Age-Dependent Compressive Strength of Fly Ash Concrete Using Non-destructive Testing Techniques

A. Fuzail Hashmi, M. Shariq and A. Baqi

Abstract Non-destructive testing methods are important methods for civil engineers to monitor the structures periodically and ensure safety and serviceability without damaging the structures. In the present study, non-destructive testing (NDT) was carried out on plain and fly ash concrete mix using two techniques, i.e. ultrasonic pulse velocity and rebound hammer to evaluate the age-dependent compressive strength. The compressive strength of the specimen obtained using NDT was also compared with the experimental results. Laboratory investigations on pulse velocity were carried out by using PUNDIT and rebound number by using rebound hammer on 100 × 200 mm cylinders of plain and fly ash concrete at the ages varying from 28 to 180 days. The amount of fly ash replacement by cement was varied from 25 to 60%. The compressive strengths of the all the specimens have been obtained from the pulse velocity and rebound number reference charts. It has been observed that the compressive strength of fly ash concrete mix and plain concrete obtained by using PUNDIT are comparatively similar at all ages due to the homogeneous nature of fly ash concrete, whereas in case of rebound hammer, the strength gets reduced significantly for high-volume fly ash concrete.

Keywords Fly ash concrete · Non-destructive testing · Pulse velocity · Rebound hammer · Compressive strength

1 Introduction

Concrete is the most widely used material in the construction industry all over the world due to its good strength and durability. The continuous growth in the infrastructure has increased the demand for developing smart and sustainable material. The production of Portland cement consumes huge quantities of natural resources and releases large amount of harmful gases directly into the atmosphere which causes global warming and other climatic changes [1]. The utilization of fly

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ash in the concrete has significant effect in the construction industry. It improves the workability and durability of concrete, reduces overall cost of structure and water demand, minimizes drying and thermal shrinkage, enhances the durability to reinforcement corrosion, alkali silica expansion and sulphate attack [2]. The most important property of the concrete is the compressive strength as other properties such as flexural and tensile strength, modulus of elasticity all are closely related to it. It has a major role in evaluating the concrete of the existing building. Number of experimental studies has been carried out about compressive strength development of fly ash concrete. At early ages, the strength of fly ash concrete appears quite low but at the later ages, there is significant increase in the strength of fly ash concrete due to the pozzolanic reaction between fly ash particles and cement particles [3, 4].

Non-destructive testing (NDT) is an important method for civil engineers to evaluate the qualitative assessment of uniformity and homogeneity of concrete and the strength of existing building without damaging it. NDT identifies the cracks damages on the surface and interior of the materials without damaging and cutting. The core test is the effective method to know the quality of concrete in the existing structure but it is expensive and time consuming, therefore it is needed to carry out a calibration operation to relate the NDT measurements and compressive strength of concrete [5]. Various structures of concrete such as beams, columns, slabs, bridges, tunnels etc needs periodic investigation through NDT. In past decades, number of NDT methods has been developed such as infrared thermography, pulse-echo and impact echo method for the prediction of strength of concrete structures. Out of these, portable ultrasonic non-destructive digital indicating tester (PUNDIT) and rebound hammer are very common and widely used [6]. For the assessment and prediction of the quality of concrete, the use of only ultrasonic pulse velocity method is not appropriately enough to judge the concrete. So, other methods like the rebound number seem to be somehow more efficient in predicting the quality and strength of concrete under certain conditions [7]. Maria et al. [8] investigated the effect of ultrasonic and sonic wave propagation in the damaged RC frame affected by seismic action and observed that NDT give a brief idea about damages in the structures but for detailed results of completely damaged buildings, it is not suitable. Raffaele [9] did destructive and non-destructive tests on a building and found that rebound hammer is not useful for assessing the existing concrete structures, whereas the ultrasonic pulse velocity methods provide more satisfactory results. Shariq et al. [10] reported that the compressive strength of GGBFS concrete obtained through ultrasonic pulse velocity (UPV) is lower at all ages for different percentages replacement of cement. Mori et al. [11] developed a new NDT method to detect the defect and flaws in the concrete structures. The method is effective and useful based on vibrant response of concrete structures subjected to impact loading. Gholizadeh [12] reviewed the various NDT methods to evaluate the composite materials and described their advantages and disadvantages in the practical use.

This paper presents an experimental investigation into the age-dependent compressive strength of plain and fly ash concrete (having different content of fly ash) and compared the results with strength obtained from non-destructive testing methods by using PUNDIT and rebound hammer at the ages varying from 28 to 180 days.

