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Characteristics of Masonry Prepared with KM Soil as Fine Aggregate in Cement Mortar and Concrete Block

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Abstract Manufactured Sand (M Sand) has become a viable alternative for the river sand in the construction industry as a potential fine aggregate. The M Sand poses environmental implications as it is produced by crushing natural resources like stones. The extensive use of M Sand may also lead to a reduction in availability due to the depletion of natural rocks in the days to come. Hence, this study attempts to assess the feasibility of utilizing the clayey soil containing Kaolinite – Montmorillonite (KM) as a predominant clay mineral, as a replacement to the Manufactured sand in the preparation of cement mortar and cement block that are used in masonry construction. In the case of concrete block masonry units, the M Sand is replaced by 25%, 50%, and 100% with KM Soil, and an attempt is also made to produce the mortars by completely replacing the M Sand with KM soil. Further, the properties of the concrete blocks and mortars prepared with KM soil are assessed and compared with the ones prepared with M Sand. Also, the performance of the stack bonded masonry prisms like compressive strength and bond strength in shear is assessed for the various masonry prism prepared with combinations of the Concrete block masonry units and mortars. The results indicate that the stack bonded masonry prism assemblies with KM soil both in cement mortar and concrete block have performed moderately well in compressive strength and shear bond strength in comparison with the one prepared with M Sand.

Keywords Manufactured Sand, Kaolinitic Montmorillonite Clay Mineral, Mortar, Masonry Prism

1. Introduction

The construction industry that intends to improve the quality of life requires a significant quantity of the natural resources that are available on the earth. Sand is one such construction material that is widely used in concrete and mortar preparation due to its abundant availability and desirable properties. However, as the availability of sand is reducing in recent days the dependency on the alternatives like Manufactured Sand (M Sand) is increasing. M Sand is produced by crushing the stones that are obtained from rocks and by removing finer particles like dust. The stones are obtained from the quarrying process which has environmental implications like disturbance to the rock formation causing cracks and damage. Also, in the quarrying process, the landfills are dumped with the wastes like small blocks, and slurry [1]. The waste generated during the process of quarrying is about 60% of the blocks extracted. The wastes also cause health hazards like infection in respiratory tracks, ears, and eyes, near the quarrying area [2]. Further, as the natural resources are limited, the extensive quarrying to meet the demand of fine aggregate requirements of construction may also lead to the scarcity of the M Sand in the near future. Henceforth, a suitable alternative to the M Sand also needs to be developed progressively. Thus, this work emphasizes studying the feasibility of adopting abundantly available clayey soil as an alternative to Manufactured Sand in the preparation of cement mortar and concrete blocks that are essentially used in masonry structures. It is already established that the properties of mortar and masonry blocks have a significant impact on the performance of the masonry and in turn, the performance of the mortar and masonry blocks is dependent on the properties of the materials used in their preparation. Henceforth, assessing the properties of the materials and their influence is of great importance.

The clayey soil essentially consists of clay minerals which influence their behavior in presence of the moisture. The clay minerals are majorly classified into 4 groups viz., 1. The Kaolin group consists of clay minerals like kaolinite, halloysite, and nacrite; 2. Smectite group consisting of clay minerals like montmorillonite, and nontronite; 3. Illite group including clay minerals like micas; 4. Chlorite group. The clayey soil depositions also possess the combination of these clay minerals in different proportions.

As the clayey soil containing Kaolinite and Montmorillonite (KM) clay mineral is abundantly available in the region of study, the KM soil is adopted in the experimental work. The Kaolinitic mineral possesses a strong attractive force and the Montmorillonite clay mineral possesses a repulsive force making it swell in presence of moisture and shrink in absence of moisture thus, in KM soil the attractive and repulsive forces get either neutralized or will have minimum dominance. Also, the formation structure of KM soil is double layer therefore there exists a tendency to imbibe more water, which would help the plasticity characteristics of mortar and concrete block.

In this work, the properties of 1:3 Cement M sand mortars and 1:3 Cement KM soil mortars are compared. Also, the concrete blocks are prepared by replacing M Sand with KM soil in the various proportion of 25%, 50%, and 100%. Further, the properties like compressive strength, stress-strain characteristics, and shear bond strength of stack bond masonry prisms are assessed to analyze the viability of using KM soil as an alternative to Manufactured Sand.

