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Effect of compressive strength on Abrasion resistance for fly ash concrete

I. Padmanaban[1] and D. Maruthachalam[2]

[1]Department of Civil Engineering, Jansons Institute of Technology, Coimbatore 641 659, TN., India
[2]Department of Civil Engineering Sri Krishna College of Engineering and Technology, Coimbatore 641 008, Tamil Nadu, India

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ABSTRACT

Concrete surface suffers damage due to various forms of wear such as erosion, cavitations, and abrasion due to various exposures. Abrasion wear occurs due to rubbing, scraping, skidding, or sliding of objects on the concrete surface. This form of wear is observed in pavements, floors, or other surfaces on which friction forces are applied due to relative motion between the surfaces and moving objects. Concrete abrasion resistance is markedly influenced by a number of factors including concrete strength, aggregate properties, surface finishing, and type of hardeners or toppings. This paper presents the study of abrasion resistance of Indian fly ash mixes with locally available ingredients. The abrasion resistance and compressive strength of concrete containing high volume fly ash (HVFA) was investigated. Class F fly ash was replaced for cement upto 60% by weight. Due to Pozzolanic reactions of fly ash content, HVFAC showed improved abrasion resistance upto 25% with the increase in age. Strong correlation exists between abrasion resistance and compressive strength which is derived at 28, 56 and 90 days. The results of the investigations show that Indian fly ash can be effectively utilized for improving abrasion resistance of concrete surface.

Key words : *Fly ash, Abrasion, Compressive strength, Wear, HVFA, LVFA, Regression*

Introduction

Concrete abrasion resistance is markedly influenced by a number of factors including concrete strength, aggregate properties, surface finishing, and type of hardeners or toppings. A large number of previous studies (BIS, 1970; IS, 383-1970) have indicated that concrete abrasion resistance is primarily dependent upon compressive strength of the concrete. The factors such as air entrainment, water-to-cement ratio, type of aggregates and their properties, etc. that affect the concrete strength, therefore, should also influence abrasion resistance. In general, hardened paste possesses low resistance to abrasion. In order to develop concrete for high abrasion resistance, it is desirable to use hard surface material, aggregate, and paste having low porosity and high strength. Data on the abrasion resistance of concrete is needed to determine appropriate mixture proportions in order to make abrasion resistant concrete. A limited amount of published work is available on abrasion resistance of fly ash concrete, especially high-volume Class F fly ash concrete.

In India, the annual production of fly ash, non combustible by-product of coal burning power plants is about 100 million tones (BIS, 1970). Disposal of fly ash is a major issue, currently only about 15% of this amount (BIS, 1997) is utilized and rest goes as landfill. Fly ash concrete has all the attributes of high performance concrete such as me-

1. Professor, 2. Associate Professor
***Corresponding author's email:** dmaruthachalam@gmail.com; padu2kin@gmail.com

chanical properties, low permeability, superior durability and environment friendly which can be effectively used for improving the economy of the nation. Presently large amount of fly ash is being utilized in subgrade of the pavement and minimum amount is used in wearing course along with cement.

The present study was undertaken to utilize effectively the class F fly ash by conducting abrasion studies on HVFA concrete. Abrasion resistance improved with the compressive strength hence to find the relationship factor of compressive strength on abrasion resistance for all ages.

Review of Relevant Research

Concrete containing Class C fly ash exhibited better abrasion resistance than both concrete without fly ash and concretes containing Class F fly ash (Tikalsky *et al.*, 1988). The abrasion resistance of fly ash concrete was found to be similar to normal concrete (Langan *et al.*, 1990). Dhir *et al.* (1991) concluded that near surface characteristics such as absorption, intrinsic permeability and vapour diffusivity are closely related with the abrasion resistance of concrete. Siddique (2003) investigated the influence of replacing cement with 0–40% Class F fly ash on the abrasion resistance of concrete up to the age of 365 days. Test results indicated that abrasion resistance of concrete depends on the age of the concrete. On the other hand, the presence of fly ash at high levels (50%) of cement replacement was found to decrease the abrasion resistance at all ages in comparison to concrete made without fly ash. Similarly, superplasticized concrete incorporating high volumes (55–66%) of Class F fly ash concretes had poorer abrasion resistance than concrete without fly ash (Bilodeau and Malhotra, 1992). Yazici and Inan (2006) developed a relationship

between mechanical properties (compressive and splitting tensile strengths) and abrasion resistance of high strength concretes (HSC) having compressive strength between 65 and 85 MPa. They concluded that abrasion resistance of high strength concrete can be estimated from compressive and splitting tensile strength results. Yen *et al.* (2007) established equations based on effective compressive strength and effective water-to-binder ratios, which were modified by cement replacement and developed to predict the 28- and 91-day abrasion resistance of concretes with compressive strengths ranging from approximately 30–100 MPa. The predicted results compared favourably with the experimental results. This study was undertaken to explore the possibility of utilizing large quantities of Class F fly ash as sand (fine aggregate) replacement in concrete, and investigate its effect on the mechanical properties and abrasion resistance of HVFA concrete.

