CHAPTER 5:
STUDY ON PHYSICAL PROPERTIES OF CEMENT PASTE AND MORTAR

5.1 GENERAL

The hardened cement paste is formed due to a hydration reaction between Portland cement and water. It mainly constitutes of CSH gel, CAH and portlandite ($Ca(OH)_2$). The microstructure of the hardened cement paste depends upon the composition of the cement particles, w/c ratio, hydration reaction temperature and admixtures (mineral or chemical). Few particles of cement remain dormant during the initial hydration reaction and are responsible for the improvement in the properties of cement paste at later stages. The space between these latent unhydrated cement particles is generally filled by hydration products such as CSH gel and portlandite.

Typically, hardened cement paste consists of two types of pores: capillary pores (10-20 µm size) and gel pores (0.5-5 nm size) [273]. Capillary pores are the empty spaces between the cement particles while gel pores signify the porosity of the CSH gel. Apart from capillary and gel pores, water is also adsorbed on the surface of the CSH gel and is also present in the empty spaces between different layers of CSH gel. However, the water present in the interlayer spaces is not in pure liquid form but ionic form [274]. The water present in these pores is responsible for setting and hardening of the cement paste.

Addition of mineral admixtures improves the properties of hardened cement paste. However, incorporation of mineral admixtures greatly influences the water requirement of the cementitious system [119], [120], [127]. Therefore, water requirement of the fresh cement paste (also known as normal consistency) with various proportions of RSA and MS were found out. In the present chapter, the setting times of the fresh cement paste admixed with RSA and MS were determined. Also, soundness of the various cementitious pastes was found out.

5.2 MIX PROPORTIONS FOR TESTING ON CEMENT PASTE AND MORTAR

Different mixtures containing distinctive amounts of OPC, RSA and MS were set up for testing on cementitious paste and mortar. Blends were prepared by replacing OPC with MS by weight at a consistent interval of 2.5% up to 10% and with RSA by weight at a regular interval of 5% up to 30%, as shown in Table 5.1. The mixtures were also prepared by replacing OPC by weight with the combination of RSA and MS, as shown in Table 5.1. Also, the paste of 100% RSA and 100% MS were prepared for studying their normal consistency only. Other tests like setting times, soundness, compressive strength etc., were not conducted on 100% RSA or 100% MS mixture.

Table 5.1 Mix proportions of cementitious materials

Mix	**Mix Proportion (%, by weight)**		
	OPC	**RSA**	**MS**
R0 (Control)	100	-	-
R5	95	5	-
R10	90	10	-
R15	85	15	-
R20	80	20	-
R25	75	25	-
R30	70	30	-
R100	0	100	-
M2.5	97.5	-	2.5
M5	95	-	5
M7.5	92.5	-	7.5
M10	90	-	10
M100	-	-	100
R5M5	90	5	5
R5M7.5	87.5	5	7.5
R10M5	85	10	5
R10M7.5	82.5	10	7.5

5.3 PHYSICAL PROPERTIES OF CEMENT PASTE

5.3.1 Normal Consistency

The amount of water required for the hydration of cement paste is generally higher in case of admixing of mineral admixtures. The results pertaining to water demand or normal consistency of different mix are given in Table 5.2 and shown in Figure 5.1.

Table 5.2 Normal consistency, setting time and expansion of cement paste and HRWR dosage for cement mortar

Mix	Normal Consistency (%)	Setting Time (min.)		Expansion (mm)	HRWR dosage (%)
		Initial Setting Time	Final Setting Time		
R0	32	155	195	0.79	-
R5	41	161	220	1.13	0.4
R10	46	175	249	1.46	0.6
R15	53	181	271	1.8	0.75
R20	58	208	303	2.14	0.95
R25	63	241	335	2.48	1.20
R30	67	271	355	2.81	1.35
R100	75	-	-	-	-
M2.5	37	160	201	0.8	0.3
M5	40	158	199	0.82	0.35
M7.5	43	155	198	0.83	0.45
M10	44	154	198	0.84	0.56
M100	73	-	-	-	-
R5M5	41	145	217	1.15	0.85
R5M7.5	42.5	139	208	1.17	1.05
R10M5	43.5	155	235	1.49	1.20
R10M7.5	45	149	223	1.5	1.45

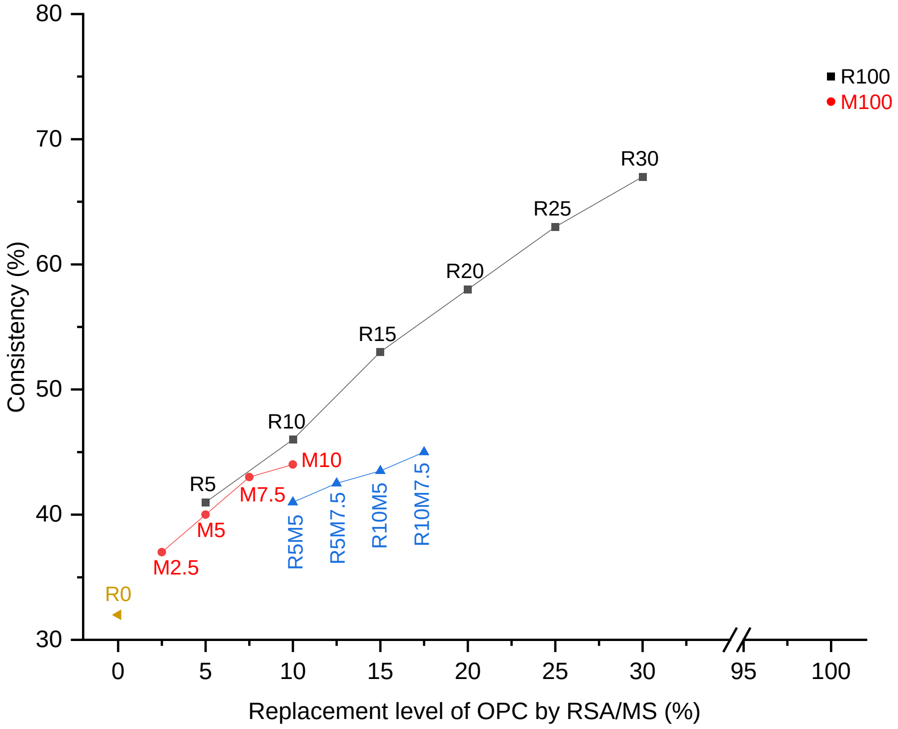

Figure 5.1 Comparison between normal consistency of cement paste of various mixtures

The normal consistency of mix R0 (control), R100 (100% RSA) and M100 (100% MS) turned out to be 32, 75, and 73%, respectively. The normal consistency of OPC-RSA paste, OPC-MS paste and OPC-RSA-MS paste were in the range of 41-67%, 37-44% and 41-45%, respectively. With respect to the water demand of control cement paste (R0), 28% to 109%, 16% to 38% and 28.12% to 40.62% extra water demand were observed in OPC-RSA paste, OPC-MS paste and OPC-RSA-MS paste respectively. This suggests that RSA used in this study is predominantly a hydrophilic compound. The increase in the normal consistency of the cement paste due to incorporation of RSA and MS can be attributed to their finer particle size and increase in the overall surface area of the cementitious particles (Table 4.3).

As per the study by Tobon et al. (2018) [121], specific surface area as compared to the particle size has a more significant influence on water demand of the cementitious paste. However, in the current study, the water requirement was higher in cement paste admixed with RSA as compared to MS even though the specific surface area of the RSA particles was less than MS particles. It was because of the presence of high amount of unburned carbon as found in the TGA analysis of RSA (Figure 4.4). The water requirement of cement paste admixed with a combination of RSA and MS was lower as compared to individual admixing of RSA or MS.

