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Research Article

Effect of metakaolin and steel slag on performance of binary blended concrete

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Abstract

In this study the effect of steel slag and metakaolin as replacement material to cement on strength and durability of binary blended concrete has been investigated. In concrete cement is the very significant material and serves as a binder. The combined effect metakaolin and steel slag as replacement to cement on concrete performance has been studied. The cement has been replaced with metakaolin and steel slag by 30% by weight of cement. For obtaining optimum dosage of metakaolin and steel slag different proportions are added as substitutionary material of cement. The compressive strength, flexural strength, electrical resistivity, and water absorptions tests are conducted to study the effect of replacement on strength and durability of concrete. There is a maximum of 25% enhancement in compressive strength of concrete has been observed in binary concrete containing 15% of steel slag and 15% of metakaolin in comparison with control concrete. Results confirm that the addition of steel slag and metakaolin in binary blended concrete enhances the concrete performance. Also, regression analysis has been performed to predict the compressive strength of concrete. The developed model will predict the compressive strength results accurately with minimum error.

1. Introduction

Concrete is the most highly consumable material in the world due to its high strength and durability. In concrete mix cement works as a binder. The manufacturing of cement releases huge amounts of global warming gasses into the atmosphere [1]. The greenhouse effect is today's most significant environmental concern, because it is inextricably linked to global warming. Global warming is now developing at a pace that might have severe and permanent implications if prompt actions to ameliorate the situation are not done [2]. There is a one ton of CO_2 is releasing into the atmosphere for every one ton of cement manufacturing [3]. As a result, the use of supplementary cementitious materials (SCMs) as substitute for cement becomes an option for developing low carbon footprint binder systems [4][5][6]. The supplementary binder materials like steel slag, metakaolin, fly-ash, rice husk ash, and ground granulated blast furnace slag (GGBS) are extensively utilized in concrete as a partial alternative to cement [7][8]. The steel slag and GGBS are by-products from the steel industries. GGBS is the slag formed at a blast furnace during the pig iron production process. Steel slag is the slag generated at a steel melting shop. In recent years, SCMs and their application in blended concrete have attracted the curiosity of people all over the globe to reduce carbon emissions while also improving the overall performance of concrete [9][1]. The addition of SCMs to concrete mixture to generate blended concrete mixes may increase the concrete characteristics. The addition 10% of metakaolin substitutionary material to

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cement improves the compressive strength by 21% as comparison to control mix [10]. The addition of steel slag also enhances the performance concrete [11]. Similarly, the addition of GGBS, silica fume, fly ash, and rice husk ash also improves the strength and durability of concrete [12][13][14]. The addition fly-ash and metakaolin as substitutionary material to cement enhances the performance of concrete [15]. The addition of 10% of fly-ash and 10% of rice husk ash as substitutionary material to cement shows optimum enhancement in strength of concrete as compared to control mix [16]. However, the utilization of these SCMs in concrete has negative effects also. The addition fly-ash or steel slag in concrete shows lower early strength results. The addition of metakaolin more than 30% reduces the strength of concrete [17]. In this research an endeavour has been made to examine the performance of binary mixed concrete including steel slag and metakaolin. The steel slag shows low early strength results and metakaolin is a highly reactive material and provides high early strength to concrete [18][19]. The main aim of the study is to achieve best binary mix by combining steel slag and metakaolin. The response surface method has been utilized to predict and optimize the compressive strength results of binary blended concrete. The response surface method shows there is a good agreement between experimental and predicted compressive strength results. The blending of these two materials as replacement to cement improves the concrete performance in initial and final stage.

2. Materials and Methods

2.1. Materials

Ordinary Portland cement (43 Grade) has been utilized in this study having a specific gravity of 3.1, and cement has been tested as for Indian Standards IS: 4031-1988. The coarse aggregate with a size smaller than 20 mm and fine aggregate confirming to Zone II were employed, with specific gravity values of 2.78 and 2.65 respectively, in accordance with IS: 383-1970. Normal portable water available in the lab has been used for preparation of concrete. Metakaolin used in this study was procured from the ASTRRA chemicals, chennai and used in this study. The procured metakaolin has a specific gravity of 2.5 and used in its current form. The steel slag used in this was procured from the emami cement limited and has a specific gravity of 2.9. The elemental composition of metakaolin and steel alag are listed in Table 1.

