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Experimental Investigation of Mechanical and Microstructural Properties of Concrete Containing Bentonite and Dolomite as a Partial Replacement of Cement

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ABSTRACT

In this study, the effect of bentonite (BT) and dolomite (DT) on the mechanical and microstructural properties of concrete was evaluated on nine mixes. Cement was replaced with bentonite and dolomite by weight with varying mix ratios. The mixes are divided as M1 (Control mix), M2 (2.5% BT), M3 (2.5% DT), M4 (5% BT), M5 (5% DT), M6 (10% BT), M7 (10% DT), M8 (2.5% BT and 2.5% DT), and M9 (5% BT and 5% DT). Concrete specimens were subjected to mechanical and microstructural analysis tests. Mechanical test results show that the addition of bentonite (2.5%, 5%, and 10%) leads to an increase in compressive strength (6.31%, 8.94%, and 13.15%) respectively. Similarly, the addition of 2.5% and 5% dolomite enhanced compressive strength by 10.52%, and 8.94% respectively, however, the addition of 10% dolomite reduced compressive strength by 6.8%. Replacement of cement with dolomite and bentonite individually also showed a small contribution to flexural and split tensile strength. Microstructural analysis shows that the addition of bentonite and dolomite filled the microstructure and refined the internal pores contributing to compressive strength. In addition, the replacement of cement with bentonite and dolomite enhanced the formation of CSH gel.

Keywords: Bentonite; dolomite; mechanical properties; microstructural analysis

INTRODUCTION

The production of Portland cement has significantly increased to a large scale due to rapid infrastructure developments which have become a threat to the environment and sustainability. The depletion of raw materials and aggregates has imparted adverse effects on the environment. Pakistan being a developing country is facing serious threats of global warming and the cost of cement is also high. It is estimated that the demand for aggregates could reach up to 47 billion tonnes per year by the end of 2023 (Ul Haq et al. 2022). The production of cement requires an immense amount of energy to attain the required temperature (1450^{o}C) (Ighalo and Adeniyi 2020). It is estimated that the production of cement adds almost 7% to total emissions of carbon dioxide worldwide which is considered an important source of global warming (Memon et al. 2012). The use of different pozzolans in concrete has increased in recent years due to their special characteristics such as high sulfate resistance, low heat of hydration, low permeability, and cementitious properties ('Use of Natural Pozzolans in Concrete (ACI 232.1R)', 1994), (Wajahat et al. 2021). Bentonite is a naturally available pozzolanic material found in Pakistan. It is estimated that over 36 million tons of bentonite are available in some districts of Pakistan which can be readily used as a natural pozzolana in concrete (Ahmad and Siddiqi, 1993). The bentonite can be used in concrete as a binder which improves early strength and plasticity. The study conducted by Memon et al.(Memon et al. 2012) and Mirza et al.(Mirza et al. 2009) advocate the potential replacement of cement with bentonite which can increase mechanical the properties of concrete. The addition of dolomite in concrete also enhances the mechanical and microstructural properties of concrete. Dolomite contains a high concentration of Magnesium and Calcium carbonate which gives early strength and reduces the water-cement ratio which helps to improve the workability of concrete (Muthukumaran and Rajagopalan 2017). The study shows that adding 5% dolomite to concrete enhances concrete's crushing and tensile strength (Belhadj et al. 2015). The addition of dolomite enhances the hardening properties of concrete and fills microstructural pores. Small particles of dolomite fill the pores due to its plastic nature and enhance the strength of concrete (Vijayaraghavan et al. 2022).

The study aims to analyze the effect of bentonite and dolomite on the mechanical properties of concrete reinforced with different dosages of PPF. In this study, cement was replaced with varying percentages of bentonite and dolomite. Bentonite and dolomite dust (powder) was obtained as a byproduct from the Kamsar crushing plant located at 2-3Km from the city of Muzaffarabad, the capital of Azad Jammu and Kashmir. The bentonite and dolomite are obtained at a large scale as a by-product from crushing plants which pose severe environmental threats to the residents of Muzaffarabad. The production of dust creates environmental pollution in Muzaffarabad and also contaminates water. Exposure to bentonite and dolomite dust may cause skin irritation and respiratory problems. A large quantity of these raw materials are produced at the site and their disposal is a grave concern. A very small quantity of dolomite is been used and recycled due to a lack of research. The study of existing literature shows there are very limited studies on the combined effect of bentonite and dolomite in concrete [7-10]. Therefore the replacement of cement with bentonite and dolomite was carried out to find an alternative binding agent that could help for sustainable construction. Bentonite and dolomite were added to concrete with different percentages and then concrete specimens were tested to determine compressive strength, flexural strength, and split tensile strength. In addition, the microstructural study of concrete samples was performed by using SEM. This study would help to determine the microstructural changes in concrete after the addition of bentonite and dolomite. Moreover, this study will contribute towards the development of a sustainable solution to the construction industry that is not only cost-effective but also has several positive environmental impacts.

