Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 7, No. 01, January, 2021

Evaluation of Concrete with Partial Replacement of Cement by Waste Marble Powder

Mushraf Majeed [1], Anwar Khitab [1*], Waqas Anwar [1], Raja Bilal Nasar Khan [1], Affan Jalil [1], Zeesshan Tariq [1]

[1] *Department of Civil Engineering, Mirpur University of Science and Technology (MUST), Mirpur-10250, Azad Jammu and Kashmir Pakistan.*

Received 15 July 2020; Revised 14 October 2020; Accepted 28 November 2020; Published 01 January 2021

Abstract

This study aims to evaluate concrete having Waste Marble Powder (WMP) as partial replacement of cement. Marble is the metamorphic form of limestone ($CaCO_3$) and WMP was chosen as substitute of cement on account of its high calcium oxide content. WMP is by-product of marble industry and is an environmental burden. The manufacturing of cement is also environmentally hazardous owing to emission of greenhouse gases. Thus, the recycling of WMP in place of cement in concrete offers two ecological advantages. Thirdly, WMP has a specific gravity of 2.6 against that of 3.15 for cement, which reduces the weight of the finished products. Based on the previous studies, five different concrete mixes were prepared having 0, 5, 10, 15 and 15% replacement levels. The samples were evaluated both through destructive and non-destructive tests. Destructive tests included compressive, tensile and flexural strengths, whereas non-destructive tests comprised of Ultrasonic Pulse Velocity (UPV) and rebound hammer. It was observed that the workability decreases with WMP inclusion owing to its higher water absorption, which inhibits lubrication of cement particles. The concrete strength improves up to a replacement level of 10% by mass of cement on account of densification created by the finer WMP and un-hydrated cement particles, which act as hard inclusions. Beyond 10%, the concrete strength starts declining due to insufficient quantity of cement matrix, binding the WMP particles. Schmidt rebound numbers authenticate the compressive strength results: The number increases up to 10% replacement level and beyond 10% it decreases. The results of UPV indicate that the velocity increases with increase in WMP content: The increase is attributed to compactness of the composite with finer WMP particles.

Keywords: Concrete; Cement; Waste Marble Powder; Destructive Testing; Non-destructive Testing; Optimum Value.

1. Introduction

Mankind has continuously used natural resources to fulfil its basic requirements. The depletion rate of natural resources exceeds the earth's refill rate by 30 percent [1]. The construction industry is the main user of natural resources. In present and past centuries, the development in industrial production plus the resulting rise in the equivalent consumption has directed to a speedy decrease in existing natural resources. After water, concrete is the second largest consumed material on earth [2]. All raw ingredients used for concreting are directly or indirectly acquired by quarrying the earth’s crust. Comprehensive use of concrete has increased the worldwide depletion of its raw materials. During the past few decades, researchers have proposed several agricultural and industrial wastes that could partially replace concrete ingredients, saving natural resources to a large extent. Jalil et al. (2019) used industrial

* Corresponding author: anwar.ce@must.edu.pk

http://dx.doi.org/10.28991/cej-2021-03091637

steel slag as partial replacement of cement in ordinary concrete [3]: They have reported that fine slag powder (passing through sieve #200) could lead to better mechanical properties than those of the control specimens. Khan et al. (2020) used waste rubber tire particles as partial replacement of sand in ordinary concrete [4]: Their study revealed that uniform dispersion of fine and rough rubber particles at low dosage (5%) could lead to enhanced adhesion with surrounding cement paste and increase the compressive strength. Munir et al. (2016) used rice husk ash as partial replacement of cement in concrete [5]: They have reported that 10-40% partial replacement of cement by rice husk ash could be sufficiently helpful in minimizing the alkali-silica reaction in concrete. Abubakr et al. (2019) used waste ceramic powder as partial replacement of cement in ordinary concrete samples [6]: Their study reports that 10-20% fine ceramic powder leads to enhancement in workability, density and flexural strength.

Stones played a vital part in the development of mankind's history since the day first [7]. Marble is one of the most important and widely used stone. It is calcareous in nature and is the metamorphic form of limestone [8]. Among all the other stones, Marble production has jumped to 50 percent of the natural stone production all over the world. A huge amount of waste marble powder is produced through process of mining, cutting and sawing. The industrial process of quarrying marble produces twenty percent of waste. Millions ton of waste are produced globally during quarrying of marble. If left open, this waste will cause adverse impact on the surroundings [9]. If dumped in landfill, it may result in poor soil structure: In addition, it can reduce the fertility of the soil. Pakistan stands sixth in the quarrying of marble worldwide. Therefore, the recycling of this waste is crucial for the safety of the environment. Among the other usage of WMP, one of its use is in concrete as partial substitute of cement or fine aggregates. In this way, waste generated from industries can be reduced in a reasonable way. As the construction industry is flourishing in Pakistan, it increases the demand for cement and other materials like coarse and fine aggregates. The method of producing concrete generates greenhouse gases, possibly a reason for global warming. The reuse of commercial waste like marble powder as replacement of cement can be very effective regarding ecological construction.

Different research groups worldwide have worked for possible recycling of WMP in cementitious composites in their own environments. A brief introduction of the important works is summarized as follows:

Hanifi et al. (2007) have reported that the concrete containing WMP results in higher compressive strength than the corresponding control specimens with same aggregates and water to cement ratio [10]. Corinaldesi et al. (2010) have reported that WMP have very fine particles with a Blaine fineness of about 1.49 m^2/gram [11]. Owing to their large specific surface area, they can result in dense and compact cementitious composites. Rao investigated the effect of WMP in mortars in different proportions: Their study showed that the recycling of WMP increased the workability and strength of mortar [12]. Sounthararajan and Sivakumar (2013) examined the cost-effectiveness of WMP in place of cement in concrete [9]. They have reported that by replacing 10% WMP with cement, one bag of cement in a lot of 10 bags can be effectively saved for producing concrete with same quality. Pathan (2014) investigated the reuse of WMP as replacement of fine aggregates in mortars and concrete [13]: According to the findings, the best strength was achieved, when 12.5% sand was replaced with WMP. Munir et al. (2018) studied the effect of WMP from local industry of Mirpur, AJK on clayey brick by partially replacing clay with WMP: They have described that owing to porous nature of WMP, sustainable bricks with slightly reduced strength can be manufactured [14]. Ahmed et al. (2020) evaluated the effect of partial replacement of cement by WMP in concrete hollow blocks. They have reported an increase in compressive strength up to 10% replacement: The increase is attributed to the angular shape of the waste marble particle, which ensures mechanical bond with the surrounding cement matrix [15].

