Study of Mechanical Properties of Concrete Developed Using Metamorphosed Limestone Powder (MLSP), Burnt Clay Pozzolana (BCP) & Wood Ash (WA) as Partial Replacement of Cement

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Abstract

In this growing era of advancements and infrastructural growth, concrete has become one of the most utilized construction material across the globe. The environmental issues may be caused by direct discarding waste materials into the environment. Waste materials are now being employed to develop eco-friendly products and can be directly used as effective additives in many materials to develop efficient characters and durability in them. Stone slurry and solid marble waste are the two most produced waste materials of Metamorphosed limestone industry. Because of growing inflation in prices of raw materials researches are being made to replace the expensive materials with a low cost or waste materials in order to achieve eco-friendly yet cost-effective materials. In this paper, cement is being replaced by the metamorphosed limestone powder, burnt clay pozzolana, and wood ash. The tests are carried out for concrete developed in combination with the replacement of 0, 5, 10, 15 and 20% cement by metamorphosed limestone powder, burnt clay pozzolana, and wood ash. The main focus of the current study is to effectively identify the optimum range of percentage replacement that can be practically useful to achieve high-performance mechanical properties of concrete.

Keywords: Concrete; Waste Materials, Cement; Mechanical Properties; Strength

1. INTRODUCTION:

Concrete is an amalgamated material prepared with cement, sand, aggregates, admixtures or superplasticizers and water. In concrete, cement is used as a binder to hold the aggregates while fine aggregate (sand) acts as a filler material to increase the density of concrete and water is used to hydrate the cement(Coo & Pheeraphan, 2015). The effective properties of cement paste in concrete decides the efficient behaviour of concrete. In order to prepare a durable , low cost yet high-performance concrete many studies are being conducted around the globe to explore this particular aspect (Almusallam, Beshr, Maslehuddin, & Al-Amoudi, 2004). Numerous new skyscrapers strengthened bond solid structures have utilized cement with a compressive quality of more than 100 MPa. With increased usage of high-quality concrete, comprehensive research work has been conducted on base mechanical properties of concrete. Research pertaining to the use of waste materials which are the by-products produced by different manufacturing processes to enhance the properties of concrete. It clearly shows the fact that human activities in different aspects of production and usage create a very strong impact on procuring waste materials in significantly higher volumes more than 2500 MT per year. Different detailed studies prove the fact that these waste materials are way more profitable in usage nature if treated properly to utilize in effective ways. The solid wastes are one of the most prominently produced wastes that may include silica fume, fly ash, blast furnace slag, burnt clay pozzolana, metamorphosed limestone powder, wood ash and waste construction materials. These waste materials are used to improvise the strength of concrete, workability behaviours, increase the water tightness, and to reduce the heat of hydration and significant thermal shrinkage for concrete. The civil engineers are primarily concentrating to develop the advanced concrete to enhance the service life of the structures and provide satisfactory performance under different climatic conditions. In the past, the proper disposal of such industrial waste materials was indeed one of the significant environmental issues across the world (Aliabdo, Elmoaty, & AbdElbaset, 2015). But now the engineers are utilizing them for plausible purposes. The fundamental objective here is to study the suitability of the metamorphosed limestone powder, burnt clay pozzolana and wood ash as pozzolanic materials to replace the cement by weight up to a certain amount in concrete. However, it is anticipated that the employ of metamorphosed limestone powder, burnt clay pozzolana and wood ash in concrete improves the base mechanical properties of ordinary concrete. These pozzolanas are verily considered as effectively acting source materials to be used for the partial replacement of bonder in concrete.

