EVALUATION OF PROPERTIES OF REACTIVE POWDER CONCRETE AND DETERMINATION OF MODULUS OF ELASTICITY BY VIDEO GAUGE EQUIPMENT

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ABSTRACT

Reactive Powder Concrete (RPC) is catching more attention now days because of its high mechanical and durability characteristics. It is developed in 1990's by the French Company Bouygues. The major difference between reactive powder concrete and conventional concrete is that no coarse aggregate is involved in reactive powder concrete, but fine sand used instead, with high percentage of silica fume and superplasticizers. The RPC concept is based on the principle that a material with a minimum of defects such as micro-cracks and voids will be able to achieve a greater load – carrying capacity and greater durability. In this present work, an attempt is made to develop reactive powder concrete using locally available materials, to achieve a target compressive strength more than 100 MPa. Heat treatment is well known method which can improve the micro structural properties, pozzolanic reactivity of silica fume and also mechanical properties and durability. The curing cycles employed are water curing and hot air curing. This paper investigates hardened and fresh properties of reactive powder concrete such as compressive strength, bond strength, modulus of elasticity and percentage flow using modern equipment and tools i.e. universal testing machine, video gauge and flow table etc.

Keywords: *Reactive powder concrete, silica fume, compressive strength, Flexural Strength, bond strength, modulus of elasticity, Curing regime.*

1. INTRODUCTION

Reactive Powder Concrete (RPC) is an ultra-high strength and high ductile composite material with advanced mechanical properties. Reactive powder concrete is a concrete without coarse aggregate, but contains cement, silica fume, sand with very low water binder ratio and high dosage of superplasticizer. The absence of coarse aggregate was considered by inventors to be key aspect for the microstructure and performance of RPC in order to reduce the heterogeneity between cement matrix and aggregate (Richard et al. 1995). The original concept of RPC was first developed, in early 1990, by researchers at Bouygues laboratory in France. The addition of supplementary material, elimination of coarse aggregates, very low water/binder ratio, heat curing and application of pressure before and during setting were the basic concepts on which it was developed (Richard et al. 1995). There is a growing use of RPC owing to the outstanding mechanical properties and durability. RPC is composed of more compact and arranged hydrates. The microstructure is optimized by precise gradation of all particles in the mix to yield maximum density. It uses extensively the pozzolanic properties of highly refined silica fume and optimization of the Portland cement chemistry to produce highest strength hydrates (Cheyrezy et al. 1995; Reda et al. 1999). RPC will be suitable for pre-stressed application and for structures acquiring light and thin components such as roofs of stadiums, long span bridges, space structures, high pressure pipes, blast resistance structures and the isolation and containment of nuclear wastes (Gowripalan et al. 2003; Bonneau et al. 1996; Hassan et al. 2005). In India the work on RPC has started from last few years. SERC, Chennai, worked towards the development of the UHSPC with and without steel fibres and the effect of various heat curing regimes adopted on the strength properties of the mixtures (Harish et al. 2008). Dili A.S. and Manu Santhanam (2004) have studied mix design, mechanical properties and durability aspects of RPC. The utility of RPC in actual construction is minimal or nil in India, it is because of non-availability of sufficient experimental data regarding production and performance of RPC. So the basic objective of the current investigation is to experience the production of RPC. The key issues of the study are to develop RPC of compressive strength up to 100 MPa, to determine the effect of W/B ratio on strength, to determine the effect of high temperature curing on the compressive strength. As the standard code is not available to design RPC, here an attempt is made to design RPC mix with locally available materials referring literature.

2. EXPERIMENTAL DETAILS

2.1. Materials and Properties

2.1.1. Cement

The Ultra-Tech 53 Grade Ordinary Portland Cement (OPC) which complies with IS: 12269-1987 is used in the present study. The physical properties are given in Table.2.1.

Table 2.1 The physical properties of Cement (OPC 53 Grade)

SR. No.	Specific gravity	3.15
1	Standard consistency	31%
2	Initial setting time (minutes)	76
3	Final setting time (minutes)	380

2.1.2. Silica Fume

The Physical and chemical properties of the silica fume provided by supplier are as follows.