EXPERIMENTAL PROGRAM

MATERIALS & MIX PROPORTIONS

The cement (ASTM Type I) used in this research follows the requirements of (ASTM C150) (*Standard Specification for Portland Cement C150/C150M*, 2019). Bentonite and dolomite were obtained from the Kamsar crushing plant located at 2-3Km from the city of Muzaffarabad. The maximum nominal sizes of fine and coarse aggregates were recorded as 4.75mm and 19mm respectively. Sieve analysis of fine aggregates was done according to the guidelines of ASTM C136/C136M-19(American Society of Testing and Materials., 2014). Concrete was cast into nine different mixes having different mix ratios of bentonite and dolomite. The details of the mix proportion of different mixes are shown in Table 1.

FIGURE 1. The casting of specimens.

FIGURE 2. Concrete specimens of different mixes.

TABLE 1. Mix proportion of concrete mixes

Mix	w/c	Water	Cement	Sand	Coarse Agg.	Bentonite	Dolomite
	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	%	%
M1	0.55	113	205	414	856	-	-
M2	0.55	113	205	414	856	2.5	-
M3	0.55	113	205	414	856	-	2.5
M4	0.55	113	205	414	856	5	-
M5	0.55	113	205	414	856	-	5
M6	0.55	113	205	414	856	10	-
M7	0.55	113	205	414	856	-	10
M8	0.55	113	205	414	856	2.5	2.5
M9	0.55	113	205	414	856	5	5

TABLE 2. Chemical composition of cement, bentonite, and dolomite

Oxides	Opc (%wt)	Bentonite(%wt)	Dolomite dust(%wt)
SiO_2	55.55	50.90	0.65
Al_20_3	32.93	16.78	0.12
Fe_20_3	3.12	6.32	0.18
MgO	1.42	1.65	2.34
CaO	4.64	7.94	30.15
Na_2O	0.3	0.62	….
K_2O	1.3	0.45	2.01
MnO	…	….	0.03
TiO	….	0.33	0.36

TESTING PROCEDURE

The compressive strength of concrete cubes was determined according to the guidelines of EN-12390 (BS EN 12390-2019 Part 3, 2019). Specimens were loaded by applying uniform load through a horizontal rubber pad. Adequate safety precautions were taken to prevent the exposure of bentonite and dolomite to hands and eyes during mixing. Compressive strength was determined by using a standard cube (150mm × 150mm × 150mm). The flexural strength of concrete beams was determined as per guidelines given by ASTM C78/C78M (ASTM C78, 2016). The beams of standard size (100×100×500) mm were used to obtain the flexural strength of concrete. Concrete cylinders having a size of (150×300) mm were used to determine split tensile strength according to the specifications of ASTM C496/C496M-17 (ASTM C496/C496M − 17, 2011). The microstructural properties of concrete samples were determined by using spectral electron microscopy (SEM). The SEM images of the concrete sample were taken at the resolution of 10 - 100 µm.