Table 1. Elemental composition of Metakaolin and steel slag using EDX analysis

Elements	Metakaolin (Weight %)	Steel Slag (Weight %)
Si	61.47	24.28
Mg	0.05	3.67
Al	17.55	4.49
Ca	0.15	2.46
Fe	0.32	14.52
O	20.46	50.58

2.2. Concrete Mix Design

Concrete mix design has been done according IS 10262-2009 [11]. The detailed mix proportions per cubic meter are given in Table 2. The word C100 refers to control mix. The aggregates, lime, fly-ash, steel slag, and sand are added into the pan mixer and mixed for 2 minutes. For proper mixing, half quantity water and chemical admixture were added to concrete and it was mixed thoroughly for 2 minutes. The remaining quantity of water and chemical admixture were added and concrete was mixed for 2 to 4 minutes up to getting uniform colour and homogeneous mix. The fly-ash and steel slag are pozzolanic materials they can react with $Ca(OH)_2$ during hydration process of cement and liberates C-S-H gel. This improves the strength and durability of concrete. To avail the sufficient amount of $Ca(OH)_2$ in concrete matrix the dosage of alternative materials are limited to 30%.

Table 2. Mix details of concrete per cubic meter

Mix Details	Metakaol in (%)	Steel slag (%)	Cement (kg/m3)	Metakaolin (kg/m3)	Steel slag (kg/m3)
C100	0	0	507	0	0
MK5SS25	5	25	354	26	127
MK10SS20	10	20	354	51	102
MK15SS15	15	15	354	76	76
MK20SS10	20	10	354	102	51
MK25SS5	25	5	354	127	26

Table 2(Con). Mix details of concrete per cubic meter

Mix Details	Sand (kg/m3)	20mm (kg/m3)	10mm (kg/m3)	Water (kg/m3)	Super Plasticizer (kg/m3)
C100	607.28	732	487	152.1	6.08
MK5SS25	603	726	484	152.1	6.08
MK10SS20	601	736	490	152.1	6.08
MK15SS15	601	724	482	152.1	6.08
MK20SS10	604	727	484	152.1	6.08
MK25SS5	598	721	488	152.1	6.08

2.3. Testing Methods

The fresh concrete property such as workability of concrete has been measured using slump cone test. The slump cone test has been performed immediately after mixing of concrete as per IS: 1199 – 2004 [20]. The cube specimens having size of 100 x 100 x 100 mm are casted after testing of the slump cone test and these cubes are used for compressive strength test. The test has been performed to 7 days and 28 days water cured samples on triplicate as per IS: 516-1959 standards [21]. The testing arrangement for compressive strength test is shown in Fig. 1.

The concrete beam specimens of size 100 x 100 x 500 mm was used for evaluate the flexural strength of concrete. The beams are tested on 7 days and 28 days curing on triplicate. The test has been performed as per the IS: 516-1959 standards [21]. The arrangement for flexural strength set up is shown in Fig. 2.

Fig.1 Testing arrangement for compressive strength test for concrete

Fig. 2 Arrangement for flexural strength test for concrete beams

A Leader RCONTM Concrete Electrical Resistivity Meter was used for measuring the concrete electrical resistance. For this study, 100 x 100 x 100 mm cubes were used. The test has been performed on 7 and 28 days cured samples on triplicate. The test has been performed as per ASTM C 1202 standards [22]. The test was performed on saturated cube in these the pores of concrete are filled with water. The testing arrangement of electrical resistivity meter as shown in Fig. 3.

One of the primary aspects of concrete durability is permeability. Concrete with decreased permeability exhibited better protection against chemical attacks. Generally the high durable concrete has lower permeability test results [23]. In this investigation, a water absorption test was carried out to know the durability of concrete. The test was carried out in triplicate on 28-day-cured concrete cubes measuring 100 x 100 x 100 mm in accordance with ASTM C 642-13 criteria [24].

