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Improvisation of Dense Matrix of Reactive Powder Concrete By Zircon Sand and Sillimanite

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Abstract: ***This paper presents a comparative study of compressive strength and ultrasonic-pulse velocity of Reactive Powder concrete (RPC) blended with micro and Nano filler materials. The material composition of RPC includes partial replacement of High Alumina Cement by alccofine and Quartz sand by zircon sand and sillimanite in order to obtain a dense concrete matrix of low level porosity. Micro-steel fibers were used to enhance the ductility of concrete composite. Polycarboxylate based super plasticizer was used to improve the workability. The experimental program comprises of compressive strength test and ultrasonic-pulse velocity test of standard water cured samples and heat treated samples at elevated temperatures of 200°C, 400°C, 600°C and 800°C. The influence of micro-filler materials in hydrated samples and microstructure of RPC specimens were examined by Scanning Electron Microscope (SEM) analysis. The results showed that the combined role of zircon sand and sillimanite as a filler material and high alumina cement as a refractory material made the RPC to exhibit ultra-high performance with increase in temperature and tends to decrease after 600°C.***

Keywords **:** ***Elevated temperature, Reactive Powder concrete, sillimanite, ultra-high performance concrete, zircon sand***

I. INTRODUCTION

Reactive Powder Concrete is a type of ultra-high strength concrete with remarkable application in special structures throughout the world. RPC has drawn the attention towards their performance at elevated temperatures as presented in [1]. Typically RPC is characterized by the material composition of quartz sand, silica fume and reinforced steel fibers. The homogeneity of concrete is enhanced by the elimination of coarse aggregate and the workability of RPC is increased by addition of Super-plasticizer. Studies revealed that to reduce the cement content in concrete mixes, silica fines can be used, which is a high potential concrete additive. In recent research works, nano-silica was suggested to replace cement in concrete for its role in reduction of carbon-dioxide emission and also the effect of varying nano-silica dosage on durability properties were investigated. Nano-silica particles presented high pozzolanic activity and could fill up the pores, resulting in homogeneous, dense and compact micro-structures which are the required characteristics of RPC. To attain the dense matrix and thereby improving the ultra-high performance of RPC the selective and innovative materials with properties related to the replacing materials are used. This study deals with the combined effect of micro-fine siliceous materials namely Zircon sand and Sillimanite in Reactive Powder Concrete at elevated temperatures of 200ºC, 400ºC, 600ºC and 800ºC. Quartz sand is used as the fine aggregate and the similar proportion of zircon sand and sillimanite each is used as the replacing material. High Alumina cement was used as the binding material which is known for its refractory properties. An emerging supplementary micro-silica called as Alccofine is used as the replacing material for high alumina cement. Polycarboxylate based super plasticizer was used. Experimental investigation involves the comparative study on the relation between the ultrasonic pulse velocity and the compressive strength values. Micro-structural analysis on the powdered samples is done by Scanning Electron Microscope (SEM) and the variation in the microstructure of RPC at elevated temperatures was analysed.

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II. MATERIAL PROPERTIES

In this work Reactive Powder Concrete is the mixture comprising of High Alumina Cement (HAC) as a binding material and Alccofine as a supplementary cementitious material, Quartz sand, Zircon Sand and Sillimanite as Fine aggregate and reinforced with Micro-steel fibers. The principle behind this study is the elimination of coarse aggregate in Reactive Powder concrete and utilizing the micro-fine materials to fill the voids formed by higher grade materials which is the main factor to attain the dense matrix and ultra-high performance as presented in [2].

High Alumina Cement

High Alumina cement is a slow setting but rapid hardening cement. As the concrete is to be exposed to high elevated temperatures of 200ºC, 400ºC, 600ºC and 800ºC, High Alumina Cement an excellent refractory material is used as the binder. At very high temperature, alumina cement concrete exhibits good ceramic bond instead of hydraulic bond as like other cement concrete.

Alccofine

Alccofine an emerging supplementary cementitious material is well known for its high performance in concrete as presented in papers [5] and [6].

It was proved by recent researches that an appreciable increase in compressive strength had been achieved by the addition of alccofine of up to 30%. This high activity micro-silica was used to replace the High Alumina Cement in RPC.

Quartz sand

RPC is incomplete without the quartz sand. Quartz sand of size ranging from 150-600µm was used as the fine aggregate. The main function of quartz sand is to improve the strength by densifying the concrete matrix and to nullify the impacts due to the absence of coarse aggregate.

