Compressive strength and workability of concrete containing fly ash as partial replacement for cement content

B.O Adinna, P. D Onodagu, V. C Umeokpala

Abstract- Making concrete with fly ash as partial substitute for cement content has been a worldwide practice since 1930s. It helps to achieve better workmanship and general savings in the cost of material and labour. For this reason fly ash is regarded as a recovered resource. The engineering and economic value of fly ash is poorly appreciated by many engineers and economic decision makers in many countries. This study therefore embarked on rediscovering the pozzolanic features of fly ash by studying the compressive strength and workability of concrete containing fly ash as partial replacement for the cement content. Concrete cubes were cast with cement partially replaced with fly ash in the following percentages by weight of cement content of a grade 20 concrete that was used: 0%, 10%, 20%, 30%, 40%, 50% and 60%. The measured average 28-days compressive strengths and slumps, for the various percentage partial replacements, respectively, were: 21.3mm^2 and 65mm for 0% , 24.3N/mm^2 and 85mm for 10%, 22.8N/mm^2 and 102mm for 20% , 18.9N/mm^2 and 110mm for 30%, 17.7N/mm^2 and 130mm for 40%, 15.5N/mm^2 and 145mm for 50%, 14.4N/mm^2 and 158mm for 60%. It was observed that the slump and average strength of the concretes containing fly ash increased and doubled that of zero percent, normal concrete. It was then concluded that fly ash should be gainfully used to substitute a part of the cement content of concrete up to 30% where ever fly ash is abundant.

Index Terms- Concrete, Coal electric power, Economic decision, Fly ash, Partial replacement, Compressive strength, Workability,

.

1 INTRODUCTION

Workability of fresh concrete and its strength in hardened state are among the most important properties of a concrete which any engineer is always anxious to know. Workability of a concrete has to do with the ease with which any concrete mix can be handled and transported from the point of mixing to the point of placing and full compaction. The more workable a concrete mix, the less labour required to cast and fully compact it. If the workability is too low, the concrete may never be fully compacted, without the need of special equipment; or the strength of the concrete in hardened state will be jeopardized. The strength of a concrete is the ability of the hardened concrete to sustain load either in compression or in tension [1].The workability of a normal concrete may range from 10 mm to 100 mm (slump) without any admixture; though water may be added to make the concrete flow better, but segregation of the concrete components may result. In the same way, strength of a normal concrete may range from 15N/mm^2 to 40N/mm^2, above this range one needs admixture to be added to the concrete mix.

Thanks to the state of the art technology in concreting. Today fresh concretes are made so workable that they can even flow, and can be pumped to points of placing; and even made to drop from impossible heights into the formwork without segregation. All these are achievable with the use of modern admixture and additives, and fly ash is among these [2], [3].

This study is concerned with concrete containing fly ash. Fly ash is an industrial waste from coal-fired thermal electric power generating plant. It is a by-product from burning pulverized coal in electric power plant for power generation. During the combustion, mineral impurities in the coal such as clay, feldspar, quartz and shell only melt, fuse in suspension and float out of the combustion chamber with exhaust or flue gases. As the fused material rises, it cools and solidifies into spherical glassy particles called fly ash. Fly ash is collected from exhaust gases by electrostatic precipitators or bag filters [4]. Chemically the fine powder works like cement, but can only act like a binder in the presence of calcium hydroxide or lime. Calcium hydroxide is a by-product of cement hydration reaction; so mixing with fly ash results in concrete with enhanced desirable properties. Fly ash is therefore a pozzolana [5].

In most industrialized nations fly ash is dumped in landfills as wastes, and this has caused environmental concerns in such areas. In undeveloped nations coal-electric-power plants are very scarce and they live in obscurity as far as fly ash is concerned. In Nigeria for instance, there are only two moribund plants, but fly ash from past operations can still be found there, in spite of the fact that the plants were out of use since 1970. This is because very few engineers really know the value of this recovered resource.

