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EFFECTIVENESS OF POLYCARBOXYLATE ETHER ON EARLY STRENGTH DEVELOPMENT OF ALCCOFINE CONCRETE

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Abstract: The possibility of using mineral admixtures as a replacement for cement may reduce the carbon dioxide emission, which causes global warming and climatic changes on the environment. The objective of this study is to investigate the properties of early strength concrete produced with a constant replacement of alccofine (i.e. 25% by mass) and a new generation of chemical admixture that is Polycarboxylate ether. The constant dosage of alccofine and different proportions of polycarboxylate ethers are mixed in concrete and tested for workability and mechanical properties of concrete. Response surface method was applied to predict, validate and optimize the experimental data using regression equation. The results show that the performance of concrete improves with the addition of alccofine and Polycarboxylate ether into concrete.

Keywords: Alccofine, Polycarboxylate ether, Response surface method, Compressive strength

1. Introduction

Concrete, which is a broadly utilized material for development on the planet have been experiencing different changes in its properties, with the headway in innovation. With the recent rapid increase in population the need for infrastructure development increased exponentially. This increased demand for new infrastructure is feeding the global demand for building materials like ordinary Portland Cement (OPC), which is the main binding constituent for producing concrete [1]. Currently, the global demand of the OPC is around 4 billion tons, which is second most required material after water and

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it is expected that this figure will increase by 8-10% in the coming years [2]. The production of cement is a highly energy intensive process, which releases one-ton of carbon dioxide (CO_2) for every ton production of cement [3]. It is estimated that by the year 2020, the CO_2 emission will rise by 50% from the current levels. The earliest concrete i.e. the traditional normal strength concrete is composed of only cement, water, fine aggregates and coarse aggregates. With an increase in population evolution and by the developments in construction industry, high early strength concrete was essential. Initially the best way to achieve higher early strength was to minimize the water-cement ratio. Afterwards, an ingredient, which is a water retarding agent or super plasticizer, was vitally important. The issue of the strength of concrete structures was a noteworthy point of significance for quite a long while.

Recently some of the researchers have reported that the micro-fine material namely Alccofine (ALC), obtained as a by-product from iron ore industry in India also possess pozzolanic nature and can be used as a partial replacement of cement in concrete. By using alccofine as an admixture a significant improvement in workability and mechanical properties of concrete was observed. Due to the ultrafine particle size, alccofine improves the micro pores filling ability and resistance to segregation, which helps in enhancing fresh, mechanical and durability properties of concrete significantly. It is much economical than all other micro pozzolanic materials like Silica Fume (SF), MetaKoaline (MK). However, very little work has been reported on the use of ALC in concrete and mortars [4].

Different types of chemical additives are used in the construction industries to improve the properties of concrete at fresh (pumpability, setting and workability properties) and hardened (the mechanical properties and durability) states. Super-plasticizers are the improved admixtures over plasticizers with highly effect plasticizing effects on wet concrete. Super-plasticizers are chemically different from plasticizers. Use of super-plasticizers allows the reduction of water in the concrete up to the extent of 30-40% without reducing the workability in the contrast possible reduction to 15% in the case of plasticizers. The use of super-plasticizers also has advantages of self-leveling, self-compacting and to produce high strength and high performance concrete. However, the mechanism of action of super-plasticizers is similar to ordinary plasticizers. Super-plasticizers are high range water reducers. The use of super-plasticizers also made it possible to use low water to cement ratios [5].

PolyCarboxylate Ethers (PCEs) are the new generation of concrete additives, which was used in the concrete constructions. PCEs have been shown to be improving the workability and to regulate the flow ability of cementations materials in the concrete [6]. The comb-shaped structures of super-plasticizers are composed of two main parts: Carboxylic groups as the backbone polyethylene oxide as the lateral chains as it is shown in *Fig. 1*.

2. Literature review

S. Kavitha and T. Felix Kala [7] explained the use of alccofine as the strength enhancer in self-compacting concrete. They found that the strength properties improved with an increase in alccofine quantity and the results of their research showed that alccofine can be used as additive in the self-compacting concrete. K. A. Latha, K. Surendra and M.V. Sekhar Reddy [8] had carried out experimental work on the cement replacement by alccofine and fly ash for M40 grade concrete. The conclusion is that the addition of alccofine shows the strength development at early stages as well as environmentally friendly to nature.