3. Results and Discussion

3.1. Workability

The Fig. 4 depicts the slump cone test results. From Fig.4 it is noticed that the addition of 15% of metakaolin and 15% of steel slag considerably improves the workability in comparison with control mix. There is a maximum of 27% improvement in slump values has been observed in concrete mix MK15SS15 in comparison with control mix. The addition of 5% metakaolin and 25% of steel slag shows 6% improvement in the slump values in comparison with control mix. The addition of 10% of metakaolin and 20% of steel slag shows 13.5% improvement in slump values of concrete as compared to control mix. Similarly, the concrete mix with 25% of metakaolin and 5% of steel slag shows 8% improvement in slump values of concrete in comparison with control mix. The addition of higher dosages of steel slag diminishes the workability. As the dosages of steel slag reduces the workability of concrete increases. On the other side the addition of metakaolin up to 15% enhances the workability of concrete. The binary concrete mix containing 15% of metakaolin and 15% of steel slag are optimum for improving the workability. The addition of steel slag improves cohesiveness and reduces the water demand in concrete thus the workability of concrete enhances [25]. While the increase in the dosage of metakaolin reduces the workability of concrete due to smaller particle size increases the water demand in concrete.

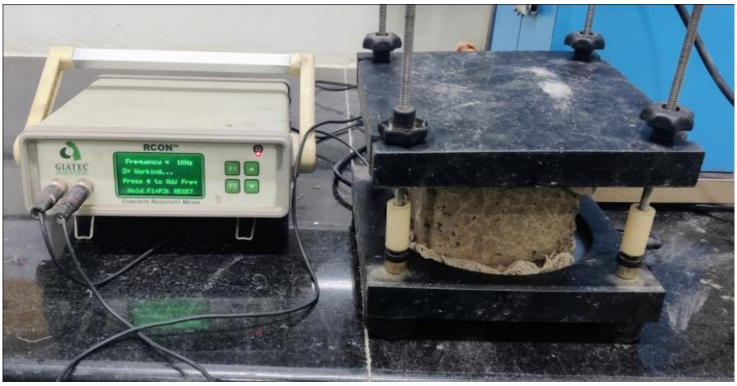


Fig. 3 Set up for measuring electrical resistivity of concrete

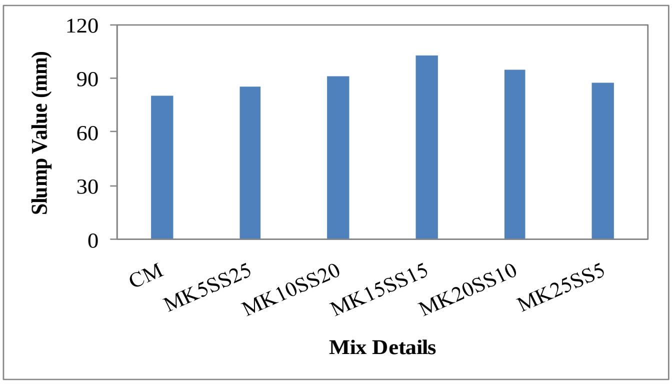


Fig. 4 Slump cone test results of various concrete mixes

3.2. Compressive Strength

The Fig. 5 depicts the compressive strength test results of various concrete mixes. From the Fig.5 it is observed that the addition of 15% of metakaolin and 15% of steel slag shows optimum improvement in compressive strength in comparison with control concrete. A 25.5% optimum enhancement in compressive strength has been noticed in mix MK15SS15 in comparison with control mix. The addition of higher dosages of steel slag diminishes the strength. The addition of metakaolin up to 15% enhances the strength in comparison with control concrete. The metakaolin is a high reactive pozzolanic material due to its higher surface area. As a result, the strength of concrete improves. From the mix MK20SS10 and MK25SS5 it is noticed that the addition of metakaolin more than 15% slightly diminishes the compressive strength. At higher dosages of metakaolin weakness the interfacial transition zone (ITZ) of concrete by forming micro-cracks due to availability of high specific surface area [26]. From the Fig.5 it is also observed that the addition of steel slag at higher concentrations reduces the compressive strength. From the mix MK5SS25, MK10SS20, and MK15SS15 it is noticed that the reduction in the dosages of steel slag increases the compressive strength. The addition of steel slag in concrete shows very little pozzolanic activity thus strength improvement is very little by the addition of steel as substitutionary material to cement [27]. The addition of steel slag up to 10.5% as replacement to cement did not negatively effect the its properties [28]. The binary concrete mixes have an advantage of higher utilization of steel slag in concrete. The mix MK5SS25 shows higher strength results than control mix. The addition of steel slag in concrete causes the reduction in cement content in concrete which is an effective to minimize environmental impacts without increasing the cost.