5.3.2 Initial and Final Setting Time

The sudden setting or slow setting of cement paste is generally avoided for construction purposes. In case of the immediate setting of cement paste, the time required for transporting, placing and compacting concrete is insufficient while slow setting delays the duration of the constructional work. The period at which cement paste starts losing its plasticity is generally regarded as its initial setting time while final setting time is the duration at which the cement paste completely loses its mobility. The results pertaining to initial and final setting time of various mix are given in Table 5.2 and shown in Figure 5.2 and Figure 5.3, respectively.

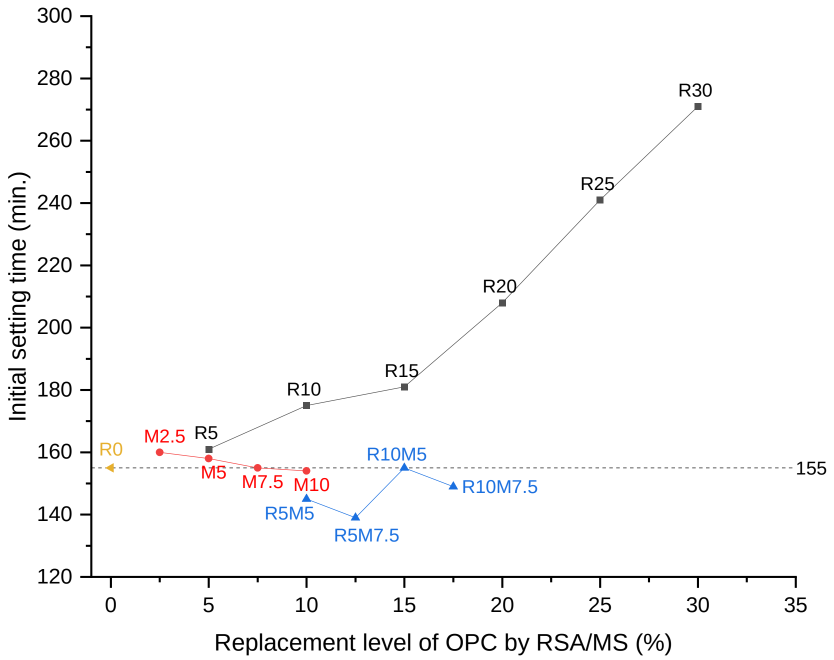

Figure 5.2 Comparison between initial setting times of cement paste of various mixes

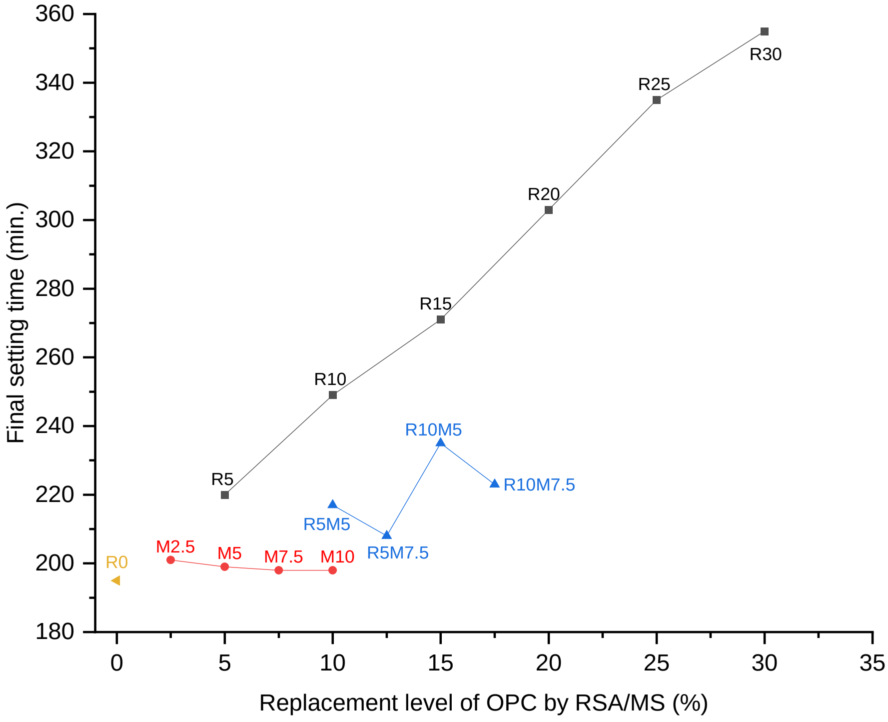

Figure 5.3 Comparison between final setting times of cement paste of multiple mixes

As compared to control cement paste (R0), 3.9% to 74.8% and 12.8% to 82% increase in the initial and final setting time respectively was observed in OPC-RSA paste. The variation in the setting times of OPC-MS paste as compared to control cement paste (R0) was nearly consistent. However, in the case of OPC-RSA-MS paste, 0 to 10.3% decrease in initial setting time and 6.7 to 20.5% increase in final setting time as compared to control cement paste was observed.

The increased setting times of OPC-RSA paste as compared to OPC paste may be attributed to higher water demand of OPC-RSA paste which can be associated with reduction in the rate of hydration reaction and increase in the time required for stiffening of paste. The cement pastes admixed with MS (OPC-MS paste) were able to maintain their setting times due to pozzolanic effect of MS and lower water demand of OPC-MS paste [121]. Similar results on OPC-MS paste were observed by Rao (2003) [275].

The setting times of OPC-RSA-MS paste were lower than the OPC-RSA paste which was as expected due to their lower water demand. However, different patterns were observed in the initial and final setting times of OPC-RSA-MS paste in comparison to OPC paste. Due to the combined pozzolanic effect of MS and RSA (which can be associated with an increase in the rate of hydration reaction), the OPC-RSA-MS paste was able to overcome the adverse effects of high water demand (due to admixing of RSA) thereby causing reduction in the initial setting time. As opposed to the results of initial setting time, the final setting times of OPC-RSA-MS paste were higher as compared to OPC paste. It may be because of lower level of compensation was provided by the combined pozzolanic effect of MS and RSA to the negative aspects of high water demand (due to admixing of RSA) thereby causing an increase in the final setting times. Therefore it can be concluded that combined pozzolanic effect of MS + RSA and the water demand (due to admixing of RSA) were the governing factors responsible for initial and final setting times respectively of OPC-RSA-MS paste [121], [276]. The higher pozzolanic effect of MS as compared to RSA can be ascertained from the fact that the difference between the final and initial setting time was lowest in OPC-MS paste. Therefore, it can be said with certainty that MS significantly increases the rate of hydration reaction as compared to RSA.

5.3.3 Soundness Test

The expansion in the hardened cement paste, which causes irreversible damage, is generally because of the presence of a high amount of free lime (CaO) or $CaSO_4$ or magnesia (MgO). Most of the standard specifications limit the content of magnesia in the Portland cement because formation of magnesium hydroxide ($Mg(OH)_2$) due to the hydration of MgO increases the volume of the hardened cement paste and destabilizes the concrete matrix [140], [277]. Excessive expansion in the hardened cement paste may lead to the development of cracks. The soundness of a hardened cement paste implies its ability to oppose this volume expansion. In the present study, soundness of cement paste of various mixes was assessed in terms of the level of expansion it undergoes. The results of soundness test are presented in Table 5.2, and the comparison between the expansion and replacement level of OPC by RSA or MS or composite of both is shown in Figure 5.4.

