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Chapter

Sustainable Recycling of Marble Dust as Cement Replacement in Concrete: Advances and Recent Trends

Ahed Habib and Maan Habib

Abstract

In recent years, many researchers in the construction industry had taken up the challenge to incorporate non-biodegradable wastes as partial replacement of cement and/or natural aggregates in the daily production of cement-based materials. Various efforts were intended to understand the influence of using marble dust in concrete due to its availability and a relatively high volume of the generation that causes serious environmental problems. Previous studies have utilized marble dust as a replacement of cement, fine aggregate, or total paste in the concrete and mortar mixtures. In general, several investigations have shown that up to a certain cement replacement ratio, marble dust can positively impact on the strength and microstructure properties of concrete. Furthermore, the results have indicated that the considerably high degree of fineness in the marble dust provides sufficient cohesiveness of mortar and concrete even in low w/c ratio conditions. Hence, this powder can be utilized as a filler to improve the flowability of cement-based materials. Consequently, this chapter aims to summarize recent investigations on the properties of concrete incorporating marble waste as cement replacement materials, highlight the potential gaps in the literature, and propose a prediction model for estimating the compressive and flexural strengths of concrete with marble dust using regression analysis.

Keywords: sustainable materials, marble dust, cement-based materials, cement replacement, mechanical properties

1. Introduction

Throughout the last few decades, considerable efforts in the scientific community were focused on providing sustainable solutions for minimizing non-biodegradable wastes by suggesting innovative waste management plans. Recently, the construction industry has started taking an active role in recycling these materials by utilizing them as a partial replacement of the constituents in cement-based productions, aiming to come up with a green alternative for conventional construction materials.

Stone marble industrial activities, including mining, processing, and finishing, have contributed to the development of several major environmental risks [1].

One of these risks is the disposal of marble wastes that are raised during the production of marble slabs. Currently, the availability and the reasonably high volume of a generation of marble dust has attracted several researchers to conduct investigations on the possibility of utilizing this waste material as a partial replacement of cement [2–4], fine aggregates [5, 6], or total paste in concrete, mortar, and asphaltic mixtures [7, 8]. The main benefit of replacing cement by marble dust comes from the reduction in the cost of the mixture, and CO2 emission related to the production of cement [9].

Previous studies have illustrated that incorporating this material in concrete affects its fresh, mechanical, durability, and porosity properties [10–12]. Its main impact on the strength carrying capacity of concrete is generally considered such that when replacing a low percentage of the cement with marble dust, the strength is improved. However, at high replacement ratios, beyond 10% to 15%, the compressive and tensile strengths of the concrete reduce. Another importance of this material, in addition to its sustainable benefits, comes from the high degree of fineness that allows utilizing it as filler in cement-based mixtures.

Therefore, this chapter is intended to offer a brief review of the utilization and mechanical properties of cement-based materials incorporating marble dust with emphasis on concrete mixtures with marble wastes cement replacement. Another aim of the study is to propose estimation models using multiple regression analysis for the compressive and flexural strengths of marble dust concrete and highlight some observations on the influence of marble dust content and properties on the change in the concrete strength capacity.

2. Engineering properties marble dust

Marble is defined scientifically as a metamorphic rock composed of recrystallized calcite ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$), while commercially as any limestone or dolomite processed and taking a polish, **Figure 1** [13]. During cutting and polishing these stones in the marble factories, a product composed of the marble dust mixed with water referred to in the literature as marble waste slurry is generated. Usually, marble dust is obtained by chemically processing the marble waste slurry to separate the wastewater from the marble dust.

The X-ray powder diffraction (XRD) pattern of marble dust is exhibited in **Figure 2**, which shows calcite ($CaCO_3$) as the main mineral component of this material. Also, **Figure 3** presents an example of a scanning electron microscope (SEM) micrographs of marble dust particles.

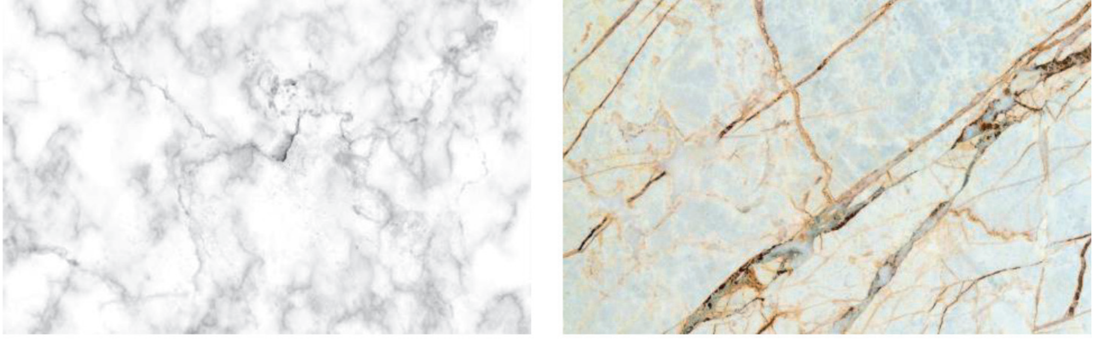

Figure 1.
Typical types of polished marbles.

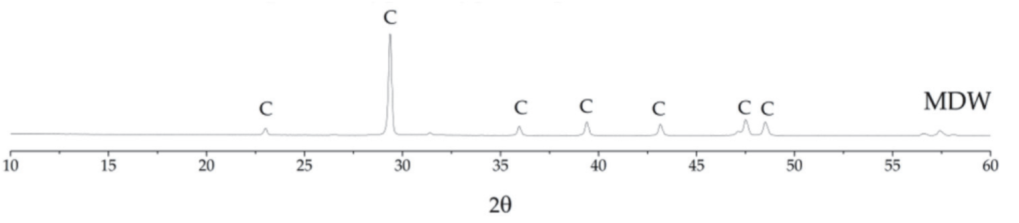

Figure 2.
XRD pattern of marble dust waste as discussed in Julphunthong & Joyklad [14] study.

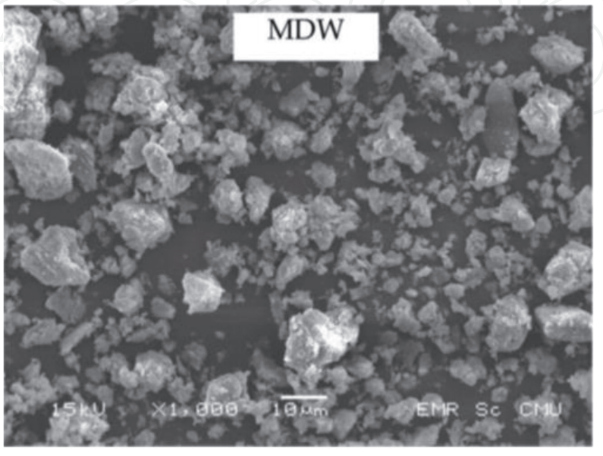

Figure 3.
SEM image of marble dust as given by Julphunthong & Joyklad [14].

