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Effect of aggregate ratio on strength of cold bonded fly ash aggregate concrete subjected to high temperatures

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Abstract: - This paper presents an experimental investigation on the mechanical properties of fly ash aggregate concrete subjected to high temperature. For this purpose, cold bonded pelletized fly ash aggregates are used as coarse aggregate. When the specimens were 28 days old, they were exposed to elevated temperatures (100°C, 200°C,and 300°C) for 2h, 4h and 6h durations. Tests were conducted to determine the compressive strength of the heated specimens and compared with the ambient temperature strength. The results show that fly ash aggregates concrete withstand a temperature up to 300°C, beyond which strength drastically decreases

Keywords: - *fly ash; artificial aggregate; temperature study; compressive strength*

I. INTRODUCTION

The production of concrete requires aggregate as an inert filler to provide bulk volume as well as stiffness to concrete. Crushed aggregates are commonly used in concrete which cause depletion of the natural resources and necessitates an alternative building material. This led to the widespread research on using a viable waste material as aggregate. Artificial manufactured lightweight aggregates can be produced from industrial by-products such as fly ash, bottom ash, silica fume, blast furnace slag, rice husk ash, slag or sludge waste or palm oil shell, shale, slate, clay etc. The use of cost effective construction materials has accelerated in recent times due to the increase in the demand of light weight concrete for mass applications. This necessitates the complete replacement or partial replacement of concrete constituents to bring down the escalating construction costs. In recent times, the addition of artificial aggregates has shown a reasonable cut down in the construction costs and had gained good attention due to quality in par with conventional aggregates. With increasing concern over the excessive exploitation of natural aggregates, synthetic lightweight aggregate produced from environmental waste is a viable new source of structural aggregate material. Fly ash is one promising material which can be used as both supplementary and cementitious materials as well as to produce light weight aggregate [1].Although concrete is generally believed to be an excellent fireproofing material, many recent studies have shown extensive damage or even catastrophic failure at high temperatures. Apart from the usual risk of fire, these concretes are exposed to high temperatures for considerable periods of time in the industries like oil, gas, nuclear and power industries.

II. LITERATURE REVIEW

Joseph and Ramamurthy [2] experimentally studied on concrete made using cold bonded fly ash aggregates. They used water binder ratio of 0.39 and coarse aggregate to total aggregate (CA/TA) ratio 0.5 and obtained a compressive strength of 55 MPa and that concrete with minimum energy consumption, using cold bonded fly ash aggregate has good workability and facilitates high volume utilization of fly ash in concrete. Kockal and Ozturan [3] discussed the Influence of different lightweight fly ash aggregates on the behavior of concrete mixtures. The performance characteristics of Light Weight Concrete (LWC) and Normal Weight Concrete (NWC) were investigated through different parameters like compressive strength etc. and the 28 day compressive strength of cold bonded fly ash light weight aggregate concrete was found to be 42.3 MPa.

Sivakumar and Gomathi [1] observed that fly ash on pelletization can be used as an efficient aggregate material and the future depletion of aggregate can be suitably reduced by use of fly ash aggregate. Priyadarshini et al. [4] based on their experimental study showed that cold bonded fly ash aggregates can be used as an aggregate replacement material in concrete. The strength property and density of concrete made with artificial fly ash aggregate and natural gravel were also studied which confirmed that introduction of fly ash aggregate in concrete reduces the compressive strength but meets the required strength to be used as a structural material. Gesoglu et al. [5] found that cold bonded fly ash aggregate with proper mechanical properties was useful in production of concrete with strength of 55 MPa with a water cement ratio of 0.55.

III. NEED FOR THE STUDY

Fly ash generally refers to coal fly ash obtained as residue during the combustion process in coal- fired power plants. As it is a waste material, it is ought to be disposed off or recycled. Waste disposal is a major concern of the day. Releasing of the material into atmosphere after simple entrainment into flue gases can cause pollution to the environment. Also toxic compounds like polychlorinated dibenzo-p-dioxin isomers which will leach into soil, water and atmosphere if the material is made into landfills. Thus on dissuading fly ash from the waste ponds, we can control the environmental pollution to a considerable extent. Hence, inventive measures are to be found out for reducing the environmental concerns on disposal issues. In such a scenario, utilizing fly ash as a construction material, in the production of artificial lightweight aggregates would consume the material in large quantities and is expected to prove to be a steadfast solution to the disposal problems. Also, the toxic metals in fly ash become immobilized in the form of insoluble compounds of cement hydration and will no longer be harmful to environment. This study attempts to develop for value addition to materials like fly ash.