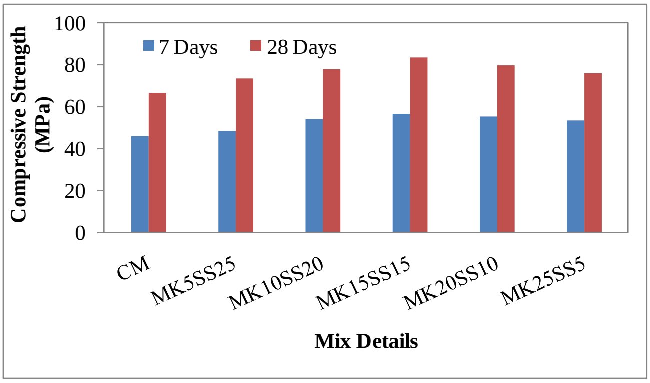


Fig. 5 Compressive strength test results of various concrete mixes

3.3. Flexural Strength

The Fig. 6 depicts the flexural strength test results of various concrete mixtures. The mix containing 15% of metakaolin and 15% of steel slag shows optimum percentage enhancement in flexural strength. An optimum improvement of 25% enhancement in flexural strength is observed for the mix MK15SS15 in comparison to control mix at an age of 28 days. The mix MK5SS25 shows 6% and 9% enhancement in flexural strength in comparison to control mix at an age of 7 and 28 days. The mix MK10SS20 shows 13.6% and 16.9% enhancement in flexural strength in comparison to control mix for 7 and 18 days cured samples. The mix MK20SS10 and MK25SS5 shows reduction in strength as compared to the mix MK15SS15. The addition of higher dosages of metakaolin reduces the flexural strength. In the same lines the addition of higher dosages of steel slag also diminishes the flexural strength. The binary mix containing 15% of steel slag and 15% of metakaolin shows optimum strength improvement in 7 and 28 days respectively. The metakaolin has high pozzolanic reactivity and thus enhances the strength of concrete. Steel slag has lower pozzolanic reactivity due to this very less improvement has been noticed in flexural strength of concrete.

3.4. Electrical Resistivity of Concrete

The Fig. 7 depicts the electrical resistivity test results of various concrete mixes. From the Fig. 7 it is seen that the inclusion of steel slag and metakaolin in concrete as replacement material to cement raises the electrical resistivity. The mix MK15SS15 shows the optimum improvement in electrical resistivity. The mix MK15SS15 shows an electrical resistivity of 18.5 kΩ-cm and 29 kΩ-cm at an age of 7 and 28 days. While the control mix shows an electrical resistivity of 11.9 kΩ-cm and 13.9 kΩ-cm at an age of 7 and 28 days. The mix MK20SS10 and MK25SS5 shows enhanced electrical resistivity test results than control mix. The mix MK20SS10 and MK25SS5 shows reduction in electrical resistivity in comparison to the mix MK15SS15. The electrical resistivity of concrete is influenced by its micro-structure characteristics, pores, and micro-cracks. The inclusion of metakaolin to concrete promotes the development of secondary C-S-H. It improves the micro-structure of concrete as a result increases its electrical resistance. Parande et al. [29] shown that inclusion of metakaolin up to 15% in concrete enhances the electrical resistivity. The steel slag has low pozzolanic reactivity and shows reduction in electrical resistivity as dosages of steel slag increases. The steel slag works as a filler material and minimizes the pores in concrete if we add minimum amount. The binary blend containing 15% of steel slag and 15% of metakaolin shows optimum improvement in electrical resistivity. The 15% of metakaolin and 15% of steel slag provides sufficient amount of secondary C-S-H also improves the denseness of concrete by minimizing the pores in concrete matrix. The SEM test results also confirm the dense structure in mix MK15SS15. Due to having dense structure and less micro-cracks the electrical resistivity of the mix MK15SS15 is very high as compared to other mixes.

