APPLICATIONS OF RICE STRAW ASH IN CONSTRUCTION OF RIGID PAVEMENTS

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ABSTRACT:*Rice straw is an agricultural by-product of paddy cultivation whose production is highest among the agro-residues produced in India. Due to high cost involved in the collection of rice straw and in the absence of alternate uses (in countries like India, Indonesia and China), most of the farmers treat it as waste material and resort to field burning even when it is banned by the government of these countries. The open-air burning of rice straw leads to emission of a greenhouse gas like CO_2. However, researchers say that emission of CO_2 due to the burning of rice straw is not taken into consideration for calculating the net amount of greenhouse gases which affects the atmosphere, based on the hypothesis that the CO_2 will be absorbed again by the rice plants during the next cultivation. The present investigation is about utilizing rice straw ash (RSA) produced from open-air burning of rice straw at a temperature of 290 ± 5 0C into the production of pavement quality concrete (PQC) for use in rigid pavements. The probable benefit accrued out of such an initiative would lead to economisation of the rigid pavements, which is about 50% costlier than the conventional bituminous pavements.*

Past works state that, open-air burnt RSA has around 80% silica content which is at par with that of an established pozzolan such as microsilica (MS). While MS has been studied extensively in the past, there was a need to explore the potential of RSA for part replacement of OPC in PQC. With this objective in view, the present study explores the level of part replacement of OPC that may be possible by admixing RSA and MS on an individual basis and also in combination for short term (3, 7 and 28 days). The effects of RSA and MS on compressive strength and hardened density of cementitious mortar were also observed.It was found that OPC can be replaced by RSAup to 10% and by MS up to 7.5% without any loss of compressive strength. The proportion of RSA and MS in concrete mixes was finalized based on the test results of cementitious mortar. Different dosages of HRWR for concrete mixeswere decided based on the slump test. The compressive, flexural and split tensile strength tests of the M40 grade admixed concrete were found out, and various equationsbetween these parameters were established. The admixing of RSA and MS increased the various strengths of concrete up to 2% and up to 42%, respectively as compared to the control concrete for all curing ages.

Key Words: Rice straw ash, Micro silica, Rigid pavement

I. INTRODUCTION

The usages of sustainable materials which can partially or fully replacecementin concrete, will not only improve the performance of concrete but will also decrease the environmental problems and the cost of concrete. Mineral admixtures are those materials which in powdered form are added in concrete before or during mixing to improve its quality. They affect the properties of hardened cement concrete. Mineral admixtures used in the appropriate amount improve workability and sulphate resistance. They also decrease the alkali-aggregate reaction, permeability and heat of hydration . They are generally of two types: cementitious materials (rich in calcium oxide content) and pozzolans (siliceous or siliceous and aluminous materials). As the name suggest, cementitious materials are those materials which possess the properties of cement. Pozzolans are those materials which have very little or no cementitious value but when they are used with cement in finely divided form and in the presence of moisture, form cementitious compounds. Some of the cementitious materials researched are ground granulated blast furnace slag (GGBFS), hydraulic hydrated lime etc. and the examples of pozzolans are diatomaceous earth, microsilica, fly ash, opaline cherts, pumicites, shales, rice husk ash, sugarcane bagasse ash etc. Rice straw ash (RSA) and microsilica (MS) are thepozzolans which have been studied in this research for their effects on properties of concrete. Microsilica also known as silica fume, is a by-product obtained during the production of silicon metal and ferrosilicon alloys.

In the production of silicon metal and ferrosilicon alloys, the highly pure quartz is reduced using carbonaceous materials in electric arc furnaces. The by-product of this carbothermic reduction is microsilica. It is an ultrafine material mainly consisting of non- crystalline silicon dioxide.

India is the largest producer of rice in the world behind China. Rice production in India and Asia is around 20% and 90% respectively of total rice production inthe world.

. The production of rice in India has increased from 107.7 million tonnes in 2002 to 168.5 million tonnes in 2017. The cultivation of rice in India is mainly done in the Kharif season with a small contribution in Rabi season.

