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Performance evaluation of reactive powder concrete with polypropylene fibers at elevated temperatures

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HIGHLIGHTS

- Performance of RPC with different fiber dosages at elevated temperatures is investigated.
- RPC with at least 0.1% polypropylene fiber dosage, checks spalling at elevated temperatures.
- 0.5% fiber dosage, has shown superior fire endurance characteristics.

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ABSTRACT

Reactive Powder Concrete (RPC) is a type of ultra-high strength concrete. Due to its dense microstructure, is vulnerable to explosive spalling at elevated temperatures. Remarkable application of RPC in special structures throughout the world has drawn the attention to understand the performance of RPC at elevated temperatures, which has not been investigated extensively yet. The main objective of this work was to evaluate the performance of RPC at elevated temperatures from 200 °C to 800 °C, by obtaining residual mechanical properties after exposure. The study aims to find an optimum fiber dosage for spalling protection of RPC. To improve the mechanical properties, RPC incorporating fiber dosage from 0.1% to 0.9% is studied. The thermal deterioration of RPC is assessed using ultrasonic pulse velocity, water absorption and sorptivity. Results shows that 0.1% fiber dosage is enough to control spalling of RPC up to 800 °C. To enhance the residual properties of RPC exposed to elevated temperatures, it is recommended to use fiber dosage of 0.5%. The study also includes microstructural analysis of RPC subjected to elevated temperatures, to assess and evaluate the formation of pores and cracks.

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1. Introduction

Concrete is a composite material consisting of various ingredients, that are entirely different in their properties from each other. It is very difficult to assess the fire resistance of concrete, due to different thermal characteristics of each ingredient. The most vencher part is presence of moisture and porosity of the concrete. The utilization of High Strength Concrete (HSC) for last few decades, throughout the world, has proved itself to be promising construction material [1]. But in case of fire performance, some research studies have shown that HSC has disadvantage to resist fire, i.e., it is more prone to explosive spalling, due to low permeability and high brittleness when compared to normal strength concrete [2]. The same observation was made in case of High Performance Concrete (HPC) due to dense microstructure and very low permeability seems to be a disadvantage, in the situations where HPC is exposed to fire [3]. From earlier studies, it is proven that HPC, is susceptible to spalling or even explosive spalling when subjected to rapid rise in temperature during fire exposure. Spalling of concrete depends on many parameters such as ingredients of mix, type of aggregate, rate of temperature exposure, thermally induced mechanical stress, density of concrete, moisture content etc. The main two reasons for explosive spalling of HPC are, thermal stress induced by rapid temperature rise and water vapour which may cause high pore vapour pressure. To overcome spalling of concrete, addition of fibers, especially polypropylene fibers to concrete is well known fact in the field of construction. Addition of polypropylene fiber has been proved to be very efficient in reducing spalling of concrete at elevated temperatures. Polypropylene fibers melt at temperature of 170 °C, whereas spalling occurs between 190 °C and 250 °C [4]. Presence of polypropylene fibers reduces the internal vapour pressure and eliminates the chances of spalling under fire. The length of fibers has significant effect in

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preventing explosive spalling of concrete. Using 12 mm length of polypropylene fibers efficiently mitigates the explosive spalling when compared to 6 mm length [5]. This is in agreement with findings of [6] who reports that as length of fiber increases such as 12, 19 and 30 mm, it proves to be more effective in preventing spalling when compared to shorter polypropylene fibers of length 3 mm and 6 mm. From literature, it is learnt that adding polypropylene fiber in HSC was good to reduce chances of spalling, but however some of researchers have reported that this has an adverse effect on strength.

RPC is a new emerging construction material in the modern era. RPC with its high strength and durability properties, has been gradually replacing HSC and HPC, especially in special structures like long span bridges, tall structures and nuclear power plants. As it is becoming commonly used, the chances of being exposed to high temperature also increases in the event of accidental fires. However, so far only a few researchers have reported on its performance at elevated temperatures. RPC has dense microstructure this seems to be a disadvantage in the situation where the fire endurance is a necessity. The absence of voids does not relieve the internal stress that creates a major problem. This problem can be solved by addition of polypropylene fibers to the mix. However only a few studies have been carried out on RPC subjected to elevated temperatures and they also revealed contrary results, necessitating further research.