Author/s	Chemical analysis (wt. %)							
	CaO	SiO_2	Fe_2O_3	Al_2O_3	MgO	Na_2O	K_2O	SO_3
[16]	52.45	1.29	0.78	0.39	0.54	-	0.11	-
[17]	40.73	6.01	0.8	0.6	15.21	0.06	0.05	0.09
[18]	41.83	8.38	0.65	0.67	10.36	0.60	0.07	0.33

Table 1.
Chemical compositions of marble dust as reported in the literature.

As reported previously, the specific gravity of this material varies over a wide range between 2.39 and 3.16 due to the difference in the structural and chemical properties of the marble stones [15]. Similarly, the chemical compositions of marble dust various based on the type of stone used. Some examples of the chemical compositions from Gesoğlu et al. [16], Vardhan et al. [17], and Ashish [18] studies can be seen in **Table 1**.

The cutting one-meter cube of marble block into slabs of 2 cm thickness each, 25% of the total amount will turn into fine particles [19]. Previous studies, Gesoğlu et al. [16], Singh et al. [20], and Li et al. [21] presented the particle size distribution of marble wastes as demonstrated in **Figure 4**, in which it depends mainly on the method of cutting the marbles and the size of the produced layer.

3. Types of marble waste utilizations and potential applications

Over the last few years, marble dust has been introduced to various kinds of cement-based materials as a partial replacement of cement [2, 5], fine aggregate [22],

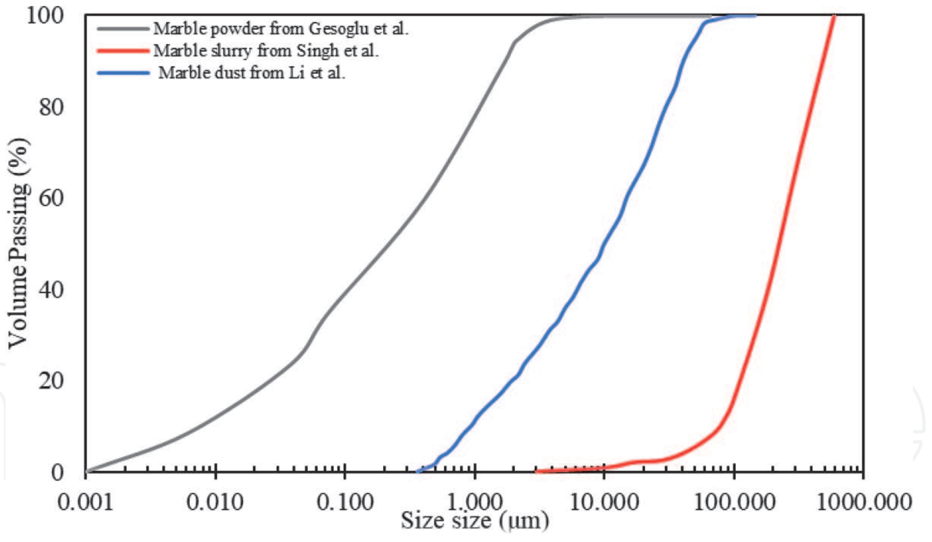

Figure 4.
Particle size distribution of marble wastes used in the literature.

Author/s	Mixture type	Type of replacement
[2–4]	Concrete	Cement
[1]	Concrete	Cement and fine aggregate
[23–25]	Self-compacting concrete	Cement
[26]	High-performance concrete	Cement
[5]	Concrete paving blocks	Fine aggregate
[27]	Concrete	Fine aggregate
[28]	Mortar	Cement
[6]	Mortar	Fine aggregate
[21]	Mortar	Total paste
[29]	Cement composites	Cement

Table 2.
A brief summary of the utilization of marble wastes in the literature.

or total paste [21]. The essential types of mixtures in which marble dust has been utilized can be epitomized as concrete, mortar, cement composites. A summary of the types of marble wastes utilization in cement-based materials can be seen in **Table 2**.

Previously Singh et al. [30] have discussed some of the potential applications of marble wastes in the construction industry. Some of these applications are presented as follows:

- It can be used as a filler for roads and embankment materials where water bound macadam can be laid.

- It can be implemented in the manufacturing process of bricks due to the existence of very fine particles in marble slurry.

- It can be utilized as a partial replacement of cement in concrete due to is the capability of being used as a filler to improve the concrete's properties.

- It can be used in the production of hollow blocks and wall tiles in addition to other clay-based products.

- It can be utilized as a substitute of limestone in various construction materials and industrial applications.

4. Mechanical properties of concrete utilizing marble waste

In this section, the mechanical properties of a concrete mixture incorporating marble waste as partial replacement of cement will be introduced. Previous studies showed, **Figure 5**, that the mechanical properties of concrete mixtures are influenced when marble waste is incorporated. Ergün [3] observed that replacing 5% of the cement content by marble powder results in increasing the compressive strength of concrete by almost 12%. Also, he reported that at the same replacement ratio, a 5% increase in the flexural strength of concrete was achieved. In contrast, higher marble dust content indicated a negative effect on the flexural capacity. Moreover, Munir et al. [31] measured a slight increase in the compressive strength of concrete when 10% of its cement was replaced by marble powder. Vardhan et al. [17] reported that utilizing marble powder as a partial substitution of up to 10% of the cement content in concrete does not have a significant negative influence on the compressive strength. A similar observation was mentioned by Rana et al. [32].

Furthermore, Rana et al. [32] reported a slight reduction in the flexural capacity of concrete when marble wastes replaced up to 10% of the cement. In contrast, higher replacement ratios caused a considerable fall in flexural strength. The modulus of elasticity of concrete with marble powder as substitution of cement was investigated by Soliman [33]. In general, they concluded that up to a 5% ratio, the modulus of elasticity is positively impacted, and beyond this value, the parameter starts to drop slightly. Nevertheless, Usysal & Yilmaz [25] clarified that an increase in the modulus of elasticity when up to 20% of the cement was changed by marble powder in a self-compacting concrete mixture, but a slight decline is observed at 30% replacement ratio. Kumar and Kumar [2] measured an increase in the splitting tensile and flexural strengths by 9.21% and 7.5%, respectively, at 15% cement substitution, while the compressive strength was reduced by 9.06%. On the other hand, using a 20% replacement ratio caused a lowering in the compressive and tensile strengths as compared to the control specimens. This reduction in the strength properties of concrete incorporating high content of marble wastes, beyond 10% in most cases, as a substitution of cement, can be attributed to the decrease in the cement content [3].