Zircon sand

Zircon sand is an effective Nano-filler material with desirable silica content and high melting point. It has its application in refractories and foundry castings. The size and excellent hardness property of zircon sand were used as the key parameter for the attainment of dense matrix and ultra high strength. The chemical composition of Zircon sand is mentioned in Table2 as follows:

Table 1: Chemical Composition of Zircon sand

Elements	Percentage
$ZrO_2 + HfO_2$	65.20
SiO_2	32.10
Al_2O_3	1.20
Fe_2O_3	0.30
TiO_3	0.80

Sillimanite

Refractory concrete withstanding temperatures up to 1600°C can be produced by using aggregates like silimanite, carborandum and dead-burnt magnesite. Sillimanite is mainly utilized in High-alumina Refractories. In this study sillimanite is used to replace quartz sand as in same proportion as zircon sand for every mix.

Micro-steel fibers

To improve the ductility of the RPC mix and to prevent the risk of spalling, 2% of micro-steel fibers of 12.5mm length and 0.3mm diameter were used.

Super plasticizer

2% polycarboxylate based super plasticizer Sika viscocrete was added for the reduction of water content without reducing workability and influence on durability of RPC was examined as in [7]

III. SAMPLE PREPARATION

In this study, RPC samples were casted in 1:1:2 mix ratio represented in Table 2. The cube samples are of size 50x50x50mm and three trial samples for each combination along with the consideration of temperature treatment were casted. The mix combinations of varying proportions are as tabulated in Table1. Water-cement ratio is 0.30 and steel fibers and are added in range of 2% by weight of cement. Super-Plasticizers are added in the range of 2% by volume of water. The casted samples after undergoing standard water curing of 28 days were heat treated at the elevated temperatures of 200ºC, 400ºC, 600ºC and 800ºC. After the process of heat treatment the samples were taken for testing and analysis.

Table 2: Mix proportion of concrete specimens

Mix	Cement (%)		Fine Aggregate (%)		
	HAC (%)	Alccofine (%)	QS (%)	ZS (%)	Sillimanite (%)
R_0	100	-	100	-	-
R_1	70	30	80	10	10
R_2	70	30	60	20	20
R_3	70	30	40	30	30
R_4	70	30	20	40	40
R_5	70	30	-	50	50

HAC-High Alumina Cement ZS – Zircon Sand QS -Quartz Sand

IV. EXPERIMENTAL PROGRAM

Experimental program involves a destructive and non-destructive Testing. The mechanical strength of RPC was investigated by Compressive strength Test. The strength values obtained from the test results were compared with that of the Ultrasonic Pulse Velocity results. The Ultrasonic Pulse velocity test was done for pre-heated samples and samples undergone heat treatment at temperature of 200ºC, 400ºC, 600ºC and 800ºC after 28 days of standard water curing and then the samples were tested for compressive strength. The Ultrasonic Pulse Velocity was done on the direct and Semi-direct faces of the cubic samples.

Scanning Electron Microscope Analysis was done on the RPC samples to examine the quartz inversion and the matrix obtained due to the presence of micro and nano filler materials. The SEM sample comprises control mix which was subjected to the heat treatment of 400ºC and R2 and R5 samples subjected to the heat treatment of 600ºC. Alccofine, a nano-silica by its incorporation enhances the fiber-matrix interfacial properties along with the influence of steel fibers as in [4]

V. RESULTS AND DISCUSSIONS

Compressive strength results of every mix at various exposure conditions clearly depict the wave like variations in the strength with increase in temperature and also with the increase in the proportion of replacement of zircon sand and sillimanite in Figure1. From the result it was observed that R2 is the optimum mix at elevated temperatures which exhibits an ultra high performance with increase in temperature till 600°C and decreases at 800°C. Therefore, RPC with alccofine upto 30% replacement of High Alumina cement resulted in good bonding strength and Zircon sand and Sillimanite upto 20% acts as the effective micro-filler materials to attain the dense matrix of the Concrete. R2 samples withstand high temperature and shows high strength with increase in temperature.

From RPC samples R3 and R4, it was observed that standard water cured samples has achieved greater strengths when compared with that of heat treated samples. The compressive strength results are presented in Table 3 and bar graph indicating the variations of compressive strength with increase in temperature for every RPC mix samples is represented in Figure 1.