An experimental investigation made in 2015 [7,8] found that, plain RPC spalled under high temperature and spalling starts at 360 °C, whereas RPC with polypropylene fibers shows no spalling. The reason behind spalling and performance of RPC prepared with different fiber dosages under elevated temperatures remains to be investigated. Furthermore, mechanical properties including compressive strength, split tensile strength and weight loss of RPC, exposed to elevated temperatures are also of great concern from the serviceability requirements. Experiments indicate that, despite the positive effects of polypropylene fibers in enhancing the residual strength of the heated RPC, an overdose of fiber could have an adverse influence on the RPCs thermomechanical properties. A proper dosage of fibers to improve the spalling resistance of RPC depends on the mix proportion and the geometry of the fibers. In case of elevated temperatures resistance performance, of RPC remains a concern, more so in relation to explosive spalling. Earlier researchers have investigated that RPC is vulnerable to explosive spalling under elevated temperatures, which seriously jeopardizes the safety of RPC applications. Yang et al. [9] studied performance of RPC under elevated temperature in the range of 400 °C–800 °C. Results show considerable reduction in strength and elastic modulus values due to elevated temperatures.

Liu and Huang [10], have reported that the residual strength of RPC at elevated temperatures decreases significantly at temperature beyond 300 °C when compared that of RPC at room temperature. The reduction in strength is mainly because of the pore pressure mechanism in RPC that prevents water vapour from free transport within and its escape from the matrix, when exposed to elevated temperatures. Pore pressure mechanism is caused due to dense microstructure and mainly due to disconnected pores. Explosive spalling occurs when the pore pressure in the matrix accumulates to a threshold, exceeding the tensile strength of concrete. Kalifa et al. [11] suggested that mixing polypropylene fibers could reduce the pore pressure of concrete and decreases the risk of spalling and also as fiber content increases pore pressure decreases. Essential problem associated in understanding, spalling of RPC including pore characteristics, pore size distribution, pore pressure and factors related to explosive spalling are yet, not exhaustively studied. However, dense microstructure of RPC prevents evaporation and escape of free water from the interior portion of RPC specimen at elevated temperatures. Due to its low permeability and discontinuous pore network, the risk of explosive spalling has jeopardized the safety of RPC structure. This hinders the commercial development and application of RPC in the field of modern constructions. Therefore, the physical parameters like weight loss, colour change, crack development, mechanical properties such as compressive strength, split tensile strength and water absorption of RPC at elevated temperatures is required to be investigated.

The effect of different fiber dosage on spalling has not been reported for RPC. Since, the RPC is more likely to spall than HSC, it is necessary to investigate and understand the spalling behavior of RPC and recommend optimum fiber dosage to prevent spalling without compromise on fresh and hardened properties. The effect of elevated temperatures up to 800 °C on fiber reinforced RPC has been the scope of this study. Mechanical properties such as compressive strength, split tensile strength and physical parameters like weight loss, crack development at different temperatures were determined. Durability properties like water absorption and sorptivity have also been studied. This study also investigates the degradation of microstructure and its effect on residual mechanical properties of RPC after exposure to elevated temperatures. To identify the deuteration portion at microstructural level, RPC specimens were subjected to Scanning Electron Microscope (SEM) analysis. The SEM results strengthen and reinforce the reason behind reduced mechanical properties after exposure. The previous researcher's results on mechanical properties of RPC containing polypropylene fibers are not in agreement with each other. This is due to differences in curing condition of specimen, material used for RPC production and the way of experimentation. The optimum fiber dosage to prevent explosive spalling and simultaneously maintaining the residual strength to the expected range for RPC is yet to be investigated in detail. Therefore, the focus of present investigation is to determine minimum dosage of polypropylene fibers required to mitigate spalling and to possess acceptable residual strength levels.

2. Experimental program

2.1. Materials

RPC is composed of cement, silica fume, quartz powder and silica sand with very low w/b ratio to achieve required workability. High range water reducing admixtures are used. RPC is cement based concrete mixture. In the present study, Ordinary Portland Cement of 53 grade was used which complies with IS:12269-2013. The chemical and physical properties of cement are shown in Tables 1 and 2 respectively. Silica fume is the second basic important ingredient of RPC which fills the voids of micro particulates in the cement. It also produces secondary hydrates products by pozzolanic reaction from the results of primary hydration. Undensified silica fume was used in the present study, which complies with ASTM C1240-03 a and IS:15388-2003. Chemical composition of undensified silica fume is presented in Table 1. The particle size of silica fume is extremely very fine of size 0.1 μm. The physical properties of silica fume are tabulated in Table 2. Quartz powder is the finest material compared to cement. The particle size of quartz powder ranges from 10 μm to 45 μm. It acts as a filler material in the mix proportion of RPC. The chemical and physical properties of quartz powder are tabulated in Tables 1 and 2 respectively. Silica sand is largest particle size material in mix proportion of RPC. In the present study silica sand was used with particle size ranging from 150 μm to 600 μm. The sand confirms to zone IV grading requirement as per IS: 383-2016. To maintain the required workability, a second generation polycarboxylic ether polymer, high range water reducing superplasticizer Master

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