ICPCM 2019

Innovative utilization of fly ash in concrete tiles for sustainable construction

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Abstract

The disposal of fly ash has been causing a severe headache to the environmentalists all across the globe. The effective utilisation of fly ash is restricted only to manufacture of bricks, producing fly ash based pozzolanic cement and use in pavements. To utilise the fly ash in high volume the innovative idea is to utilize it as a replacement of fine aggregate in concrete tiles. The present investigation deals with the manufacturing and characterisation of concrete tiles with fly ash as a replacement of fine aggregate. A mix design for M 40 grade concrete was carried out. Fine aggregate was replaced with fly ash, where the fly ash content varied from 0%-40% with an interval of 10%. Various physical strength parameters such as wet transverse strength, water absorption and resistance to wear were determined for the concrete tiles. Also the natural frequencies of tiles were determined by subjecting them to dynamic tests. The influence of fly ash content was studied for all the strength parameters. The experimental results indicate that there is significant improvement in strength and durability characteristics over control concrete when fine aggregate is replaced with fly ash up to 30% replacement. This ensures the suitability of the use of fly ash based concrete tiles. Since fly ash is used for sand replacement, it helps in minimizing the depletion of mineral resources.

Keywords: Fly ash, Pozzolanic; Concrete Tiles; Fine Aggregate; Strength Parameters.

1. Introduction

With the progressing world, industrialization has become an inseparable part of the modern economy. Coal driven power sectors are the backbone of every industry and every developing nation. The increasing reliance of coal fueled power sectors is increasing the generation of fly ash every year. The concern for the environmental impact due to huge amount of fly ash production is grabbing attention of everyone worldwide. With increasing population, increasing cost of land, problems related to leaching and huge environmental nuisance, land disposal of fly ash is not an option anymore. So utilization of fly ash in various field is of current research interest leading towards a sustainable and better future. Due to urbanization and huge population explosion, the natural resources are depleting much faster, which is causing severe headache to all the pioneers in research, development and industry. In a developing nation like India, the demand for building materials like cement, fine aggregate and natural coarse aggregate is increasing exponentially to support its construction industries. So innovative utilization of fly ash for construction purposes will not only solve fly ash disposal problems, but it also will help in reducing depletion of mineral resources.

Society's expanding reliance on sand has resulted in its depletion causing real difficulties in construction area which needs to be dealt with. Siddique [1] replaced fine aggregate with class F fly ash and studied the split tensile, compressive and flexural behaviour of concrete specimens up to 50% replacement level. Test results for abrasion characteristics and compressive strength of concrete were studied by Siddique [2] when sand was substituted with class F fly ash. Parvathi and Prakash [3] studied properties of concrete subjected to elevated temperature up to 800°C for partial replacement of fine aggregate with Fly ash. The test results showed increase in shear strength, flexural strength and compressive strength of the concrete. Singh and Siddique [4] studied the strength and microstructural properties of concrete, which contained coal bottom fly ash as a substitution for fine aggregate. The use of coal bottom fly ash increases the water cement ratio in order to obtain same workability as that of conventional concrete. Kanthi and Kavitha [5] replaced sand with fly ash and examined the results for various strength behaviour of concrete such as flexural strength, modulus of elasticity and compressive strength.

When it comes to the application of fly ash in concrete tiles, the available literature is very few. Mishulovich and Evanko [6] conducted their research on the effect of fly ash with moderately high carbon content on ceramic tiles. The process involved subjecting the tiles to a temperature that would be sufficient for the oxidation of carbon before the formation of liquid phase. Partial replacement of cement and sand with fly ash in tile adhesive was investigated by Andic et al. [7]. A statistical relationship between tensile adhesion, flexural strength and compressive strength was studied. Rajamannan [8] et al. studied the effects of addition of fly ash in ceramic tiles and examined their mechanical properties. The use of fly ash in little amount improved the strength parameters of the tiles.