IV. MATERIALS AND METHODOLOGY

Cold bonded pelletızatıon

Cold bonding is nothing but normal water curing. In this study, fly ash aggregates are formed by cold bonded technique. The ratio of binder material (Ordinary Portland Cement) and Class F fly ash is 1:4 for the present study. The physical properties of the binder material are depicted in Table 1. The different types of pelletizer machine used to make the pellet are disc or pan type, drum type, cone type and mixer type. Here normal concrete mixer is used for making the aggregates. Fly ash and the binder (Physical properties of cement used is shown in Table 1) are mixed well initially for 2 minutes in pelletizer and water is sprinkled into it. Spraying is to be done carefully to make sure that the water has been sprinkled not in the same place to avoid slurry muddy balls [4]. The fresh pellets formed were then kept at room temperature for a day to attain initial strength and then water cured for 28 days. Moisture content and angle of the rotation influence the size growth of pellets (Sivakumar and Gomathy,2011). Initially some percentage of water is added to the binder and then poured in to the mixer drum, remaining water is sprinkled during the rotating period because, while rotating without water in the mixer, the fly ash powder tends to form lumps. The pellets are formed approximately in duration of 20 minutes [1]. From the literature survey, it is observed that fly ash aggregate concrete shows lower values of compressive strength compared to normal aggregate concrete, but exceeds 17 MPa which is the minimum criteria to be used as structural concrete material. The round shape of the aggregates improves the workability of concrete as well, thus minimizing the need for plasticizers [1].

Table 1 Physical properties of cement

Sl.no.	Properties	Value
1	Specific gravity	3.20
2	Standard consistency (%)	32
3	Initial setting time (min.)	40
4	Final Setting time (min.)	600

Table 2Physical properties of fly ash

Sl.no.	Properties	Result
1	Specific gravity	1.88
2	Water absorption (%)	5.32

Methodology

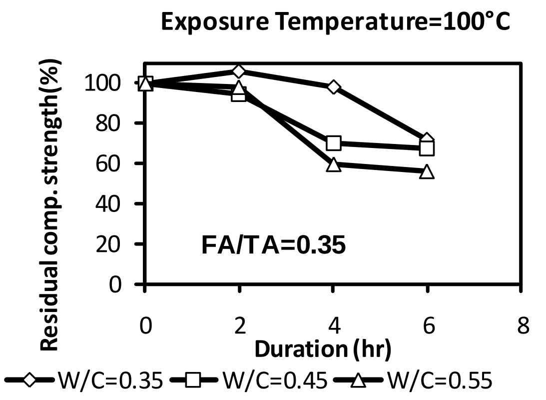
It is proposed to study the following in the present work. The concrete mix with cold bonded pelletized fly ash aggregates is designed. Moulds of 150x150x150 mm are used for making fly ash aggregate concrete for the compressive strength study. Moulds are properly maintained by cleaning and oiling before each casting. Vibrating table was used for better compaction and filled in three layers. A total 216 cubes (150mm x 150mm x 150mm) are prepared. The quantity of materials required for one cubic meter of concrete are tabulated in Table 3.In this experimental programme, unstressed residual strength test is used to study the effects of high temperature on the cold bonded pelletized fly ash aggregates. The specimens after attaining strength by water curing for 28 days were placed in the electric furnace. It is a cylindrically shaped furnace having a diameter of 400mm and a depth of 600mm. The temperatures can be set accordingly using a temperature controller. The maximum temperature of the furnace is 750°C-800°C. The specimens are heated to 100°C, 200°C and 300°C for 2h, 4h and 6h and to compare it with ambient temperature strength. Graphs are plotted to study the relative increase or decrease in compressive strength on exposure to temperatures. The trend is studied and compared with expected trend according to previous studies.