2. Materials and Methodology

2.1. Cement

The 43 grade commercially available Ordinary Portland Cement (OPC) conforming to IS: 8112 - 1989 [3] is used in this experimental study. The cement used had a specific gravity of 3.15 and a consistency of 29%.

2.2. Fine Aggregate

The locally available Manufactured sand (M sand) with physical properties like the bulk density of 1428 kg/m^3, water absorption of 1.5%, and specific gravity of 2.65 is adopted. Figure 1 shows the curve of distribution of particle size obtained as per IS 2386 – 1963 [4] guidelines.

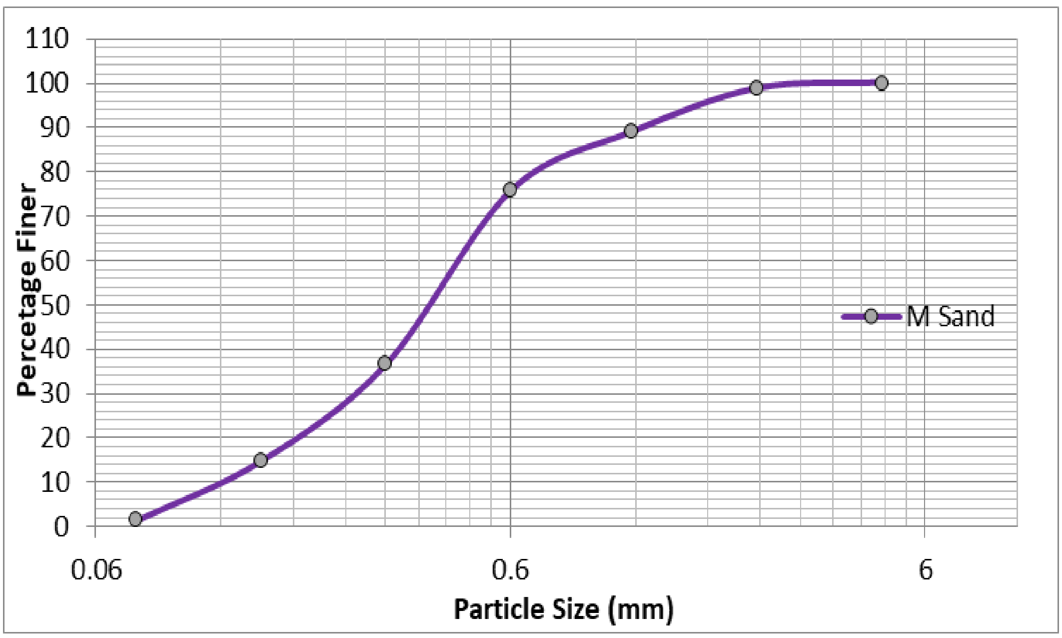

Figure 1. Particle Size Distribution Curve for M Sand

2.3. Coarse Aggregate

20 mm downsize crushed granite aggregate with 2.62 specific gravity is used as coarse aggregate.

2.4. Soil

The properties and behavior of clayey soils depend on the predominant clay mineral that they are made up of. Therefore, the clayey soil obtained from the various location were tested to identify the predominant clay mineral by using the Free Swell ratio (FSR) and liquid limit of soil obtained with water and non-polarized liquid as suggested by K. Prakash et al. [5]. According to K Prakash et al. [5], the ratio of swell in the volume of soil in water to swell in the volume of kerosene is known as the free swell ratio. They concluded that the predominant soil mineral in clayey soil can be assessed based on FSR as shown in Table 1. They also suggested that the degree of the expansiveness of clay soil can be assessed by the relation of the liquid limit of soil in distilled water and kerosene as shown in Table 2.

Table 1. Soil Classification - based on the Free Swell ratio and dominant clay Minerals [[5]]

Free swell ratio	Dominant clay Mineral
<1.0	Kaolinite
1.0-1.5	Kaolinite and Montmorillonite
1.5-2.0	Montmorillonite
2.0-4.0	Montmorillonite
>4.0	Montmorillonite

Table 2. Predominant Clay mineral based on Liquid Limit [5]

Relation between WLW and WLK	Dominant clay Mineral
WLW < WLK	Kaolinite
WLW > WLK	Montmorillonite
WLW = WLK	Kaolinite and Montmorillonite

* W_{LW}: Liquid limit in Distilled Water; W_{LK}: Liquid limit in Kerosene

Based on the methodology suggested by K. Prakash et al. [5] and by following the procedure mention in [6], the soil samples from the various location are categorized based on the clay mineral as shown in Table 3 and the soil sample containing K-M clay mineral is considered for study as it has both flocculant and dispersive forces which would nullify the effect of each other.