When it comes to combining beauty and functionality, no product outshines cement concrete tiles. They last far longer than ceramic tiles and can be customized with our own idea and provide us with versatility and flexibility. Cota et al. [9] studied the properties of concrete tiles when quartz aggregate was replaced with waste glass and Portland cement was replaced with metakaolin. Permeability, dynamic modulus, bulk modulus and length changes were examined due to alkali silica reaction expansion. Metakaolin was used as a replacement of cement in order to achieve lower alkali silica reaction expansion. Wang et al [10] utilised high alumina fly ash (HAFA) in ceramic tiles and studied the influence of HAFA and sintering temperature on tile properties.

Above survey shows that significant amount of work has been done on the utilisation of fly ash as a replacement of sand. Also some literatures are available on the utilization of fly ash in ceramic tiles. But, the research on utilization of fly ash in fabrication of concrete tiles is yet to be carried out. Therefore, this study was conducted to assess the feasibility of application of fly ash in high amount in concrete tiles without affecting the strength parameters as per Indian Standard Specifications. The scope of this study includes preparing mix for different percentages of fly ash as a replacement of fine aggregate, preparation of tile specimens and evaluating wet transverse strength, water absorption, resistance to wear and natural frequencies of concrete tiles.

2. Materials

Ordinary Portland Cement of 53 grade was used for the study complying with IS 12269:2013 [11] . Its specific gravity was 3.14 having intial and final setting times 70 mins and 480 mins respectively. For fine aggregate, natural sand was used having maximum size 4.75 mm and specific gravity 2.64 confirming to Zone-III having fineness modulus 2.313. Coarse aggregates used in this study were of 10 mm nominal size having specific gravity 2.86. Both the aggregates comply to IS 383:1970 [12]. The fly ash used here is of class F type confirming to ASTM C 618 [13]. Silica was mainly present in the fly ash with few percentage of alumina, iron oxide and calcium oxide.

3. Experimental Procedure

3.1 Mix Proportion

For the present study fly ash of varying proportion (0% - 40%) with a replacement of fine aggregate was used. M40 grade concrete is being considered for the present work and the concrete mix was prepared with a water-cement ratio 0.4 with the addition of superplasticizer Conplast FOSROC 430 G8 as per IS 9103:1999 [14]. The mix was prepared as per IS 10262:2009 [15]. The mix proportion for replacement of fine aggregate with fly ash is presented in Table 1.

Table 1. Proportion of Fresh Concrete mixture for fine aggregate replacement with fly ash

Mixture No.	Cement (kg/m^3)	Fly Ash (%)	Fly Ash (kg/m^3)	w/c ratio	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	Super Plasticizer (%)
SR-0	416.0	0	0	0.4	925.45	1002.57	0.5
SR-10	416.0	10	84.13	0.4	832.91	1002.57	1.00
SR-20	416.0	20	166.23	0.4	740.36	1002.57	1.2
SR-30	416.0	30	252.39	0.4	647.82	1002.57	1.4
SR-40	416.0	40	336.52	0.4	555.27	1002.57	1.5

3.2 Preparation of Specimens

Cement, sand, coarse aggregate, water and superplasticizer were mixed thoroughly in the concrete mixer. Then it was filled in square tile moulds of size 31 cm×31 cm and thickness 2.8 cm. All the filled tile moulds were vibrated using table vibrator. After casting all the specimens were finished with a steel trowel and it was kept for 24 hours. After 24 hours they were demoulded from the moulds and kept in the water tank for curing. For replacement of sand with fly ash same procedure was repeated.

3.3 Test methods

After curing, the concrete tiles were subjected to various static and dynamic tests to determine the strength and durability parameters. The wet transverse strength test of tiles was conducted as per IS 1237:2012 [16]. A MOR (Modulus of Rupture) testing machine was used for this test and the test set up is shown in Fig 1. Ply wood padding of 3 mm thickness and 20 mm wide were placed between the tiles and each of the supports. The load was applied gradually until the tile broke. The load causing the breaking of the tile was recorded and wet transverse strength was calculated. For water absorption, the tile specimens were immersed completely in clean water for 24 hours. After 24 hours the specimens were removed from the water and were wiped dry and weighed immediately to get the saturated mass. The tiles were reweighed after keeping them in an oven at a temp of 65 ± 1 o C for 24 hours.

