Available online www.ejaet.com

European Journal of Advances in Engineering and Technology, 2017, 4(7): 549-554

Research Article **ISSN: 2394 - 658X**

Behaviour of Concrete Utilizing Metakaoline: A Review

Basant K Bansal, Digvijay S Chouhan, Trilok Gupta and Ravi K Sharma

Department of Civil Engineering, College of Technology and Engineering,
Maharana Pratap University of Agriculture and Technology, Rajasthan, India
b.k.bansal20@gmail.com

ABSTRACT

Concrete is the major component of construction industries used extensively as a building material. Cement is one of the basic component of concrete used as binding material. With the increasing demand of concrete demand of cement is also increasing throughout the world. The production of cement is accompanied with huge energy consumption and emission of harmful gases that results in environmental pollution. In order to overcome these problems, it is necessary to reduce the use of cement in concrete by its partial replacement by some supplementary cement products. Based on recent researches and studies it has been observed that the use of metakaolin as a supplementary cementing material in concrete improves not only the properties of concrete but also reduces the environmental pollution. Metakaolin react with $Ca(OH)_2$ and convert into CSH gel which result in improve the strength properties. This paper reviews the use of metakaolin as a supplementary cementing material in concrete. The paper incorporates detailed literature investigation based on the topic and detailed here.

Keywords: Metakaolin, Cement, Sustainable construction

INTRODUCTION

Concrete is the most extensively used material in civil engineering and is the primary component in most infrastructures. According to Portland cement association about 3.8 billion m^3 concrete is produced annually. Cement is a main binding material which is used in concrete production. With increasing demand of concrete, demand of cement is also increasing in all over the world. Portland cement production is one of the major cause of CO_2 and oxides of other harmful gases emission in environment [1-2]. These oxides emission in the cement production is due to the calcinations of $CaCO_3$ and combustion of fossil fuels [3]. Moreover, a large amount of energy is also consumed in the cement production [4]. There is required to produce sustainable concrete by using other pozzolonic materials. Strength of concrete is most important, it is also very much needed that the concrete should be durable, workable and provide a good service life [5]. In the past few years, many research & modification has been done to produce eco-friendly concrete modified with cementing materials such as fly ash, silica fume rise husk, ballast furnace etc.

Metakaolin is a pozzolonic material which is derived from natural mineral and manufactured specially for cementing applications [6]. Some researchers show that metakaolin can be used in concrete as a partial replacement of cement. It improves properties of concrete as similar to other supplementary cementing materials. Calcium hydroxide reacts with the added pozzolans resulting in formation of additional calcium silicate hydrate because of these technical advantages this can be used as a partial replacement of cement. Concrete can be modified with addition of this cementing material which improve the microstructure as well as decrease concentration of $Ca(OH)_2$ through the pozzolanic reaction and it also allows the reduction of the cement consumption. This paper reviews on the use of metakaolin as a partial replacement of cement to produce concrete.

PROPERTIES OF METAKAOLIN AND CONCRETE MODIFIED WITH METAKAOLIN

Metakaolin is an artificial pozzolanic material which is obtained from thermal treatment or calcinations of kaolin clay at temperature around 700-850ºC [7]. Due to its high pozzolanic activity, the inclusion of metakaolin improves the mechanical and durability properties [8]. Hence the environmental problems can be reducing and the life of buildings also increase by the use of metakaolin. When metakaolin is used in concrete as a partial replacement of cement it reacts with $Ca(OH)_2$ which is byproduct of hydration reaction of cement and results in additional CSH gel which results in increased strength [9]. The use of Metakaolin becomes ample ingredients in the production of concrete of more than 40Mpa or where service environments, exposure conditions or life cycle cost considerations dictate the use of High Performance concrete. For High Strength Concrete Silica Fume/Micro Silica can be used. When these are replaced by metakaolin, concrete of equivalent strength and durability properties developed along with several additional features like reduced water permeability and workability [6].

Properties of Fresh Concrete Utilizing Metakaolin

It is generally noticed that metakaolin make adverse effects on the workability of concrete. Ding *et al* [10] observed the effect of metakaolin and silica fume and it noticed that metakaolin offered a much better workability than silica fume for a given mixture proportion. Slump was increase up-to 10% when replacement level was 10%. Concrete mixtures modified by metakaolin less high-range water reduction admixture than silica fume mixtures to achieve similar workability at same W/C ratio [11]. Metakaolin decrease the workability of concrete.

