Regression Analysis of OPC-MK-RM-Based Ternary-Blended Concrete Based on Its Experimental Results

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Regression Analysis of OPC-MK-RM-Based Ternary-Blended Concrete Based on Its Experimental Results

Rathan Raj Rajendran and E. B. Perumal Pillai

Abstract The performance and strength needs are not adequately satisfied by the advancement in concrete technology as well as the development of new materials and components. Part replacement of cement by mineral admixtures in concrete overcomes many problems and leads to improvement in the strength as well as durability of concrete. This paper deals with the regression analysis of various experimental results on compressive strength of Ordinary Portland Cement (OPC)-Metakaolin (MK)-Red Mud (RM)-based ternary-blended concrete with different water-binder ratios (*w*/*b*) 0.40, 0.38, 0.36, and 0.33. For all *w*/*b* ratios, the compressive strength was determined at different days of curing. In all the *w*/*b* ratios the regression analysis using SPSS software and the regression curve had been carried out by replacing 0–14% of the mass of OPC with MK and RM separately and a combination of MK:RM of different proportions of 50:50, 60:40, 70:30, and 80:20. The analysis was also done using neural network. From the experimental results the strength activity index was high in 8% replacement of OPC by MK and 4% by RM whereas in the combination of MK:RM at 10% for the proportion 80:20 shows the highest strength activity index.

Keywords Metakaolin · Red mud · Strength activity index · Regression models

1 Introduction

Concrete, the utmost popular and the powerful building material is being used nowadays for all types of infrastructural projects. Bearing in mind, the worldwide use of concrete for most of the constructions and its increasing demand for new

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structures, the technical advantages of materials such as mineral admixtures and waste materials from industries are further complimented by other economic, ecological, and environmental considerations. Concrete provides a safe haven to many of the toxic elements present in industrial wastes through chemical binding. Technical solution to handle and dispose waste materials will cause less harm to our environment. However, in spite of the overwhelming technical, environment, and economical benefits derived from the use of mineral admixtures and waste materials in concrete, there is still a considerable misinformation on their use in concrete. The integrity and durability of concrete structures are closely linked with the characteristics of these materials used, but there is no clear understanding of this interrelationship between material characteristics and structural performance.

In this paper, a brief investigation about the utilization of Metakaolin (MK) as mineral admixture and Red mud (RM) as waste material in cement concrete were studied and the results are presented.

Several researches have proposed modifications to conventional methods. Within the limit of available raw materials, the selection of the suitable materials, proportions and mixes conducted in the field and laboratory have typically proven adequate concrete characteristics [1, 2]. With adequate mechanism of proportion and replacement of materials, concrete with compressive strengths of 60 MPa is possible in construction.

The increase in concrete strength when metakaolin partially replaces cement in concrete under three elementary factors namely cement hydration, pozzolanic activity, and relative strength [3]. The strength development of Jamaican red mud formed by the addition of hydrated lime, condensed silica fume and lime stone was preliminarily investigated [4]. The investigation results provide a suitable composites construction material without Portland cement as binder to the construction industry.

2 Experimental Investigation

2.1 Materials Used

The following are the materials that were used in this investigation:

- Ordinary Portland Cement confirming by BIS: 12269-1987.
- Metakaolin in dry densified form conforming to ASTM C 1240.
- Red mud is a byproduct in dry densified form.
- NSF-based Superplasticizer confirming by BIS: 9103 [5] and ASTM C-494 [6].
- Broken granite stones confirming by BIS: 383 [7].
- River sand confirming by BIS: 383 [7].
- Portable water used for concreting and curing.

2.2 Mix Proportions

A formulated mix design procedure by combining the BIS, ACI method, and the available literatures on HSC was used in this investigation. The formulation of mix and detailed design procedure [8] is explained by the author in his previous publication.

Based on the published mix design procedure, a HSC mixture proportions with a characteristic target mean compressive strength of 30, 40, 50, and 60 N/mm^2 were designed without any mineral admixtures. However, the use of several trial mixtures is important in the design of HSC. Therefore, to get the optimum proportions, trial mixes were arrived by replacing 0, 2, 4, 6, 8, 10, 12, and 14% of the mass of cement by MK and RM separately also in the proportion ratios of MK:RM (50:50, 60:40, 70:30, and 80:20) respectively. In all the above combinations, a superplasticizer by name CONPLAST SP430 was used at 1% by weight of the binder for obtaining workable concrete. The quantities of different material requirement per m^3 of concrete for the trial mixes of different *w*/*b* ratios are available in the author another publication [9].

