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Influence of silpozz and rice husk ash on enhancement of concrete strength

K.C. Panda*[1] and S.D. Prusty[2]

[1]*Department of Civil Engineering, ITER, SOA University, Bhubaneswar, Odisha, India, 751030*
[2]*Post Graduate Student, Department of Civil Engineering, ITER, SOA University, Bhubaneswar, Odisha, India*

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Abstract. This paper presents the results of a study undertaken to investigate the enhancement of concrete strength using Silpozz and Rice Husk Ash (RHA). The total percentage of supplementary cementitious material (SCM) substituted in this study was 20%. Six different concrete mixes were prepared such as without replacement of cement with silpozz and RHA (0% silpozz and 0% RHA) is treated as conventional concrete, whereas in other five concrete mixes cement was replaced by 20% of silpozz and RHA as (0% silpozz and 20% RHA), (5% silpozz and 15% RHA), (10% silpozz and 10% RHA), (15% silpozz and 5% RHA) and (20% silpozz and 0% RHA) with decreasing water-binder (w/b) ratio i.e. 0.375, 0.325 and 0.275 and increasing super plasticiser dose. New generation polycarboxylate base water reducing admixture i.e., Cera Hyperplast XR-W40 was used in this study. The results of this research indicate that as w/b decreases, super plasticiser dose need to be increased so as to increase the workability of concrete. The effects of replacing cement by silpozz and RHA on the compressive strength, split tensile strength and flexural strength were evaluated. The concrete mixture with different combination of silpozz and RHA gives higher strength as compared to control specimen for all w/b ratios and also observed that the early age strength of concrete is more as compared to the later age strength. It is also observed that the strength enhancement of concrete mixture prepared with the combination of cement, silpozz and RHA is higher as compared to the concrete mixture prepared with cement and silpozz or cement and RHA.

Keywords: rice husk ash (RHA); silpozz; compressive strength; flexural strength; split tensile strength

1. Introduction

The use of high strength concrete (HSC) and high performance concrete (HPC) has increased all over the world. The failure of concrete structures in moderate and strongly aggressive environment has led to development of HSC and HPC. For production of HSC and HPC, the supplementary cementitious materials such as fly ash (FA), ground granulated blast-furnace slag (GGBS), silica fume (SF) and rice husk ash (RHA) and Metakaolin are being used as part of binders for concrete. This is due to the potential ability of these materials to enhance the properties and performance of concrete through their filler effect as well as pozzolanic reaction (Johari *et al.*

∗Corresponding author, Associate Professor, E-mail: kishoriit@gmail.com

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2011). The chemical admixture is also play a significant role for production of HSC and HPC. Some of the researchers have been carried out a work on HSC and HPC using these materials. Hassan *et al*. (2000) presented a laboratory study on the influence of two mineral admixtures, SF and FA on the properties of super plasticised high performance concrete. Mazloom *et al*. (2004) studied the effects of mineral and chemical admixtures namely FA, GGBS, SF and super plasticisers on the porosity, pore size distribution and compressive strength development of HSC in seawater curing condition exposed to tidal zone. Jaturapitakkul *et al*. (2004) presented a method of improving coarse FA in order to replace condensed SF in making HSC. Sensale (2006) studied on the development of compressive strength up to 91 days of concretes with RHA, in which residual RHA from a rice paddy milling industry in Uruguay and RHA produced by controlled incineration from the USA were used for comparison. Two different replacement percentages of cement by RHA, 10% and 20%, and three different water/cementitious material ratios (0.50, 0.40 and 0.32), were used. Sakr (2006) used SF and RHA as supplementary cementing materials to improve concrete properties. Physical, mechanical and shielding properties of different types of heavy weight concrete were studied. Yazici (2007) studied by using FA, pulverized granulated blast furnace slag (PS) and SF replacement with portland cement. Three different curing methods were applied to the specimens and concluded that high strength concrete can be obtained with high volume mineral admixture. Givi *et al*. (2010) studied the compressive strength, water permeability and workability of concrete by partial replacement of cement with agro-waste rice husk ash. Two types of RHA with average particle size of 5 micron (ultra fine particles) and 95 micron and with four different contents of 5%, 10%, 15% and 20% by weight were used. Replacement of cement up to maximum of 15% and 20% respectively by 95 and 5 μm RHA produces concrete with improved strength. However, the ultimate strength of concrete was gained at 10% of cement replacement by ultra fine RHA particles. Ghandehari *et al*. (2010) studied on the effect of high temperatures on the mechanical properties of HSC. Different concrete mixtures were prepared with water to cementitious material ratios of 0.40, 0.35 and 0.30 containing SF at 0%, 6% and 10% replacement. After heating 100°C, 200°C, 300°C and 600°C, the compressive strength, the split tensile strength and the corresponding ultra sonic velocity were measured. Raman *et al*. (2011) experimentally studied the suitability of quarry dust as a partial substitute for sand in HSC containing RHA. Two grades of HSC mixes were designed to achieve the high strength 60 MPa and 70 MPa at 28 days with and without the incorporation of RHA. Johari *et al*. (2011) studied the influence of supplementary cementitious materials, namely SF, metakaolin, FA and GGBS, on the engineering properties of HSC. Very few works have been carried out using the combination of both SF and RHA in HPC and HSC. Hwang *et al*. (2012) used fuller's ideal gradation curve to theoretically design blended ratio of all solid materials of HPC, with the aid of error function, and studied the effect of RHA on the performance of HPC. The authors concluded that the proposed method for HPC can save over 50% of the consumption of cement and limit the use of water and also observed the strength efficiency of cement in HPC is 1.4 - 1.9 times higher than that of the traditional method. In the present study, silpozz and RHA is used for enhancement of concrete strength with decreasing w/b ratio. Silpozz is a super pozzolanic material with silica content of about 90% and can be used as a substitute material for SF. This paper presents the results of an investigation on the enhancement of concrete strength using two different supplementary cementitious materials such as silpozz and RHA and also the chemical admixture used such as new generation polycarboxylate base water reducing admixture i.e., Cera Hyperplast XR-W40.

2. Experimental investigation

2.1 Materials used and properties

The cement used for the present work is Ordinary Portland Cement (OPC), 43 grade. The physical properties of cement obtained experimentally and the value specified by IS: 8112-1989 is presented in Table 1. The sand was supplied from ‘Trisulia’, situated on the river base of Kathajodi and its tributary Kuakhia, Odisha. Sand is used as fine aggregate which is passing through IS 4.75 mm sieve. The Natural Coarse aggregate (NCA) which is passing through IS 20 mm sieve, was used in the present study. It was supplied by the crusher at Tapanga, near Khurda, Odisha. The properties of fine aggregate and coarse aggregate are presented in the Table 2.

