Utilization of industrial by-products as supplementary cementitious materials in bottom ash based cement mortar: A Review

V.Prabakaran[1], P.Ramadoss [2], R.Hindhumadhi[3],

[1]Associate Professor, Department of Civil Engineering, Puducherry Technological University, Puducherry

[2]Professor, Department of Civil Engineering, Puducherry Technological University, Puducherry

[3]PG Scholar, Department of Civil Engineering, Puducherry Technological University, Puducherry

Abstract: *Cement composites like mortar and concrete are the materials that have been used all over the world for a very long period. Cement is one of the major and irreplaceable ingredients which is the binder material in the production of mortar and concrete. Production of cement involves emission of large amounts of carbon dioxide gas into the atmosphere which is a major contributor for greenhouse effect and the global warming. Worldwide, due to high consumption of natural resources of aggregate in construction they are depleting rapidly. Over exploitation of sand have serious physical, ecological and social impacts. On the other hand, the industrial wastes are increasing year by year, which are creating problems. Since in most developing countries including India, there is no specific treatment plan for these wastes, therefore these wastes are sent to landfill instead of being reused and recycled. The disposal into the land causes dust, loss of vegetation, hazardous gas emission, toxic materials accumulation, wastage of large land site, ground and surface water contamination due to leaching and runoff, health issues etc. The idea of partial replacement of industrial by-products (fly ash, silica fume, Alccofine and bottom ash) in cement mortar is an effective approach in reducing the sand and cement demand as well as providing an eco-friendly method for waste disposal, reducing environmental pollution. The strength and durability of the cement based substances also gets improved. Partial replacement of supplementary cementitious materials in cement mortar and improvement of strength of mortar have been focused on this study review.*

Keywords: **Cement composite, Industrial by-product, Supplementary cementitious materials, Bottom ash, Fly ash, Silica fume, Alccofine.**

1. Introduction

In the modern era, cement composites like mortar and concrete are the most widely used construction material in the world. Cement is the binder material for producing mortar and concrete. Around 90% of the total carbon footprints of concrete manufacturing comes from cement production. Carbon dioxide (CO2) accounts about 7% of globally releasing greenhouse gases (GHG). The share of the CO2 is very high when compared to other GHGs in the energy sectors. The proportion of CO2 emission not only shows the harmful impact on the ecological balance but also accelerates the GHG effect and in turn causing an increase in global warming. Even though the production of cement releases the GHGs as a byproduct, still there is huge demand for this material worldwide for the expanding infrastructure development. The rapid urbanization and industrialization in last few decades have led to depletion of the construction materials like sand and accumulation of industrial wastes (by- products). The detrimental effect of excessive dredging of sand from river bedsmon environment has led to perceiving an ideal substitute for natural aggregate. Worldwide, many industrial wastes such as coal bottom ash, fly ash, GGBS, rice husk ash, Alccofine, silica fume, and metakaolin etc., are produced in huge quantity. These industrial by-products are increasing year by year, which are creating problem from sustainability point of view. They require a massive area of land for their safe disposal. The increasing cost of landfilling and various health hazard associated with its dumping has enforced to find some other methods of its disposal. Recycling of industrial by-products in construction industry can be a promising approach for sustainable growth. Partial replacement of industrial by-products (such as fly ash, Alccofine, silica fume and bottom ash) in cement mortar is an effective way of utilising them in a useful manner, since these waste materials are not further used in the industry from which they originate. On one side it helps in reducing the sand and cement demand and on other side it provides eco-friendly method for waste disposal, reducing environmental pollution. It also provides improvement in strength and durability of the cement based substances. Therefore, the present paper aims to summarize the existing research on partially replacing cement with fly ash, silica fume and Alccofine, and sand with bottom ash with focus on fresh and hardened properties.