India is a developing country as per the World Trade Organization (WTO). Around 2/3rd of the total population of India lives in rural areas. According to World Bank, per capita income of India was 1800 USD in the year 2017 which was way behind per capita income of more developed countries like USA(59,501 USD), Singapore (54,530 USD),

South Korea (28,380 USD) and China (16,660USD). To overcome this huge deficit in per capita income and shed the tag of 'developing country' by the year 2047, Government of India has taken several steps to improve the infrastructure of the country like better transportation, housing for the entire population, better education and health facilities etc. Therefore, in India, use of alternative construction material which is cheap as well as abundantly available would allow for the construction of more rigid pavements in a given budget. Rice straw is cheap as well as abundantly available in India. Therefore, usage of rice
straw ash wouldnot only decrease theconstruction cost of the rigid pavements but may also improve its quality. In the few studies done in the past on usage of rice straw ash as a partial replacement of cement in general concrete, the ash was produced under controlled burning of rice straw at high temperatures, and then the ash was ground to finer size [33], . It can be concluded from some of the previous studies that the production of rice straw ash using enhanced burning techniques increases its qualities.However, the enhanced techniques (burning at high temperatures and mechanical grinding) used for the production of rice straw ash can be costly and are not readily available everywhere. The absence of sufficient literature on the potential uses of RSA as a pozzolan in PQC presented many challenges which gave the urge for this investigation. Therefore, this thesis explores the production of M40 grade PQC with new cementitious material obtained by admixing RSA as pozzolan (when produced as a result of uncontrolled burning and without any further processing like pulverization) with OPC and comparing the results with the cementitious material of an established pozzolan like microsilica. Simultaneously, results of admixing both these pozzolans with OPC were compared with the control mix produced with OPC alone. Towards meeting these objectives, the present study was divided into eight segments as itemized below:

OBJECTIVES

1. To investigate the material properties of rice straw ash, microsilica, OPC, aggregates and chemical admixture.
2. To study the physical properties of cement pastes of OPC admixed with rice straw ash and microsilica and investigate their mineralogical behaviour.
3. To investigate the compatibility of chemical admixture with cement paste admixed with rice straw ash and microsilica.
4. To evaluate the physical properties of mortar of OPC admixed with rice straw ash and microsilica.
5. To find the right proportion of materials by concrete mix design for M40 grade PQC.
6. To study the mechanical properties of concrete of OPC admixed with varying proportions of rice straw ash and microsilica and to evaluate their mineralogical as well as microstructural behaviour.
7. To study the durability properties of concrete of OPC admixed with RSA and MS.
8. To assess the structural design and rate analysis of rigid pavements of different concrete mixes for cost comparison

II. MATERIALS USED

In this experimental program, the primary stage includes the preliminary research on selecting the raw materials.

AGGREGATE

Basalt based crushed coarse aggregates of a maximum nominal size of 20 mm and 10 mm as per IS 383 and IRC 44] were obtained from Dalla quarry in Sonebhadra district of the state of Uttar Pradesh, India.

Riverbed sand was used as fine aggregate conforming to Zone II as per IS 383 and was obtained from Chopan quarry in Sonebhadra district of the state of Uttar Pradesh, India.

CEMENT, RICE STRAW ASH AND MICROSILICA

The cement utilized was OPC of 43 grade confirming to IS 8112 [252]. 920D- grade microsilica was used which was obtained from Elkem South Asia Pvt. Ltd. Rice straw was obtained from the agricultural farm of the Banaras Hindu University. It was burnt in the open air without any enhanced burning technique. The burning temperature of rice straw was around 290
± 5 oC as was measured by an infrared thermometer.

It was comparable to the temperature at which the combustion of most types of wood take place (300 oC) . The open air burning of rice straw leads to emission of greenhouse gases like CO2, CO, CH4 and N2O .