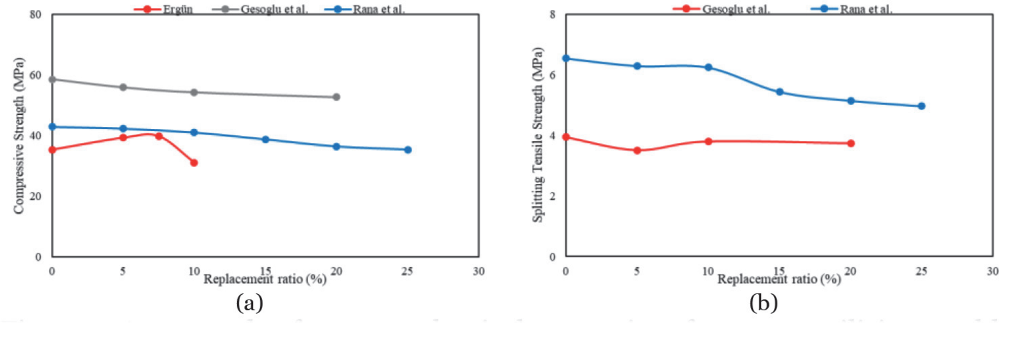

Figure 5.
An example of some mechanical properties of concrete utilizing marble waste as cement replacement (a) compressive strength, (b) splitting tensile strength.

5. Prediction of concrete compressive strength

In this section, a prediction model for the compressive strength of concrete incorporating marble wastes as partial replacement of cement will be addressed.

5.1 Collected data

The collected dataset for generating the prediction models in this study are displayed in **Tables 3** and **4**. First of all, the papers that discussed the utilization of marble dust were collected. Thereafter, those studies that investigated the compressive and flexural strength of concrete utilizing marble waste as cement replacement were shortlisted, and their data were obtained using GetData graph digitizer software [36].

Several parameters are going to be used in developing the estimation model for marble dust compressive strength (f_{cm}) and its flexural strength (f_{tm}). These parameters are the control compressive strength (f_{cc}) or flexural strength (f_{tc}), marble dust content (MD_C), its CaO content (MD_{CaO}), and its specific gravity (MD_{SG}). The last three inputs are basically used to take the effect of marble waste properties on concrete behavior. Because this material does not have a standardized characteristic in which its properties depend on the type of rocks being processed in the factories.

5.2 Multiple linear regression

As mentioned previously, the multiple linear regression method will be used for building the mathematical expression of the estimation model. In general, it is a statistical way to establish a linear relationship between a dependent variable and two or more independent predictors [37]. The mathematical model that describes this method of estimation was discussed by Achen [38], as written in (Eq. (1)).

$$y_i = \beta_0 + \beta_1 x_{1i} + \ldots + \beta_k x_{ki} + \varepsilon_i \tag{1}$$

where y_i is the i^{th} observation on the dependent variable; $x_{1i}, \ldots, x_{ki}$ are the i^{th} observations on the independent variables; β_0 is an intercept term; $\beta_1, \ldots, \beta_k$ are the coefficients to be estimated; and ε_i is a random error component of the i^{th} observation, also known as the residual.

After creating a prediction model, it is essential to test its goodness-of-fit. On this matter, the coefficient of determination (Eq. (2)) was adopted in this study in which values closer to one represents a good fitting model.

$$R^2 = 1 - \frac{\sum \left(y_i - \hat{y}_i\right)^2}{\sum \left(y_i - \bar{y}\right)^2} \tag{2}$$

where y_i is the actual value, $\hat{y}_i$ is the predicted one, and $\bar{y}$ is the mean of the actual values.

Thereafter, the adequacy of the prediction model is evaluated by conducting a residual analysis through first plotting the residuals, (Eq. (3)), against one of the independent variables and then scaling these values using the standardized residuals method (Eq. (4)) to obtain potential outliers.

$$e_i = \left(y_i - \hat{y}_i\right) \tag{3}$$

Author/s	Marble waste properties			Compressive strength		
	Content (kg)	CaO (%)	Specific Gravity	f_{cc} (MPa)	f_{cm} (MPa)	Δf_c (%)
Ergün [3]	15	51.7	2.68	35.4	39.4	-10.15
Ergün [3]	22.5	51.7	2.68	35.4	39.9	-11.28
Ergün [3]	30	51.7	2.68	35.4	31.1	13.83
Gesoğlu et al. [16]	26	52.45	2.71	58.57	55.94	4.70
Gesoğlu et al. [16]	52	52.45	2.71	58.57	54.34	7.78
Gesoğlu et al. [16]	104	52.45	2.71	58.57	52.75	11.03
Rana et al. [32]	20.25	65.2	2.87	43	42.4	1.42
Rana et al. [32]	40.5	65.2	2.87	43	41.1	4.62
Rana et al. [32]	60.75	65.2	2.87	43	38.8	10.82
Rana et al. [32]	81	65.2	2.87	43	36.44	18.00
Rana et al. [32]	101.25	65.2	2.87	43	35.4	21.47
Sardinha et al. [34]	15.4	54.2	2.73	39.2	37.3	5.09
Sardinha et al. [34]	30.7	54.2	2.73	39.2	34.3	14.29
Sardinha et al. [34]	61.4	54.2	2.73	39.2	28	40.00
Sardinha et al. [34]	15.4	54.2	2.73	52.1	46.2	12.77
Sardinha et al. [34]	30.7	54.2	2.73	52.1	44.4	17.34
Sardinha et al. [34]	61.4	54.2	2.73	52.1	35.8	45.53
Sardinha et al. [34]	15.4	54.2	2.73	53.6	53.5	0.19
Sardinha et al. [34]	30.7	54.2	2.73	53.6	47.95	11.78
Sardinha et al. [34]	61.4	54.2	2.73	53.6	37.4	43.32
Singh et al. [20]	42.2	26.63	2.67	38.54	39.88	-3.36
Singh et al. [20]	63.3	26.63	2.67	38.54	41.35	-6.80
Singh et al. [20]	84.4	26.63	2.67	38.54	35.09	9.83
Singh et al. [20]	105.5	26.63	2.67	38.54	33.12	16.36
Singh et al. [20]	39.4	26.63	2.67	31.37	32.44	-3.30
Singh et al. [20]	59.1	26.63	2.67	31.37	33.65	-6.78
Singh et al. [20]	78.8	26.63	2.67	31.37	27.01	16.14
Singh et al. [20]	98.5	26.63	2.67	31.37	25.74	21.87
Singh et al. [20]	35.1	26.63	2.67	23.54	24.65	-4.50
Singh et al. [20]	52.65	26.63	2.67	23.54	23.08	1.99
Singh et al. [20]	70.2	26.63	2.67	23.54	20.42	15.28
Singh et al. [20]	87.75	26.63	2.67	23.54	20.03	17.52
Aliabdo [1]	20	83.22	2.5	39.93	37.3	7.05
Aliabdo [1]	30	83.22	2.5	39.93	38.4	3.98
Aliabdo [1]	40	83.22	2.5	39.93	38.8	2.91
Aliabdo [1]	60	83.22	2.5	39.93	34.6	15.40
Aliabdo [1]	20	83.22	2.5	48.73	51.76	-5.85
Aliabdo [1]	30	83.22	2.5	48.73	52.64	-7.43
Aliabdo [1]	40	83.22	2.5	48.73	53.12	-8.26

