. It was observed that maximum compressive strength would be achieved by 10% marble replacement. It was reported that replacement of cement and sand by marble powder up to 10% could increase the compressive strength, split tensile strength, and durability characteristics of concrete specimens.

Latha et al. [7] performed an experimental investigation into concrete's strength characteristics with waste marble powder as a cementitious material. The study concluded that concrete workability increased with cement replacement with waste marble powder up to 20% and found the optimum replacement level of marble powder between 10% to 15% partial replacement with cement. The test results showed that waste marble powder had improvement in the performance of hardened concrete. Sharma and Kumar [8] examined the use of marble powder as a partial replacement in cement, 10% marble powder as a replacement for cement and reported that increasing marble powder significantly decreases the workability of fresh concrete. The research concludes that cement and sand replacement with marble powder at 10% improves the mechanical properties and concrete's durability. In a study made by Shirule et al. [9] conducted in which cement was replaced with marble dust powder, it has been observed that compressive strength, flexural strength, and split tensile strength of concrete increased with the addition of marble powder up to 15% replacement level in comparison with the conventional concrete specimen. Followed by a sudden decrease in the strength at a 20% replacement level. Accordingly, they reported that the optimum percentage of replacement is 15% of the cement content.

Uygunoglu et al. [10] concluded that the use of marble or recycled aggregates in self-compacting concrete at low waste ratios did not decrease the strength significantly. Bilgin et al. [11] showed that 10% by weight of marble powder could be applied to the industrial brick mortar without affecting the final product's mechanical properties and adding more than ten weight percent of waste marble improves water absorption but eliminates mechanical properties. Gencela et al. [12] deduced that with increment in marble content, the w/c ratio increases due to higher specific surface of fine marble aggregates. Sadek et al. [13] derived that using waste powders as mineral additives in self-compacting concrete improves its mechanical, physical properties, and durability-related properties compared with the control mix of the same cement content. Furthermore, the use of 10% silica fume beside waste powders in ternary blended cement was proved to have a unique effect on concrete behavior than using marble waste powders only in binary blended types of cement. Singh et al. [14] found that percentage air content decreased for up to 15% replacement because of denser mix produced on the incorporation of marble slurry in concrete. Slump decreases with an increase in cement replacement with waste marble slurry because of the very fine texture of the material and very high-water absorption. Singh et al. [15] found that the use of marble powder in concrete in the range of 10-15% increases the compressive strength and split tensile strength of concrete by 15-20%. The use of plasticizers enhances the strength due to the w/c reduction.

This research tries to fill the gap and present a thorough study that includes an experimental, and finite element evaluation to investigate the responses of such large-scale beams using waste marble powder. this research presents a detailed study and offers an experimentally quantified approach that can be utilized to implement the effect of using waste marble powder on the response of reinforced concrete beams.

II. Materials

Concrete mixtures examined were made in the laboratory using the following materials: cement, gravel, sand, cement, and waste marble powder.

2.1. Waste Marble Powder

The marble powder was obtained in wet form as an industrial by-product directly from the deposits of marble factories as shown in Figure 1, Shaq El-Thoaban area, East Cairo, which forms during the sawing, shaping, and polishing processes of marble. Therefore, for its use in concrete it is important to dry it, so it was put in an oven to dry at a temperature of 110 ˚C for 24 hours with the aim to reach a constant weight [5]. It marble powder was tested and the specific gravity found to be 2.56 and the value of Blaine fineness is 4100 cm^2/gm.

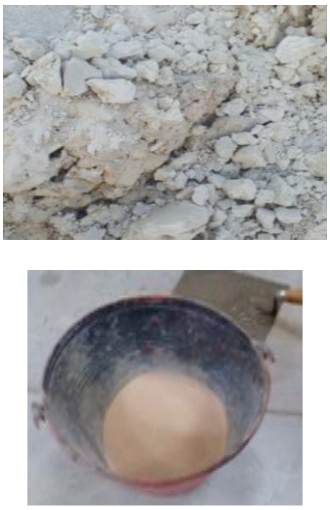

Figure 1. **Waste marble powder**

To analyze the marble powder from a chemical point of view X-ray diffraction was carried out, the identification of the most probable phases is carried out using PANalytical computer certified program with the aid of the International Center of

Diffraction Database (ICDD) received with the X-ray diffraction equipment.

