

# A Study on the Mechanical Properties of Reactive Powder Concrete Using Granite Powder and Nano Silica

S.Snigdha Malya <sup>1</sup>, V.K. Visweswara Rao <sup>2</sup>

M.Tech Student, Department of Civil Engineering, G. Pulla Reddy Engineering College, Kurnool, A.P, India<sup>1</sup>

Assistant Professor, Department of Civil Engineering, G. Pulla Reddy Engineering College, Kurnool, A.P, India<sup>2</sup>

**ABSTRACT:** Reactive Powder Concrete is a developing composite material that allows the concrete industry to optimize material use. Generate economic benefits and building structures which are strong, durable and sensitive to environment. RPC is a new ultra-high performance concrete with wide range of capabilities. RPC was developed in the 1990s by Bouygues' laboratory in France. RPC represents a new class of Portland cement based material with compressive strengths of 200 MPa range. By introducing fine steel fibers RPC can achieve flexural strength up to 50 MPa. It has no coarse aggregates and contains small steel fibres that provide additional strength. RPC include Portland cement, silica fume, fine sand, superplastizer, water and steel fibres. In this study, RPC is produced with nano material to achieve target compressive strength more than 180MPa. Also mechanical properties such as compressive strength, flexural strength and split tensile strength were studied.

**KEYWORDS:** Steel fibers, compressive strength, split tensile strength, flexural strength, quartz powder, silica fume, nano silica

## I. INTRODUCTION

The demand for high strength construction materials is the force behind the development of Reactive Powder Concrete. The pre-stressed hybrid pedestrian bridge at Sherbrooke in Canada, shown in fig 1, completed in 1997 was the first engineering structure application of RPC. In 1997 and 1998, RPCs were cast in beams of Cattenom and Civaux power plants as the first industrial application. The first UHPC road bridge was designed and constructed at Bourg-les-Valence in France in 2001.



**Fig.1.** Sherbrooke Bridge

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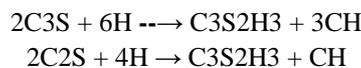
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Ultra high performance concrete is characterized primarily with high strength (>150MPa), and when it is reinforced with steel fibers, exhibits high ductility.

Original Reactive Powder Concrete (RPC), otherwise known as ultra high performance concrete (UHPC), was developed through microstructural enhancement techniques for cementitious materials. RPC term has been used to describe a fibre-reinforced, superplasticized, silica fume cement mixture with very low water-cement ratio, characterized by the presence of very fine aggregates instead of ordinary aggregate. In fact, it is not a concrete because there is no coarse aggregate in the cement mixture. Fibers are incorporated in RPC in order to enhance the fracture properties of the composite material. The advantages of Reactive Powder Concrete (RPC) include higher durability, ductility and strength in comparison with normal concrete and fiber reinforced concrete due to its extremely low porosity, dense matrix, high tensile/compressive strength, and ductile tensile behavior. In comparison with normal steel reinforced concrete, the application of RPC is expected to improve the resistance of buildings and infrastructures under extreme mechanical and environmental loads.

In Reactive Powder Concrete (RPC) silica fume by itself, do not contribute to the strength dramatically, although it does contribute to the strength property by being very fine pozzolanic material and also creating dense packing and acting as pore filler of cement paste. Silica fume is much more reactive than fly ash or any other natural pozzolana. The reactivity of pozzolana can be quantified by measuring the amount of Ca (OH)<sub>2</sub> in the cement paste at different times. Pozzolanic silica is added in the stoichiometric quantity necessary to react with all the calcium hydroxide that would be produced assuming complete cement hydration. The Hydration reaction is as follows;



[Where C = CaO; S = SiO<sub>2</sub>; H = H<sub>2</sub>O]

The C<sub>3</sub>S<sub>2</sub>H<sub>3</sub> is referred to as C-S-H or calcium silicate hydrate. The calcium hydroxide (CH) produced by hydration occupies 20 – 25% of the cement paste by volume and makes no contribution to strength and durability. Addition to amorphous silica fume and fly ash forms further desirable C-S-H at the expense of calcium hydroxide.