Table 1 Physical properties of cement

Characteristics	Value obtained experimentally (OPC)	Value specified by IS 8112:1989 (OPC-43 grade)
Normal consistency, Percent	34	NA
Fineness (m^2/kg)	330	225 (min)
Initial setting times (minutes)	125	30 (min)
Final setting times (minutes)	420	600 (max)
Specific gravity	3.15	3.15
Compressive strength, MPa (3 Days)	30.05	23 (min)
Compressive strength, MPa (7 Days)	45.75	33 (min)
Compressive strength, MPa (28 Days)	52.39	43 (min)

Table 2 Properties of fine and coarse aggregates

Characteristics	Fine aggregate value obtained experimentally as per IS: 383-1970	Coarse aggregate value obtained experimentally as per IS: 383-1970
Abrasion value (%)	-	27.02
Bulk density (kg/m^3)	1568	1418
Crushing value (%)	-	28.70
Fineness modulus	3.48 (Zone1)	7.95
Impact value (%)	-	24.00
Specific gravity	2.63	2.84
Water absorption (%)	0.30	0.10

2.2 Mineral admixture

The supplementary cementitious materials such as silpozz and RHA were used in this study to enhance the concrete strength.

The production of silpozz is obtained by burning of rice husk in specially designed furnace in between 600°C-700°C. The furnace temperature is controlled by the air volume let inside the furnace. The furnace is also designed not to exceed temperatures above 700°C. Rice Husk is burnt

Fig. 1 Silpozz Samples

in controlled temperatures which are below 700°c. This ash generated is amorphous in nature and is called amorphous silica. The trade name of the amorphous silica is known as silpozz. Silpozz is a super-pozzolan, with silica content of above 90% having particle size of 25 microns mostly (website silpozz). Silpozz can be used as an admixture in a big way to make special concrete mixes. There is a growing demand for fine amorphous silica in the production of special cement and concrete mixes.

Silpozz is a carbon neutral green product and has the potential to be used as a substitute of silica fumes or micro silica as a much lower cost, without compromising on the quality aspect. Adding silpozz to the concrete mixture even in low replacement will dramatically enhance the strength and impermeability of concrete mixtures, while making the concrete durable to chemical attacks, abrasion and reinforcement corrosion, increasing the compressive strength by 10% to 20%. The silpozz sample used in the present study is shown in Fig. 1.

Fig. 2 Rice husk ash samples

Rice milling generates a byproduct know as husk. This surrounds the paddy grain. During milling of paddy about 78% of weight is received as rice, broken rice and bran. Rest 22% of the weight of paddy is received as husk. This husk is used as fuel in the rice mills to generate steam for the parboiling process. This husk contains about 75% organic volatile matter and the balance 25% of the weight of this husk is converted into ash during the firing process, is known as RHA.

Table 3 Chemical composition of silpozz and RHA

Oxides (%)	Chemical composition of silpozz	Chemical composition of RHA
SiO_2	88.18	88.64
Al_2O_3	1.61	1.23
Fe_2O_3	0.56	1.19
Carbon	2.67	2.33
CaO	1.59	1.09
MgO	1.63	1.76
K_2O	1.67	1.98
Others	2.09	1.78
Moisture	0.79	1.87

Table 4 Physical properties of silpozz and RHA

Characteristics	Physical properties of Silpozz	Physical properties of RHA
Bulk Density	0.23 grams/cc	0.58 grams/cc
LOI	< 6.0%	< 6.0%
Physical state	Solid-Non Hazardous	Solid-Non Hazardous
Appearance	Powder	Powder
Colour	Grey	Grey Black
Odor	Odorless	Odorless
Specific gravity	2.3	2.3
Mean particle size	< 25 microns	< 35 microns
Surface area	17.1 m^2/gram	17.1 m^2/gram

This RHA in turn contains around 85%-90% amorphous silica. When blended with cement, makes it most eco-friendly versatile supplementary cementing material to concrete. The RHA sample used in the present study is shown in Fig. 2. The chemical compositions of silpozz and RHA are presented in Table 3. The physical properties of silpozz and RHA are presented in Table 4.

2.3 Chemical admixture

In this study, CERA HYPERPLAST XR-W40, high end super plasticisers are used for the production of high strength and high performance concrete. The property of super plasticiser is new generation polycarboxylate base water reducing admixture helps in the production of self-compacting concrete, retains slump for extended periods of time, aids in cement savings and ensures high early and ultimate strength. Such type of super plasticisers is used for concrete containing large amounts of supplementary cementitious materials such as FA, GGBS, and SF. Ideal for self-leveling and higher grade concretes.

2.4 Details of concrete mixture

The mix design of concrete was targeted for M30 grade, and designed as per standard specification IS: 10262-1982 to achieve the target mean strength of 39.9 MPa. Six types of concrete mixtures were prepared. First concrete mixture was control specimen without replacement of any mineral admixture and other five concrete mixtures were made by replacing 20% of cement with different combination of silpozz and RHA by mass to enhance the concrete strength. The same mixtures were prepared in three different water binder ratios (*w/b*). The *w/b* used for preparation of concrete mixture was 0.375, 0.325 and 0.275 with different quantity of SP used for meeting the desired workability. In this study, total eighteen mixtures were prepared. For each w/b, six mixes were prepared. M1 indicate concrete mixture for *w/b* 0.375, M2 indicate concrete mixture for *w/b* 0.325 and M3 indicate concrete mixture for *w/b* 0.275. S0R0 indicate 0% silpozz and 0% RHA, S0R20 indicate 0% silpozz and 20% RHA, S5R15 indicate 5% silpozz and 15% RHA, S10R10 indicate 10% silpozz and 10% RHA, S15R5 indicate 15% silpozz and 5% RHA, and S20R0 indicate 20% silpozz and 0% RHA. Further details on the mix proportions along with their identifications are shown in Table 5 and details on mix quantity per m^3 of concrete are shown in Table 6.

Table 5 Details of concrete mix proportion (M1, M2 and M3) along with identification

Concrete mix proportion	*w/b* ratio	Super plasticisers (%)	Mix Identity
M1 Concrete mix with 100% cement + 0% silpozz + 0% RHA	0.375	-	M1S0R0
M1 Concrete mix with 80% cement + 0% silpozz + 20% RHA	0.375	0.30	M1S0R20
M1 Concrete mix with 80% cement + 5% silpozz + 15% RHA	0.375	0.25	M1S5R15
M1 Concrete mix with 80% cement + 10% silpozz + 10%RHA	0.375	0.25	M1S10R10
M1 Concrete mix with 80% cement + 15% silpozz + 5% RHA	0.375	0.20	M1S15R5
M1 Concrete mix with 80% cement + 20% silpozz + 0% RHA	0.375	0.25	M1S20R0
M2 Concrete mix with 100% cement + 0% silpozz + 0% RHA	0.325	0.30	M2S0R0
M2 Concrete mix with 80% cement + 0% silpozz + 20% RHA	0.325	0.35	M2S0R20
M2 Concrete mix with 80% cement + 5% silpozz + 15% RHA	0.325	0.30	M2S5R15
M2 Concrete mix with 80% cement + 10% silpozz + 10% RHA	0.325	0.30	M2S10R10
M2 Concrete mix with 80% cement + 15% silpozz + 5% RHA	0.325	0.35	M2S15R5
M2 Concrete mix with 80% cement + 20% silpozz + 0% RHA	0.325	0.35	M2S20R0
M3 Concrete mix with 100% cement + 0% silpozz + 0% RHA	0.275	0.45	M3S0R0
M3 Concrete mix with 80% cement + 0% silpozz + 20% RHA	0.275	0.45	M3S0R20
M3 Concrete mix with 80% cement + 5% silpozz + 15% RHA	0.275	0.50	M3S5R15
M3 Concrete mix with 80% cement + 10% silpozz + 10% RHA	0.275	0.95	M3S10R10
M3 Concrete mix with 80% cement + 15% silpozz + 5% RHA	0.275	0.90	M3S15R5
M3 Concrete mix with 80% cement + 20% silpozz + 0% RHA	0.275	0.90	M3S20R0