CHEMICAL ADMIXTURE AND WATER

The decrease in workability due to the incorporation of RSA and MS was compensated by the usage of sulphonated naphthalene polymer-based high range water reducer (HRWR). Conplast SP430 HRWR was procured from Fosroc Chemicals (India) Pvt Ltd. The datasheet about the characteristics of Conplast SP430 superplasticizer as obtained from the supplier is given in Table 4.6. Potable water was used for mixing and curing as per IS 456. Its temperature was maintained at 27 ± 2 0C.

III. EXPERIMENTAL STUDY

The physical properties that concrete displays upon the application of forces are known as mechanical properties. The mechanical strength of concrete signifies the maximum amount of stresses it can withstand. The concrete having high strength can be associated with good quality. Pavement Quality Concrete (PQC) is a concrete having sufficient quality such that it can be used as the surfacing on rigid pavements. In the present study, PQC was designed for grade of M40. The compressive, flexural and split tensile strength of the M40 grade concrete admixed with RSA and MS were found out and various equations between these parameters were established. Also, the mineralogical characteristics of concrete were studied by XRD analysis while microstructural characteristics of concrete were observed by SEM as well as petrographyanalysis.

MIX PROPORTIONS FOR TESTING ON CEMENT CONCRETE

In the previous chapter, it was concluded that the compressive strength of mortar admixed with RSA rises up to 5% replacement of OPC (R5) and then decreases on further replacement. The compressive strength at 10% replacement was lower than the strength at 5% replacement but was higher than the control mix R0 (100% OPC). Mortar of mix R5 (5% RSA) was already showing improved strength properties while properties of mortar of mix R10 were at the borderline. Therefore only mix R10 (10% RSA) was selected for further testing based on the hypothesis that concrete of mix R5 would have shown improved mechanical and durability properties while there was uncertainty about the properties of concrete of mix R10. To study the effect of admixing MS on mechanical and durability properties of concrete, 4 mixes were selected: M2.5 (2.5% MS), M5 (5% MS), M7.5 (7.5% MS) and M10 (10% MS). Similarly, to study the effect of admixing composite of RSA and MS, 4 mixes were selected: R5M5 (5% RSA, 5% MS), R5M7.5 (5% RSA, 7.5% MS),
R10M5 (10% RSA, 5% MS) and R10M7.5 (10% RSA, 7.5% MS).

MIX DESIGN OF M40 GRADE PQC

The w/b ratio was kept fixed at 0.39. The mix design of concrete having characteristic cube compressive strength of 40 MPa at 28 days are given in Table 6.1. The ratio between amount of coarse aggregates and fine aggregates was finalized at 0.65 and 0.35, respectively. The ratio between amount of 20 mm and 10 mm maximum nominal size coarse aggregates was maintained at 0.6 and 0.4 respectively. Based on these ratios, the overall combined gradation of aggregates was verified with the limits specified in IRC 44 [226]. The combined gradation of aggregates is shown in Table 6.2. The reduction in workability was compensated by using superplasticizer. The dosage of HRWR for each
mix (Table 6.1) was decided by slump test, keeping the slump at 50 ± 10 mm.

IV. RESULTS AND DISCUSSION

The results obtained in this research work were presented here.

Compressive Strength

It was observed in the past that admixing of supplementary cementitious materials improvises the compressive strength of cement mortars. The results pertaining to compressive strength of msortar admixed with RSA and MS are given in Table. Figure shows the graphical representation of the effect of different days of curing (3, 7, 28, 60, 90 and 365 days) on compressive strength of different mortar mixes. Table gives the percentage increase or decrease in the compressive strength of different mortar mixes with respect to control mortar (R0) at various ages of curing. Compare the compressive strength of different mortar mixes (at 3, 7, 28, 60, 90 and 365 days of curing respectively) at similar replacement level by RSA and MS. It is to be noted that the compressive strength of mortar of mix R30 (30% RSA) was not conceived because R30 mortar cubes disseminated when kept in water for curing purpose after 24 hours of casting.