Table 2.2 Technical Specification of Silica Fume (Grade 92D)

SR. No.	**Properties**	
1	Form	Ultra-fine amorphous powder
2	Colour	Grey
3	Specific gravity	2.3
4	Bulk Density	700 kg/m^3 Densified
5	Specific surface	25 m^2/g
6	Particle size	15 μm
7	Sio2	92%
8	H2O	1%

2.1.3. River Sand

Particle size of river sand used in experiment is ranging from 600 microns to 150 microns. Fineness Modulus and Specific gravity of river sand are 1.904 and 2.7 resp.

2.1.4. Superplasticizer

The very low W/B ratio required for RPC can be achieved with use of superplasticizer (SP) to obtain good workability. In this study, super plasticizer called **Powercrete R62** from polygel industry Mumbai was used. It is an extremely high range water reducing agent which meets the requirements of IS: 9103-1999. The properties of superplasticizer are given in Table 2.3.

Table 2.3 Properties of Superplasticizer

Properties	**Powercrete R62**
Type of S.P.	Polycarboxylate polymer
Appearance	Dark brown
pH Value	6
Sp. Gravity	1.1
Solid content	40%
Recommended dosage	0.3 to 1.2%

Fig.2.1. Cement

Fig.2.2. Silica fume

Fig.2.3Natural sand

Fig.2.4. Superplasticizer

2.2 EXPERIMENTAL PROCEDURES

2.2.1.Mix Proportioning

To study the influence of the constituent materials,9 different mix proportions are considered by varying water-binder ratio, silica fume and superplasticizer dosage. Cement of quantity 1000 kg/m^3 was kept constant for all the mixes. The water-binder ratio of the mixes is varied from 0.2to 0.3. with interval of 0.05. Silica fume was added by 10 to 20 percent with interval of 5 by weight of cement. Superplasticizer dosage varied from 1.5 to 2.5 percent for all the mixes. Detailed mix proportioning is mentioned in Table 2.4.

Table2.4 Mix proportioning of Reactive powder concrete

MIX	CEMENT	SILICA FUME	RIVER SAND	SUPERPLLASTICIZER	W/B
TM1	1	0.10	1.071	0.025	0.2
TM2	1	0.10	0.868	0.02	0.25
TM3	1	0.10	0.758	0.015	0.30
TM4	1	0.15	0.986	0.025	0.2
TM 5	1	0.15	0.845	0.02	0.25
TM 6	1	0.15	0.70	0.015	0.30
TM 7.	1	0.20	0.74	0.025	0.22
TM 8	1	0.20	0.751	0.02	0.25
TM 9.	1	0.20	0.680	0.015	0.30

2.2.2 Mixing Procedure

The manual method is used to mix the ingredients of RPC. The mixing sequence is as follows: 1. Dry mixing the powders (including cement, silica fume and river sand) about 3 minutes. 2. Addition of sixty percentage volume of water and mix about 5 minutes. 3. Addition of the remaining water and superplasticizer, and mixed till consistent mix is formed.

2.2.3 Sample Preparation and Curing

The experimental work consisted of tests of standard size control specimens of reactive powder concrete, the casting and tests were conducted to find the compressive strength on the cubes of size 70.6 mm X 70.6 mm X 70.6 mm. The specimens were cured at both normal temperature water curing for 28 days and at 150° C hot air curing for 24 hours and remaining days at normal temperature water curing. In addition to this to evaluate flexural strength and bond strength, the beams of size 100 mm X 100 mm X 500 mm and cube of size 150 mm X150 mm X150 mm are cast and cured at normal temperature for 28 days.

2.2.4 Testing

Twelve cube specimens were cast and tested with each RPC mix proportion to evaluate compressive strength at 7 and 28 days for both normal and hot air curing. Three beam specimens were cast and testes with each RPC mix proportions to evaluate flexure test and modulus of elasticity at 28 days of normal curing using universal testing machine and video gauge equipment. Three cube specimens were cast and testes with each RPC mix proportions to evaluate bond strength at 28 days of normal curing using universal testing machine.