It is also observed that the cement paste undergoes distinct densification. The improvement offered by this densification includes an increase in strength and decrease in permeability. Strength of the RPC is almost one digit higher than that of normal high strength concrete. Builders of high rise concrete structures also could benefit from higher strength concrete by large reduction in dead load

## OBJECTIVE:

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 more than 180 Mpa
- To reduce fine aggregate content so, fine aggregate is replaced with Granite powder. Since target compressive strength is not achieved, nano material is used in RPC mix.
- RPC mixes are designed by variation in Granite content and nano material.

## II. LITERATURE REVIEW

Extensive research works both National and International level has been used done on the use of various admixtures in mortars and concrete with common goal. To modify the properties of traditional concrete to the desired level suitable to the specific circumstances. To bring down the increasing cost economics of cement, building block and high strength concrete.

Many researchers have carried out studies on RPC in the past years to assess the properties and its behaviour. Researchers have studied on choosing ingredients, choice of curing regime, particle packing of mix proportions to assess the mechanical and durability properties. Some of the works carried out are discussed below

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**Richard and Cheyreyzy [1995]<sup>24</sup>** developed an ultra high strength ductile concrete designed RPC (Reactive Powder Concrete) with the basic principles of enhancing the homogeneity by eliminating the coarse aggregate and enhancing the microstructure by post-set heat treatment, In addition, the ductility and tensile strength of concrete is increased by incorporating small, straight, high tensile microfibers. Two types of concretes are developed and designated as RPC 200 and RPC 800. These concretes had exceptional mechanical properties, which resulted in elimination of reinforcement, and reduction of materials resulting in reduction of self-weight resulting in cost savings.

**Chan Yin-Wen and ChuetShu-Hsien [2002]<sup>3</sup>** has studied the bond characteristics of steel fiber on matrix of reactive powder concrete by changing the content of silica fume ,arriving optimum content of silica fume, various silica fume contents ranging from 0% to 40% were used in the mix proportions. The bond characteristics in terms of bond strength and pullout energy, etc. The bond strength and pullout energy were higher at between 20% and 30% silica fume dosage. Result show that the incorporation of silica fume in RPC matrix effectively enhances the steel fiber matrix bond characteristics due to the interfacial toughing effect upon fiber slip.

**Dattatreya.J.K et al., [2007]<sup>9</sup>** studied several particle packing models to develop a mix proportion for the reactive powder concrete. The optimization of granular packing of the ingredients was an important factor for getting enhanced mechanical and durability properties. RPC mixes in which the process of optimization of granular fraction was extended to include the quartz powder also in addition to fine aggregate. The optimized granular packing of ingredients like silica fume, quartz powder, standard sand with cement and experimental results were compared with the theoretical packing models

**Halit Yazici et al.,[2009]<sup>14</sup>** studied the effect of curing conditions on mechanical properties of reactive powder concrete (RPC) containing mineral admixtures. The admixtures ground granulated blast furnace slag (GGBFS) and class-C fly ash (FA) were researched under standard curing,autoclave curing and steam curing were studied. Mechanical properties like compressive strength flexural strength and toughness were evaluated. Test results showed that, steam and autoclave curing enhance the compressive strength of RPC mixes with admixtures compared to the standard curing. Decreasing the cement content reduces heat of hydration and shrinkage which are normally important problems for conventional RPC. On the other hand, flexural strength and toughness of RPC decreased considerably after steam and autoclave curing compared to 28-day standard curing.

**Zheng Wenzhong et al., [2013]<sup>33</sup>** have studied compressive strength and tensile strength of reactive powder concrete at elevated temperature. The influence of temperature, time duration, size of specimens and explosive spalling in the heat treatment range of 20<sup>0</sup> C-800<sup>0</sup> C were evaluated. The result shows that steel fiber 2% by volume content can prevent explosive spalling of RPC and enhance the compressive and tensile strength. Cube compressive strength decreases at temperatures 100<sup>0</sup> C, above 600<sup>0</sup> C and increases at temperature from 200<sup>0</sup> C to 500<sup>0</sup> C. As the fiber content increases, the cube compressive strength of RPC increases at below 300<sup>0</sup> C but decreases above 300<sup>0</sup> C. The tensile strength of RPC with steel fiber decreases at temperatures below 200<sup>0</sup> C increases at temperature ranging from 200<sup>0</sup> C to 300<sup>0</sup> C and decreases at temperatures above 300<sup>0</sup> C.