Table 6 Details of mix (M1, M2 and M3) quantity per m^3 of concrete

Mix Identity	Mix quantity of different constituents per m^3 of concrete							
	Cement (kg)	Sand (kg)	NCA (kg)	Silpozz (kg)	RHA (kg)	Super Plasticiser (kg)	Water (kg)	Slump in mm
M1S0R0	511.00	527.00	1209.27	-	-	0	191.60	36
M1S0R20	408.80	527.00	1209.27	0	102.20	1.533	191.60	40
M1S5R15	408.80	527.00	1209.27	25.55	76.65	1.277	191.60	42
M1S10R10	408.80	527.00	1209.27	51.10	51.10	1.277	191.60	46
M1S15R5	408.80	527.00	1209.27	76.65	25.55	1.022	191.60	44
M1S20R0	408.80	527.00	1209.27	102.20	0	1.277	191.60	38
M2S0R0	511.00	527.00	1209.27	-	-	1.533	166.08	20
M2S0R20	408.80	527.00	1209.27	0	102.20	1.788	166.08	24
M2S5R15	408.80	527.00	1209.27	25.55	76.65	1.533	166.08	26
M2S10R10	408.80	527.00	1209.27	51.10	51.10	1.533	166.08	38
M2S15R5	408.80	527.00	1209.27	76.65	25.55	1.788	166.08	25
M2S20R0	408.80	527.00	1209.27	102.20	0	1.788	166.08	26
M3S0R0	511.00	527.00	1209.27	-	-	2.299	140.53	22
M3S0R20	408.80	527.00	1209.27	0	102.20	2.299	140.53	29
M3S5R15	408.80	527.00	1209.27	25.55	76.65	3.066	140.53	34
M3S10R10	408.80	527.00	1209.27	51.10	51.10	4.854	140.53	36
M3S15R5	408.80	527.00	1209.27	76.65	25.55	4.599	140.53	38
M3S20R0	408.80	527.00	1209.27	102.20	0	4.599	140.53	42

2.5 Casting and testing of specimen

The required quantity of all dry materials such as coarse aggregate, fine aggregate, cement, silpozz and RHA were weighed (by mass) and placed in the concrete mixture, and it was thoroughly mixed in dry condition for one minute. Than the specified quantity of water was then added during mixing. Further required quantity of SP was then added for meeting the desired workability. Workability of fresh concrete was measured by slump test immediately after mixing. The slump value was lying in between 20 mm to 46 mm. For testing hardened properties, the concrete specimens were cast in steel mould and compacted by using table vibrator, demolded after 24 hours, and cured under tap water for 7, 28 and 90 days. The specimens were removed from water after the specified curing period and wiped out excess water from the surface. The specimens were tested in compression testing machine to know the compressive and split tensile strength and flexural testing machine to know the flexural strength. The compressive strength of the concrete was determined by using (150×150×150 mm) cube specimens. Cylindrical specimens of 100 mm diameter×200 mm height were used to determine the split tensile strength. Flexural strength of the prism was determined by using (100×100×500 mm) specimens. The hardened concrete properties are evaluated at 7, 28 and 90 days of curing.

3. Results and discussions

The workability of fresh concrete mixture was measured by slump test. Fresh concrete mix was prepared and then slump test was conducted immediately after the mixing. The slump values of concrete mixtures obtained experimentally are given in Tables 6 for *w/b* 0.375, 0.325 and 0.275. The characteristics of the hardened concrete specimens were obtained by testing the specimens at the specified time that is 7 days, 28 days, and 90 days. The compressive strength, flexural strength and split tensile strength test are conducted to know the hardened concrete properties of the specimen. The compressive strength was computed by using the expression: $f_{ck}=P/B^2$ for cubes. Where, f_{ck}=Compressive strength in MPa, P=maximum applied load in Newton and B=Size of the cube specimen in mm. The split tensile strength was computed by the expression: $f_{sp}=2P/\pi Ld$. Where, f_{sp}=the split tensile strength in MPa, P=maximum compressive load on the cylinder in Newton, L=length of the cylinder in mm and d=diameter of the cylinder in mm. The flexural strength was computed using the expression: $f_b=PL/BD^2$ Where, f_b=flexural strength in MPa, P=maximum applied load (N), L=Span length in mm, B=width of the specimen in mm and D=depth of the specimen in mm.

Table 7 The summary of compressive strength test results

Mix Identification	7 days compressive strength (MPa)	Change in strength wrt corresponding control specimen (%)	28 days compressive strength (MPa)	Change in strength wrt corresponding control specimen (%)	90 days compressive strength (MPa)	Change in strength wrt corresponding control specimen (%)
M1S0R0	42.30	0	56.25	0	65.88	0
M1S0R20	43.36	2.50	58.50	4.00	67.40	2.31
M1S5R15	47.50	12.29	60.60	7.73	68.45	3.90
M1S10R10	53.80	27.19	64.35	14.40	72.35	9.82
M1S15R5	46.85	10.76	58.35	3.73	67.48	2.43
M1S20R0	43.58	3.02	57.60	2.40	66.55	1.02
M2SORO	54.25	0	64.15	0	72.13	0
M2S0R20	55.66	2.60	65.85	2.65	73.15	1.41
M2S5R15	61.08	12.60	70.40	9.74	78.45	8.76
M2S10R10	65.80	21.30	73.25	14.18	81.30	12.71
M2S15R5	63.50	17.05	71.95	12.16	79.28	9.91
M2S20R0	58.11	7.12	68.40	6.63	76.50	6.10
M3SORO	63.31	0	72.45	0	79.25	0
M3S0R20	67.45	6.54	76.80	6.00	83.25	5.04
M3S5R15	71.42	12.81	79.45	9.70	85.25	7.57
M3S10R10	72.78	14.96	81.12	11.90	87.23	10.10
M3S15R5	73.45	16.02	84.12	16.11	89.25	12.62
M3S20R0	66.58	5.16	75.46	4.15	82.39	3.90

