Residual Compressive Strength of Ternary Blended Concrete at Elevated Temperatures

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Abstract

An experimental investigation was conducted to study the performance of industrial wastes, utilising in the preparation of concrete, at elevated temperatures on residual compressive strength of concrete. The objective of the study was to examine the Residual Compressive Strength of Ternary Blended Concrete (TBC) consists of ordinary Portland cement (OPC), fly ash and silica fume. The OPC was partially replaced by 15% fly ash (FA) and 5% silica fume (SF). The blended concrete was prepared using water - binder ratios of 0.55, 0.45 and 0.35 the specimens were cured in water for 28 days and then subjected to elevated temperatures up to 600^0C for 4, 8 and 12 h duration. After heating of the samples in the furnace, the samples were allowed to cool to room temperature and then tested for compressive strength. The results indicated that the ternary blended concrete is more effective in resisting the effect of temperature on the residual compressive strength when compared to normal strength concrete (NSC).

Key words: *elevated temperatures, fly ash, silica fume, residual compressive strength, ternary blended concrete*.

1. Introduction

Concrete containing industrial by-products/mineral admixtures like fly ash, ground granulated blast furnace slag, silica fume, metakaolin and rice husk ash etc., is used extensively throughout the world because of its high performance, especially strength and durability point of view. Concrete, in general, fire sustaining material at moderate temperatures. During past two decades, it was reported by many researchers that the concrete structures exposed to fire incidences for long time, remain intact with minor damages. The extensive use of concrete as a structural material for the high-rise buildings, tunnels, jet air runways, nuclear reactor pressure vessels, storage tanks for hot crude oil and hot water, coal gasification and liquefaction vessels resulted in concrete being exposed to high temperature. Characteristics such as color, compressive strength, modulus of elasticity, concrete density and surface appearance are affected by high temperatures [[M.S. Morsy et al, Y.Xu et al, H.Tanyildizi et al and M.Saad Morsy et al cited by [1]]. It was recognized that the behaviour of concrete subjected to high temperatures is a result of many factors such as heating rate, peak temperatures, dehydration of C-H-S gel, phase transformations, and thermal incompatibility between aggregates and cement paste [[M.Foldvar and W.Sha et al cited by [1]]. K.Srinivasa Rao et al [3] investigations revealed that the effect of elevated temperature on compressive strength of HSC made with OPC and PPC and concluded that the concrete performed better by retaining more residual compressive strength compared to concrete made with OPC at later ages HSC made with PPC. Gyu-Yong KIM et al [4] conducted tests at various temperatures (20 - 700^oC) for concretes made with w/b ratios of 46%, 32% and 25% respectively and reported that the relative values of compressive strength and elastic modulus decrease with increasing compressive strength grade of specimen. M.Mahdy et al[5] conducted tests and investigated the effect of transient high temperature on strength of heavy weight high strength concrete by exposing to three exposure durations (0,1hr, 2hr) at temperatures of 100, 300, 500 and 700^oC and reported that as the temperature increased to 100^oC, the strength decreased compared to room temperature strength. It was also reported that with the further increase in temperature, the specimens recovered the strength loss and reached peak strength of 10 to 30% above room temperature strength. At the temperature 500 and 700°C, the strength in each case dropped sharply. The experimental investigation carried out using ordinary Portland cement (OPC) and silica flour by M.S.Morsy et al [1] observed the influence of the effect of elevated temperature on mechanical properties, phase composition and microstructure of silica flour concrete. The OPC was partly replaced by 0, 5, 10, 15 and 20% of silica flour, cured for 28days and the hardened concrete was exposed to temperatures from 100 to 800°C for 2 hours. It was observed that the addition of silica flour to OPC improves the performance of the produced blended concrete when exposed to elevated temperatures up to 400°C and the strength, elasticity modulus and deformation of concrete are irreversibly influenced by temperature elevation mainly to 100°C and 200°C. The compressive strength, indirect tensile strength, phase composition and microstructure of silica flour concrete were compared with those of the pure ordinary Portland concrete Ivan Janokta [6].

In both developed and developing countries recent researchers aimed at the energy conservation in the cement and concrete industry, focused on the use of less energy intensive materials such as fly-ash, slag and natural pozzlolanas. Later some attention has been given to the use of pozzolana, silica fume as partial replacement to Portland cement. Unlike natural pozzolanas and fly ash, the silica reaction involving silica fume is rapid and therefore, a long curing period is not necessary.

