Strength Properties of Metakaolin Admixed Concrete

Nova John

Department of Civil Engineering, SCMS School of Engineering & Technology, Ernakulam, Kerala

Abstract- Supplementary cementitious materials (SCMs) have been widely used all over the world in concrete due to their economic and environmental benefits; hence, they have drawn much attention in recent years**.**Mineral admixtures such as fly ash, rice husk ash, silica fume etc are more commonly used SCMs. They help in obtaining both higher performance and economy. Metakaolin is also one of such non - conventional material which can be utilized beneficially in the construction industry. This paper presents the results of an experimental investigations carried out to find the suitability of metakaolin in production of concrete. In the present work, the results of a study carried out to investigate the effects of Metakaolin on strength of concrete are presented. The referral concrete M30 was made using 53 grade OPC and the other mixes were prepared by replacing part of OPC with Metakaolin. The replacement levels were 5%, 10%, 15% upto 20%(by weight) for Metakaolin. The various results which indicate the effect of replacement of cement by metakalion on concrete are presented in this paper to draw useful conclusions. The results were compared with reference mix. Test results indicate that use of replacement cement by metakalion in concrete has improved performance of concrete up to 15%.

Index Terms- Metakaolin, Compressive strength, Pozzolan, OPC.

I. INTRODUCTION

The use of supplementary cementitous materials (SCMs) is fundamental in developing low cost construction materials for use in developing countries. By addition of some pozzolanic materials, the various properties of concrertelike workability, durability, strength, resistance to cracks and permeability can be improved. Many modern concrete mixes are modified with addition of admixtures, which improve the microstructure as well as decrease the calcium hydroxide concentration by consuming it through a pozzolanic reaction. The subsequent modification of the microstructure of cement composites improves the mechanical properties, durability and increases the service-life properties. When fine pozzolana particles are dissipated in the paste, they generate a large number of nucleation sites for the precipitation of the hydration products. Therefore, this mechanism makes paste more homogeneous. This is due to the reaction between the amorphous silica ofthe pozzolanic and calcium hydroxide, produced during the cement hydration reactions. In addition, the physical effect of the fine grains allows dense packing within the cement and reduces the wall effect in the transition zone between the paste and aggregate. This weaker zone is strengthened due to the higher bond development between these two phases, improving the concrete microstructure and properties. In general, the pozzolanic effect depends not only on the pozzolanic reaction, but also on the physical or filler effect of the smaller particles in the mixture. Therefore, the addition of pozzolanas to ordinary portland cement (OPC) increases its mechanical strength and durability as compared to the referral paste, because of the interface reinforcement. The physical action of the pozzolanas provides a denser, more homogeneous and uniform paste.

Metakaolin is apozzolanic material which is manufactured from selected kaolins, after refinement and calcination under specific conditions. It is a highly efficient pozzolana and reacts rapidly with the excess calcium hydroxide resulting from OPC hydration, via a pozzolanic reaction, to produce calcium silicate hydrates and calcium aluminosilicatehydrates. It differs from other supplementary cementitious materialslike fly ash, slag or silica fume, in that it is not a by-product of an industrial process; it is manufactured for a specific purpose under controlled conditions. It is produced by heating kaolin, one of the most abundant natural clay minerals, to temperatures of 650-900°C. This heat treatment or calcination, serves to break down the structure of kaolin. Bound hydroxyl ions are removed and resulting disorder among alumina and silica layers yields a highly reactive, amorphous material with pozzolanic and latent hydraulic reactivity, suitable for use in cementing applications. Metakaolin is a fine, natural white clay which contains the highest content of siliceous, so called as High Reactivity Metakaolin(HRM). During the cement hydration process, water reacts with Portland cement and forms calcium-silicate hydrate (CSH). The by-product of this reaction is the formation of calcium hydroxide (lime). This lime has weak link in concrete, and hence reduces the effect of the CSH. When Metakaolin is added in the hydration process, it reacts with the free lime to form additional CSH material, thereby making the concrete stronger and more durable.