### III. MATERIAL PROPERTIES

**Cement:** Ordinary Portland cement (OPC) of Ultra Tech brand and 53 grade conforming to IS: 12269-1987, specific gravity of cement is 3.1

**Water:** Potable water was used for mixing.

**Quartz Powder:** For RPC mixes designed to be temperature cured, additional silica is necessary to modify the CaO/SiO ratio of the binder. In these cases powdered quartz flour with a mean particle size of 10 – 15 µm was employed. Quartz powder is brought from Chandra Swadi Minerals Kurnool. Specific gravity is 2.6 and particle size ranges from 10 to 45µm.

**Granite:** Granite used in this study is brought from The Industrial Area Kallur Kurnool. Two different gradations are used, having size between 2.36 mm and 1.18mm, between 1.18mm and 600 micron in different proportions.

**Fine Aggregate:** RPC is produced using manufactured sand having particle size less than 2.36mm.Two different gradations are used, having size between 2.36 mm and 1.18mm, between 1.18mm and 600 micron in different proportions

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**Silicafume:** A highly reactive silica pozzolan is an essential component of reactive powder concrete. Silicafume is brought from Astra chemicals Ltd, Chennai. Properties of silicafume are mentioned in the following table 1

**Table 1 Physical properties of Silica fume**

Property	Result
Particle size	0.5µm - 1µm
Pack density	0.76 gm/cc
Moisture content	0.058%
Specific gravity	2.63

**Superplasticizer:** Master Glenium sky 8233 formely B-233 which is poly-carboxylic ether based superplasticizer is used. It is brought from BASF India Ltd construction chemicals –Secundarabad. Properties of superplasticizer are mentioned in the following table 2

**Table 2 Physical properties of Super plasticizer**

Aspect	Light brown liquid
Relative Density	1.08±0.01at 25°C
pH	≥ 6
Chloride ion content	<0.2%

**Steel fibers:** Hook end steel fibers are used with aspect ratio of 56 having dia of 0.45mm and length of 25mm. It is brought from STEWOLS INDIA (P) LTD. The properties of steel fibers are as follows

**Table 3 Chemical composition of steel fibers**

Chemical composition of mild steel fibers	%
C	0.030
Mn	0.330
Si	0.035
P	0.014
S	0.009

**Table 4 Mechanical properties of Steel fibers**

Mechanical properties of steel fibers	
Dia	0.45mm
Length	25mm
Tensile strength	1175Mpa
Tolerance for diameter and length	(±)10% (AS PER ASTM)

**Nano silica:**

Nano Silica used is confirmed to ASTM C1240 and IS 15388:2003. Nano Silica is brought from Astra chemicals Ltd, Chennai. Properties of nano silica are mentioned in the following table 5

**Table 5 Physical properties of Nano silica**

Property	Result
Specific surface area (m <sup>2</sup> /Kg)	202
SiO <sub>2</sub> content (%)	99.88
Particle size	17 nano
Density (g/l)	44

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## IV. EXPERIMENTAL PROGRAMME

In this study, water curing and thermal curing is used. Cube specimens of size 70.6mm x 70.6mm x 70.6mm, cylindrical specimen of size 100mm dia x 200mm high and beam specimens of size 100mm x 100mm x 500mm were cast and they are exposed to a temperature of 200°C in oven for duration of 24, 48 and 72 hours at the age of third day followed with water curing till 28 days. Use of the nano material increases the compressive strength from 120 MPa to 188 MPa. From this study, it is observed that, nano material, quartz powder, curing regimes affects the compressive strength and maximum compressive strength is achieved when 1.5% Nano Silica is used.

### MIX PROPORTION

As there is no mix design for RPC, mix design is referred from literature. From previous papers, it is observed that water/binder ratio is 0.2. The optimal dosage of steel fibers ratio is 2% by volume or about 155kg/m<sup>3</sup>. Quartz powder is used as filler and super plasticizer is added in mix to provide workability. Mix proportions of RPC mix with variation in Granite and variation in nano material are mentioned in the following mentioned tables