Author/s	Marble waste properties			Compressive strength		
	Content (kg)	CaO (%)	Specific Gravity	f_{cc} (MPa)	f_{cm} (MPa)	Δf_c (%)
Aliabdo [1]	60	83.22	2.5	48.73	48.44	0.60
Bostanci [35]	25	43.5	2.86	46	41.33	11.30
Bostanci [35]	50	43.5	2.86	46	38.44	19.67
Uysal & Yilmaz [25]	55	55.49	2.71	75.9	76.2	-0.39
Uysal & Yilmaz [25]	110	55.49	2.71	75.9	77.5	-2.06
Uysal & Yilmaz [25]	165	55.49	2.71	75.9	70.8	7.20
Kumar & Kumar [2]	22.28	55.09	2.63	33.18	34.67	-4.30
Kumar & Kumar [2]	44.56	55.09	2.63	33.18	35.85	-7.45
Kumar & Kumar [2]	66.84	55.09	2.63	33.18	30.22	9.79
Kumar & Kumar [2]	89.12	55.09	2.63	33.18	29.19	13.67

Table 3.
Collected data for the compressive strength estimation model.

Generally, a good fit is observed when the residuals of the estimation model are scattered randomly along the independent variable axis by representing positive and negative values. Furthermore, a potential outlier is identified when a value in standardized residuals exceeds approximately 3 [39, 40].

$$d_i = \frac{e_i}{\sqrt{MS_E}} \tag{4}$$

where MS_E is the mean squared error.

5.3 Compressive strength regression model

In this section, a prediction model for the compressive strength of concrete incorporating marble dust as a cement replacement will be discussed. In general, to overcome the dependency of the prediction model on the size of the testing specimen, the compressive strength of the control mixture will be used as an input to the model in which the output will represent the compressive strength of marble dust concrete specimen that has the same size as the inputted one. The analysis of variance of the predicted model is collected in **Table 5**, and the estimation model is depicted in (Eq. (6)) with an R^2 value of 0.9 representing a reasonably good fitting indicator. As recorded in **Table 5**, the p-value of the input parameters was below 5% for the cases of Marble dust content and its specific gravity and the control compressive strength. In comparison, the CaO content had a higher value. Although this observation does not give a very solid conclusion to what is the most influencing parameter on the compressive strength, it can supply a rough idea that marble specific gravity has a higher effect on the compressive strength than the marble content and its CaO. A similar conclusion is derived using the simple linear regression approach, **Figure 6**, between these factors and the change in the compressive strength (Eq. (5)), where higher R^2 values refer to the better correlation and consequently the more considerable effect.

$$\Delta f_c = \frac{f_{cc} - f_{cm}}{f_{cc}} \times 100 \tag{5}$$

$$f_{cm} = 51.6 + 1.0123 f_{cc} - 0.0468 MD_c - 0.0473 MD_{CaO} - 18.6 MD_{SG} \tag{6}$$

Author/s	Marble waste properties			Flexural strength		
	Content (kg)	CaO (%)	Specific Gravity	f_{tc} (MPa)	f_{tm} (MPa)	Δf_t (%)
Ergün [3]	15	51.7	2.68	5.3	5.3	0.00
Ergün [3]	22.5	51.7	2.68	5.3	5.1	3.92
Ergün [3]	30	51.7	2.68	5.3	5	6.00
Rana et al. [32]	20.25	65.2	2.87	6.55	6.3	3.97
Rana et al. [32]	40.5	65.2	2.87	6.55	6.25	4.80
Rana et al. [32]	60.75	65.2	2.87	6.55	5.44	20.40
Rana et al. [32]	81	65.2	2.87	6.55	5.14	27.43
Rana et al. [32]	101.25	65.2	2.87	6.55	5	31.00
Singh et al. [20]	42.2	26.63	2.67	7.8	8.17	-4.53
Singh et al. [20]	63.3	26.63	2.67	7.8	8.15	-4.29
Singh et al. [20]	84.4	26.63	2.67	7.8	7.32	6.56
Singh et al. [20]	105.5	26.63	2.67	7.8	7.1	9.86
Singh et al. [20]	39.4	26.63	2.67	6.83	7	-2.43
Singh et al. [20]	59.1	26.63	2.67	6.83	7.02	-2.71
Singh et al. [20]	78.8	26.63	2.67	6.83	6.16	10.88
Singh et al. [20]	98.5	26.63	2.67	6.83	6.08	12.34
Singh et al. [20]	35.1	26.63	2.67	5.7	5.803	-1.77
Singh et al. [20]	52.65	26.63	2.67	5.7	5.905	-3.47
Singh et al. [20]	70.2	26.63	2.67	5.7	5.408	5.40
Singh et al. [20]	87.75	26.63	2.67	5.7	5.12	11.33
Kumar & Kumar [2]	22.28	55.09	2.63	5.33	5.43	-1.84
Kumar & Kumar [2]	44.56	55.09	2.63	5.33	5.63	-5.33
Kumar & Kumar [2]	66.84	55.09	2.63	5.33	5.73	-6.98
Kumar & Kumar [2]	89.12	55.09	2.63	5.33	4.7	13.40

Table 4.
Collected data for the flexural strength estimation model.

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	6838.16	1709.54	98.05	0
Marble dust content	1	86.85	86.85	4.98	0.031
CaO	1	22.52	22.52	1.29	0.262
Specific gravity of marble dust	1	149.57	149.57	8.58	0.005
Control compressive strength	1	5249.81	5249.81	301.11	0
Error	44	767.15	17.44		
Total	48	7605.31			

Table 5.
Analysis of variance for the compressive strength model.