While Mineral Additives are also known as Pozzolanic Materials. They are the natural residues of different processes and they can fulfill our demands and can be replaced with chemical admixtures. Pozzolanic materials are: (i) Natural Pozzolanas (Shales and Clay, Cherts, Diatomaceous Earth and Pumicites and Volcanic Tuffs) (ii) Artificially existing Pozzolanas (Metamorphosed limestone powder, Burnt clay pozzolana, Wood Ash, Slag (GGBFS), Fumes of silica, Rice Husk and commonly available Metakaolin). These improve numerous characteristics of concrete, for example, these reduce the warmth of hydration and warm shrinkage, effectively increases the water snugness impact , reduces the plane soluble base total response, improvises the protection from assault by sulphate soils and ocean water, elevates the potential extensibility, lowers the defencelessness ability towards the disintegration and filtering, improvises efficient workability and lowers the gross costs (Agarwal, 2006; Aliabdo, Elmoaty, & Auda, 2014; Cheah & Ramli, 2011; Coo & Pheeraphan, 2015; Ergün, 2011; Kiran & Sharma, 2017; Krishnasamy & Palanisamy, 2014; Mansoor et al., 2018; Mohamed, 2011; Omar, Elhameed, Sherif, & Mohamadien, 2012; Puri & Srinivasan, 1959; Ranjan, Srivastava, & Kumar, 2015; Shirule, Rahman, & Gupta, 2012; Siddique, 2007, 2012; Siddique & Klaus, 2009; Torkaman, Ashori, & Momtazi, 2014; Turk, Karatas, & Gonen, 2013; Vardhan, Goyal, Siddique, & Singh, 2015).That is why these materials have been tested by researchers as partial replacement to cement and sometimes sand/filler as well.

In this study, three different waste materials have been tested for strength performance of concrete as a replacement of a binder i.e. cement. This procedure is designed to utilize the sustainable waste management in the field the of construction materials as well.

2. EXPERIMENTAL PROCEDURES:

2.1 Mechanism

Usage of different wastes in concrete and enhancing the base mechanical properties of concrete helps to produce eco-friendly yet efficient structures. Usage of waste marble powder, wood ash, and burnt clay pozzolana was explored the an aspect of strength improvisation by replacement of cement in varying percentages of the volume of cement being used. Cement has been tested to be by using M25 grade concrete in combination with the replacement of 0, 5, 10, 15 and 20% cement by metamorphosed limestone powder, burnt clay pozzolana, and wood ash. It improvised the binder properties and effectively reduced the usage of cement. Addition of pozzolana clay allows better binding properties to prevail leading to achieve higher strengths and low cracking concerns. Wood ash was finely ground to powder in order to achieve required consistency to be utilized in concrete. Fine powder of wood ash serves as replacement of vital ingredients of concrete. In this way, we can develop fine quality, durable and all above sustainable Eco-friendly concrete building blocks. After the development of concrete, the mechanical properties of concrete were tested to understanding the strength behaviour of concrete.

2.2 Materials

Across Pakistan large volumes of metamorphosed limestone powder, burnt clay pozzolana and wood ash are generated that went untreated into river waters or landfills. Similarly, there is a large industry of brick production in Pakistan that produces tons of wastages per day across the country. Utilization of wood ash is also an efficient improvisation in concrete that renders finely reliable characters to concrete. All these materials were analyzed for detailed properties and their respective behaviors as shown in Table.1.

Table 1. Properties of utilized Cement & Additives

Materials	Fineness	Consistency	Initial setting time (minutes)	Final setting time (minutes)	Compressive Strength (MPa)	
					3 days	7 days
CEM	4%	32%	60	265	16.29	23.14
MLSP	6.85%	34%	75	275	9.73	14.89
BCP	5.6%	30%	45	255	12.08	17.41
WA	7.49%	28%	40	225	8.67	11.93

2.3. Testing

The use of materials like metamorphosed limestone powder, burnt clay pozzolana and waste wood ash in the production of concrete had been presented in this paper. Waste materials that were to be added were analysed for their base properties like consistency measures, fineness, and sieve analysis were conducted before the utilization of these materials. For the understanding the impact of cement replacement with these materials on strength of concrete, three major mechanical properties were to be tested that are explained as under:

2.3.1. Compressive Strength

The 7, 28 days of curing led to the compressive strength of concrete (ASTM C 39) using burnt clay pozzolana at 10% by weight in place of cement to be effectively greater than the normal compressive strength achieved by ordinary concrete. While in all other cases, the compressive strength of concrete using metamorphosed limestone powder, burnt clay pozzolana, and wood ash at different proportions (5, 10, 15 and 20%) by the weight as a replacement of cement that was lesser than the effective compressive strength of normal concrete.