The compressive strength was found to increase after four hours of exposure to an elevated temperature up to 300°C. An obvious reduction in the compressive strength was observed after exposure to 700°C, increasing the temperature up to 900°C caused serious deterioration where decreasing ratio in compressive strength reached to 81% of the controlled concrete (Bishr.H.A.M) [2].

The scope of this work is to provide experimental data on the residual compressive strength, a very important property for safe design of concrete structures, of the ternary blended concrete subjected to elevated temperatures, using industrial wastes like fly ash and silica fume as admixtures.

2. MATERIALS AND METHODS

2.1. Materials

Locally available 53 grade of Ordinary Portland Cement (Ultra Tech Brand) confirming to IS: 12269 was chosen for investigations. The cement was used in composition with fly ash (SiO_2 = 60.9%) and silica fume (SiO_2 = 92%), super plasticizer CONPLAST 430 (Fosroc Chemical India Ltd), river sand (Specific gravity of Fine Aggregate = 2.53) in accordance with IS 2386-1963 standard specifications and coarse aggregate (machine crushed angular granite metal of 20mm) with specific gravity, bulk density and fineness modules of coarse aggregate are found to be 2.70, 1560 kg/cu m and 7.1 respectively. Locally available potable water was used for mixing and curing.

2.2. Mix proportions

Mix proportions for w/b ratios:
For w/b ratio of 0.55, concrete mix 1.00:2.27:3.34
For w/b ratio of 0.45, concrete mix 1.00:1.78:2.73
For w/b ratio of 0.35, concrete mix 1.00:1.26:2.11

2.3. Casting of specimens

A total of 180, (90 for normal + 90 for ternary blended), concrete cubes were cast using steel moulds of size 100mm x 100mm x 100mm with normal and Ternary Blended Concrete containing 5% Silica Fume and 15% Fly Ash with w/b 0.55, w/b 0.45 and w/b 0.35 by vibration with needle vibrator. All specimens were demoulded after 24 hours and cured in water for 27 days.

2.4. Testing

The specimens of both normal and ternary blended concrete, after 28 days of curing, were exposed to 200°C,400°C and 60°C for a duration of 4,8 and 12 hours in furnace and allowed to cool to room temperature. The tests were conducted using 2000 kN compression testing machine as per standard procedure for compressive strength. The average strength of three samples was taken per batch.

3. RESULTS AND DISCUSSION

3.1. Compressive strength

Figures 1 to 3 shows the compressive strength of TBC and normal concrete for 0.55, 0.45 and 0.35 w/b ratios after exposure to 4, 8 and 12 hours duration for 200°C, 400°C and 600°C. The decrease in the compressive strength is seen in for all w/b ratios and temperature exposures in both normal and ternary blended concretes. Particularly, sharp drop in compressive strength of concrete for 0.35 w/c ratio and at 600°C is observed. The reduction in the compressive strength up to 200°C temperatures which can be attributed to the driving out of capillary water from the pores hydration. The increase in the compressive strength is observed between the temperatures 200°C and 400°C which can be due to the evaporation of free water content and with the addition of pozzolanic materials (fly ash and silica fume) which accelerate the hydration. A significant decrease in compressive strength was observed between temperatures 400oC and 600°C which is attributed to the loss of non evaporable water from gel pores.

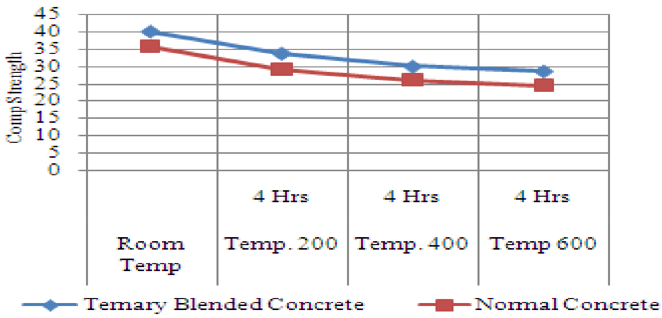

Figure 1.Compressive strength of concrete specimens for 0.55 w/c ratio at room temp, 200°C, 400°C and 600°C