			
Fig.2.5. Flow table test	Fig.2.6. Compression test	Fig.2.7. Flexure test	Fig.2.8. Bond test

3. RESULT AND DISCUSSIONS

Different trial mixes are cast with varying percentages of silica fume and water content to optimize the proportion of mix. All samples are tested & analysed for fresh properties of concrete i.e. flow test. These samples are also tested for hardened properties of concrete i.e. Compressive Strength, Flexural strength, Bond Strength and Modulus of Elasticity.

3.1. Fresh Properties of RPC

Fresh properties of RPC for different mixes are calculated in the form of percentage flow and represented in the form of graph below.

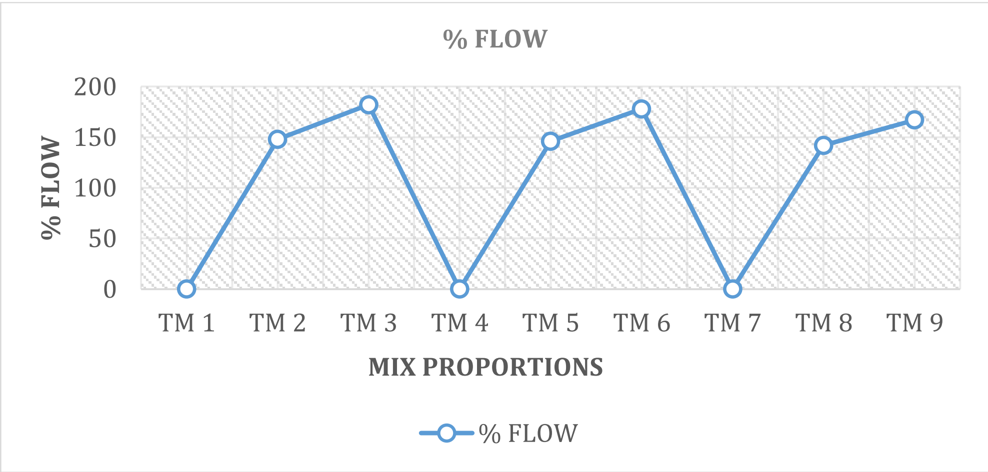

Fig 3.1 Graphical presentation of fresh Properties of reactive powder concrete (i.e. flow)

3.1.1. Observation and discussions

1) Low w/b ratio (0.20) mixes are difficult to achieve full compaction whereas high w/b ratio (0.30) mixes are more susceptible to entraining air bubbles, which then leads to formation of large capillary voids and thus considerable reduction in strength.
2) The mixes with water/binder ratio 0.2 i.e. TM1, TM4, TM7 observed as not workable.
3) The mixes will become workable with w/b ratio 0.25 and more than that.
4) The workability drastically increases with w/b ratio 0.30 for mixes TM3, TM6, TM9.
5) As % of silica fumes increases the workability get reduces.

3.2. Compressive Strength of RPC

For mix proportions and to get maximum compressive strength different mixes are cast. The result of all mixes with different curing condition i.e. normal curing and hot air curing are presented in the graph below.