Table 5.3 Compressive strength of cement mortar admixed with RSA and MS

Mix	Compressive Strength (MPa)					
	3 days	7 days	28 days	60 days	90 days	365 days
R0	23.67	34.17	43.33	47.33	48	49
R5	25	34.67	45.33	48	49.33	50
R10	24.33	34.33	43.67	47.67	48.33	49.33
R15	19.33	29	35.83	38.33	39	40
R20	18	25	30.67	32	33	33.67
R25	17	24	29.33	30	30.67	31
M2.5	27.33	35.33	49.67	52.33	53	53.67
M5	32.33	37.17	51.17	54.33	55	55.33
M7.5	33.33	38.67	52.67	56.33	57.67	58
M10	23.5	34	47.67	51.17	52.17	53.33
R5M5	26	35.11	47	51	52	53
R5M7.5	29	36.67	50.67	53	53.67	54.33
R10M5	25	35	46	50	51.33	52
R10M7.5	25.67	35.33	46.67	50.5	51.67	52.33

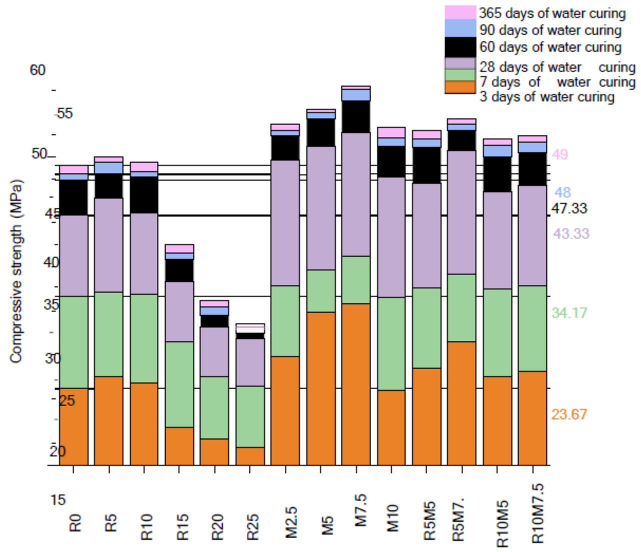

Figure 1. Graphical comparisons between compressive strength of mortar at various ages of water curing

Hardened Density

The hardened density of mortar depends on the amount and specific gravity of the components like cement, mineral admixtures and sand. Since the quantity of sand was constant in all the tested mortars, it can be said that the hardened density depends mainly on cementitious materials and the age of curing. The results of hardened density of mortars at various ages of curing are given in Table and the effects of curing age on the hardened density are shown in Figure below.

Table 5.5 Hardened densityof cement mortar admixed with RSA and MS

Mix	Hardened Density (g/cm³)					
	3 days	7 days	28 days	60 days	90 days	365 days
R0	2.62	3.24	3.53	3.88	3.92	4.73
R5	2.53	3.04	3.38	3.69	3.72	4.13
R10	1.87	2.30	2.64	2.95	2.97	3.75
R15	1.63	2.09	2.40	2.67	2.69	3.19
R20	1.56	1.96	2.26	2.51	2.53	3.10
R25	1.55	1.94	2.23	2.49	2.51	3.07
M2.5	2.56	3.05	3.38	3.74	3.77	4.22
M5	2.48	2.98	3.31	3.64	3.67	3.99
M7.5	2.41	2.92	3.17	3.47	3.50	3.75
M10	1.80	2.28	2.54	2.77	2.80	3.56
R5M5	1.83	2.30	2.58	2.86	2.89	3.63
R5M7.5	1.66	2.15	2.47	2.77	2.80	3.22
R10M5	1.61	2.02	2.33	2.56	2.59	3.18
R10M7.5	1.58	1.98	2.28	2.52	2.55	3.14