This research is the continuation of the works of Munir et al. (2018) [14] and Ahmed et al. (2020) [15], involving recycling of WMP in clayey bricks and hollow concrete blocks, respectively. WMP is abundantly produced in Pakistan and is dumped in earth fills: This necessitates its proper recycling. Present work intends to examine the effect of recycling WMP in ordinary concrete specimens: The research also focuses to address some unexplained phenomenon like decrease of compressive strength beyond 10% replacement and reduction in flexural strength at all replacement levels. Additionally, the destructive tests are supplemented with non-destructive ones. The concrete specimens were prepared using local materials. Before sample preparation, all the ingredients were examined through physical properties, XRD, XRF and SEM. The prepared specimens were tested against slump, compressive, tensile and flexural strength as well as Schmidt Hammer and Ultrasonic pulse velocity as per standard ASTM methods. The replacement levels were kept as 0, 5, 10, 15 and 20% by mass of cement. Based on the results, an optimum level was also achieved. It was concluded that 10% replacement of cement by WMP could be very useful in decreasing pollution posed by cement production and WMP. Manufacturing of cement involves the depletion of natural resources and high energy requirements. The partial replacement of cement (10%) by WMP will promote its recycling: As mentioned above, one bag of cement out of 10 can be saved in ordinary concrete constructions.

2. Research Methodology

The research methodology was adapted in accordance with Figure 1. All the materials were collected, characterized and mixed to form concrete samples. The samples were examined by standard destructive, non-destructive and microscopy tests.

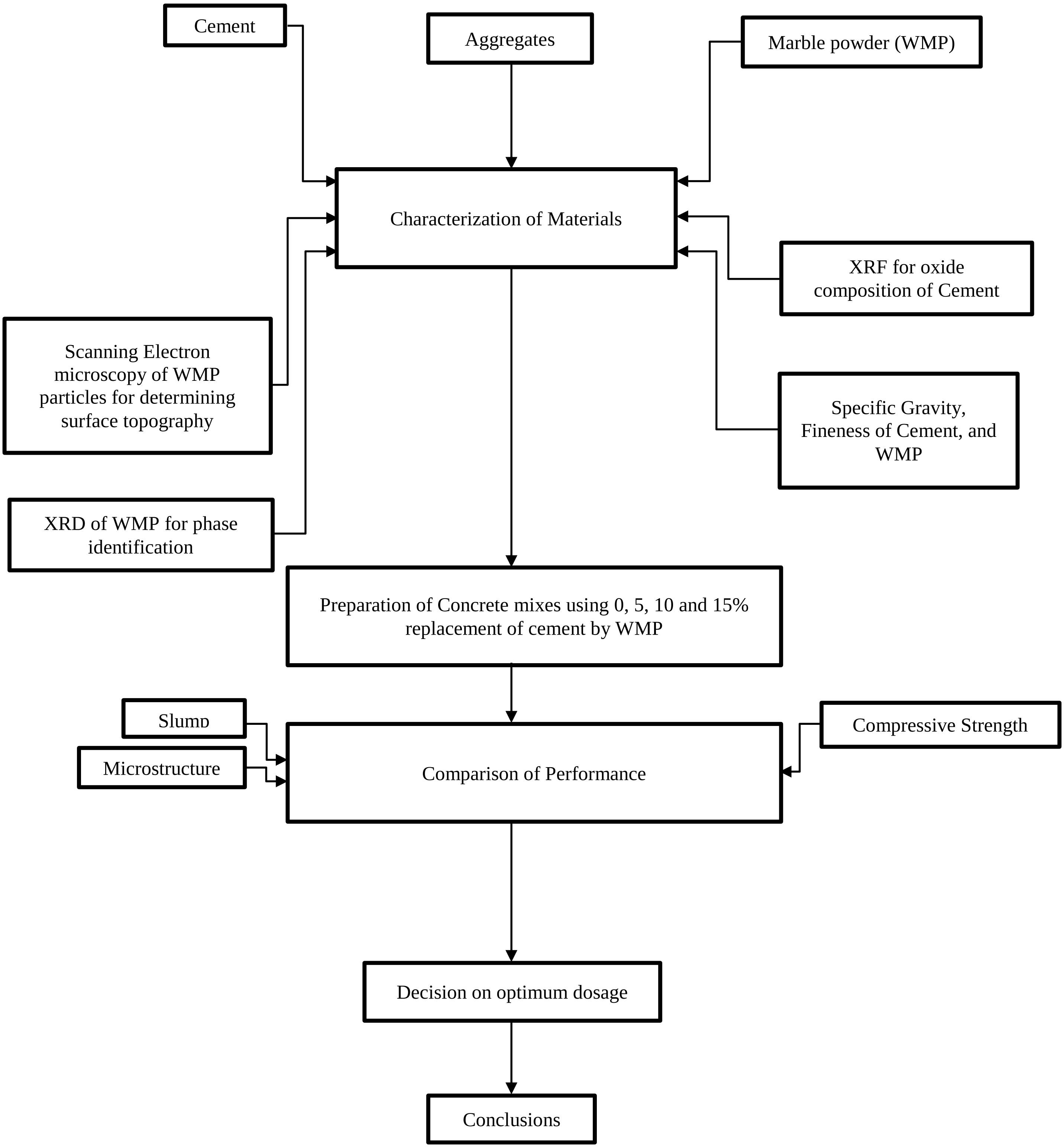

Figure 1. Research Methodology

In this research, Ordinary Portland Cement (OPC) conforming to ASTM C150 Type-I cement, was used. For compliance with the above-mentioned standards, Fauji Cement (PS: 232-2008 ®-53 Grade) manufactured in Pakistan was acquired. Physical properties of OPC are described in Table 1.