2. Objective of the study

The main objective of this study is to understand and to ascertain the effect of using industrial by-products as supplementary cementitious materials, in bottom ash based cement mortar. This study involves comparing the mechanical properties of the cement mortar of different mixes. The study defines which industrial by-products will enhance the strength of the cement mortar.

3. Literature review

R.Balamuralikrishnan (2021). Their study focuses on the effect of addition of Alccofine on the compressive strength of cement mortar cubes. They prepared cement mortarfor the mix proportion of 1:3, with partial replacement of cement by Alccofine. Four combinations of cement mortar cubes were prepared using Alccofine (for percentage variation from 0% to 20% with an increment of 5%) along with two types of cement and sand. The four combinations were: (a) OPC + Ennore sand + Alccofine, (b) OPC + River sand + Alccofine, (c)PPC + Ennore sand + Alccofine and (d) PPC + River sand + Alccofine. They concluded that, among all the combinations, the maximum compressive strength of cement mortar cubes is achieved by using 10% Alccofine with OPC and Ennore sand. The strength of cubes mainly depends upon the percentage of Alccofine based on its high pozzolanic nature to form a denser Calcium Silicate Hydrate (CSH) gel. Addition of Alccofine provided some significant contribution to cement in its strength. When percentage of Alccofine is increased beyond 10%, it acts as filler material for cement mortar cubes.

B.L.N. Sai Srinath (2021). This paper presents a review of utilization of Alccofine as a supplementary cementitious material to improve the fresh, mechanical & durability properties of concrete. It was concluded that, Alccofine enhances the strength, workability, and durability properties of the concrete. The optimum Alccofine dosage may be varied between 10% and 15%. With addition of Alccofine, the compressive strength increases due to its fineness and better packing property. The ultra-fine particles of Alccofine provide much better and smoother surface finish. Alccofine decreases the use of High Range Water Reducer (HRWR) in concrete to attain proper slump. The reduction in water demand arises due to the existence of the glass content which has inbuilt water-repelling properties. Due to the nature of finer pore structure of Alccofine and its stability towards chemicals, it provides more resistance towards chloride diffusion. This in turn reduces the deep penetration of chlorides elements into the concrete and guards the embedded steel against being corroded. This results in the improved durability of concrete.

Nitin Ankur (2021). Their study focuses on performance of cement mortars containing coal bottom ash. They concluded that, incorporation of coal bottom ash (CBA) resulted in lower workability at all replacement levels (5– 100%) than the mixes prepared without bottom ash. CBA provides porous structure which results in higher water absorption, resulting in additional water demand for covering the surface of the CBA particle, consequently increasing the flowability. The additional water tends to increase the porosity of the matrix resulting in lowering the compressive strength. The adverse effect caused due to additional water demand in CBA can be compensated with the addition of super-plasticizers. The density of the mortars prepared with bottom ash is generally low at all replacement levels. It is useful in lightweight construction. The reduction in the densities is the result of the increase in void proportions and lower specific gravity due to the incorporation of CBA. The performance of bottom ash based mortars in terms of mechanical properties like compressive strength, tensile strength, and flexural strength increases upto 40% replacement of fine aggregate by bottom ash, and beyond this replacement level, bottom ash based mortars exhibit lower values of the mechanical properties. The replacement of stronger material with weaker ones and higher pore fraction at higher replacement levels could be the cause of decrease in the compression strength values. Higher porosity leads to the maximization of lateral tension around the pores whenever a specimen is subjected to compressive forces. This results in lower compressive strength values at higher replacement levels. In microstructural analysis, it was found that upto 40% replacement of fine aggregate by bottom ash results in dense microstructure, and with further addition, the porous structure of CBA comes into action and pore size in the binder paste consequently rises drastically.

S.C. Boobalan (2021). This paper presents a comprehensive review on strength properties for making Alccofine based high performance concrete. It was concluded that, the optimum dosage for Alccofine 1203 is 15%, which enhances the durability, strength and workability of High performance concrete. The CaO present in Alccofine induces the pozzolanic reactions which forms additional C- S-H gel. This results in achieving higher strength in concrete. When optimum percentage of Alccofine is used, it acts as water reducer, improving the workability and strength of the concrete.

