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Development of Modified Recycled Aggregate for the Production of Sustainable Concrete

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***Abstract*: This paper deals with the treatment methods of recycled aggregate (RA) for its high water absorption which is due to the old mortar and micro-cracks on the surface of the recycled aggregate. Geopolymer paste which is made using class C & F fly ash are used for coating the recycled aggregate in order to reduce the water absorption (WA). The parameters which influence the coating of RA are fly ash content, molarity of alkaline solution, Liquid alkaline to ash ratio (LA/ash). The effect of each parameter on coating RA are analysed using Response surface methodology. It is observed that all the parameters has influenced the water absorption property of RA. LA/ash ratio depends on the molarity of the alkaline solution in reducing the WA of recycled aggregate. Coating of recycled aggregate with class C fly ash performed better than class F and uncoated recycled aggregate concrete. The optimal content of fly ash content, LA/ash ratio and molarity of solution are arrived using the statistical analysis are 4%, 0.35 and 9M respectively**.

***Keywords* : recycled aggregate, class C, class F, flyash, compressive strength, water absorption.**

I. INTRODUCTION

The rapid urbanization leads to the construction of new infrastructure by demolition of old buildings which leads to the huge amount of demolition waste. Depletion of natural aggregate for the production of concrete urges us to utilize the alternate source for aggregate in concrete. Recycled aggregate (RA) is identified as one of the sustainable material which has greater potential to be utilized in concrete ([1] [2] [3] [4]). One of the recycled aggregate has the properties of higher porosity, increased water absorption (WA), reduced density and durability [5]. The poor quality of recycled aggregate is due to the weaker interfacial transition zone (ITZ) which is present at the interface of cement phase and aggregate phase [6]. Recycled aggregate properties depends upon the parent concrete strength. The aggregates extracted from the C&D waste of high performance concrete performed better than normal strength concrete [7]. Concrete produced with recycled aggregate is observed to have relatively larger reduction in stiffness than the strength reduction ([8] [9] [10]). The treatment of recycled aggregate for the improvement of ITZ to reduce the water absorption become necessary to increase the usage of recycled aggregate in the construction industry. Recycled aggregate coated with cement, fine aggregate with water resulted in improved properties equivalent to natural aggregates [11]. Concrete with recycled aggregate impregnated with silica fume solution has increased the concrete strength of about 15% than the non-impregnated aggregate concrete [12]. Recycled aggregate treated with lyophobic agents reduced the bonding with new cement mortar and ultimately leads to reduction in strength of concrete [13]. The strength property of RAC is influenced by different mixing procedures were formulated in which sand envelope mixing procedure (SEMA) gives higher strength [14]. Application of fly ash in Recycled aggregate concrete (RAC) resulted in improved performance against chloride resistance [15].

It is observed that there are limited studies on usage of fly ash to enhance the recycled aggregate properties. In this study, both class C & F fly ash are used with geopolymer binding solution in coating the recycled aggregate for reducing the water absorption and strength ITZ. As there are different parameter involved in the study of WA properties, statistical analysis (i.e Response surface methodology) is adopted [16]. The individual effect and combined effect of all parameters are studied in detail using the analysis. At the end of the response surface equations are arrived which are used to get the response surface plots. From the interaction effects and response plots the optimal value of all the parameters are identified for the production of best recycled aggregate of improved performance.

II. MATERIALS USED

In the current mix proportion, processed class C and class F fly ash from thermal power plants were used in the geo-polymeric mix. Laboratory grade of sodium hydroxide (NaOH) in pellets forms (98.1% purity) and sodium silicate (Na_2SiO_3) (51.24 % solids) solutions were used as alkaline activators. Recycled aggregate (20mm approx. size) collected from the nearby demolition site was used in the study. Fine aggregate passing through 2.35 mm sieve was used for the geopolymer concrete

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III. MIX PROPORTION

Preliminary trials were conducted by coating the recycled aggregate with different fly ash (viz., class F & C fly ash) using different proportions of geopolymeric solution. Based on the experimental trials, the mix proportion for coating the recycled aggregate were arrived. The dosage of fly ash ranging from 2% to 8% to the weight of the aggregate and liquid alkaline to ash ratio (LA/ash) of 0.2 to 0.4 were arrived. NaOH to Na_2SiO_3 ratio of 1:1 ratio was used to make the alkaline activator solution. Molarity of NaOH was taken in the range of 6 to 12.