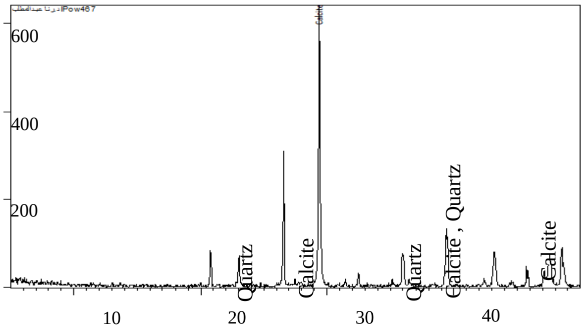

Figure 2. X-ray diffraction of the marble powder

X-ray diffraction analysis, Figure 2, shows that the examined material contains about 88% of calcium carbonate, $CaCO_3$ and the presence of quartz, which could be estimated at about 3%, the remaining part of the marble powder consist of amorphous silica or silicates. The chemical properties of marble powder used is shown in Table 1.

Table 1. Chemical properties of Marble Powder (%)

SiO_2	Al_2O_3	Fe_2O_3	CaO	$CaCO_3$	MgO	$MgCO_3$	SO_3
11.38	0.23	0.09	45.18	88.5	0.20	0.42	0.008

2.2. Cement

The cement used in this study is normal Portland cement N42.4, where its properties are conforming to ASTM C150-07. The Blaine fineness is 3154.7 cm^2/gm and specific gravity is 3.15.

2.3. Aggregates

The coarse and fine aggregates used in the concrete mix with aggregates size given in Figure 3. The coarse aggregate used is local natural crushed gravel, its specific gravity is 2.65 and the absorption capacity equals 0.68%. Natural sand (5 mm) maximum size, with 0.9% passing the 75 µm (No. 200 ASTM) sieve was used. Its specific gravity is 2.55, and its SSD condition water absorption of 2.0%.

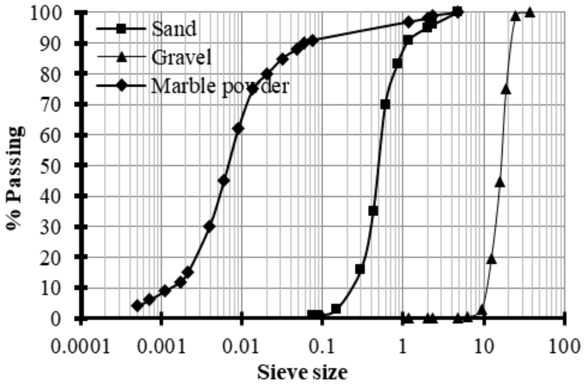

Figure 3. Sieve analysis test for waste marble powder and aggregates

2.4. Mixture proportions

In this study, nine series of concrete mixtures, designed according to British method (BS-5328) [16], classified into two main groups are shown below in Table 2. Group A is a group of 4 mixtures are conducted by adding marble powder with various contents of the total cement volume as a partial replacement of cement. Group B is a group of 4 mixed with a different range of marble powder as a partial replacement of fine aggregates.

The produced concrete series are coded according to the reduction percent ratio in the concrete mix and using water-cement ratio equals to 0.45, as given in Table 3. In addition to a control mixture with no replacement.