Table 4 shows the physical properties and Table 5 shows the proctor compaction test results of selected soil samples respectively by adopting the Indian Standard testing procedures [7][8][9][10]. Figure 2 represents the curve of the particle size distribution for KM Soil.

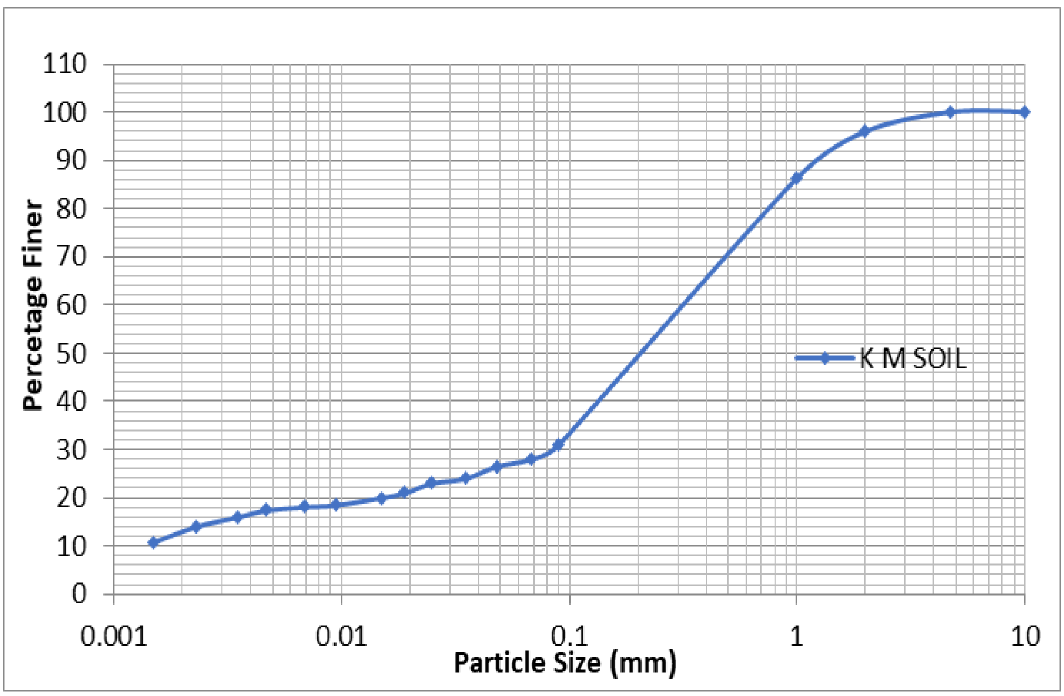

Figure 2. Particle Size Distribution Curve for KM Soil

Table 3. Categorization of Soil Samples

Sample of Soil	Specific Gravity (G)	Free Swell Ratio	Liquid WL (%)		Clay Mineralogy	Reason
			Distilled Water (WLD)	Kerosene (WLk)		
1	2.65	0.9	40	63	K	FSR range < 1.0 &WLW > WLK
2	2.61	1.6	44	40.5	M	FSR range > 1.5 & WLW < WLK
3	2.65	1.8	55	41.2	M	FSR range > 1.5 &WLW < WLK
4	2.6	1.2	36	36	K-M	FSR range 1.0 to 1.5& WLW = WLK

Table 4. Physical Properties of Soil

Properties	Results
Free Swell Ratio	1.2
Specific Gravity	2.6
Liquid limit (%)	36.5
Plastic limit (%)	20.9
Shrinkage limit (%)	13
Sand (%)	70
Silt (%)	16
Clay (%)	13

Table 5. Proctor Compaction Test Results

Properties	Results
Optimum Moisture Content (%)	12.75
Max. Dry Density (kg/m^3)	18.5

3. Study on Mortar

3.1. Mortar Flow Test

The mortar to be used in masonry should be workable (flow) to offer sufficient spread and to offer proper adhesion between masonry blocks. In this experimental work, the properties of 1:3 cement mortar prepared with M Sand and 1:3 cement mortar prepared with complete replacement of M Sand with KM soil are assessed and compared. The flow table test is adopted as per BS: 4551-1980 [11] to assess the workability. To attain sufficient spread, the mortar flow of 90% is tried achieved by varying the water content in the mix and the result of the mortar flow table test with the corresponding water-cement ratio is tabulated in Table 6.