Rahul Raj Kundanati (2020). In this paper, mechanical properties of mortar by using Alccofine and graphene oxide were studied. They prepared cement mortars by partially replacing cement with Alccofine and adding water dispersed graphene oxide in 1:3 cement sand mortar mix. The w/c ratio was maintained at 0.30 along with water reducing agent. Here, initially cement was replaced by Alccofine 1203 at 10%, 15% and 20%. Compressive strength test showed improvement at 15% replacement of cement by Alccofine, when compared to conventional mortar. The raw material contained low calcium silicates along with other compounds, due to which the particle size distribution was uniformly refined, reducing the water content whilst maintaining the workability, resulting in better

compressive strength. The flexural strength improved at 15% replacement of cement by

Alccofine. This increase was due to the dense pore structure andinherent calcium oxide of Alccofine.

Abhishek Srivastava (2020). This paper presents study on properties of alternate sands which could be used as fine aggregate. For bottom ash, it was concluded that, the porous nature of coal bottom ash particles leads to reduction in workability of mortar at particular water content, since available water is absorbed by the porous particles. So, more amount of water is added to increase workability, which leads to strength reduction. To meet the increased water demand, superplasticizers should be used rather than increasing water content. The optimum replacement percentage of natural sand with coal bottom ash was found in the range of 20-40%. Further addition caused lowering of strength. Reduction in density and effective cross section caused by higher porosity of the coal bottom ash mortar, results in formation of local tension zone around the pores during compression and promotes local failure, leading to reduction in strength. For flexural strength, there was improvement in flexural strength for 20% replacement, but beyond that its started decreasing. The tensile strength of mortar marginally increases when 20% of sand was replaced by coal bottom ash. With higher replacement, a fall was observed in tensile strength value. When the macroscopic behaviour of mortar mix was investigated by SEM analysis, it was found that inclusion of coal bottom ash in mortar initially increased the number of pores in the mix, but the voids got reduced with curing age.

Ali Abdulhasan Khalaf (2018). In this work, they prepared mortar mix of ratio 1:3 with w/c ratio of 0.4. The cement was replaced by fly ash in various proportions ranging from 0% to 20% by weight of cement with an increment of 5% in each mix. The fly ash based mortars gave longer setting time in terms of initial and final setting times. The more the percentage of fly ash replacement, longer is the setting time. 10% replacement of fly ash gave highest compressive strength when compared to other percentage of replacement. The compressive strength development depends upon two major parameters: the percentage of fly ash replacement and the age.

Ardra Mohan (2018). This paper deals with the study of strength and durability properties of self compacting concrete (SCC) incorporating silica fume and Alccofine. Here, concrete specimens were prepared by replacing cement with 5, 10 and 15% silica fume or Alccofine by weight with a w/c ratio of 0.34. The workability was slightly reduced by the inclusion of silica fume. The water requirement was extended by the higher surface region of silica fume which lessens the quantity of water available for fluidization. As Alccofine have better molecule dispersion it gives thick lattice pore structure bringing about to diminished water substance and better workability. Mechanical strength tests were performed and it was concluded that 10% silica fume replacement gives better compressive strength when compared with SCC without supplementary cementitious materials (SCM) and Alccofine as SCM. This may be due to the fineness of silica fume and physical character of better packing. Silica fumes at higher substitutions furthermore have achieved decrease in quality. There was increase in split tensile strength at 10% substitution of silica fume. This was due to the pozzolanic nature of SCM which provides a modified paste characteristics and good transition zone.