Resistance to wear of the concrete tiles is determined by abrasion test as mentioned in IS: 1237:2012. For this test, square-shaped specimens measuring 71.0 ± 0.5 mm were considered, which were cut from the concrete tiles. Before testing, the specimens were dried to constant mass at a temperature of 105 ± 5 ^{o}C. The grinding disc was run at a speed of 30 rpm. The disc was stopped after one cycle of 22 revolutions. After each cycle the specimen was rotated anti-clockwise. The resistance to wear was measured after completion of 220 revolutions. The arrangement for resistance to wear test is shown in Fig 2.

Fig. 1. MOR Testing Machine

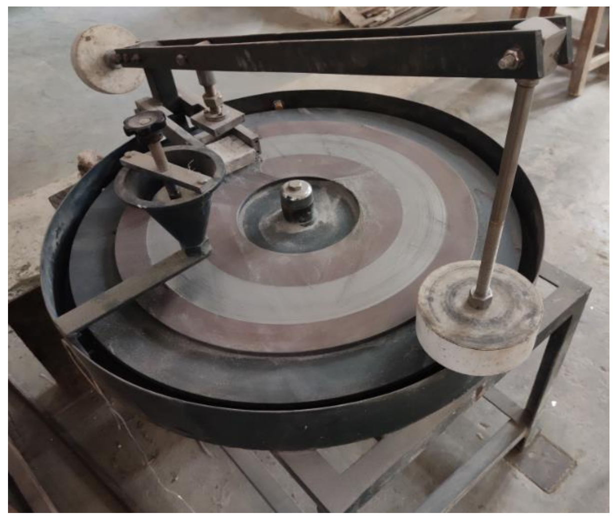

Fig. 2. Resistance to wear Test Set up

Concrete tiles may be subjected to dynamic loading during their service life. So, to study the variation in dynamic stiffness, concrete tiles were tested to determine the natural frequency using Bruel and Kjaer, Denmark vibration analyser. The test set up includes FFT analyser (Model B&K 3560-C), accelerometer (B&K 4507), modal hammer (B&K 2302-5), PULSE lab shop software with Notebook and test specimens (concrete tiles size 31 cm× 31 cm × 2.8 cm). The boundary condition of tile for the experimental work was all sides free *(F-F-F-F)* and it is shown in Fig. 3. The FFT analyser, transducers, modal hammer and cables are shown in Fig. 4.