Table 2. Concrete mixtures coding and descriptions

Mixture code		Description	
Group A	Mix-WCR1	Cement replacement	mixture with 5% cement replacement
	Mix-WCR2		mixture with 10% cement replacement
	Mix-WCR3		mixture with 15% cement replacement
	Mix-WCR4		mixture with 20% cement replacement
Group B	Mix-WSR1	Sand replacement	mixture with 10% sand replacement
	Mix-WSR2		mixture with 30% sand replacement
	Mix-WSR3		mixture with 40% sand replacement
	Mix-WSR4		mixture with 50% sand replacement

Table 3. The design mix ratios of the concrete types for 1 m^3

Mixture			Weight (kg)			
			Cement	Marble Powder	Fine aggregates	Coarse aggregates
Group A	Cement replacement	Control	485	0	615	1145
		Mix-WCR 1	460	25	615	1145
		Mix-WCR 2	435	50	615	1145
		Mix-WCR 3	415	70	615	1145
		Mix-WCR 4	390	95	615	1145
Group B	Sand replacement	Mix-WSR 1	485	60	556	1145
		Mix-WSR 2	485	180	435	1145
		Mix-WSR 3	485	240	375	1145
		Mix-WSR 4	485	308	308	1145

III. EXPERIMENTAL TESTING PLAN

3.1. Slump Test

Concrete mixing was done in a laboratory pan mixer following ASTM C192/192M-06 [17]. Slump tests were performed on the mixes to measure consistency as described in ASTM C1611 / C1611M [18]. The mixes were then prepared and cured according to ASTMC192/192M-06 [19] as shown in Figure 4. 150x150x150mm molds were used for casting the concrete cubes. Nine specimens were tested for each mix and compacted on a vibrating compactor and the curing method described in the standard was made where all cubes and cylinders were immersed in water tank and then kept in shaded area before the test day. The experimental plan included six reinforcement concrete beams, the size of the beam specimen is 150mm width, 250mm depth and 2 m span length.

Figure 4. Specimens' preparations for the experimental investigation

Values of slump are reported in Table 4 that evidences a noticeable decrease of the slump value from reference mixture Control because of the amount of marble powder as shown in Figure 5.

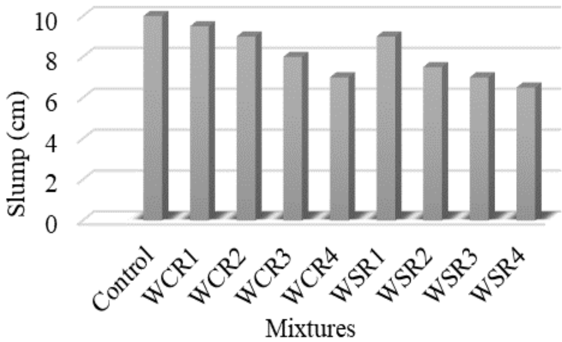

Figure 5. Slump test results for the group A and B

Figure 6. Compressive strength testing of specimen

The concrete cubes were tested at 7, 14, and 28 days and the results are tabled in Table 4. Figures 7 and 8 present the compressive strength results of Group A and B, respectively. It is observed from the results at 7days that the concrete early gains strength by adding waste marble powder more than the control mix, especially Group A. The compressive strength increased by using waste marble powder as a partial replacement with cement till 15% replacement as this ratio gives a 12.22% increase. Using 20% cement replacement leads to a decrease in the compressive strength by 5.25%. A 10% cement replacement gives the highest compressive strength, 23.19 % increase at 28 days. The mixtures of fine aggregate replacement results showed the optimum replacement is 30%, which gives a 20% increase in the compressive strength at 28 days. Increasing the replacement ratio to 40 and 50%, the compressive strength increases but 12.9 and 13.2% at 28-days. Test three cubes for compressive strength for each curing period mentioned under the relevant specifications (7 days, 14 days, 28 days).