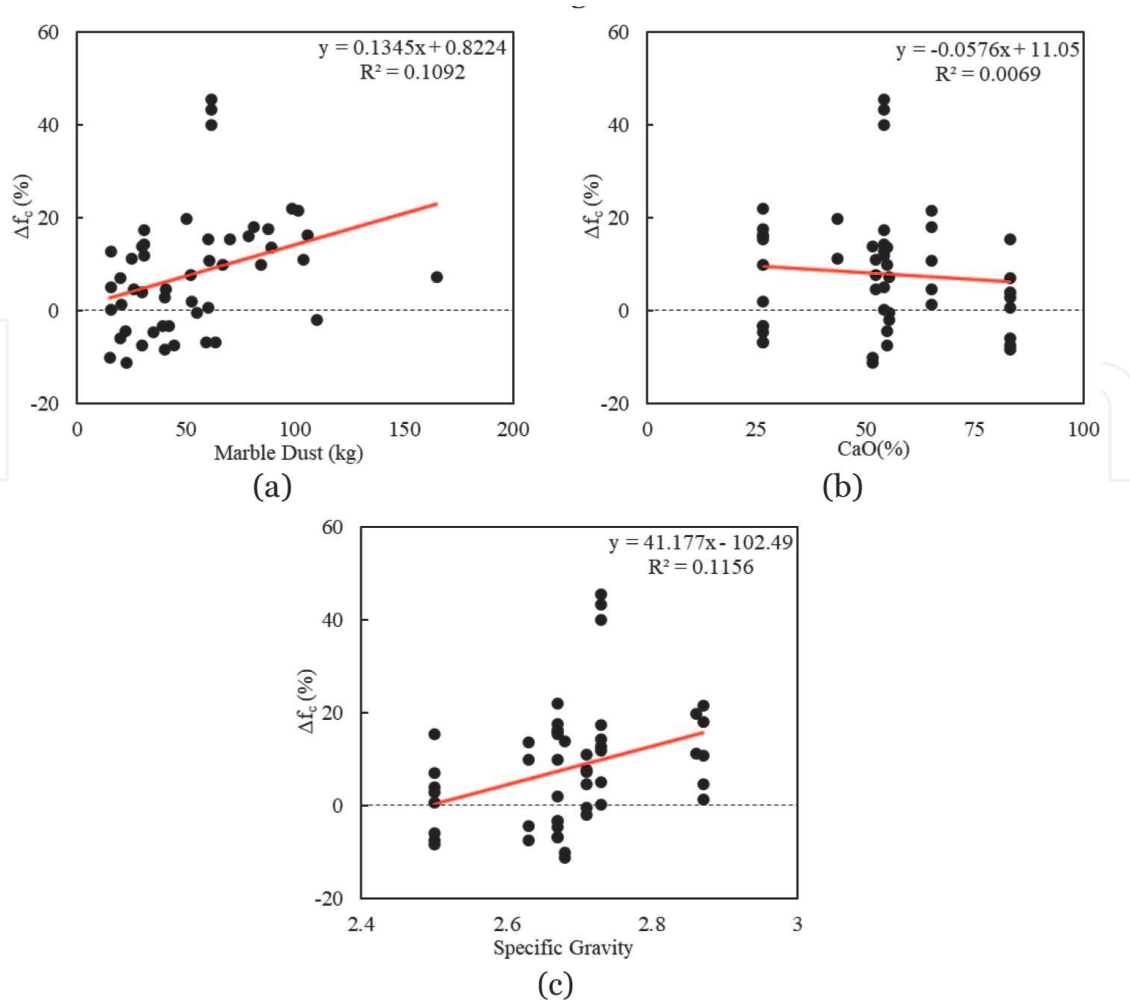

Figure 6.
Influence of marble dust properties on the change in the compressive strength (a) marble dust conten, (b) CaO in the marble dust, (c) specific gravity of the marble dust.

The performance of the interpolation model is represented in **Figure 7**. It is seen that the regression line between the measured and predicted values is mainly lying over the equality line, and the points are distributed all over it, which represents a good fitting model. The residuals of this predictor are seen in **Figure 8**, and these

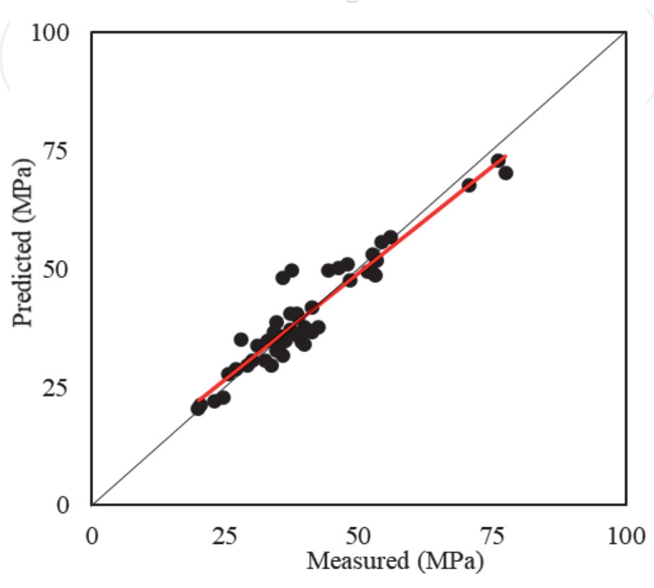

Figure 7.
Performance of the proposed compressive strength prediction model.

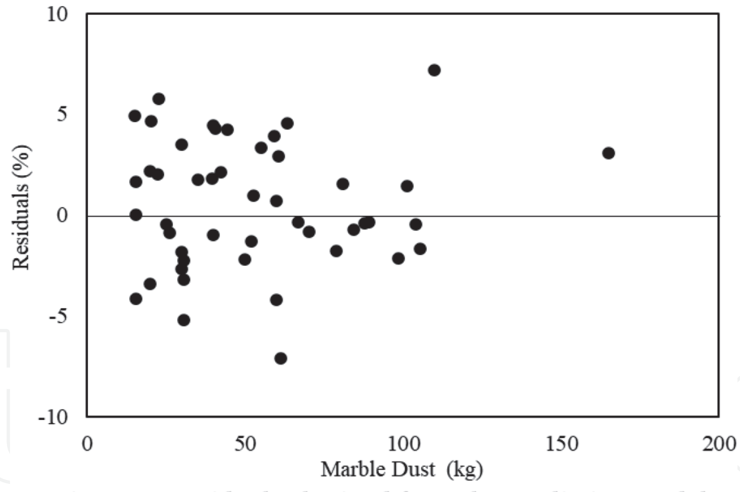

Figure 8.
Residuals obtained from the compressive strength prediction model.

values follow the basic requirements of being randomly scattered along the dependent variable axis, which is the marble dust content, in this case, meaning that the proposed model is appropriate for the given dataset.