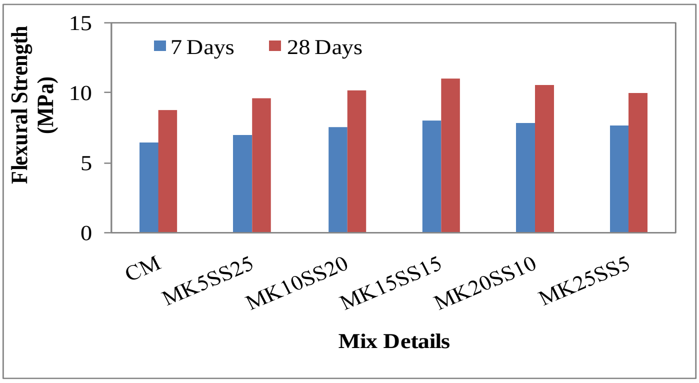


Fig. 6 Flexural strength test results of various concrete mixes

3.5. Water Absorption

The Fig. 8 displays the test results of several concrete mixes. From the Fig.8 it is observed that the mix MK15SS15 shows optimum reduction in water absorption. There is a 43.4% diminution in water absorption is noticed for the mix MK15SS15 in comparison with control concrete. The mix MK5SS25 and MK10SS20 shows decrease in water absorption test results in comparison to control concrete. The mixes MMK20SS10 and MK25SS5 shows less reduction in water absorption as compared to the mix MK15SS15. The test results confirm that the mix MK15SS15 is a high durable concrete mix as compared to other concrete mixes. The mix MK15SS15 shows better compressive and flexural strength test results. It confirms that the mix MK15SS15 is having very dense structure and less voids and pores. Because of this the water absorption is very less in the mix MK15SS15.

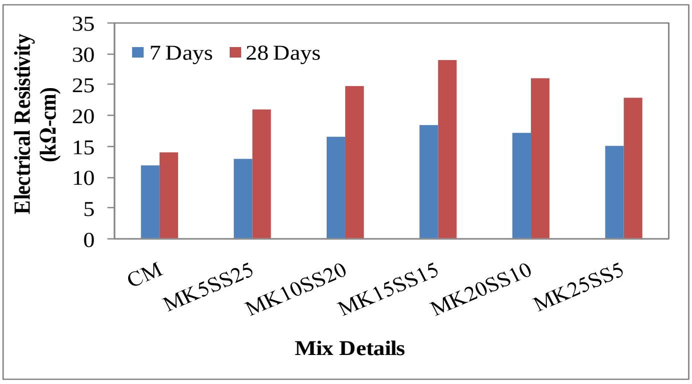


Fig. 7 Electrical resistivity test results of various concrete mixes

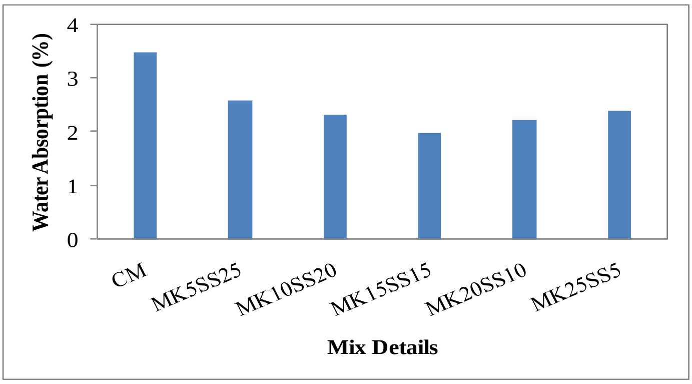


Fig. 8 Water absorption test results of different concrete mixes

3.6. Scanning Electron Microscope

A high-resolution scanning electron microscope (SEM) was utilised to examine the sample's micro-structure. The 28 days cured concrete samples are utilized for this study. The cubes of size 10 x 10 x 10 mm were prepared from the broken pieces. These samples were coated with gold in a sputter coater for SEM observation in order to produce good SEM images. The testing was done on ZEISS SEM machine. The Fig.9 shows the SEM images of control concrete and the mix MK15SS15 for 28 days cured samples. The micro-structure of MK15SS15 seems to be more homogeneous and compact than the control mix in Fig.9. The presence needle type crystal ettringite is observed in control mix. The inclusion of 15% metakaolin and 15% steel slag as a cement replacement resulted in the decrease of needle-like crystals of ettringite and the formation of fibrous calcium silicate hydrates and calcium alumina silicate hydrates. As a result strength and durability of concrete enhances.