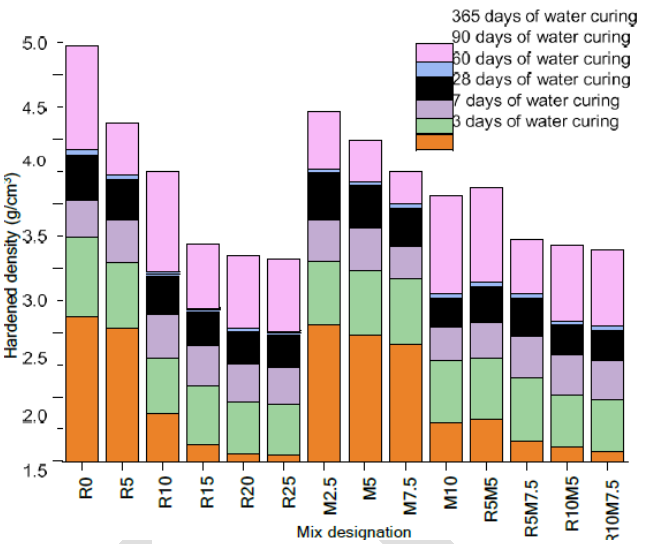

Figure 2. Graphical comparisons between hardened densities of mortar at various ages of water curing

MIX DESIGN OF M40 GRADE PQC

The w/b ratio was kept fixed at 0.39. The mix design of concrete having characteristic cube compressive strength of 40 MPa at 28 days are given in Table. The ratio between amount of coarse aggregates and fine aggregates was finalized at 0.65 and 0.35, respectively. The ratio between amount of 20 mm and 10 mm maximum nominal size coarse aggregates was maintained at 0.6 and 0.4 respectively. Based on these ratios, the overall combined gradation of aggregates was verified with the limits specified in IRC 44 . The combined gradation of aggregates is shown in Table 6.2. The reduction in workability was compensated by using superplasticizer. The dosage of HRWR for each mix (Table 6.1) was decided by slump test, keeping the slump at 50 ± 10 mm.

Table 6.1 Quantity of materials (kg) per m³ of concrete

Mix	Binder			Aggregate	Water	HRWR
	OPC	RSA	MS			
R0	406	-	-	1913	158	1.624
R10	365.4	40.6	-	1913	158	6.09
M2.5	395.85	-	10.15	1913	158	3.654
M5	385.7	-	20.3	1913	158	4.263
M7.5	375.55	-	30.45	1913	158	4.872
M10	365.4	-	40.6	1913	158	5.278
R5M5	365.4	20.3	20.3	1913	158	6.902
R5M7.5	355.25	20.3	30.45	1913	158	8.12
R10M5	345.1	40.6	20.3	1913	158	9.744
R10M7.5	334.95	40.6	30.45	1913	158	10.15

COMPRESSIVE STRENGTH

Most of the times, the results of compressive strength test of concrete are used for determining whether the mixture of concrete meets the stipulations mentioned in thestandard specifications. Compressive strength is one of the fundamental mechanical properties of concrete. The evolution of concrete strength helps in deciding the steps involved in the construction of a rigid pavement and also helps in estimating the time needed for its construction .
The effects of replacement of OPC by MS and RSA on the compressive strength of the M40 grade pavement quality concrete can be observed in Table and Figure below .

Table 6.3 Compressive strength of concrete

Mix	Compressive Strength (MPa)					
	3 days	7 days	28 days	60 days	90 days	365 days
R0	27.55	37.00	48.77	52.00	52.93	53.04
R10	27.59	37.20	48.88	52.52	53.04	53.56
M2.5	28.09	38.00	53.02	55.01	55.70	56.16
M5	28.80	38.80	54.08	55.93	56.50	57.20
M7.5	29.15	39.20	55.01	56.62	57.31	57.66
M10	26.31	32.80	51.07	54.08	55.12	55.93
R5M5	27.91	37.80	50.96	53.38	54.08	55.23
R5M7.5	28.54	38.70	53.61	55.46	56.16	56.62
R10M5	27.64	37.70	48.99	53.04	53.97	54.08
R10M7.5	27.74	37.74	49.22	53.21	54.03	54.60