The standardized residuals were obtained to determine the outliers, **Figure 9**, which their values more than three. Hence, it can be noticed that almost no outliers has occurred in this study, which indicates a good fitting capability. Another check on the prediction model is shown in **Figure 10**, in which the distribution on the predicted values is compared to this of the experimental one. Indeed, the histograms are slightly changed in the case of estimation; however, the general distribution is conserved after prediction.

Finally, it can be observed that the proposed prediction model delivers a useful capability for estimating the compressive strength of concrete mixtures utilizing marble dust as a replacement of cement.

5.4 Flexural strength regression model

The analysis of variance of the predicted model is summarized in **Table 6**, and the prediction model is stated in Eq. (8) with an R^2 value of 0.93 representing a

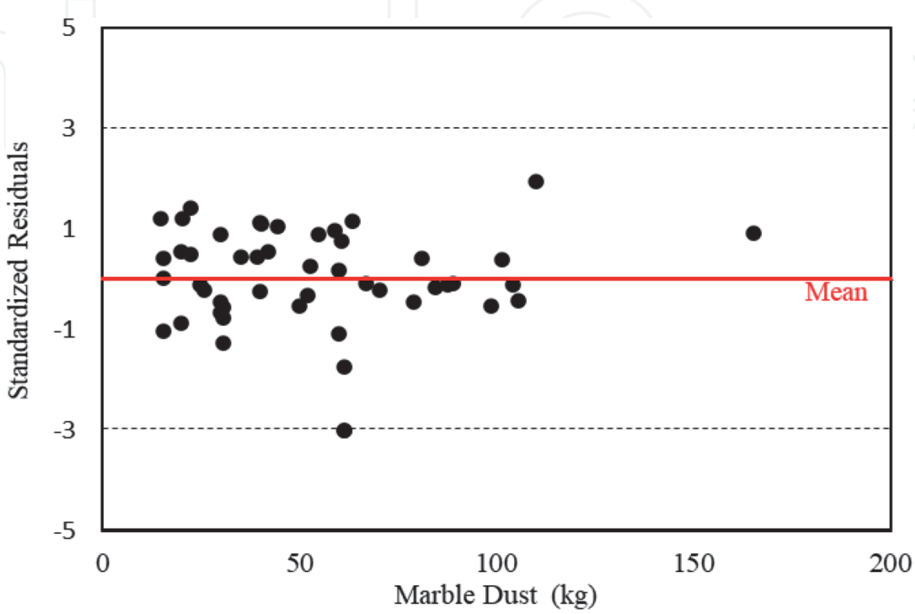

Figure 9.
Standardized residuals of the proposed compressive strength prediction model.

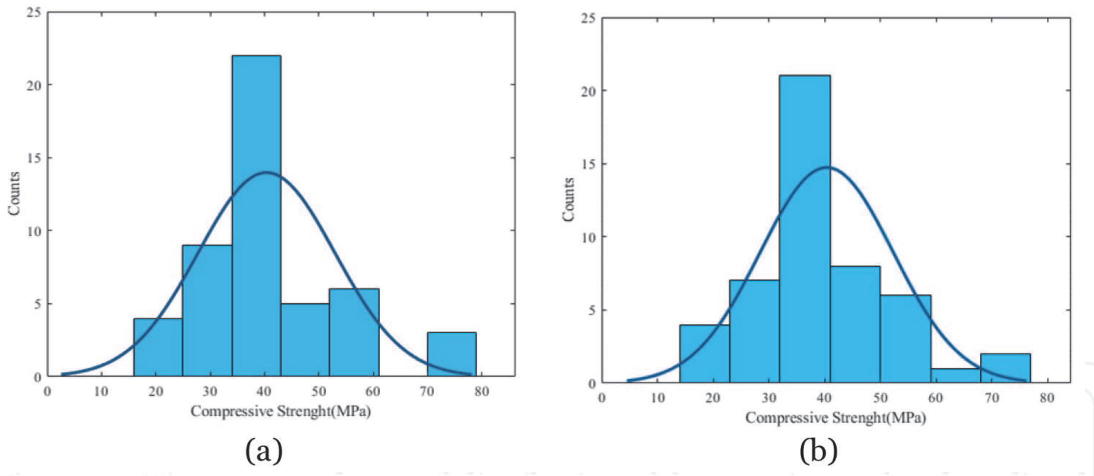

Figure 10.
Histogram and normal distribution for the compressive strength (a) experimental dataset, and (b) predicted values.

Analysis of variance					
Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	4	20.66	5.16	61.27	0
Marble dust content	1	2.77	2.77	32.86	0
CaO	1	0.00	0.00	0.04	0.837
Specific gravity of marble dust	1	1.00	1.00	11.85	0.003
Control compressive strength	1	11.62	11.62	137.85	0
Error	19	1.60	0.08		
Total	23	22.26			

Table 6.
Analysis of variance for the flexural strength model.

reasonable good fitting indicator. In similar to the compressive strength, the specific gravity of the marble dust has the most influence on the flexural strength as compared to the CaO and effect. Also, the same conclusion can be acquired using the simple linear regression approach, **Figure 11**, between these factors and the change in the flexural strength (Eq. (7)).

$$\Delta f_t = \frac{f_{tc} - f_{tm}}{f_{tc}} \times 100 \tag{7}$$

$$f_{tm} = 10.29 + 1.1452 f_{tc} - 0.0137 MD_c - 0.00133 MD_{CaO} - 3.93 MD_{SG} \tag{8}$$

The performance of the estimation model is described in **Figure 12**. It can be seen that good fitting is obtained for the given dataset with a reasonably high R^2 value in comparison to the compressive strength. The residuals of this model are placed in **Figure 13**. It can be discovered that these values are randomly scattered along the marble dust content axis, which represents that the proposed model fits the given dataset.

