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REGRESSION ANALYSIS OF MECHANICAL STANDPOINT OF BACILLUS SUBTILIS MICROBIAL CONCRETE ON META KAOLIN BASED CONCRETE

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Abstract

For the purpose of repairing fractures in the concrete structure, metakaolin (MK), which may partly substitute cement and enhance concrete characteristics, will be used in combination with bacteria that can precipitate calcite, according to the findings of this study. The healing of crack in concrete is often ensured through self-healing mechanism due to potential metabolism activity of the Bacillus bacteria. In this study, MK is utilized to substitute cement by 5%, 10%, and 15%, with B. Subtilis in the concentration of 107 cfu/ml. The compressive strength, water absorption and split tensile strength were assessed during 7, 14 and 28 days on the concrete samples of size $100 \times 100 \times 100$ (in mm). The bacterial solution was incorporated in the concrete mix during mixing process in the controlled environment in measured concentration. It was investigated that B. Subtilis along with MK in concrete helps in reducing the porosity of the concrete. Thus, an improved compressive strength of the concrete is achieved the values of R2 have been determined by regression analysis for "Compressive Strength and Tensile Strength" and "Compressive Strength and Water Absorption" of Bacillus Subtilis bacterial concrete kaolin based concrete.

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1. Introduction

Concrete is commonly employed in the construction, with the majority of its components being used in a variety of industries. Concrete is a highly trustworthy material in terms of strength. Continuous usage of cement concrete has a bad consequences on the environment, putting the ozone layer in jeopardy responsible for global warming into the environment [1], [2]. Cement is a binder used as a bonding agent in a variety of building applications. Cement is typically used to bind sand and gravel (aggregates) together rather than on its own. Cement is also used to harden a variety of different materials [3]. Physical qualities of cement are influenced by its ingredients and grinding aid [4], [5]. Various grinding aids in the form of solids and liquids are introduced during the cement making process. Energy conservation and greenhouse gas (GHG) emission reduction have become increasingly important in recent years. The bulk exploitation of waste material as a resource material for the creation of value-added commodities receives a lot of attention. Cracks in concrete not only lowered its strength, but also allowed dangerous materials to enter.

Many research studies have been conducted to better understand the reason of micro-crack generation in concrete and to provide that it is protected from hazardous salts. In most investigations, different pozzolana ingredients were used in concrete mix [6], [7], including metakaolin, rice husk ash, fly ash, silica flume, and slag (GGBS), which are all good source of aluminosilicate. Various studies and researches show favourable results in support of these supplementary cementitious materials. MK particles are often less than 2 μm in size, which is much finer than cement particles but not as fine as silica fume. It is usually used to substitute 5 to 20 percent of the cementitious material. MK increases concrete performance by forming secondary C-S-H when it reacts with calcium hydroxide. MK does not darken concrete as SF does (the white-colored SF is fairly limited in tonnage), making it acceptable for color-matching and other architectural purposes. The influence of metakaolin inclusion on concrete's susceptibility to sulphate attack was shown to be good. The use of Metakaolin in concrete combined with bacteria can result in constructions that are cleaner, greener, and more long-lasting. B. Megaterium [8], B. Subtilus [9], and B. cereus [10] are among the bacteria employed in structural concrete. Tziviloglou et al. [11]

investigated the impact of mortar and concrete's self-healing properties. They discovered that bacteria cultured in an alkaline environment performed better in the environment [12]-[14]. This research follows the addition of bacteria B. subtilis solution which is directly added to the concrete mix and partial substitute of cement with metakaolin in different percentages as 5%, 10% and 15%. The combination of bacillus subtilis and metakaolin in cement concrete proved to bring about a significant increase in the compression strength along with decrease in water absorption.

2. Materials

A. Bacterial cultivation and growth

In this study, B. Subtilis is used as a bio-additive to precipitate calcite inside the concrete. The strain was purchased from the IMTECH Chandigarh in dried powdered form. B. Subtilis is a gram negative bacterium. It produces calcium carbonate during microbial enzymatic activity hence; can be used to improve the characteristics of the cement concrete.