Table 1. Physical characteristics of the cement

Chemical Parameters	Laboratory Results
Loss on Ignition %	1.76
Insoluble Residue %	0.46
Sulphate as SO_3 %	2.80
MgO %	1.70
Setting and Soundness	
Initial Setting period (Minutes)	37 min
Final Setting period (Minutes)	600 min
Lechatelier's Expansion Value	10

The chemical composition of the cement is shown in Table 2.

Table 2. Chemical composition of the cement

Sr. No.	Oxides	Percentage
1	CaO	64.19%
2	SiO_2	21.45%
3	Al_2O_3	5.20%
4	Fe_2O_3	3.25%
5	SO_3	2.70%
6	MgO	1.90%
7	K_2O	1.0%
7	L.O.I	1.88%
8	Na_2O	0.25%

Lawrencepur river sand was used and its characteristics are shown in Table 3. Based on the sieve analysis results presented in Figure 2, the Fineness Modulus (FM) of the sand was found to be 2.7: This value declares it a coarse sand. According to Agarwal, the optimum value of FM values of sand for density, strength and pump-ability are 2.8, 2.7 and 2.5 respectively [16]: This suggests that Lawrencepur sand is suitable for quality concrete works.

Table 3. Physical Properties of sand

Physical Properties	Results
Fineness modulus	2.70
Specific gravity	2.64
Water absorption	1%
Silt or clay content	0.5%
Bulk density	1700 kg/m^3
Grading	well graded

Waste Marble Powder (WMP) was acquired from a local marble industry: The powder and its particle shape are shown in Figure 3. The particles were mostly observed to have broken cylindrical shape. The waste was oven dried at 100 ± 10 ºC for 24 hours and then sieved through sieve # 200 for acquiring same fineness as that of cement. The physical properties of WMP are mentioned in Table 4.

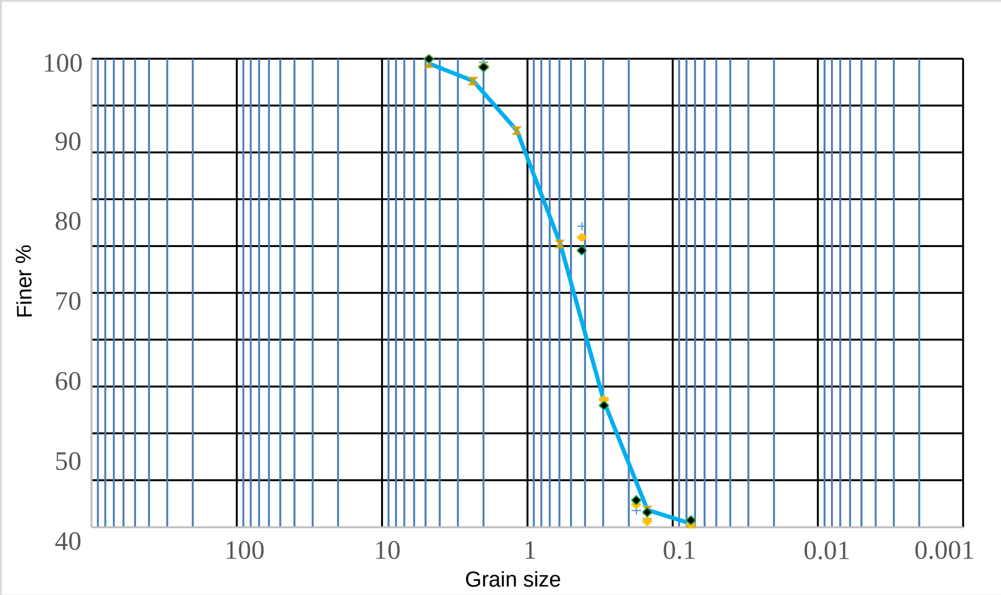

Figure 2. Sieve Analysis of sand

Figure 3. Waste Marble Powder (WMP) and its particle shape [15]

Table 4. Physical properties of WMP

Physical Properties	Results
Odor	Odorless
Specific gravity	2.68
Tone/Colour	White
Phase	Powder

The XRD of the WMP is shown in Figure 4. The XRD pattern of Marble indicates the presence of the crystalline phases of Calcite($CaCO_3$), Quartz(SiO_2), Dolomite {$CaMg(CO_3)_2$} with the highest peak proportion of Calcite. The chemical composition of WMP as determined by XRF is shown in Table 5. The results of XRD and XRF are in line with each other, both showing a high proportion of CaO, and a small portion of Quartz as SiO_2.