**Table -6 Mix Proportion of RPC with Variation in Granite powder**

Materials	M-0 100% S	M-1 30% GP	M-2 40% GP	M-3 50% GP	M-4 60% GP
<b>Cement</b>	750	750	750	750	750
<b>Silica fume</b>	187.5	187.5	187.5	187.5	187.5
<b>Quartz powder</b>	300	300	300	300	300
<b>Sand</b>	934.5	654.15	560.7	467.25	373.8
<b>Granite powder</b>	-	280.35	373.8	467.25	560.7
<b>Super plasticizer</b>	11.25	11.25	11.25	11.25	11.25
<b>Steel fibers</b>	156.2	156.2	156.2	156.2	156.2
<b>Water</b>	187.5	187.5	187.5	187.5	187.5
<b>Net w/b</b>	0.2	0.2	0.2	0.2	0.2
<b>SP %</b>	1.5	1.5	1.5	1.5	1.5

S- sand, GP – granite powder

**Table 7 Mix Proportion of RPC with Variation in Nano Material**

Materials	M-0 0%NS	M-1 0.5% NS	M-2 1% NS	M-3 1.5% NS	M-4 2% NS
<b>Cement</b>	750	750	750	750	750
<b>Silica fume</b>	187.5	187.5	187.5	187.5	187.5
<b>Quartz powder</b>	300	300	300	300	300
<b>Sand</b>	934.5	654.15	560.7	467.25	373.8
<b>Nano silica</b>	-	3.75	7.5	11.25	15
<b>Super plasticizer</b>	11.25	11.25	11.25	11.25	11.25
<b>Steel fibers</b>	156.2	156.2	156.2	156.2	156.2
<b>Water</b>	187.5	187.5	187.5	187.5	187.5
<b>Net w/b</b>	0.2	0.2	0.2	0.2	0.2
<b>SP %</b>	1.5	1.5	1.5	1.5	1.5

S - sand, NS – Nano silica

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## MIXING PROCEDURE

The mixing procedure adopted for mixing RPC is followed by based on literature research.

- A pan mixer machine (40 kg capacity) was used to mix the RPC.
- Premix (dry ingredients) was placed in mixer pan, and mixed for about 3minutes while the mixer was rotating at a slow speed. Water (with  $\frac{1}{2}$  of SP) was added to premix slowly over the course of 2 minutes.
- After 1 minute, the remaining SP was added to premix and mixing was continued at slow speed for two or three minutes.
- Additional mixing was performed at this speed until a uniform mixture was achieved and the mixture was transformed to a flowable self-compacting consistency. The total mixing time for the various mixtures ranged from 20 to 25 minutes.
- Finally steel fibers were added to the mix slowly, when flowable consistency was achieved. After the fibers were added, mixing was continued for 2 minute to ensure that the fibers were well dispersed.

## SPECIMEN PREPARATION AND CURING

For each mix, 3 cubes and 3 cylinders are cast. Size of cube is 70.6mm×70.6mm×70.6mm and cylinder size is 100mm dia × 200mm high and beams of 100mm x 100mm x 500mm Cubes, cylinders and beams are placed in oven at temperature of 200°C. After thermal curing for 24, 48, 72 hours they are placed in water till the date of testing



## TESTING

Cubes and cylinders are tested for compressive strength and split tensile strength at 28 days respectively. They are tested under Compression testing machine (CTM) of 2000KN capacity. As per 363R-929.99 Modulus of elasticity (GPa) is calculated which is related to compressive strength (Mpa). Following expression is used,

Theoretical Modulus of Elasticity =  $3.65\sqrt{f_c}$

Where,  $f_c$  is compressive strength in MPa



(a) Compression test



(b) split tensile test



(c) flexural strength test

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## V. RESULTS AND DISCUSSIONS

Arriving a optimal composition with locally available materials is important to achieve compressive strength more than 180 Mpa. Hence the effect of several parameters on compressive strength were investigated which comprise of percentages of quartz powder and duration of temperature and curing regimes. During the mixing it was observed that the mixes appeared to be very sensitive to any variation of the quartz powder, sand to be added to the mixes. Till a date there is no standard guidelines for mix design of RPC, literature was referred to the design mixes.