Properties of Hardened Concrete Utilizing Metakaolin

On hardened concrete compressive, tensile, and flexure strength tests have been observed and reported below -

Compressive Strength

There have been many studies on the strength development of concrete containing metakaolin. These studies have demonstrated clearly that with intelligent use considerable improvement in strength, especially at early stage of curing, can be produced. Caldarone *et al* [11] produced concrete with 5% and 10% metakaolin which showed increased strength. They reported that metakaolin –pozzolana cement exhibited strengths, which were slightly more than silica fume-pozzolana cement mixtures at the same level of cement replacement by the pozzolana. Similar influences of metakaolin on the strength of concrete have been reported by researchers [12]. From this investigation there are identify three factors, which influence the contribution that metakaolin makes on properties of concrete. These are (a) the filler effect, which is immediate (b) the acceleration of pozzolana cement hydration, which occurs within the first 24 hours (c) the pozzolanic reaction, which has its maximum effect within the first 7-14 days for all metakaolin levels between 5% to 30% with 5% incremental order. John [13] analyzed the effects of metakaolin on strength of concrete. An experimental investigation carried out to find the suitability of metakaolin in production of concrete. The referral concrete M30 was made using 53 grade OPC and the other mixes were prepared by partial replacement of cement with metakaolin in range of 5% to 20% in 5% incremental order at water cement ratio 0.45. Various experiments were carried out to find the strength. Results showed that strength improved up to 15% replacement of cement by metakaolin. Jian-Tong Ding *et al* [10] Investigated the effects of metakaolin and silica fume on the properties of Concrete. Cement was partially replaced with high reactive metakaolin and silica fume in range of 0% to 15% in 5% incremental order at w/c ratio 0.35. Results show that the strength of metakaolin modified concrete increased at all ages. Cement replacement up-to 12% with metakaolin leads to increase in compressive strength for M35 grade of concrete [14]. Metakaolin improve compressive strength of concrete within the replacement range of 10-12%.

Split Tensile Strength

Concrete mixes were prepared to investigate the mechanical behaviour of concrete. Cement was partially replaced with metakaolin and the replacement level was 0% - 20% with 5% incremental order at 0.4 w/c ratio. Split tensile strength test was performed on cylindrical specimen after 28 days of curing. The tensile strength value of concrete increases with increases percentages of cement replacement with metakaolin up to a percentage of 15% [15]. Other investigation was carried out to investigate the behaviour of concrete with different replacement level of metakaolin for M20 and M25 grade of concrete and found that specimen get higher strength at 15% replacement level for both grade of concrete. Strength of concrete increase as the percentage of metakaolin increased till 15% [1]. The split tensile strength increases with increasing amount of metakaolin upto 15% replacement of cement.

Table-1 Chemical Properties of Metakaolin

Chemicals composition	Anbarasan *et al*	Aiswarya *et al*	Narmatha *et al*	Nova john	Sawant *et al*
SiO_2	51.52	62.62	54.3	52-54	51.52
Al_2O_3	40.18	28.63	38.3	44-46	40.18
Fe_2O_3	1.23	1.07	4.28	0.6-1.2	1.23
MgO	0.12	0.15	0.08	0.03	0.12
CaO	2.00	0.06	0.39	0.09	2.00
Na_2O	0.08	1.57	-	0.10	0.08
K_2O	0.53	3.46	0.50	0.03	-
TiO_2	2.27	0.36	-	0.65	-
LOI	-	2.00	0.68		-

Flexural Strength

Flexure strength was performed on for each mix, total 12 number of beam specimen of size 100mmx100mmx500mm. Replacement level was 0-20% with 5% incremental order. Test was performed in flexure testing machine. Flexure strength of the specimens which content metakaolin was compared with control specimen. The flexure strength at the replacement 5%, 10%, 15% and 20% was increases 4.76%, 11.11%, 14.28% and 7.94% respectively as compare to controlled mix. Specimen which content 15% metakaolin show better flexure strength [15]. Same investigation was carried out by John [13]. Results of flexure strength at 28 days of curing were compared with control mixes. The flexure strength at 28 days of curing for control mix achieved 5.84Mpa and for other mixes which containing 5%, 10%, 15% and 20% of replacement got a strength gain of 4.79%, 8.22%, 15.24%, and 10.45% respectively in comparison with control mix. Kulkurni *et al* performed the flexure strength test on specimen which containing 0%, 5%, 10% and 15% replacement of cement with metakaolin for M20 and M25 grade of concrete [16]. Literature showed that flexural strength increased up-to 10 % replacement of cement with metakaolin.