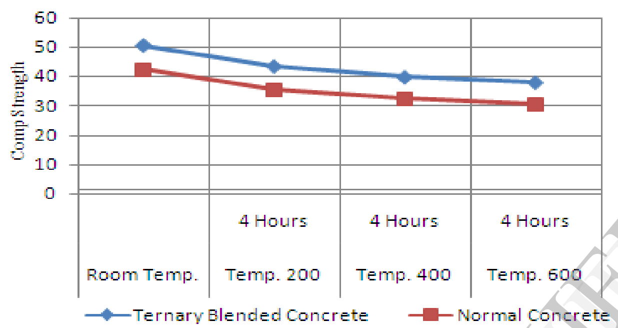

Figure 2. Compressive strength of concrete specimens for 0.45 w/c ratio at room temp, 200°C,

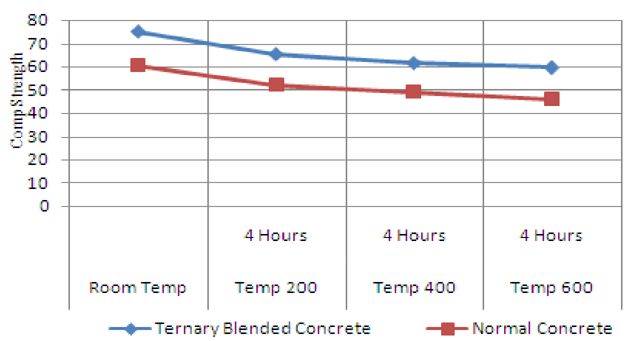

Figure 3.Compressive strength of concrete specimens for 0.35 w/c ratio at room temp, 200°C, 400°C and 600°C

Figures 4 to 6 shows the percentage decrease of compressive strengths concrete specimens for 0.55, 0.45 and 0.35 w/b ratios after exposure to 4, 8 and 12 hours duration for 200°C, 400°C and 600°C.

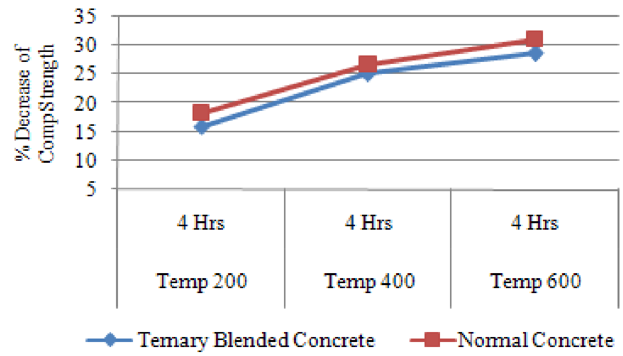

Figure 4.Percentage decrease of compressive strength of concrete specimens for 0.55 w/c ratio at room temp, 200°C, 400°C and 600°C

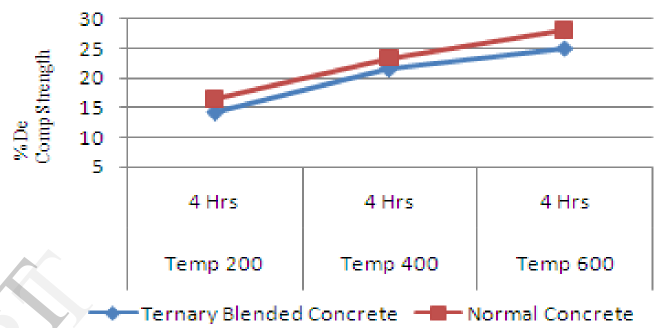

Figure 5. Percentage decrease of compressive strength of concrete specimens for 0.45 w/c ratio at room temp, 200°C, 400°C and 600°C

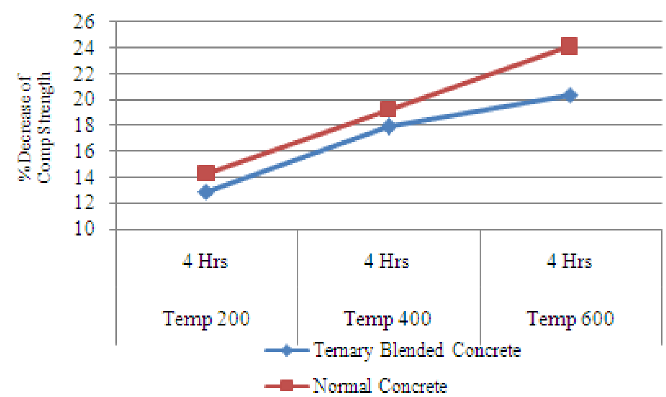

Figure 6. Percentage decrease of Compressive Strength of Concrete specimens for 0.35 w/c ratio at Room Temp, 200°C, 400°C and 600°C