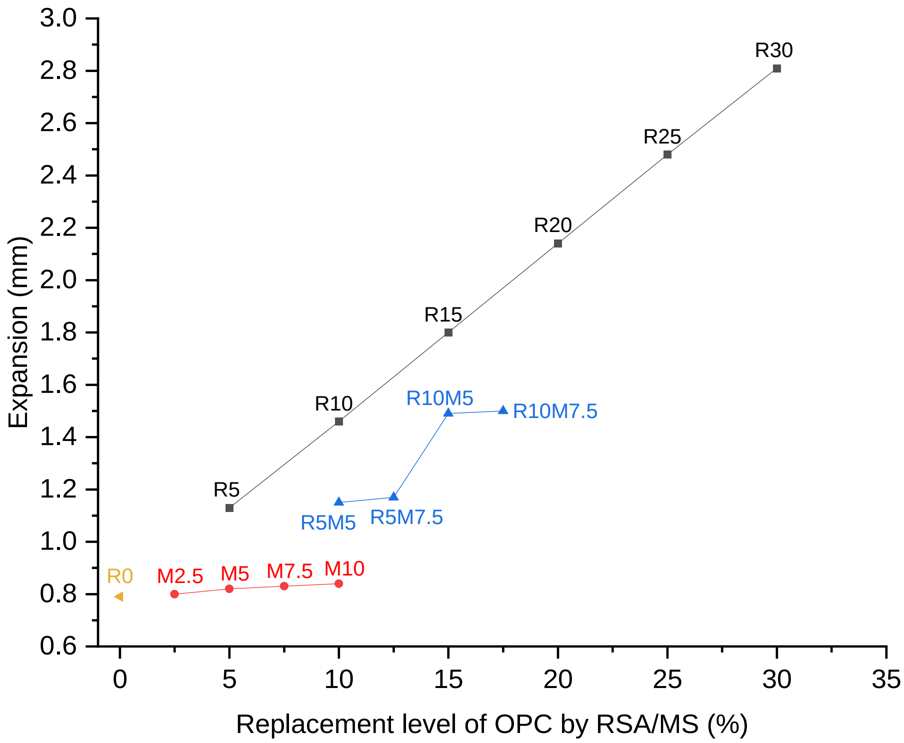

Figure 5.4 Comparison between expansion in cement paste of various mixtures

As compared to the expansion in control mix R0, 43% to 256% and 46% to 90% increase in the expansion was observed in OPC-RSA paste and OPC-RSA-MS paste respectively. The variation in the expansion of OPC-MS paste as compared to control cement paste (R0) was less than 7% which could be neglected.

It was observed that the expansion in the OPC-RSA paste was significantly higher than other mixes, and this increase was directly proportional to the amount of admixed RSA. However, expansion was well within the permissible limit as specified in IS 8112 [252]. This significant increase in the expansion due to admixing of RSA could be attributed to the high amount of magnesia content (7.54%) in RSA as given in Table 4.4 [148], [277].

For OPC-MS paste, it was found that the expansion was roughly constant as compared to that of control paste (R0), regardless of the amount of blended MS. It may be attributed to the similar magnesia content of the OPC (0.79%) and MS (1.29%), which was much lower than the magnesia content of RSA (7.54%). For similar reasons, the expansion in OPC-RSA-MS paste was smaller than the OPC-RSA paste but higher than the OPC-MS paste and control paste (R0).

5.3.4 Marsh Cone Test

The Marsh cone test is used to assess the compatibility between superplasticizer and the cement paste admixed with mineral admixtures. The fluidity of the cement paste slurry can be associated with the amount of time it requires to flow out of the Marsh cone [278]. The lower the flow time is, the higher will be the fluidity of the cement paste slurry. In the current study, Marsh cone test was performed on the cement paste slurry to determine the optimum dosages of HRWR for cement mortar with varying proportions of RSA and MS. As w/c ratio was constant (0.44), HRWR was used to compensate for the loss in workability due to an increase in the overall surface area of particles [22]. The w/c ratio was calculated with the help of Equation 5.1 as per IS 4031 (VI) [237] where 'P' is the normal consistency of control cement paste (R0). The results of Marsh cone test are presented in Table 5.2, and the comparison between HRWR dosage and replacement level of OPC by RSA and MS is shown in Figure 5.5.

$$water\ content = \left(\frac{P}{4} + 3\right)\ \%\ of\ combined\ mass\ of\ (cement +\ sand)\ in\ mortar\ cube \qquad 5.1$$

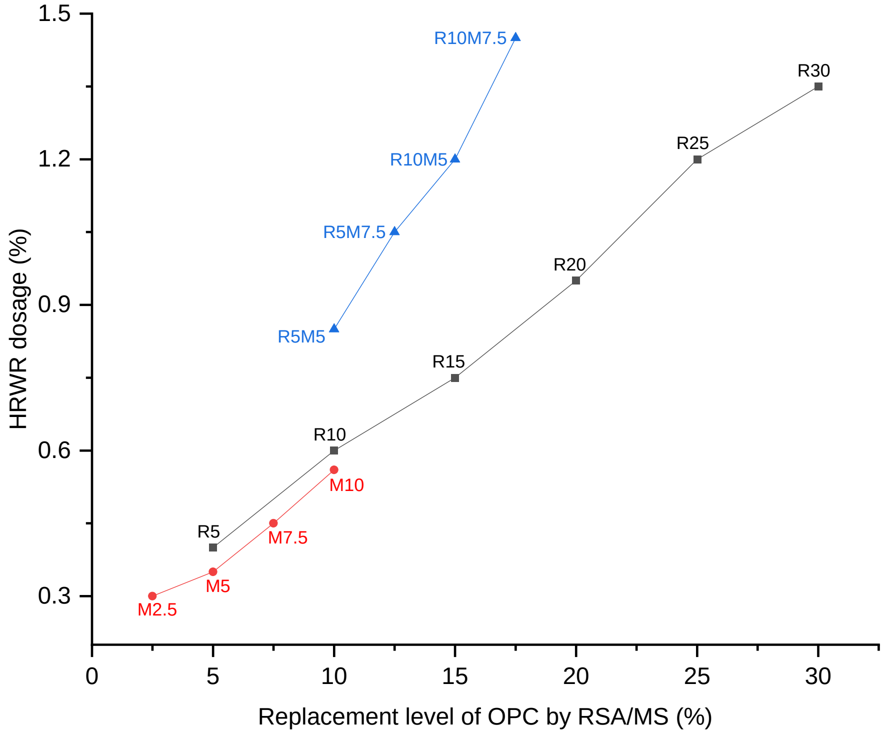

Figure 5.5 Comparison between HRWR dosages for cement mortar of various mixtures

The increase in HRWR dosage was linearly proportional to the amount of blended RSA and MS. As expected; it was lower in OPC-MS paste as compared to OPC-RSA paste due to its low water demand. Amongst all the mixes, the HRWR dosage was highest in OPC-RSA-MS paste which was due to the combined effect of high water demand of RSA as well as finer particles of MS.

5.3.5 Mineralogical Analysis

The XRD analysis of cement paste admixed with RSA and MS at 28 days of curing is given in Figure 5.6 and 5.7, respectively. The XRD diffractograms of OPC-RSA paste (Figure 5.6) show that mostly hydration products like C-S-H gel and portlandite ($Ca(OH)_2$) are found in the sample. The peaks of portlandite reduced with increase in the blended amount of RSA in the paste because pozzolanic action of RSA may have led to the consumption of portlandite and formation of secondary/additional C-S-H gel. However, few peaks of C-S-H gel were reduced at higher replacement level of OPC by RSA because of reduction in optimum quantity of OPC required in hydration reaction. This phenomenon is also known as the dilution effect of cement. The reduction in portlandite content affects the pozzolanic action of RSA as well. Also, the presence of calcite peak provides the evidence for reduction in the peaks of portlandite by carbonation. Moreover, the peak of calcite increased with an increase in the amount of RSA, signifying that admixing of RSA increases the carbonation rate which was in agreement with the similar studies in the past on GGBFS [279] and RHA [280], [281]. It could be attributed to the counteracting effect of the pore volume and pore size reduction over the reduction in $Ca(OH)_2$ content and to the utilization of non-pulverized RSA [279]. Also, this contrary behaviour of RSA could be credited to the increasing w/b ratio with an increase in RSA content [279] (OPC-RSA paste were prepared with their respective normal consistency as w/b ratio). Few peaks of unhydrated compounds like alite and belite were also observed in all the mix; however, these peaks were considerably lowered due to admixing of RSA. It means that RSA increases the rate of hydration reaction of OPC possibly by nucleation site effect. The XRD analysis of OPC-RSA paste also shows small amounts of quartz (from RSA), ettringite and gypsum in all the tested OPC-RSA paste samples. However, the peaks of ettringite got more prominent with an increase in the blended amount of RSA which gives possible reasons for the results of soundness test as ettringite is highly expansive in nature (Table 5.2).

