

STRENGTH STUDY OF MORTAR WITH PARTIAL REPLACEMENT OF CEMENT WITH MICRO SILICA

Mohd Imran¹, Er. Sameer Malhotra², Er. Tarandeep Singh³

¹M.Tech Scholar, Gurukul Vidyapeeth Institute of Engineering and Technology.

²Assistant Professor, Gurukul Vidyapeeth Institute of Engineering and Technology.

³Assistant Professor, Swami Vivekanand Institute of Engineering and Technology.

ABSTRACT:- In this study the effect of replacement of cement with microsilica in cement paste was analyzed on the microstructure and mechanical properties of cement mortars. Microsilica content was varied as 3%, 6%, 9% and 12% by weight replacement of cement to investigate the effects on the fresh properties such as Standard Consistency, Setting Time, Flow Test and hardened properties of cement paste such as compressive Strength at primitive and advanced ages. The Specimens were evaluated at early 3rd, 7th, 28th and 56th day of curing ages. The study has revealed that the replacement of cement with microsilica leads to sustainable construction practices.

INTRODUCTION

The production of the prime constituents of cement mortar i.e. cements and fine aggregates pose a threat to the environment and the use of enormous amount of drinking water lead to scarcity of these resources in long run. As per estimation, one ton of Portland cement clinker production yields one ton of green house gases (GHGs) such as carbon dioxide responsible for global warming. Construction technology can aid to sustainable development by using less energy and natural resources along with production of lesser waste material. The concern also focuses on the properties of the mortar in the fresh and hardened state. Thus, the paste should not only be workable, but the constructed material should be durable and of high compressive strength. The workability of mortar is controlled by particle size distribution (PSD) and the mechanical properties such as strength and durability are controlled by the mix grading and resulting particle packing. Further, the hydration behavior water, the requirement for flow depends upon the degree of dispersion of cement in water. The degree of flocculation in a cement paste is also related to water content and early hydration. The particle size distribution, particle packing and water demand in cement mortar can be controlled by using water reducing admixtures and mineral admixtures such as fly ash, ground granulated blast furnace slag, microsilica etc.

Cement mortar is the most widely used building compound made by mixing cement and fine aggregates with the required amount of water in compliance with Indian standard code, IS 2250-1981. It is basically used as a paste for binding together of various construction blocks such as bricks, stones, cinder blocks, etc and other forms of masonry such as plastering over bricks or other. The quality of cement mortar is characterized in terms of its mobility, placeability, water retention, strength and durability and depends upon its constituent materials. A good mortar should be economic, easily workable, capable of good adhesion, durable and resistant to chemical attack.

Microsilica is a grey colored powder, somewhat similar to Portland cement or some fly ashes with particle size approximately 150nm. It is defined as very fine non-crystalline silica that is produced in electric arc furnaces as a by-product during production of alloys containing silicon or elemental silicon. The production of microsilica involves the reduction of high purity quartz (SiO₂) in electric arc furnaces at temperatures in excess of 2,000°C.

METHODOLOGY

The cement used for the experimental studies was ordinary Portland cement 43 grade. The physical characteristics and chemical composition of cement have been given in table 1 and 2. Micro-silica was obtained as a by-product of local industry and was used as such without any modification. The physical characteristics and chemical composition of microsilica have been given in table 3 and 4.

Table 1 Physical characteristics of cement

Property	Value
Fineness	278 m ² /kg
Standard Consistency	33.0%
Initial setting time	150 min
Final setting time	200 min
Soundness Le-Chat expansion	1.5 mm
Compressive strength at 3 days	34.1 MPa
Compressive strength at 7 days	42.6 MPa
Compressive strength at 28 days	54.7 MPa

Table 2 Chemical composition of cement

Oxides	% by mass
CaO-0.7SO ₃	0.82
2.8 SiO ₂ + 1.2Al ₂ O ₃ + 0.65Fe ₂ O ₃	
Al ₂ O ₃	1.26
Fe ₂ O ₃	
Insoluble residue	2.63
Magnesia	1.08
Sulphuric anhydride	2.60
Total Chlorides	0.010
LOI	0.96

Table 3 Physical characteristics of microsilica

Property	Value
Particle size (typical)	<1 μm
Bulk density As-produced	135–475 kg/m ³
Bulk density Slurry	1,420–1,540 kg/m ³
Bulk density Densified	550–700 kg/m ³
Specific gravity	2.22
Surface area (BET)	12,500–27,000 m ² /kg