Sajedeh Sadat Ghazizadeh Hashemi (2017). This study focuses on microstructural characteristics and mechanical properties of bottom ash mortar. Cement mortar specimens were casted by replacing the silica sand by bottom ash in the range of 0- 100% at increments of 20% with water to cement ratio of 0.55. It was found that the flowability of a mortar decreases with an increase in the volume of bottom ash. The bottom ash contains higher porosity, which leads to higher water absorption. So, more water is required to cover the surface of bottom ash particle and to increase the flowability. The addition of water increases the porosity of the matrix, and thus, a reduction in the compressive strength. Therefore, to avoid such an adverse effect, an increase in flowability can be provided by adding a superplasticizer. The compressive strength of the cement based mortar improved when the silica sand replacement with bottom ash is limited to below 40% of the total fine aggregate. However, a high-volume bottom ash replacement had a contrary outcome on the compressive strength of the mortar. The cause of decrease in the compressive strength of the bottom ash concrete mixture was due to the replacement of the stronger material (silica sand) with a weaker one (bottom ash), and the increase in the pore fraction of the concrete. Additional porosity to the matrix lead to a decrease in effective cross section. Therefore, when the material was under compression, a lateral tension maximized around the pores and a local failure occurred in these areas. SEM micrographs of specimens showed that, when the silica sand was replaced with 40% bottom ash, the composite showed a dense structure. In these specimens, the pore size was reduced. This is attributed to the pozzolanic reaction of bottom ash which causes an expansion through the material and filling of some pores over time. The porous structure of bottom ash is dominant in samples with high volume of this fine aggregate.

B.Kaviya (2017). This paper presents study on partial replacement of cement using Alccofine, M30 grade concrete were prepared. Cement was partially replaced by Alccofine at various percentages of 5%, 10% and 15%. For compressive strength, the optimum percentage of Alccofine replacement was 10%. For split tensile strength, the optimum percentage of Alccofine replacement was 10%.

Lakhbir Singh (2016). This paper presents the study on effect of partial replacement of cement by silica fume, on the mechanical properties of concrete. Concrete specimens of M30 grade were prepared. Cement was replaced by silica fume at percentages varying from 0% to 15% by weight, with an increment of 5%. The results of mechanical strength tests concluded that during compressive strength test, the optimum percentage replacement of silica fume was found to be 10%. The Compressive strength tends to increase with increasing percentages of silica fume in the mix and decreases after 10% replacement. For split tensile strength test also, the optimum percentage of silica fume replacement was found to be 10%. The split tensile strength tends to increase with increasing percentages of silica fume in the mix and decreases after 10% replacement.

K.Gayathri (2016). This paper presents study on cementing efficiency of Alccofine in concrete. Here, M20 grade concrete was prepared with w/c ratio of 0.5. Cement was replaced by Alccofine at various percentages from 0% to 20% with an increment of 5%. 15% replacement of cement by Alccofine provided maximum strength when compared to all other mixes. Further increase in replacement reduced the strength.

Harjinder Singh (2015). In this work, three proportions of mortar mixes, 1:3, 1:4 and

1:6, with different percentages of silica fumes replacement with sand/cement was prepared. Here, the w/c ratio considered was 0.5. In the first mix, the sand was replaced by silica fume at varying percentages of 5%,10% and 15%. And in the second mix, the cement is replaced by silica fume at 5%, 10% and 15%. The increase in compressive strength was found to be maximum for the mix proportion 1:3 for all the percentages of silica fume addition. Therefore, richer mix is more responsive in addition of silica fume. For 1:3 ratio, the compressive strength of mortar increased by 40% with the replacement of sand by 15% of silica fume. And for the same ratio, the compressive strength of mortar increased by 37% with the replacement of cement by 10% of silica fume. The compressive strength of silica fume modified mortar increased by 10% in the case of sand replacement in comparison to cement replacement by equal proportion in the same mix.