Durability Properties of Concrete Utilizing Metakaolin

Durability is the important factor to judge the life of concrete, Water absorption test, rapid chloride test is reported to study the durability properties of concrete utilizing metakaolin as a partial replacement of cement as below:

Water Absorption

Investigation was carried out by Dinkar *et al* [17]. Absorption test and rapid chloride test were carried out to determine water absorption capacity and chloride permeability of concrete specimen. Results shows that the water absorption also reduced as the metakaolin replacement levels increased and all the concrete samples containing metakaolin showed very low chloride permeability.

Sulphate Resistance

Investigation was carried out by Khatib *et al* to determine the effect of metakaolin on the sulphate resistance properties of concrete. It was observed that expansion was decreased with increase in metakaolin within range of 5 to 20%. Metakaolin based concrete showed more chemical resistance as compared to plane portland cement based concrete [18]. It was observed from studies that significant reduction in the average pore size is obtained when the cement was replaced by 20% metakaolin. Metakaolin influence the pore structure in pastes and mortar and produces sustainable pore refinement. This leads to significant modification to the water transportation properties and diffusion rates of harmful ions. It was reported that metakaolin reduces the volume of capillary pores of sizes. Metakaolin produce a long term reduction in pore solution hydroxide ion concentration [12,18-19]. However, although there was a reduction in pore solution pH, from which it can be concluded that inclusion of up to 20% metakaolin will have little effect on the risk of chloride induced corrosion of embedded steel [12].

CASE STUDIES

Concrete utilizing metakaolin has been generally used for high strength concrete –

Case Study I: Strength Properties of Metakaolin Admixed Concrete [13]

In this case study the suitable % of metakaolin was investigated so that we can replace an optimum amount of cement with metakaolin. The results of study were carried out to investigate the effects of metakaolin on strength of concrete for that a referral concrete M30 was made using 53 grade OPC and the other mixes were prepared by partial replacement of cement with metakaolin. The replacement level was 0% to 20% by weight with 5% incremental order at water cement ratio 0.45. The compressive strength test, tensile strength test and flexural strength test were carried out to investigate the effect of metakaolin on various properties of concrete. The results were compared with reference mix.

The compressive strength test was carried out at 7 and 28 days of curing whereas split tensile strength and flexural strength were carried out at 28 days as per IS: 516 - 1981. The concrete specimens were tested for compressive strength and tensile splitting strength in a compression testing machine of capacity 2000KN and flexural Strength was tested in flexure strength testing machine. The development of compressive strength with age for all mixes indicated that the metakaolin admixed mixes attains higher compressive strength as compare to the control mix. The compressive strength development depends upon the metakaolin dosage and age of concrete. Concrete utilizing 15% replacement had maximum ultimate strength 41.19 N/mm^2 and 51.56N/mm^2 after 7 and 28 days of curing respectively. 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. The tensile strength of concrete specimen was increases with increase in percentage of metakaolin. The tensile strength was found maximum as 3.04 Mpa for 15 % metakaolin content and as the metakaolin content exceeds the value of 20%, the split tensile strength decreases to 2.95 Mpa. Concrete containing 15% of metakaolin had maximum value of split tensile strength. The flexural strength test was performed at 28 days of curing and the results shows that the flexural strength of concrete mix increases with increase in metakaolin. The flexural strength at 28 days curing for control mix was 5.84 Mpa and for other mixes M1, M2, M3 and M4 it was 6.12Mpa, 6.32Mpa, 6.73Mpa and 6.45Mpa respectively. Result indicated a strength gain of 4.79%, 8.22%, 15.24% and 10.45% respectively in comparison with control mix. The maximum value of flexural strength was obtained for 15% replacement of cement with metakaolin. The inclusion of metakaolin results in faster early age strength development of concrete and the test results indicated that use of metakaolin as a partial replacement of cement in concrete has improved performance of concrete up to 15% replacement.