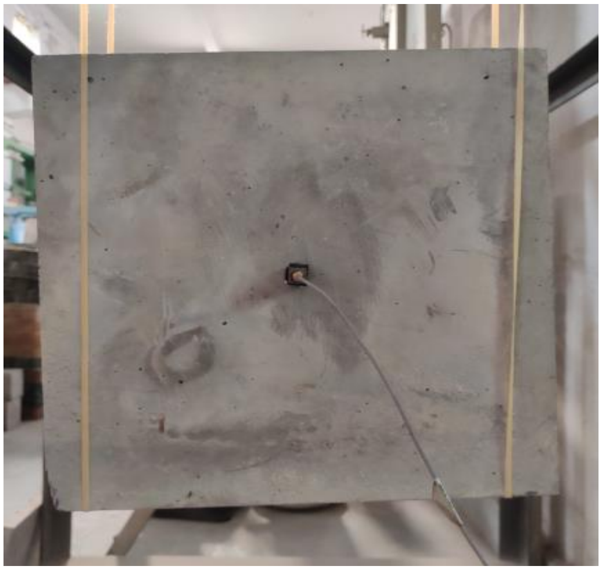

Fig. 3. Concrete Tiles with F-F-F-F Boundary Condition

Fig. 4. FFT Analyser Set up

4. Results and Discussion

4.1 Wet Transverse Strength

The wet transverse strength of fly ash based concrete tiles was determined at the age of 28 days. The 7-day and 28-day wet transverse strength with 0% - 40% fly ash addition as a replacement of fine aggregate is plotted in Fig. 5. The 28-day wet transverse strength of control mix was 4.6 MPa which increased to 5.57 MPa by inclusion of 20% fly ash. From Fig.5, it is noticed that the wet transverse strength of the concrete tiles containing 10% - 30% fly ash were significantly higher than control mix tiles. Concrete tiles with 10%, 20% and 30% fly ash exhibited 6.95%, 21.08%, 1.3% higher 28-day strength than tiles without fly ash respectively. The increase in strength may be attributed to reaction of fly ash with the surplus lime produced by the hydration of Portland cement. The reduction in strength for tiles containing 40% fly ash may be due to non-reactivity of increased surplus fly ash. Although, the 28-day wet transverse strength for 40% replacement of fine aggregate with fly ash is 4.49 MPa which is more than the minimum prescribed limit of 3 MPa as per IS 1237:2012 [16].

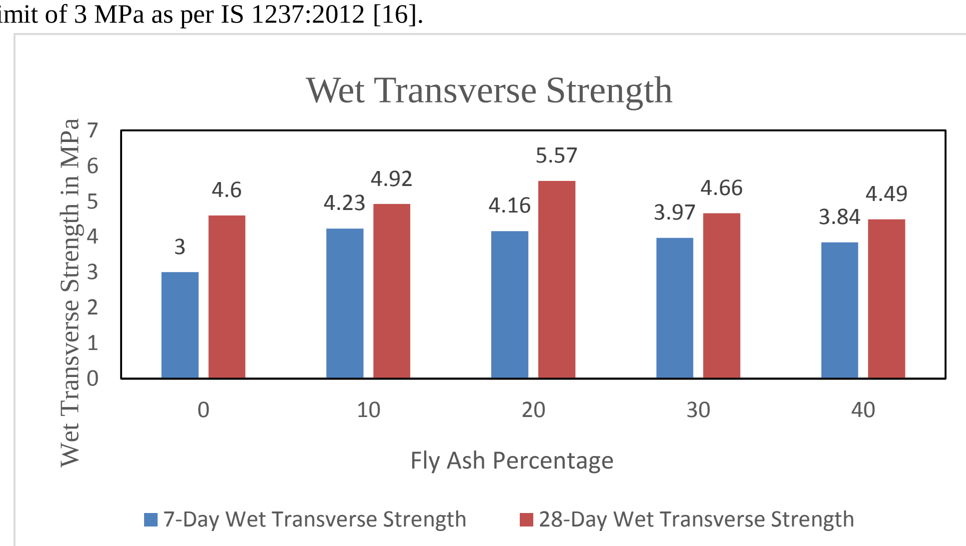

Fig. 5. Fine Aggregate replacement with fly ash vs Wet Transverse strength

4.2 Water Absorption

The water absorption of fly ash blended tiles with 0% - 40% fly ash is presented in Fig. 6. The water absorption percentage is reduced gradually up to 20 % replacement of fine aggregate with fly ash, after that it is increased. 10.3% and 19.7% improvement in water absorption percentage is noticed at 10% and 20% replacement of fine aggregate with fly ash. This may be attributed to reduction of pores due to filled up micro pores with fly ash making denser and cohesive concrete tiles. All the water absorption percentages are well within the maximum prescribed limit of 10% as per IS 1237: 2012 [16].