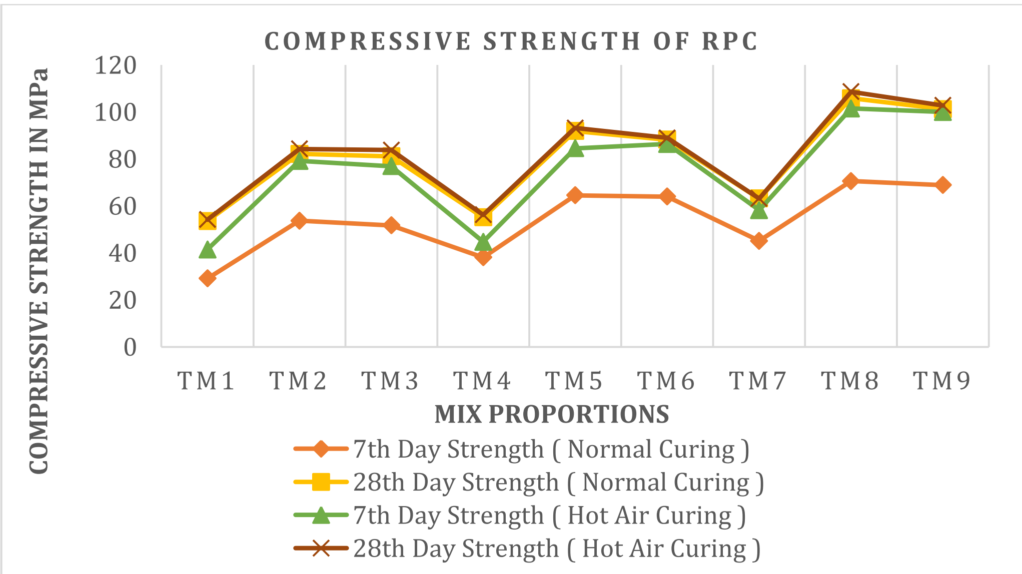

Fig 3.2Graphical presentation of compressive strength of reactive powder concrete.

3.2.1. Observation and discussions

1) It is observed that the compressive strength tends to increase with the increase in silica fume content. The highest compressive strength was observed for TM 8 in which silica fume content is 20%.
2) The maximum compressive strength of RPC obtained in the present study is 108.63 MPa for TM 8.
3) The strength of concrete cured by hot air method has increased up to 45% on 7 days and 3% on28 days compared to normal curing.
4) The increased strength is due to the rapid hydration of cement at higher curing temperatures of 150°C compared to that of 27°C. Moreover, the pozzolanic reactions are also accelerated by the high curing temperatures.

3.3. Flexural Strength of RPC

Flexural strength test is carried on beams of RPC with two-point loading on universal testing machine. The results are presented in the graph below.

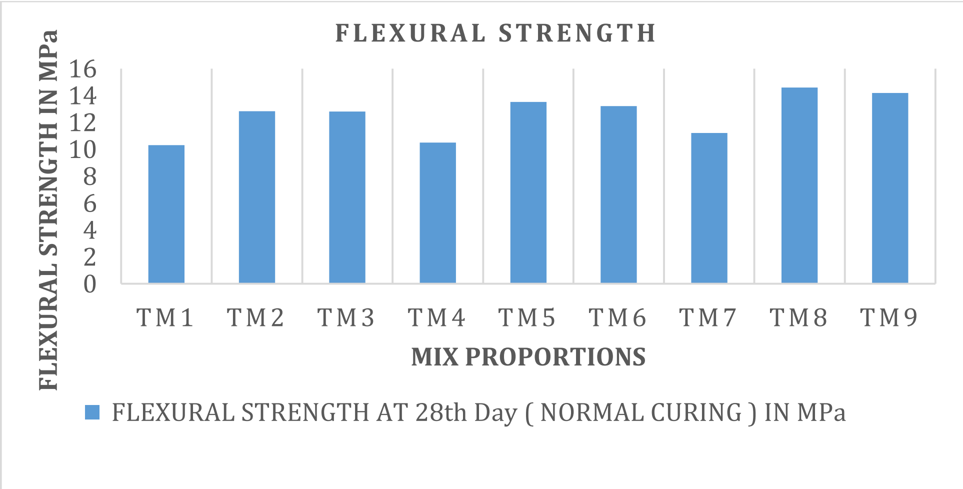

Fig 3.3 Graphical presentation of Flexural strength of reactive powder concrete.

3.3.1. Observation and discussions

1) It is observed that the flexural strength tends to increase with increase in silica fume content. The highest flexural strength was observed for TM 8 in which silica fume is 20%.
2) The maximum flexural strength of RPC obtained in the present study is 14.59 MPa for TM 8
3) The flexural strengths of RPC obtained in this study are almost two times the flexural strength i.e. $0.7\sqrt{f_{ck}}$ given in IS code 456:2000.

3.4. Bond Strength and Modulus of Elasticity of RPC

The bond strength is determined as per IS 2770 (I): 1967.The strains are recorded using video gauge equipment and Modulus of Elasticity is determined from strains and corresponding stress. The results of bond strength and modulus of elasticity are presented in the graph below.