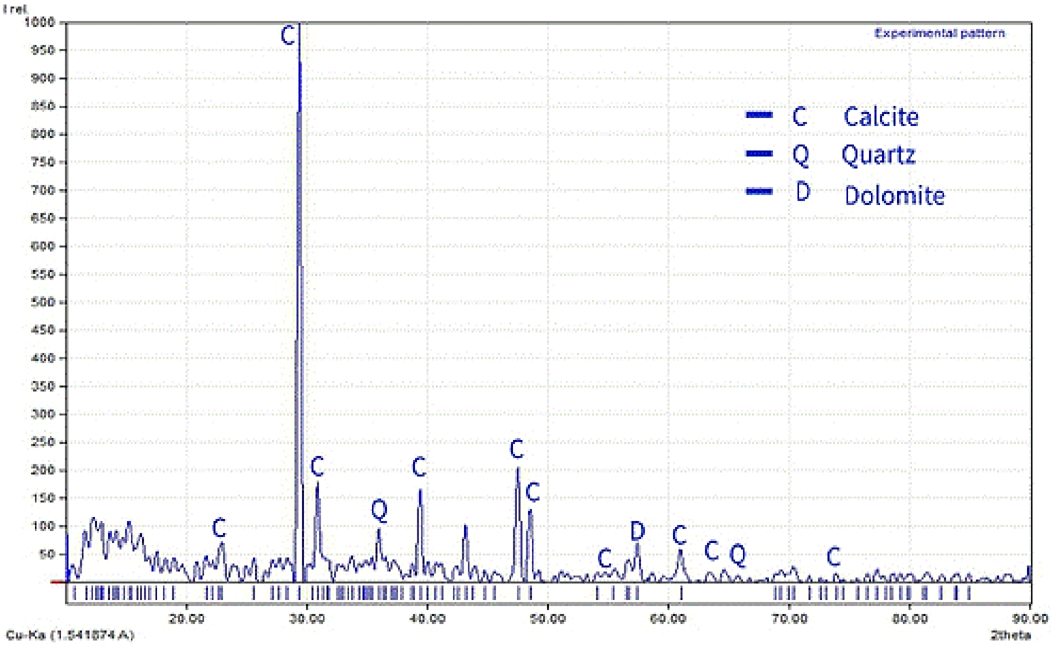

Figure 4. XRD pattern of WMP

Table 5. Chemical composition of WMP

Oxide	% age
SiO_2	1.28
CaO	56.16
Al_2O_3	0.85
Fe_2O_3	0.34
K_2O	0.10
LOI	41.08

The accumulated percentage of SiO_2, Al_2O_3 and Fe_2O_3, as given in Table 5 is too small to declare WMP a pozzolana. However, the material has a high percentage of CaO, comparable to that of cement, given in Table 2: This can render cementing properties to WPM. The peaks of Calcite shown in Figure 4 range from narrow to broad, showing some amorphousness.

Batches were made in accordance with the specified proportions of cement and marble powder, while the other materials like sand, aggregates, and water were used with constant ratio throughout. Mix design ratio was set as 1:1⁄, 2:3 and the w/c ratio of 0.45 was maintained for all the mix proportions during preparation of concrete. Different sets of specimens were prepared, and each set comprised of 3 beams and 9 cylinders. Total 30 beams and 45 cylinders were cast. The composition of control specimens, and the specimens with 5, 10, 15 and 20% replacement are presented in Table 6.

Table 6. Composition of the specimens

Sr. No.	Mix Designation	WMP (%)	Cement (kg/m^3)	Fine Aggregates (kg/m^3)	Coarse Aggregates (kg/m^3)	Water (l/m^3)	Marble Powder (kg/m^3)
1	M_0	0	415	622	1245	186.75	0
2	M_1	5	394.5	622	1245	186.75	20.5
3	M_2	10	373.5	622	1245	186.75	41.5
4	M_3	15	352.75	622	1245	186.75	62.25
5	M_4	20	323	622	1245	186.75	82

Owing to the fact that WMP contains fine particles and might affect the workability, the fresh samples were tested for slump, after the curing of the samples was complete, they were examined both via destructive and non-destructive tests. The destructive tests consisted of compressive, split cylinder tensile and flexure strength, while the non-destructive tests were comprised of Schmidt Hammer Rebound and Ultrasonic Pulse Velocity. Additionally, microstructure was studied to explain the results.

3. Results and Discussion

3.1. Workability

Workability was checked through slump test in accordance with ASTM C 143 [17]. The test results are summarized in Table 7. The WMP particles have an average fineness of 1.5 m^2/g while the cement has that of 0.225 m^2/g. As WMP particles consumed more water owing to their higher specific area and porous nature, lesser water was available for the lubrication of cement: This in turn lowered the workability. Further, the slump decreased with increase in WMP replacement level. The results are in line with the previous studies, where the induction of fine-sized aggregates resulted in loss of workability of the concrete [18, 19].

Table 7. Slump values

S. No.	Mix	Slump (mm)
1	M_0	63
2	M_2	61
3	M_3	57
4	M_4	53
5	M_5	49

3.2. Compressive Strength

The compressive strength test was conducted as per standard ASTM C39/C39M method [20]. The results are summarized in Figures 5 and 6.