3 Results and Discussions

3.1 Effects of Metakaolin on Cube Compressive Strength

The variation of rate of development of cube compressive strength of concrete with metakaolin in terms of strength activity index is measured for the four *w*/*b* ratios of 0.40, 0.38, 0.36, and 0.33 is given in Fig. 1. The rate of development of strength of metakaolin concrete in compression increases monotonically with a raise in metakaolin level at all four *w*/*b* ratios and at all curing times. The strength activity index is maximum for mixes with 8% replacement of cement by metakaolin in all *w*/*b* ratios. The same was observed by other researchers [10, 11]. The development of compressive strength in terms of strength index increases as the metakaolin content increases from 0%, the compressive strength gradually increases up to 8% and thereafter, it gradually falls off.

Figure 2 shows the regression analysis of experimental results on various concrete mixes with MK of all water-binder ratios. The relationship between 28 days compressive strength of concrete and *w*/*b* ratio of metakaolin based concrete was obtained as

$$f_{ck} = 1.569(w/b)^{-3.52} \quad (1)$$

where,

f_{ck} Cube compressive strength of concrete at the age of 28 days in N/mm^2 and
w/*b* water-binder ratio

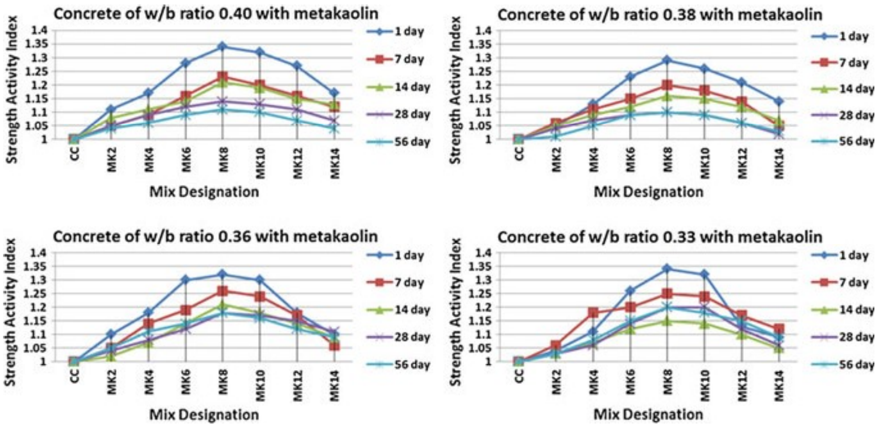
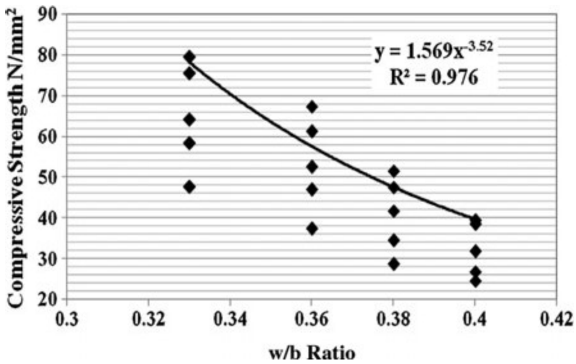


Fig. 1 Variation of strength activity index concrete with metakaolin

Fig. 2 Relationship between compressive strength and *w*/*b* ratio of metakaolin based concrete



Hence it was experiential that the compressive strength of concrete with addition of MK and different *w*/*b* ratios also varied like conventional concrete and their best fit curves also obey Abram's law for conventional concrete, compressive strength f_{ck} = A/(Bw/c).