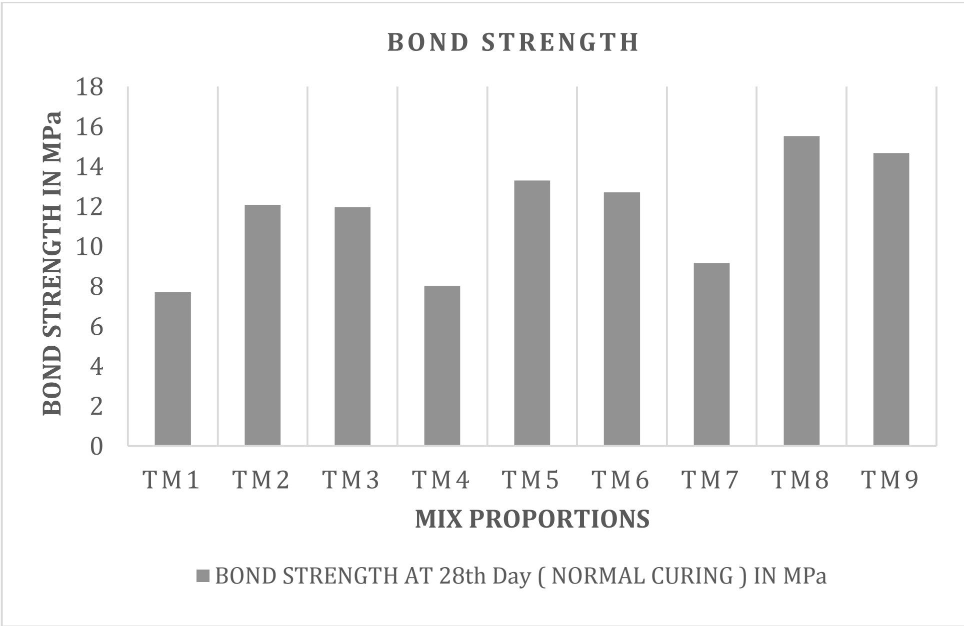

Fig 3.4. Graphical presentation of Bond strength and Modulus of Elasticity of reactive powder concrete

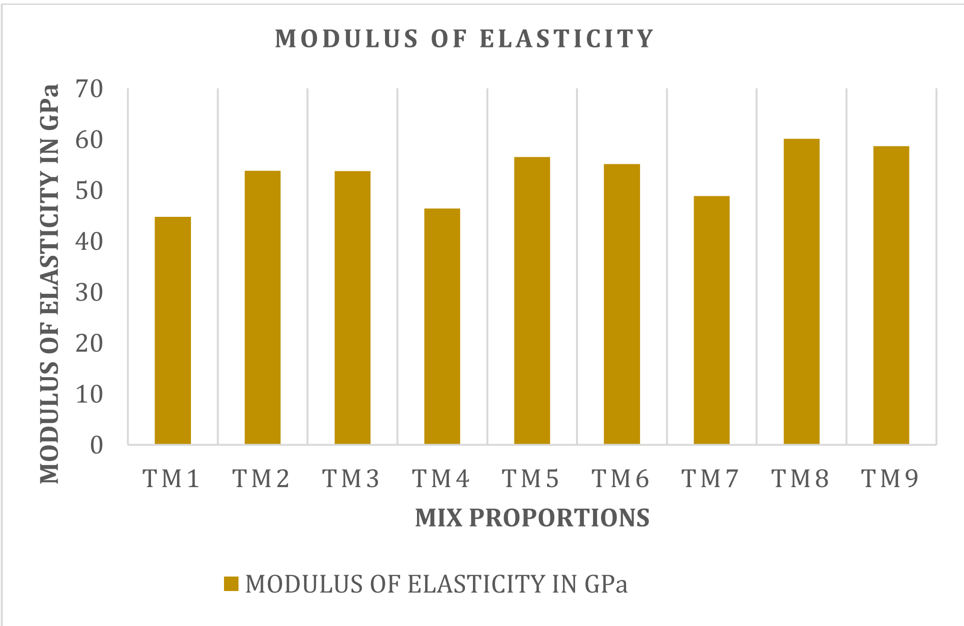

Fig 3.5. Graphical presentation of Modulus of Elasticity of reactive powder concrete.