RESULTS AND DISCUSSIONS

COMPRESSIVE STRENGTH

The compressive strength of concrete specimens was determined after 7, 14, and 28 days of casting. There was a small change in the strength of the concrete after 7 days however, the difference in strength was evident at 14 and 28 days as compared to the control sample. The results obtained for compressive strength are shown in Fig 3. Study shows that the addition of bentonite by 2.5%, 5%, and 10% enhanced compressive strength by 2.7%, 8.3%, and 12.2% respectively after 14 days of casting. Similarly, the addition of bentonite by 2.5%, 5%, and 10% enhanced compressive strength by 6.3%, 8.9%, and 13.15% respectively after 28 days of casting. The increase in the compressive strength of concrete is attributed due to the pozzolanic reaction of bentonite with cement (Masood *et al.* 2020). The reaction of calcium hydroxide and kaoline accelerates the formation of C-S-H gel which enhances the mechanical properties of concrete (Vijayaraghavan *et al.* 2022). The study conducted by Inzamam Ul Haq et al. (Ul Haq *et al.* 2022) shows that the addition of 10% enhances the compressive strength of concrete. S. Taklymi (Taklymi, Rezaifar and Gholhaki 2020) confirmed that the replacement of cement with kaoline by 2/7% can increase compressive strength up to 6%. Results obtained in this study reveal that the addition of a small amount of dolomite also positively impacted compressive strength. The concrete mixes containing 2.5% and 5% dolomite exhibited 10.5% and 8.4% increases in compressive strength respectively when specimens were tested at 28 days. The improvement in compressive strength due to the addition of dolomite is regarded due to its filling effect which improved the density of microstructure by filling pores. Experimental results obtained in this study show that the addition of 10% dolomite in concrete reduced its compressive strength by 6.8%. Similarly, the concrete mixes M8 (2.5% BT and 2.5% DT) and M9 (5% BT and 5% DT) showed 18% and 24.7% less strength respectively as compared to the control mix. The trend of reduction in compressive strength is due to incomplete reaction as a result of the agglomeration of bentonite and dolomite which hindered hydration reaction which is also evident in microstructural images. The results derived from this study are in line with similar studies (Zia and Ali 2017), (M. A. Ismail 2007). Therefore, the results obtained for compressive strength suggest that optimum dosages of bentonite and dolomite for compressive strength are 10% and 5% respectively which can be used in concrete for affordable and sustainable construction.

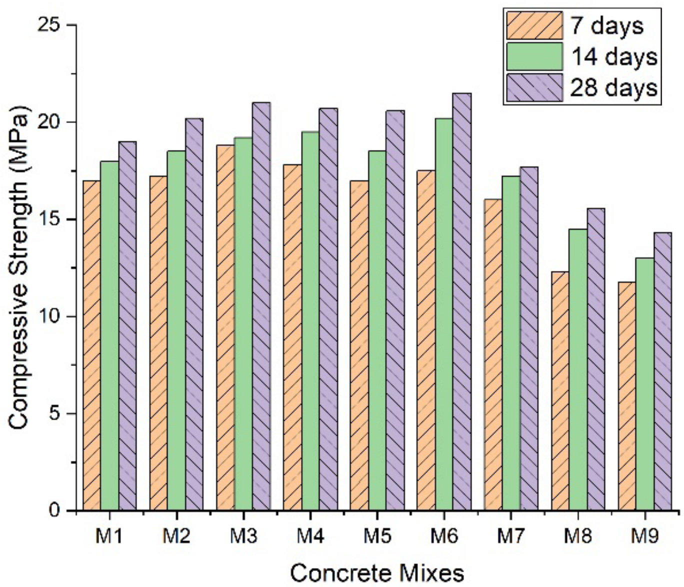

FIGURE 3. Compressive strength of concrete specimens.

FLEXURAL STRENGTH

The specimens of concrete beams were used to determine the flexural capacity of concrete and the variation in flexural strength of different mixes is represented in Fig.4. Study shows that the addition of small dosages of bentonite and dolomite showed little contribution towards flexural strength. Incorporation of bentonite in cement by 2.5% and 5% showed an improvement in flexural strength up to 2.20% and 0.20% respectively after 14 days. The improvement in flexural strength is due to the densification of the matrix due to the presence of fine particles of bentonite (V Satyanarayana and Yashwanth, 2019). A concrete mix containing 10% bentonite showed a 6.4% reduction in flexural strength. High bentonite content retarded the pozzolanic reaction of cement with bentonite which resulted in the formation of unstable hydration products that led to a reduction in flexural strength which is also confirmed by a similar study carried out by A. Karimipour et al. (Karimipour and de Brito 2021). The specimens containing 2.5%, 5%, and 10% dolomite showed 6%, 8%, and 4% improvement in flexural strength respectively when samples were tested after 28 days of casting. Similarly, the concrete mix M8 (2.5% BT and 2.5% DT) did not show any contribution to flexural strength and the mix M9 (5% BT and 5% DT) showed an 8% reduction in flexural strength as compared to the control mix. A similar study also reports a reduction in flexural strength at high dosages of bentonite and dolomite (Khushnood et al. 2014). Hence the optimum dosage of bentonite and dolomite for flexural strength is 2.5% and 5% respectively.