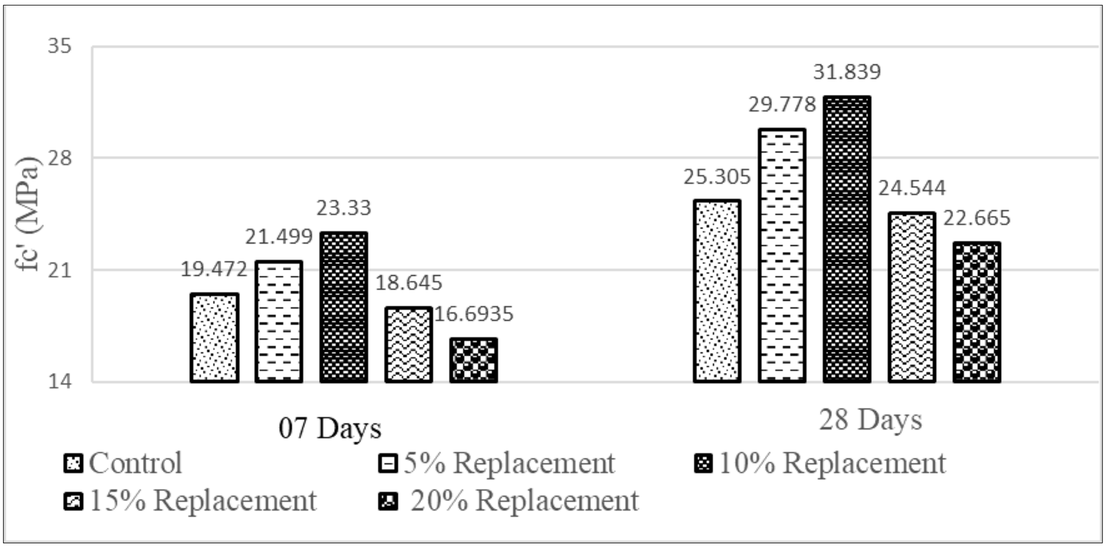

Figure 5. Compressive strength as a function of replacement

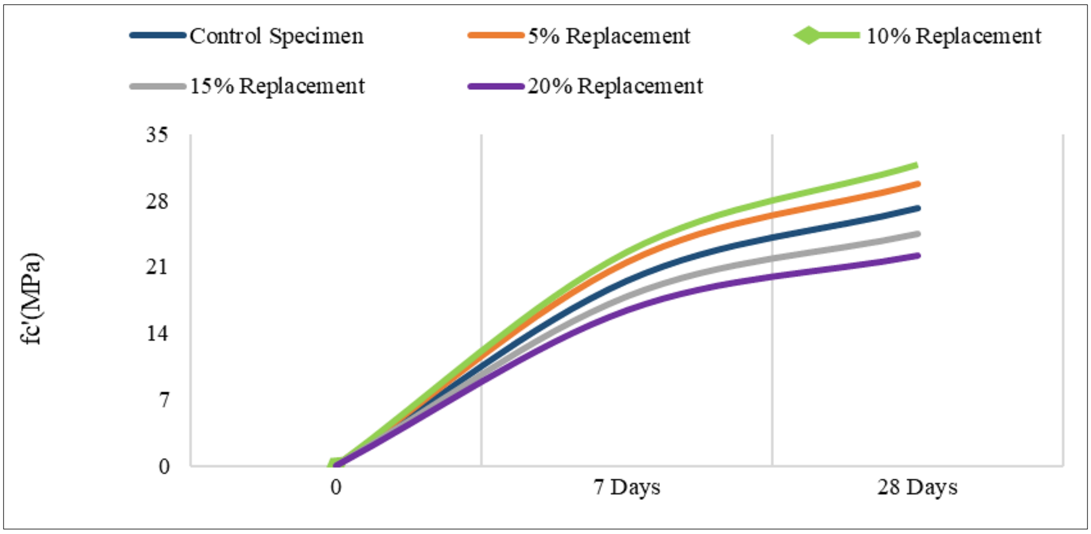

Figure 6. Development of compressive strength as a function of replacement level

The results show that both 7 and 28 days' strengths increase with increase in replacement level up to 10%: Afterwards, decline was observed. Based on the current study, it can be concluded that the optimum value for compressive strength is about 10%. Up to 10% replacement, the effect of higher fineness of WMP particles seems dominant, which increases the compactness and density of the mix, Also, water to cement ratio is lesser owing to higher absorption of WMP particles, which increases strength and reduces slump and voids [21, 22]. The dense microstructure of concrete containing 10% WMP is shown in Figure 7 [15]. According to Aïtcin, in a dense cement paste, the water available for hydration is low. The hydrates formed on the surface of a cement particle are left with little space to fully grow: This in turn leaves their centers as un-hydrated, which act as hard inclusions imparting high compressive strength [23]. The dense cement matrix containing 10% WMP is shown in Figure 7 [15].

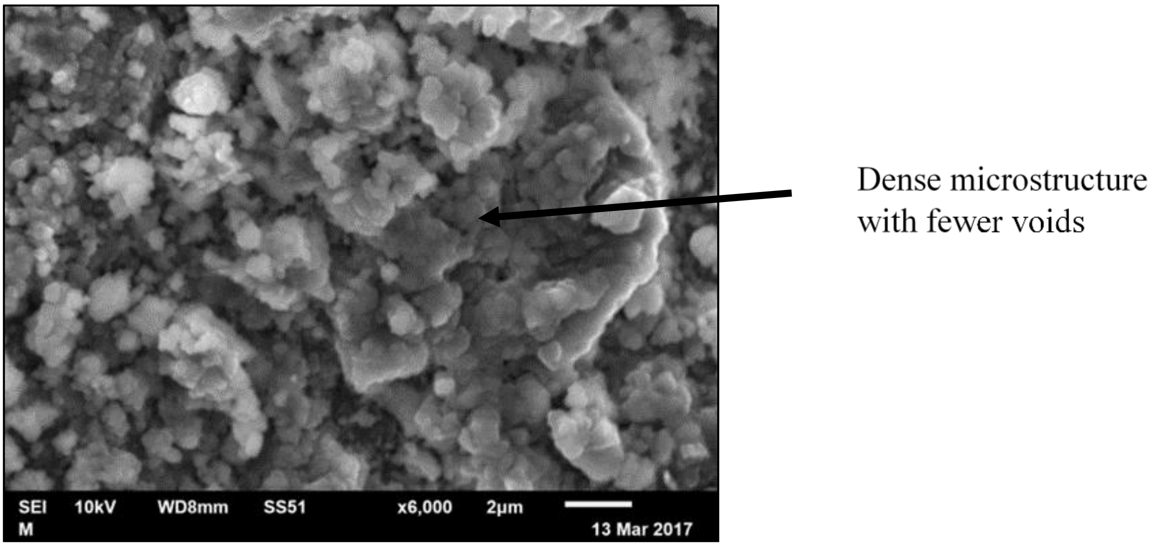

Figure 7. SEM image of highly dense concrete specimen containing 10% WMP [15]

Beyond 10% replacement, it appears that the higher fineness becomes a problem itself as it needs an enhanced quantity of surrounding cement paste for bonding, which is already limited due to the higher replacement of cement by WMP. The results are in line with previous studies conducted while comparing the effects of dune sand and river sand on workability and strength of concrete: It was concluded that the finer dune particles increased strength at lower replacement levels and decreased strength at higher replacement levels [24].

3.3. Tensile Strength

The tensile strength test was performed as per standard ASTM C496/C496M method [25]. The results are summarized in Figures 8 and 9.

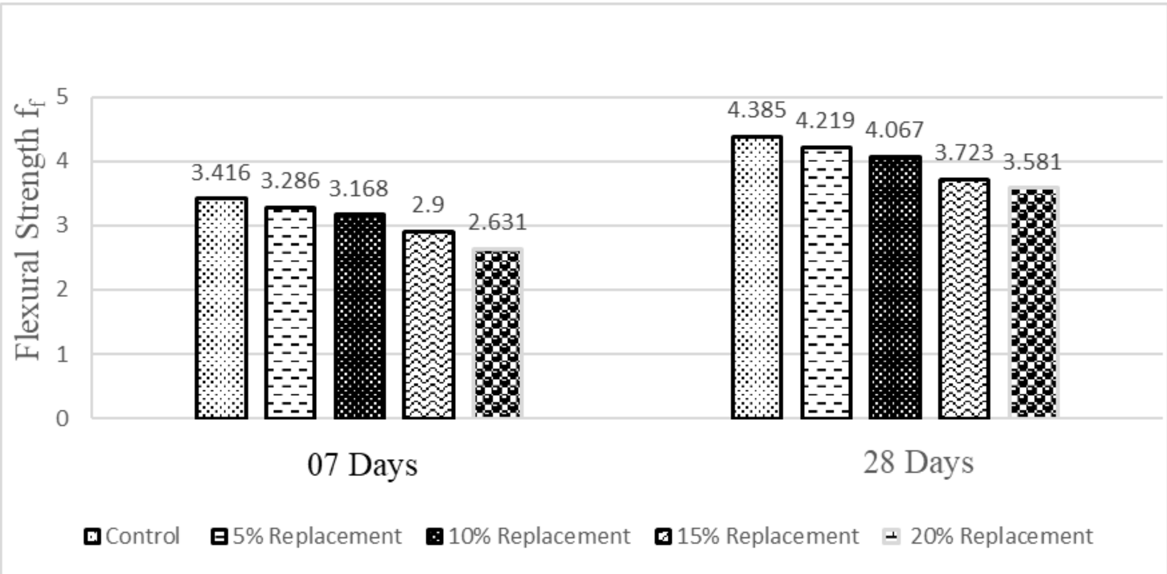

Figure 8. Variation of split cylinder tensile strength as a function of replacement