Compressive strength is evaluated by using the following formula:

$$\text{Compressive Strength (MPa)} = P/A, \qquad (1)$$

Where,
P = compressive load at failure (N)
A = cross-sectional area of cylinder, (mm^2)

2.3.2. Tensile Strength

The 7- and 28-days tensile strength of concrete (ASTM C 496) using burnt clay pozzolana at 10% by weight in place of cement was greater than the tensile strength of normal concrete. While in all other cases, the effective tensile strength of modified concrete using metamorphosed limestone powder, burnt clay pozzolana, and wood ash at different proportions (5%, 10%, 15%, and 20%) by weight in place of cement was lesser than the tensile strength of normal concrete. In general, the tensile strength of the cylinder is 10% of its compressive strength.

The effective tensile strength of concrete can be evaluated by the following formula:

$$\text{Tensile Strength (MPa)} = 2P/\pi DL, \qquad (2)$$

Where,
P = compressive load at failure (N)
L = length of the cylinder (mm)
D = diameter of the cylinder (mm)

2.3.3. Flexural Strength

The flexural strength of concrete(ASTM C 78) using metamorphosed limestone powder, burnt clay pozzolana, and wood ash was higher than flexural strength of normal concrete when cement is replaced by weight up to 15% and the flexural strength was reduced by adding further metamorphosed limestone powder, burnt clay pozzolana and wood ash.

The flexural strength is computed by the following formula:

$$\text{Flexural Strength (MPa)} = 3Pl/bd^2, \qquad (3)$$

Where,
P = total load at failure point (N)
l = effective beam span between supports (mm)
b = total width of beam (mm), d = measured depth of beam

Flexural strength can also be computed as:

$$\text{flexural strength (MPa)} = 0.7\sqrt{fc'}, \quad (4)$$

3. RESULTS:

3.1. Performance Analysis

In the current effectively conducted evaluation of mechanical properties the maximum compressive strength is achieved at 7 days for 10% replacement level of burnt clay pozzolana with cement so this is considered as optimum replacement level and the optimum gained strength is 13.50 MPa after 10% replacement while the compressive strength of specimen at control mix i.e. 0% replacement level was 12.26 MPa. For effective compressive strength of the cylinder specimen at 28 days, the maximum strength is achieved for 10% replacement level of burnt clay pozzolana with cement so this is considered as optimum replacement level and the optimum gained strength was 18.21 MPa after 10% replacement while the compressive strength of specimen at control mix i.e. 0% replacement level was 15.91 MPa as shown in Fig.1. In case of the tensile strength of cylinder specimens cured at 7 days, we have the strength of 1.165 MPa at the control mix i.e. 0 % replacement level while the maximum tensile strength was 1.25 MPa at 10% replacement level of burnt clay pozzolana. For the tensile strength of cylinder specimens cured at 28 days, we have the strength of 1.58 MPa at the control mix i.e. 0 % replacement level while the maximum tensile strength was 1.67 MPa at 10% replacement level of burnt clay pozzolana as shown in Fig.2. For the flexural strength of beams, the maximum 7 days strength was achieved for 5% replacement level of burnt clay pozzolana with cement which is 3.36 MPa while the flexural strength of beam specimen at control mix i.e. 0% replacement level was 2.62 MPa. For the effective flexural strength parameter of casted beams at 28 days of curing, the maximum strength was achieved for 5% replacement level of metamorphosed limestone powder with cement which was 4.58 MPa while the flexural strength of beam specimen at control mix i.e. 0% replacement level was 3.38 MPa as shown in Fig.3.