Table 4 Compressive strength of the designed mixtures

Mixture		Slump (mm)	Compressive strength (N/mm^2)		
			7-days	14-days	28-days
Control		10	25.7	32.2	40.0
Group A	WCR1	9.5	40.2	43.4	44.7
	WCR2	9.0	44.6	47.2	49.4
	WCR3	8.0	40.2	43.6	45.0
	WCR4	7.0	35.0	36.2	38.0
Group B	WSR1	9.0	29.0	39.0	44.3
	WSR2	7.5	38.0	42.0	48.2
	WSR3	7.0	35.7	36.9	45.3
	WSR4	6.5	35.4	37.8	45.4

3.2. Compressive Strength Test

Compressive strength tests were conducted on concrete cubes of size 150x150x150 mm according to BS EN 12390-3:2019 [20] using ADR Control Pro 3000 BS EN Compression Machine, as shown in Figure 6.

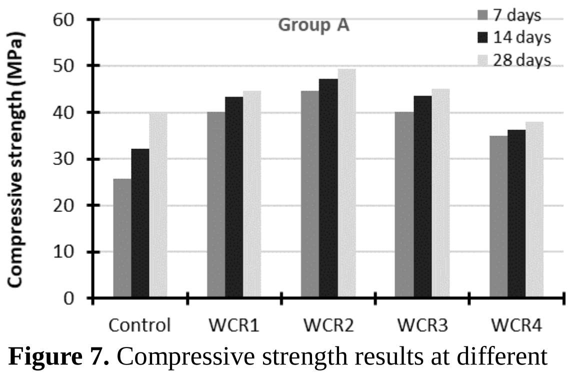

Figure 7. Compressive strength results at different ages for group A

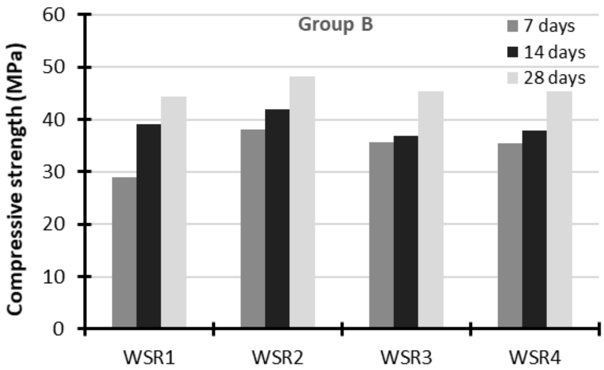

Figure 8. Compressive strength results at different ages for group B

3.3. Split Tensile Strength Test

A Split tensile strength test on the concrete cylinder size 150x300 mm is a method to determine the concrete's tensile strength. The procedure is based on the ASTM C496 / C496M-17 Standard Test [21], using ADR Control Pro 3000 BS EN Compression Machine. Split strength test results are given in Figure 9. Split strength increased by 15.28% using 10% cement replacement and an increase by 26.39% using 50% sand replacement compared to control mix. As shown in Figure 9, split tensile strength reduced by 7.78 % by 20% cement replacement with marble powder was used, and it was the same when a 15% replacement of cement compared to control mix.

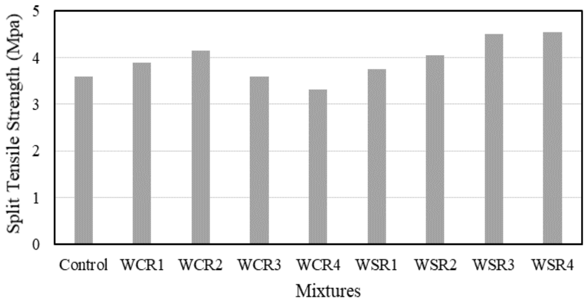

Figure 9. Comparison of the mixtures split tensile strength

In this study ACI Committee 318 (1999) equation (1) that evaluate the relationship between the compressive and split tensile strengths of the conventional concrete is used to compare the experimental results of the compressive and split tensile strengths. In Figure 10, the dashed lines indicate the trend lines of the relationship between the compressive and split tensile strengths of the conventional concrete obtained using ACI Committee 318 (1999) equation; the plain line indicates the same for the concrete used in this study. This result indicates that the split tensile strength of the concrete with marble powder partial replacement is likely to be lower than that of the conventional concrete for the given compressive strength using ACI Committee 318 (1999) equation.