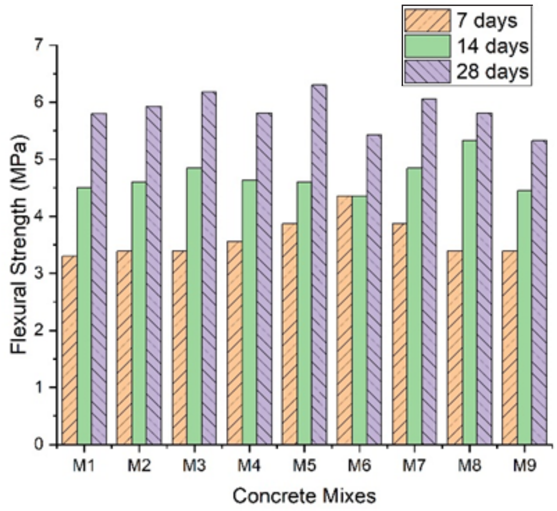

FIGURE 4. Flexural strength of concrete specimens

SPLIT TENSILE STRENGTH

The results of split tensile strength obtained from testing cylindrical specimens are shown in Fig.4. Study reveals that the addition of bentonite in concrete has little contribution to split tensile strength however the high dosages of dolomite adversely affected the split tensile strength. It was observed that the specimens having a high dosage of bentonite and dolomite were susceptible to tensile load and ruptured at less load as compared to the control sample. Incorporation of bentonite in cement by 2.5% showed an improvement in split tensile strength up to 2.20%, however, the addition of 5% and 10% bentonite led to a decrease in split tensile strength by 2.9% and 9.2% respectively. Results show that specimens containing 2.5% and 5% dolomite in cement showed enhancement in split tensile strength up to 8.50% and 4% respectively, however, the addition of 10% dolomite led to a decrease in split tensile strength by 6.6% respectively when specimens were tested after 28 days of casting. Similarly mixing 5% bentonite along with 5% dolomite in cement exhibited 18% less split tensile strength as compared to the control sample. The decrease in tensile strength is due to the present high concentration of bentonite and dolomite which prevented complete hydration and reduced the quality of bonding between aggregates and matrix as evident from SEM images. Similar results were obtained in a study conducted by J.Luo (Luo et al. 2019). Therefore the optimum dosage of both bentonite and dolomite for split tensile strength is 2.5%.

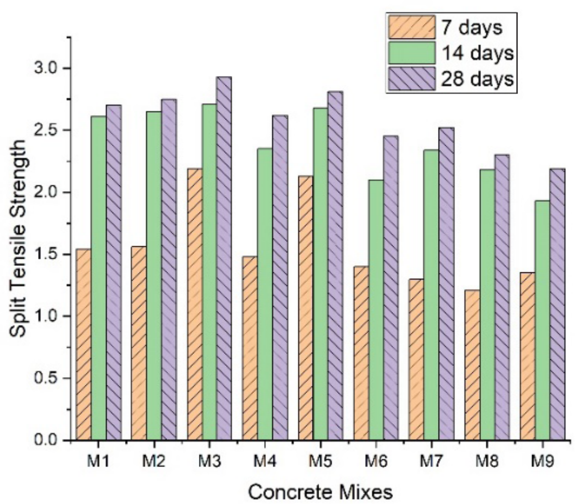

FIGURE 5. Split Tensile strength of concrete specimens

MICROSTRUCTURAL ANALYSIS

The microstructural analysis of concrete specimens was performed by using scanning electron microscopy (SEM) to evaluate the effect of bentonite and dolomite on the morphological properties of concrete. The internal structure of the control sample having no replacement of cement is represented in Figure 6(a) showing the formation of calcium hydroxide and ettringite. The SEM image of concrete containing bentonite is shown in Figure 6(b) revealing compact and dense microstructure. The voids in concrete were filled due to a pozzolanic reaction which created a high concentration of CSH gel by consuming calcium hydroxide. Increasing the dosage of bentonite from 2.5% to 10% created a homogenous mixture of concrete as evident in Figure 6(d). The samples containing dolomite also showed improvement in the microstructure of concrete by filling pores due to its filling action as evident in Figure 6(c) while showing a high concentration of calcium hydroxide. Higher dosages of bentonite and dolomite retarded the hydration process due to agglomeration with cement which resulted in weak microstructure as shown in Figure 6(e). The addition of bentonite and dolomite imparted a positive effect in developing the dense microstructure of concrete.