3.1 Compressive strength

The compressive strength test was performed on 150 mm cube specimens at the age of 7, 28 and 90 days. Three specimens were tested at each testing age and the average strength results of concrete mixes M1, M2 and M3 for *w/b* 0.375, 0.325 and 0.275 are presented in Table 7. It is observed from Table 7, in M1series, all concrete mixes M1S0R20, M1S5R15, M1S10R10, M1S15R5 and M1S20R0 exhibited higher compressive strength than the control specimen (M1S0R0). The compressive strength of control specimen M1S0R0, at 7, 28 and 90 days are 42.30 MPa, 56.25 MPa and 65.88 MPa respectively, whereas the compressive strength of M1S10R10, is 53.80 MPa, 64.35 MPa and 72.35 MPa respectively, the gain in compressive strength with respect to the corresponding control specimen is 27.19%, 14.40% and 9.82% respectively. The concrete mix M1S10R10 achieved the highest compressive strength than other mixes. In this investigation, early strength enhancement is considered from the age of 7 to 28 days, the gain in strength is higher as compared to the later age (90 days) strength. In M2 series also, the result of all concrete mixes i.e., M2S0R20, M2S5R15, M2S10R10, M2S15R5 and M2S20R0 exhibited higher compressive strength as compared to the control specimen (M2S0R0). The compressive strength of control specimen M2S0R0 at 7, 28 and 90 days are 54.25 MPa, 64.15 MPa and 72.13 MPa respectively, whereas the compressive strength of M2S10R10 is 65.80 MPa, 73.25 MPa and 81.30 MPa respectively, the gain in compressive strength with respect to the corresponding control specimen is 21.30%, 14.18% and 12.71% respectively. In M2 series, with reduced *w/b* i.e., 0.325 and due to different combination of silpozz and RHA improves the compressive strength of concrete with respect to M1 specimen. Similarly in M3 series, the compressive strength of all concrete mixes i.e. M3S0R20, M3S5R15, M3S10R10, M3S15R5 and M3S20R0 exhibited higher strength as compared to control specimen (M3S0R0). The compressive strength of control specimen M3S0R0 at 7, 28 and 90 days are 63.31 MPa, 72.45 MPa and 79.25 MPa respectively, whereas the compressive strength of M3S15R5 is 73.45 MPa, 84.12 MPa and 89.25 MPa respectively, the gain in compressive strength with respect to the corresponding control specimen is 16.02%, 16.11% and 12.62% respectively. With reduced *w/b* i.e., 0.275 and due to different combination of silpozz and RHA improves the compressive strength of concrete with respect to M1 and M2 specimens. It is observed that, the gain in compressive strength is more in early age as compared to the later age. For the control mix, the strength enhancement should be principally dependent on the rate of OPC hydration. In the case of other mixes containing silpozz and RHA, their strength enhancement should be dependent on the rate of OPC hydration as well as the reaction between silpozz, RHA and calcium hydroxide, $Ca(OH)_2$. Therefore, the influence of the silpozz and RHA, on the strength enhancement relative to the control mix could be quantified. As all specimens concerned, the maximum strength is observed in M3S15R5 specimen. The gain in strength with respect to M1S0R0 after 7, 28 and 90 days is 73.64%, 49.54% and 35.47% respectively.

The graphical representation of compressive strength for concrete mixes M1 with *w/b* 0.375 versus age in days is shown in Fig. 3 and the compressive strength of concrete mixes (M1) for different age of curing is shown in Fig. 4. It is observed that, as curing period increases the compressive strength of all concrete specimen increases. It is also observed that the gain in strength is more from 7 to 28 days as compared with 28 to 90 days. The early age enhancement of strength is due to the combination of high end superplasticiser, silpozz and RHA. The compressive strength of all concrete mixes prepared by replacement of cement with different percentage of silpozz and RHA is higher as compared to the control mix (M1S0R0). The cement replacement with 10% of silpozz and 10% of RHA, gives maximum strength as compared to other.

The graphical representation of compressive strength for concrete mixes M2 with *w/b* 0.325 versus age in days is shown in Fig. 5 and the compressive strength of concrete mixes (M2) for different age of curing is shown in Fig. 6.

It is observed that, as curing period increase the compressive strength of all concrete specimen increases. The same trend is also observed as the concrete mix M1. The reduced *w/b* and increasing super plasticiser dose enhance the early age compressive strength of concrete. The maximum percentage of increase in compressive strength w.r.t control specimen (M2S0R0) is observed in M2S10R10 specimen at all age, whereas the minimum percentage of increase in strength is observed in M2S0R20 specimen. The results demonstrate that the inclusion of silpozz and RHA as partial OPC replacement provide greater strength enhancement.

The graphical representation of compressive strength for concrete mixes M3 with *w/b* 0.275

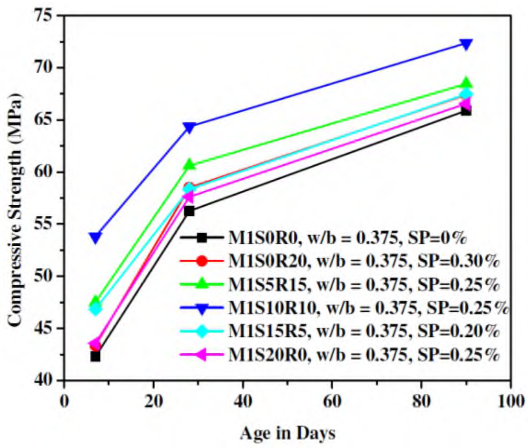

Fig. 3 Compressive strength versus age for mix M1

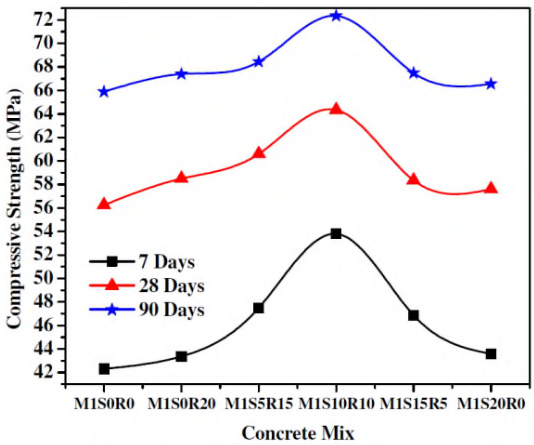

Fig. 4 Compressive strength versus concrete mix (M1)

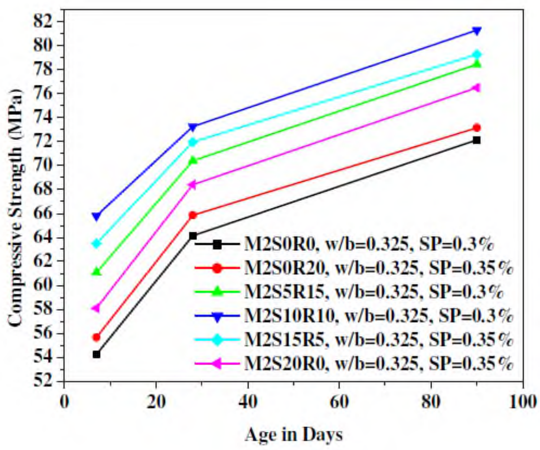

Fig. 5 Compressive strength versus age for mix M2

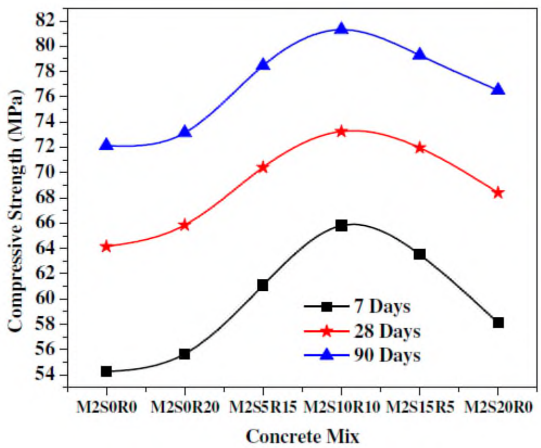

Fig. 6 Compressive strength versus concrete mix (M2)