Table 6. Mortars Flow Table Test Results

Type	Aggregate Type	Flow (%)	Water-cement ratio
CMS	NA	90	0.48
CKMSM	K-M Soil	90	0.6

*CMS: 1:3 Cement M Sand Mortar; CKMSM: 1:3 Cement KM Soil Mortar

3.2. Compressive Strength and Elastic Property of Mortar

The mortar with a desirable flow of 90% is tested for compressive strength as per IS: 2250 – 1981 [12]. Also, the stress and strain relationship for the mortars was assessed as per IS 516- 1959 [13] on cylindrical specimens of 150 mm height and 300 mm diameter which were cured for 28 days. The specimens were saturated in water for 48 hours before the testing. The longitudinal compressometer was used to calculate the change in length of the specimen. The modulus of elasticity of mortars was calculated from the initial tangent modules drawn at 25 percent of the ultimate stress on the stress-strain curve.

Table 7 lists the evaluated compressive strength and modulus of elasticity of the different mortars. The Compressive stress and strain variation curves for both the Cement mortar prepared with Manufacturing Sand and KM soil are represented in Figures 3 and 4 respectively.

Table 7. Mechanical Properties of Mortar

Type	Compressive Strength (MPa)	Modulus of Elasticity (MPa)
CMS	38.5	4816.7
CKMSM	14.42	3896.4

*CMS: 1:3 Cement M Sand Mortar; CKMSM: 1:3 Cement KM Soil Mortar

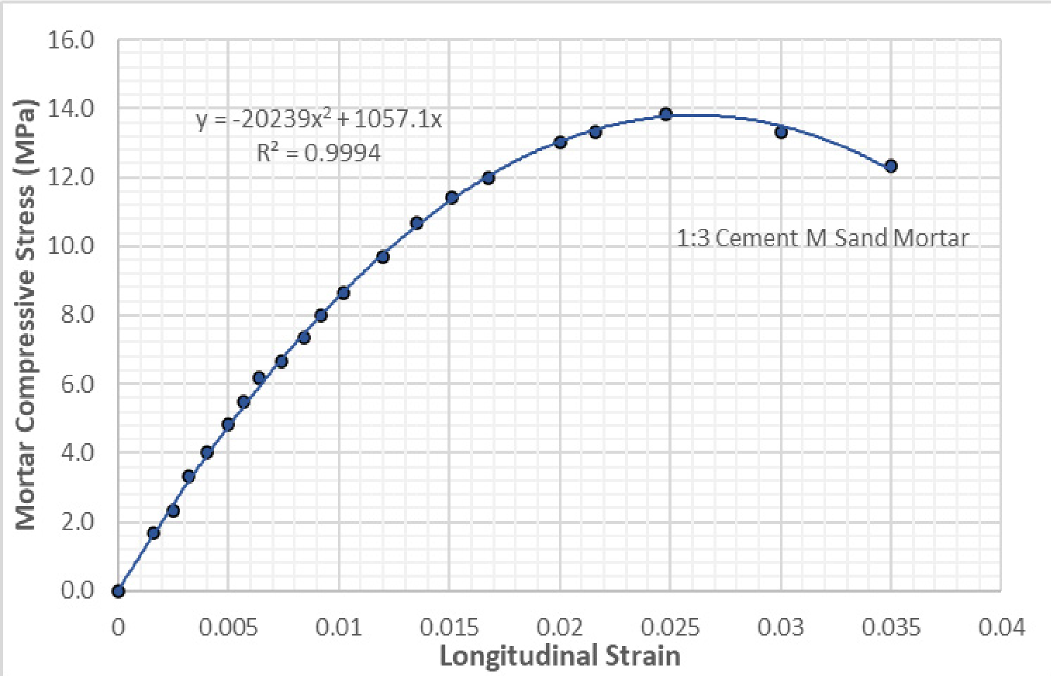

Figure 3. Compressive Stress v/s Strain variation curve for 1:3 cement M Sand mortar