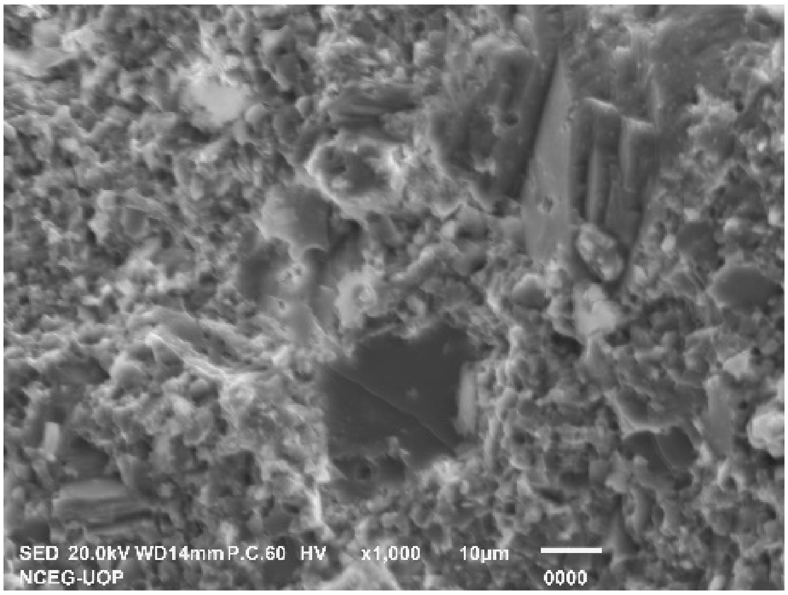

FIGURE 6(a). Control mix (M1).

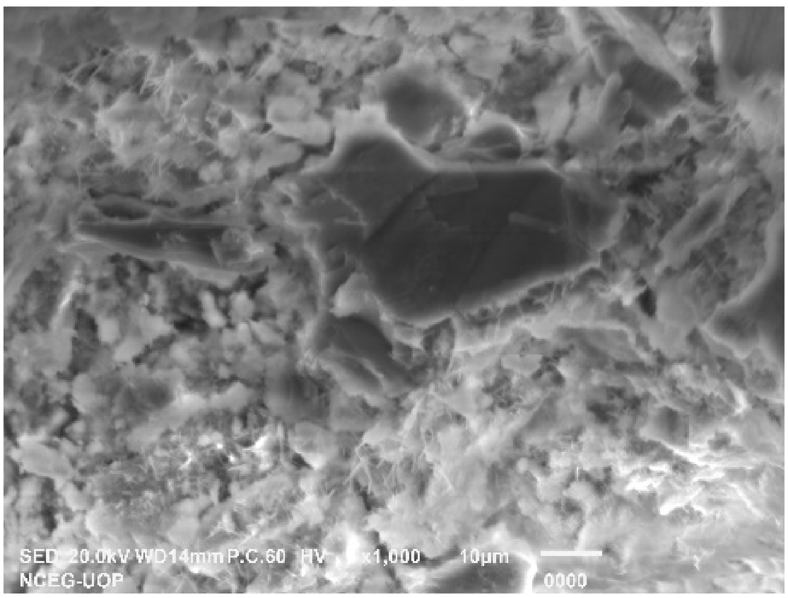

FIGURE 6(b). Mix (M2) containing 2.5% bentonite.

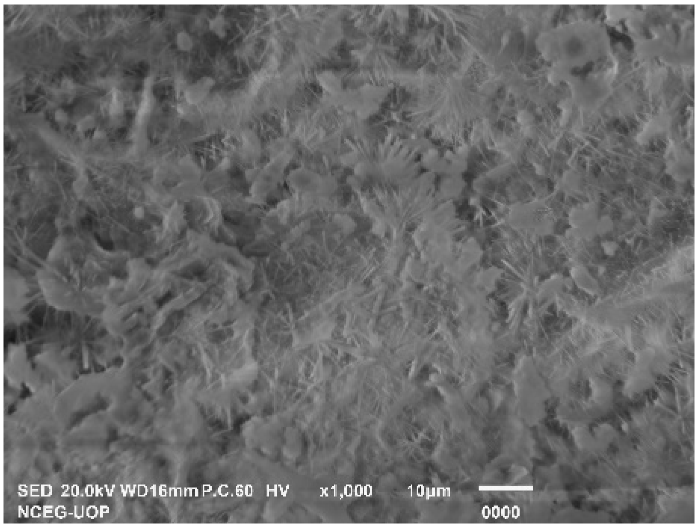

FIGURE 6(c). Mix (M3) containing 2.5% dolomite.