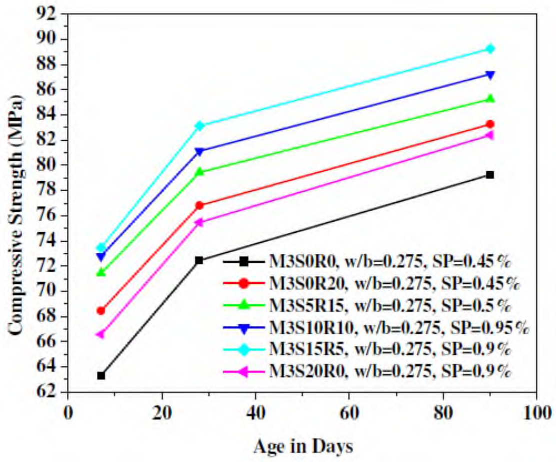

Fig. 7 Compressive strength versus age for mix (M3)

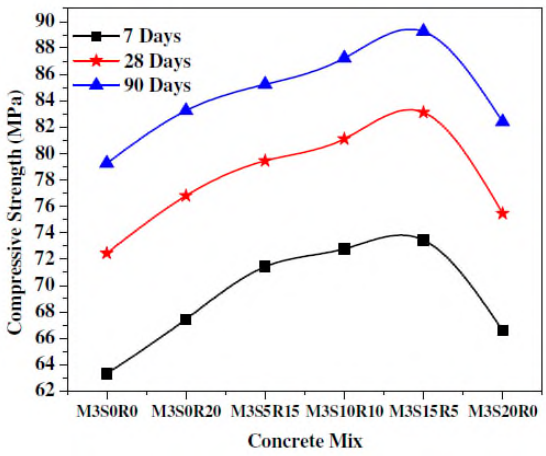

Fig. 8 Compressive strength versus concrete mix (M3)

versus age in days is shown in Fig. 7. The compressive strength of concrete mixes (M3) for different age of curing is shown in Fig. 8. The compressive strength increases rapidly at early age and becomes maximum for specimen M3S15R5 as compared to the control specimen M3S0R0. According to Johri *et al*. (2011), the greater early strength development could be attributed to the combined influence of acceleration in OPC hydration and the “microfiller effect” as part of the cement was replaced by SF. According to Detwiler and Mehta (1989) and Goldman and bentur (1993), due to extreme fineness, SF particles provide nucleation sites for calcium silicate hydrate, C-S-H, and $Ca(OH)_2$. In addition, the ultrafine SF particles act as microfiller, densifying the trasition zone, thus, enhancing the matrix-aggregate bond and increasing the concrete strength. According to Hanehara *et al*. (1998), the onset of pozzolanic reaction in a cement-SF system normally takes place after 3-4 days, and this is confirmed by the results of the present study. It is observed from all series that the compressive strength of specimen for series M1, M2 is more at 10% replacement of silpozz and 10% replacement of RHA, whereas for series M3 is more at 15% silpozz and 5% RHA. The results indicate that as *w/b* decreases, silpozz plays significant role for enhancement of concrete strength.

3.2 Split tensile strength

In this study, the split tensile strength test was performed on cylinder specimens at the age of 7, 28 and 90 days. Three specimens were tested at each testing age and the average strength results of concrete mixes for *w/b* 0.375, 0.325 and 0.275 are presented in a Table 8. It is observed from Table 8, in M1series, all concrete mixes M1S0R20, M1S5R15, M1S10R10, M1S15R5 and M1S20R0 exhibited higher split tensile strength than the control specimen (M1S0R0). The split tensile strength of control specimen M1S0R0 at 7, 28 and 90 days are 3.41 MPa, 4.35 MPa and 4.85 MPa respectively, whereas for specimen M1S10R10 is 3.79 MPa, 4.68 MPa and 5.22 MPa respectively. The gain in split tensile strength with respect to the corresponding control specimen is 11.14%, 7.60% and 7.60% respectively. The concrete mix M1S10R10 achieved the highest split tensile strength than other mixes.

Table 8 The summary of split tensile strength results

Mix Identification	7 days split tensile strength (MPa)	Change in strength wrt corresponding control specimen (%)	28 days split tensile strength (MPa)	Change in strength wrt corresponding control specimen (%)	90 days split tensile strength (MPa)	Change in strength wrt corresponding control specimen (%)
M1S0R0	3.41	0	4.35	0	4.85	0
M1S0R20	3.48	2.05	4.47	2.80	4.98	2.68
M1S5R15	3.58	5.00	4.55	4.60	5.10	5.20
M1S10R10	3.79	11.14	4.68	7.60	5.22	7.60
M1S15R5	3.64	6.70	4.62	6.20	5.15	6.20
M1S20R0	3.52	3.20	4.52	4.00	5.05	4.10
M2SORO	3.81	0	4.52	0	5.21	0
M2S0R20	3.85	1.05	4.72	4.42	5.45	4.60
M2S5R15	3.95	3.67	4.78	5.70	5.58	7.10
M2S10R10	4.35	14.20	5.10	13.00	5.91	13.44
M2S15R5	4.20	10.23	4.92	9.00	5.71	9.60
M2S20R0	4.05	6.30	4.85	7.30	5.65	8.00
M3SORO	4.65	0	5.54	0	6.08	0
M3S0R20	4.76	2.36	5.72	3.25	6.18	1.64
M3S5R15	4.95	6.45	5.92	6.80	6.38	5.00
M3S10R10	5.05	8.60	5.98	8.00	6.55	7.73
M3S15R5	5.10	9.60	6.02	8.60	6.67	9.70
M3S20R0	4.91	5.60	5.84	5.42	6.25	2.80

In M2 series, all concrete mixes M2S0R20, M2S5R15, M2S10R10, M2S15R5 and M2S20R0 exhibited higher split tensile strength than the control specimen (M2S0R0). The split tensile strength of control specimen M2S0R0 at 7, 28 and 90 days are 3.81 MPa, 4.52 MPa and 5.21 MPa respectively, whereas for specimen M2S10R10 is 4.35 MPa, 5.10 MPa and 5.91 MPa respectively. The gain in split tensile strength with respect to the corresponding control specimen is 14.20%, 13.00% and 13.44% respectively. In M2 series, with reduced *w/b* i.e., 0.325 and due to different combination of silpozz and RHA enhance the split tensile strength of concrete with respect to M1 series. Similarly in M3 series, all the mixes M3S0R20, M3S5R15, M3S10R10, M3S15R5 and M3S20R0 exhibited higher split tensile strength than the control specimen (M3S0R0). The split tensile strength of control specimen M3S0R0 at 7, 28 and 90 days are 4.65 MPa, 5.54 MPa and 6.08 MPa respectively, whereas for specimen M3S15R5 is 5.10 MPa, 6.02 MPa and 6.67 MPa respectively. The gain in split tensile strength with respect to the corresponding control specimen is 9.60%, 8.60% and 9.70% respectively.

The graphical representation of split tensile strength of concrete versus age in days for mixes M1 is shown in Fig. 9 and split tensile strength of concrete mixes (M1) for different age of curing is shown in Fig. 10. It is observed that, as age of curing increases the split tensile strength of concrete increases in all concrete mixes. The rate of increment of strength is more from 7 to 28 days as compared with 28 to 90 days. The maximum split tensile strength observed in M1S10R10 specimen as compared to control specimen M1S0R0.