Table 3: Compressive Strength Results

Mix	Compressive strength at Temperatures (N/mm^2)				
	SWC	200° C	400° C	600° C	800° C
R0	37.04	33.54	34.24	48.24	25.36
R1	36.66	43.16	51.92	49.2	32.08
R2	37.74	45.8	52.1	53.4	34.08
R3	41.7	40.96	28.44	29.24	16.32
R4	46.7	35.96	25.34	30.54	27.48
R5	43.22	38.8	31.7	33.68	36.02

SWC – Standard Water Curing

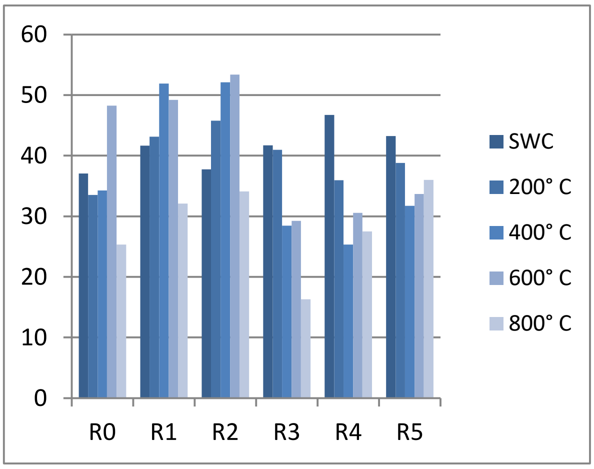


Figure 1: Compressive Strength results

Comparative Study: With reference to [8], a comparison between compressive strength and Ultra-sonic Pulse Velocity values was made to predict the unknown parameter from the known one. Best values of UPV under excellent category and poor category values of every individual mix was plotted with the corresponding values of the compressive strength and analysed. It was observed that excellent value of UPV having value greater than 4.5 directly corresponds to the ultra high strength value of the mix and poor UPV value corresponds to the lowest compressive strength of the same mix. Therefore UPV and compressive strength exhibits a perfect relationship in the RPC samples so that the prediction of strength of the Reactive Powder Samples by means of Ultrasonic pulse velocity test can be achieved easily and without any need of difficult statistical approaches.

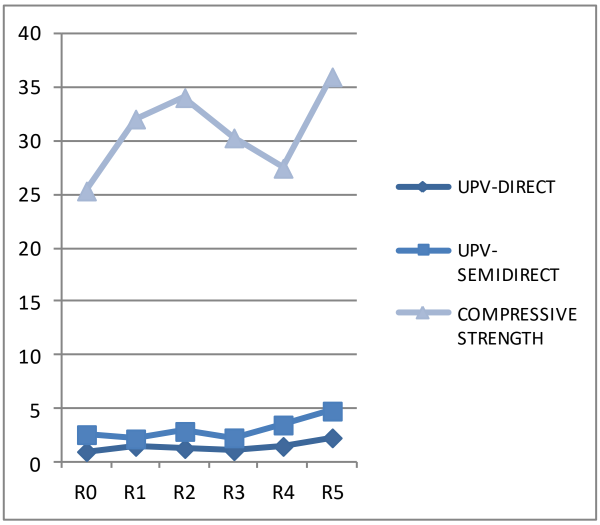


Figure 2: Compressive strength Vs UPV – Poor Category

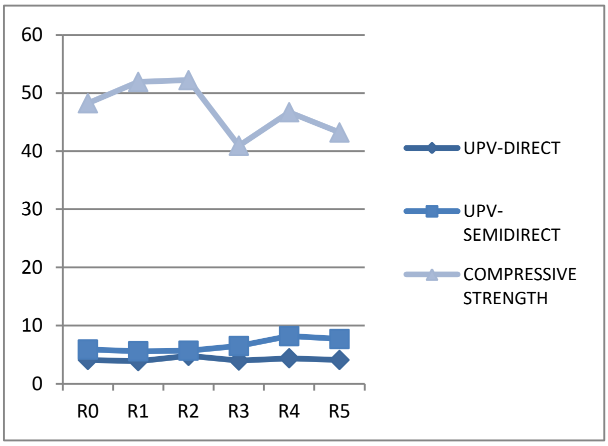


Figure 3: Compressive strength Vs UPV – Excellent category

Scanning Electron Microscope: To observe the morphology and the extent to which hydration products formed at the micro-level, SEM was performed on 28 days hydrated samples using a field emission Scanning Electron Microscope. This approach determines the chemical compositions, crystalline structure and crystal orientations qualitatively. The transformation of quartz sand from α-quartz to β-quartz between the samples subjected to the heat treatment of 400ºC and 600ºC, simply trigonal to hexagonal form was observed which is accompanied by change in volume along with the increase in temperature in Figure 4 and Figure 5. The linear expansion of the crystalline structure was found on the analysis in Figure 6. High alumina cement acts as a binding material and the formation of ceramic bonds at high temperatures was observed and at highest temperature the ceramic bonds were broken.