Table 4 Chemical composition of microsilica

Oxides	% by mass
SiO ₂	98
Al ₂ O ₃	0.03
Fe ₂ O ₃	0.02
CaO	0.5
MgO	0.3
K ₂ O	0.7
Na ₂ O	0.3

SO ₃	-
LOI	2.8

Table 5 Physical characteristics of Fine Aggregate

Property	Value
Bulk Density (Loose)	1670 kg/m ³
Bulk Density (Compacted)	1910 kg/m ³
Specific Gravity	2.72
Water Absorption	1.19%
Moisture content	0.16%
Material finer than 75 μ	0.4%

Table 6 Physical characteristics and chemical composition of water

Property	Value
Volume of 0.02 N H ₂ SO ₄ to neutralize 100 mL of water using mixed indicator	23.9 mL
Volume of 0.02 N NaOH to neutralize 100 mL of water using phenolphthalein	0.5 mL
Organic components	135 mg/L
Inorganic solids	465 mg/L
Sulphates	9.2 mg/L
Total Chlorides	85.6 mg/L
Suspended matter	<1
pH	6.79

Table 7. Description of Mortar Mixes

Designation	Microsilica (%)
NM	0%
M1	3%
M2	6%
M3	9%
M4	9%

Fine aggregate was procured from the local available source and conformed to Indian Standard Specifications, IS: 383-1970. A lump of clay and other foreign materials were separated out carefully. Sand was washed and dried before testing. It was sieved through 4.75 mm sieve and conformed to grading zone II.

The physical characteristics of Fine aggregate have been given in table 5. The water used for the cement mortar was the potable water as supplied in the structures laboratory. The physical characteristics and chemical composition of water have been given in table 6.

CASTING OF MORTAR CUBES

Mortar of one part of cement and 3 parts of sand was prepared. Quantity of material for one cube was calculated 800gm which contain 200gm of cement and 600gm of sand. Quantity of water was calculated using consistency of cement.

Water required for casting one cube of mortar = $(P/4+3)$ % of total material

Where, P is the consistency of cement as described in IS: 4031 (Part 4) – 1988.

The dimensions of cubes are 70.6mmx70.6mmx70.6mm. Cement, sand and water were hand mixed and the mix was placed in the cubes in three layers in each layer 25 blows of tamping rod were given for proper compaction. The mix was prepared using different proportions of microsilica ranging from 3% to 12%. Description of Mortar Mixes was given in table 7.

RESULTS & DISCUSSION

CONSISTENCY OF MORTAR

The observed values of consistency of mortars, without and with replacement of cement with microsilica plotted in fig 1. The consistency of mortars increased with increasing percentage of microsilica from 3% to 12%. The consistency of the mortar is related to the fineness of the particles present in the mortar. The particles of microsilica has greater specific surface of the particles. As the percentage of microsilica increases, the hydration process is faster and the water required for the hydration increases, resulting in an increase in consistency of mortars.

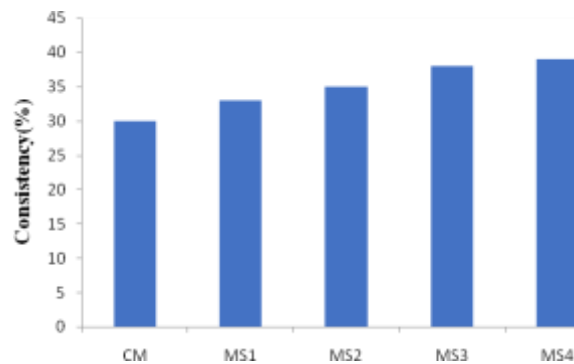


Fig 1. Consistency of mortars

SETTING TIME OF MORTAR

The observed values of setting time of mortars, without and with replacement of cement with microsilica have been plotted in fig 2. The setting time of mortars increased with increasing percentage of microsilica from 3% to 12%.