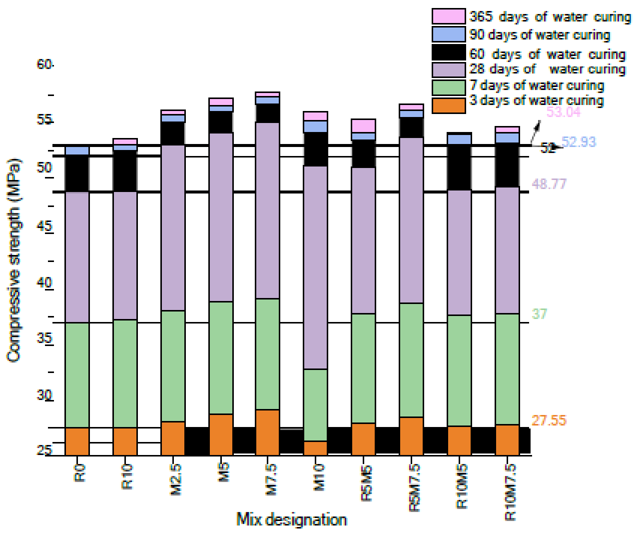

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Figure 3. Graphical comparison of compressive strength of concrete at various ages of water curing

FLEXURAL STRENGTH

Reinforced concrete is by a long shot, much superior to either steel or concreteindependently and is stronger in both compression as well as tension. Plain concrete is weak in tension due to its brittle nature and approximately ten times stronger in compression . Therefore, the tensile strength is preferred over compressive strength for the mixdesign of concrete for rigid pavements (reinforcements are only occasionally used in rigidpavements) however it is not mandatory. The effects of RSA, MS and their composite on flexural strength of the admixedconcrete are given in Table and shown in Figure.The relative percentage changes in flexural strength admixed concrete as compared to control concrete (R0) at various days of curing aregiven in Table and shown in Figure below.

Table 6.5 Flexural strength of concrete

Mix	Flexural Strength (MPa)					
	3 days	7 days	28 days	60 days	90 days	365 days
R0	4	4.8	5.62	6.3	6.4	6.45
R10	4.02	4.9	5.65	6.35	6.45	6.5
M2.5	4.4	5.2	5.9	6.65	6.7	6.8
M5	5	5.8	6.24	6.7	6.8	6.85
M7.5	5.1	6	6.5	6.8	6.9	6.95
M10	3.86	4.6	5.8	6.6	6.65	6.75
R5M5	4.3	5.1	5.75	6.55	6.6	6.7
R5M7.5	4.8	5.7	6.07	6.67	6.73	6.81
R10M5	4.1	4.95	5.67	6.45	6.5	6.6
R10M7.5	4.25	5	5.7	6.5	6.55	6.65

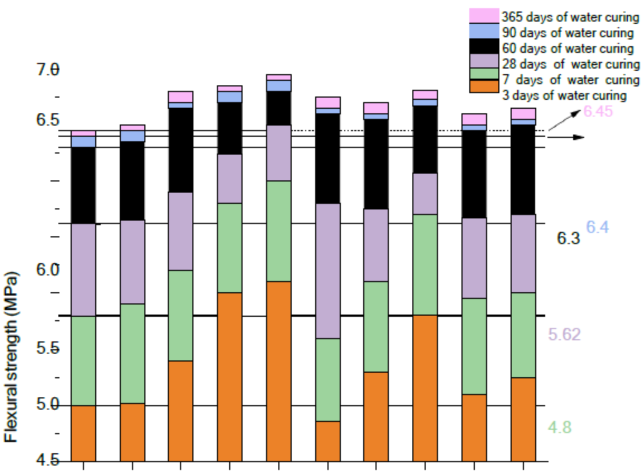

Figure 4 Graphical comparison of flexural strength of concrete at various ages of water curing.

SPLIT TENSILE STRENGTH

In general, there are two types of tensile strength: flexural strength and split tensile strength. In the previous section, the effects of RSA, MS and their composite on flexural strength of concrete was discussed. The effects of admixing RSA and MS on split tensile strength of the concrete are given in Table and shown in Figure The relative percentage changes in split tensile strength of admixed concrete as compared to control concrete (R0) at various ages of curing are given in Table and shown in Figure below.