IV. SAMPLE PREPARATION

The collected recycled aggregate was dry mixed with fly ash for 2 minutes and subsequently alkaline activators are added mixed constantly until it spreads evenly on the aggregates. The freshly coated aggregates were then cured in oven at 65℃ for 24 hours. Aggregate samples were taken out and tested for WA as per IS standards to find the best mix for coating the recycled aggregate. WA test is done by checking its initial weight and placing them under water for 24 hours. Later the aggregates are taken from water and wiped with dry cloth before final weight is taken. The percentage difference between final and initial weight gives the water absorption values.

V. MATHEMATICAL ANALYSIS

In this experimental analysis, different parameters are influencing the properties of recycled aggregate. Hence in order to study the effects of parameters, response surface methodology is adopted. In this method, quadratic model analysis is adopted to study the effects of parameters (Montgomery, 2001). The parameters which influence the water absorption properties are identified and the corresponding ranges (Table I) are fixed based on the preliminary trials conducted.

Table I. Parameters and their ranges

S.No	Parameters	Range
1	Percentage of Fly ash	2% to 8%
2	LA/Ash	0.2 to 0.4
3	Molarity of NaOH	6 to 12

Fly ash content is calculated based on the weight of recycled aggregate which has to be coated. The ratio of NaOH to Na2SiO3 solution used is 1:1. The sodium silicate solution has solid content of 51.24%. Table 2 shows the different combinations of trials which has to be carried out for response surface methodology.

Experimental trials were conducted for the above said combinations (Table II) and corresponding values were noted. After entering the water absorption values as the response in SAS software, the level of significance of each parameters individually and combinations were checked. Analysis of Variance table (ANOVA), shows whether the parameters are significant or not (viz., p-value is < 5%).

Table II. Mix Combinations for coating of recycled aggregates

S.No	Fly ash %	LA/ash	Molarity of NaOH
1.	3.22	0.24	7.22
2.	6.78	0.24	7.22
3.	3.22	0.36	7.22
4.	6.78	0.36	7.22
5.	3.22	0.24	10.78
6.	6.78	0.24	10.78
7.	3.22	0.36	10.78
8.	6.78	0.36	10.78
9.	2	0.3	9
10.	8	0.3	9
11.	5	0.2	9
12.	5	0.4	9
13.	5	0.3	6
14.	5	0.3	12
15.	5	0.3	9
16.	5	0.3	9

Response surface equations were used for plotting 2D response graphs for different combinations of parameters. The optimal mix proportion for the coating of recycled aggregate is identified from the response plots.

6.0 Results and Discussion

6.1 Effect of LA/ash ratio and fly ash

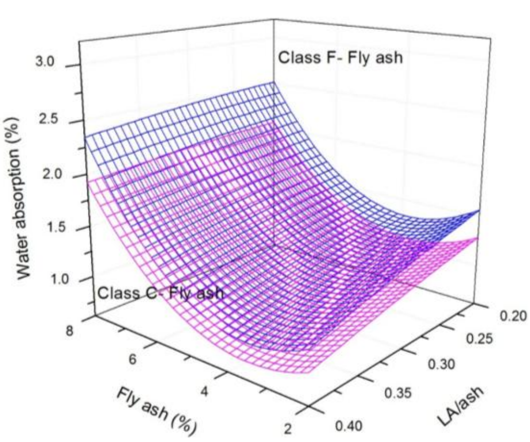

Fig 2. Water absorption variation with fly ash (%) and LA/ash ratio at 6M

Fig. 2 shows the WA of recycled aggregate coated with 12 M sodium hydroxide solution. Initially, increase in fly ash percentage results in decrease of WA due to the coating of old mortar and filling of micro cracks in the aggregates.