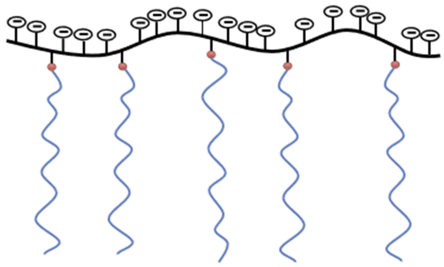


Fig. 1. Comb-shaped structure of PCE

Alccofine showed higher results than fly ash in lateral strength properties. S. Sharma, G. Ajay and D. Sharma [9] conducted experimental research on improving the strength of the concrete by using foundry slag as an alternative to normal aggregate and alccofine as a cement substitute. They concluded that the high strength concrete can be obtained by replacing the fine aggregate with 10 to 45% of the foundry slag and replacing the cement with 15% of alccofine. C. Sudha, V. Umamaheawaran, P.R.k. Rajkumar and T.Ravichandran [10] conducted experimental research on the replacement of cement using additives like alccofine, metakaolin, Ground-Granulated Blast-Furnace Slag (GGBS), silica fume and river sand substitute with M-sand. According to their investigation, alccofine with M-sand showed higher strength than conventional concrete. A. K. Gupta and Saurav [11] carried out experimental research into the partially substitution of cement with alccofine. They found that cement replacement with alccofine has improved the workability and pump-ability of the concrete. The addition of alccofine increases the compressive strength of concrete by 13% at 28 days. They concluded that 10 % alccofine replacement gave higher strengths compared to conventional concrete mixtures. Sanjay, Devinder and Saurabh [12] investigated the strength properties of alccofine concrete and concluded that the alccofine increases the hardened properties compared to conventional concrete. Alccofine concrete shows higher workability and retains the workability for sufficient time. A.C. Saoji and M.S. Pawar [13] studied the effect of alccofine on self-compacting concrete and they examined self-compacting concrete behavior in combination with fly ash and fly ash-alccofine. With 10% of alccofine, SCC mixes improved the fresh and hardened properties compared to traditional concrete mixes.

3. Mechanism of PCE

The backbone of PCE, which is negatively charged, allows the absorption of colloidal particles that are positively charged. Due to the absorption of PCE, which involve the attaching of carboxyl groups (COO-) groups on colloidal surface there is a change in the zeta potential of the particles suspended. The repulsion due to the displacement of polymer on the surface of the particles ensures dispersion of suspended particles thereby avoiding friction.

4. Research objective

There are many studies on the effect of alccofine (below 15%) and with addition of chemical admixtures on concrete. But in this research, the effects of constant volume of alccofine (i.e. 25%) with the addition of PCE on mechanical properties of sustainable concrete mixtures were investigated. And also the effect of PCE on fresh and hardened properties of alccofine concrete was studied.

5. Experimental details

5.1. Materials

Concrete mixes were prepared using commercially available 43 grade of ordinary Portland cement. Fine aggregate of Zone II and coarse aggregate were used with specific gravity of 2.78 and 2.68 respectively [14]. Distilled water was used with fixed water/binder ratio 0.45 for all specimen preparations. Alccofine being ultra-fine material was easy to add to the mix. In this research, the replacement of cement with alccofine was 25% and varying dosage of Auramix 400 composed primarily of PCE was used as super-plasticizers, which conforms to ASTM C494: Type G. The properties of PCE are shown in *Table I* and the physical and chemical properties of ultra-fine slag as shown in *Table II*.

Table I

Properties of PCE

Chemical	Aspect	Relative density	Chloride ion content
PCE	Light yellow	1.09	Nil

Table II

Physical and chemical properties of ultrafine slag

Physical		Chemical (%)	
Bulk density	600-700 kg/m3	Clacium oxide	30-34
Surface area	12000 cm2/gm	Silicon oxide	18-25
Average particle size	4-6 Microns	Magnesium oxide	6-10
		Iron oxide	0.8-3.0

5.2. Fabrication of concrete samples

The binder to aggregate ratio was obtained as 1:1.40:2.65 for M30 grade concrete (water-binder ratio=0.45) [14]. Alccofine was added as a constant replacement (i.e. 25%) to all concrete mixes. *Table III* shows the quantities of different materials were used in production of 1 m^3 concrete and the percentage of PCE was altered in this research work. All ingredients (dry cement, alccofine, fine aggregate, coarse aggregate and water) were mixed in a concrete mixer and with addition of varying dosage of super-plasticizer [15]. The fresh concrete mix was poured into the steel molds and kept in room temperature of 28^{0}C and relative humidity of 78% and then remolded after 24 hours and kept or curing in fresh water for 3, 7 and 28 days.