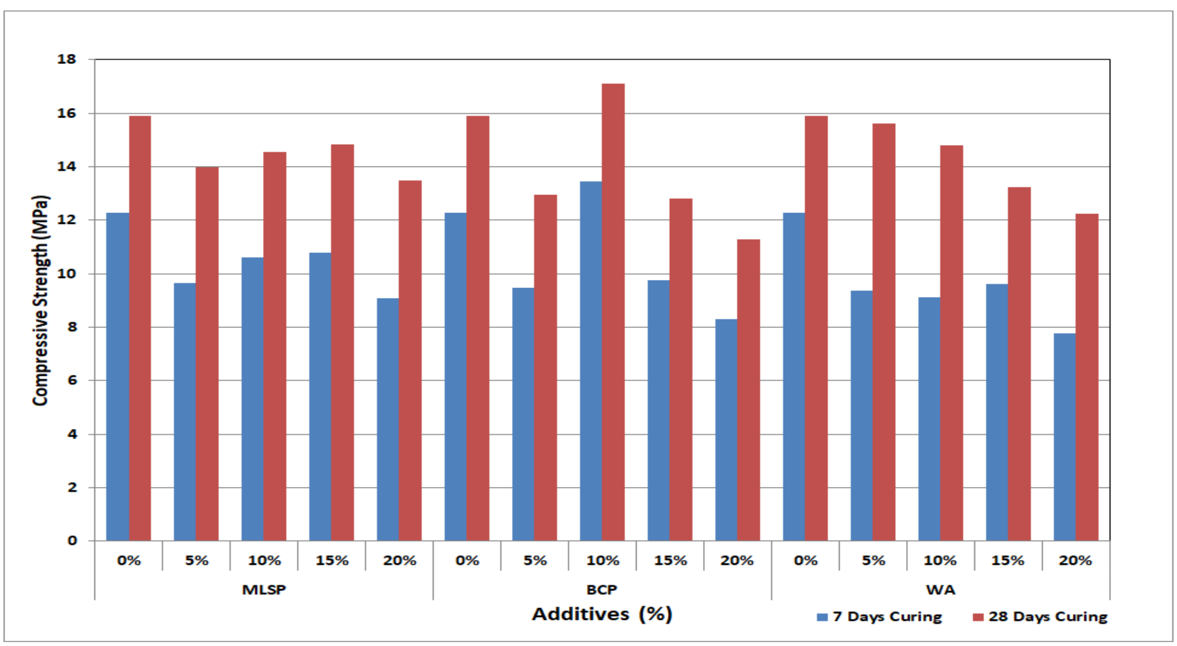
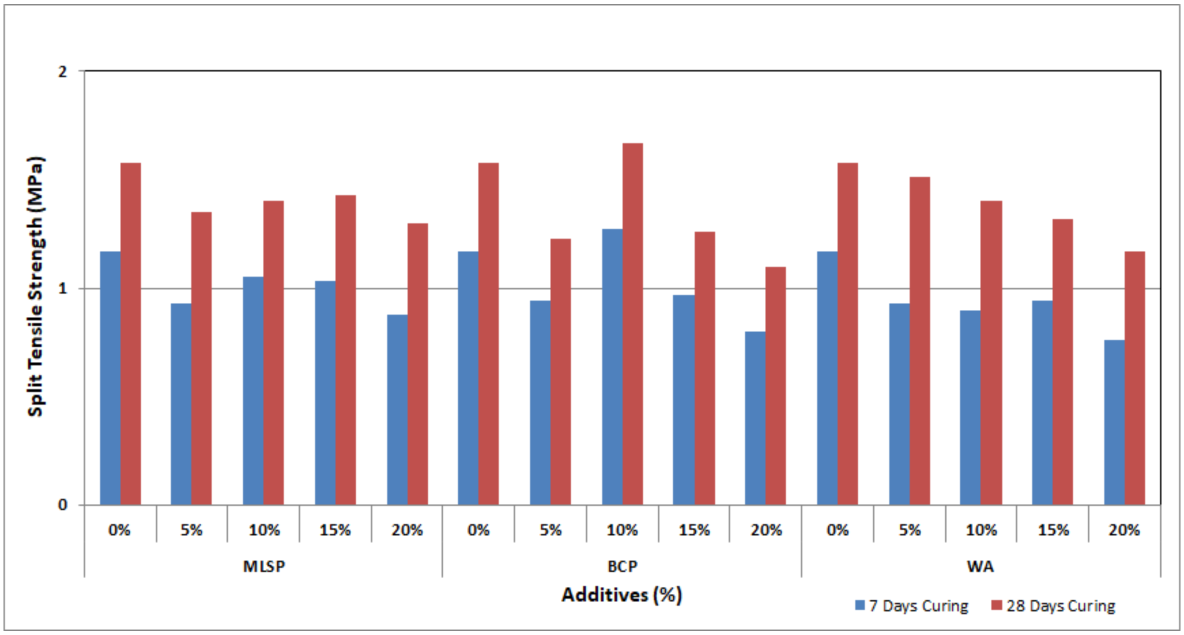