II. RESEARCH SIGNIFICANCE

Enhancing the structural properties of concrete isone of the major concerns in construction industries nowa day. Many researchers clearly demonstrated thedevelopment of structural properties of cement concrete blended with Metakaolin. Some of them are given below:

Murthy et al., (2012) investigated the effect of Metakaolin on the modulus of elasticity of concrete. The cement is partially replaced by Metakaolin at different percentages such as 7.5, 10, 12.5, 15 and 17.5 by weight of cement. The modulus of elasticity is determined by testing of cylinders of size 150mm diameter and 300mm height at various percentages of Metakaolin after curing for 28 days.Variation of Young's modulus at different percentages of Metakaolin is compared with controlled concrete as 0% replacement of cement. The value of Young's modulus increase from 0% up to 10% of Metakaloin addition and then decrease.Murali et al., (2012) investigated the properties of concrete with varying percentage replacement of metakaolin. Four mixes were obtained by repalacing 0, 5, 7.5 and 10% mass of cement by metakaolin. The admixture metakaolin when used at optimum quantity tend to increase the strength of concrete mix when compared with conventional concrete. Metakaolin increased the compressive strength, split tensile strength and flexural strength of concrete.Akasha et al., (2008) studied the effect of metakaolin by 0%, 10%, 15% and20% replacement of Portland cement pastes and mortars and the parameters such as compressive and tensile strengths were investigated. The use of metakaolin material effectively improved the mechanical strength of mortarincluding tensile and compressive strength,Poon et al. (2001) conducted studies on rate of pozzolanic reaction of metakaolin in cement pastes. The results obtained indicate that the rates of initial reactivity in metakaolin blended cement pastes were higher than in silica fume or fly ash blended cement pastes. Due to its high initial reactivity, metakaolin resulted in a higher rate of compressive strength development for cement pastes when compared with silica fume.Brooks and Joharis (2001) investigated the effect of metakaolin on creep and shrinkage of concrete. The studies revealed that the reduction in early age autogenous shrinkage is greater at higher replacement levels. Also, comparing with control concrete, greater part of the total shrinkage of the metakaolin concrete is considered to be autogenous shrinkage. This observation does not appear to be influenced by the replacement level. Total creep, basic creep and drying creep of the concrete are considerably reduced due to metakaolin inclusion particularly at higher replacement levels.Curcio et al. (1998) studied the effect of 15% replacement of cement in mortar with four metakaolin samples and compared to concrete containing silica fume. Results showed that in mortars using metakaolin samples, the compressive strength development at early stages is at a higher rate than that of silica fume. 10-15% replacement by metakaolin increases compressive strength at 14 days with respect to control sample by about 30% with OPC .

III. EXPERIMENTAL PROGRAM

The main aim of this experimentation is to study the effect of partial replacement of cement by metakaolin on the properties of concrete. To study this effect the following parameters were considered in this experimentation:

A. Materials Used

- Cement

Ordinary Portland Cement (53 grade) Dalmia cement conforming to IS 8112 was used. The different laboratory tests were conducted on cement to determine standard consistency, initial and final setting time, and specific gravity as per IS 4031 and IS 269-1989. The results are tabulated in Table 1. The results conforms to the IS recommendations.

Table 1: Physical properties of Ordinary Portland Cement-53 grade

Properties		**Results**	**Permissible limit as per IS: 12269-1987**
Standard consistency		32.25%	Varies from 26% to 33%
Specific gravity		3.15	Varies from 3.1 to 3.15
Setting Time	Initial	60 minutes	Should not be less than 30 Min
	Final	480 minutes	Should not be more than 600 Min

- Coarse Aggregate

The crushed granite aggregate were collected from the local quarry. The coarse aggregate was used in the experimentation were of 20mm and down size aggregate and tested as per IS: 2386-1963 (I, II and III) specifications. Specific gravity of coarse aggregate was found to be 2.64. Particle size distribution Curve for coarse aggregate is given in Figure 1.