B. Metakaolin (MK)

Metakaolin is a kind of calcined clay that is made by calcining kaolin clay, and it has sparked considerable interest in its application in recent years. It is made by heating kaolin to a certain temperature. Several researchers proposed different optimal temperatures (600°C-850°C) and heating times (1-12 h) for processing kaolin to get MK with a higher pozzolanic level, see Table 1. As a result of its pozzolanic characteristics, MK can be used to replace cement in concrete; however, the durability and strength of MK concrete are unclear. In current study, MK is substituted in 5%, 10% and 15% by weight of cement.

Table 1. Composition of Metakaolin.

Content	CaO	SiO2	Al2O3	Fe2O3	MgO	Na2O	K2O
Cement	43.65	27.63	6.89	4.65	1.09	0.14	0.02
Metakaoline	0.39	54.3	38.3	4.28	0.08	0.12	0.50

3. Mix Proportion

A. Bacterial cultivation

Cultivation of bacteria requires essential nutrient source for growing the bacteria. These include nitrogen source, carbon source, and water with trace elements. Nutrient broth is prepared using peptone (5g/L), NaCl (5g/L), and beef extracts (1g/L). While preparing bacterial suspension, all apparatus is carefully sterilised. On nutrient agar media on a Petri plate, a pure culture of the bacterium Bacillus subtilis was created. On the Petri plate, the populations of Bacillus subtilles seem to be white. Few colonies, or a loop full of necessary bacteria, are introduced into the established culture medium in a flask as part of inoculation using a platinum inoculating loop. This infected material was then retained for overnight incubation at 370C with a 150 rpm orbital shaker, followed by an Optical Density (OD) test to measure the concentration. The bacterial count is maintained at 107 cells per milliliter.

B. Mix Composition

In this research work, Grade of concrete M25 is used for preparing cement specimen in accordance to IS 10262-2009. Furthermore, MK in 5%, 10% and 15% by mass of cement is replaced in this study. The Mix design prepared follows the guidelines of the Indian standard codes IS456: 2005. The details of design mix are shown in Table 2nd. All of the mixtures have a bacterial concentration of 107 cfu/ml.

Table 2. Concrete Mix Proportions.

Mixture(Kg/m3)	Control	MK5	MK10	MK15
Cement	451.72	429.134	406.539	383.415
MK	0%	5%	10%	15%
MK	0	22.586	45.171	67.756
Natural sand	619.323	619.323	619.323	619.323
Coarse aggregate	1295.23	1295.23	1295.23	1295.23
W/C ratio	0.43	0.43	0.43	0.43
Water	158.1	158.1	158.1	158.1

4. Result and Discussion

A. Compressive Strength test

Using compression testing equipment in a controlled environment, the compressive strength of bacterial samples was evaluated. It was observed that the compression test of bacterial concrete cubes (OPC+ 5% MK, OPC+ 10% MK, OPC+15% MK, and OPC + 20% MK) at 7 days were higher in compared with conventional concrete. It shows 11.79%, 19.06%, 22.46%, and 15.47% increase in compressive strength in comparison with conventional concrete at 7-day curing period respectively. However, the continuous curing period and incorporation of bacterial solution impart its strength than normal. During 28 days, OPC+ 15% MK mix shows maximum strength; revealing up to 27.27% rise in strength. Comparatively, the strength of OPC+20% MK was seen to de declining in all days as 15.47%, 18.34%, and 10.9% when compared with OPC+15% MK mixes.

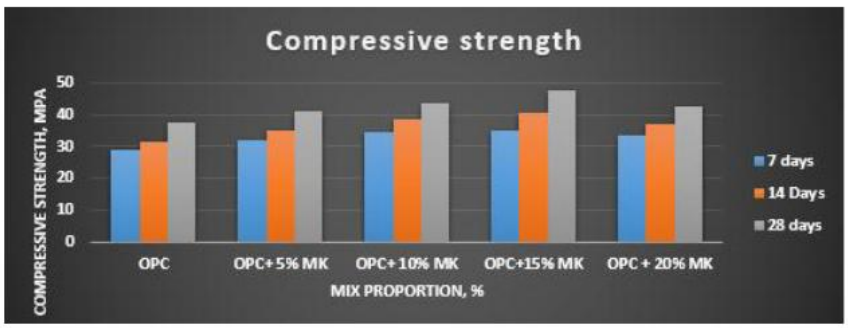

Figure 1. Compression strength of bacterial metakaolin concrete.