Figure 1. Compressive strength of Concrete Cylinder (MPa) under 7 days and 28 days



curing

Figure 2. Tensile strength of concrete cylinder (MPa) under 7 days and 28 days curing

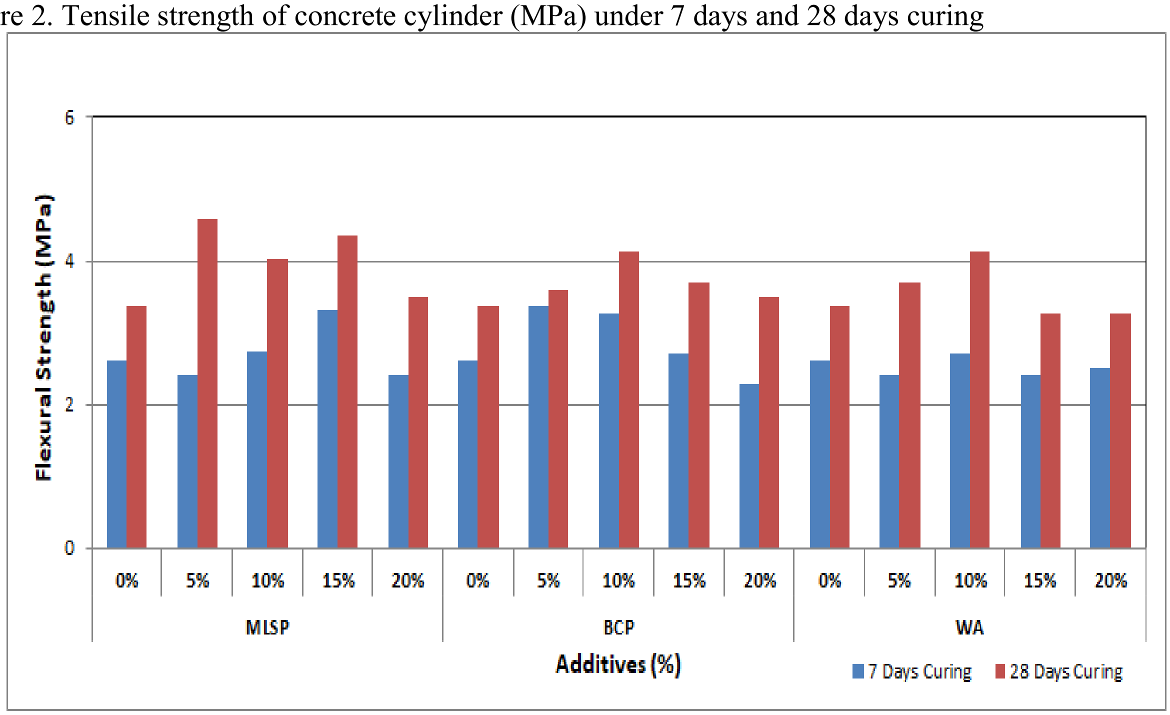
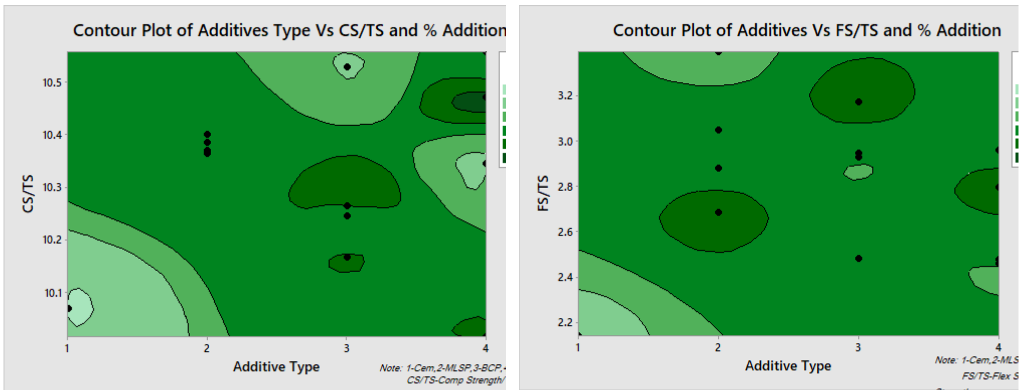