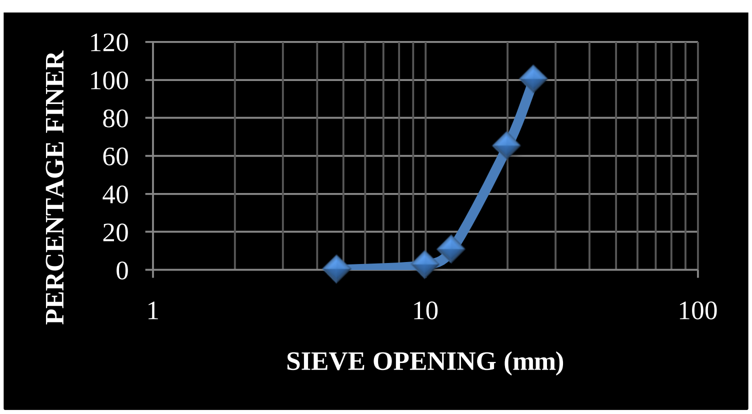

Figure 1: Particle size distribution Curve for coarse aggregate

➢ Fine aggregate

Locally available river sand was used as fine aggregate. The sand used was having a specific gravity of 2.62 and confirmed to grading zone-II as per IS: 383-1970 specification. Physical properties of tested fine aggregate are given in Table 3.3

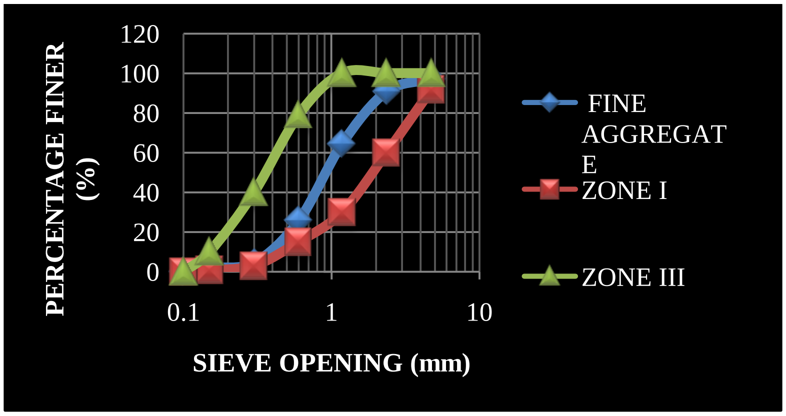

Figure 2: Particle size distribution for fine aggregate

➢ Metakaolin

The mineral admixture Metakaolin was obtained from the ENGLISH CLAYLIMITED company at CochuVeli in Trivandrum. The Metakaolin was in conformity with the general requirements of pozzolana. Properties of Metakaolin are given in below Table 2 & 3.

.

Figure 3: Metakaolin

Table 2: Physical Properties of Metakaolin

Particulars	Values
Appearance	Off- White Powder
pH (10% solids)	4.0 - 5.0
Bulk Density (Kg/1)	0.4 - 0.5
Specific Gravity	2.6
Loss on Ignition (%)	1.5
Lime Reactivity	1050mg $Ca(OH)_2$/g
Grit (+300#)	<1%
D 50	1.5~2

Table 3: Chemical Composition of Metakaolin

Chemical Composition	Mass (%)
SiO_2	52.0 - 54.0
Al_2O_3	44.0 - 46.0
Fe_2O_3 (Max)	0.60 - 1.2
TiO_2(Max)	0.65
CaO (Max)	0.09
MgO (Max)	0.03
Na_2O (Max)	0.10
K_2O (Max)	0.03

➢ Water

Ordinary potable water free from organic content, turbidity and salts was used for mixing and for curing throughout the investigation.