Results encourage the use of metakaolin, as pozzolanic material for partial cement replacement in producing high strength concrete. Utilization of supplementary cementitious material like Metakaolin in concrete can useful for environmental, technical and economic issues which are related to cement production.

Case Study 2: Evaluation of Strength of Plain Cement Concrete with Partial Replacement of Cement by Metakaolin & Fly Ash [16]
This study was carried out to investigate the optimum percentage of metakaolin and fly ash which can be used in concrete as a partial replacement of cement. The compressive strength and flexural strength tests were performed to determine the optimum percentage. The experimental investigation was divided into four phases. Concrete mix designed as per IS 10262-2009 for M20 and M25 grade of concrete. Cement was partially replaced in range of 0% to 15% with 5% incremental order for both metakaolin and fly ash. Casting of specimens and then curing of cubes and beams for 7 days and 28 days and after that testing of specimens were carried out. The beam specimens were simply supported with a concentrated load applied at mid span. Load was applied by using UTM of 40 tons capacity in 40kg increments up to failure load. At each load increment cracks were inspected, marked, and photographed. Continuous monitoring was carried out all through the testing. Compression test was performed after 7 and 28days of curing period, the specimens were taken outside from the curing tank and tested under a compression testing machine of 200-ton capacity. The crushing load was noted and the average compressive strength of three specimens was determined. There were forty-eight cube samples of size 150x150x150mm for different percentages of metakaolin and fly ash in partial replacement of cement, casted to determine the compressive strength. 48 beam specimens of size 750mmx150mmx150mm were cast for flexural strength test. Average of three cubes was taken for compressive strength and average of three beams were taken for flexural strength. Strength of concrete M20 and M25 was 19.11 N/mm^2 and 19.55 N/mm^2 respectively after 7 days of curing for 10% replacement of cement. Similarly, for 15 % replacement of cement it was 19.15 N/ mm^2, and 19.60 N/ mm^2. Strength of both concrete samples after 28 days of curing was 19.78 N/mm^2 and 24.70 N/mm^2 for 10 % replacement of cement and 19.85 N/mm^2, 24.71 N/mm^2 for 15% replacement of cement. The flexural strength test was performed according to B.S. 1881: part 118, 150x150x750mm specimens were tested. Strength for concrete M20 and M25 was 9.7 N/mm^2 and 10.17 N/mm^2 respectively at age of 7 days for 10% replacement of cement. Similarly, for 15 % replacement of cement it was 9.9 N/mm^2, 10.35 N/mm^2 after 7 days of curing. The strength of both samples M20 and M25 was 10.16 N/mm^2, 10.25 N/mm^2 for 10% replacement of cement and 10.27 N/mm^2, 10.77 N/mm^2 for 15% replacement after 28 days of curing. Metakaolin and fly ash mixed concrete showed improvement in flexural strength as compare to conventional concrete. Plain concrete is a brittle material and fails suddenly and test results indicated that addition of Metakaolin & Fly ash to concrete changes its brittle mode of failure into a more ductile one and improves the concrete ductility. The compressive strength and flexural strength of concrete increases with metakaolin & fly ash content up to 15% replacement of cement. if there further increases in replace of cement by more than 15% strength its starts reducing.
Result indicated that if cement replaced by metakaolin and fly ash up to 10-15% there is increased in compressive strength as well as in flexural strength for concrete. Therefore, it always preferable to use metakaolin & fly ash with 10% replacement of cement and it gives us better result.

Case study 3: Effect of Metakaolin Content on the Properties of High Strength Concrete [17]
This study shows the influence of metakaolin on the mechanical and durability properties of high strength concrete for 0.3 water cement ratio. Metakaolin containing concrete with cement replacement of 5, 10 and 15 % were designed for target strength of 90 Mpa and slump of 100 ± 25 mm. Trials mixtures were prepared to obtain target strength of more than 90 Mpa for the control mixture at 28 days and the water cement ratio for all the mixtures were kept constant at 0.30. Four different mixtures (MK0, MK5, MK10 and MK15) were employed to examine the influence of low water cement ratio on the mechanical and durability of concrete containing MK. The control mixture (MK0) did not include MK. In other mixes MK5, MK10 and MK15, cement content was partially replaced with 5%, 10%, and 15% MK (by mass) respectively. Three 100x100x100mm size cubes were cast for the compressive strength. Three 100x200mm cylinders were cast for the splitting tensile test. Three cylindrical samples of size 150x300mm were cast for the modulus of elasticity test. Two samples of size 100x100x100mm were cast for water absorption study. Two samples of size 150x150x150mm were cast for water permeability test. Three cubes of size 150x150x150mm were cast for the water penetration depth test and two cylindrical samples of size 100x200 mm cylinders for the rapid chloride penetrability test.The workability of the fresh concrete was measured by the standard slump test apparatus. The compressive strength test was performed, at a loading rate of 2.5 KN/s at the age of, 3, 7,