- *Author :Adinna B.O ,is a senior lecturer in Nnamdi Azikiwe university Awka Nigeria,PH_+2348125018455, E-mail: adinnaboniface@yahoo.com*
- *Co-Author: Onodagu P. D ,is a senior lecturer in Nnamdi Azikiwe university Awka,Nigeria, PH_+ 2348039461000, E-mail: dinwokepitaonodagu@gmail.com.*
- *Co-Author:*Umeokpala V .C currently pursuing masters degree program in civil engineering, PH_+2348062445509,E-mail:valentinechibike@gmail.com

The aim of this work is to study the effects on compressive strength and workability of concrete when partially substituting Portland cement binder with fly ash in the concrete mix, with the objective of helping to popularize the use of fly ash for gainful partial replacement of cement in concrete for construction purposes among engineers and other stakeholders. The relevance of this work is that it may inspire individuals to see and use fly ash as a recovered resource in concreting, and help the various governments to prefer the choice of generating power using coal in order to beef up the operating potentials of local construction industries [3].

2 MATERIAL AND METHOD

(i)Material and Equipment

The materials used were washed sand (deposited by flowing river) as fine aggregate, Portland cement and fly ash as binder; water was also used. The river sand was a well graded, naturally clean sand with maximum size of 2.0mm (medium sand). The coarse aggregate was crushed granite, free of rock dust and maximum size of 12mm to 16mm. Fly ash was obtained from a coal-fired electric power plant in Oji-River, Enugu State of Nigeria. The fly ash was passed through a 45μ sieve to remove contaminants and ensure that the size of fly ash particles can effectively blend with cement for better pozzolanic reaction. The fly ash was produced from a bituminous coal and therefore a class F fly ash by classification. Grade 42.5N Portland limestone cement (by Nigerian standard) was used throughout the experiment. Equipment used include 150 by 150 by 150-mm cube mould, weighing balance, mould oil, trowel, shovel, slump cone, glass plate, meter rule, curing tank, tamping rod and a universal testing machine.

(ii) Experimental procedures

The quantities of sand, gravel, cement, fly ash and water were carefully calculated and weighted out, using mix proportion of 1:2:4, for two concrete cubes at a time. Cement, fly ash and sand were thoroughly mixed with shovel on a non-absorbent surface, before the gravel was added; and mixed further, before water was added and final mixing was done until the paste became uniformly plastic. Water-to-binder ratio of 0.59 was used. The paste was fed in three layers into the slump cone placed on the glass plate. Each layer was uniformly tamped 25 times. The top was stroke level, the cone was raised and slump measured. Using the same paste, concrete cubes were cast to B.S 1889 standard. This process was applied to 0%, 10%, 20%, 30%, 40%, 50% and 60% cement replacement with fly ash by weight of cement content. A total of 56 cubes were cast, 8 cubes for every percentage replacement. The cubes were cured in water for 28 days, during which 2 cubes from each percentage replacement were tested for strength with the universal testing machine at 7 days, 14 days, 21 days and 28 days. The results were tabulated and analyzed.

3 RESULTS

The results of the compressive strength and slump tests are given in Table 1. In column 2 of the Table the quantities of fly ash used in substituting Portland cement are tabulated. The resulting slump values are given in column 3, while the average compressive strengths are given in columns 4 to 7 for the various curing periods.

Table 1: Slump and compressive strength tests results

S/N	**Fly ash replace-ment (%)**	**Slump value (mm)**	**Average compressive strength (N/mm^2)**			
			7 days	**14 days**	**21 days**	**28 days**
1.	0	65	11.1	13.8	16.6	21.3
2.	10	85	13.2	15.6	18.4	24.3
3.	20	102	12.2	13.6	15.6	22.8
4.	30	110	9.5	10.4	12.6	18.9
5.	40	130	8.7	9.6	10.3	17.7
6.	50	145	7.3	8.1	9.8	15.5
7.	60	158	6.7	7.7	8.5	14.4

3 DISCUSSION OF RESULT

From the results it can be observed in Table 1 that the slump (indicator of workability) increased uniformly with increase in fly ash content as Portland cement was replaced with fly ash in the concrete. This is often attributed to the fineness and spherical nature of the fly ash particles which acts as ball bearings in the fresh concrete [5],[6]. This means that the labour required to cast a concrete containing fly ash is much reduced compared to the normal concrete. It also means that concretes containing fly ash can be useful in concretes for thin walled structure, structural members with congested reinforcements, and in obtaining high strength and good surface finish with good savings in cost of labour and materials [5].