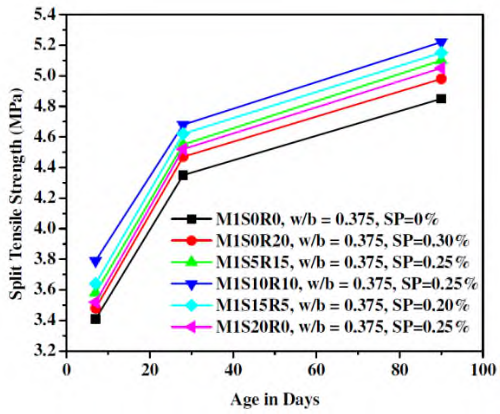

Fig. 9 Split tensile strength versus age for mix M1

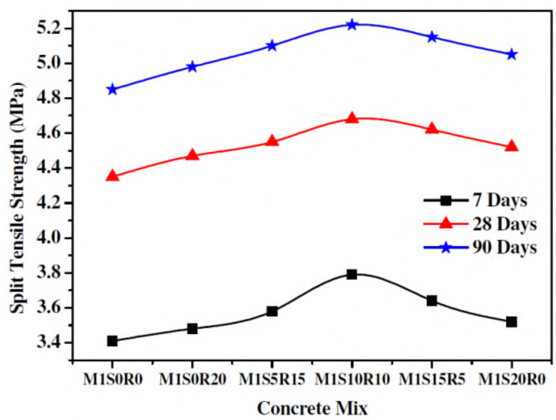

Fig. 10 Split tensile strength versus concrete mix (M1)

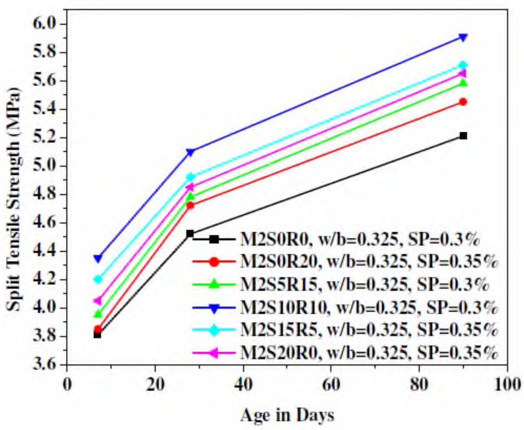

Fig. 11 Split tensile strength versus age for mix M2

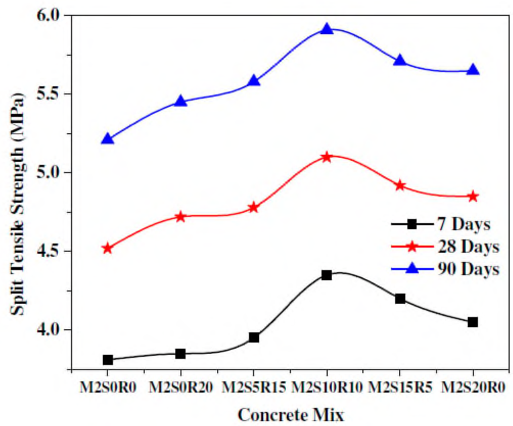

Fig. 12 Split tensile strength versus concrete mix (M2)

The graphical representation of split tensile strength of concrete mixes M2 versus age in days is shown in Fig. 11 and the split tensile strength of concrete mixes (M2) for different age of curing is shown in Fig. 12**.** It is observed that, as age of curing increases the split tensile strength of concrete increases in all concrete mixes. As combination of silpozz and RHA concerned, 10% silpozz and 10% RHA gives maximum split tensile strength at all ages.

The graphical representation of split tensile strength of concrete mixes M3 versus age in days is presented in Fig. 13 and the split tensile strength of concrete mixes for different age of curing is presented in Fig. 14. It is observed that, the split tensile strength is increasing gradually in all age than control specimen (M3S0R0). As *w/b* decreases, 15% silpozz and 5% RHA gives maximum split tensile strength than all other specimens.

3.3 Flexural strength

In this study, the flexural strength test was performed on prism specimens at the age of 7, 28 and 90 days. Three specimens were tested at each testing age and the average strength results of concrete mixes for *w/b* 0.375, 0.325 and 0.275 are presented in a Table 9.

In M1 series, all concrete mixes M1S0R20, M1S5R15, M1S10R10, M1S15R5 and M1S20R0 exhibited higher flexural strength than the control specimen (M1S0R0). The test results show that the flexural strength of control mix M1S0R0 at 7, 28 and 90 days is 4.7, 6.25 and 6.8 respectively, whereas for mix M1S10R10 is 5.12, 6.78 and 7.23 respectively, the gain in flexural strength with respect to the corresponding control mix is 9%, 8.50% and 6.32% respectively. The concrete mix M1S10R10 achieved the highest flexural strength than other mixes. In M2 series, all the concrete mixes M2S0R20, M2S5R15, M2S10R10, M2S15R5 and M2S20R0 exhibited higher flexural strength than the control specimen (M2S0R0). The flexural strength of control mix M2S0R0 at 7, 28 and 90 days are 5.15 MPa, 6.45 MPa and 7.05 MPa respectively, whereas the flexural strength of M2S10R10 is 5.64 MPa, 6.92 MPa and 7.75 MPa respectively, the gain in flexural strength with respect to the corresponding control specimen is 9.50%, 7.30% and 10.00% respectively. For concrete mix M3, and for *w/b* 0.275, the flexural strength test results of all mixes are higher as compared to the control specimen (M3S0R0). The flexural strength results of mix M3S15R5 at 7, 28 and 90 days are 6.54, 7.55 and 8.38 respectively, whereas the flexural strength of control mix (M3S0R0) is 6.12, 6.95 and 7.54 respectively. The gain in flexural strength with respect to the corresponding control specimen is 7.00%, 8.60% and 11.14% respectively. This represents that, the mix M3S15R5 achieved the highest strength than other mixes. It is observed from the test results that, early age flexural strength of concrete mix is more in M1 series. As *w/b* decreases, later age flexural strength is more as observed in M3 series.

The graphical representation of flexural strength of concrete mixes (M1) versus age in days is shown in Fig. 15 and the flexural strength of concrete mixes (M1) for different age of curing is shown in Fig. 16. It is observed that, as age of curing increases, the flexural strength of concrete increases in all the concrete mixes. The rate of increment of strength is more from 7 to 28 days as compared with 28 to 90 days. The graphical representation of flexural strength of concrete mixes (M2) versus age in days is shown in Fig. 17 and the flexural strength of concrete mixes (M2) for different age of curing is shown in Fig. 18. It is observed that, as age of curing increases, the flexural strength of concrete specimen increases.