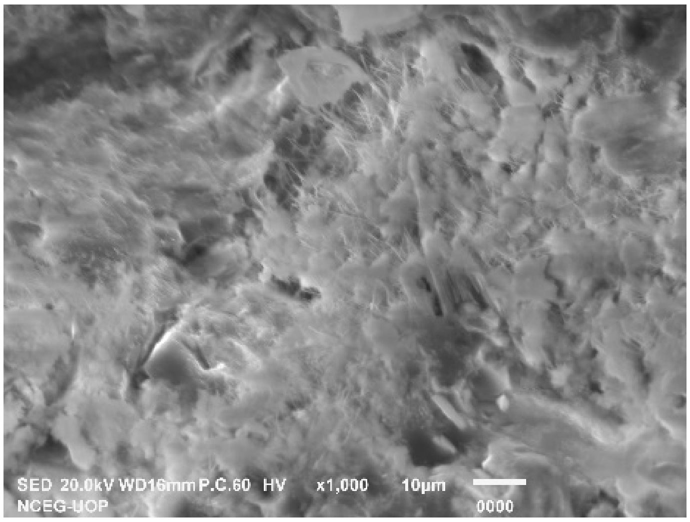

FIGURE 6(d). Mix M(6) containing 10% bentonite.

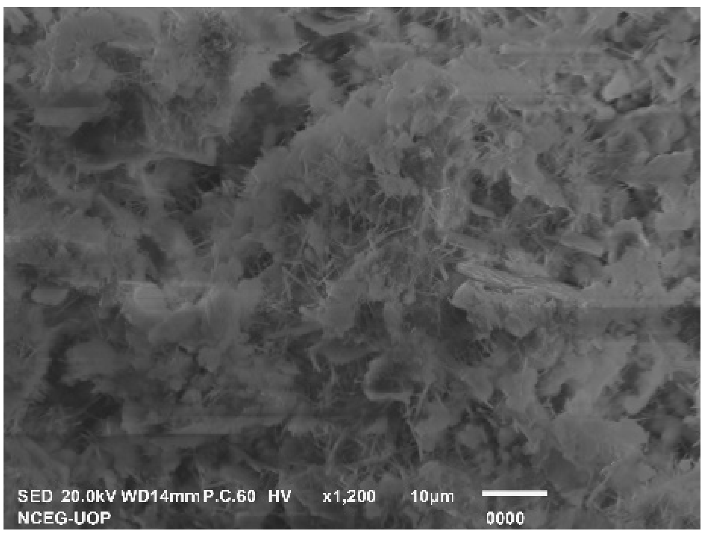

FIGURE 6(e). Binary mix (M9) containing 5% bentonite and 5% dolomite.

CONCLUSION

The following conclusions are made from this study.

1. Study shows that the addition of bentonite by 2.5%, 5%, and 10% enhanced compressive strength by 2.7%, 8.3%, and 12.2% respectively after 14 days of casting due to the filling effect of bentonite. Similarly, the introduction of bentonite in cement by 2.5% and 5% showed an improvement in flexural strength up to 2.20% and 0.20% after 14 days respectively.
2. The concrete mixes containing 2.5% and 5% dolomite exhibited 10.5% and 8.4% increases in compressive strength respectively when specimens were tested at 28 days. High dosages of dolomite resulted in low compressive, flexural, and split tensile strength due to retardation in the hydration reaction. The binary mixes of bentonite and dolomite showed little contribution to strength.
3. SEM images show that the addition of bentonite created denser microstructure and refined pores which enhanced the mechanical properties of concrete. The pore-filling property of dolomite also contributed to the crushing strength of concrete.
4. The study reveals beneficial aspects of incorporating bentonite and dolomite therefore, the use of optimum dosages of bentonite and dolomite can help to enhance the performance of concrete and reduce the consumption of cement which will help toward economical and sustainable construction.

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DECLARATION OF COMPETING INTEREST

None

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