2 Experimental Program

In this experimental investigation, the concrete mix was selected from the method of trial according to the guidelines of IS 10262 [13]. The experimental research was carried out for M20 mix. The test specimen was cast using cement, fly ash, coarse aggregate and fine aggregate. The properties of the materials such as fine aggregate, coarse aggregate, cement and fly ash used in the experimental investigation were confirmed as per the specification given in the Indian Standard Codes. The cement replacement by equal weights of 25, 40 and 60% by fly ash was done in plain concrete mixes to obtain fly ash concrete. The details of normal and fly ash concrete mixes are given in Table 1. The concrete cylinders of dimension 100 × 200 mm were cast by taking 0, 25, 40 and 60% partial replacement of ordinary Portland cement (OPC) with fly ash. Three samples were prepared for each percentage of fly ash. NDT has been carried out on these specimens by using rebound hammer and PUNDIT as shown in Fig. 1. The ultrasonic pulse velocity and rebound number measurements for normal and fly ash concrete were taken at the age of 28, 56, 90, 156 and 180 days. The samples were also tested in the compression testing machine to evaluate compressive strength at different ages for all percentages of fly ash. The specimens were kept at ambient temperature after 28 days curing until the time of test. Before taking the readings, the specimens were cleaned with dry cloth and rubbed with sand paper at both the ends. In the case of PUNDIT test, the lubricant was applied on the specimen at both the ends to make the surface smooth. Rebound hammer is basically dependent on the surface hardness, whereas PUNDIT is based on the ultrasonic pulse velocity. The repeated pulses with frequency of 20 kHz and above are generated by PUNDIT. The transmitter emitting ultrasonic pulses is placed on the free surface of concrete, whereas the receiver is placed at the other surface of concrete. The travel time of the ultrasonic waves through the concrete was noted down. Hence, by knowing the total length of travel path in concrete, the velocity of ultrasonic waves was obtained. Based on the value of pulse velocity, the condition of the structure can be evaluated.

Table 1 Fly ash concrete mix proportion

Per cent replacement of fly ash (%)	Cement (kg/m^3)	Fly ash (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	W/C ratio	Slump (mm)
0	400	0	850	1050	0.5	55
25	300	100				58
40	240	160				60
60	160	240				70

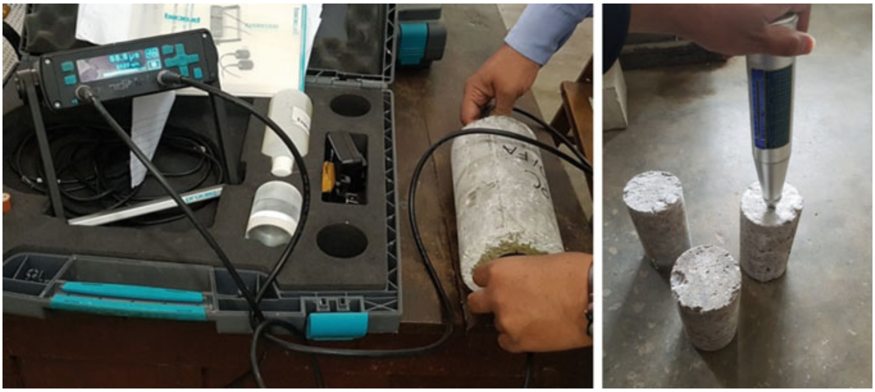

Fig. 1 Specimens under test using PUNDIT and rebound hammer

3 Results and Discussion

3.1 Compressive Strength Obtained Using PUNDIT

The variation of compressive strength of plain concrete and fly ash concrete is shown in Table 2. It has been observed that the compressive strength obtained using PUNDIT does not reduce drastically for high-volume fly ash (HVFA) concrete. At the age of 28 days, the compressive strength of fly ash concrete mixes containing 25, 40 and 60% of fly ash is observed to be 98%, 93% and 85%, respectively of plain concrete, whereas at the age of 180 days, the compressive strength of fly ash concrete mixes containing 25, 40 and 60% of fly ash is observed

Table 2 Compressive strength obtained using PUNDIT

Fly ash (%)		Compressive strength at different ages (days)				
		28	56	90	156	180
0	Pulse velocity (Km/s)	4.22	4.30	4.37	4.45	4.47
	Comp. strength obtained from graph (MPa)	**20.5**	**23**	**26**	**28**	**30**
25	Pulse velocity (Km/s)	4.22	4.295	4.375	4.44	4.465
	Comp. strength obtained from graph (MPa)	**20**	**23**	**26.5**	**28**	**29.5**
40	Pulse velocity (Km/s)	4.21	4.295	4.35	4.42	4.425
	Comp. strength obtained from graph (MPa)	**19**	**22**	**25**	**27**	**28**
60	Pulse velocity (Km/s)	4.15	4.21	4.25	4.32	4.35
	Comp. strength obtained from graph (MPa)	**17.5**	**20**	**22**	**23.5**	**25**

to be 98%, 93% and 83%, respectively, of plain concrete. The above observation reveals that the compressive strengths of plain and fly ash concrete are not significantly differ at all ages for all substitution of cement with fly ash. Also, the compressive strengths of HVFA concrete are not reduced up to a greater extent due to the homogeneous nature of fly ash concrete.