Figures 7 to 9 shows percentage weight loss of concrete specimens for 0.55, 0.45 and 0.35 w/c ratios at temperatures of 200°C, 400°C and 600°C. The percentage weight loss is from 3.62 to 5.02 for 0.55 w/b ratio for TBC and is from 4.02 to 6.73 for normal concrete at temperatures of 200°C, 400°C and 600°C. The percentage weight loss is from 3.51 to 5.1 for 0.45 w/b ratio for TBC and is from 3.86 to 7.18 for normal concrete at temperatures of 200°C, 400°C and 600°C. The percentage

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weight loss is from 3.33 to 5.03 for 0.35 w/b ratio for TBC and is from 3.72 to 7.03 for normal concrete at temperatures of 200°C, 400°C and 600°C. The weight loss is due to evaporation of water from large capillaries and voids in the drying stage and due to loss of non evaporable water from gel pores and small capillary pores at dehydration stage and finally due to dissociation of aggregates by releasing carbon dioxide at temperature over 800°C (Sri Ravindrarajah,R et al) [7].

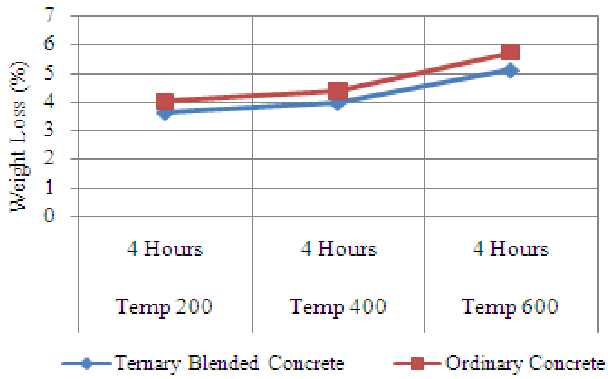

Figure 7. Percentage weight loss of concrete specimens for
0.55 w/c ratio at temp. 200°C, 400°C and 600°C

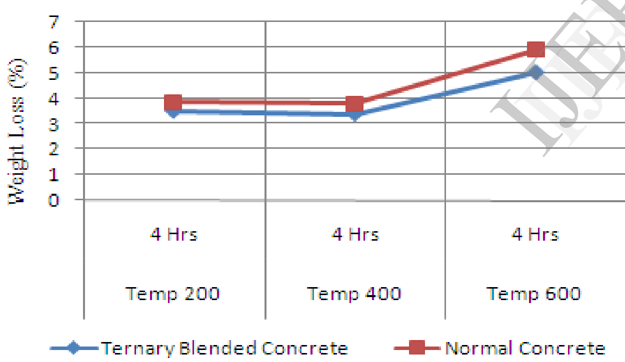

Figure 8. Percentage weight loss of concrete specimens for
0.45 w/c ratio at temp. 200°C, 400°C and 600°C

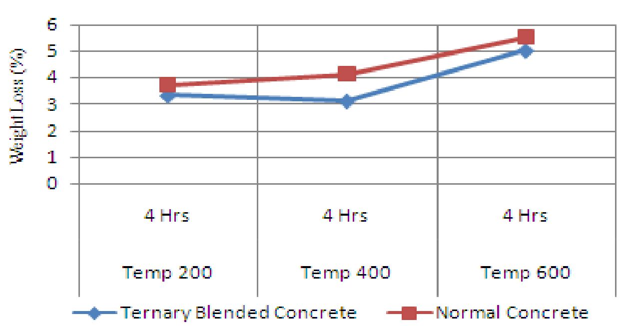

Figure 9. Percentage weight loss of concrete specimens for 0.35 w/c ratio at temp. 200°C, 400°C and 600°C

Figures 10 to 12 shows pulse velocity of 0.55, 0.45 and 0.35 w/c ratio at temp. 200°C, 400°C and 600°C . Considerable decrease in the ultrasonic pulse velocity is due to the expansion of small pores on heating and exerts significant internal pressure within the system which results in the formation of internal micro cracks.
The ultrasonic pulse velocity for w/b ratio of 0.55 was decreased from 3890 m/sec to 1970 m/sec for TBC and from 3760 m/sec to 1890 m/sec for normal concrete for the temperatures from 200°C to 600°C. The ultrasonic pulse velocity for w/b ratio of 0.45 was decreased from 4200 m/sec to 2360 m/sec for TBC and from 4140 m/sec to 2265 m/sec for normal concrete for the temperatures from 200°C to 600°C. The ultrasonic pulse velocity for w/b ratio of 0.35 was decreased from 4330 m/sec to 2620m/sec for TBC and from 4050 m/sec to 2490 m/sec for normal concrete for the temperatures from 200°C to 600°C (Sri Ravindrarajah, R et al) [7].