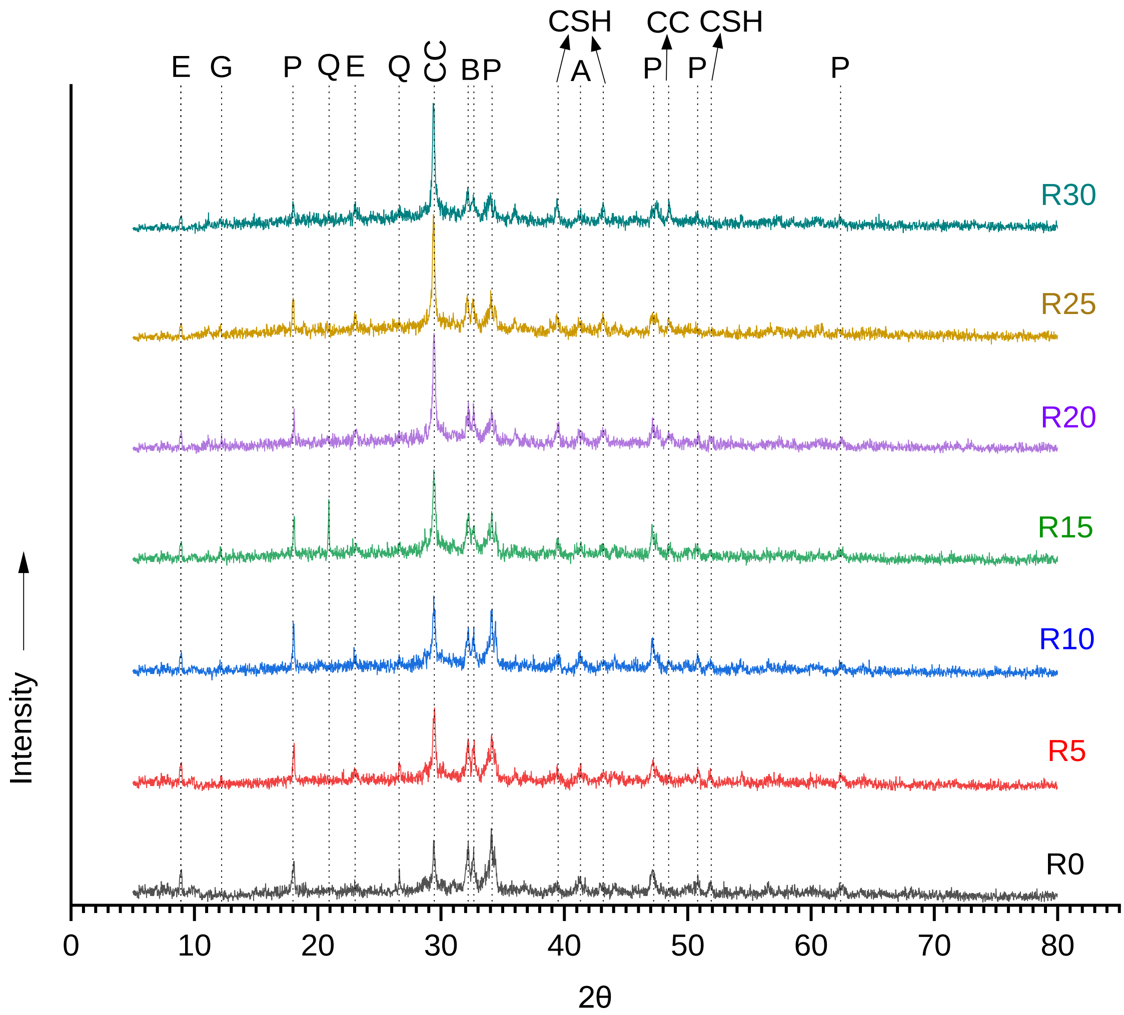

Figure 5.6 XRD diffractograms of OPC-RSA paste

(E - Etrringite; G – Gypsum; P – Portlandite; Q – Quartz; CC – Calcite; B – Belite; CSH – Calcium Silicate Hydrate; A – Alite)

The XRD diffractograms of OPC-MS paste (Figure 5.7) shows notability of hydrated compounds like portlandite, C-S-H gel and calcite and unhydrated components of OPC like alite and belite. Substantially increase in the peaks of C-S-H gel in OPC-MS paste was suggestive of highly pozzolanic behaviour of MS as compared to RSA. Similar to OPC-RSA paste, the portlandite content reduces in OPC-MS paste due to the pozzolanic action of MS. Also, the prominence of unhydrated belite suggests that mortar or concrete admixed with MS will keep on gaining considerable strength even at late days of curing. Similar peaks of calcite in OPC-MS paste and control paste (R0) suggest that admixing of MS may or may not affect the rate of carbonation. Considerably lower peaks of ettringite and gypsum in OPC-MS paste were suggestive of better resistance to expansion as compared to OPC-RSA paste.