B. Mix proportion

For the present investigation, mix design for M30 grade of concrete was carried out using the above coarse aggregate, fine aggregate, and the binder. The proportion of the materials by weight was 1:1.47:2.52 (Cement: Fine aggregate: Coarse aggregate). The cement constituent was subsequently replaced with percentage of metakaolin (by mass). The percentage of the Cement was varied between

0% and 20%, at 5% intervals, with the Metakaolinwhich gives a total of five mixes. In each mix, water cementitiousmaterials ratio wasfixed at 0.45 and the fine and coarse aggregate kept constant. The various combinations are as presented in Table 4.

Table 4: Detail of Concrete Mixes

Ingredients	**Mixes**				
	Control	**Metakaolin 5%**	**Metakaolin 10%**	**Metakaolin 15%**	**Metakaolin 20%**
	C	**M_1**	**M_2**	**M_3**	**M_4**
Cement (kg/m^3)	437.78	415.89	394	372.11	350.22
Metakaolin(kg/m^3)	-	21.89	43.78	65.67	87.56
Water(kg/m^3)	197	197	197	197	197
Fine Aggregate(kg/m^3)	643.68	643.68	643.68	643.68	643.68
Coarse Aggregate(kg/m^3)	1104.36	1104.36	1104.36	1104.36	1104.36

C. Experimental Procedure

- Mixing of Constituent Materials

The cement and Metakaolin were measured and mixed together until a uniform colour was obtained. The blendedmix was spread on already measured fine aggregate placed on an impermeable platform and mixed thoroughlybefore the coarse aggregate and water were added.

- Casting and Curing of Specimens

The specimens were cast in well lubricated moulds. Concrete wereplaced on themould and compacted thereafter and theywere left at room temperature for 24hrs before being transferred into the curing tank. After 24 hours, they wereimmersed in water curing tanks until their testing ages.To investigate the effect of inclusion of metakaolin (as part replacement of cement), 150mm cube specimens, 150mm diameter and 300mm height cylinder specimes and 100mm × 100mm × 500mm size beam specimens were cast for referral and other mixes having variable metakaolin content.

- Testing of Specimens

The compressive strength of different mixes was found out at 7 and 28 days whereas Split Tensile Strength and Flexural Strength were found out at 28 days as per the procedure laid down in IS: 516 - 1981.The concrete specimens were tested for compressive strength and tensile splitting strength in a compression testingmachine of capacity 2000KN and flexural Strength was tested in a Flexure Strength Testing Machine respectively. Three specimens were used in computing the mean on each testing age of each mix and the final results are tabulated in comparison with reference mix.

- Compressive strength, F_{cu}, estimated as:

$$F_{cu} = \frac{P}{A}$$

where,P = magnitude of the load that causes breaking (expressed in Kilo Newton)
A = cross sectional area of cube (mm^2)

- Tensile splitting strength, F_{sp}, estimated as:

$$F_{sp} = \frac{2P}{\pi Dl}$$

where,P = maximum load causing splitting of the cylinder
D = Diameter of specimen in mm
l = Length of the specimen in mm

- Flexural strength, F_b, estimated as:

$$F_b = \frac{pl}{bd^2}$$

where, b is the width of specimen
d is the depth of specimen
l is the length of the span on which the specimen is supported
p is the maximum load applied to the specimen.