3.4.1. Observation and discussions

1) For mixes with 10% ,15% and 20% silica fume content it is observed that the Bond strength and Modulus of Elasticity is higher for the mixes with W/B ratio 0.25.
2) The highest Bond strength and Modulus of Elasticity was observed for TM8 i.e. 15.52 MPa and 60.11 GPa in which silica fume content is 20%.
3) The Modulus of Elasticity of RPC obtained in this study is upto15 % more than the Modulus of Elasticity i.e. $5000\sqrt{f_{ck}}$ given in IS 456:2000.

3.5. Effect of Water-to-Binder Ratio on RPC

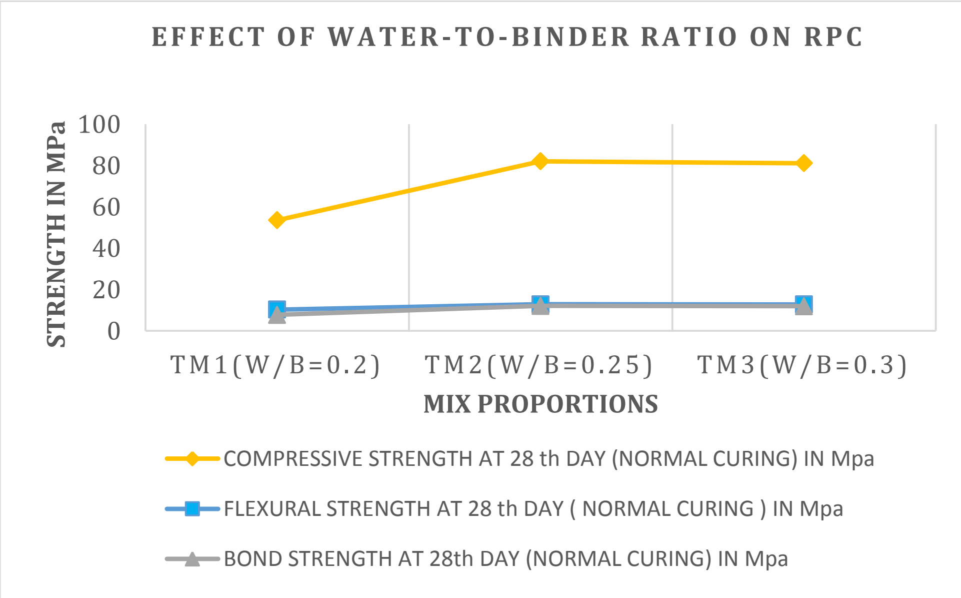

Fig 3.6. Effect of Water-to-Binder Ratio on RPC

The strength of concrete is very much dependent upon the hydration reaction in which water plays a critical role, particularly the amount of water used. The effect of W/B ratio on different strength parameter of RPC is shown in Fig3.6. The result demonstrates that an optimal W/B ratio that gives the highest compressive strength of RPC in the present study is 0.25. The reduction in strength at lower W/B ratio may be due to the lack of adequate amount of mixing water in RPC to ensure adequate compaction and proper hydration to occur. Beyond this optimal W/B ratio of 0.25, it was found that strength decreases with increasing W/B ratios. This may be because of more water which is susceptible to entraining air bubbles due to the folding action of the mixing process. As a result, more voids are left in the matrix which increase the porosity and thus considerably reduce the strength.