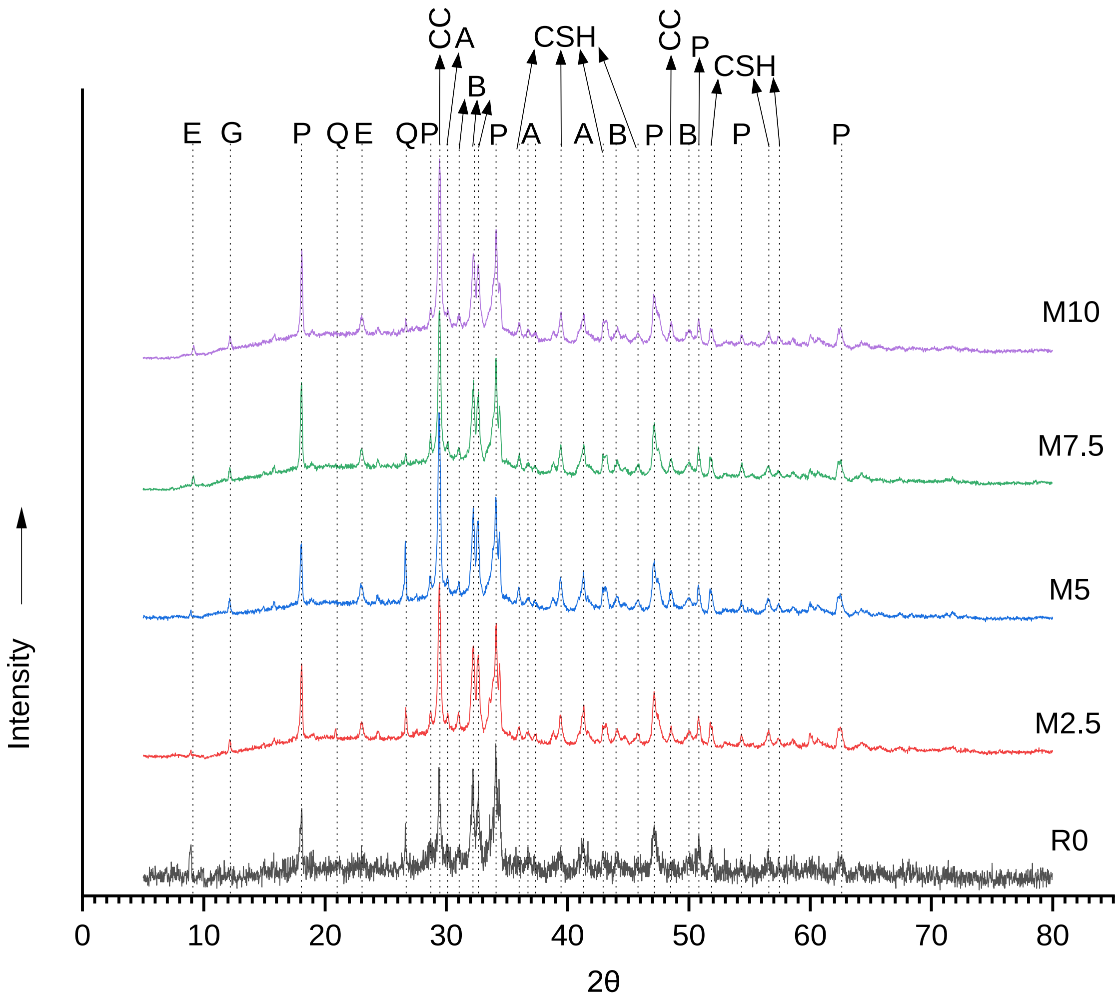

Figure 5.7 XRD diffractograms of OPC-MS paste

(E - Etrringite; G – Gypsum; P – Portlandite; Q – Quartz; CC – Calcite; B – Belite; CSH – Calcium Silicate Hydrate; A – Alite)

5.4 PHYSICAL PROPERTIES OF CEMENT MORTAR

5.4.1 Compressive Strength

It was observed in the past that admixing of supplementary cementitious materials improvises the compressive strength of cement mortars [85], [136], [186], [282]. The results pertaining to compressive strength of msortar admixed with RSA and

MS are given in Table 5.3. Figure 5.8 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 5.4 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. Figure 9 to Figure 14 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

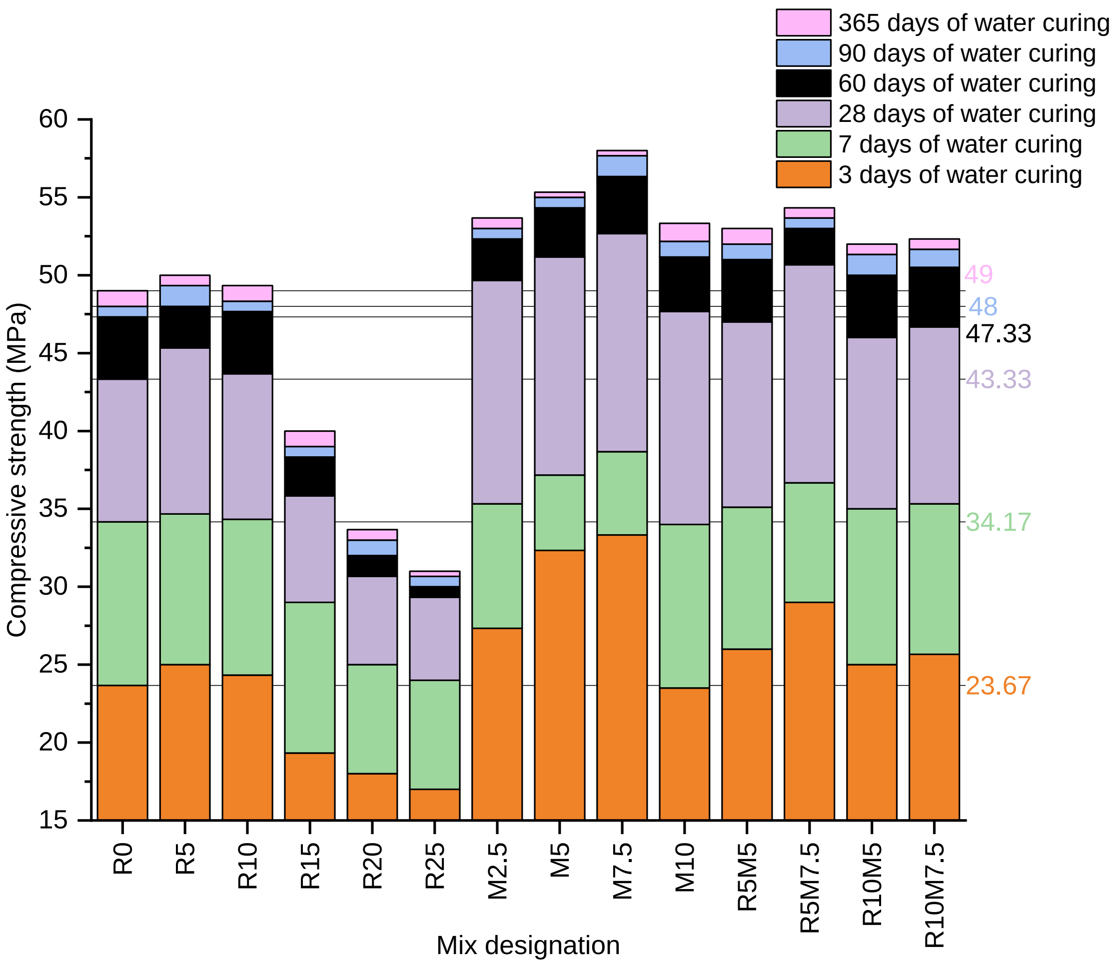

Figure 5.8 Graphical comparisons between compressive strength of mortar at various ages of water curing

Table 5.4 Percentage change in compressive strength of cement mortar admixed with RSA and MS w.r.t. control mortar R0

Mix	Percentage Change in Compressive Strength (%)					
	3 days	7 days	28 days	60 days	90 days	365 days
R5	5.62	1.46	4.62	1.42	2.77	2.04
R10	2.79	0.47	0.78	0.72	0.69	0.67
R15	-18.34	-15.13	-17.31	-19.02	-18.75	-18.37
R20	-23.95	-26.84	-29.22	-32.39	-31.25	-31.29
R25	-28.18	-29.76	-32.31	-36.62	-36.10	-36.73
M2.5	15.46	3.39	14.63	10.56	10.42	9.53
M5	36.59	8.78	18.09	14.79	14.58	12.92
M7.5	40.81	13.17	21.56	19.02	20.15	18.37
M10	-0.72	-0.50	10.02	8.11	8.69	8.84
R5M5	9.84	2.75	8.47	7.75	8.33	8.16
R5M7.5	22.52	7.32	16.94	11.98	11.81	10.88
R10M5	5.62	2.43	6.16	5.64	6.94	6.12
R10M7.5	8.45	3.39	7.71	6.70	7.65	6.80

It can be observed in Table 5.3 that up to 10% partial replacement of OPC by RSA was possible in mortar cubes without any loss of compressive strength. For the mortar of mix R5 and R10, the percentage increase in the compressive strength w.r.t. control mortar (R0) at various days of curing was in the range of 1.42% to 5.62% and 0.47% to 2.79% respectively (Table 5.4). It indicates that the replacement of OPC by RSA up to 10% makes the microstructure of mortar matrix denser. Upon replacing OPC by RSA for more than 10%, a significant reduction in the compressive strength was observed, which could be attributed to the dilution effect of cement. Therefore it could be said that at more than 10% replacement level, the pozzolanic and filler effect of RSA could not offset the strength reduction due to reduced OPC content. Another reason for the decline in strength at a higher level of replacement by RSA could be due to the presence of unburned carbon. As the proportion of RSA particles was increased in the mix R15, R20 and R25, amount of unburned carbon increases thus leading to high water demand which can be associated with reduced compressive strength [136]. Such was the magnitude of reduction that even 7 days compressive strength of control mortar (R0) was greater than 365 days compressive strength of mix R20 and R25 (Figure 5.8). OPC-RSA mortars attained approximately 90% compressive strength at 28 days of curing as compared to 365 days of curing.