3.7. Regression Analysis

The Multi-variable regression analysis may be used to determine the optimal amount of cement replacement in binary blended mixtures [30]. A multi-variable regression analysis was used in this work to investigate the effect of substituting cement with varying quantities of steel slag and metakaolin on the compressive strength of concrete, and a model was constructed for it. The dosage of metakaolin (x_1), dosage of steel slag (x_2), and age of the concrete (x_3) are considered as the input parameters and the compressive strength is being the output parameter. Regression analysis yielded the following first-order multi-linear response surface model:

$$Y= 2027-66x_1-66x_2+1.427x_3 \quad (1)$$

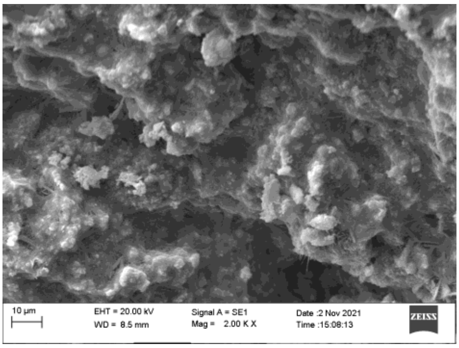
where;

Y = Compressive strength of concrete (MPa)

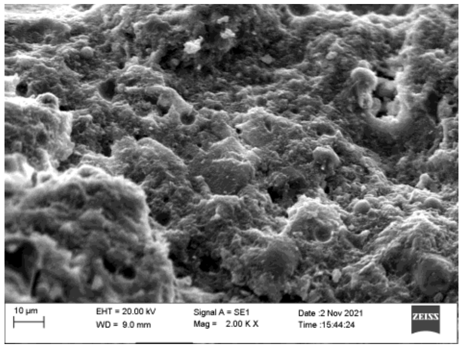
x_1 = Dosage of metakaolin (%)

x_2 = Dosage of steel slag (%)

x_3 = Age of concrete (Days)



(a)



(b)

Fig.9 SEM test results of (a) Control mix (b) MK15SS15 mix

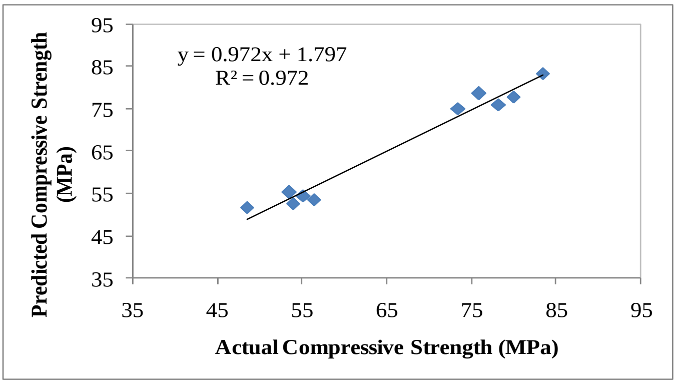


Fig. 10 The actual and predicted compressive strength results

The Fig. 10 depicts the actual and predicted compressive strength values. The smaller the magnitude of error between anticipated and experimental values, the more often the normality assumption is met. It should be emphasised, however, that regression equations are particular to the variables and their features, and so cannot be generalised, but are highly effective in predicting the outcome from a given response. From Fig.10 the disparity in total variance is just 0.028 percent, the created model's coefficient of determination (R^2 = 0.972) demonstrates that it falls within a permissible error range. Considering the R^2 value of the developed model it is a good fit model.

4. Conclusions

The effect of steel slag and metakaolin on concrete performance has been studied. The increase in the dosage of steel slag increases the workability of concrete. While the increase in the dosage of metakaolin diminishes the workability of concrete. The combination of 15% of metakaolin and 15% of steel slag shows optimum workability results. The addition 15% of steel slag and 15% metakaolin shows optimum development in strength and durability of concrete also. There is a maximum of 25% enhancement in compressive strength of concrete has been noticed in the mix MK15SS15 in comparison to control mix. The durability of concrete also considerably improved. This was confirmed by the electrical resistivity and water absorption tests. The SEM test results also confirm the improvement in micro-structure of concrete. The addition of 20% of metakaolin and 10% of steel slag diminishes the strength of concrete as compared to the mix MK15SS15. Similar trend has been followed in the mix MK25SS5 also. The addition of higher dosages of metakaolin weakness the ITZ of the matrix and diminishes the strength of concrete. The higher dosage of steel slag also diminishes the strength of concrete due to its less pozzolanic activity. The electrical resistivity and water absorption test results also confirm that the mixes MK20SS10 and MK25SS5 are less durable as compared to the mix MK15SS15. Regression analysis has been used to develop a model for predicting the compressive strength. The model's coefficient of determination R2 = 0.972 value confirms it is a good fit model. The results confirm that the developed regression equation will predict the compressive strength results accurately with minimum error. The test results suggest that the addition of 15% of metakaolin and 15% of steel slag as substitutionary material to cement are optimum for enhancing the workability, strength, and durability of concrete.