PUNDIT determines the strength in terms of homogeneity, integrity, internal flaws and cracks of the material. The ultrasonic waves get scattered when it travels through cracks and flaws present inside the concrete. It takes more time to cover the same distance in cracked concrete than sound concrete which is free from surface cracks and internal defects. As a result of which the pulse velocity gets decreased and hence the strength of concrete gets reduced. The pulse velocity in concrete is normally affected by path length of the waves in the concrete, cross-dimension of the specimen which is being tested, existence of reinforcement steel and humidity of the concrete. However, the pulse velocity will not be affected by the profile of the concrete specimen, provided that the least lateral dimension (i.e. the dimension which is measured perpendicular to the wave propagation) is not as much of that the wavelength of the vibrating pulse. Fly ash concrete have good uniformity and durability, thats why the strength does not reduce much for high-volume fly ash concrete when evaluated using PUNDIT.

3.2 Compressive Strength Obtained Using Rebound Hammer

The variation of compressive strengths of plain concrete and fly ash concrete obtained using rebound hammer is given Table 3. It has been found that the strength obtained using rebound hammer reduced drastically for high-volume fly ash concrete. The strength development is quite slow in the case of HVFA concrete. This is due to the fact that the surface of fly ash concrete is not as hard as that of plain concrete. At the age of 28 days, the compressive strength of fly ash concrete mixes containing 25, 40 and 60% of fly ash is observed to be 87%, 81% and 65%, respectively, of plain concrete, whereas at the end of 180 days, the compressive strength of fly ash concrete mixes containing 25, 40 and 60% of fly ash is observed to be 84%, 76% and 72%, respectively. The rebound hammer basically measures the rebound of a spring-loaded mass striking in opposition to the surface of concrete. The test hammer hits the surface of concrete at a definite energy. The rebound of a hammer is dependent on the stiffness of the concrete and is calculated by the test equipment. The rebound number obtained from the hammer is used to find out the compressive strength of concrete with the help of reference chart. A lower rebound value indicates that the concrete has low strength and low stiffness as a result of which large energy is absorbed when a hammer strikes the surface of concrete. The hammer is placed at right angles to the flat and smooth surface of concrete at the time of conducting test. The readings in the rebound hammer is

Table 3 Compressive strength obtained using rebound hammer

Fly ash (%)		Compressive strength at different ages (days)				
		28	56	90	156	180
0	Rebound number	23	24	25	26	28
	Comp. strength obtained from graph (MPa)	**18.3**	**20**	**21.3**	**24.6**	**26.6**
25	Rebound number	20	23	24	25	26
	Comp. strength obtained from graph (MPa)	**16.0**	**18.67**	**20.0**	**20.6**	**22.6**
40	Rebound number	20	22	23	23	20
	Comp. strength obtained from graph (MPa)	**15.0**	**17.0**	**18.6**	**19**	**20.3**
60	Rebound number	14	20	20	21	23
	Comp. strength obtained from graph (MPa)	**12**	**16**	**16.5**	**17**	**19.3**

affected by the direction of the hammer, when the hammer is oriented upward, gravity increases the rebound distance of the mass, and vice versa for a test conducted on a floor slab. This method of testing does not give a straight measurement of the strength of the material. It simply gives a brief idea and indication of the surface properties of the concrete, it is appropriate for making comparisons among different samples.

3.3 Variation of Compressive Strength Obtained Using PUNDIT and Rebound Hammer

The compressive strength obtained using ultrasonic pulse velocity (UPV) is significantly high in comparison to the strength obtained using rebound hammer as shown in figs. For plain and 25% fly ash concrete, the experimental values of compressive strength are equivalent to the values obtained from PUNDIT, whereas for rebound hammer, compressive strengths are quite low at all ages as shown in Figs. 2 and 3. For HVFA concrete, the values of compressive strength obtained from PUNDIT are more at all ages in comparison to experimental values and values obtained from rebound hammer as shown in Figs. 4 and 5. The values of compressive strength obtained from rebound hammer remain low at all ages and for all replacement of fly ash. It is due to the porous nature of concrete matrix and slower rate of hydration which results in the reduction of compressive strength of concrete. For HVFA concrete, the strength obtained using rebound hammer is very low at initial ages because the surface is soft. But with respect to time due to the pozzolanic behaviour of fly ash the surface of the concrete hardened, and as a result of which the strength increases somehow. Thus, the readings of rebound hammer and