T. S. Thandavamoorthy (2015). This paper deals with feasibility of making concrete using lignite coal bottom ash as fine aggregate. Here, M25 grade concrete were prepared with w/c ratio of 0.45. Fine aggregate was partially replaced by bottom ash at various percentages of 25%, 50% and 100%. For compressive strength, the optimum percentage of bottom ash replacement was 25%. With higher percentages of bottom ash the strength decreased. For split tensile strength, the optimum percentage of bottom ash replacement was 25%. With higher percentages of bottom ash the strength decreased. The flexural strength of bottom ash concrete with 25% level had achieved the highest increase in flexural strength.

Fouzia Shaheen (2015). They studied regarding the effect of metakaolin and Alccofine on strength of concrete. M40 grade concrete with w/c ratio of 0.45 were prepared. Cement was replaced by metakaolin and Alccofine. The replacement levels of metakaolin were selected as 5% and 7.5% and the replacement levels of alccofine were selected as 5%, 10% and 15% by weight of cement. The compressive strength and flexural strength of concrete was increased with increase in replacement levels of metakaolin and Alccofine. The increase in compressive strength is due to the void filling ability of metakaolin and Alccofine. Additional calcium silicate hydrate is formed by reaction of silica of pozzolan and calcium hydroxide produced by the cement hydration. The maximum increase in compressive strength was achieved with 10% replacement of Alccofine. The maximum increase in flexural strength was achieved with 10% replacement of Alccofine. The dense pore structure and the calcium oxide of Alccofine increased the flexural strength.

Siddharth P Upadhyay (2014). In this work, M60 grade concrete was prepared with w/c ratios as 0.45 and 0.5. Cement was replaced by Alccofine at percentages ranging from 4%-12% with an increment of 2%. Mechanical strength test was performed on the prepared specimens. It was found that, the maximum compressive strength was obtained at 10% Alccofine replacement. The addition of Alccofine increased the characteristics of concrete like filling ability and resistance to segregation.

P. Ramadoss (2013). In this work, lignite based bottom ash was used as partial replacement of fine aggregate in mortar. Masonry mortar of ratios 1:3 and 1:4, incorporating bottom ash as partial replacement of fine aggregate at 20, 30, 40 and 50% by weight were prepared for a water/cement ratio of 0.5. It was observed from SEM analysis

that, bottom ash contains high silica content due to which it could be used as fine aggregate.

An improvement in compressive strength of 1.7% for masonry was obtained at 20% replacement of sand by bottom ash, compared to control mix. This may be due to filler effect of bottom ash, beyond which there is no improvement in strength. The compressive strength decreased at higher percentage of bottom ash replacement since more amount of water was added to maintain the consistency of mortar. Flexural tensile strength was increased by 2.0% at 20% bottom ash replacement, and then there is no improvement in strength.

S L Patil (2012). They performed technical analysis for compressive strength of fly ash concrete. M20 grade concrete mix was prepared with w/c ratio of 0.5. The cement was replaced by fly ash in various proportions ranging from 5% to 50% by weight of cement in steps of 5%. The initial setting time increased with increase in fly ash replacement. This was due to the retardation of cement hydration due to fly ash. The workability increased from 25mm (for 0% fly ash) to 120mm (for 25% fly ash) which was due to the soothing effect of fine fly ash particles. The concrete containing 10% of fly ash (replacing cement), gained a compressive strength about 6% higher than the concrete without fly ash content. So, optimum percentage of fly ash is 10%.

H.K. Kim (2011). In this study, they investigated the flow, water absorption, and mechanical characteristics of normal and high-strength mortar incorporating bottom ash as fine aggregates. Mix proportions with various w/c ratios (50%, 38%, 30%, 24%, and 20%) were prepared to evaluate the effects of fine bottom ash aggregates on normal and high strength mortar. Two types of mixtures were made (one with normal fine aggregate and other with fine bottom ash aggregate) for varying w/c ratios. The results of the tests performed indicated that when normal fine (NF) aggregates were replaced by fine bottom ash (FBA) aggregates, the mortar flow was increased. The increase in flowability was due to the absorbed water in FBA aggregates. Water absorption of FBA aggregates is more than NF aggregates. The absorbed water by FBA aggregates spilled out during the mixing process, due to which the viscosity gets reduced and mortar flow gets increased. With increase in FBA content in mortar, the compressive strength decreased. The lower compressive strength of mortar was due higher porosity.