WA is observed to increase with increase in fly ash content beyond an optimal content which is due to the reduction in bonding of fly ash with binding solution. Increase in LA/ash ratio leads to decrease in WA which is due to the increase in availability of binding solution and its strong bonding with fly ash and aggregates. The behavior is observed to be similar in both class C and F fly ash.

At 12M solution, the geopolymeric reaction is faster, which leads to uneven coating of aggregates and, in turn leads to higher WA. The unreacted fly ash on the surface of aggregates does not bond well to the aggregate and leads to relatively higher WA. At 6M solution, the rate of reaction is observed to be reduced and hence aggregates are uniformly coated with fly ash and, ultimately leads to reduced WA. Fig. 6.9 to 6.11, it is observed that the optimal content of ash content in all the cases is 4%.

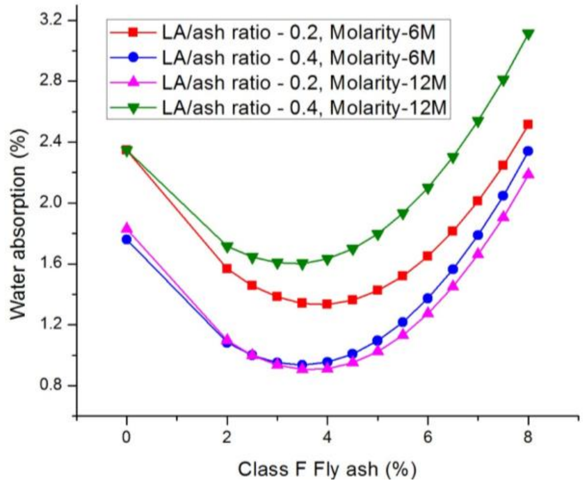

Fig. 3. Effect of Class F Fly ash on WA

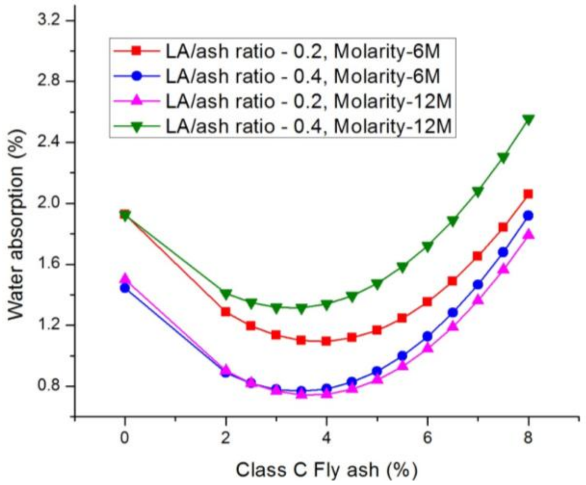

Fig. 4. Effect of Class C Fly ash on WA

6.2 Effect of Molarity and fly ash

Fig. 5 and Fig. 6 shows the influence of fly ash and molarity on WA of recycled aggregate at liquid alkaline/ash ratio of 0.2 and 0.4 respectively.

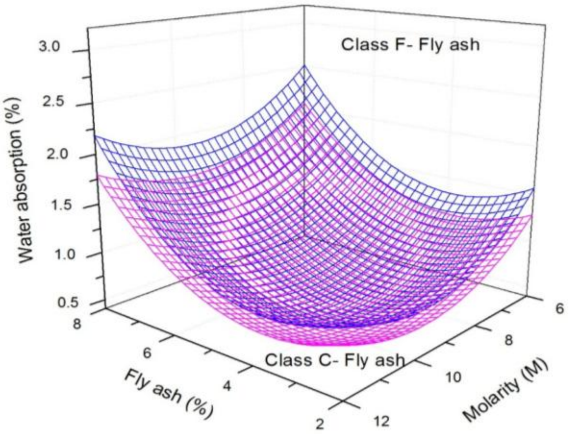

Fig. 5. Water absorption variation with fly ash (%) and molarity at LA/ash ratio of 0.2