The final strength (28-days strength) also increased with increase in fly ash content; including the early strength (7-days strength). These increases stopped at 20% fly ash content, and then reduced continuously to half the starting values at 60% replacement. Referring to Table 1, the initial and final strengths at 7-days and 28-days curing period for 0% cement replacement (the normal concrete and also the control) were 11.1N/mm^2 and 21.3N/mm^2, but increased to 13.2N/mm^2 and 24.3N/mm^2, respectively, at 10% fly ash content, and then reduced to 6.7N/mm^2 and 14.4$N/mm^{2,}$ respectively, at 60% fly ash content. This is in agreement with the findings of Pati and Kale, [8]
The accompanying increase in workability as the strength increased with replacement of cement with fly ash simply indicates that the water content of the mix can be reduced, while maintaining a required consistency as fly ash replaces cement in the concrete mix. This, from concrete technology principles, can improve the strength of the concrete [3]

The foregoing discussions practically show that fly ash is not just an industrial waste, but also a recovered resource. This assertion can form a base for making choice of power generating method in countries with abundant deposit of coal; not just for steady power supply, but also for the local construction industries to grow as fly ash will be generated; and more so because more uses of fly ash are being discovered[3],[9]

4 CONCLUSION

In conclusion, fly ash is a very important additive for concrete; though fly ash is an industrial waste, it can be view as a recovered resource in view of its usefulness in concreting and other fields. One can rely on the potentials of fly ash as a recyclable waste to make wise choice in power generation for sustainable economic development.

Fly ash up to 30% replacement of cement content can be used in normal concreting without any significant change in the general strength of the hardened concrete; concretes with more than 30% replacement can be used for large mass concrete elements.

5 RECOMMENDATION

It is hereby recommended that fly ash should be used to replace cement content up to 30% in normal concreting. Concretes containing over 30% replacement should be used for large mass concrete to prevent cracks due to high heat of hydration. Where fly ash is abundant, it should be used regularly in concreting to reduce the depletion of natural resource, limestone and shale, used for cement production. Developing and under developed countries should show preference for electric power generated with coal (where possible) to enjoy the economic benefits of fly ash.

References

[1]A.M. Neville,"Properties of concrete" 4th ed, John Wiley and sons, London, pp113 – 118, 1996.

[2]R.H. Elvery, "Concrete practice", C.R. Books Ltd, Lennox House, Norfork Street,pp 129 – 131, 1963

[3]Juan Rodriquez, "Seven most used concrete admixtures", The Balance Magazine 2017, www.thebalance.com accessed 26/03/18

[4] D.B. Kim D.B, Michael C. Tim F, Patrick. H, "What is Fly Ash? "Concrete construction magazine, 2007,

[5]T.Gidion. and M. Harum, " Using cementitious materials such as fly ash to replace a part of cement in producing High strength concrete in hot weather" 10P conf. series: Material Science and Engineering 316, 2018.

[6] J.H. Feber, "40 years of Ash marketing in USA" Proceedings of the utilization of Ash workshop, May 13-15, University of North Dakota, Grand Forks ND; pp 1-1-7, 1987.

[7] M.S. Shetty, "Concrete Technology", S. chand company Ltd, New Delhi, 124 - 137, and 2009.

[8]S.L. Pati Kale and J.N. Summan, "Fly Ash in concrete", International Journal of Advanced Engineering Research and Studies Vol.1 issue 1, 2012

[9] Engr. Mansoar –Ul-Hassan, "Power generation methods technology and economical strategy", *International Technical Journal* Vol. 1. No 1, 2014.