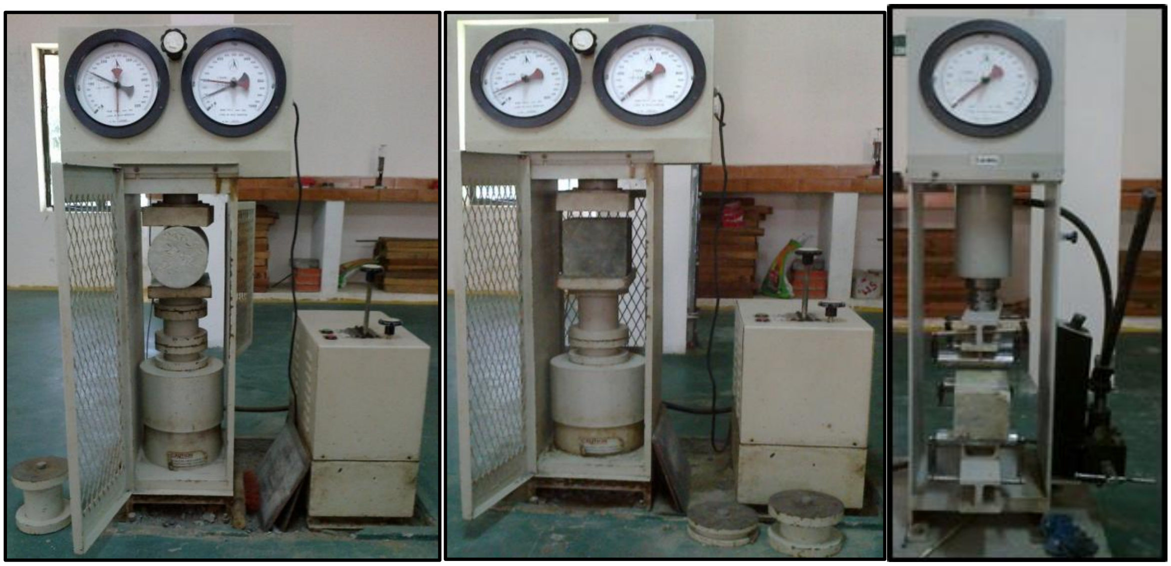

Figure 4: Testing of Specimens in Compression Testing Machine & Flexural Strength Testing Machine

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

- Compressive strength Result

The development of compressive strength with age for all mixes investigated is presented in Table 5& Figure 5.From the plot it is clear that the Metakaolin admixed mixes attains higher compressive strength values than the control mix. The compressive strength development depends upon the metakaolin dosage and age of concrete. 15% replacement percentage had higher ultimate strength than concrete made with Portland cement. It has a higher proportion of the strength-enhancing calcium silicate hydrates (CSH) than concrete made with Portland cement only, and a reduced content of free lime, which does not contribute to concrete strength.

Table 5: Compressive Strength of all Mixes

MIX	Compressive Strength (N/mm^2)	
	7 days	28 days
C	28.74	37.04
M_1	32.07	38.22
M_2	38.07	43.7
M_3	41.19	51.56
M_4	38.96	45.49