It can be observed in Table 5.3 that up to 7.5% partial replacement of OPC by MS was possible in mortar cubes without any loss of compressive strength at all ages of curing. For the mortar of mix M2.5, M5 and M7.5, the percentage increase in the compressive strength w.r.t. control mortar (R0) at various days of curing was in the range of 3.39% to 15.46%, 8.78% to 36.59% and 13.17% to 40.81% respectively (Table 5.4). Mortars, in general, comprise of hardened cement paste, fine aggregates and ITZ [136], [283]. MS densifies the cementitious matrix and lowers the w/b at ITZ. This behaviour of MS was similar to RSA; however, MS is highly reactive due to its high surface area and ultra-fine particle size as compared to RSA. The incorporation of MS by more than 7.5% reduces the compressive strength of mortar at early days of curing (3 and 7 days). However, the compressive strength at later days of curing (28 days and onwards), was greater than the strength of control mortar (R0). It stipulates that when OPC is replaced by 10% MS (M10), dilution effect becomes more dominant as compared to filler and pozzolanic effect thereby reducing the reaction activity of MS at early ages of curing. The maximum compressive strength was observed in the mortar of mix M7.5. Such was the positive effect of admixing MS that compressive strength of control mortar (R0) at 365 days of curing was lower than compressive strength of mortar of mix M2.5, M5 and M7.5 at 28 days of curing (Figure 5.8).

In the case of OPC-RSA-MS mortar, it was observed that mortar of mix R5M7.5 has the maximum compressive strength as compared to control mortar (R0) with percentage increase in strength ranging from 7.32 to 22.52% (Table 5.4). The compressive strength of OPC-RSA-MS mortar was higher mainly due to fine particle size and high silica content of both RSA and MS. It can be seen in Figure 5.9 to Figure 14 that when the quantity of MS was increased from 5% to 7.5%, keeping the amount of RSA constant in the mortars, the compressive strength increases. The admixing of composite of RSA and MS enhances the compressive strength due to their synergistic effect [282].