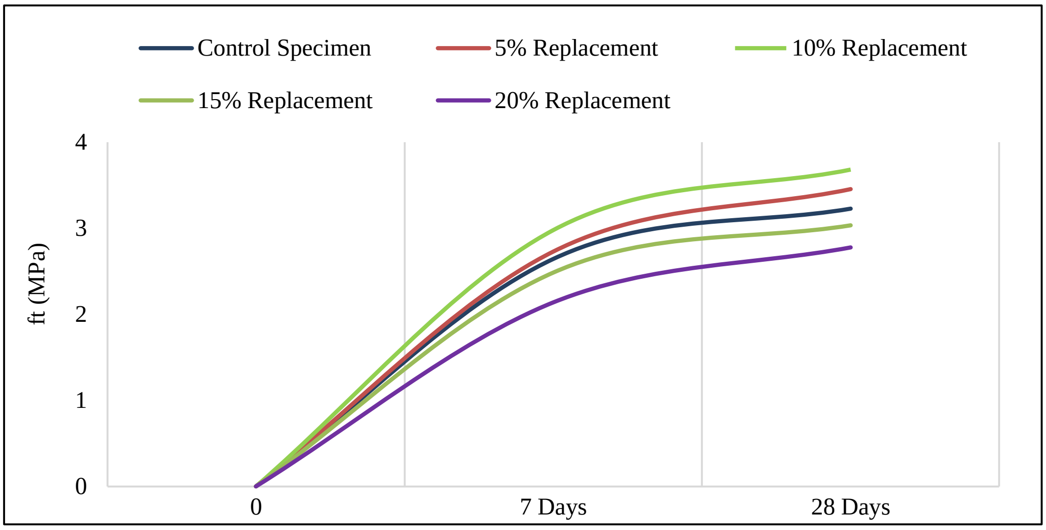

Figure 9. Development of flexural strength as a function of replacement level

The trend of gain of tensile strength is nevertheless similar to that compressive strength. It is obvious that the parameter follows the same rules and principles as those for compressive strength. And it can be well concluded that the optimum value for replacement is also 10% for tensile strength.

3.4. Flexural Strength

The flexural strength test was performed as per standard ASTM C78/C78M method [26]. The results are summarized in Figures 10 and 11.

Flexural strength familiarized as the modulus of rupture, or transverse breaking strength is identified as the stress of the material against bending. From the above results, it is clear that the flexural strength of concrete decreases as the percentage of WMP increases. The decrease in flexural strength indicates that behavior of WMP-containing concrete in flexure is not exactly the same as that in compressive and tensile strengths. The scarcity of bond due to lesser cement quantity is the main reason for decreasing flexural strength. The bond continuously weakens with increasing replacement; this renders different behavior to concrete in flexural strength than in the compressive and tensile strength. Munir et al. (2018) used the same WMP as partial replacement of clay in bricks and similar decline in flexural strength was observed with increasing WMP content [14]: They have attributed this decrease to poor distribution and agglomeration of WMP particles at higher dosages. Similar effect has been reported by Iloabachie et al. (2017) while working with the effect of un-carbonized coconut shell on flexural strength of polyester composite [27]. According to Sadeghbeigi (2012), the flexural strength is an index of the bond strength of the material and while particle size and its packing/filling are important, it is the maturity of the cement bond that adds more to flexural strength [28]. That is for this reason, while compressive strength increases up to 10% replacement level, the flexural strength decreases for all replacement levels.