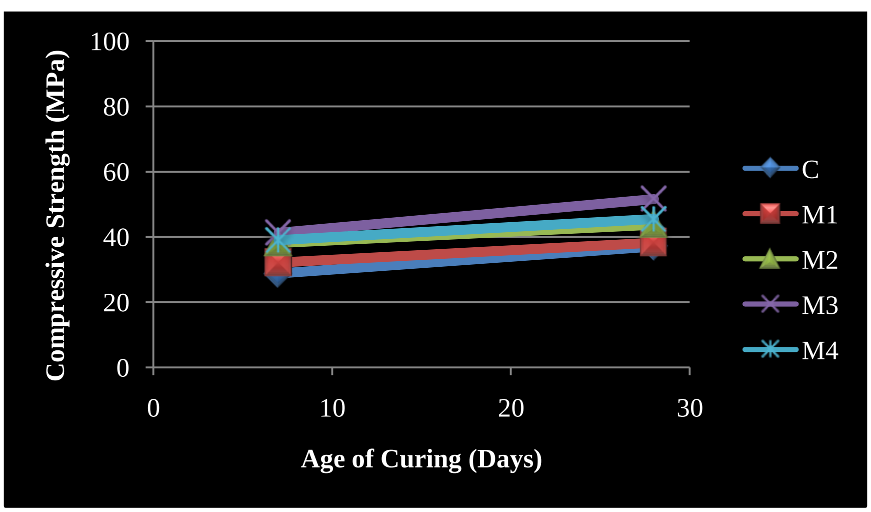

Figure 5: Variation of Compressive Strength

- Split Tensile Strength Result

The results of split tensile strength of cylinder for 28 days are given in Table 6 and the variation of split tensile strength of all mixes is clearly shown in Figure6. The tensile strength value of concrete increases with increase in percentage of cement replacement with metakaolinupto a percentage of 15%. The tensile strength increases a maximum of 3.04Mpa for 15 % metakaloine content and as the metakaolin content exceeds the value of 20%, the split tensile strength decreases to 2.95 MPa. The split tensile strength gain is maximum at 15% replacement of cement with metakaolin.

Table 6: Split Tensile Strength of all Mixes

MIX	Split Tensile Strength (N/mm^2) 28 days
C	2.79
M_1	2.81
M_2	2.9
M_3	3.04
M_4	2.95

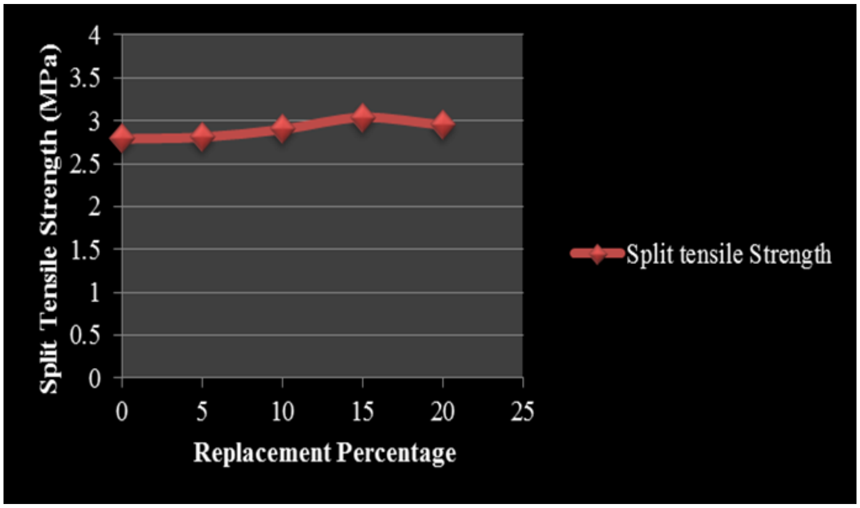

Figure 6: Variation of Split Tensile Strength

- Flexural Strength Result

The results of flexural strength at 28 days are tabulated in Table 7and are illustrated in Figure 7. It shows that the flexural strength of concrete mix also increases with increase in metakaolin replacement. The flexural strength at 28 days curing for control mixture (C) is achieved 5.84 Mpa. For the Mixes M1, M2, M3 andM4 a strength gain of 4.79%, 8.22%, 15.24% and 10.45% was obtained respectively in comparison with control mix 'C'. The maximum value of flexural strength was obtained for 15% replacement.

Table 7: FlexuralStrength of all Mixes

MIX	Flexural Strength (N/mm^2) 28 days
C	5.84
M_1	6.12
M_2	6.32
M_3	6.73
M_4	6.45