Muhannad Ismeik (2009). In this work they prepared concrete mix with w/c ratios of 0.30, 0.35 and 0.40. Silica fume and fly ash were replaced in the range of 0 to 15% and 0 to 25% respectively. For compressive strength, for all w/c ratios, 10% replacement of cement with silica fume improved the compressive strength with respect to control. The increase in strength was initially due to filling of voids and the pozzolanic action of silica fume. The optimum percentage of fly ash replacement was 15% which showed an improvement in compressive strength. Higher percentage of fly ash reduced the strength. For flexural strength, the optimum silica fume replacement percentage in 15%. The increase in strength was due to the pozzolanic reaction and improved interfacial bond between paste and aggregates.

4. Conclusion

Following conclusions have been drawn from the literature study on various industrial by-products used by many researchers for partial replacement in cement mortar:

- Various industrial by-products (such as bottom ash, fly ash,silica fume and Alccofine)

can be used as partial replacement of cement and sand in mortar for improving strength.

- Bottom ash could be used as partial replacement of sand. The maximum strength in cement mortar is attained at 20% replacement of sand by bottom ash. This may be due to filler effect of bottom ash. Beyond this replacement, there is no further improvement in strength. The replacement of stronger material with weaker ones and higher pore fraction at higher replacement levels could be the cause of decrease in the compression strength values. Higher porosity leads to the maximization of lateral tension around the pores whenever a specimen is subjected to compressive forces. This results in lower compressive strength values at higher replacement levels.

- When normal fine aggregates were replaced by bottom ash, the mortar flow was increased. The increase in flowability was due to the absorbed water in bottom ash. Water absorption of bottom ash is more than normal fine aggregates. The absorbed water by bottom ash gets spilled out during the mixing process, due to which the viscosity gets reduced and mortar flow gets increased. When more amount of water is added to increase workability, it leads to strength reduction. To meet the increased water demand, superplasticizers should be used rather than increasing water content.

- The optimum percentage of Alccofine replacement is 10-15%. With addition of Alccofine, the strength increases due to its fineness and better packing property. And also, the CaO present in Alccofine induces the pozzolanic reactions which forms additional C-S-H gel. This results in achieving higher strength.

- The optimum percentage of silca fume replacement is 10-15%. With addition of silica fume, the strength increases due to the fineness of silica fume and physical character of better packing, and also the pozzolanic nature of silica fume which provides a modified paste characteristics and good transition zone.

- With addition of fly ash replacement, the mortar strength increases. The optimum percentage of fly ash replacement is 10- 15%. The increase in strength is due to better packing efficiency and pozzolanic nature of fly ash.

- The workability of mortar increased with addition of fly due to the soothing effect of fine fly ash particles. The initial setting time increased with increase in fly ash replacement due to the retardation of cement hydration due to fly ash.

5. References

[1] Balamuralikrishnan, R., & Saravanan, J. (2021). Effect of addition of alccofine on the compressive strength of cement mortar cubes. Emerging Science Journal, 5(2), 155–170.

[2] Srinath, B. L. N. S., Patnaikuni, C. K., Balaji, K. V. G. D., Kumar, B. S., & Manjunatha, M. (2021). A prospective review of alccofine as supplementary cementitious material. Materials Today: Proceedings, 47(xxxx), 3953–3959.

[3] Ankur, N., & Singh, N. (2021). Performance of cement mortars and concretes containing coal bottom ash: A comprehensive review. Renewable and Sustainable Energy Reviews, 149(June), 111361.