### A. DENSITY OF UHSC SPECIMENS

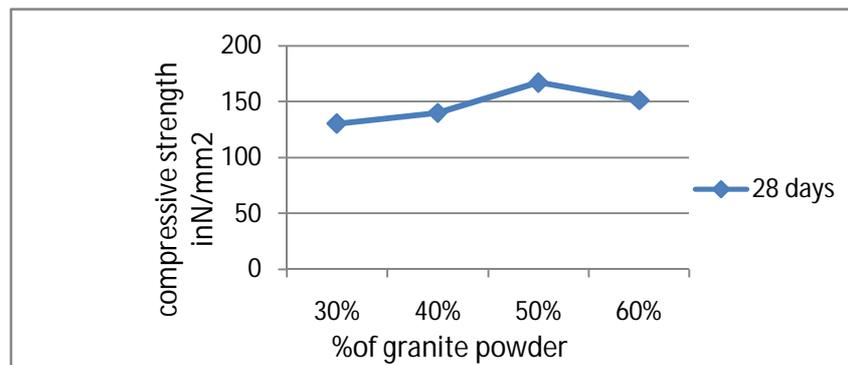
The density of all specimens is varied between 23.44 - 26.06 KN/m<sup>3</sup>

### B. EFFECT OF GRANITE POWDER ON COMPRESSIVE STRENGTH OF RPC

Target mean strength is not achieved when Granite powder is used. When Granite powder content is increased, it is observed that strength is decreased. Maximum compressive strength for both 7 day and 28 days curing is observed at 50% Granite powder for samples which are thermally cured for 72hours.

**Table 8 Regime Compressive Strength of RPC with Variation in Granite powder**

Day of curing	Mix proportions			
	30%	40%	50%	60%
7 days	120.37	123.38	133.41	124.38
28 days	130.46	140.09	167.31	151.22



**Fig 2 Variation of Compressive Strength versus % of Granite powder**

### C. EFFECT OF NANO MATERIAL ON COMPRESSIVE STRENGTH OF RPC

Nano material effects comprise interparticle void filling, acceleration of cement hydration, formation of additional C-S-H by pozzolanic reaction, higher compressive strength, improved frost resistance, lower permeability. Nano silica do not only fill in the voids left by the larger size particles, but by being highly reactive they react with calcium hydroxide and additionally act as nucleation sites for the production of very fine calcium- silicate- hydrate (C-S-H) phase. Small quantity of nano material is enough to increase its mechanical properties, if excess amount of nano silica is used, it reduces compressive strength. Maximum compressive strength is achieved when 1.5% nano silica is used.

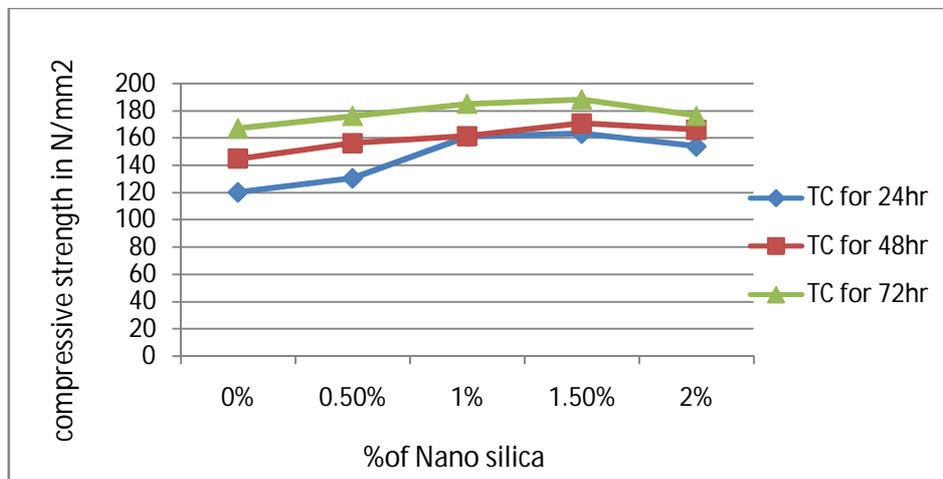
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**Table 9 Compressive Strength of RPC Mix in Mpa**