3.2 Effects of Red Mud on Cube Compressive Strength

Figure 3 shows the variation of rate of development of compressive strength of concrete with red mud in terms of strength activity index for the four water-binder ratios. The rate of development of compressive strength of red mud-based concrete increases up to 4% replacement of red mud in all *w*/*b* ratios. However beyond 4% the strength starts decreasing for all mixes. The increase in the rate of development

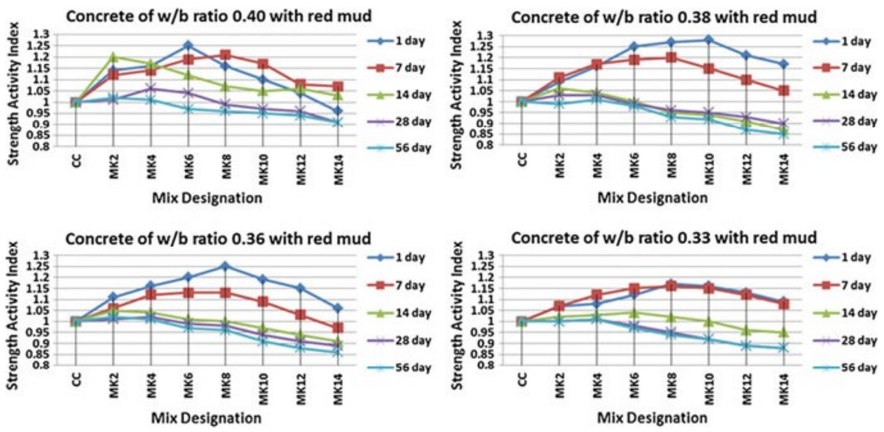


Fig. 3 Variation of strength activity index concrete with red mud

of compressive strength may be due to the fact that the cement replacement of around 4% increases the finer particles in the mix, which increases its density by filling the voids.

Another reason for increase in strength may be due to extra availability of Al_2O_3, SiO_2, and TiO_2 whose presence up to certain percentage increases the strength of concrete by combining with other constituents of cement during the progress of hydration. The compressive strength of concrete obtained from cement and neutralized red mud increases up to 5% replacement for constant water to (cement + red mud) ratio [12].

Figure 4 shows the regression analysis based on the experimental results of various concrete mixes with red mud of all water-binder ratios. The relationship between 28 days compressive strength and water-binder ratio of red mud based concrete was obtained as

$$f_{ck} = 2.493\,(w/b)^{-2.94} \tag{2}$$

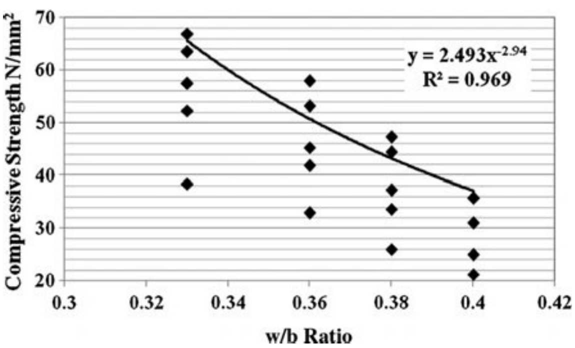


Fig. 4 Relationship between compressive strength and *w*/*b* ratio of red mud based concrete

3.3 *Effects of Metakaolin and Red Mud Blend on Cube Compressive Strength*

The influence on cube compressive strengths in terms of strength activity index for the four *w*/*b* ratios of concrete containing various MK and RM blends of MK:RM of different proportions of 50:50, 60:40, 70:30, and 80:20 as partial cement replacement at various ages is shown in Fig. 5. The rate of development of strength increases with the metakaolin content of the blend. In all the *w*/*b* ratios at 10% of total replacement, a maximum of strength occurs at 80% metakaolin and 20% red mud. The increase in strength is associated with acceleration of the hydration reactions of metakaolin; the red mud particles are acting as a filler materials in concrete, and this phenomena is same for all the mixes. Also in all the replacement levels and of different MK:RM proportions the variations of the strength activity indexes are very small. Beyond the 10% replacement levels there are remarkable reductions in the strength activity index, it shows that 10% replacement is acting as the optimum replacement level which gave higher strengths.