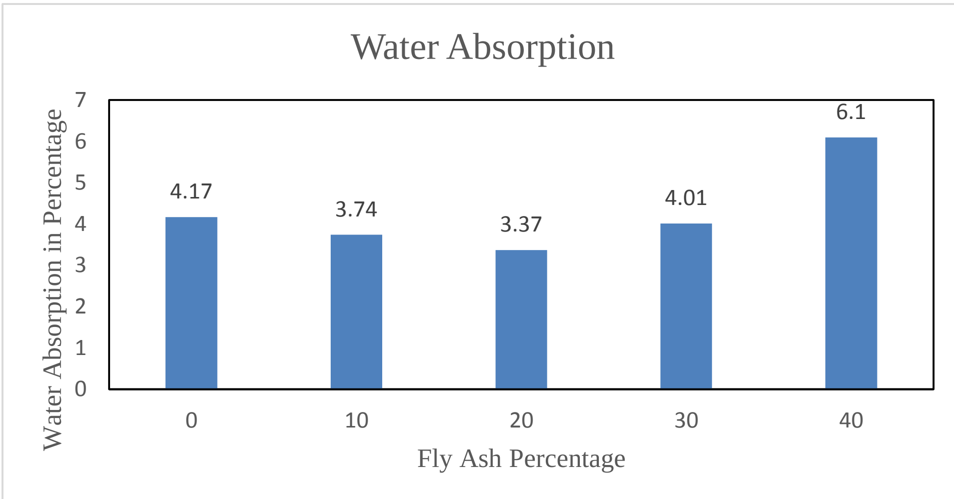

Fig. 6. Fine Aggregate replacement with fly ash vs Water Absorption

4.3 Resistance to wear

The effect of fly ash content on resistance to wear of concrete tiles is shown in Fig. 7. The resistance to wear of concrete is improved significantly up to 20% replacement of fly ash. The resistance to wear for control mix is 0.392 mm, while the resistance for 10% and 20% fly ash blended tiles is 0.364 mm and 0.34 mm respectively giving an improvement of 7.1% and 15.29% over control concrete. This enhancement in resistance may be attributed to densification of the mix and increased strength due to pozzolanic activity of silica in fly ash with surplus hydrated lime as a result of hydration of Portland cement. For 30% and 40% replacement of fly ash the loss in thickness is more than the control concrete may be due to increase in fine particles. All the resistance to wear values are well within the prescribed limit of 2 mm as maximum prescribed limit of 2 mm as per IS 1237:2012 [16].

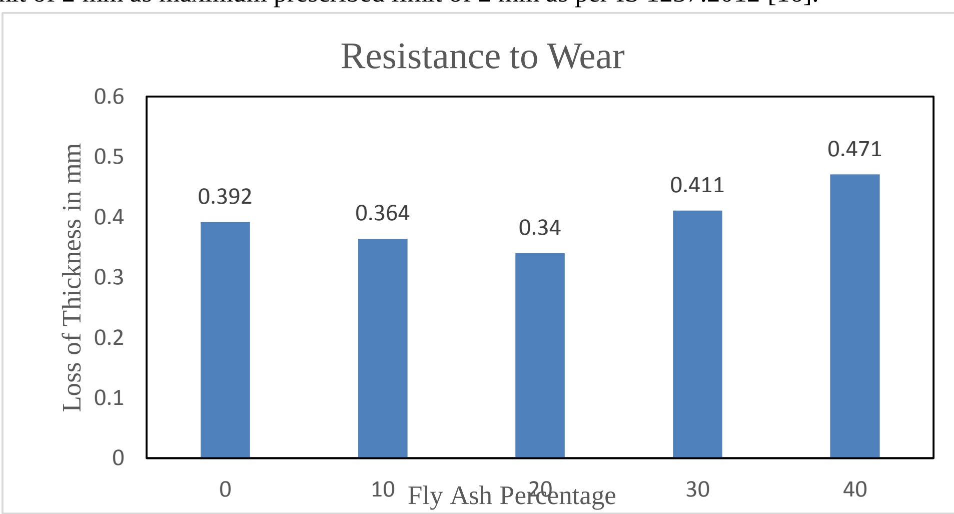

Fig. 7. Fine Aggregate replacement with fly ash vs Loss of thickness due to Abrasion

4.4 Natural Frequency

Table 2. presents the effect on natural frequency of concrete tiles when fly ash is used as a substitute for fine aggregate. It is observed that natural frequencies of fly ash tiles are less than the value for control mix tiles. As observed in Table 2, the natural frequency of vibration reflecting the dynamic stiffness is marginally decreasing with increase of percentage of fly ash in the mix. As expected, the second highest natural frequency is significantly higher and follows similar trend with the fundamental frequency.