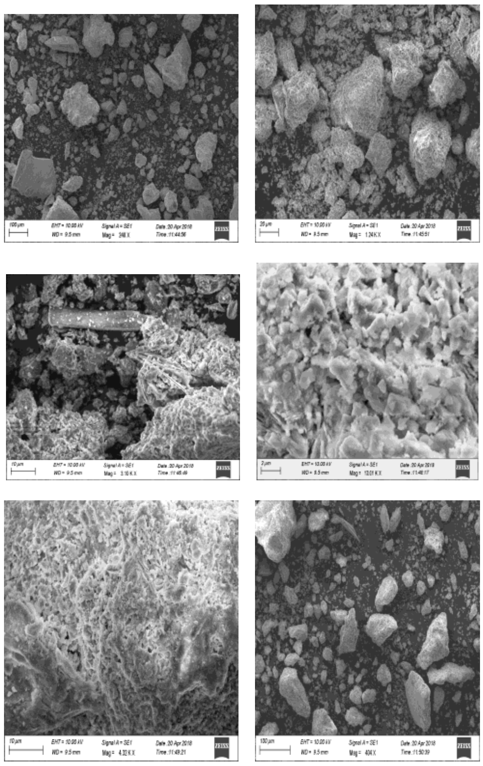


Figure 4: SEM images of R0-400°C

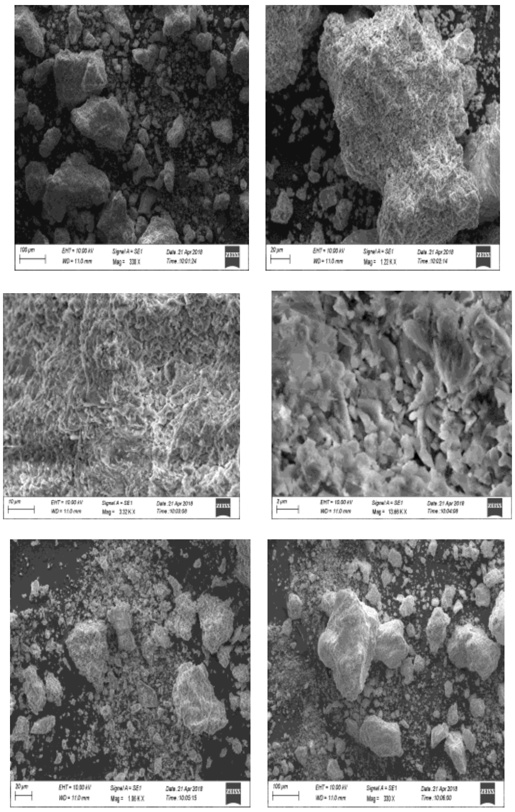
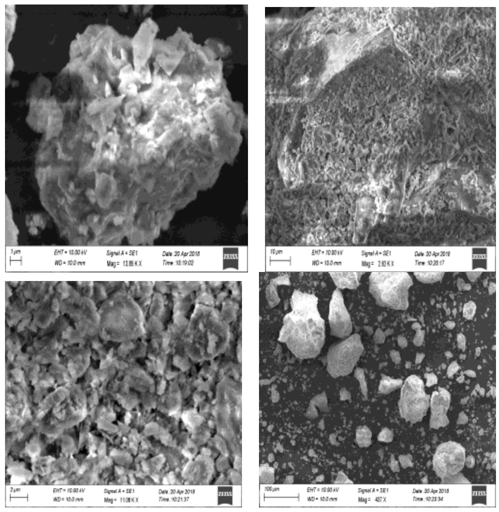


Figure 5: SEM images of R2-600°C



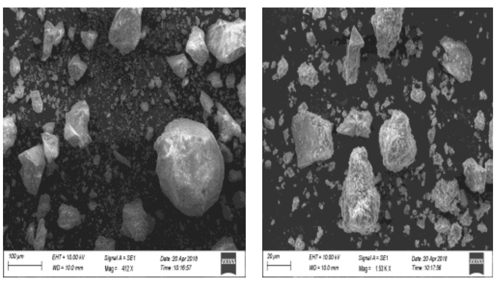


Figure 6: SEM images of R5-600°C

VI. CONCLUSION

Zircon sand and Sillimanite is the effective Nano-fine filler material plays a significant role in obtaining a dense concrete matrix and helps to attain ultra high strength at elevated temperatures upto 20% replacement of Quartz sand. Alccofine upto 30% replacement of High Alumina Cement proved to be an effective alternative material and maintained the ability to withstand high temperature. Ultra high Performance of Reactive Powder Concrete under study, at elevated temperatures was attained mainly by the innovative materials used and their particle size distribution. The correlation between the compressive strength and Ultrasonic Pulse Velocity was proved to be successful with least deviation by the prediction of strength from the ultrasonic pulse velocity values. As RPC eliminates the use of reinforcement bars and gains strength by means of steel fibres, it is highly economical and has emerging applications.

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