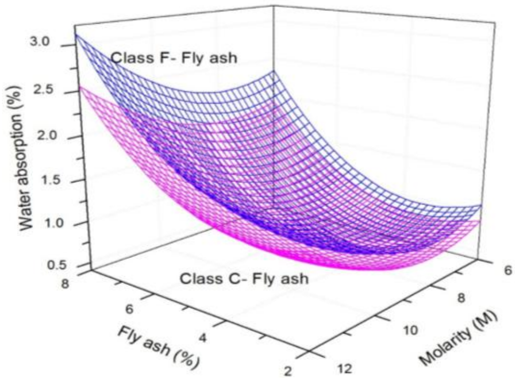

Fig. 6. Water absorption variation with fly ash (%) and molarity at LA/ash ratio of 0.4

WA is observed to enhance with increase in fly ash up to an optimal limit. At any fly ash content, increase in molarity resulted in reduction in WA up to an optimal level which is due to the faster reaction of binding solution with fly ash. Beyond the optimal limit of molarity, the rate of reaction is accelerated which leads to improper coating of aggregate and in turn leads to higher WA. At lesser molarity (i.e. 6M), WA is observed to be increased which is due to the less effectiveness of the geopolymeric solution to bind with the fly ash and aggregate. The optimal molarity percentage at which lesser WA of aggregates is achieved can be arrived from the Fig. 7 and Fig. 8. At any liquid alkaline to ash ratio and fly ash content, the optimal molarity at which the proper coating and reduced WA achieved is identified as 9M.

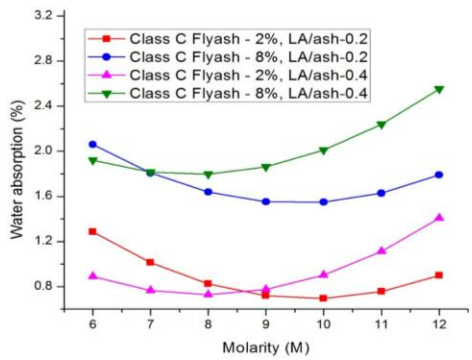

Fig. 7. Effect of molarity at different LA/ash ratio in Class C Fly ash mix

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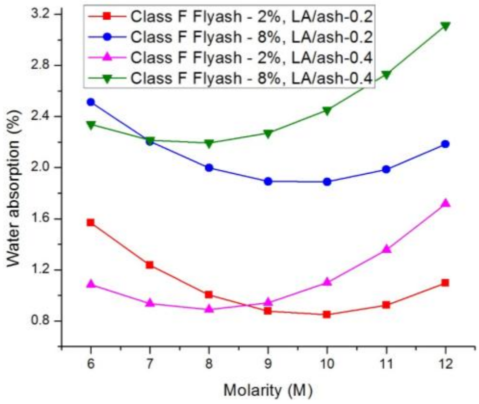

Fig. 8. Effect of molarity at different LA/ash ratio in Class F Fly ash mix

6.3 Effect of LA/ash ratio and Molarity

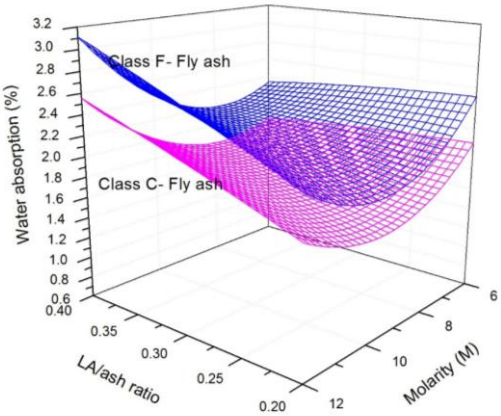

Fig. 9. Water absorption variation with LA/ash ratio and molarity at 4% fly ash

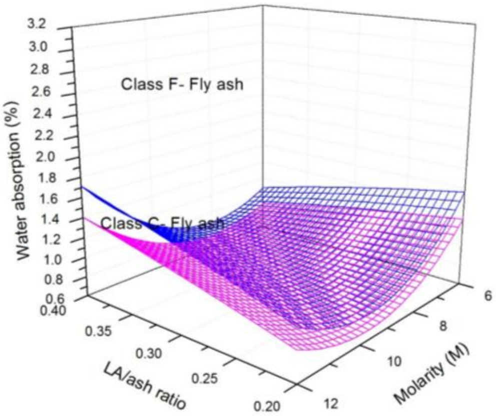

Fig. 10. Water absorption variation with LA/ash ratio and molarity at 2% fly ash

The influence of liquid alkaline to ash ratio on WA varies based on molarity of solution. At 6M solution, increase in LA/ash ratio leads to marginal reduction in WA which is due to relatively uniform coating of aggregates than 12M solution where the reaction is faster, which leads to improper coating with higher water absorption. From the Fig. 11 and Fig. 12, the optimal LA/ash ratio at which the water absorption is minimal for different combination of fly ash and molarity is identified as 0.3.