Material and Methods

Materials Used

Ordinary Portland Cement (OPC-53 grade) conforming to IS12269-1987 was used in the investigation. Locally available river sand as fine aggregate conforming to Zone II of IS: 383-1970 [11] and the coarse aggregate of 20mm size crushed granite stone obtained from the local quarry was used. Potable water was used for the casting specimens and for curing purposes. Sulphonated naphthalene polymer SUPAFLO- superplasticizer, 1% by weight of binder (Cement + Fly ash) was added as admixture to enhance workability. Class F Fly ash procured from Mettur Thermal Power Plant was used as partial replacement of cement by weight. Mix proportioning of HVFAC is a more critical process than normal conventional concrete in view of high fines content and low water-binder ratio. Jiang and Malhotra (2000), suggested a mix proportioning method based on combination of empirical results and absolute volume method. The mix proportion based on the above method was arrived for M 60. The details of various fly ash mixes are given in the Table 1. A total of 84 tile specimens using 6 different mixes were cast in the present study.

Abrasion studies

Abrasion studies were conducted on 70 × 70 × 25 mm thick specimens as per IS: 1237-1980 procedure for abrasion test. The reduction in thickness due to abrasive action of aluminum oxide was determined. A total of eighty four specimens (84 Nos.) were prepared by using prefabricated mould. The grinding path of the disc of the abrasion-testing machine was evenly strewn with 20 gms of abrasive powder. The specimen was placed in the holding device with the surface to the ground facing the disc and loaded at the center with 300 N. The grinding disc was put in motion at a speed of 30 rev/min. After every 22 revolution the specimen was turned about the vertical axis through an angle of 90º in the clockwise direction and it was repeated for 9 times there by giv-

Table 1. Details of various fly ash mixes

Mix designation	FA-0	FA-10	FA-20	FA-30	FA-40	FA-50	FA-60
Fly ash in %	0	10	20	30	40	50	60
Water-binder ratio	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Cement kg/ m^3	500	450	400	350	300	250	200
Fly ash kg/ m^3	0	50	100	150	200	250	300
Fine aggregate kg/ m^3	700	680	660	640	620	600	580
Coarse aggregate kg/m^3	1000	1000	1000	1000	1000	1000	1000
Water lit/m^3	180	180	180	180	180	180	180
Superplasticizer kg/m^3	5	5	5	5	5	5	5

ing total number of 220 revolutions. The depth of wear was noted for every 5 minutes as done by Rafat Siddique (2004) (5) for fly ash concrete.

Results and Discussion

Abrasion test results at the age of 28, 56, 90 and 365 days are given in Table 2. The relation between the depths of wear with time is shown in Figs. 1, 2, 3 and 4 at various ages. At the age of 28 days the minimum and the maximum depth of wear observed for the fly ash mix is 1.83 mm and 2.8 mm respectively. But whereas at the age of 365 days, the minimum and maximum depth of wear is 1.61 mm and 2.1 mm respectively. With the increase in age, the compressive strength of fly ash mixes are improving to greater extent and achieving almost the target strength at the age of 90 days. This property enhances the performances of the fly ash mix hence the reduction in wear.

The abrasion effect on fly ash mixes with respect to ages is shown in Table 2, the depth of wear is reducing with increase in ages. With the increase in fly ash quantity for the mixes FA 0, FA 10, FA 20, FA 30, FA 40, FA 50 and FA 60, depth of the wear is increasing in all ages. The large quantities of fly ash have contributed to the wear of greater depth. At the age of 28 days, the maximum wear exhibited by fly ash mix FA 60 is 2.8 mm which is 55.56% higher than control mix FA-0. The maximum wear exhibited by fly ash mix FA 60 is 2.6 mm at the age of 56 days which is 52.94 % higher than control mix FA-0, whereas it is 56.25 % higher than control mix FA-0 at