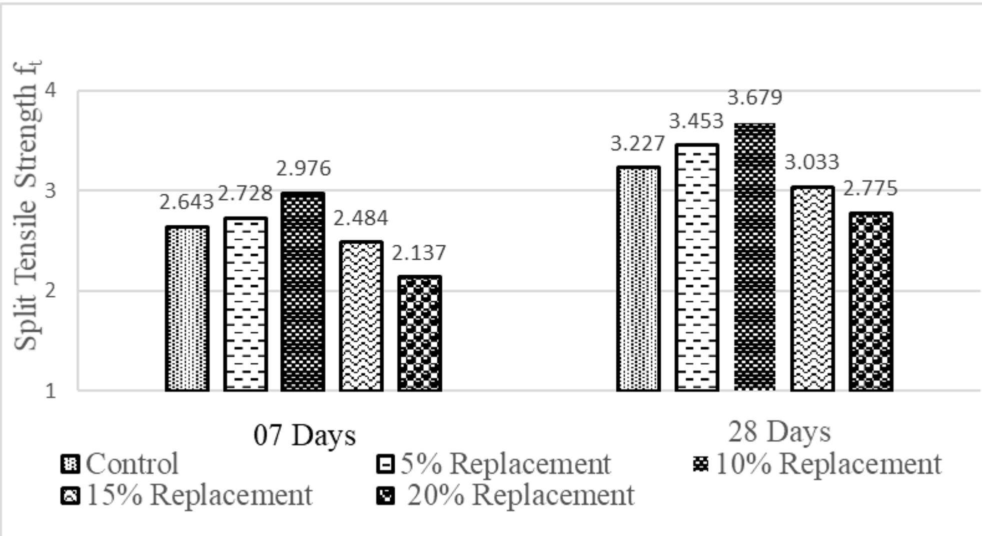

Figure 8. Variation of flexural strength as a function of replacement

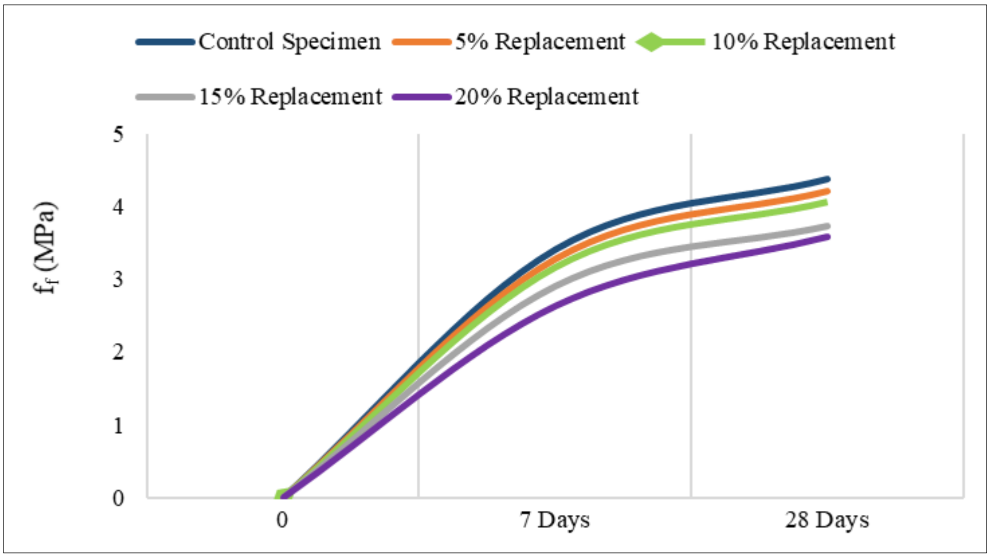

Figure 9. Development of flexural strength as a function of replacement level

3.5. Non Destructive Tests

3.5.1. Schmidt Rebound Hammer

All specimens were tested according to ASTM C805/C805M – 18 standards [29]. The rebound values for the control and the specimens with WMP replacement are described in Table 8. All the values represent an average of twelve results. The rebound numbers are also compared with the experimental values obtained from destructive compressive strength test.

Table 8. Rebound number as a function of replacement proportion

S.N.	Test specimens	Rebound number	f_c' (MPa)
1	M_0	23	25.3
2	M_2	25.8	29.8
3	M_3	28.5	31.8
4	M_4	19.3	24.5
5	M_5	16.4	22.7

The results indicate that the rebound number is proportional to the compressive strength. Nevertheless, the accuracy of the compressive strength using rebound hammer lies between ± 15 and ± 20% [30]. According to Gehlot et al. (2016), the rebound numbers from 26 to 32 are an approximation of the actual compressive strength in MPa: With an accuracy of ± 10 to ± 20%, the rebound numbers of M_0, M_5 and M_{10} match with the corresponding compressive strengths [31].

3.5.2. Ultrasonic Pulse Velocity (UPV)

The UPV values were determined as per ASTM C597–09 standard method [32]. The values are presented in Table 9.

Table 9. Rebound number as a function of replacement proportion

S.N.	Test specimens	UPV (km/s)	f_c' (MPa)
1	M_0	3.8	25.3
2	M_2	3.85	29.8
3	M_3	3.86	31.8
4	M_4	3.88	24.5
5	M_5	3.89	22.7

UPV test is mainly intended to evaluate the quality and homogeneity of the material and to detect internal imperfections and voids/cracks etc. [33]. The increase of UPV with increase in replacement level indicates that the inclusion of WMP increases the compactness of the material, even though the compressive strength decreases beyond 10% replacement.

4. Conclusions

Based on the experimental results, following conclusions are withdrawn:

- WMP enhances the compressive and tensile strength of concrete up to 10% replacement. The enhancement is attributed to the interlocking of WMP within cement matrix, and lesser water to cement ratio;
- Beyond 10% replacement, the scarcity of cement content owing to higher WMP results in insufficient bond development, which ultimately reduces strength;
- Nevertheless, WMP is not a pozzolanic material. Its utility as cementing material due to higher lime content is also limited: Its CaO content is mainly crystalline;
- WMP reduces flexural strength at all replacement levels: This is mainly due to insufficient cement bond development;
- Schmidt hammer test has well verified the quality of the concrete, containing WMP. The rebound numbers seem to be an indicator of the compressive strength;
- UPV values indicate that the increase in WMP replacement level increases the homogeneity of the material, although the strength overall decreases.

5. Declarations

5.1. Data Availability Statement

The data presented in this study are available in article.

5.2. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Gupta, Monika Shekhar. "Sustainable Concrete Production through Use of Marble Powder as Partial Replacement of Cement in Concrete Mix." International Journal of Engineering Science and Computing (2017): 15505–15507.

[2] Şahan Arel, Hasan. "Recyclability of Waste Marble in Concrete Production." Journal of Cleaner Production 131 (September 2016): 179–188. doi:10.1016/j.jclepro.2016.05.052.

[3] Jalil, Affan, Anwar Khitab, Hamza Ishtiaq, Syed Hassan Bukhari, Muhammad Tausif Arshad, and Waqas Anwar. "Evaluation of Steel Industrial Slag as Partial Replacement of Cement in Concrete." Civil Engineering Journal 5, no. 1 (January 27, 2019): 181. doi:10.28991/cej-2019-03091236.

[4] Khan, Raja Bilal Nasar, and Anwar Khitab. "Enhancing Physical, Mechanical and Thermal Properties of Rubberized Concrete." Engineering and Technology Quarterly Reviews 3, no. 1 (2020): 33–45. doi:10.5281/zenodo.3852541.

[5] Munir, Muhammad Junaid, Syed Minhaj Saleem Kazmi, Anwar Khitab, and Muhammad Hassan. "Utilization of rice husk ash to mitigate alkali silica reaction in concrete." In Proceedings of 2nd International Multi-disciplinary Conference, vol. 19, (2016): 20.

[6] Abubakr, M., Khitab, A., Sadiq, S., Anwar, W., Tayyeb, S.: "Evaluation of Ordinary Concrete Having Ceramic Waste Powder as Partial Replacement of Cement." In: International Conference on Sustainable Development, Mehran University of Engineering & Technology, Jamshoro, Pakistan (2019): 1-4.

[7] Kore, Sudarshan D., and A.K. Vyas. "Impact of Marble Waste as Coarse Aggregate on Properties of Lean Cement Concrete." Case Studies in Construction Materials 4 (June 2016): 85–92. doi:10.1016/j.cscm.2016.01.002.