Figure 1. Flexural strength of concrete cylinder (MPa) under 7 days and 28 days curing

3.2 Analysis of Factors

During the analysis major focus was to find the replacement material for cement as it is a costly material and need manufacturing process while industrial wastes are the available raw materials. To investigate the impact of the change of additive and replacing it with cement needs further confirmation before deciding about the commercial use of the additives. To further deep analysis a relationship has been built via contour plots which are basically between ratios. Compressive/Tensile strength ratios and Flexural/Tensile strength ratio have been plotted against the types of additives. From Plot (Fig.4.a) we can observe that the highest strengths are with cement, but only dominant replacement is additive 3 (i.e. BCP) is true alternative. Similarly, in Plot (Fig.4.b) again clear dominance can be observed by additive 3(i.e. BCP).



(a) **(b)**

Figure 4. Contour Plot: (a) Comp/Tens Vs Type of Additives (b) Flex/Tens Vs Type of Additives

4. CONCLUSIONS:

Concrete is one of the most used materials in construction industry comprises of cement, sand, aggregates, and water as major ingredients. For centuries it is under discussion that what are the major influencing factors which contributing the strength of concrete. Research has started by testing its mechanical to physical properties and later fresh and hardened properties. Sometimes it tends to physics and everything is led by forces and revolving terms are stress and strain. Sometimes it starts with chemistry like chemical reactions. In this research focal point is a replacement is of cement as from all ingredients cement is one of the costly items and need an industrial production. Cement has been tested by incorporating it in the concrete ineffective combinations of replacements ranging from 0, 5, 10, 15 and 20% of used cement by metamorphosed limestone powder (MLP), burnt clay pozzolana (BCP), and wood ash (WA). These three materials are usually considered industrial waste are available at a lower cost than that of cement. For effective compressive strength of the cylinder specimen at 28 days, the maximum strength is achieved for 10% replacement level of burnt clay pozzolana (BCP) with cement so this is considered as optimum replacement level and the optimum gained strength was 18.21 MPa after 10% replacement while the compressive strength of specimen at control mix i.e. 0% replacement level was 15.91 MPa. For the tensile strength of cylinder specimens cured at 28 days, we have the strength of 1.58 MPa at the control mix i.e. 0 % replacement level while the maximum tensile strength was 1.67 MPa at 10% replacement level of BCP. For the effective flexural strength parameter of casted beams at 28 days of curing, the maximum strength was achieved for 5% replacement level of MLP with cement which was 4.58 MPa while the flexural strength of beam specimen at control mix i.e. 0% replacement level was 3.38 MPa. Although the highest strengths are with cement, only dominant replacement is MLP but BCP was found satisfactory in all three-test condition. This study can help in the construction of concrete structure like rigid pavements which are saved and need rough construction pattern. In case of 100 km of long road a large quantity of cement can be saved by applying 15% replacement of cement with MLP or 10% replacement of cement with BCP. It can be successful as loading conditions for rigid pavement roads are different than that of building and structures.

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REFERENCES:

Agarwal, S. (2006). Pozzolanic activity of various siliceous materials. *Cement and Concrete research, 36*(9), 1735-1739.

Aliabdo, A. A., Elmoaty, A. E. M. A., & AbdElbaset, M. M. (2015). Utilization of waste rubber in non-structural applications. *Construction and Building Materials, 91*, 195-207.