References

[1] Palod R, Deo SV, Ramtekkar GD. Effect on mechanical performance, early age shrinkage and electrical resistivity of ternary blended concrete containing blast furnace slag and steel slag. Mater. Today Proc., 2020; 32:4 917-922. https://doi.org/10.1016/j.matpr.2020.04.747

[2] Padavala AB, Potharaju M, Kode VR. Mechanical properties of ternary blended mix concrete of fly ash and silica fume. Mater. Today Proc., 2021; 43: 2198-2202. https://doi.org/10.1016/j.matpr.2020.12.127

[3] Chee C, Kok C, Ramli M, Gin L. The engineering properties and microstructure development of cement mortar containing high volume of inter-grinded GGBS and PFA cured at ambient temperature. Constr. Build. Mater., 2016; 122: 683-693. https://doi.org/10.1016/j.conbuildmat.2016.06.105

[4] Ouldkhaoua Y, Benabed B, Abousnina R, Kadri E, Khatib J. Effect of using metakaolin as supplementary cementitious material and recycled CRT funnel glass as fine aggregate on the durability of green self-compacting concrete. Constr. Build. Mater., 2020; 235: 117802. https://doi.org/10.1016/j.conbuildmat.2019.117802

[5] Vijay K, Babu KH, Indrasena YV. Effect of Wood-Ash as Partial Replacement to Cement on Performance of Concrete Effect of Wood-Ash as Partial Replacement to Cement on Performance of Concrete. IOP Conf. Ser. Earth Environ. Sci. Pap., 2021; 796:1 1-6. https://doi.org/10.1088/1755-1315/796/1/012020

[6] Gencel O, Karadag O, Hulusi O, Bilir T. Steel slag and its applications in cement and concrete technology: A review. Constr. Build. Mater., 2021; 283: 122783. https://doi.org/10.1016/j.conbuildmat.2021.122783

[7] Duchesne J. Alternative supplementary cementitious materials for sustainable concrete structures: a review on characterization and properties. Waste and Biomass Valorization, 2021; 12:3 1219-1236. https://doi.org/10.1007/s12649-020-01068-4

[8] Pacewska B, Wilińska I. Usage of supplementary cementitious materials: advantages and limitations. J. Therm. Anal. Calorim., 2020; 142:1 371-393. https://doi.org/10.1007/s10973-020-09907-1

[9] Sern LJ, Cheah CB, Ramli MB. The setting behavior, mechanical properties and drying shrinkage of ternary blended concrete containing granite quarry dust and processed steel slag aggregate. Constr. Build. Mater., 2019; 215: 447-461. https://doi.org/10.1016/j.conbuildmat.2019.04.162

[10] Poon CS, Kou SC, Lam L. Compressive strength, chloride diffusivity and pore structure of high performance metakaolin and silica fume concrete. Constr. Build. Mater., 2006; 20: 858-865. https://doi.org/10.1016/j.conbuildmat.2005.07.001

[11] Jiang Y, Ling T, Shi C, Pan S. Characteristics of steel slags and their use in cement and concrete - A review. Resour. Conserv. Recycl., 2018; 136: 187-197. https://doi.org/10.1016/j.resconrec.2018.04.023

[12] Ofuyatan OM, Adeniyi AG, Joshua O. Evaluation of fresh and hardened properties of blended silica fume self-compacting concrete (SCC). Res. Eng. Struct. Mater., 2021; 7:2 211-223. https://doi.org/10.17515/resm2020.228ma1023

[13] Li G, Tan H, He X, Zhang J, Deng X, Zheng Z, Guo Y. G. Li et al., The influence of wet ground fly ash on the performance of foamed concrete. Constr. Build. Mater., 2021; 304: 124676. https://doi.org/10.1016/j.conbuildmat.2021.124676

[14] Vishvanath N, Deo SV, Murmu M. Effect of Fly Ash and Rice Husk Ash as Partial Replacement of Cement on Packing Density and Properties of Cement. Int. J. Innov. Technol. Explor. Eng., 2019; 8:7 1940-1945.