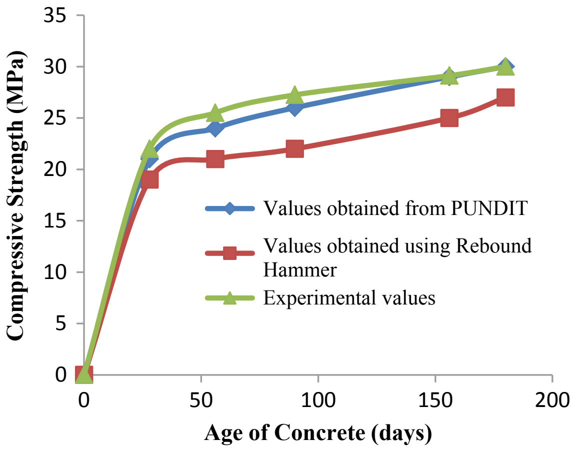

Fig. 2 Variation of strength of plain concrete

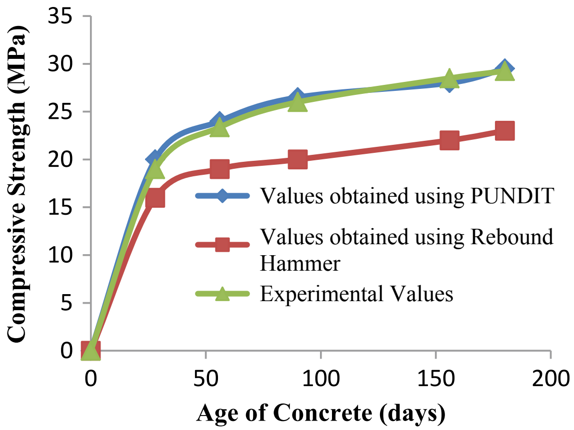

Fig. 3 Variation of strength of 25% fly ash concrete

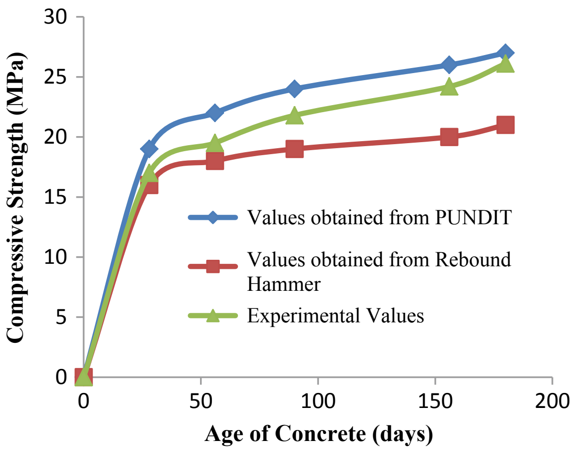

Fig. 4 Variation of strength of 40% fly ash concrete

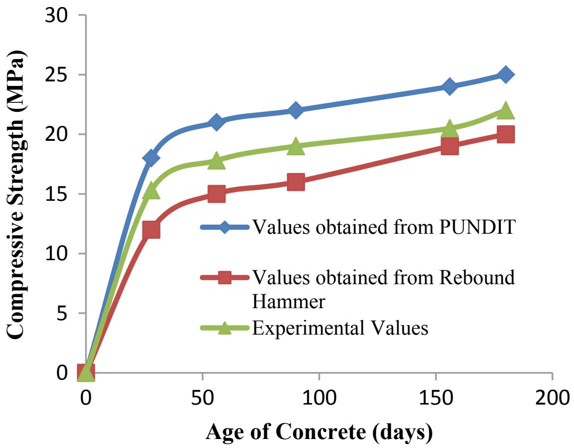

Fig. 5 Variation of strength of 60% fly ash concrete

the hardness of the surface of concrete can be correlated with compressive strength of concrete. As far as PUNDIT test concerned, it gives higher compressive strength due to the good uniformity and durability of fly ash concrete. Ultrasonic pulse velocity (UPV) measures transit time which gives information about the uniformity of concrete, cracks, cavities and defects present inside the concrete.

4 Conclusion

The experimental investigation revealed that the compressive strength of fly ash concrete obtained using rebound hammer has been found to be lower than the compressive strength obtained using ultrasonic pulse velocity at all ages and for all percentage replacements of cement by fly ash. For high-volume fly ash concrete, the percentage variation is more at initial ages but at later ages, this variation gets reduced. Both of the NDT techniques, i.e. PUNDIT and rebound hammer do not assess the strength of concrete accurately. They just measure the surface hardness, cracks and internal defects in concrete. These are just indicative tests, other destructive testing is essential for the better evaluation of quality of concrete.

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