B. Split-Tensile Strength Test

The results for tensile strength can be seen in Figure 2. The interpretation of result for tensile strength shows the similar trend as can be seen in compressive strength. The concrete shows increased strength up to 15% MK replacement for all curing period and shows 13.45%, 14.03%, and 18.77% increase in split tensile strength of OPC+15% MK during 7, 14, and 28 days respectively. However, for OPC+20% MK shows deduction in 4.48%, 4.66%, and 9.06% strength when compared with OPC+15% MK mixes during 7, 14, and 28 days respectively.

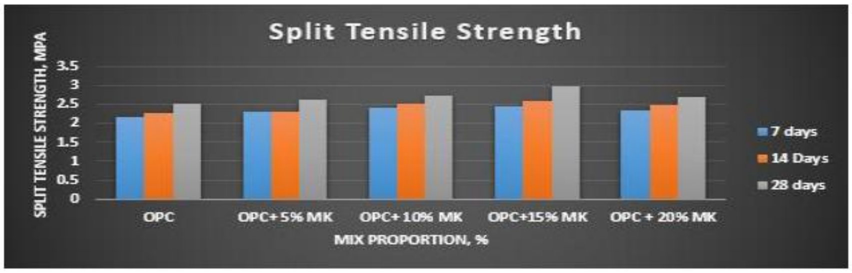

Figure 2. Tensile strength of bacterial metakaolin concrete.

C. Water Absorption

The Water Absorption of concrete samples was checked and compared with normal concrete during 14 and 28 days curing periods respectively. The results for water absorption of bacterial concrete can be seen in Figure 3.

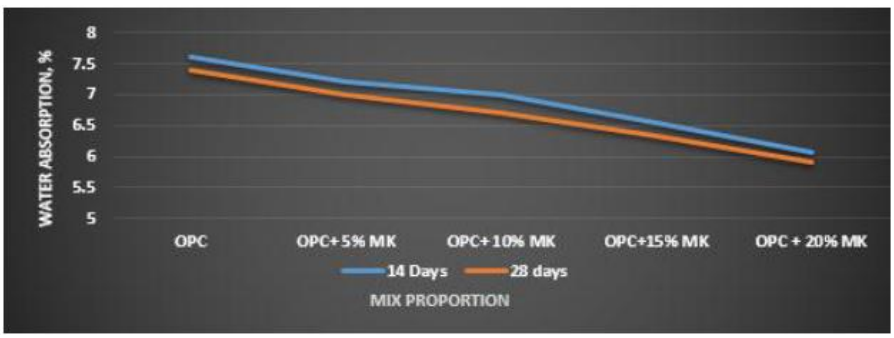

Figure 3. Water absorption of bacterial metakaolin concrete.

It was seen that the Water Absorption of specimens were decreasing as the substitution of cement with metakaolin happens. The maximum water retaining was seen in OPC +20% MK mixes as 6.08% and 5.91% for 14 and 28 days respectively. However, with the curing period passes the samples shows marginal drop in water absorption.

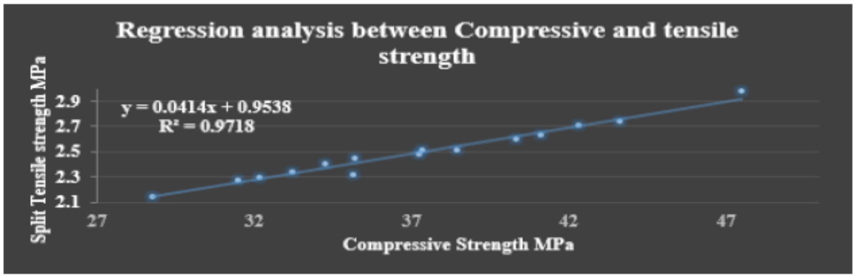

Figure 4. Regression analysis between Compression and tensile strength.