The standardized residuals approach was used to investigate the occurrence of potential outliers, as indicated in **Figure 14**. In general, it can be observed that no points have exceeded 3, which means no outliers have existed. In addition, the

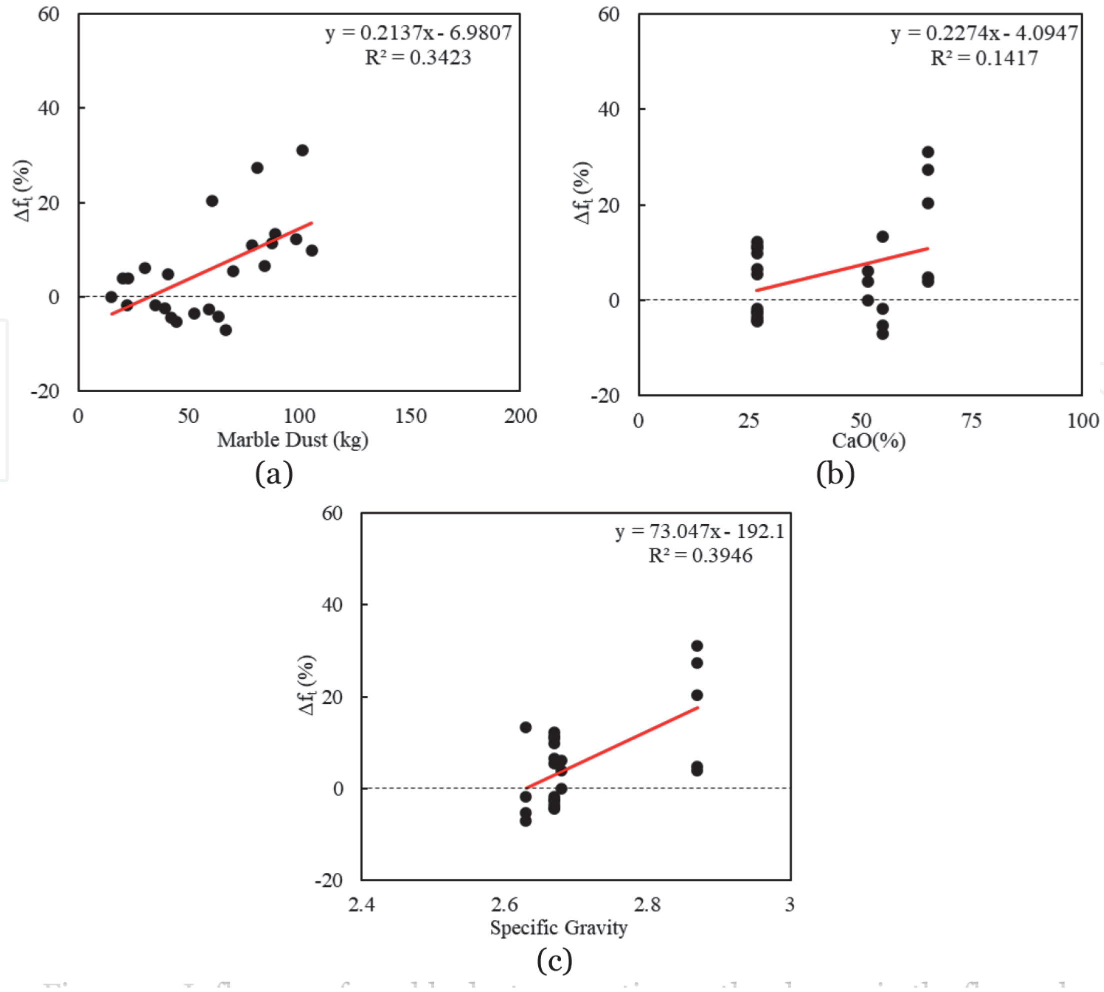

Figure 11.
Influence of marble dust properties on the change in the flexural strength (a) marble dust conten, (b) CaO in the marble dust, (c) specific gravity of the marble dust.

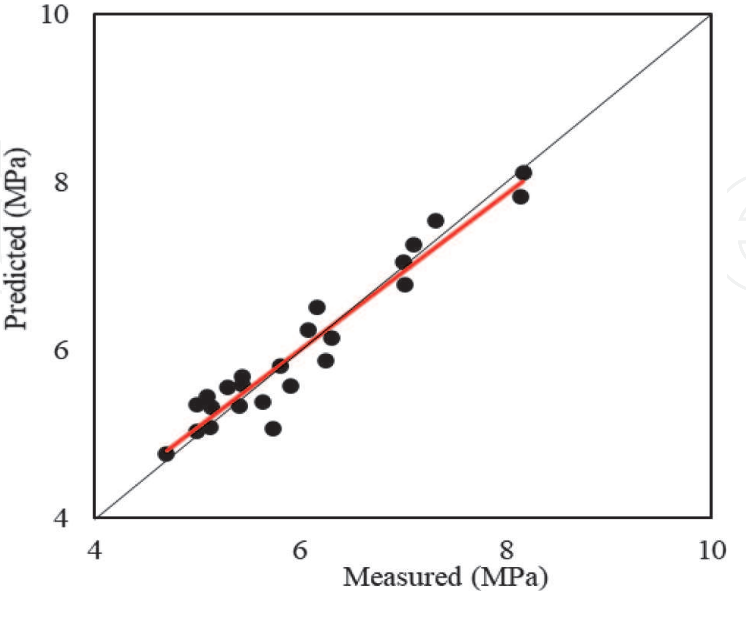

Figure 12.
Performance of the proposed flexural strength prediction model.

distribution of the predicted values as compared to the experimental one can be found in **Figure 15**. A slight variation can be seen, although the behavior is generally conserved in both cases, reflecting a suitable fitting capability for the dataset.

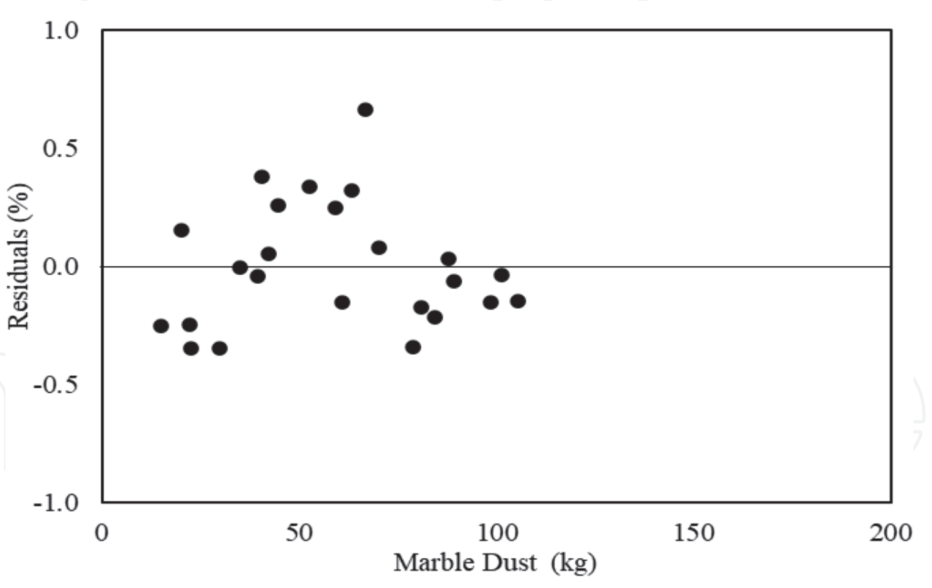

Figure 13.
Residuals obtained from the flexural strength prediction model.

