A Literature Review on Combinations of Various Ternary Cements for Mortar and Concrete

Vineet Kumar[1], AnkitBatra, Anuj Parashar
Civil Engineering Department
UIET, MDU Rohtak

***Abstract*- Several cements are produced in previous decades to meet specific requirements. A modern type of cement which is cost saving, resource saving and energy efficient is produced recently. This type of cement is known as ternary cements consist two or more pozzolanic material with ordinary clinker. This reduces overall clinker content in cement. In this study, previous works on ternary cements are summarized in such a way so that, it can help for its future application and research studies. Due to its recent development wide number of doubt and problems are associated with these new ternary cements. Some of these problems are also discussed in this summary.**

Keywords: Pozzolan, SupplementaryCementanious Materials, Ternary blended cements

I. INTRODUCTION

Concrete is one of the major construction materials worldwide. This construction material is incomplete without a binding material i.e. cement. Cement is used from several decades in construction material and it is modified as per the demand of construction industry.The blended cements or pozzolanic cement becomes as a new option and accepted for various applications. Some more cement types were discovered such as Calcium Aluminate Cement, Calcium Sulfo-Aluminate Cement etc. but pozzolanic cement is the most widely used efficient way to overcome that problem like resource saving, cost effective, CO_2 emission control, etc. Some of supplementary cementanious materials (SCMs) and their properties are given below in Figure 1.

Cement industries are responsible for approximately 5% of the CO2 emissions globally in two forms i.e. CO2 emission from raw material and CO2 emission from fuel which together produce approx. 800-850 kg CO2 emission in one tone of clinker formation. China and India are the largest consumers of cement in the world. China itself produces more then 50% of cement of total world production as shown below in Figure 2. Many efforts were made to decrease this huge CO_2 emission. Pozzolanic cement helps in reducing the cost of its production and controlling the CO_2 emission for its production. Some standards also permit a high replacement of pozzolanic material with ordinary clinker (up 65% for fly ash in European standard).

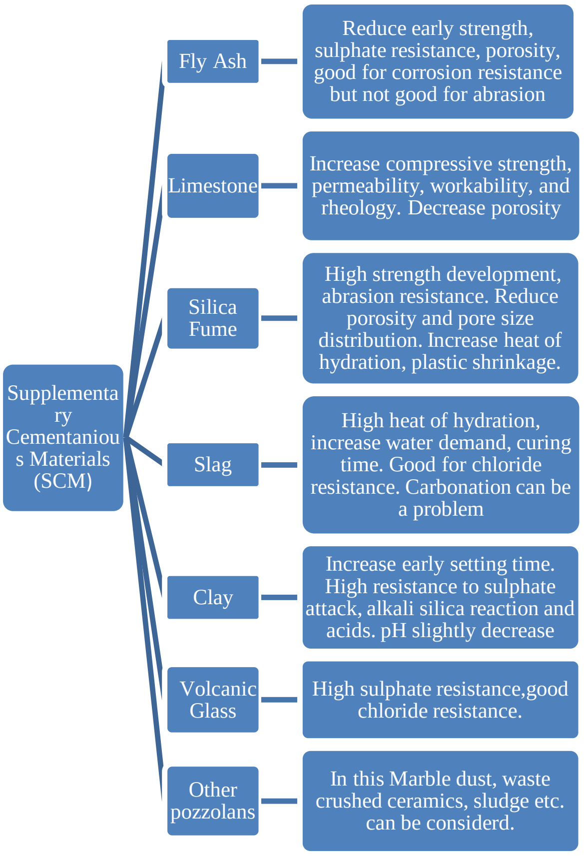

Fig 1: - SCMs and their effects

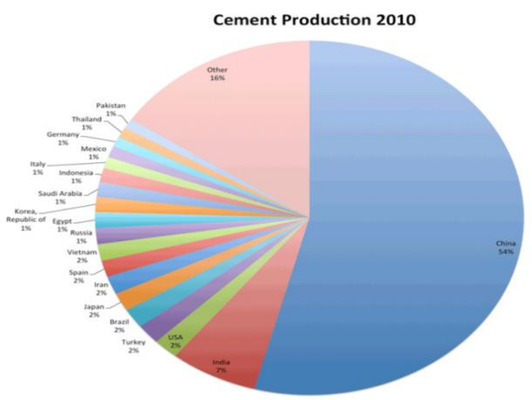

Fig 2: - Cement production in 2010(source Wikipedia)

In mid ninety due to increases in production of cement, some researcher had tried to mix two or three pozzolanic materials with ordinary clinker to form ternary cements as shown below in Figure 3.Some of mixes like fly ash with silica fume are used in worldwide for making high strength concrete. The main aim of its production is cost saving, resource saving and energy efficient cement. Some country's also standardizes ternary cement. ASTM standard C595/C595M defines ternary blended cement as "blended hydraulic cement consisting of Portland cement with either a slag cement, a pozzolan, or a limestone". European code EN 197/1, 2002 and Canadian code CAN/CSAA23.2 2000 also standardizedthese cement. Brazil code EB-2138/91 standard defines two types of ternary cement as CPII-E and CPII-Z. Mexico recently standardized composite cement in NMX C-414-0/99.