3.6. Influence of Curing Regime on compressive strength of RPC

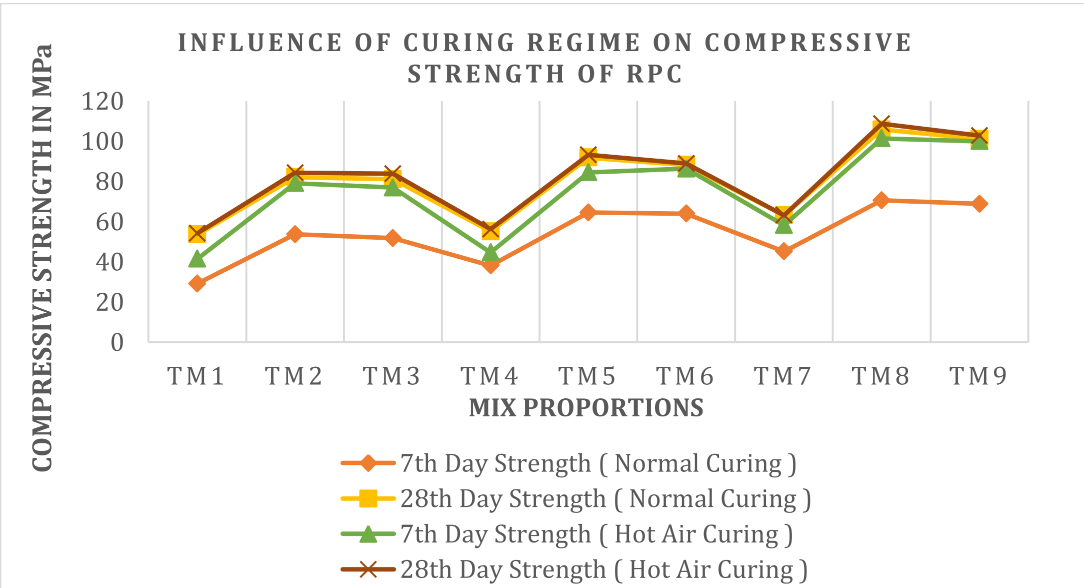

Fig 3.7 Influence of Curing Regime on compressive strength of RPC.

The effect of curing regime on compressive strength for different mixes is shown in Fig.3.7. Two curing methods were exercised, one with normal water curing at 27ºC, and other at 150ºC hot air curing for 24 hours and then followed by normal water curing till age of testing. The compressive strength increased up to 45% on 7th day and 3% on 28th day for TM5 and TM8 when cured in hot water as compared to normal curing. The increased strength is due to the rapid hydration of cement at higher curing temperatures of 150°C compared to that of 27°C. Moreover, the pozzolanic reactions are also accelerated by the higher curing temperatures.

3.7. Fresh and Hardened properties of RPC

Fresh and hardened properties of RPC for all mixes are tabulated below:

Table3.1. Fresh and Hardened properties of RPC

Trial mix	Com strength normal curing (MPa)		Com strength hot air curing 150^0 C. (MPa)		workability (% flow)	Flexural strength (MPa)	Bond strength (MPa)	Modulus of Elasticity (GPa)
	7 days	28 days	7 days	28 days		28 days	28 days	28 days
TM1	29.14	53.55	41.45	54.15	0	10.30	7.71	44.74
TM2	53.66	82.09	79.10	84.24	48	12.84	12.08	53.81
TM3	51.73	81.12	76.91	83.77	180	12.81	11.96	53.74
TM4	38.12	55.10	44.68	56.18	0	10.49	8.02	46.41
TM5	64.48	91.84	84.48	93.16	46	13.51	13.30	56.52
TM6	63.95	88.15	86.36	88.92	162	13.20	12.70	55.14
TM7	45.13	63.14	58.18	64.12	0	11.21	9.16	48.84
TM8	70.55	105.81	101.44	108.63	38	14.59	15.52	60.11
TM9	68.84	101.17	99.94	102.77	158	14.19	14.68	58.68

4.CONCLUSIONS:

Investigating and optimizing the mechanical properties of RPC had the following outlines: -

1. The particles smaller than 600micron of any ingredient shall be limited.
2. Low w/b ratio (0.20) mixes are difficult to achieve full compaction whereas high w/b ratio (0.30) mixes are more susceptible to entraining air bubbles, which then leads to formation of large capillary voids and thus considerable reduction in strength.
3. The compressive strength of RPC increases with increase in silica fume content.
4. The strength of concrete cured by hot air method has increased up to 45% on 7 days and 3% of 28 days compared to normal curing. The increased strength is due to the rapid hydration of cement at higher curing temperatures of 150°C compared to that of 27°C. Moreover, the pozzolanic reactions are also accelerated by the higher curing temperatures.
5. The maximum compressive strength, Flexural strength, Bond strength and Modulus of Elasticity of RPC obtained in the present study is 108.63 MPa, 14. 59MPa, 15.52 MPa and 60.11 GPa. resp. for TM8.
6. The mix proportion of TM 8 can be suggested for achieving the grade of concrete more than M100.The proportion of TM 8 are (C) 1 :(S. F) 0.2:(S) 0.751 With water to binder ratio 0.25. The dosage of super plasticizer is 2%.

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