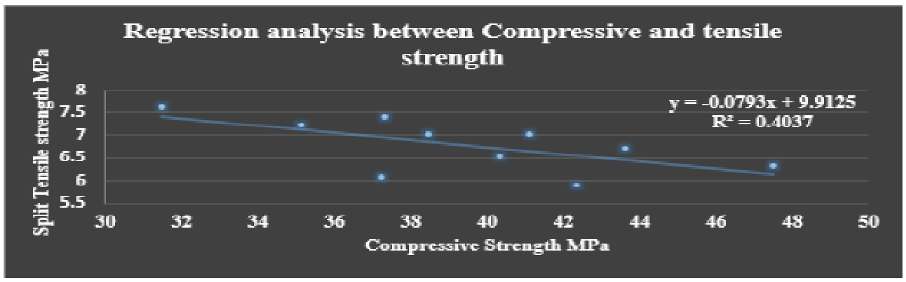

Figure 5. Regression analysis between Compressive and water absorption.

When the results of the tests were analyzed using linear regression R2 [15], the relationship between both the compression strength of microbial concrete and tensile strength of microbial concrete was discovered. According to the following graph, the percentage relationships between “compressive strengths and splitting tensile strengths” and “compressive strengths and water absorption test” are shown, as is the coefficient of determination for each relationship (R2). A good connection exists between the regression bend and the statistics of compressive strength and splitting tensile strength values, as shown by the aforementioned value of R2 (0.9718). In Figure 4, it can be shown that the higher the splitting tensile strength is, the greater the compressive strength will be [16], [17].

5. Conclusion

Bacteria added to metakaolin concrete improve compressive strength at all intervals. During 7 days, the compression strength of OPC+05% MK, OPC+ 10% MK, OPC+15 % MK, and OPC + 20 % MK bacterial concrete cubes increased by 11.79 %, 19.06 %, 22.46 %, and 15.47 %, respectively. During 28 days, OPC+ 15% MK mix shows maximum strength; revealing up to 27.27% rise in strength. The highest strength was achieved in OPC+15% MK mix at 7, 14, 28 days respectively. OPC+15% MK mix were showing 13.45%, 14.03%, and 18.77% increase in tensile strength during 7, 14, and 28 days respectively. OPC+20% MK mix shows reduced compressive and split tensile strength while 20% Mk provision ensure the greater water intake during all curing days. Calcite formation in pores by bacteria resulted in decreased porosity and water absorption in bacteria-added concrete mixes compared to bacteria-free concrete mixtures. The maximum water retaining was seen in OPC+20% MK mixes as 6.08% and 5.91% for 14 and 28 days respectively. Results of linear regression correlation (R2) between compressive and split tensile strength were obtained, and it was discovered that the complete model adequately had the greatest connection among the various evaluations of linear regression. This study concluded that Metakaolin can be an excellent substitute for cement, and because it is less inexpensive, can be used up to 15% of the time. As a result, there is a potential that metakaolin might be utilized in the manufacture of high-strength concrete, although more studies are needed.

Reference

[1] M. V. S. Rao, V. S. Reddy and C. Sasikala, Performance of Microbial Concrete Developed Using Bacillus Subtilus JC3, J. Inst. Eng. Ser. A, 98(4) (2017), 501-510, doi:10.1007/s40030-017-0227-x.

[2] N. N. T. Huynh, N. M. Phuong, N. P. A. Toan and N. K. Son, Bacillus Subtilis HU58 Immobilized in Micropores of Diatomite for Using in Self-healing Concrete, Procedia Eng. 171 (2017), 598-605, doi:10.1016/j.proeng.2017.01.385.

[3] K. Vijay and M. Murmu, Effect of calcium lactate on compressive strength and self-healing of cracks in microbial concrete, Front. Struct. Civ. Eng. 13(3) (2019), 515-525, doi:10.1007/s11709-018-0494-2.

[4] A. Shukla, N. Gupta and A. Gupta, Development of green concrete using waste marble dust, in Materials Today: Proceedings, 2020, no. xxxx, doi:10.1016/j.matpr.2020.02.548.