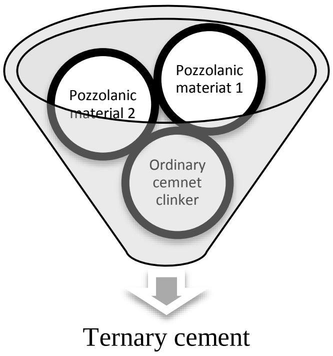

Fig 3: Concept behind ternary blended cements

Ternary blended cements can actually reduce clinker content up to 50% or more, as studied by several authors. Some of the ternary cement combination are fly ash–silica fume, fly ash–slag, slag– silica fume, limestone-fly ash, fly ash-metakaolin, limestone -glass powder, limestone filler - blast furnace slag, limestone + metakaolin, activated paper sludge-fly ash. In a country like India where maximum of its electricity is produced by thermal power plants, it is efficient to discuss various combinations with fly ash first.

II. IMPORTANCE OF THE STUDY

When pozzolanic materials studied separately, most of the times they haveshown a similar behavior in terms of reaction with cement phase. In general the pozzolanic materials to form CSH consume CH, which is produce form the hydration of cement.

(Pozzolan) S+ CH (slow reaction takes place) $\rightarrow$ CSH

This behavior is easily understood and also published by many authors.But ternary cements are not studied so deeply.No enough knowledge is avilable for final hydration product in combination and also no idea about the impact of many durability problems especially when used in combination of two SCM. For its wider application we have to investigate problems associated with it, testing techniques, its hydration etc. At different stages hydration may enhance or diminish by a particular pozzolan, which may bepozzolanic activity and can contribute to the heat evolved. This also affects the water demand for hydration. This study will help in understanding in requirement for the development of ternary blended cements and problems associated with various combinations.

III. LITERATURE REVIEW

Due to less literature available on ternary cements it is not possible to meet any final conclusion of various mixes on various properties. So at present this problem can't be solved and only the mix combinations with some of available properties are observed and review in this paper.

A. *Fly ash (FA)- Silica fume (SF):*

In 1993 Popovics S. investigated FA and SF with ordinary Portland cement in mortar with various combinations. He observed that FA alone increase the flow of mix where SF alone with cement makes the consistency of mix stiffer. He concluded that 5% SF and 25% FA together gives better strength even from silica fume and fly ash alone.

In 2000 Khan et al.,investigated porosity and strength development properties for high performance concrete. A finer pulverized fly ash (PFA) 20-25% by crushing in ball mill increasedsuper plasticizer dosage in concrete where SF does not affectthe dosage. Minitab statistical software wasanalyzed statistically for the effect PFA and SF on compressive strength and porosity.They found compressive strength decreased with an increase in PFA for a particular SF content, at all ages and increase in SF result in increase of compressive strength. In similar effects with compressive strength, porosity follows a relation with it. In final conclusion PFA reduce the strength and porosity increased.

Radlinski et al., 2009 studied FA and SF in ternary cement. They found that 20% FA and 5% of SF gives synergistic effect after 7 days and compressive strength is increased which results in low sorptivity. Also the chloride ion penetration resistance was also increased. These results were similar to Khan et al., 2000.

Nehdi et al., 2002, investigatedperformance of SF+ FA and SF+ slag with the help offactorial experimental plan. Superplasticizerrequirement, settingtime, dryingshrinkage, compressive strength, cost analysis, sulphate expansion was calculated with that rational method. Result shows that high replacement of FA is compromising with the early strength. Cost analysis indicates that use of costly mineral admixture, such as SF is not economical above 5%. A good quality slag can be replacedup to 60% without any serious disadvantage.

B. *Fly ash + Limestone:*

Elkhadiri et al., observed physico-chemical properties and mechanical behavior on mortar specimen in 2002. Results were also compared with blended cements. Low effect on water content with FA was noticed but increased setting time was also found. The addition of FA during grinding also acted as a grinding agent. Where limestone doesn't affect the water demand. In some cases FA increased strength and also decreased in some special types. Limestone behaves better then FA. In combination of 77% clinker, 2% gypsum, 7.5% fly ash, 13% limestone gives a packing structure to mixtures and a good mechanical properties.