$$f_{sp} = 0.4 \text{ to } 0.7\ (0.56)\ f^{0.5} \qquad (1)$$

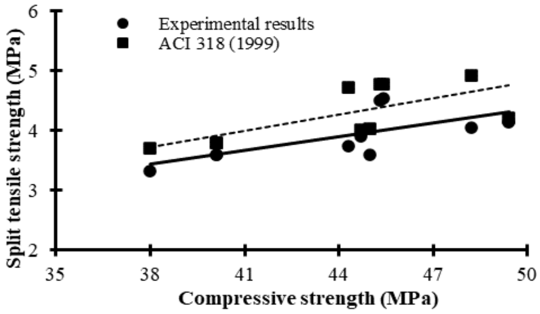

Figure 10. Comparison between predicted conventional concrete split tensile strength and actual split tensile strength for same compressive strength for both replacement with marble powder.

3.4. Flexure Strength Test

In this experimental study, a conventional reinforced concrete beam and modified concrete beams prepared with partial replacement of cement by marble powder and fine aggregate by marble powder were considered. Six full-scale beams were tested in total using Computer Controlled Servo Hydraulic Universal Testing Machine 600KN. The first beam was casted with control mix with no replacement. Three beams were casted with concrete mixtures made by replacing waste marble powder with cement by ratios; 10%; 15%; 20%, and two beams with concrete mixtures by replacement waste marble powder with the fine aggregates; 20%; 40%, as presented in Table 5.

Table 5. Beam replacement levels of cement and fine aggregate description

Beam No.	Mixture code	Description
Beam 1	Control	mixture with 0% replacement
Beam 2	Mix-WCR2	mixture with 10% cement replacement
Beam 3	Mix-WCR3	mixture with 15% cement replacement
Beam 4	Mix-WCR4	mixture with 20% cement replacement
Beam 5	Mix-WSR1	mixture with 10% sand replacement
Beam 6	Mix-WSR2	mixture with 30% sand replacement

All the beams had a rectangular cross-section of 150mm wide, 250mm depth, and a span of 2 m, illustrated in Figure 11. They had the same structure, size, and reinforcement (2ø12 top rft and 2ø16 bottom rft). The beams were loaded using a concentrated three-point load setup, a concentrated load was applied directly at the center of the supported beams with clear span 1.6 m as in Figure 12. The beams were loaded in constant load steps, and concrete strain gauges were installed to measure the concrete's strains, while beam deflections were measured by displacement meters.

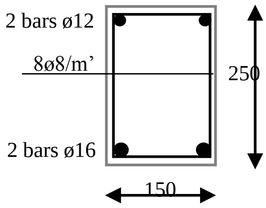

Figure 11. Cross-sectional view of beam specimen

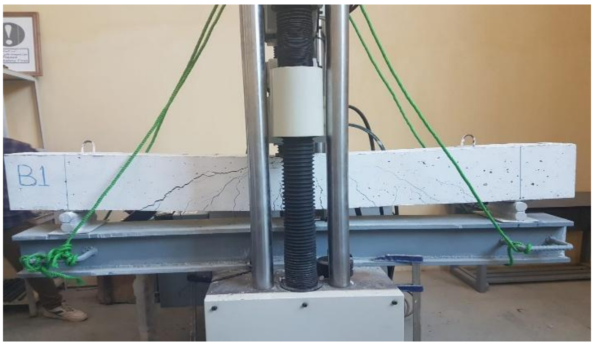

Figure 12. Three-point bending test setup for the beams

The load-deflection curves of each beam are shown in Figures 13 and 14. From the results shown, the ultimate load of all beams is relatively close and the beams casted with 10% replacement of marble powder showed a higher flexure resistance than the other replacement percentages and compared to the control mix.