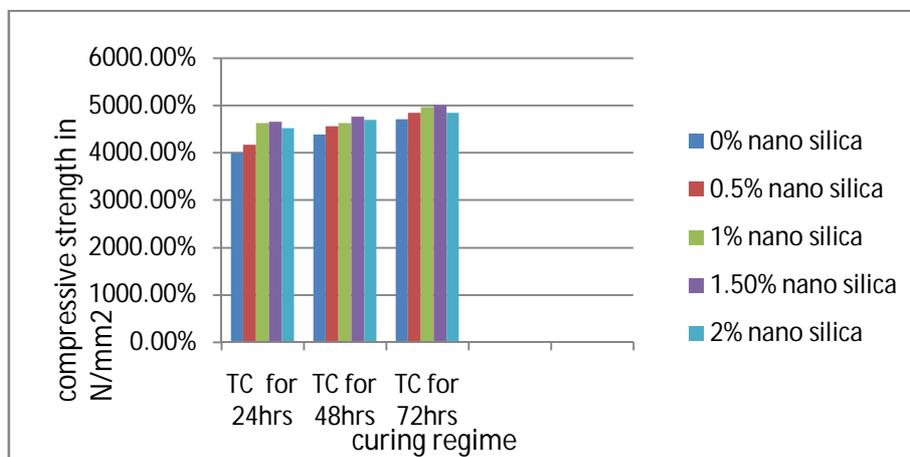
% of Nano silica	0%	0.5%	1%	1.5%	2%
Thermal Curing for 24hrs	120.41	130.66	160.98	163.44	154.07
Thermal Curing for 48hrs	144.98	156.43	161.6	171.02	166.34
Thermal Curing for 72hrs	167.31	176.45	185.44	188.58	176.6



**Fig 3 Variation of Compressive Strength versus % of Nano silica**

### D. EFFECT OF CURING REGIME ON COMPRESSIVE STRENGTH OF RPC

Because of thermal curing, pozzalanic reaction of quartz powder, silicafume and nano material takes place. If thermal curing is not done they just act as filler materials. In uhpc when the samples are palced in oven at temperature of 200°C, Tobermorite, Xonotlite and Scawatite are formed and these are identified by SEM and XRD analysis. It is observed that maximum compressive strength is achieved for samples which are thermally cured for 3 days



**Fig 4 Variation of Compressive Strength versus Curing Regime**

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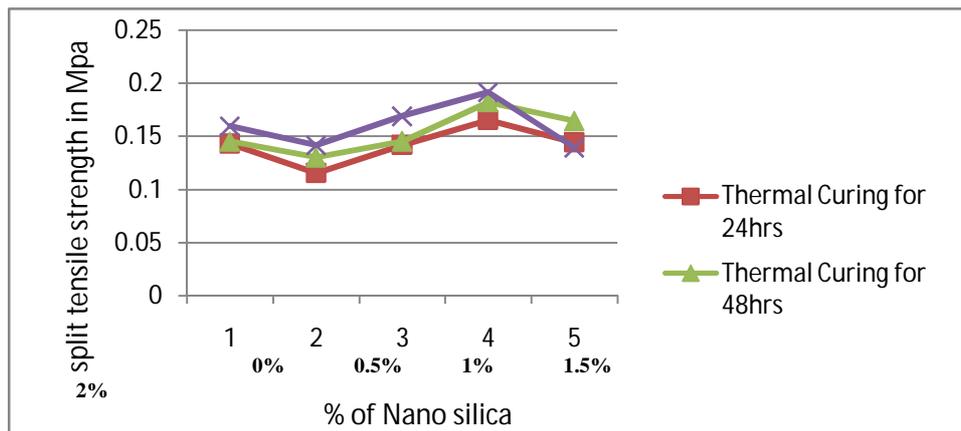
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### E. SPLIT TENSILE STRENGTH OF RPC

Split tensile strength results with varying nano material and different curing conditions are presented in the following table. It is observed that maximum split tensile strength is achieved at one day thermal curing with 1.5% nano silica and Strength is increased at three days thermal curing.

**Table 10 Split Tensile Strength of RPC Mix in Mpa**

% of Nano silica	0%	0.5%	1%	1.5%	2%
Thermal Curing for 24hrs	14.34	12.96	14.18	16.54	14.45
Thermal Curing for 48hrs	14.50	14.54	14.54	19.14	16.44
Thermal Curing for 72hrs	15.96	14.15	15.32	18.22	13.912



**Fig 5 Variation of Split Tensile Strength versus Curing Regime**

### F. THERETICAL MODULUS OF ELASTICITY OF RPC

The theoretical modulus of elasticity results with varying nano silica and different curing conditions are presented in the following table Variation of theoretical modulus of elasticity versus curing regime is presented. It is observed that three days thermal curing gives good results.