Table III

Mix details of different grades of concrete

Mix	Cement	AF	FA (%)	CA	W/B	PCE
AFC	328.59	109.53	614.59	1162.53	0.45	0
PCE1	328.59	109.53	614.59	1162.53	0.45	0.20
PCE2	328.59	109.53	614.59	1162.53	0.45	0.30
PCE3	328.59	109.53	614.59	1162.53	0.45	0.40

5.3. Fresh property

The fresh concrete mixtures were prepared with super-plasticizers (PCE) and have tested to check its fresh properties according to IS: 1199-1959 [16].

5.4. Mechanical properties

Specimens for mechanical properties of different concrete mixes were prepared with constant replacement of cement with alccofine (25%) and varying dosage of PCE. Cube specimens of size 150 mm casted and tested for compressive strength at 3, 7 and 28 as per IS 516-1959 [17] specification and cylindrical specimens of size 150 mm x 300 mm (*D* x *L*) and prism of 100 mm x 100 mm x 500 mm (*B* x *D* x *L*) were casted to find the variation of splitting tensile strength and flexural strength respectively. The splitting tensile tests were carried out at 7 and 28 days as per IS 5816-1999 [18] specification and flexural strengths were evaluated as per IS 516-1959 specification.

6. Results and discussion

6.1. Fresh properties

Compacting factor test is designed generally for use in the laboratory sometimes used in sites. The super-plasticizers also produce a homogeneous cohesive concrete generally without any tendency for segregation and bleeding [19]. Test results are shown in *Fig. 2*. From obtained results it can be seen that as super-plasticizers increases the workability of concrete also increases but decelerate the setting time of the concrete. There, the PCE showed much better performance, as was consistently shown by the given W/B ratio.

6.2. Effect of PCE on compressive strength

Concrete cube specimens were casted and tested with varying dosage of PCE to evaluate the early (3 and 7 days) and later strength (28 days) of the alccofine concrete as shown in *Fig. 3*. It has been recognized that super-plasticizer increases the compressive strength of concrete at early ages compared to reference mix. The early age (3 days) compressive strength of mixes PCE1, PCE2 and PCE3 was improved by 20.36%, 28.18% and 26.32% respectively, in comparison to the normal mix (Alccofine concrete mix). The compressive strength of concrete with optimum dosage of 0.3% PCE was 27.89%, 37.58% and 30.88% with respect to alccofine concrete at 7 days. It should be noted that concrete with PCE is not showing much deviation in strength for 28 days, the improvements were 11.73%, 13.46% and 14.85% as in comparison with AFC concrete mix. PCE dosage up to 0.3% by weight of cement is found to be advantageous for compressive strength because at this dosage better dispersion of cement particles were occurred in concrete and the addition of PCE beyond that level decrease the compressive strength [20], [21]. This is because added PCE create void packets as well as increase bleeding and segregation. Therefore presence of voids tends to decrease the strength of concrete in compression.