For study of conversion in hydration product and synergy between FA and limestone Weerdt et al., 2011 investigated on different mix of ternary mix. With increased limestone content in binary mix, decreases the compressive strength and also increased amount of bound water at all ages.Max strength was obtained at 30% FA and 5% lime replacement at all ages. This mix gives similar result for CH content at all ages. In presence of lime stone ettringite, calcium monocarbonate hydrate and calcium hemicarbonatehydrate observed in XRD, where in absence only calcium monosulphate hydrate and ettringite was found. Presences of lime in ternary mix havean impact in stabilizing ettringite by reacting with the aluminates, which are provided by FA and thus form calcium carboaluminate hydrates. This will finally cause to additional formation of ettringite, more chemically bound water and a larger volume of hydrates, which leads to less porosity and thus causing high strength.

C. Fly ash + Fly ash:

Antiohos et al., in 2007 study the effect of two different types of FA in ternary cements in such a way so that, one type of FA can compensate the shortcoming of other. On hydration up to 7 days control specimen gives better results then any other FA combination. But at the age of 90 days pozzolanic activity wasnoticed for improvement of strength. Portlandite, ettringite, monosulphateand C4AH13 are observed in XRD as a main hydration product. At 90-days age, decrease in peak of portlandite indicates consumption of CH in pozzolanic reaction. Small calcium silicate peak also left even at 90 days ageconfirming the non-completion of hydration of FA. 50:50 ratio blends was found most effective.

D. Fly ash + Metakaolin:

Snelson et al., investigated the heat evolution during hydration, and the heat of hydration in binary and ternary MK - FA cement in 2007. They found FA decrease heat output but not at 40% replacement and MK increase heat output and goes on increasing with its increase in percentage, which could be due to high water demand. In 120 h cumulative heat of hydration of MK, results are similar to PC. Only 15 % MK with 5% FA showed increased heat evolution in compare to referencemix.

E. Limestone (LS) + Alminosilicate glass:

In order to understand a modern SCM Moesgaard et al., 2011 investigated ternary cement mortar. Glass was used to reduce CO_2 emission during hydration. LS contribute to early hydration reaction. In ternary mix heat generation was faster then glass but lower then limestone. As there was no mono-sulfate was observed in XRD analysis, it was concluded that mono-sulfates got converted to monocarbonates that releases sulfates for the formation of ettringite.Overall later strength was higher then control mix.

Ghrici et al., 2007investigatedvarious mechanical and durability properties with LS filler and natural pozzolana(NP) as a partial cement replacement. Due to high reactivity of LS hydration increased and strength also increased but later strength is decreased due to dilution effect. In sorptivity test, at 28 days age concrete containing 30% of natural pozzolana show a reduction in coefficient from 56% to 29% when the (w/b) ratio altered from 0.6 to 0.4. Similar behavior was observed in chloride penetration test but in case LS, mix containing 15% LS this penetration increase. Capillary pores were reducer. It can be considered that NP can be used to improve hydrochloric acid resistance and LS can improve sulfuric acid resistance. Also ternary mix gives better results for chloride ion penetration test.

F. Limestone + Metakaolin: -

Antoni et al., 2012 recently investigated ternary cement with limestone and MK. Flexural strength, compressive strength,thermogravimetry analysis, XRD, and rietveld analysis was performed in order to understand pozzolanic reaction. In a blend, which has 15% of LS and 30% of MK, the formation of hydration product was enhanced. To estimate mass degree of reaction, mass balance calculation was done. But it was made with small error, as strätlingite formation is ignored which was observed in XRD. Porosity was higher for all mix except one but pore size was refined for all mixes. Both SCM together can give excellent performance. 45% replacement in 2:1 ratio of MK and LS can give good strength at all ages. Complete CH was consumed in pozzolanic reaction.

G. Fly ash + paper sludge

Goñi et al., in 2012 investigated activated paper sludge (APS) and FA as SCM in ternary cement. Thepozzolanic activity at early age was observed higher.Large size pores (approx.12nm)was higher then small one (approx. 5nm),butin late age the smaller pores increased. This can be due to different packing of basic units of CSH gel i.e. loose packing (12nm) gel and the low-density (5 nm) gel.Compressive strength also decreased at replacement of 50% cement by APS and FA.