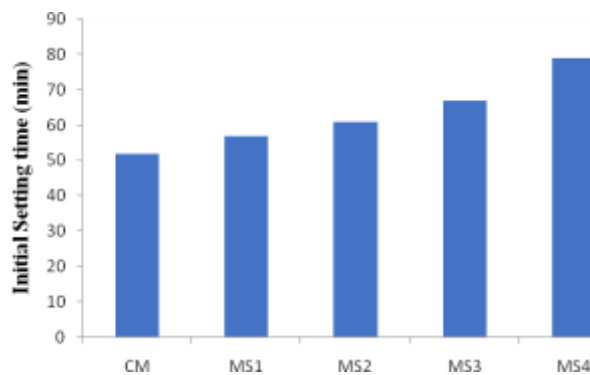


Fig 2. Initial Setting time of mortars

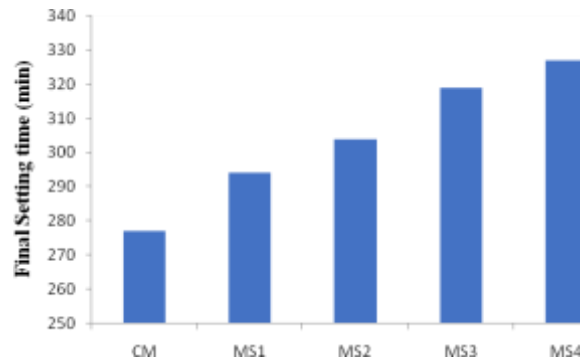


Fig 3. Final Setting time of mortars

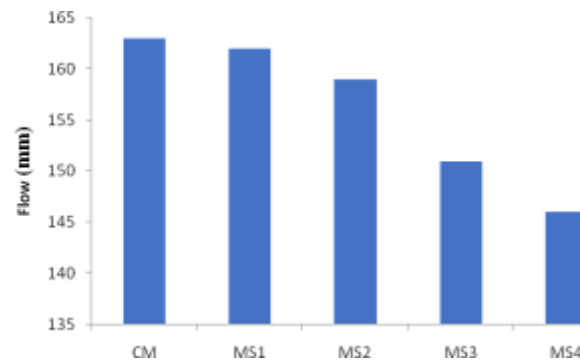


Fig4. Flow of mortars

The setting time of the mortar is related to the thickness of the mortars. The particles of microsilica are fines, the thickness of the mortars decreased. As the percentage of microsilica increased, the thickness of the mortars decreased further and the setting process gets decelerated, resulting in an increase in setting time of mortars.

FLOW OF MORTAR

The observed values of flow of mortars, without and with replacement of cement with microsilica have been plotted in fig 4. The flow of mortars was found to decrease with increasing percentage of microsilica from 3% to 12%. The flow of the mortar is related to the fineness of the particles and the specific surface of the particles present in the mortar. The particles of microsilica has greater specific surface of the particles and result in better packing of the cement matrix. As the percentage of microsilica increases, the packing of the cement matrix is enhanced and the empty spaces in the matrix are better filled. As a result, water cannot bleed over the surface of the matrix. This increases the stiffness of the mortars resulting in a decrease in flow of mortars.

COMPRESSIVE STRENGTH OF MORTAR

3 DAYS

The compressive strength of control mix (MM) was found to be 25.96 MPA at 3 days curing age. The compressive strength of all the mortar mixes, M1, M2, M3 and M4 (with replacement of cement with microsilica) at 3 days was higher as compared to MM as plotted in fig 5. However, it was found that the compressive strength of mortars increased with increasing percentage of microsilica from 3% to 9%, but decreased at 12% percentage of microsilica.

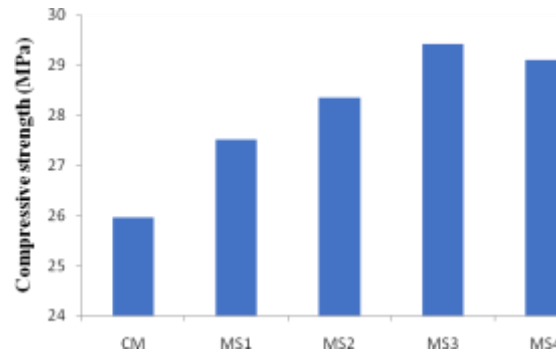


Fig 5. Compressive strength of mortars at 3 days

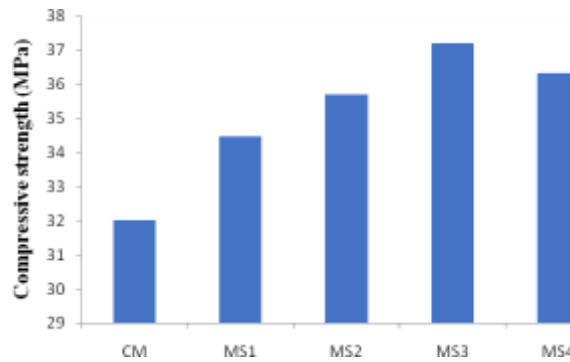


Fig 6. Compressive strength of mortars at 7 days

The mix M1, M2 and M3 showed an increase of 5.97%, 9.17% and 13.33%, but M4 showed an increase of 12.10% as compared to MM. The maximum compressive strength was observed for M3 as 29.42 MPa.