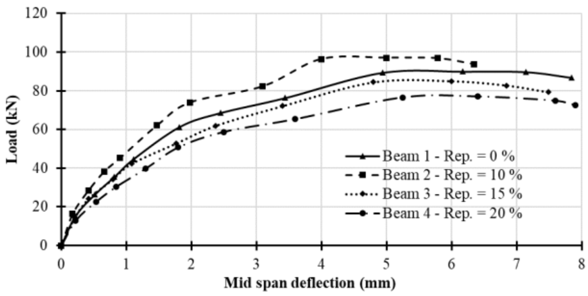

Figure 13. Load-Deflection behaviour for group A

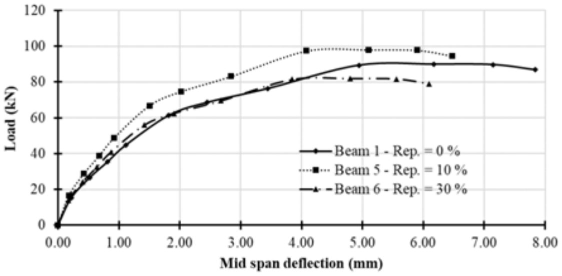

Figure 14. Load-Deflection behaviour for group B

IV. Numerical Model

In this study, A numerical finite element analysis (NFEA) model is developed using ABAQUS software for six reinforced concrete beams to evaluate the flexure behavior of using marble powder in concrete. A NFEA is presented for reinforced concrete beams with waste marble powder laminates using the ABAQUS program. The finite element models are developed using the concrete damage plasticity approach for concrete and truss elements for the reinforcement. The results obtained from the ABAQUS finite element analysis are compared with the experimental data for six beams. The comparisons are made for load-deflection curves at mid-span, and failure load.

Steel plates were added at support and loading locations in the finite element models (as in the actual beams) to avoid stress concentration problems. An elastic modulus equal to 200,000 N/mm^2 and Poisson's ratio of 0.3 were used for the plates. The steel plates were assumed to be linear elastic materials.

C3D8R shell element was used to model the concrete. This element has eight nodes linear brick with three degrees of freedom at each node – translations in the nodal x, y, and z directions. This element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. Modeling of reinforcing steel, T3D2 two-node linear 3D truss was used to model steel reinforcement. This element is a 3D space element, and it has two nodes with three degrees of freedom – translations in the nodal x, y, and z directions. This element is also capable of plastic deformation. The beam reinforcement. An embedded region is used to simulate a perfect bond between the concrete and steel reinforcement considered.

For the concrete damage plasticity model, the selected values of its parameters, given in Table 6, gave the best fit with the experimental results and fell in the recommended range as reported by Jankowiak and Lodygowski [22], Sümer and Aktaş [23], and SIMULIA [24].

Table 6 Plasticity parameters for concrete damage plasticity modeling.

Dilation Angle	Eccentricity	fb0/fc0	K	Viscosity Parameter
38	0.1	1.12	0.667	0

The load-deflection curves of each beam are shown in Figures 15 and 16. It can be seen that the ultimate load of all beams is relatively close. However, the maximum deflection varies with the replacement percentage and concrete strength. From the results shown, the beams cast with 10% replacement of marble powder showed a higher flexure resistance than the other replacement percentages and the control mix.