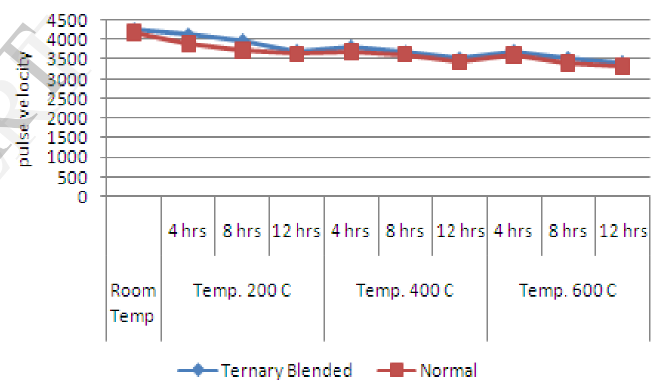

Figure 10. Pulse velocity of 0.55 w/b ratio concrete specimens

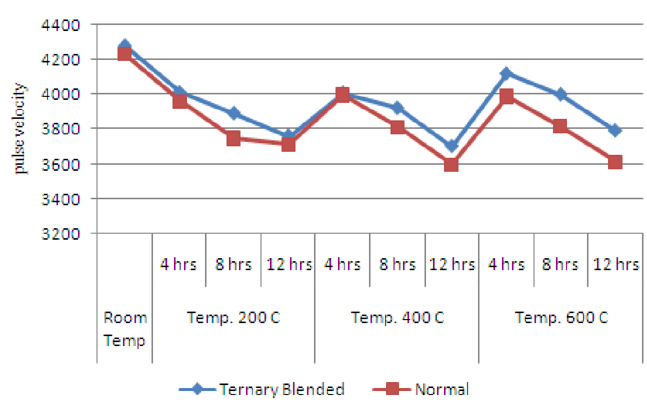

Figure 11. Pulse velocity of 0.45 w/b ratio concrete specimens

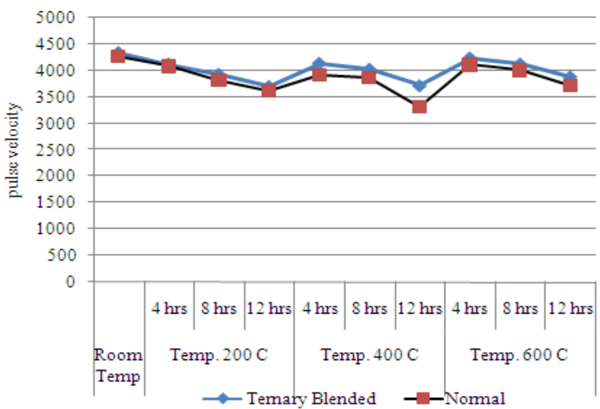

Figure 12. Pulse velocity of 0.35 w/b ratio concrete specimens

4. CONCLUSIONS

The following conclusions can be drawn from the present study:

1. A gradual reduction in compressive strength was found with increase in temperature from 200°C to 600°C for exposure duration of 4 hours.
2. The percentage decrease in weight loss is higher for higher exposure time and the loss of weight is less for lower w/b ratios.
3. The Ternary Blended Concrete has shown improved resistance for higher temperature for lower water/binder ratios.
4. Fly ash and silica fume, the industrial wastes, can be utilized for the replacement of OPC in the concrete constructions which saves the environment by reducing the emission of carbon content in manufacturing of cement.

5. SCOPE OF FURTHER STUDIES

The present investigation can be carried out to study the flexural strength, split tensile strength, using different available industrial and natural pozzolanas along with hybrid fibres, of TBC and tertiary blended concretes at elevated temperatures.

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3. I.S. 456-2000 Indian Standard Plain Reinforced Concrete- code of Practice.
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