H. Limestone + Blast-furnace slag:

Menendez et al., 2001 developed a model based on quadratic response surface. Isoresponse curve for ternary cement at different ages are plotted.They observed that hydration of slag depends on its finesse and reactivity. LS and slag help each other in such a way that limestone improves early strength and slag helps in later strength by refining the fine pores. Use of this combination is found cost efficient and better in compare with ordinary mix. 20%LS,20% slag with 60% Portland cement gives 50.6 MPa compressive strength at the age of 90 days. This type of blend can actually help in producing high strength concrete with low resourced cements.

IV. SUMMARY

Ternaryblends were developed to overcome the problem of cost and improving the properties without increasing the cost. It is observed in all studies that, it is efficient way to get better strength and durability in compare with control mix. Synergistic effects of two material combos can handle some materials properties. Thou it is really a efficient way to achievebetter properties but still a lot more study is required on it. Hydration properties can be different with different combination. Also the testing techniques are to be developed because existing techniques may or may not be applicable on ternary cement. Effect on superplasticizer dosage, water demand,curing, sulfate attack, acid attack etc., are to be observed for better future of ternary cement.

V. REFERENCES

[1] Antiohos SK, Papadakis VG, Chaniotakis E, Tsimas S, Improving the performance of ternary blended cements by mixing different types of fly ashes, Cement and Concrete Research. 37 (2007) 877–885.

[2] Antoni M, Rossen J, Martirena F, Scrivener K, Cement substitution by a combination of metakaolin and limestone, Cement and Concrete Research. 42 (2012) 1579–1589.

[3] ASTM standard Designation: C595/C595M (2012), "Standard Specification for Blended Hydraulic Cements", corrected editorially in July 2012, United States of America (USA).

[4] DeWeerdt K, BenHaha M, LeSaout G, Kjellsen KO, Justnes H,Lothenbach B, The effect of temperature on the hydration of composite cements containing limestone powder and fly ash, Materials and Structures. 45 (2012) 1101–1114.

[5] Elkhadiri I, Diouri A, Boukhari A, Aride J, Puertas F, Mechanical behaviour of various mortars made by combined fly ash and limestone in Moroccan Portland cement, Cement and Concrete Research. 32 (2002) 1597–1603.

[6] Ghrici M, Kenai S, Said-Mansour M, Mechanical properties and durability of mortar and concrete containing natural pozzolana and limestone blended cements, Cement & Concrete Composites. 29 (2007) 542–549.

[7] Goñi S, Frias M, Vegas I, García R, Vigil de la Villa R, Quantitative correlations among textural characteristics of C–S–H gel and mechanical properties: Case of ternary Portland cements containing activated paper sludge and fly ash, Cement & Concrete Composites. 34 (2012) 911–916.

[8] Khan MI, Lynsdale CJ, Waldron P, Porosity and strength of PFA/SF/OPC ternary blended paste, Cement and Concrete Research. 30 (2000) 1225-1229.

[9] Mehta PK, Monterio PJM, Concrete Microstructure, Properties, and Materials.3 (2006).

[10] Menendez G, Bonavetti V, Irassar EF, Strength development of ternary blended cement with limestone filler and blast-furnace slag, Cement & Concrete Composites. 25 (2003) 61–67.

[11] Moesgaard M, Herfort D, Steenberg M, Kirkegaard LF, Yue Y, Physical performances of blended cements containing calcium aluminosilicate glass powder and limestone, Cement and Concrete Research. 41 (2011) 359–364.

[12] Nehdi ML, Sumner J, Optimization of ternary cementitious mortar blends usingfactorial experimental plans, Material and Structures. 35 (2002) 495-503.

[13] Popovics S, Portland Cement-Fly Ash-Silica Fume Systems in Concrete, Advance Cement Based Materials. 1 (1993) 83-91.

[14] Radlinski M, Olek J, Investigation into the synergistic effects in ternary cementitious systems containing portland cement, fly ash and silica fume, Cement & Concrete Composites. 34 (2012) 451–459.

[15] Snelson DG, Wild S, O'Farrell M, Heat of hydration of Portland Cement–Metakaolin–Fly ash (PC–MK–PFA) blends, Cement and Concrete Research. 38 (2008) 832–840.

[16] Vance K, Kumar A, Sant G, Neithalath N, The rheological properties of ternary binders containing Portland cement, limestone, and metakaolin or fly ash, Cement and Concrete Research. 52 (2013) 196–207.

[17] Weerdt KD, Ben Haha M, Le Saout G, Kjellsen KO, Justnes H, Lothenbach B, Hydration mechanisms of ternary Portland cements containing limestone powder and fly ash, Cement and Concrete Research. 41 (2011) 279–291.

[18] Weerdt KD, Kjellsen KO, Sellevold E, Justnes H, Synergy between fly ash and limestone powder in ternary cements, Cement & Concrete Composites.33 (2011) 30–38.