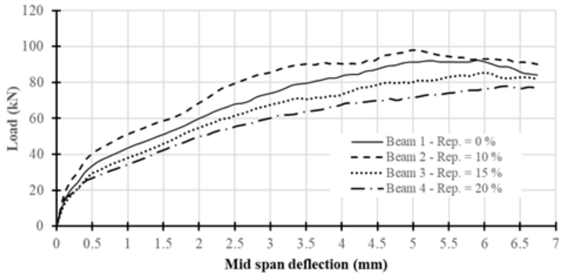

Figure 15. Numerical Load-Deflection behaviour for group A

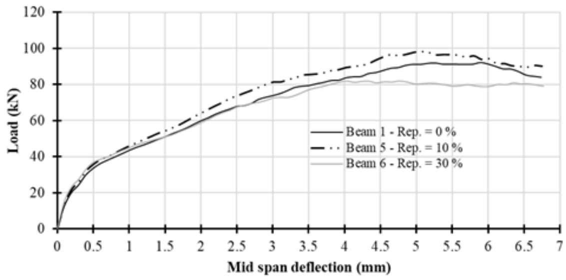

Figure 16. Numerical Load-Deflection behaviour for group B

A comparison was made for the beams load-deflection curves gathered from experimental and finite element results showing a good agreement in finite element analysis with the experimental results throughout the behavior and failure mode. Table 7 shows a comparison between the experimental beams' ultimate loads and the final loads from the finite element models. The results showed that with 10% replacement the ultimate load increased by 6.5% in case of cement replacement and the increase reached to 7.6% in case of fine aggregate replacement. By increasing replacement percentages, a decrease in the values reached to 10% with 30% fine aggregate replacement and 16% decrease by 20% cement replacement.

Table 7 Ultimate load for the flexure beam testing

Beam	Experimental ultimate load (kN)	NFEA ultimate load (kN)
Beam 1	92.03	92.30
Beam 2	97.10	97.85
Beam 3	85.67	85.54
Beam 4	77.00	77.77
Beam 5	98.98	98.16
Beam 6	81.97	82.07

V. CONCLUSIONS

This research offers a detailed study through a numerical and an experimentally approaches that can be utilized to implement the effect of using waste marble powder on the response of reinforced concrete beams. Also, the study determines the effect of using this waste in the design mix of concrete and its effect on the concrete mechanical properties such as compressive, split tensile, and flexure strength. A numerical model using ABAQUS is developed for six beams with a concrete mixture with the lowest possible cement amount, which also met the strength requirement. The results were validated by an experimental investigation where six specimens were casted and tested. An experimental investigation is performed on concrete mixtures to study the effect of using waste marble powder as a partial replacement of cement with 4 different percentages (5%, 10%, 15%, 20%) and partial replacement of fine aggregates is partially replaced with (10%, 30%, 40%, 50%). The results show that 10% replacement of waste marble powder with cement achieve the maximum flexure strength by 6.5%, compressive strength by 23% and split tensile strength by 15%. However, 30% replacement of waste marble powder with fine aggregates showed increase in the compressive by 20%, split tensile strength by 12.5% and flexure strength optimum results found to be at 10% replacement increase by 7.6%. It is evident from the results that, the cement replacement by marble powder work and active in at 28 days. Therefore, we suggest a future work to study how the Waste Marble Powder affecting on long term after 90 days or more.