28 and 90 days on 3,000 KN capacity machine. The split tensile strength was also tested on the same machine at the age of 28 days. The elastic modulus was determined at the age of 28 days. The specimens were placed vertically between the plates of the compression testing machine and tested. This test conforms to ASTM C 469 (ASTM 2006c) for static modulus of elasticity of concrete in compression. Permeability characteristics of the concrete were assessed at 28 days using Water Permeability Test. The compressive strength results of samples show that all the concretes made in this study are high strength, as even the seven-day compressive strength varied between 78 and 80 Mpa. The 28-day strength varied between 91Mpa to 99 Mpa, and the 90-day strength varied between 101Mpa to 106Mpa. The 15 % replacement MK mixture had exhibited lower strengths comparatively than the other MK percentages, but comparable strength at all the ages to that of control concrete. All the concrete samples including the control had achieved their target strength of 90 Mpa at 28 days and at 90 days all the concrete samples achieved strength of more than 100 Mpa. Results shows that the compressive strength was highest for the mix containing 10% metakaolin achieved strengths of 102.5Mpa and 106Mpa at 28 and 90 days respectively.

The average value of the 28-day tensile strength for the concretes made was about 4.85 Mpa, which corresponds to 5.15% of the compressive strength for the same concrete. From the results it can be concluded that similar to compressive strength the splitting tensile strength also exhibited the highest strength at MK 10 mixture. It observed from results that as the compressive strength increases, the tensile strength also increases. Using MK as a partial replacement for cement decreased the plastic density of the mixtures. The results indicated that by utilizing local metakaolin and cement designed for a low water cement ratio of 0.3, high strength and high performance concrete can be developed and compressive strength of more than 100 Mpa can be obtained. The optimum replacement level of OPC by MK was 10 %, which gave the highest compressive strength in comparison to that of other replacement levels. This was due to the dilution effect of partial cement replacement. These concrete also exhibited a 28-day splitting tensile strength of the order of 5.15 % of their compressive strength and showed relatively high values of modulus of elasticity. Splitting tensile strength and elastic modulus results was also followed the same trend to that of compressive strength results showing the highest values at 10 % replacement. As far as the durability properties are concerned, local metakaolin found to reduce water permeability, absorption, and chloride permeability as the replacement percentage increases.

CONCLUSION

Metakaolin is an artificial and eco-friendly cementing material. The review of past studies shows that metakaolin is a very effective pozzolonic material and results in improved strength at earlier stage as well as long term strength. The concluding remarks for the use of metakaolin as a partial replacement of cement are as follows:

- Workability of concrete decrease with increasing % of metakaolin.
- Metakaolin improve compressive strength of concrete within the replacement range of 10-12%.
- Flexural strength of concrete increases with increase in replacement level of metakaolin up-to 10 %.
- Maximum split tensile strength achieved at 15% replacement of cement with metakaolin.
- Metakaolin improve the durability properties. It reduces the permeability of water and also reduces the chloride diffusion rate.

The production of metakaolin requires less energy demand and will also reduce the emission of greenhouse gases. Therefore, utilization of metakaolin in production of concrete will solve the various problem and challenges associated with the production of cement and approaches towards sustainable development.

REFERENCES

[1] BV Surendra and TN Rajendra, An Experimental Investigation on Strength Properties of Concrete with Partial Replacement of Cement by Fly Ash and Metakaolin and with M-Sand as Fine Aggregates, *International Research Journal of Engineering and Technology*, **2016**, 3 (7), 2150-2153.