[8] Khitab, A., Anwar, W.: "Classical Building Materials." In: Advanced Research on Nanotechnology for Civil Engineering Applications, IGI Global (2016): 1-27.

[9] Southararajan, V. M., and A. Sivakumar. "Effect of the lime content in marble powder for producing high strength concrete." ARPN Journal of Engineering and Applied Sciences 8, no. 4 (2013): 260-264.

[10] Binici, Hanifi, Hasan Kaplan, and Salih Yilmaz. "Influence of marble and limestone dusts as additives on some mechanical properties of concrete." Scientific Research and Essays 2, no. 9 (2007): 372-379. doi:10.5897/SRE.9000594.

[11] Corinaldesi, Valeria, Giacomo Moriconi, and Tarun R. Naik. "Characterization of Marble Powder for Its Use in Mortar and Concrete." Construction and Building Materials 24, no. 1 (January 2010): 113–117. doi:10.1016/j.conbuildmat.2009.08.013.

[12] Rao, B. Krishna. "Study on marble powder as partial replacement of cement in normal compacting concrete." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) 13, no. 4 (2016): 01-05. doi:10.9790/1684-1304030105.

[13] Pathan, Veena G., and Md Gulfam Pathan. "Feasibility and Need of use of Waste Marble Powder in Concrete Production." IOSR Journal of Mechanical and Civil Engineering (2014): 23-26.

[14] Munir, Muhammad J., Safeer Abbas, Moncef L. Nehdi, Syed M. S. Kazmi, and Anwar Khitab. "Development of Eco-Friendly Fired Clay Bricks Incorporating Recycled Marble Powder." Journal of Materials in Civil Engineering 30, no. 5 (May 2018): 04018069. doi:10.1061/(asce)mt.1943-5533.0002259.

[15] Ahmed, Salman, Anwar Khitab, Khalid Mehmood, and Seemab Tayyab. "Green Non-Load Bearing Concrete Blocks Incorporating Industrial Wastes." SN Applied Sciences 2, no. 2 (January 24, 2020). doi:10.1007/s42452-020-2043-6.

[16] Wanna, Surachet, Warangkana Saengsoy, Pisanu Toochinda, and Somnuk Tangtermsirikul. "Effects of Sand Powder on Sulfuric Acid Resistance, Compressive Strength, Cost Benefits, and CO2 Reduction of High CaO Fly Ash Concrete." Edited by Shengwen Tang. Advances in Materials Science and Engineering 2020 (December 27, 2020): 1–12. doi:10.1155/2020/3284975.

[17] ASTM C143/C143M: Standard Test Method for Slump of Hydraulic-Cement Concrete., West Conshohocken, Pennsylvania United States (2015). doi:10.1520/C0143_C0143M-15A.

[18] Lee, Kyung-Ho, Keun-Hyeok Yang, Ju-Hyun Mun, and Nguyen Van Tuan. "Effect of Sand Content on the Workability and Mechanical Properties of Concrete Using Bottom Ash and Dredged Soil-Based Artificial Lightweight Aggregates." International Journal of Concrete Structures and Materials 13, no. 1 (January 29, 2019). doi:10.1186/s40069-018-0306-z.

[19] Salau, M A, and A O Busari. "Effect of Different Coarse Aggregate Sizes on the Strength Characteristics of Laterized Concrete." IOP Conference Series: Materials Science and Engineering 96 (November 2, 2015): 012079. doi:10.1088/1757-899x/96/1/012079.

[20] ASTM C39: "ASTM C39: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." ASTM International (2015): 1–7. doi:10.1520/C0039.

[21] Khitab, A.: "Materials of Construction." Allied Books, Lahore, Pakistan (2012).

[22] Falade, F. "Influence of Water/cement Ratios and Mix Proportions on Workability and Characteristic Strength of Concrete Containing Laterite Fine Aggregate." Building and Environment 29, no. 2 (January 1994): 237–240. doi:10.1016/0360-1323(94)90073-6.

[23] Hewlett, P.C., Liska, M. "Lea's Chemistry of Cement and Concrete." Butterworth-Heinemann, Elsevier (2019). doi:10.1016/C2013-0-19325-7.

[24] Luo, Fu Jia, Li He, Zhu Pan, Wen Hui Duan, Xiao Ling Zhao, and Frank Collins. "Effect of Very Fine Particles on Workability and Strength of Concrete Made with Dune Sand." Construction and Building Materials 47 (October 2013): 131–137. doi:10.1016/j.conbuildmat.2013.05.005.

[25] ASTM C496 / C496M-17: Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, West Conshohocken, PA (2017). doi:10.1520/C0496_C0496M-17.

[26] ASTM C78/C78M: Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). , West Conshohocken, Pennsylvania United States (2018).

[27] Iloabachie, I., Obiorah, S., Ezema, I., Okpe, B., Chima, O., Chime, A.: "The effects of particle size on the flexural strength, tensile strength and water absorption properties of uncarbonized coconut shell /polyester composite." International Journal of Advanced Engineering and Technology 1 (2017): 22–27.

[28] Sadeghbeigi, R.: "Fluid Catalytic Cracking Handbook". Elsevier (2012). doi:10.1016/c2010-0-67291-9.

[29] ASTM C805/C805M-18: Standard Test Method for Rebound Number of Hardened Concrete., West Conshohocken, PA (2018).

[30] Hannachi, S., Guetteche, M.N.: "Review of the Rebound Hammer Method Estimating Concrete Compressive Strength on Site." Proceedings of International Conference on Architecture and Civil Engineering (ICAACE'14) (2014): 118–127.

[31] Gehlot, T., Sankhla, S.S., Gupta, A.: "Study of Concrete Quality Assessment of Structural Elements Using Rebound Hammer Test." American Journal of Engineering Research (AJER) 5 (2016): 192–198.

[32] ASTM C597-09: Standard Test Method for Pulse Velocity through Concrete. (2009). doi:10.1520/C0597-09.

[33] Sutan, N. Mohamed, and M. Meganathan. "A Comparison between Direct and Indirect Method of Ultrasonic Pulse Velocity in Detecting Concrete Defects." Journal of Nondestructive Testing 8, no. 5 (2003): 1-9.