REFERENCES

[1]. R. Malpani, S. K. Jegarkal, R. Shepur, R. Kiran, V. K. Adi. Effect of marble sludge powder and quarry rock dust as partial replacement for fine aggregates on properties of concrete, International Journal of Innovative Technology and Exploring Engineering, Vol. 4, No. 1, 39-42, 2014.
[2]. H. A. El-Sayed, A. B. Farag, A. M. Kandeel, A. A Younes, M. M. Yousef. Characteristics of the marble processing powder waste at Shaq El-Thoaban industrial area, Egypt, and its suitability for cement manufacture, HBRC journal, Vol. 14, No. 2, 171-179, 2018.
[3]. K. Celik, C. Meral, A. P. Gursel, P. K. Mehta, A. Horvath, P. J. Monteiro. Mechanical properties, durability, and life-cycle assessment of self-consolidating concrete mixtures made with blended portland cements containing fly ash and limestone powder, Cement and Concrete Composites, Vol. 56, 59-72, 2015.
[4]. R. Ciccu, R. Cosentino, C. Montani, A. El Kotb, H. Hamdy, Strategic study on the Egyptian marble and granite sector, Industrial Modernisation Centre (IMC), Cairo, 2005.
[5]. V. Corinaldesi, G. Moriconi, T. R. Naik. Characterization of marble powder for its use in mortar and concrete, Construction and building materials, Vol. 24, No. 1, 113-117, 2010.
[6]. I. S. Kishore, C. M. Chowdary. A study on waste utilization of marble dust in high strength concrete mix, International Journal of Civil Engineering and Technology, Vol. 6, No. 12, 2015.
[7]. G. Latha, A. S. Reddy, K. Mounika. Experimental investigation on strength characteristics of concrete using waste marble powder as cementitious material, Growth journal, Vol. 4, No. 12, 2015.
[8]. N. Sharma, R. Kumar. Review on use of waste marble powder as partial replacement in concrete mix, SSRG International Journal of Civil Engineering, 2348-8352, 2015.
[9]. P. A. Shirule, A. Rahman, R. D. Gupta. Partial replacement of cement with marble dust powder. International Journal of Advanced Engineering Research and Studies, Vol. 1, No. 3, 2249, 2012.
[10]. T. Uygunoglu, B. Topçu-İlker, A. G. Çelik. Use of waste marble and recycled aggregates in self-compacting concrete for environmental sustainability, Journal of cleaner production, Vol. 84, 691-700, 2014.
[11]. N. Bilgin, H. Yeprem, A. Arslan. Use of waste marble powder in brick industry, Construction and Building Materials, Vol. 29, 449-457, 2012.
[12]. O. Gencela, C. Ozel, F. Koksal, E. Erdogmus, G. Martínez-Barrera, W. Brostow. Properties of concrete paving blocks made with waste marble, Journal of Cleaner Production, Vol. 21, No. 1, 62-70, 2012.
[13]. D. M. Sadek, M. M. El-Attar, H. A. Ali. Reusing of marble and granite powders in self-compacting concrete for sustainable development. Journal of Cleaner Production, Vol. 121, 19-32, 2016.
[14]. M. Singh, et al. A study on environmental and economic impacts of using waste marble powder in concrete. Journal of Building Engineering, Vol. 13, 87-95, 2017.
[15]. M. Singh, A. Srivastava, D. Bhunia. An investigation on effect of partial replacement of

cement by waste marble slurry, Construction and Building Materials, Vol. 134, 471-488, 2017.
[16]. BSI-5328: (Part 2). Methods for specifying concrete mixes. British Standard, London, United Kingdom, 1997.
[17]. ASTM C192/192M-06, Standard practice for making and curing concrete test specimens in the laboratory, ASTM International, West Conshohocken, PA, 2018.
[18]. ASTM C1611 / C1611M-18, Standard Test Method for Slump Flow of Self-Consolidating Concrete, ASTM International, West Conshohocken, PA, 2018.
[19]. ASTM C192/192M-06, Standard practice for making and curing concrete test specimens in the laboratory, ASTM International, West Conshohocken, PA, 2018
[20]. BS EN 12390-3:2019. Standard Test Method for Compressive Strength, British Standards Institution, London, 2019.
[21]. ASTM C496 / C496M-17. Standard Test Method for Split Tensile Strength of Cylindrical Concrete Specimens, ASTM International, West Conshohocken, PA, 2017.
[22]. T. Jankowiak, T. Lodygowski. Identification of parameters of concrete damage plasticity constitutive model. Foundations of civil and environmental engineering, Vol. 6, No. 1, 53-69, 2005.
[23]. Y. Sümer, M. Aktaş. Defining parameters for concrete damage plasticity model, Challenge Journal of Structural Mechanics, Vol. 1, No.3, 149-155, 2015.
[24]. SIMULIA. Abaqus/CAE User's Manual, Providence, RI, USA, 2012.

R. Morsy. "Study the Effect on the Flexural Behavior of Reinforced Concrete Beams Using Waste Materials." *International Journal of Engineering Research and Applications (IJERA)*, vol.12 (10), 2022, pp 24-32.