7 DAYS

The compressive strength of control mix (MM) was found to be 32 MPA at 7 days curing age. The compressive strength of all the mortar mixes, M1, M2, M3 and M4 (with replacement of cement with microsilica) at 7 days was higher as compared to MM as plotted in fig 6.

However, it was found that the compressive strength of mortars increased with increasing percentage of microsilica from 3% to 9%, but decreased at 12% percentage of microsilica. The mix M1, M2 and M3 showed an increase of 7.72%, 11.56% and 16.22%, but M4 showed an increase of 13.53% as compared to MM. Thus, the similar trend in compressive strength as that observed at 3 days of curing age was observed. Further, the maximum compressive strength was observed for M3 as 37.19 MPa.

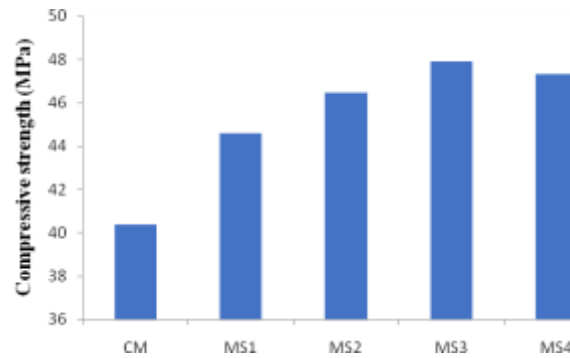


Fig 7. Compressive strength of mortars at 28 days

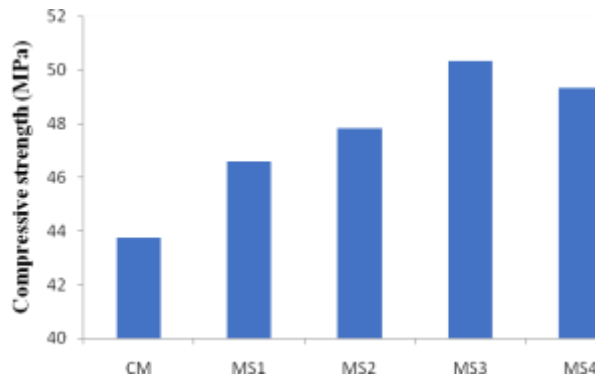


Fig 8. Compressive strength of mortars at 56 days

28 DAYS

The compressive strength of control mix (MM) was found to be 32 MPA at 7 days curing age. The compressive strength of all the mortar mixes, M1, M2, M3 and M4 (with replacement of cement with microsilica) at 28 days was higher as compared to MM as plotted in fig 7.

However, it was found that the compressive strength of mortars increased with increasing percentage of microsilica from 3% to 9%, but decreased at 12% percentage of microsilica. The mix M1, M2 and M3 showed an increase of 10.45%, 15.06% and 18.68%, but M4 showed an increase of 17.17% as compared to MM. Thus, the similar trend in compressive strength as that observed at 3 days of curing age was observed. Further, the maximum compressive strength was observed for M3 as 47.91 MPa.

56 DAYS

The compressive strength of control mix (MM) was found to be 32 MPA at 7 days curing age. The compressive strength of all the mortar mixes, M1, M2, M3 and M4 (with replacement of cement with microsilica) at 56 days was higher as compared to MM as plotted in fig 8. However, it was found that the compressive strength of mortars increased with increasing percentage of microsilica from 3% to 9%, but decreased at 12% percentage of microsilica. The mix M1, M2 and M3 showed an increase of 6.44%, 9.28% and 15.04%, but M4 showed an increase of 12.68% as compared to MM. Thus, the similar trend in compressive strength as that observed at 3 days of curing age was observed. Further, the maximum compressive strength was observed for M3 as 50.34 MPa.

The comparative study reveals that the mortars mixes, with replacement of cement with microsilica, M1, M2, M3 and M4 exhibited increased compressive strength than the controlled mix, MM. This observation can be attributed to the pozzolanic

activity of microsilica, a pozzolanic material. Hydration of cement produces calcium hydroxide and results in pores in the cement matrix. Microsilica reacts with calcium hydroxide and produces calcium silicate hydrate gel and fills the pores of the cement matrix. As a result, compressive strength of the cement mortars increases.