[4] Boobalan, S. C., Srivatsav, V. A., Nisath, A.M. T., Babu, A. P., & Gayathri, V. (2021). A comprehensive review on strength properties for making Alccofine based high performance concrete. Materials Today: Proceedings, 45, 4810–4812.

[5] Kundanati, R. R., Malpani, T., & Sairam, V. (2019). Study on Mechanical Properties of Mortar using Alccofine and Graphene Oxide. Materials Today: Proceedings, 22, 2431– 2438.

[6] Srivastava, A., & Singh, S. K. (2020). Utilization of alternative sand for preparation of sustainable mortar: A review. Journal of Cleaner Production, 253, 119706.

[7] Khalaf, A. A., Idan, F. K., & Nasser, K.Z. (2018). Effect the Local Fly Ash on Cement Mortar Properties. Journal of University of Babylon, Engineering Sciences, 26(5), 11–12.

[8] Mohan, A., & Mini, K. M. (2018). Strength and durability studies of SCC incorporating silica fume and ultra fine GGBS. Construction and Building Materials, 171, 919–928.

[9] Hashemi, S. S. G., Mahmud, H. Bin, Djobo, J. N. Y., Tan, C. G., Ang, B. C., & Ranjbar, N. (2018). Microstructural characterization and mechanical properties of bottom ash mortar. Journal of Cleaner Production, 170(September), 797–804.

[10]Kaviya, B., Rohith, K., Kindo, S., Kumar, M. J., & Divya, P. (2017). Experimental Study on Partial Replacement of Cement Using Alccofine. International Journal of Pure and Applied Mathematics, 116(13), 399– 405.

[11]Al-Eraky, M. M., Mohamed, N., Kamel, F., Al-Qahtani, A., Madini, M. A., Hussin, A., & Kamel, N. M. F. (2016). of Advanced Research Teaching Professionalism By Vignettes in Psychiatry for Nursing Students. International Journal of Advanced Research, 4(6), 625–634.

[12]Gayathri. K, Ravichandran. K, & Saravanan. J. (2016). Durability and Cementing Efficiency of Alccofine in Concretes. International Journal of Engineering Research And, V5(05), 460– 467.

[13]Harjinder Singh, Sikha Bansal (2015). Effect of Silica Fume on the Strength of Cement Mortar. International Journal of Research in Engineering and Technology, 04(02), 623–627.

[14]Thandavamoorthy, T. S. (n.d.). Feasibility of Making Concrete Using Lignite. 19–30.

[15]Shaheen, F., & Fazil, M. S. (2015). Effect of Metakaolin and Alccofine on Strength of Concrete. An International Journal (ESTIJ, 5(4), 2250–3498.

[16]Upadhyay, S. P., & Jamnu, M. A. (2014). Effect on Compressive Strength of High Performance Concrete Incorporating Alccofine and Fly Ash. Journal of International Academic Research for Multidisciplinary, 2(2), 125–130.

[17]Ramadoss, P., & Sundararajan, T. (2014). Utilization of Lignite-Based Bottom Ash as Partial Replacement of Fine Aggregate in Masonry Mortar. Arabian Journal for Science and Engineering, 39(2), 737–745.

[18]Pati, S. L., Kale, J. N., & Suman, S. (2012). Research Paper FLY ASH CONCRETE : A TECHNICAL ANALYSIS FOR. International Journal of Advanced Engineering Research and Studies E- ISSN2249-8974 IJAERS, 4–5.

[19]Kim, H. K., Jeon, J. H., & Lee, H. K. (2012). Flow, water absorption, and mechanical characteristics of normal- and high-strength mortar incorporating fine bottom ash aggregates. Construction and Building Materials, 26(1), 249–256.

[20]Ismeik, M. (2009). Effect of mineral admixtures on mechanical properties of high strength concrete made with locally available materials. Jordan Journal of Civil Engineering, 3(1), 78–9