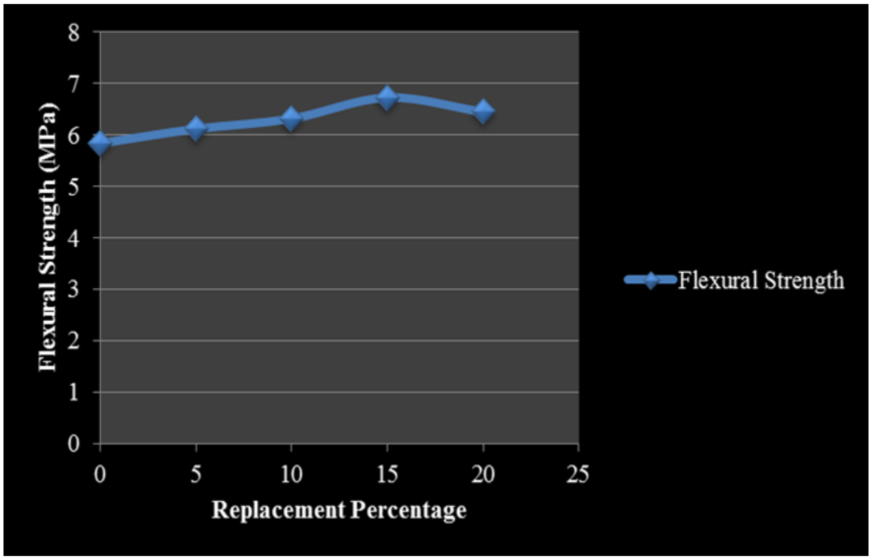

Figure 7: Variation of Flexural Strength

V. CONCLUSION

From the present investigation on the effect of partial replacement of cement with metakaolin in cement concrete, following conclusions can be drawn:

- The inclusion of metakaolin results in faster early age strength development of concrete.
- The strength of all Metakaolinadmixedconcretemixes overshoot the strength of OPC.
- Mix with 15% metakaolin is superior to all other mixes.
- The increase in metakaolin content improves the compressive strength, Split Tensile Strength and Flexural Strength upto 15% replacement.
- The results encourage the use of Metakaolin, as pozzolanic material for partial cement replacement in producing high strength concrete.
- The utilization of supplementary cementitious material like Metakaolinin concrete can compensate for environmental, technical and economic issues caused by cement production.

Inclusion of Metakaolinserves as an invaluable means to protect environmental resources, which may result in more viable constructions in the future.

REFERENCES

[1] Shetty, M. S.”Concrete Technology”,S. Chand & Company Ltd., 2005, New Delhi.

[2] Murali.G., Sruthee P., “Experimental study of concrete with Metakaolin as Partial replacement of cement”, International Journal of Emerging trends in Engineering and development, Issue 2, Vol.4, May 2012, ISSN 2249-6149.

[3] Vikas Srivastava., Rakesh Kumar., Agarwal V.C., “Metakaolin inclusion: Effect on mechanical properties of concrete”, *J. Acad. Indus. Res.* Vol. 1(5), pp. 251-253, October 2012, ISSN: 2278-5213.

[4] Akasha.A.M., Abdussalam.H.M., “Strength Characteristics of Cement Mortar Using Metakaolin asPartially Replacement Cement”,*ICCBT 2008*, A (44) ,pp501-506.

[5] SivakumarA., Prakash M., “Characteristic studies on the mechanical properties ofquarry dust addition in conventional concrete”,*Journal of Civil Engineering and Construction Technology*, Vol. 2(10), pp. 218-235, October 2011, ISSN 2141-2634.

[6] DeviM., Kannan K., “Analysis of strength and corrosion resistance behavior of inhibitors in concrete containing quarry dust as fine aggregate”, *ARPN Journal of Engineering and Applied Sciences,* Vol. 6, No. 11, November 2011 ISSN 1819-6608 .

[7] Ilangovana R., Mahendrana N.,Nagamanib K., “Strength And Durability Properties Of Concrete Containing Quarry Rock Dust As Fine Aggregate”, *ARPN Journal of Engineering and Applied Sciences,* Vol. 3, No. 5, October 2008 ISSN 1819-6608.

[8] IS 10262:2009 Concrete Mix Proportioning Guidelines - Code of Practice, Bureau of Indian Standard, New Delhi 110002.

[9] IS 456:2000 Indian Standard, Plain and Reinforced Concrete - Code of Practice, Bureau of Indian Standard, New Delhi 110002.

AUTHORS

First Author – Nova John,Department of Civil Engineering, SCMS School of Engineering & Technology, Ernakulam, Kerala
Email address: novajohn.nova@gmail.com