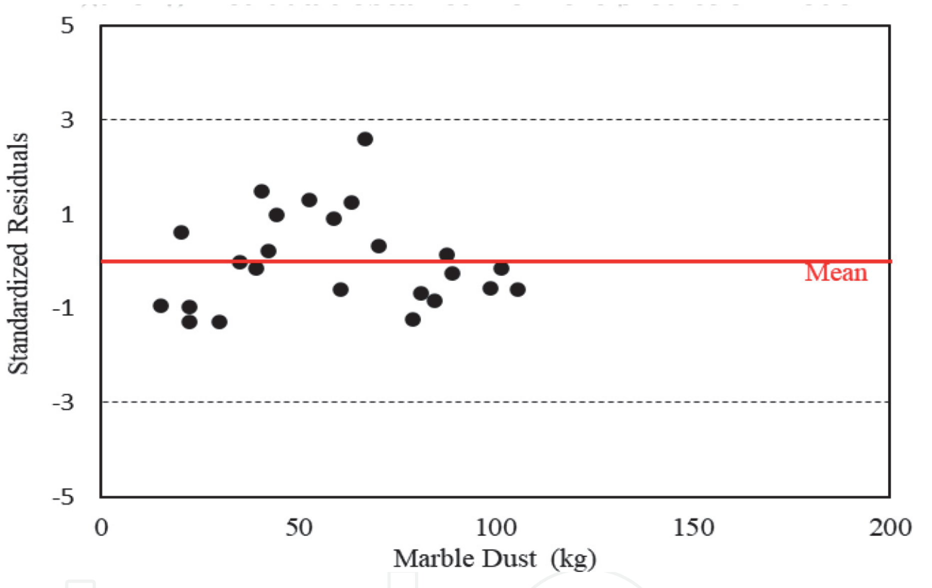

Figure 14.
Standardized residuals of the proposed flexural strength prediction model.

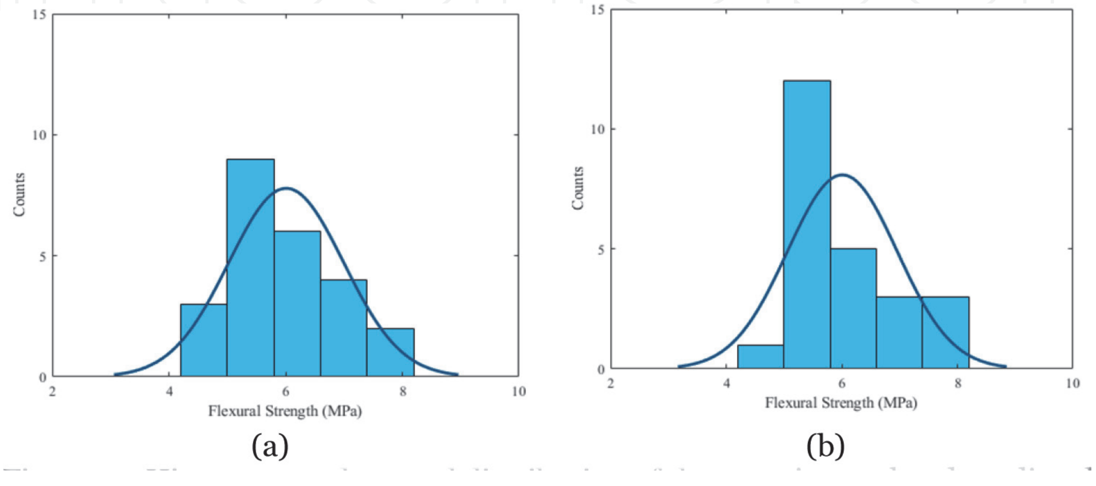

Figure 15.
Histogram and normal distribution for the flexural strength (a) experimental dataset, and (b) predicted values.

6. Future trends

Many efforts were focused on the influence of marble dust on the properties of several types of cement-based materials. However, it was observed that the literature is still in need of some comprehensives studies that can help the scientific community to understand the influence of using marble dust as a filler in sustainable concrete mixtures that incorporate recycled aggregates such as plastic or rubber. Such a mixture might provide a promising sustainable solution for ultimate waste management plans in developing countries where such materials are highly available. Another research gap is mainly related to the dynamic properties of mixtures incorporating marble dust, as such studies are minimal. Moreover, it is essential to display some numerical studies that can propose prediction models based on the marble dust content in the concrete mixture.

7. Conclusion

This chapter has focused on briefly reviewing the utilization and mechanical properties of cement-based materials incorporating marble dust with emphasis on concrete mixtures with marble wastes cement replacement. In addition, it aimed to propose two estimation models using multiple regression analysis for the compressive and flexural strengths of marble dust concrete. On the base of the statements above, the following points are drawn:

- It is quite challenging to narrow down the ranges of marble dust properties and to standardize them due to the massive variate in the origin of the rocks being processed while obtaining this material.

- Marble dust can be used as a filler material in concrete to improve the microstructure of the mix.

- Up to a certain replacement ratio, generally considered as 10% in several studies, the incorporation of marble waste can positively influence the compressive strength capacity of the mixture.

- Several potential applications of marble dust in the construction industry have already been considered in the literature, including its utilization as a filler in cement-based materials, a partial replacement of concrete constituents, and a substitute of limestone in various industrial applications.

- The specific gravity of marble dust can be considered as one of the main characteristics that affect the strength properties of the investigated concrete mixtures.

- The proposed estimation models can reliably be used to predict the compressive and flexural strengths of concrete utilizing marble dust as a partial replacement of cement.

Further research efforts are still needed in this field to cover some of the gaps in the literature on the behavior of recycled aggregate concrete incorporating this material to develop the understanding of both scientists and engineers working in the construction industry. It is also recommended to comprehensively study the influence of marble dust chemical properties on the performance of the produced cement-based material can to come up with detailed mathematical relationships similar to the ones presented in this study due to the inconsistency in the experimental results due to the wide variety in the natural waste properties.

Author details

Ahed Habib[1*] and Maan Habib[2]

1 Eastern Mediterranean University, Famagusta, North Cyprus, via Mersin 10, Turkey

2 Al-Balqa Applied University, Amman, Jordan

*Address all correspondence to: ahed.habib@cc.emu.edu.tr

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