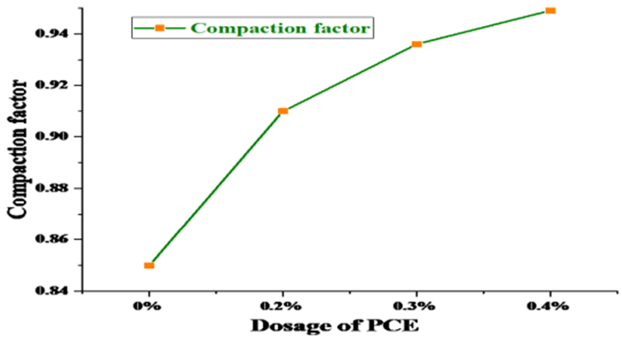


Fig. 2. Fresh properties of the concrete with PCE admixtures

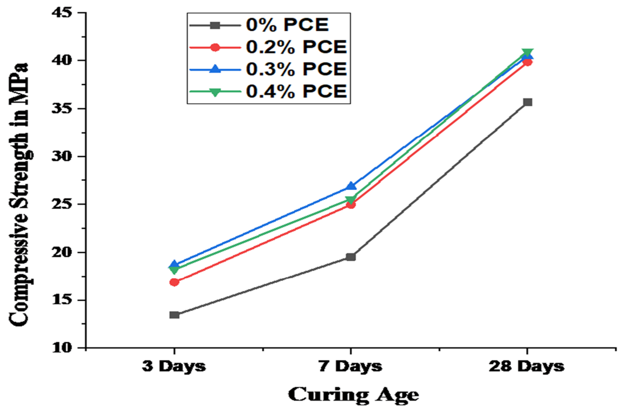


Fig. 3. Compressive strength of alccofine concrete with varying dosage of PCE at 3, 7 and 28 days

6.3. Effect of PCE on split tensile strength

Fig. 4 shows the split tensile strength of cylindrical specimens was casted with different proportion of PCE admixture. Results shows increase in split tensile strength in good amount as chemical admixtures dosage. For chemical admixture of varying PCE dosage the strength increases by 9.37%, 17.91% and 15.25% compared to reference mix AFC at 7 days. Similarly 7.27%, 14.61% and 18.39% increase in strength is observed for 0.2%, 0.3% and 0.4% PCE dosage respectively with respect to AFC mix that was tested for 28 days [22].

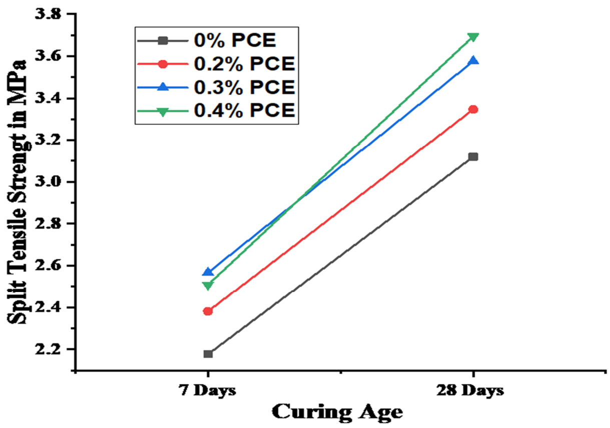


Fig. 4. Split tensile strength of alccofine concrete with varying dosage of PCE at 7 and 28 days

6.4. Effect of PCE on modulus of rapture

Beam specimens were tested under two point loading to obtained modulus of rupture. *Fig. 5* shows the results obtained for modulus of rupture for 7 and 28 days. It can be seen from a result that as dosage of PCE increases modulus of rupture also increases. For 0.2%, 03% and 0.4% PCE dosage the increase in the strength was observed as 14.89%, 31.10% and 27.77% respectively compared with AFC mix. Similarly behavior is observed for 28 days test results like the rate of development of modulus of rupture was low as compared to 7 days.

7. Response surface method

In this research Response Surface Method (RSM) was used for predicting the compressive strength of the concrete. Response surface method is a statistical and mathematical technique which can be used for refining, developing and optimizing processes in the research and industrial field [23].

In the present research, two independent variables selected were 'dosage of Polycarboxylate ether' and 'curing age' and the dependent response variable was compressive strength of concrete. By using this method, which employs the regression analysis, response surface, counter and residuals plots of the variables were evaluated in addition to main effect [24].

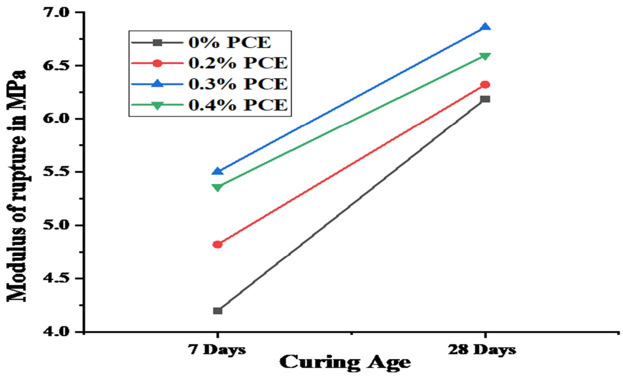


Fig. 5. Modulus of rupture of alccofine concrete with varying dosage of PCE at 7 and 28 days

In this study, Minitab was used to obtain the values of the coefficients by virtue of regression analysis for 95% confidence levels (α=0.05) wherein the following form [25], [26],

$$Z = A + BX + CY + DX2 + EY2 + FXY, \tag{1}$$

where Z is the compressive strength of concrete; X is the percentage of PCE; Y is the curing age.