Figure 6 shows the regression analysis based on the experimental results of various concrete mixes with a combination of Metakaolin and red mud of all *w*/*b* ratios. The relationship between 28 days compressive strength water-binder ratio of MK-RM blend based concrete was obtained as

$$f_{\mathrm{ck}} = 2.508(w/b)^{-2.99} \tag{3}$$

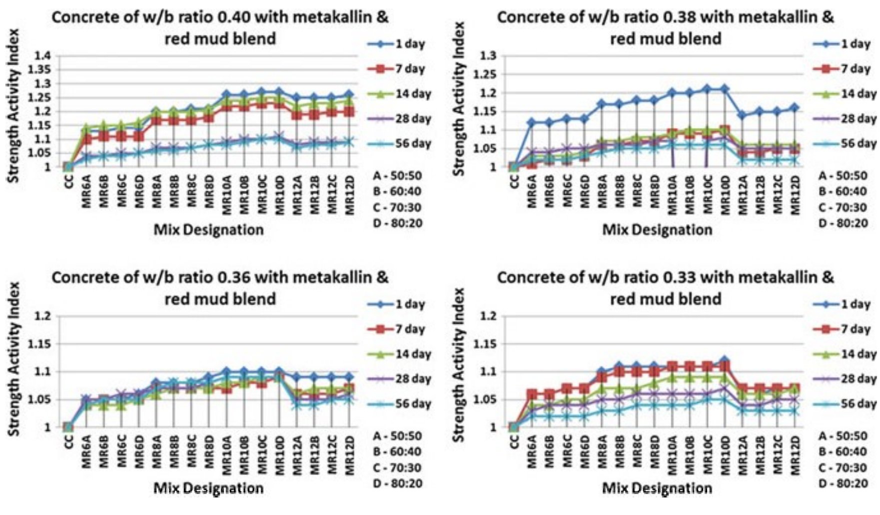


Fig. 5 Variation of strength activity index concrete with metakaolin-red mud blend

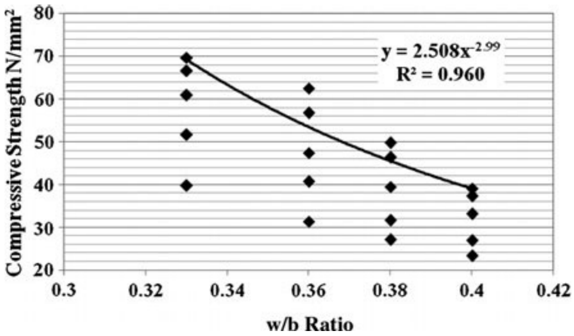


Fig. 6 Relationship between compressive strength and *w*/*b* ratio of metakaolin-red mud blend

3.4 *Relationship Between Cube Compressive Strength and the Independent Variables*

The regression analysis was carried out using SPSS software and the regression curve was drawn. This analysis was calculated based on the experimental results of various concrete mixes with cement replacement by MK, RM, and MK-RM blend of all *w*/*b* ratios. The following independent variables such as *w*/*b* ratio (*w*/*b*), cement (*C*), MK, RM, and curing days (*D*) were considered to prepare the regression fit with the compressive strength (f_{ck}) as the dependent variable. The relationship between compressive strength of concrete with MK, RM, and MK-RM blend and the independent variables was obtained as follows:

$$f_{ck} = 478.38 - 820.56\ (w/b) - 0.363\ (C) - 0.283\ (\mathrm{MK}) + 0.428(D)$$
$$f_{ck} = 355.76 - 624.85\ (w/b) - 0.229(C) - 0.283\ (\mathrm{MK}) + 0.318(D)$$
$$f_{ck} = 311.80 - 566.73\ (w/b) - 0.180(C) - 0.110\ (\mathrm{MK}) - 0.137(\mathrm{RM}) + 0.415(D)$$

Which is subjected to upper and lower bounds of examination indicates below:

$$0.33 < w/b < 0.4 \quad 311.75 < C < 439.39 \quad 7.25 < \mathrm{MK} < 61.52$$
$$7.25 < \mathrm{RM} < 61.52 \quad 1 < D < 56$$

The analysis was also done using neural network. The results obtained from regression analysis and neural network analysis were found to be closer to each and the points fit on the regression curve and the neural network curve were found to be very much coinciding with the experimental results. Figures 7, 8 and 9 show the influence of metakaolin, red mud, and metakaolin-red mud blend on the cube compressive strength based on regression analysis and neural network analysis.