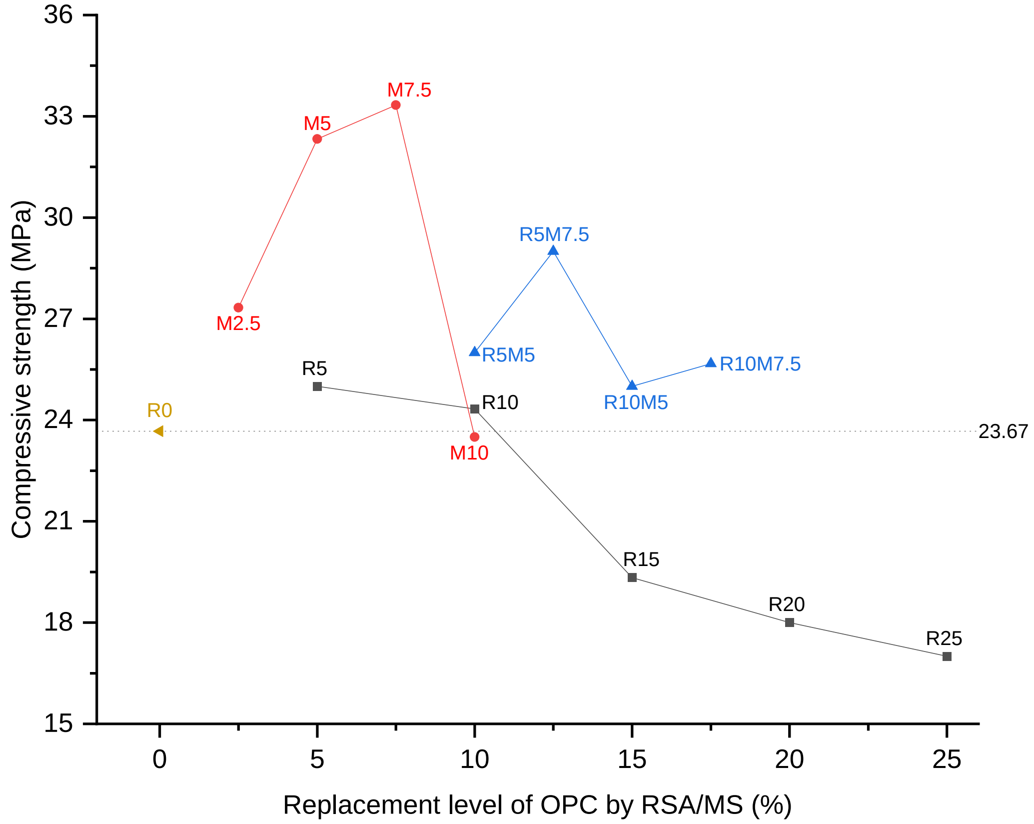

Figure 5.9 Compressive strength of mortar at 3 days of water curing

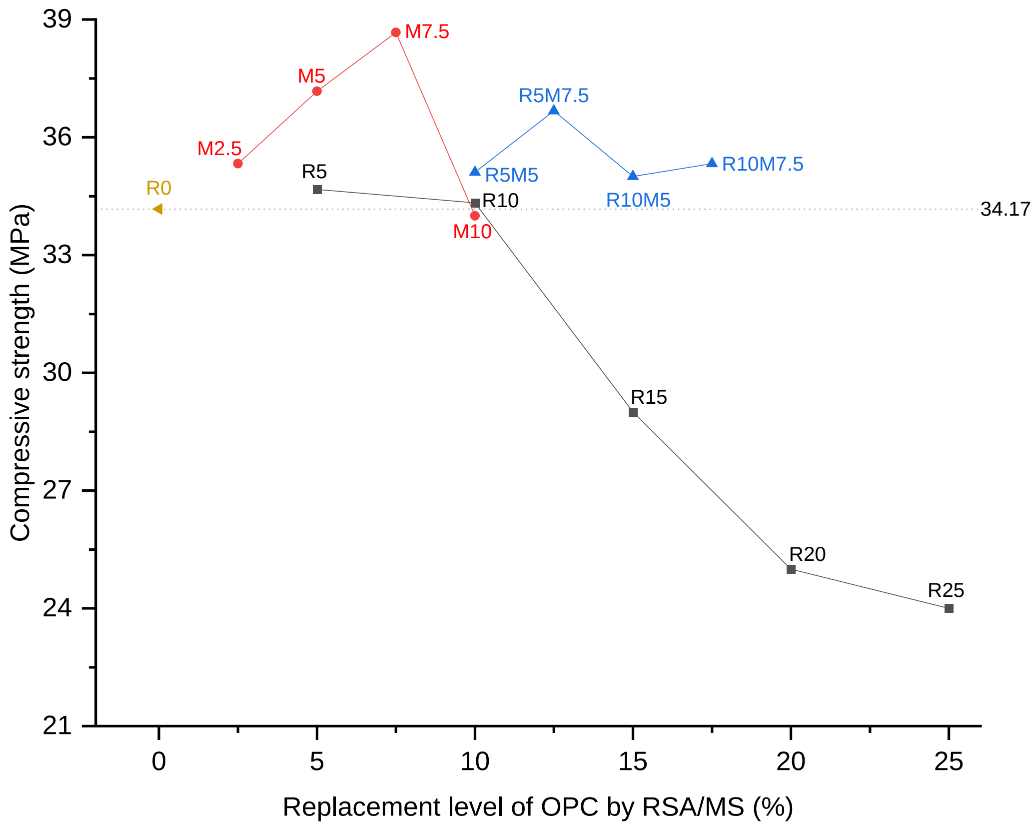

Figure 5.10 Compressive strength of mortar at 7 days of water curing

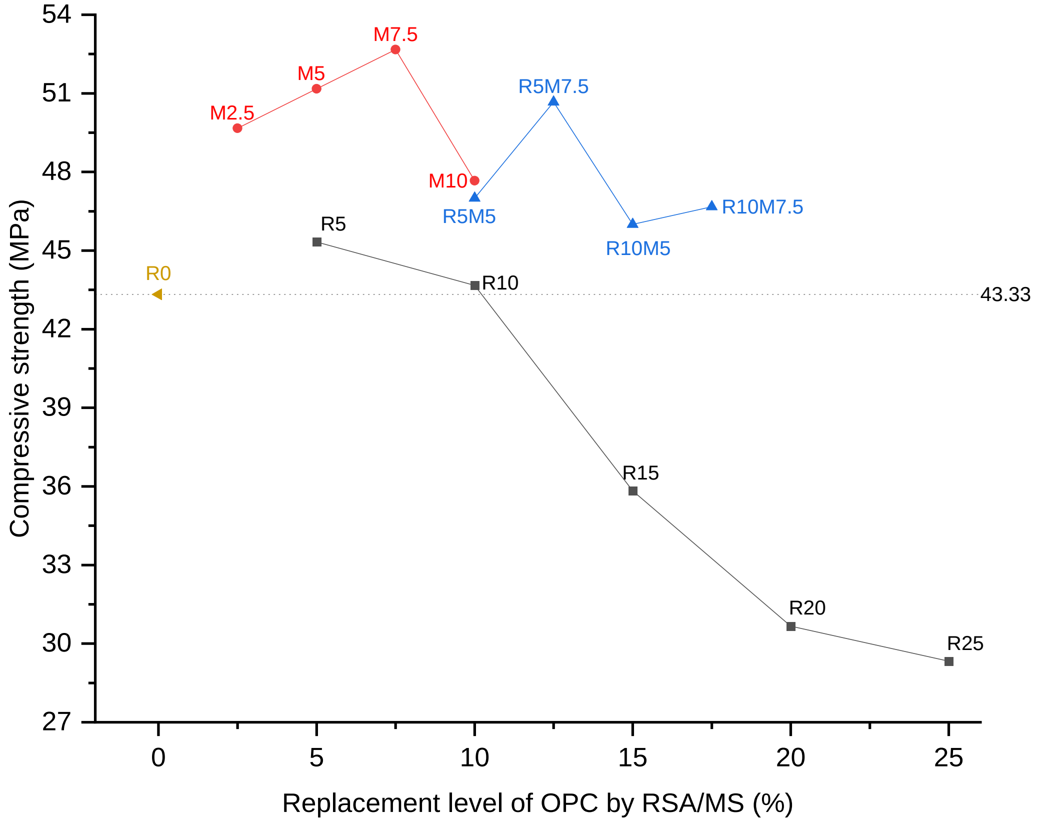

Figure 5.11 Compressive strength of mortar at 28 days of water curing

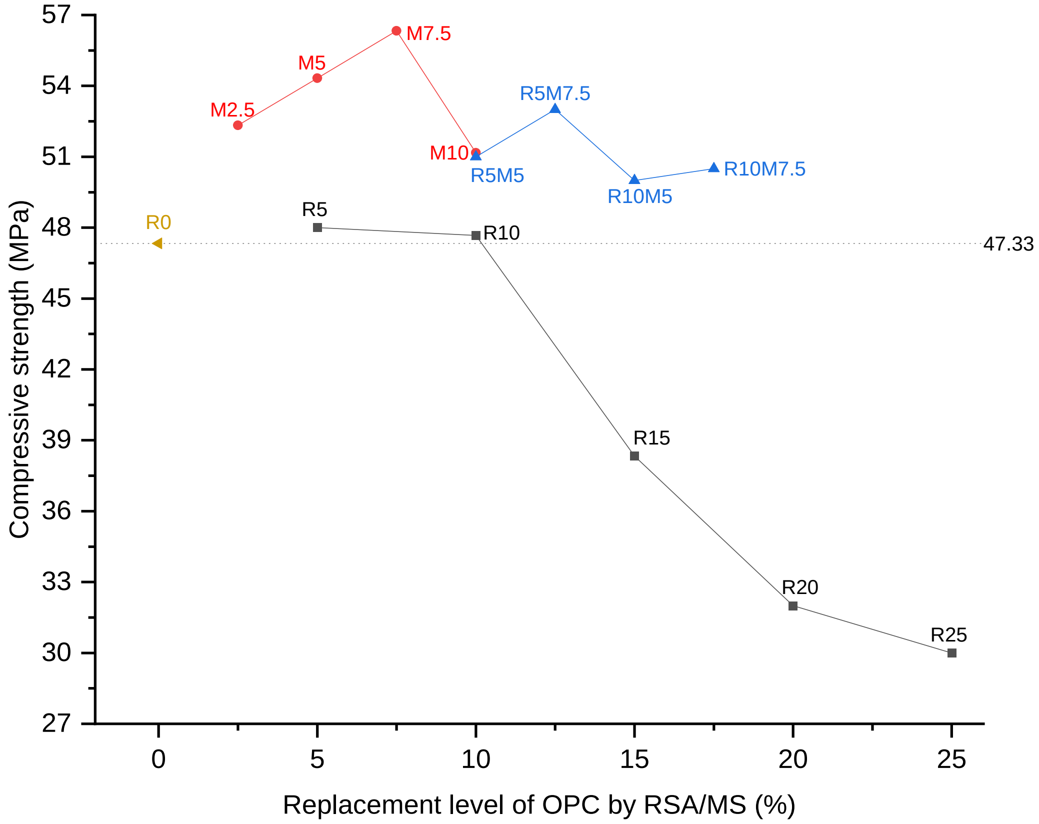

Figure 5.12 Compressive strength of mortar at 60 days of water curing

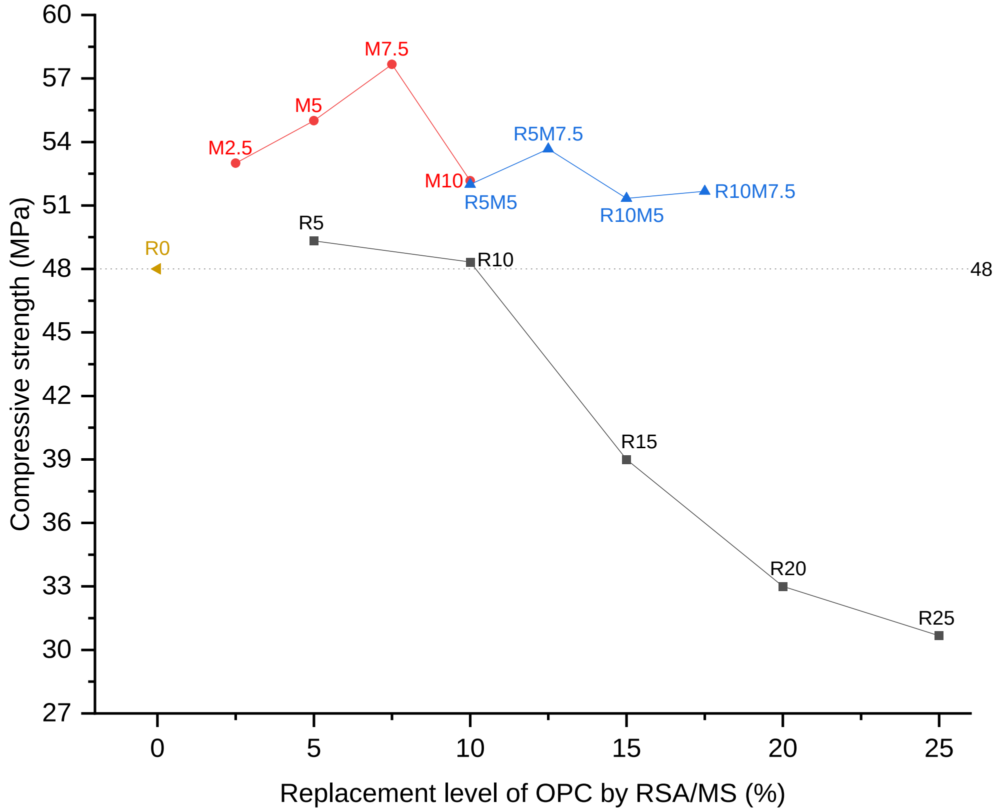

Figure 5.13 Compressive strength of mortar at 90 days of water curing

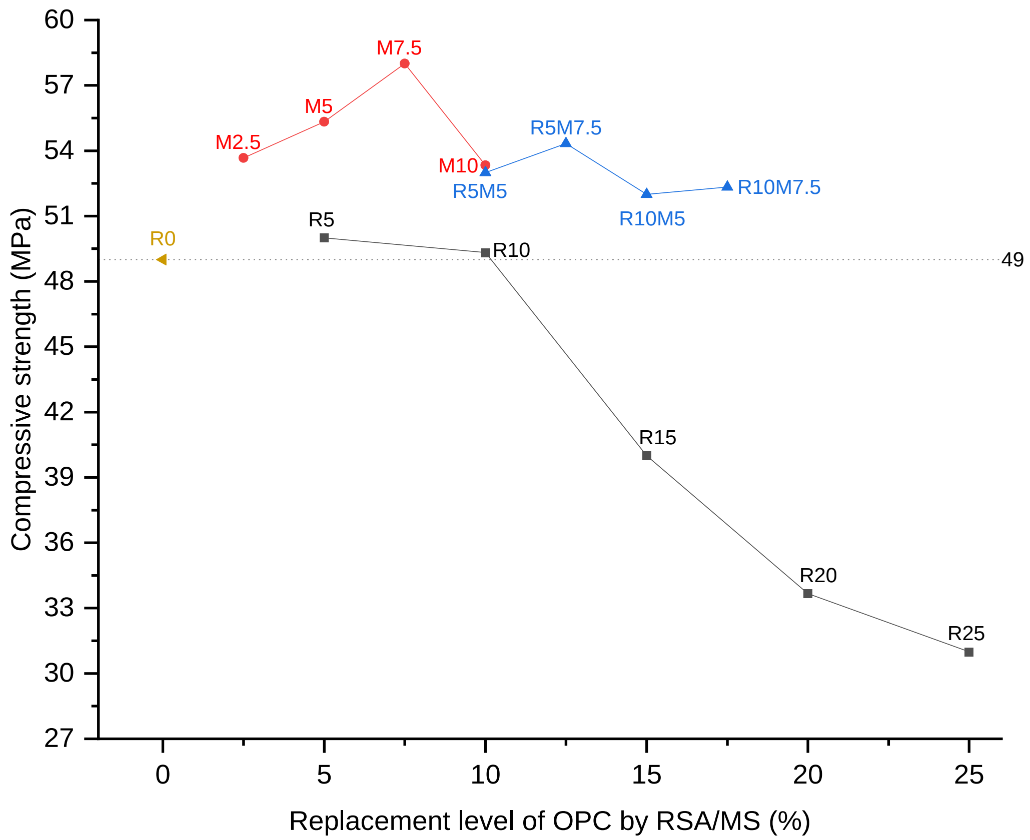

Figure 5.14 Compressive strength of mortar at 365 days of water curing

It can be seen in Figure 5.9 to Figure 14 that at 5% replacement level of OPC, the compressive strength of mortar admixed with MS was maximum at all ages of curing. At 10% replacement level of OPC, the compressive strength of mortar admixed with composite of RSA and MS was maximum at 3 and 7 days of curing (Figure 5.9 and 5.10 respectively) while the compressive strength of mortar admixed with MS only was maximum at later days of curing (Figure 5.11 to 5.14). At 15% replacement level of OPC, compressive strength of mortar admixed with composite of MS and RSA was highest at all ages of curing (Figure 5.9 to Figure 14).

5.4.2 Hardened Density