The coefficient values evaluated were A = 6.226, B = 32.90, C = 2.323, D = -46.4, E = -0.04568 and F = -0.041.

Table IV shows the predicted and experimental values of compressive strength along with residual error.

The regression model obtained from response surface analysis and contour plots consisted compressive strength (Z) versus the curing age (Y) and the %PCE (X) as shown in *Fig. 6a* and *Fig. 6b*, respectively.

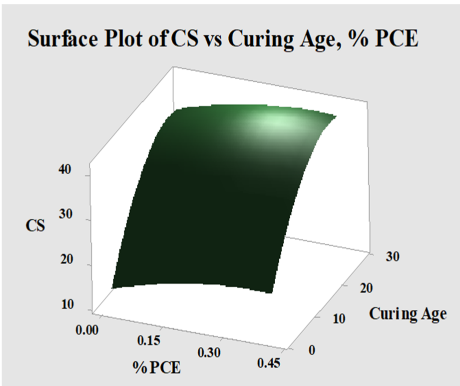
The graph between fitted and residual values shows the closeness of predicted compressive strength to experimentally observed data. The points near to the reference line in *Fig. 7* designate less error and the points far from the reference line show more error [27]. The errors observed in *Fig. 7* were found to be within acceptable range of tolerance with two residual values very close to the reference line. In the range of 0-0.5 and 0.5-1.0 the observed residual values were 3 and 2 respectively. Similarly, under the reference line 3 and 2 residual values were found to be in the range 0-0.5 and 0.5-1.0 respectively [28].

The percentage of error less than 5% was observed for the predicted response surface plot thereby showing 95% confidence level as it is shown in *Fig. 8*.

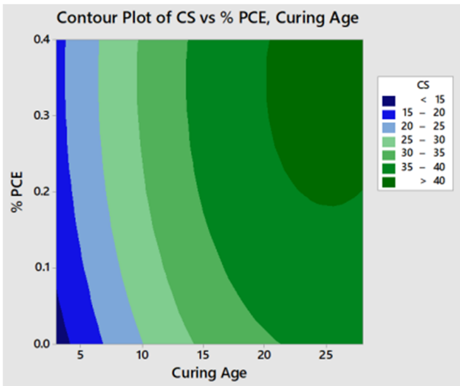
Table IV

Predicted and experimental values by using regression analysis

X (%)	Y(d)	Z experimental (MPa)	Z predicted (Mpa)	Residual (Mpa)
0.0	7	19.520	20.2498	-0.729849
0.0	3	13.420	12.7842	0.635810
0.0	28	35.670	35.4624	0.207629
0.2	7	24.966	24.9160	0.049961
0.2	3	16.852	17.4832	-0.631188
0.2	28	39.856	39.9563	-0.100319
0.3	7	26.856	25.8565	0.999480
0.3	3	18.688	18.4401	0.247927
0.3	28	40.472	40.8107	-0.338679
0.4	7	25.549	25.8686	-0.319593
0.4	3	18.216	18.4685	-0.252550
0.4	28	40.968	40.7366	0.231369



a)



b)

Fig. 6. a) Response surface plot;
b) Contour plot for ‘Compressive strength’ vs ‘%NCHA’, ‘curing age’

8. Conclusion

Strength properties (compressive, split tensile and modulus of rupture) were conducted on alccofine concrete with and without super plasticizers in different proportions by weight of cement. From the test results obtained following broad conclusion can be made which are as follows:

- PCE dosage upto 0.3% by weight of cement is found to be advantageous for compressive strength and the addition of PCE beyond optimum level decreases the compressive strength. This is because added PCE create void packets in the concrete. Therefore presence of voids tends to decrease the strength of concrete in compression;