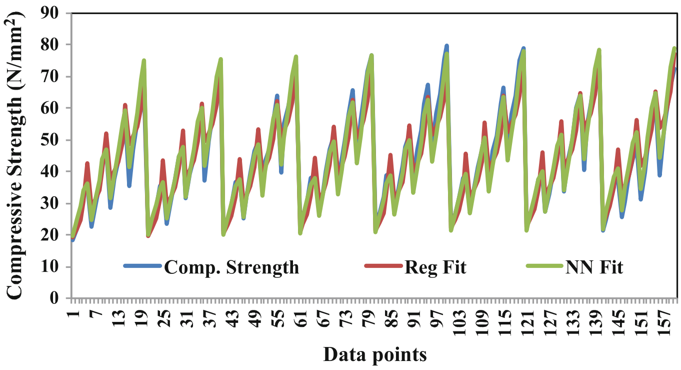


Fig. 7 Influence of metakaolin on cube compressive strength based on regression and neural network analysis

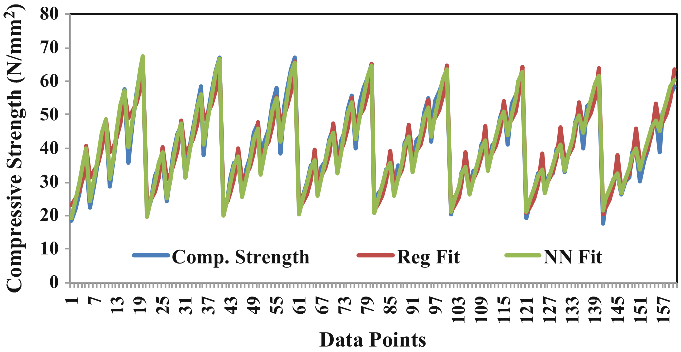


Fig. 8 Influence of red mud on cube compressive strength based on regression and neural network analysis

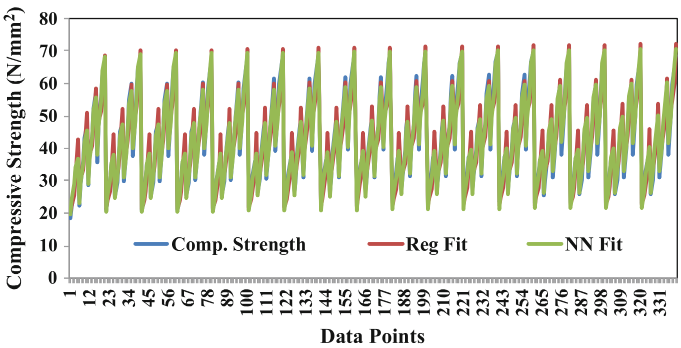


Fig. 9 Influence of metakaolin-red mud blend on cube compressive strength based on regression and neural network analysis

4 Conclusion

Based on the studies on concrete with metakaolin, red mud, and MK-RM combinations the following are the conclusions were drawn.

- The optimum percentage replacement of cement by metakaolin and red mud for all *w/b* ratios of concrete mixes was found to be 8 and 4% for achieving the maximum strength activity index at the age of 28 days. For metakaolin-red mud blend the optimum percentage replacement was found to be 10% with MK:RM ratio 80:20.
- Based on regression analysis the relationship between strength and *w/b* ratio was arrived at, for cement with metakaolin, red mud and metakaolin-red mud blend are as follows.

$$f_{ck} = 1.569\ (w/b)^{-3.52}$$
$$f_{ck} = 2.493\ (w/b)^{-2.94} \quad \text{and}$$
$$f_{ck} = 2.508\ (w/b)^{-2.99}$$

- For all the replacement levels and for different MK:RM proportions, the strength activity index variations are insignificant. The increases in strength activity index due to these replacements were never more than 20%.
- In all the *w/b* ratios with all MK:RM proportions replacement, the little raise in compressive strength is due to pozzolanic and acceleration of hydration reactions of MK alone. Hence it is not suggested that the secondary cementitious materials should be used for enhancing the strength

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