Table 1. Natural Frequency of Tiles for fine aggregate replacement with fly ash

Mixture No.	Fly Ash (%)	1st Frequency	2nd Frequency
SR-0	0	16.0	1332
SR-10	10	16.0	1328
SR-20	20	8.0	1308
SR-30	30	8.0	1264
SR-40	40	8.0	1184

5. Conclusion

From the experimental investigation the following conclusions are drawn.

- Up to 40% substitution of fine aggregate with fly ash, the concrete tiles possess required physical strength parameters.
- Enhancement of strength is observed up to 30% substitution of fine aggregate with fly ash compared to the control mix.
- It is found that for 20% replacement of fine aggregate with fly ash, the 28-day wet transverse strength is increased 21. 09% than control mix.
- The water absorption test results show an improvement of 19.18 % over control mix for 20 % replacement of fine aggregate with fly ash.
- With increase of fly ash content, the natural frequency of tiles decreases.
- Resistance of wear was enhanced with increment in fly ash content up to 20 % as replacement of fine aggregate.

References

[1] R. Siddique, Effect of fine aggregate replacement with Class F fly ash on the mechanical properties of concrete, Cem. Concr. Res. 33 (2003) 539–547.

[2] R. Siddique, Effect of fine aggregate replacement with Class F fly ash on the abrasion resistance of concrete, Cem. Concr. Res. 33 (2003) 1877–1881.

[3] V.K. Parvati, K.B. Prakash, Feasibility Study of Fly Ash as a Replacement for fine aggregate in concrete and its behaviour under sustained elevated temperature, Int. J. Sci. Eng. Res. 4 (2013) 87–90.

[4] M. Singh, R. Siddique, Strength properties and micro-structural properties of concrete containing coal bottom ash as partial replacement of fine aggregate. Constr. Build. Mater., 50 (2014) 246-256.

[5] A. Kanthi, M. Kavitha, Studies on Partial Replacement of Sand with Fly Ash in Concrete, Eur. J. Adv. Eng. Technol. 1 (2015) 89–92.

[6] A. Mishulovich, J.L. Evanko, Ceramic Tiles from High-Carbon Fly Ash, Cent. Appl. Energy Res. (2003).

[7] Ö. Andiç, K. Ramyar, Ö. Korkut, Effect of fly ash addition on the mechanical properties of tile adhesive, Constr. Build. Mater. 19 (2005) 564–569.

[8] B. Rajamannan, C.K. Sundaram, G. Viruthagiri, N. Shanmugam, Effects of Fly Ash Addition on the Mechanical and Other Properties of Ceramic Tiles, Int. J. Latest Res. Sci. Technol. 2 (2013) 486–491.

[9] F.P. Cota, C.C.D. Melo, T.H. Panzera, A.G. Araújo, P.H.R. Borges, F. Scarpa, Mechanical properties and ASR evaluation of concrete tiles with waste glass aggregate, Sustain. Cities Soc. 16 (2015) 49–56.
[10] H. Wang, M. Zhu, Y. Sun, R. Ji, L. Liu, X. Wang, Synthesis of a ceramic tile base based on high-alumina fly ash, Constr. Build. Mater. 155 (2017) 930–938.
[11] IS: 12269-2013, Ordinary Portland Cement, 53 Grade - Specification, Bur. Indian Stand. New Delhi. (2013).
[12] IS: 383-1970, Specification for coarse and fine aggregates from natural sources for concrete, Bur. Indian Stand. New Delhi, (1970).
[13] ASTM C 618, Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, Annu. B. ASTM Stand. (2019)
[14] IS: 9103-1999, Concrete Admixtures - Specification, Bur. Indian Stand. New Delhi. (1999).
[15] IS: 10262-2009, Concrete Mix Proportioning - Guidelines, Bur. Indian Stand. New Delhi. (2009).
[16] IS: 1237-2012, Cement concrete flooring tiles - Specification, Bur. Indian Stand. New Delhi. (2012).