[2] DS Chouhan, Y Agrawal, T Gupta and RK Sharma, Utilization of Granite Slurry Waste in Concrete: A Review, *Indian Journal of Science and Technology*,**2017,** 8(1), 1-9.

[3] P Jaishankar and EV Rao, Experimental Study on Strength of Concrete by using Matakaolin and M-Sand, *International Journal of Chem Tech Research*, **2016,** 9(5), 446-452.

[4] A Anbarasan and M Venkatesan, Strength Characteristics and Durability Characteristics of Silica Fume and Metakaolin Based Concrete, *International Journal of Innovation in Engineering and Technology.,* **2015,** 5(1), 1-7.

[5] A Niveditha and S Manivel, Effects of Partial Replacement of Cement by Metakaolin in Sifcon, *International Journal of Engineering and Management Research*, **2014,** 4(2), 100-103.

[6] SN Patil, AK Gupta, & SS Deshpande. Metakaolin-Pozzolanic material for cement in high strength concrete. *In Proceedings of the 2nd International Conference on Emerging Trends in Engineering*, **2013**, 46-49.

[7] HS Kim, SH Lee and HY Moon, Strength Properties and Durability Aspects of High Strength Concrete Using Korean Metakaolin, *Construction and Building Material*,**2007,** 21(6), 1229-1237.

[8] H Paiva, A Velosa, P Cachim and VM Ferreira, Effect of Metakaolin Dispersion on the Fresh and Hardened State Properties of Concrete, *Cement and Concrete Research*,**2012,** 42(4), 607-612.
[9] S Aiswarya, AG Prince and C Dilip, A Review on use of Metakaolin in Concrete, *Engineering Science and Technology*, **2013,** 3(3), 592-597.
[10] JT Ding and Z Li, Effects of Metakaolin and Silica Fume on Properties of Concrete, *ACI Materials Journal*, **2013,** 99(4), 393-398.
[11] MA Caldarona, KA Gruber and RG Burg, High Reactivity Metakaolin: A New Generation Mineral Admixture, *Concrete International*, **1994,** 16(11), 37-41.
[12] JM Khatib and S Wild, Pore Size Distribution of Matakaolin Paste, *Cement Concrete Research*,**1996,** 26(10), 1545-1553.
[13] N John, Strength Properties of Metakaolin Admixed Concrete,*International Journal of Scientific and Research Publications*, **2013,**3(6), 1888-1894.
[14] YR Suryawanshi, AG Kadam, SS Ghogare, RG Ingale and PL Patil, Experimental Study on Compressive Strength of Concrete by Using Metakaolin, *International Research Journal of Engineering and Technology*, **2015,** 2(2), 235-239.
[15] AR Vipat and PM Kulkarni, Performance of Metakaolin Concrete in Bond and Tension, *International Journal of Engineering Sciences* and *Research Technology*, **2016,** 5(3), 762-765.
[16] NK Kulkarni andAA Haname, Evaluation of Strength of Plain Cement Concrete with Partial Replacement of Cement by Metakaolin and Fly Ash, International *Journal of Scientific Research and Education*, **2015,** 3(5), 3443-3450.
[17] P Dinkar, PK Sahoo and G Sriram, Effect of Metakaolin Content on the Properties of High Strength Concrete, *International Journal of Concrete Structures and Materials*, **2013,** 7(3), 215–223.
[18] DM Roy, P Arjunan and MR Silsbee, Effect of Silica Fume, Metakaolin and Low-Calcium Fly Ash on Chemical Resistance of Concrete, *Cement and Concrete Research*,**2001,** 31(12), 1809–1813.
[19] JA Kostuch, V Waltersand TR Jones, High Performance Concrete Incorporating Metakaolin- A Review, *Concrete*, **2000,** 2, 1799-1811.
[20] P Bredy, M Chabannet and J Pera, Microstructure and Porosity of Metakaolin Blended Cements, *Proceedings of Materials Research Society*, **1988**, 136-275
[21] BB Sabir, S Wild and J Bai, Metakaolin and Calcined Clays as Pozzolans for Concrete: A Review, *Cement* and *Concrete Composites*, **2001,** 23(6), 441-454.
[22] RM Sawant and YM Ghugal, Recent Trends: Use of Metakaolin as Admixture: A Review, *American Journal of Engineering Research*, **2015,** 4(12), 8-14.
[23] *www.cement.org/,* ***2016***