Table 2. Maximum wear of fly ash Mixes

Mix	Fly ash %	Average Maximum wear in mm			
		28 days	56 days	90 days	365 days
FA-0	0	1.8	1.7	1.6	1.5
FA-10	10	1.83	1.73	1.7	1.61
FA-20	20	2.01	1.9	1.88	1.65
FA-30	30	2.1	1.98	1.9	1.67
FA-40	40	2.29	2.2	2.15	1.88
FA-50	50	2.5	2.4	2.31	1.99
FA-60	60	2.8	2.6	2.5	2.1

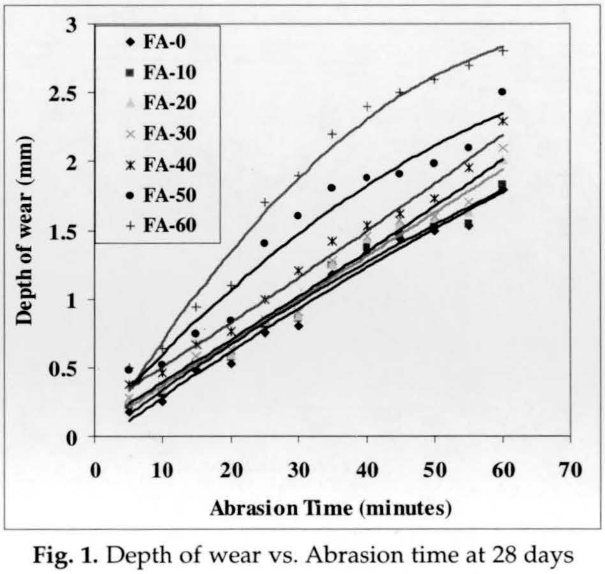

Fig. 1. Depth of wear vs. Abrasion time at 28 days

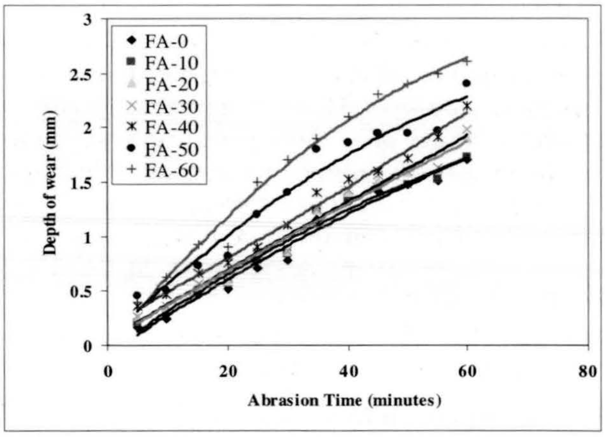

Fig. 2. Depth of wear vs. Abrasion time at 56 days

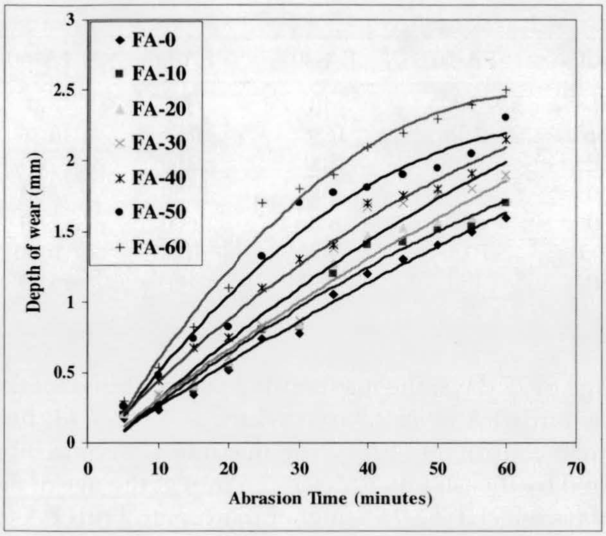

Fig. 3. Depth of wear vs. Abrasion time at 90 days

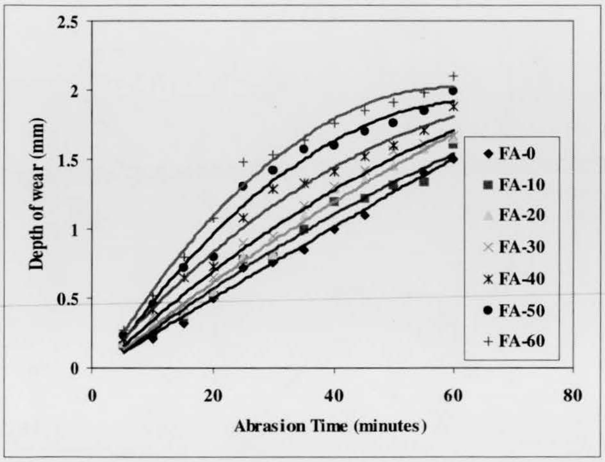

Fig. 4. Depth of wear vs. Abrasion time at 365 days

90 days. At the age of 365 days, for the fly ash mixes FA-10, FA-20, FA-30, FA-40 FA-50 and FA-60, the percentage variation of wear higher than control mix FA-0 is by 7, 10, 11, 25, 32 and 40 respectively. Hence, at the age of 365days, percentage of wear for all the mixes has reduced to considerable extent compared to the ages at 28, 56 and 90 days. The maximum percentage improvement in wear resistance for the fly ash mixes FA-10, FA-20, FA30, FA-40, FA 50 and FA 60 at the age of 365 days is 12, 18,20,18,20 and 25 respectively when compared to the corresponding mixes at 28 days

Linear Regression Models