- Split tensile strength also increase as PCE dosage was increased. The increase in spit tensile strength for 7 and 28 days for 0.3% PCE dosage is observed to be 17.91% and 0.4% of PCE is obtained 15.19% respectively compared concrete without PCE (i.e. AFC mix);
- As PCE dosage was increases, increase in modulus of rupture was observed for all specimens. For 7 and 28 days increase in flexural strength of AFC for 0.3% of PCE dosage was observed to be 31.10% and 10.87% when compared with AFC mix. Improved compressive strength is due to filling of pores effectively by ettringite in the concrete by chemical admixtures (PCE);
- The experimental data was modeled by using the response surface method in Minitab software, which employed regression analysis for predicting the values where in the error were formed to be tolerance acceptable range (95% confidence level) thus implying reliable prediction.

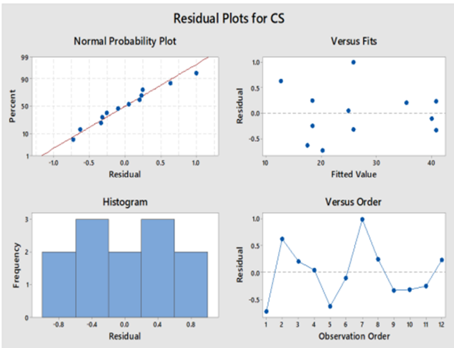


Fig. 7. Residual plot for compressive strength

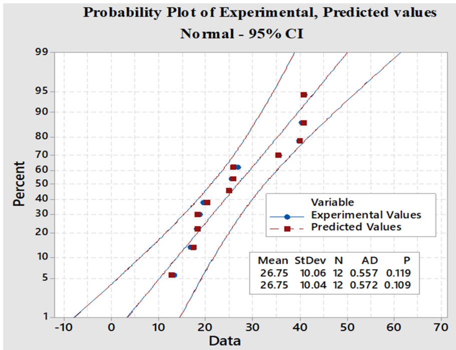


Fig. 8. Probability plot for experimental and predicted values

From the above results it can be concluded that compressive strength of alccofine concrete with PCE up to 0.3% increases compressive strength but beyond that it tends to decrease the compressive strength. On the other side the split tensile strength and modulus of rupture increases as dosage of PCE in alccofine concrete increases.

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References

[1] Jindal B. B., Singhal D., Sharma S. K., Ashish D. K., Parveen, Improving compressive strength of low calcium fly ash geopolymer concrete with alccofine, Advances in Concrete Construction, Vol. 5, No. 1, 2017, pp. 17–29.

[2] Ondova M., Stevulova N., Palascakova L., Estokova A. The study of concrete properties prepared with a proportion of fly ash, *Pollack Periodica*, Vol. 9, Supplement 1, 2014, pp. 105–115.

[3] Saxena S. K., Kumar M., Singh N. B. Effect of alccofine powder on the properties of pond fly ash based geopolymer mortar under different conditions, *Environmental Technology and Innovation*, Vol. 9, 2018, pp. 232–242.

[4] Richardson A. Strength development of plain concrete compared to concrete with a non-chloride accelerating admixture, *Structural Survey,* Vol. 25, No. 5, 2007, pp. 418–423.

[5] Bhavikatti M. A., Karjinni V. Combined effect of hardening accelerator and method of curing in the strength development of pavement concrete, *International Journal of Civil and Structural Engineering*, Vol. 2, No. 4, 2012, pp. 1060–1069.

[6] Jindal B. B., Singhal D., Sharma S. K., Parveen, Suitability of ambient cured alccofine added low-calcium fly ash-based geopolymer concrete, *Indian Journal of Science and Technology*, Vol. 10, No. 12, 2017, pages 1-10.

[7] Kavitha S., Kala T. F. Effect of bamboo fiber in self-compacting concrete partially replacement cement with GGBS and alccofine, *International Journal of Civil Engineering and Technology*, Vol. 8, No. 3, 2017, pp. 158–166.

[8] Reddy M. V. S., Ashalatha K., Surendra K. Studies on eco-friendly concrete by partial replacement of cement with alccofine and fine fly ash, *ARPN Journal of Engineering and Applied Sciences*, Vol. 11, No. 5, 2016, pp. 3445–3448.