Aliabdo, A. A., Elmoaty, A. E. M. A., & Auda, E. M. (2014). Re-use of waste marble dust in the production of cement and concrete. *Construction and Building Materials, 50*, 28-41.

Almusallam, A. A., Beshr, H., Maslehuddin, M., & Al-Amoudi, O. S. (2004). Effect of silica fume on the mechanical properties of low quality coarse aggregate concrete. *Cement and concrete composites, 26*(7), 891-900.

Cheah, C. B., & Ramli, M. (2011). The implementation of wood waste ash as a partial cement replacement material in the production of structural grade concrete and mortar: An overview. *Resources, conservation and Recycling, 55*(7), 669-685.

Coo, M., & Pheeraphan, T. (2015). Effect of sand, fly ash, and coarse aggregate gradation on preplaced aggregate concrete studied through factorial design. *Construction and Building Materials, 93*, 812-821.

Ergün, A. (2011). Effects of the usage of diatomite and waste marble powder as partial replacement of cement on the mechanical properties of concrete. *Construction and Building Materials, 25*(2), 806-812.

Kiran, M. K., & Sharma, M. A. (2017). An Experimental Study on Partial Replacement of Cement With Brick Dust (Surkhi) In Concrete. *Journal of Civil and Construction Engineering, 3*(3).

Krishnasamy, T. R., & Palanisamy, M. (2014). Bagasse ash and rice husk ash as cement replacement in self-compacting concrete. *Gradevinar, 67*(1), 23-30.

Mansoor, J., Shah, S. A. R., Khan, M. M., Sadiq, A. N., Anwar, M. K., Siddiq, M. U., & Ahmad, H. (2018). Analysis of Mechanical Properties of Self Compacted Concrete by Partial Replacement of Cement with Industrial Wastes under Elevated Temperature. *Applied Sciences, 8*(3), 364.

Mohamed, H. A. (2011). Effect of fly ash and silica fume on compressive strength of self-compacting concrete under different curing conditions. *Ain Shams Engineering Journal, 2*(2), 79-86.

Omar, O. M., Elhameed, G. D. A., Sherif, M. A., & Mohamadien, H. A. (2012). Influence of limestone waste as partial replacement material for sand and marble powder in concrete properties. *HBRC Journal, 8*(3), 193-203.

Puri, M., & Srinivasan, N. (1959). *Effect of partial replacement of cement with Surkhi on various properties of pavement concrete*: Central Road Research Institute.

Ranjan, A., Srivastava, V., & Kumar, R. (2015). Effect of Fly Ash Replacement with Surkhi on Workability of Self-compacting Concrete. *Journal of Academia and Industrial Research (JAIR), 4*(1), 40.

Shirule, P., Rahman, A., & Gupta, R. D. (2012). Partial replacement of cement with marble dust powder. *International Journal of Advanced Engineering Research and Studies, 1*(3), 175-177.

Siddique, R. (2007). *Waste materials and by-products in concrete*. Berlin: Springer Science & Business Media.

Siddique, R. (2012). Utilization of wood ash in concrete manufacturing. *Resources, conservation and Recycling, 67*, 27-33.

Siddique, R., & Klaus, J. (2009). Influence of metakaolin on the properties of mortar and concrete: A review. *Applied Clay Science, 43*(3-4), 392-400.

Torkaman, J., Ashori, A., & Momtazi, A. S. (2014). Using wood fiber waste, rice husk ash, and limestone powder waste as cement replacement materials for lightweight concrete blocks. *Construction and Building Materials, 50*, 432-436.

Turk, K., Karatas, M., & Gonen, T. (2013). Effect of fly ash and silica fume on compressive strength, sorptivity and carbonation of SCC. *KSCE Journal of Civil Engineering, 17*(1), 202-209.

Vardhan, K., Goyal, S., Siddique, R., & Singh, M. (2015). Mechanical properties and microstructural analysis of cement mortar incorporating marble powder as partial replacement of cement. *Construction and Building Materials, 96*, 615-621.