Further, as the percentage of microsilica in cement matrix is increased, the pozzolanic effect of microsilica is increased and compressive strength of the cement mortars is enhanced. However, the sudden decrease in compressive strength at higher percentage of microsilica can be attributed to the reason that higher percentage of microsilica can result in friction among particles leading to reduced packing and hence reduced compressibility.

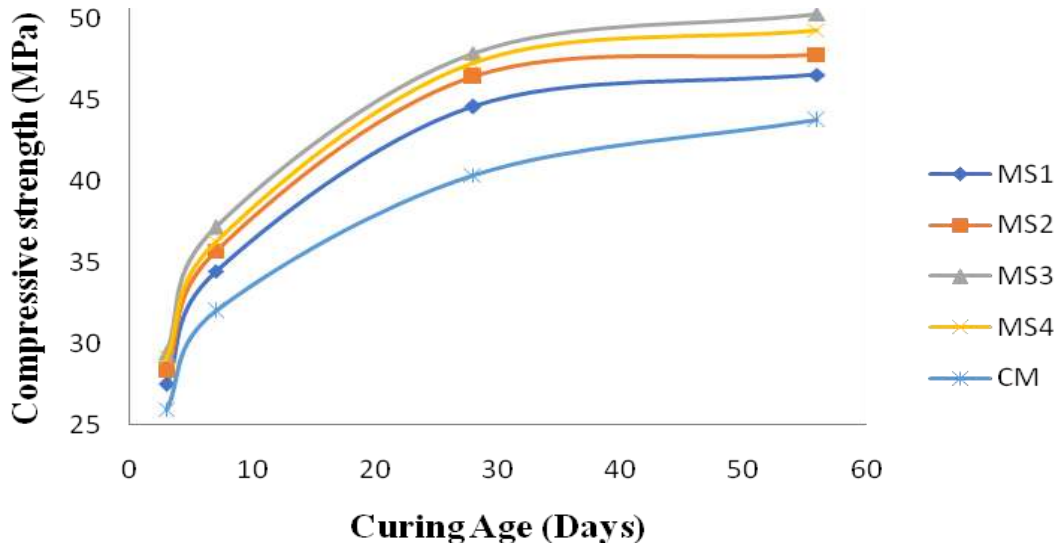


Fig 9. Compressive strength of mortars as a function of curing age

EFFECT OF CURING DAYS

The data was further comparatively analyzed in terms of age of curing days at 3, 7, 28 and 56 days. The compressive strength of control mix (MM) was found to increase from 3 days to 56 days of curing as plotted in fig 9. Similar behavior was observed in all the mortar mixes with replacement of microsilica. The percentage increase in compressive strength of MM was found as 23.27%, 55.51% and 68.57% at 7 days, 28 days and 56 days of curing as compared to compressive strength at 3 days. The percentage increase in compressive strength of M1 was 25.30%, 62.09% and 69.32% at 7 days, 28 days and 56 days of curing as compared to compressive strength at 3 days. The percentage increase in compressive strength of M2 was 25.97%, 63.90% and 68.74% at 7 days, 28 days and 56 days of curing as compared to compressive strength at 3 days. The percentage increase in compressive strength of M3 was 26.41%, 62.85% and 71.11% at 7 days, 28 days and 56 days of curing as compared to compressive strength at 3 days. The percentage increase in compressive strength of M4 was 24.85%, 62.54% and 69.45% at 7 days, 28 days and 56 days of curing as compared to compressive strength at 3 days.

The data revealed that as compared to MM, the percentage increase in mortars with replacement of cement with microsilica, M1, M2, M3 and M4 was higher at increasing days of curing age. This observation confirms that the pozzolanic activity of microsilica strengthens the mortar mixes and hence increases the durability of such mixes as compared to control mix. Similar trends have been reported by other researchers during their investigations.

CONCLUSIONS

On the basis of this study, the following conclusions can be stated:

1. Replacement of cement with microsilica leads to increase in consistency and delay of the setting process. This also increases the stiffness of the mortar and decrease of the flow.
2. The compressive strength of all the mortar mixtures containing microsilica from 3%, 6%, 9% and 12% was higher as compared to the mortar mixture without microsilica.
3. The compressive strength all the mortar mixes increased with increase in age. Thus, the 56 days compressive strength of all the mortar mixes were found to be higher as compared to the compressive strength at 3 days.
4. The compressive strength of the mortar mixes with replacement of cement with microsilica increased with increase in percentage of microsilica from 3% to 9%, but decreased to some extent at 12% of microsilica.

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