[9] Sharma D., Sharma S., Goyal A. Utilization of waste foundry slag and alccofine for developing high strength concrete, *International Journal of Electrochemical Science*, Vol. 11, No. 1, 2016, pp. 3190–3205.

[10] V. Umamaheswaran, C. Sudha, P. T. Ravichandran and P. R. Kannan Rajkumar, Use of M sand in high strength and high performance concrete, *Indian Journal of Science and Technology*, Vol. 8, No. 28, 2015, pages 1–8.

[11] Saurav, Gupta A. K. Experimental study of strength relationship of concrete cube and concrete cylinder using ultrafine slag alccofine, *International Journal of Scientific & Engineering Research*, Vol. 5, No. 5, 2014, pp. 102–107.

[12] Gupta S., Sharma S., Sharma D. A review on alccofine a supplementary cementitous material, *International Journal of Modern Trends in Engineering and Research*, Vol. 3, No. 2, 2013, pp. 148–153.

[13] Pawar M. S., Saoji A. C. Effect of alccofine on self-compacting concrete, *International Journal of Engineering and Science*, Vol. 2, No. 6, 2013, pp. 5–9.

[14] *IS 10262*, Guidelines for concrete mix design proportioning, Bureau of Indian Standards, 2009.

[15] El Mir A., Nehme S. G. Effect of air entraining admixture on the properties of self-compacting concrete incorporating supplementary cementations materials, *Pollack Periodica*, Vol. 12, Supplement 3, 2017, pp. 85–95.

[16] *IS 1199 (1959),* Methods of sampling and analysis of concrete, Bureau of Indian Standards, 1959.

[17] *IS 516 (1959)*, Method of tests for strength of concrete, Bureau of Indian Standards,1959.

[18] *IS 5816 (1999),* Method of test splitting tensile strength of concrete, Bureau of Indian Standards, 1999.

[19] Mohan A., Mini K. M. Strength and durability studies of SCC incorporating silica fume and ultra fine GGBS, *Construction and Building Materials*, Vol. 171, 2018, pp. 919–928.

[20] Reddy P. N., Naqash J. A. Durability and mechanical properties of concrete modified with ultra-fine slag, *International Journal of Innovative Technology and Exploring Engineering*, Vol. 8, No. 5, 2019, pp. 230–234.
[21] Reddy P. N., Naqash J. A. Strength prediction of high early strength concrete by artificial intelligence, *International Journal of Engineering and Advanced Technology*, Vol. 8, No. 3, 2019, pp. 330–334.
[22] Kavyateja B. V., Jawahar J. G., Sashidhar C. Investigation on ternary blended self compacting concrete using fly ash and alccofine, *International Journal of Recent Technology and Engineering*, Vol. 7, No. 5S2, 2019, pp. 447–451.
[23] Vu-Bac N., Rafiee R., Zhuang X., Lahmer T., Rabczuk T. Uncertainty quantification for multiscale modeling of polymer nanocomposites with correlated parameters, *Composites Part B: Engineering*, Vol. 68, 2015, pp. 446–464.
[24] Vu-Bac N., Silani M., Lahmer T., Zhuang X., Rabczuk T. A unified framework for stochastic predictions of mechanical properties of polymeric nanocomposites, *Computational Material Science,* Vol. 96, Part B, 2015 pp. 520–535.
[25] Hasan M. M., Kabir A. Prediction of compressive strength of concrete from early age test result, *4th Annual Paper Meet and 1st Civil Engineering Congress*, Dhaka, Bangladesh, 22-24 December 2011, pp. 978–984.
[26] Jindal B. B., Singhal D., Sharma S. K., Parveen. Prediction of mechanical properties of alccofine activated low calcium fly ash based geopolymer concrete, *ARPN Journal of Engineering and Applied Sciences*, Vol. 12, No. 9, 2017, pp. 3022–3031.
[27] Jindal B. B., Parveen, Singhal D., Goyal A. Predicting relationship between mechanical properties of low calcium fly ash-based geopolymer concrete, *Transactions of the Indian Ceramic Society*, Vol. 76, No. 4, 2018, pp. 258–265.
[28] Sharma D., Sharma S., Goyal A. Utilization of waste foundry slag and alccofine for developing high strength concrete, *International Journal of Electrochemical Science*, Vol. 11, 2016, pp. 3190–3205.