The hardened density of mortar depends on the amount and specific gravity of the components like cement, mineral admixtures and sand [284]. 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 5.5, and the effects of curing age on the hardened density are shown in Figure 5.15.

Table 5.5 Hardened density of cement mortar admixed with RSA and MS

Mix	Hardened Density (g/cm^3)					
	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

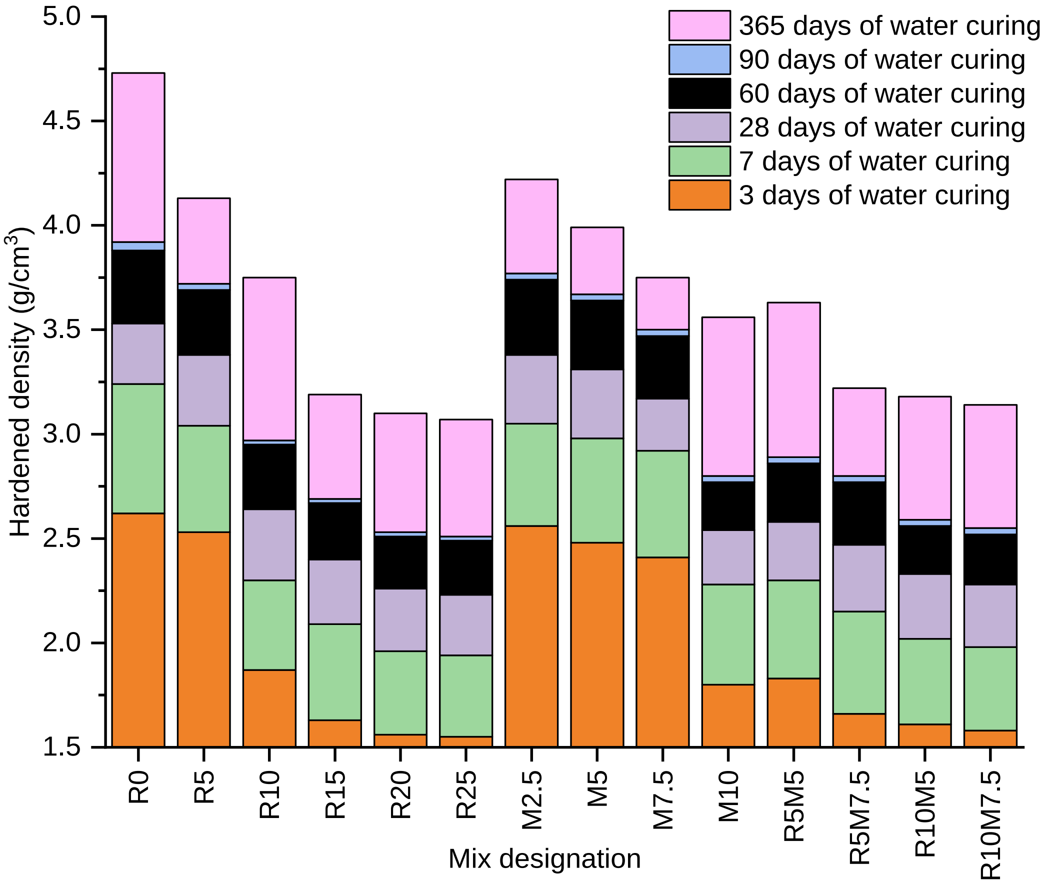

Figure 5.15 Graphical comparisons between hardened densities of mortar at various ages of water curing

It can be seen in Table 5.5 that the hardened density of all the mortar mixes increased with curing age. However, admixing of RSA and MS decreased the hardened density of the mortars as compared to the control mortar (R0). The difference between the hardened density of control mortar and admixed mortar was directly proportional to the quantity of RSA or MS in the mixture. At similar replacement level of OPC, the maximum reduction in hardened density as compared to control mortar (R0) was observed in OPC-MS mortar because of lowest density of MS.

5.5 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 consistency of 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. The initial 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 strength of 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 followed by a composite of (RSA + MS) and RSA.