Table 3Quantity of materials per cubic meter of concrete

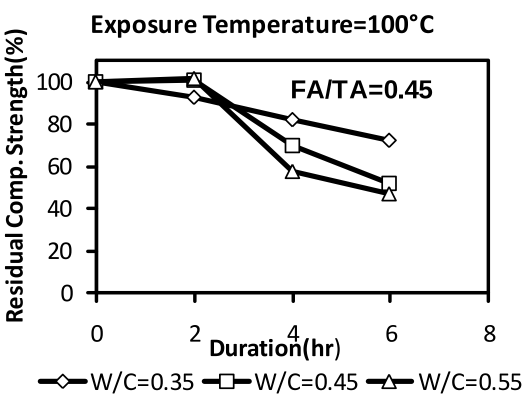
FA/TA	W/C	Water (in kg)	Cement (in kg)	Fine aggregate (in kg)	Coarse aggregate (in kg)	Designation
0.35	0.35	186	530	585	795	F-A
	0.45	186	415	620	840	F-B
	0.55	186	340	645	870	F-C
0.45	0.35	186	530	755	675	F-D
	0.45	186	415	800	715	F-E
	0.55	186	340	825	740	F-F
0.55	0.35	186	530	920	550	F-G
	0.45	186	415	975	585	F-H

V. RESULTS AND DISCUSSIONS

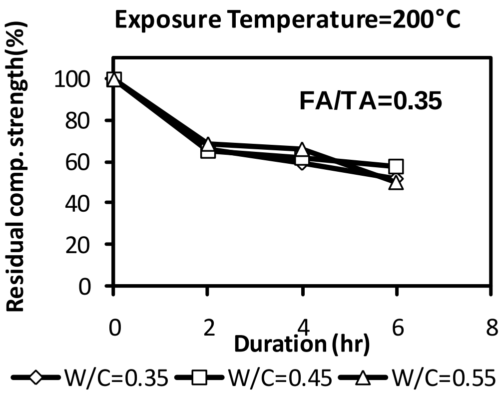
Generally, it is expected that for unheated specimens, as water cement ratio and or fine aggregate to total aggregate ratio increases, the compressive strength should decrease. Also, as the temperature increases, the strength is expected to decrease. The increase of strength at high temperatures may be due to the formation of Tobermorite which is a product of unhydrated fly ash and lime at high temperatures. However no tests have been performed to confirm the formation of tobermorite in this study. From literature survey, the probable reasons for increase or decrease in strength due to exposure to temperature are found out. The expectation is that as temperature magnitude or duration increases the compressive strength should decrease. Also, we know as water cement ratio increases or fine aggregate to total aggregate ratio increases strength of the concrete decreases.