[5] A. Shukla, N. Gupta and K. Kishore, Experimental investigation on the effect of steel fiber embedded in marble dust based concrete in Materials Today: Proceedings, 2020, no. xxxx, doi: 10.1016/j.matpr.2020.02.607.

[6] A. Shukla, N. Gupta, A. Gupta, R. Goel and S. Kumar, Natural Pozzolans a Comparative Study: A Review, IOP Conf. Ser. Mater. Sci. Eng. 804(1) (2020), doi:10.1088/1757-899X/804/1/012040.

[7] A. Gupta, N. Gupta, A. Shukla, R. Goyal and S. Kumar, Utilization of recycled aggregate, plastic, glass waste and coconut shells in concrete - A review, IOP Conf. Ser. Mater. Sci. Eng. 804(1) (2020), doi:10.1088/1757-899X/804/1/012034.

[8] N. Chahal, R. Siddique and A. Rajor, Influence of bacteria on the compressive strength, water absorption and rapid chloride permeability of concrete incorporating silica fume, Constr. Build. Mater. 37 (2012), 645-651, doi:10.1016/j.conbuildmat.2012.07.029.

[9] A. Talaiekhozan, A. Keyvanfar, A. Shafaghat, R. Andalib, M. Z. A. Majid and M. A. Fulazzaky, A Review of Self-healing Concrete Research Development, J. Environ. Treat. Tech. 2(1) (2014), 1-11.

[10] N. De Belie, Application of bacteria in concrete: a critical evaluation of the current status, RILEM Tech. Lett. 1 (2016), 56 doi:10.21809/rilemtechlett.2016.14.

[11] E. Tziviloglou et al., Bio-based self-healing concrete: From research to field application, Adv. Polym. Sci. 273 (2016), 345-386, doi:10.1007/12_2015_332.

[12] A. Shukla and N. Gupta, Study on the efficacy of natural pozzolans in Cement Mortar, in Calcined Clays for Sustainable Concrete, Rilem Publication, Springer (2020), 469-480.

[13] A. Shukla, N. Gupta, A. Gupta, R. Goel and S. Kumar, Study on the Behaviour of Green Concrete by the use of Industrial waste Material: A Review, IOP Conf. Ser. Mater. Sci. Eng. 804(1) (2020), doi: 10.1088/1757-899X/804/1/012036.

[14] N. Gupta, A. Shukla, A. Gupta, R. Goel and V. Singh, A Review on the selection of the variant Water in Concreting, IOP Conf. Ser. Mater. Sci. Eng. 804(1) (2020), doi: 10.1088/1757-899X/804/1/012037.

[15] Prateek Agrawal, Vishu Madaan, Aditya Roy, Rajani Kumari and Harshal Deore, FOCOMO: Forecasting and monitoring the worldwide spread of COVID-19 using machine learning methods, Journal of Interdisciplinary Mathematics 24(2) (2021), 443-466, doi:10.1080/09720502.2021.1885812.

[16] H. A. Algaifi et al., Mathematical prediction of the compressive strength of bacterial concrete using gene expression programming, Ain Shams Eng. J., no. xxxx, 2021, doi:10.1016/j.asej.2021.04.008.

[17] M. Jalal, P. Arabali, Z. Grasley, J. W. Bullard and H. Jalal, Behavior assessment, regression analysis and support vector machine (SVM) modeling of waste tire rubberized concrete, J. Clean. Prod. 273 (2020), 122960, doi:10.1016/j.jclepro.2020.122960.

[18] Charu Gupta, Prateek Agrawal, Rohan Ahuja, Kunal Vats, Chirag Pahuja and Tanuj Ahuja, Pragmatic Analysis of Classification Techniques based on Hyperparameter Tuning for Sentiment Analysis, International Semantic Intelligence Conference (ISIC'21), Delhi, (2021), 453-459.

[19] K. Goel, C. Gupta, R. Rawal, P. Agrawal and V. Madaan, FaD-CODS Fake News Detection on COVID-19 Using Description Logics and Semantic Reasoning, International Journal of Information Technology and Web Engineering (IJITWE) 16(3) (2021), 1-20.