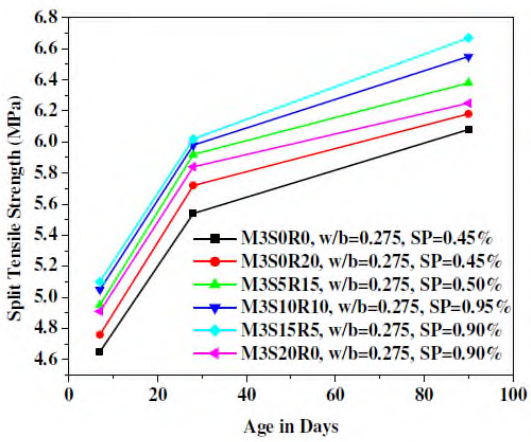

Fig. 13 Split tensile strength versus age for mix M3

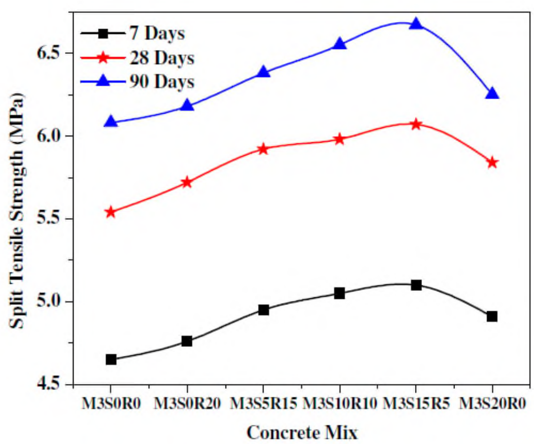

Fig. 14 Split tensile strength versus concrete mix (M3)

Table 9 The summary of flexural strength results

Mix Identification	7 days flexural strength (MPa)	Change in strength wrt corresponding control specimen (%)	28 days flexural strength (MPa)	Change in strength wrt corresponding control specimen (%)	90 days flexural strength (MPa)	Change in strength wrt corresponding control specimen (%)
M1S0R0	4.70	0	6.25	0	6.80	0
M1S0R20	4.80	2.13	6.38	2.10	6.95	2.20
M1S5R15	4.95	5.32	6.55	4.80	7.10	4.41
M1S10R10	5.12	9.00	6.78	8.50	7.23	6.32
M1S15R5	4.98	6.00	6.58	5.30	7.18	5.60
M1S20R0	4.88	3.82	6.45	3.20	7.03	3.38
M2SORO	5.15	0	6.45	0	7.05	0
M2S0R20	5.25	1.90	6.54	1.40	7.24	2.70
M2S5R15	5.31	3.10	6.68	3.50	7.43	5.40
M2S10R10	5.64	9.50	6.92	7.30	7.75	10.00
M2S15R5	5.45	6.00	6.78	5.12	7.54	7.00
M2S20R0	5.32	3.30	6.62	2.64	7.35	4.30
M3SORO	6.12	0	6.95	0	7.54	0
M3S0R20	6.25	2.12	7.24	4.20	7.88	4.51
M3S5R15	6.32	3.30	7.35	5.80	8.13	7.82
M3S10R10	6.45	5.40	7.48	7.60	8.28	10.00
M3S15R5	6.54	7.00	7.55	8.60	8.38	11.14
M3S20R0	6.20	1.30	6.98	0.43	7.67	1.72

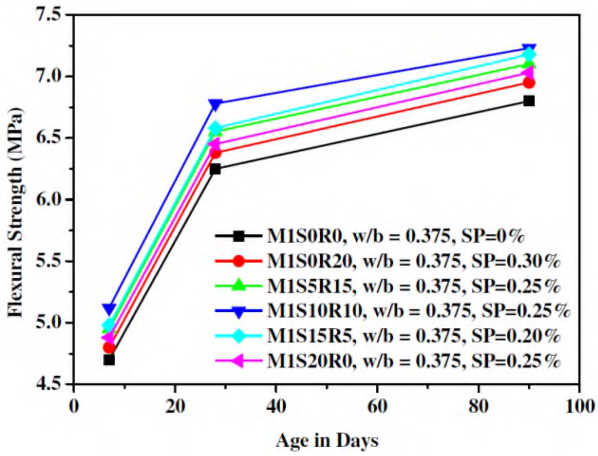

Fig. 15 Flexural strength versus age for mix M1

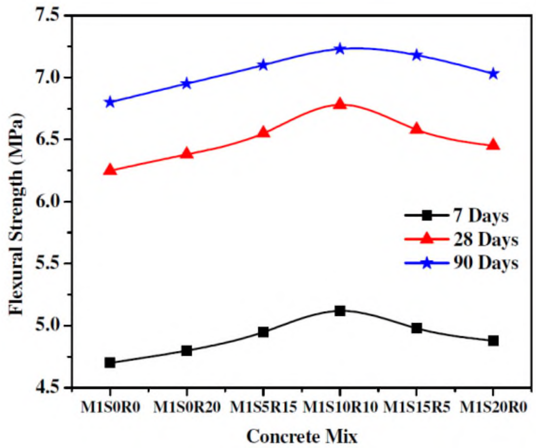

Fig. 16 Flexural strength versus concrete mix (M1)

The flexural strength of all concrete mixes is higher as compared to control specimen. M2S10R10 exhibited highest strength as compared to other mixes.

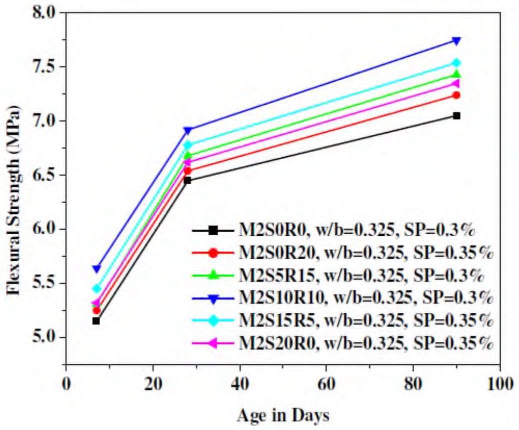

Fig. 17 Flexural strength versus age for mix M2

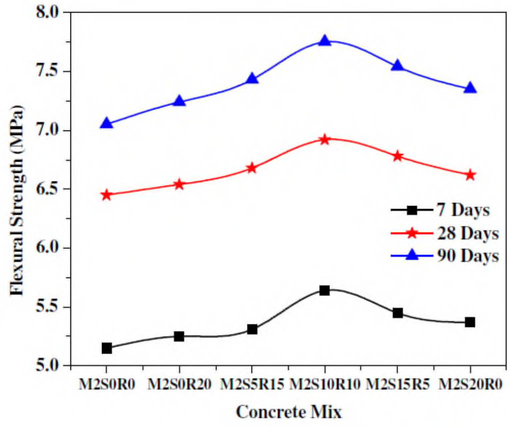

Fig. 18 Flexural strength versus concrete mix (M2)