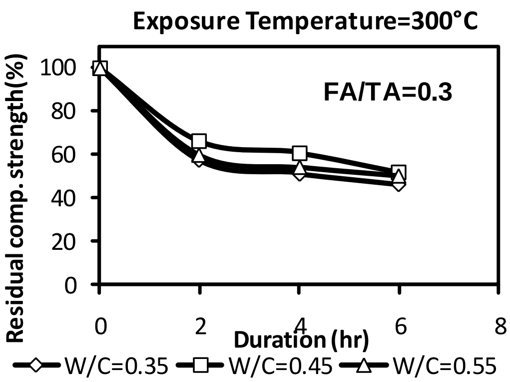
(a) Temperature 100°C



(a) Temperature 100°C

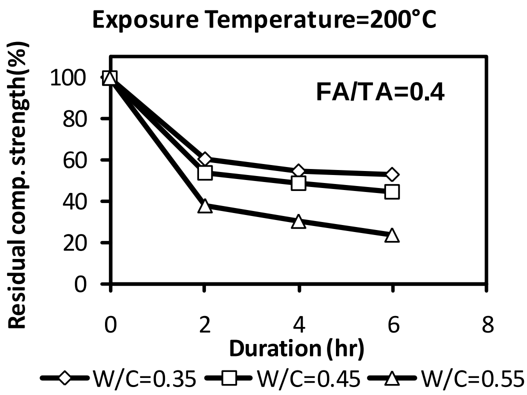


(b) Temperature 200°C

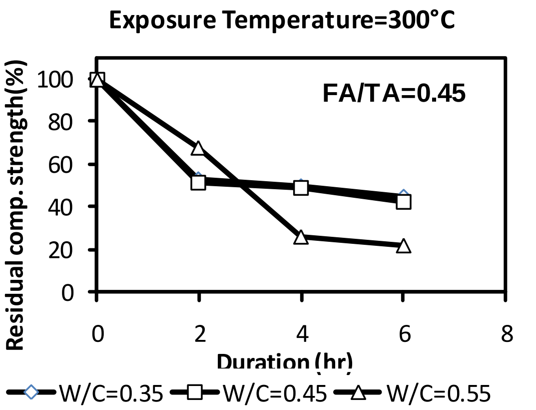


(c) Temperature 300°C

Fig. 1Residual compressive strength of concrete with FA/TA =0.35 versus duration at different exposure levels



(b) Temperature 200°C

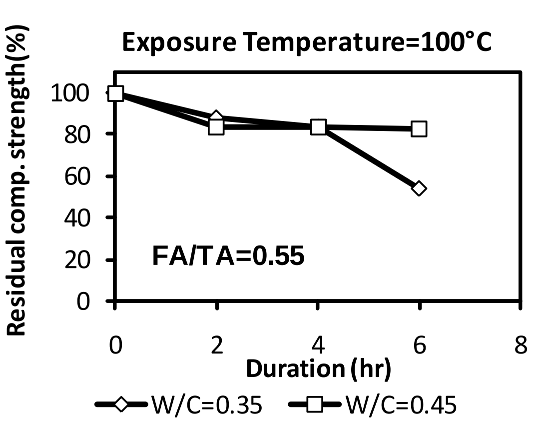


(c) Temperature 300°C

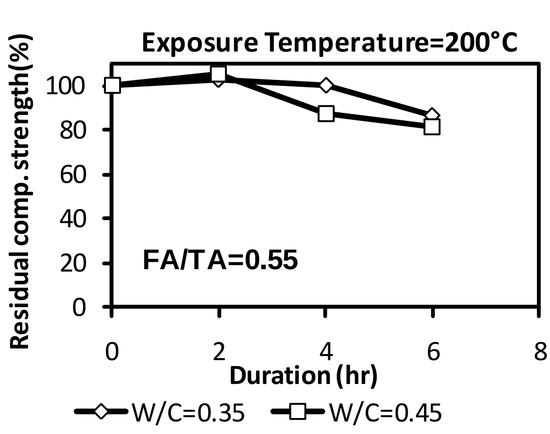
Fig. 2 Percentage variation in compressive strength with duration for concrete cubes with FA/TA =0.45 exposed to durations

The variation of cube compressive strength of cold bonded pelletised fly ash aggregate concrete of FA/TA ratio of 0.35 and different water cement ratio with the duration at different exposure levels of 100°C , 200°C and 300°C is compared and is given in Fig. 1(a) to 1(c).

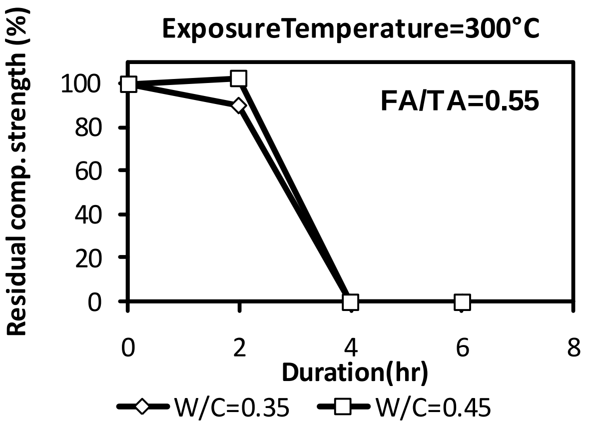
From Fig.1, it can be observed that, the variation of compressive strength for concrete with cold bonded fly ash aggregate has similar trend at 200°C and 300°C exposure temperature. But at an exposure temperature of 100°C, concrete with water cement ratio 0.35 has less reduction in strength compared with that of water cement ratios 0.45 and 0.55 respectively. However those concrete with water cement ratio 0.45 and 0.55 shows a similar trend. It can be also observed from Fig.1(a) that the reduction of compressive strength for w/c = 0.45 and w/c = 0.55 are 29.79% and 40.64% respectively for 4h duration at an exposure temperature of 100°C. Thereafter the reduction is constant for 6h exposure. From Fig.1(b), it is seen that, the strength descend follows the expected pattern and decreases to 50% of the initial strength by 6h duration exposure to 200°C for all w/c ratios. Again from Fig.1(c), it is observed that the strength decreases by up to 53.58 percent for w/c ratio = 0.35 after 6h exposure to 300°C. The Figures 2(a) to 2(c) compare the variation of cube compressive strength of cold bonded pelletised fly ash aggregate concrete of FA/TA ratio of 0.45 and different water cement ratio with the duration at different exposure levels of 100°C , 200°C and 300°C.