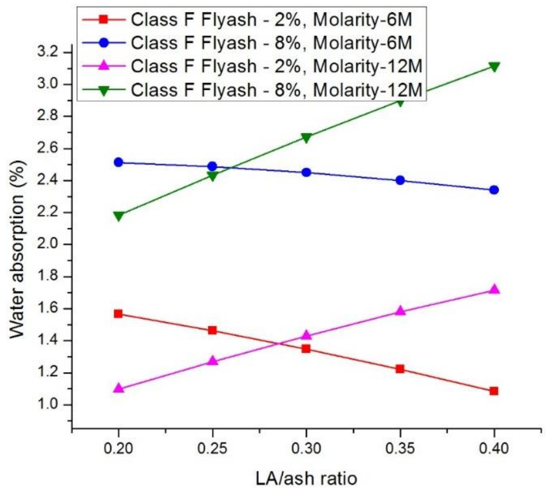

Fig. 11. Effect of Molarity and Class F Fly ash on WA

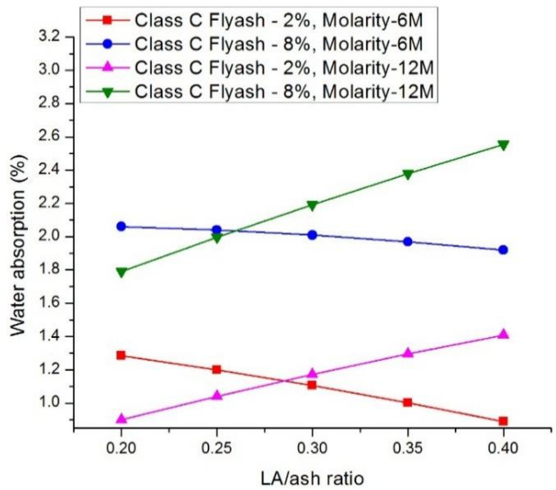

Fig. 12. Effect of Molarity and Class C Fly ash

The coating of aggregates with class C fly ash resulted in relatively lesser water absorption than class F fly ash. From the above study, the optimum value of all parameters in coating the recycled aggregate and reducing the water absorption is identified and tabulated in Table III.

Table III. The Optimal values of parameters

S.No	Parameters	Optimal value
1	Fly ash or GGBS content	4%
2	Molarity of NaOH	9
3	Liquid Alkaline/Ash Ratio	0.3

VI. SUMMARY

From the experimental study, the following important points were summarized.

- Increase in fly ash percentage resulted in increased water absorption of recycled aggregates beyond an optimal limit (i.e. 4%)

- Molarity has a major influence on the uniform coating of recycled aggregate to reduce the water absorption of recycled aggregates. Water absorption initially decreases with molarity but increases beyond the optimal limit (i.e. 9M)
- Liquid alkaline to ash ratio (LA/ash) depends on the molarity of the alkaline solution in reducing the WA of recycled aggregate
- The coating of recycled aggregate with Class C fly ash has relatively lesser water absorption than Class F fly ash
- Concrete manufactured with coated recycled aggregate can lead to the production of sustainable concrete with improved strength properties

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The author has completed the UG and PG from Anna University. He has completed his doctorate from Indian Institute of Technology Madras in the year 2017. He has published 5 journals which includes science and scopus indexed journals, in addition to conferences. He has 4 years of teaching experience and 1 year industrial experience. He has guided number of UG and PG projects in Hindustan Institute of Technology and Science. He has significant contribution in the area of concrete technology, sustainable construction and recycled aggregate concrete.

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