[15] Moser RD, Jayapalan AR, Garas VY, Kurtis KE. Cement and Concrete Research Assessment of binary and ternary blends of metakaolin and Class C fl y ash for alkali-silica reaction mitigation in concrete. Cem. Concr. Res., 2010; 40:12 1664-1672. https://doi.org/10.1016/j.cemconres.2010.08.006

[16] Kanthe VN, Deo SV, Murmu M. Effect of fly ash and rice husk ash on strength and durability of binary and ternary blend cement mortar. Asian J. Civ. Eng., 2018; 6: 1-8. https://doi.org/10.1007/s42107-018-0076-6

[17] Homayoonmehr R, Akbar A, Mirdarsoltany M. Influence of metakaolin on fresh properties, mechanical properties and corrosion resistance of concrete and its sustainability issues : A review. J. Build. Eng., 2021; 44: vol. 44, 103011. https://doi.org/10.1016/j.jobe.2021.103011

[18] Mohan C, Goyal R. Analysing mechanical properties of concrete with nano silica, silica fume and steel slag. Mater. Today Proc., 2021; 45:6 4520-4525. https://doi.org/10.1016/j.matpr.2020.12.1032

[19] Badogiannis E, Kakali G, Tsivilis S. Metakaolin as Supplementary Cementitious Material Optimization of kaolin to metakaolin conversion. J. Therm. Anal. Calorim., 2005; 81: 457-462, 2005. https://doi.org/10.1007/s10973-005-0806-3

[20] IS: 1199 -1959, "Methods of Sampling and Analysis of Concrete," Bur. Indian Stand., no. 11, pp. 1-49, 2004.

[21] IS: 516 - 1959, "Methods of Test for Strength of Concrete," Bur. Indian Stand., no. 18, pp. 1-30, 1959.

[22] ASTM C1202, "Standard Test Method for Electrical Indication of Concretet's Ability to Resist Chloride Ion Penetration," Am. Soc. Test. Mater., no. C, pp. 1-8, 2012.

[23] Ramezanianpour AA, Pilvar A, Mahdikhani M, Moodi F. Practical evaluation of relationship between concrete resistivity, water penetration, rapid chloride penetration and compressive strength. Constr. Build. Mater., 2011; 25:5 2472-2479. https://doi.org/10.1016/j.conbuildmat.2010.11.069

[24] ASTM C 642-13, "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete," Am. Soc. Test. Mater., pp. 11-13, 2008.

[25] Xiaolu GUO, Huisheng SHI, Kai WU. Effects of Steel Slag Powder on Workability and Durability of Concrete. J. Wuhan Univ. Technol. Sci. Ed., 2014; 733-739. https://doi.org/10.1007/s11595-014-0988-2
[26] Abdelmelek N, Lubloy E. Evaluation of the mechanical properties of high strength cement paste at elevated temperatures using metakaolin. J. Therm. Anal. Calorim., 2020; 1:2 1-16.
[27] Rosales J, Cabrera M, Agrela F. Effect of stainless steel slag waste as a replacement for cement in mortars. Mechanical and statistical study. Constr. Build. Mater., 2017; 142: 444-458. https://doi.org/10.1016/j.conbuildmat.2017.03.082
[28] Tsakiridis PE, Papadimitriou GD, Tsivilis S, Koroneos C. Utilization of steel slag for Portland cement clinker production. J. Hazard. Mater., 2008; 152: 805-811. https://doi.org/10.1016/j.jhazmat.2007.07.093
[29] Parande AK, Babu BR, Karthik MA, Kumar KKD, Palaniswamy N. Study on strength and corrosion performance for steel embedded in metakaolin blended concrete/mortar. Constr. Build. Mater., 2008; 22: 127-134. https://doi.org/10.1016/j.conbuildmat.2006.10.003
[30] Palod R, Ramtekkar SVDGD, Utilization of waste from steel and iron industry as replacement of cement in mortars. J. Mater. Cycles Waste Manag., 2019; 1-15. https://doi.org/10.1007/s10163-019-00889-3