(a) Temperature 100°C



(b) Temperature 200°C



(c) Temperature 300°C

Fig. 3Residual compressive strength of concrete with FA/TA =0.55 versus duration at different exposure levels

In Fig. 2, there is no similar trend in cases of exposure to temperatures 100°C, 200°C and 300°C. It can be also observed from Fig.2(a) that, for a constant FA/TA ratio 0.45, the concrete with w/c=0.35 shows a steady decrease in strength when compared to w/c=0.45 and w/c= 0.55. The decrease is found to be 27.45% as exposure duration increased from 2h to 6h to temperature of 100°C. It can be seen from Fig. 2(b) that a drop of strength by 50% occurred during 2h duration exposure to 200°C for FA/TA=0.45. Thereafter no remarkable decrease in strength is observed at 4h duration and 6h duration. From Fig.2(c), it can be seen that for the concrete with FA/TA= 0.45, there is a reduction in strength in the range of 45% to 65% for all water cement ratios at 2h duration exposed to 300°C. But concrete with w/c= 0.55 showed a higher reduction in strength at 4h and 6h duration when compared to w/c=0.35 and 0.45. Again, concrete with w/c =0.35, 0.45 and 0.55 showed a similar trend between 4h and 6h duration.

The Fig 3(a) to 3(c) compare the variation of cube compressive strength of cold bonded pelletised fly ash aggregate concrete of FA/TA ratio of 0.55 and different water cement ratio with the duration at different exposure levels of 100°C , 200°C and 300°C. Fig 3 shows that, no similar trend in strength descent is shown by concrete with FA/TA=0.55 at exposure temperatures 100°C, 200°C and 300°C. It can be also observed from Fig.3 (a) that at a constant FA/TA ratio 0.55, the concrete with w/c=0.35 has a sudden decrease in strength to 50% of the initial strength when compared to w/c=0.45, where strength reduction is only by 10%. Also in the latter case,the strength which reduced to 90% of the original by 4h duration of exposure, has not reduced further by 6h exposure to 100°C. But in the former case the major reduction in strength is found to occur after 4h exposure to 100°C.It can be seen from Fig. 2(b) that ,for FA/TA=0.55,strength decreases only by 14% and 20% during 6h duration to an exposure temperature of 200°C for w/c=0.35 and w/c=0.45 respectively. From Fig.3(c), it can be seen that for the concrete with FA/TA= 0.55, there is a reduction in strength to zero percentage for both water cement ratios at 4h duration exposed to 300°C.

The reason for the initial increase in strength may be attributed to the increase in content of hydration products occurring in that temperature range. The decrease in strength as exposed duration increases can be to the fact that weakening of cement paste- aggregate bond may occur as temperature or duration increases. The reason for explosive spalling can be attributed to expansion of pores inside of the coarse aggregates formed during the time of its production.

VI. CONCLUSIONS

Based on the experimental study of cold bonded fly ash aggregate (FA) concrete, following conclusions are arrived at.

- The strength of the concrete decreases with increase in the exposure temperature.
- The strength of the concrete inversely proportional to duration of exposure to temperature.
- There is a drastic decrease in strength of concrete when exposed to high temperature (>300˚C).
- Spalling of concrete occurs with explosive sound when exposed to high temperature (>300˚C).

The cold bonded fly ash aggregate (FA) concrete can be used as fire protection material up to a temperature of 300˚C.

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