From the experimental investigation, with large quantity fly ash content, it is clear that wear of the fly ash mix is reducing with increase in ages. The correlations can be established by linear relations at the various ages as shown in Figs. 5, 6 and 7. Linear regression analysis of the relation between Wear (d) and the compressive strength (f_c) at their respective ages are given in the following empirical equations 1,2and 3 at 28, 56 and 90 days respectively.

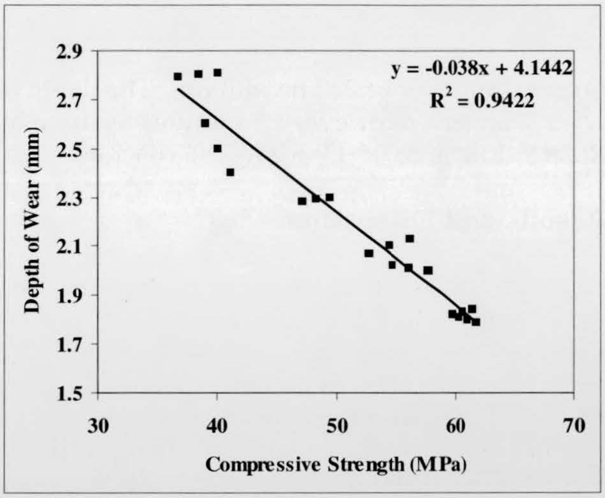

Fig. 5. Relation between compressive Strength and wear at 28 days

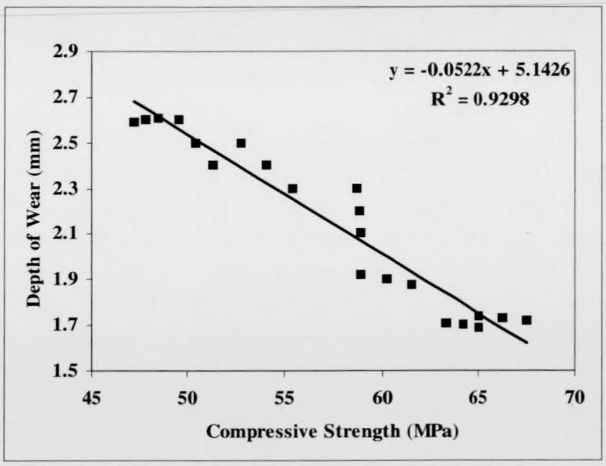

Fig. 6. Relation between Compressive Strength and wear at 56 days

Depth of wear = - 0.038 f_c + 4.1442 $R^2 = 0.94$ at 28 days (1)

Depth of wear = - 0.0522 f_c + 5.1426 $R^2 = 0.92$ at 56 days (2)

Depth of wear = - 0.0691 f_c + 6.2548 $R^2 = 0.88$ at 90 days (3)

The negative value of f_c is due to the negative slope and the depth of wear decreases with increase

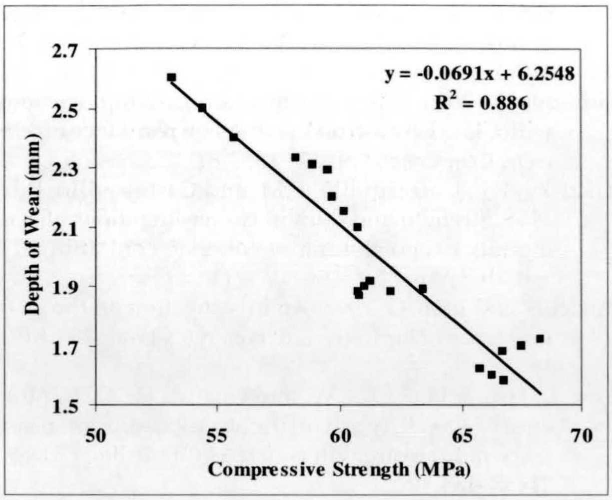

Fig. 7. Relation between Compressive Strength and wear at 90 days

in age. Over the ages compressive strength of the high volume fly ash mixes also improves which provides an added advantage in increase in wear resistance with the increase in ages.