**Table 11 Theoretical Modulus of Elasticity of RPC Mix in Gpa**

% of Nano silica	0%	0.5%	1%	1.5%	2%
TC for 24hrs	40.05	41.72	46.31	46.66	45.30
TC for 48hrs	43.94	45.65	46.39	47.73	47.07
TC for 72hrs	47.21	48.48	49.71	50.12	48.50

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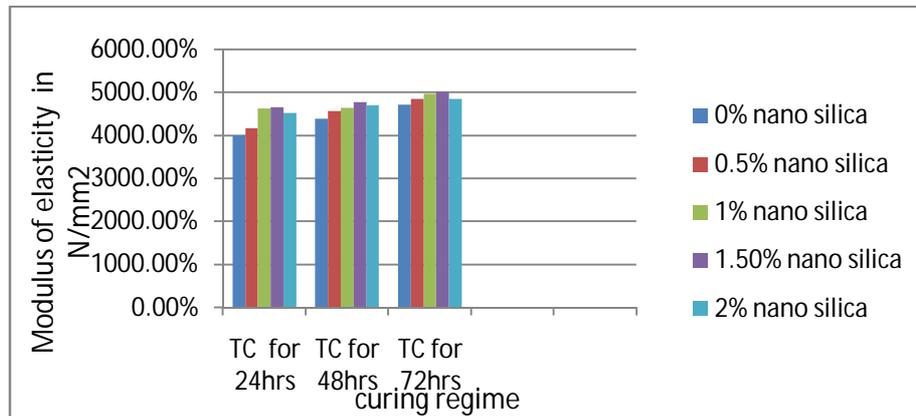


Fig 6 Variation of Modulus of Elasticity versus Curing

### G. FLEXURAL STRENGTH OF RPC

The flexural strength of RPC results with varying the optimum percentage of nano silica and different curing conditions are presented in the following Target mean strength is achieved when 1.5% of nano silica is used. Maximum flexural strength for 28 days curing is observed at 1.5% of nano silica for samples which are thermally cured for 72hours

Table 12 flexural strength of RPC Mix in Mpa

Days of curing	Mix proportions	
28 days	0%	1.5%
	9.46	12.40

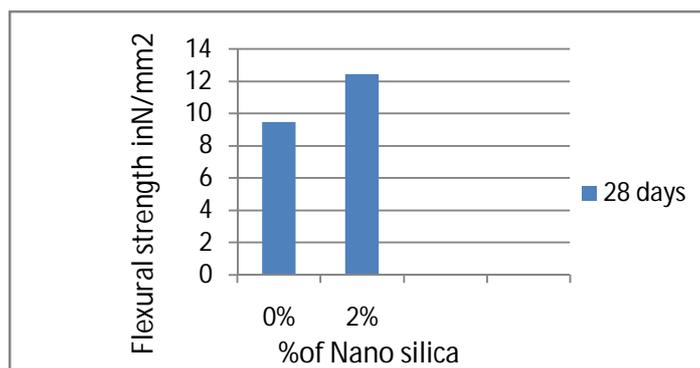


Fig 7 Variation of Flexural Strength versus % of Nano silica

## VI. CONCLUSIONS

From this study the following conclusions are given

- Reactive Powder Concrete with compressive strength of more than 180 MPa can be produced using nano materials.
- Compressive strength of RPC with 1.5% nano silica is optimum at 200°C thermal curing in 72 hours.
- The maximum compressive strength of 188.58 Mpa obtained for mix with 1.5% nano silica and 72 hours thermal curing at 200 °c

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- The maximum split tensile strength of 19Mpa obtained for mix with 1.5% nano silica and 48 hours thermal curing at 200 °C
- The maximum Modulus of Elasticity of 50.12GPa obtained for mix with 1.5% nano silica and 72 hours thermal curing at 200 °C
- The maximum flexural strength of 12.40MPa obtained for mix with 1.5% nano silica and 72 hours thermal curing at 200 °C
- Maximum compressive strength, split tensile strength, flexural strength and Modulus of Elasticity attained at nano silica of 1.5%.

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