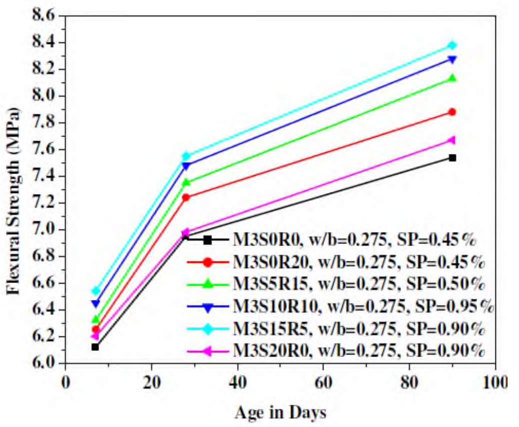

Fig. 19 Flexural strength versus age for mix M3

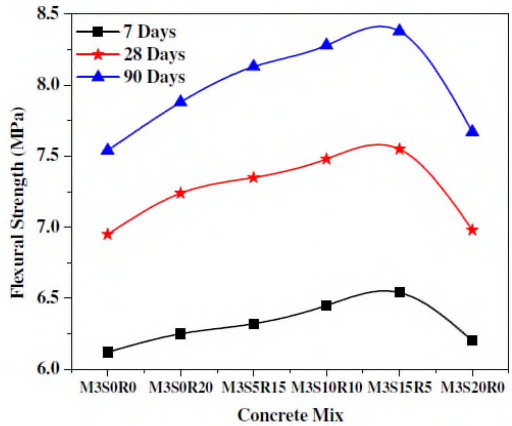

Fig. 20 Flexural strength versus concrete mix (M3)

The graphical representation of flexural strength of concrete mixes M3 versus age in days is presented in Fig. 19 and the flexural strength of concrete mixes (M3) for different age of curing is shown in Fig. 20. It is observed that, as curing period increases, the flexural strength increases in all concrete mixes. M3S15R5 exhibited highest strength as compared to others. The results show that later age strength is more with age.

3.4 Comparison of test results

The comparison of compressive strength test results of all concrete mixes (M1, M2 and M3) for *w/b* (0.375, 0.325 and 0.275) is presented in Fig. 21. It is observed that, the compressive strength of all concrete mixes is higher for *w/b* 0.275. As concrete mixes M1, M2 and M3 concerned, the mix M3S15R5 exhibited highest strength as compared to others.

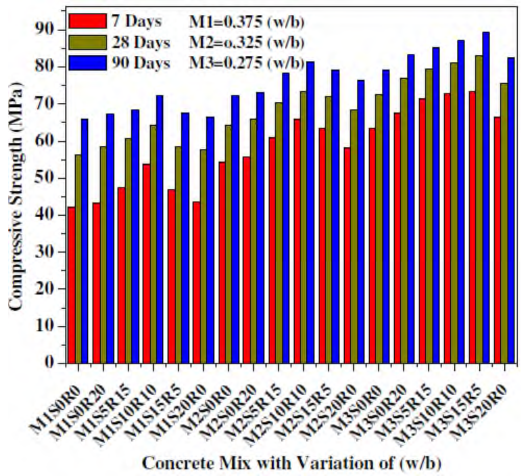

Fig. 21 Comparison of compressive strength for all concrete mixes (M1, M2 and M3)

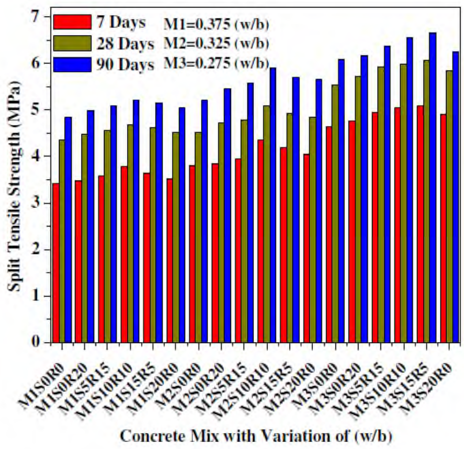

Fig. 22 Comparison of split tensile strength for all concrete mixes (M1, M2 and M3)

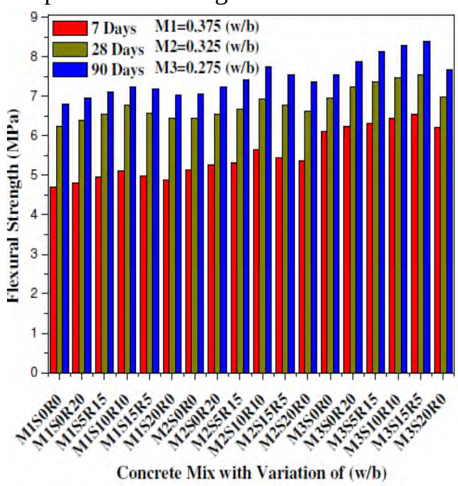

Fig. 23 Comparison of flexural strength for all concrete mixes (M1, M2 and M3)

The comparison of split tensile strength test results of all concrete mixes (M1, M2 and M3) for *w/b* (0.375, 0.325 and 0.275) is presented in Fig. 22. As *w/b* ratio concerned, the split tensile strength of all concrete mixes is higher for *w/b* 0.275. As concrete mixes (M1, M2 and M3) concerned, M3S15R5 exhibited highest split tensile strength as compared to others.

The comparison of flexural strength test results of all concrete mixes (M1, M2 and M3) for *w/b* (0.375, 0.325 and 0.275) is presented in Fig. 23. As *w/b* concerned, the flexural strength of all concrete mixes is higher for *w/b* 0.275. As concrete mixes concerned, M3S15R5 exhibited highest flexural strength as compared to other mixes. It is concluded that as *w/b* decreases, silpozz plays a significant role to enhance the concrete strength. 15% of silpozz with 5% RHA give maximum strength as compared to others.

4. Conclusions

This paper present the results of an experimental investigation carried out on strength enhancement of concrete mixes using silpozz, RHA and super plasticiser. Eighteen concrete mixes are used in three different series, with *w/b* i.e. 0.375, 0.325 and 0.275 and evaluated the effect of silpozz and RHA on enhancement of concrete strength. The compressive strength, split tensile strength and flexural strength results are presented. Based on the above results the following conclusions may be drawn

1. The fresh concrete results of this research indicate that as *w/b* decreases, super plasticiser dose need to be increased, so as to increase the workability of concrete.

2. As age of curing increases, compressive strength, flexural strength and split tensile strength of concrete increases.

3. The effect of silpozz and RHA enhance the compressive strength, flexural and split tensile strength of concrete at all ages.

4. The strength enhancement of concrete mix prepared with combination of cement, silpozz and RHA is higher as compared to the concrete mix prepared with combination of cement and silpozz or cement and RHA.

5. The strength enhancement of concrete mixes containing silpozz and RHA, is dependent on the rate of OPC hydration as well as the reaction between silpozz, RHA and calcium hydroxide $Ca(OH)_2$. Therefore, the influence of the silpozz and RHA, on the strength enhancement is relatively higher as comparable with control mix.

6. As *w/b* ratio decreases, the compressive strength, flexural strength and split tensile strength of concrete increases at all age.

7. The enhancement of strength at early age is higher as compared to the later age due to presence of high end super plasticiser and microfiller effect of silpozz and RHA.

8. At all age of curing, the strength of all concrete mixes prepared with the different combination of silpozz and RHA is higher than control mix.

9. For water-binder ratio 0.375 and 0.325, the concrete mix containing 80% cement, 10% silpozz and 10% RHA gives maximum compressive strength, flexural strength and split tensile strength.

10. As *w/b* decreases in the concrete mix, and for the maximum strength enhancement, the requirement of silpozz is more than RHA. Hence, for *w/b* 0.275, the concrete mix containing 80% cement, 15% silpozz and 5% RHA gives maximum compressive strength, flexural strength and split tensile strength.

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