Abrasion resistance of fly ash concrete varies inversely with compressive strength of the fly ash mix as shown in Figure 8. The relation between abrasion resistance and compressive strength is given by equation 4

Depth of wear = - 0.0391 f_c + 4.3074 R^2 = 0.8348 (4)

From the equation 5, it is inferred that abrasion resistance of fly ash concrete has a strong correlation

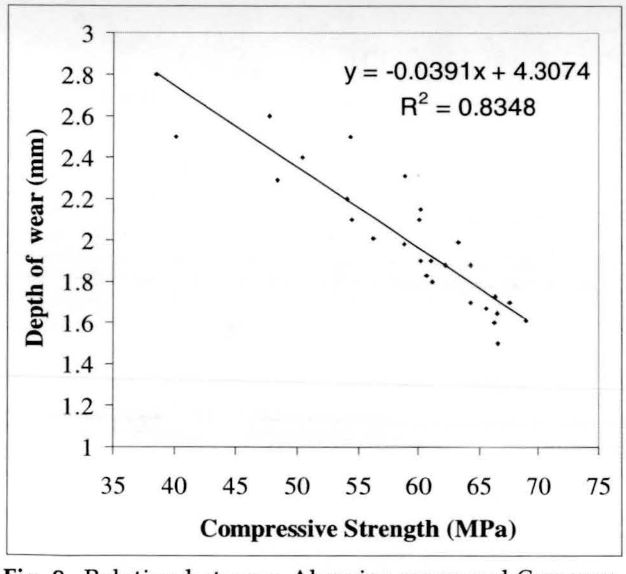

Fig. 8. Relation between Abrasion wear and Compressive Strength

with the compressive strength. The results based on empirical equation are shown in Figure 9. The prediction of results based on the empirical relation lies within ± 10% variations. The equation 5 shows a good correlation which can be used in prediction of the results based on the compressive strength.

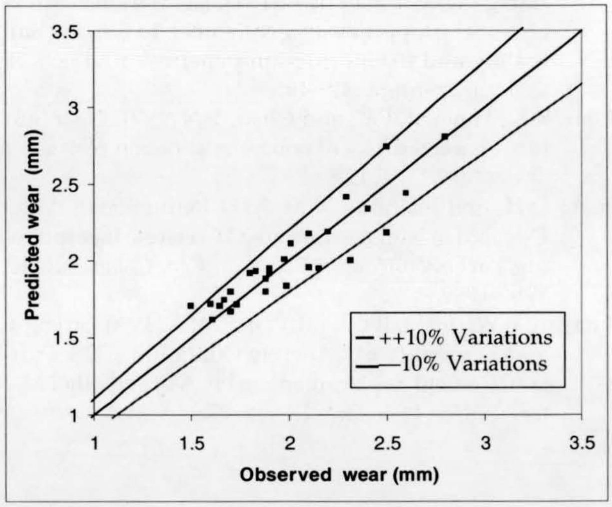

Fig. 9. Relations between Predicted and Observed Wear

Conclusions

Based on the experimental investigation the following conclusions are drawn.

1. The mix FA-10 shows better performance characteristics at the age of 28 days but at the age of 365 days for the fly ash mixes FA-10, FA-20, FA-30,FA-40 FA-50 and FA-60, the percentage variation of wear higher than control mix FA-0 is by 7, 10,11, 25,32 and 40 respectively
2. Compressive strength has direct correlation with abrasion resistance. Increase in compressive strength results in improved abrasion resistance.
3. The empirical relations obtained can be used to predict the abrasion resistance of the tile specimen based on compressive strength. Predicted values of abrasion resistance based on compressive strength lies within ± 10 variations in the present investigation.
4. Age affects the wear resistance characteristics. The maximum percentage improvement in wear resistance for the fly ash mixes FA-10, FA-20, FA30, FA-40, FA 50 and FA 60 at the age of 365 days when compared to the corresponding

mixes at 28 days is 12, 18, 20, 18, 20 and 25 respectively.

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