Table 6.7 Split tensile strength of concrete

Mix	Split Tensile Strength (MPa)					
	3 days	7 days	28 days	60 days	90 days	365 days
R0	2.26	2.97	3.89	4.12	4.2	4.25
R10	2.3	2.99	3.95	4.19	4.25	4.27
M2.5	2.55	3.18	4.17	4.42	4.5	4.52
M5	2.9	3.46	4.53	4.81	4.9	4.93
M7.5	3.2	3.68	4.81	5.09	5.16	5.2
M10	2.47	3.11	4.39	4.65	4.75	4.8
R5M5	2.4	3.11	4.03	4.27	4.35	4.4
R5M7.5	2.87	3.44	4.23	4.75	4.85	4.9
R10M5	2.33	3.01	3.99	4.23	4.3	4.32
R10M7.5	2.37	3.04	4	4.24	4.32	4.35

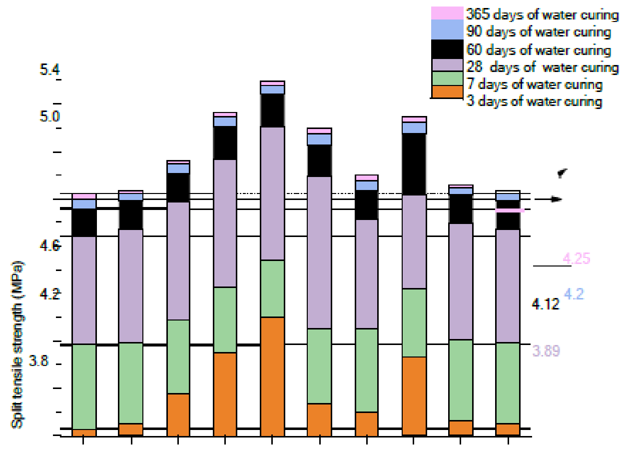

Figure 5 Graphical comparison of split tensile strength of concrete at various ages of water curing.

V. CONCLUSIONS

The experiments which were performed in this chapter to analyse the physical properties of cement paste and mortar admixed with RSA and MS led to the following conclusions:

- Incorporation of RSA and MS increases the water demand of the cement paste.

However, normal consistency of OPC-MS paste was lower than the OPC-RSA paste. Admixing of the combination of RSA and MS to the cement paste lowers the normal consistency as compared to normal consistency of OPC-

RSA and OPC-MS paste. However, normal consistencyof OPC-RSA-MS paste remains greater than the control paste (100% OPC).

• Initial and final setting times of cement paste significantly increases due to admixing of RSA while they remain largely unaffected due to admixing of MS. Theinitial setting time of cement paste decreases while the final setting time of cement paste increases due to admixing of composite of RSA and MS.

• The soundness of cement paste significantly increases due to admixing of RSA while it remains largely unaffected due to admixing of MS. The blending of composite of RSA and MS increases the soundness in cement paste.

• The HRWR dosage for admixed mortar increases linearly with an increase in the proportion of RSA or MS in the admixed paste. The maximum increase in HRWR dosage was due to admixing of composite of RSA and MS, followed by individual admixing of RSA and MS.

OPC can be replaced by RSA up to 10% and MS up to 7.5% by weight of OPC without any loss of compressive strength of mortar at all the ages of curing.

• The compressive strength of mortar of mix M10 (10% MS) was lower than the compressive strengthof control mortar R0 (100% OPC) at early days of curing (3 and 7 days).

• However, it was greater at later days of curing (28 days onwards). Also, the compressive strength of mortar increases due to admixing of (RSA + MS) at all ages of curing.

• The compressive strength of mix R5 (5% RSA), M7.5 (7.5% MS) and R5M7.5 (5% RSA and 7.5% MS) was maximum amongst mixes blended with RSA, MS and composite of (MS + RSA) respectively while the compressive strength of mix M7.5 (7.5% MS) was maximum amongst all the mixes of the current study.

• MS provided more stability to the mortar matrix as compared to RSA (measured in terms of compressive strength).

• The blending of RSA, MS or composite of both decreases the hardened density of the mortar cubes with maximum reduction being due to admixing of MS followedby a composite of (RSA + MS) and RSA.

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