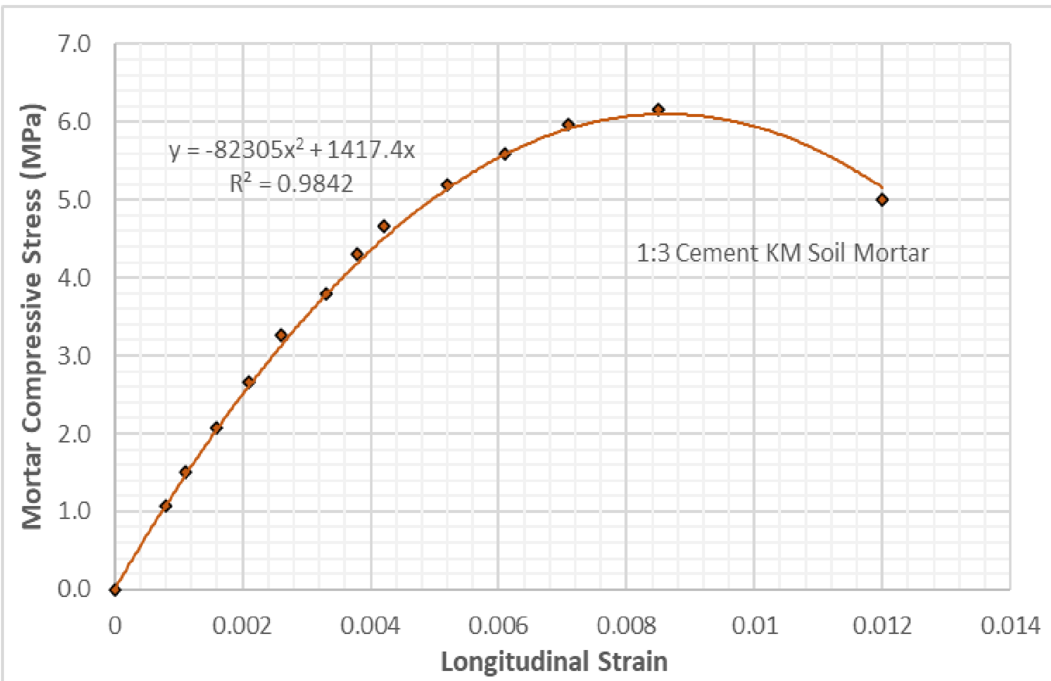

Figure 4. Compressive Stress v/s Strain variation curve for 1:3 cement KM Soil mortar

From Figures 3 and 4, it can be seen that the stress-strain curve is linear at lower stress levels and as the stress increase the curve becomes nonlinear showing softening behavior. The curve also shows a drooping portion in both the mortars showing ductile behavior. It is also observed that the elasticity modulus is sensitive to the compressive strength and hence the modulus of elasticity of 1:3 cement mortar with M sand is higher than that of 1:3 cement KM soil mortar.

4. Study on Concrete Block

As the masonry block is an essential part of masonry which influences the properties of masonry, an attempt is made to understand the properties of M40 concrete blocks that are produced by replacing the M sand with KM Soil in varying percentages of 25%, 50%, and 100%.

4.1. Compressive Strength and Stress-Strain Relation of Concrete Block

Compressive strength and Stress-Strain relationships of concrete block are a vital property, as it determines the bearing capacity of the element. The concrete M40 was adopted and the mix proportion was done as per IS 10262 -2000 [14] guidelines. The compressive strength and Stress-strain relationship were obtained for all the concrete blocks prepared with KM Soil and are compared with that of blocks prepared with M sand. The test is performed as per IS 516-1959 guidelines on concrete blocks of size 150x150x150 mm which are cured for 28 days. As shown in Figure 5, a 100 mm strain gauge and a 50 mm strain gauge are mounted to the saturated concrete block to measure longitudinal and lateral deformation respectively.

The variation of compressive stress versus longitudinal strain is plotted for each specimen as shown in Figure 6. The compressive strength and elasticity modulus calculated by plotting an initial tangent modulus at 25 percent of the ultimate stress is shown in Table 8.

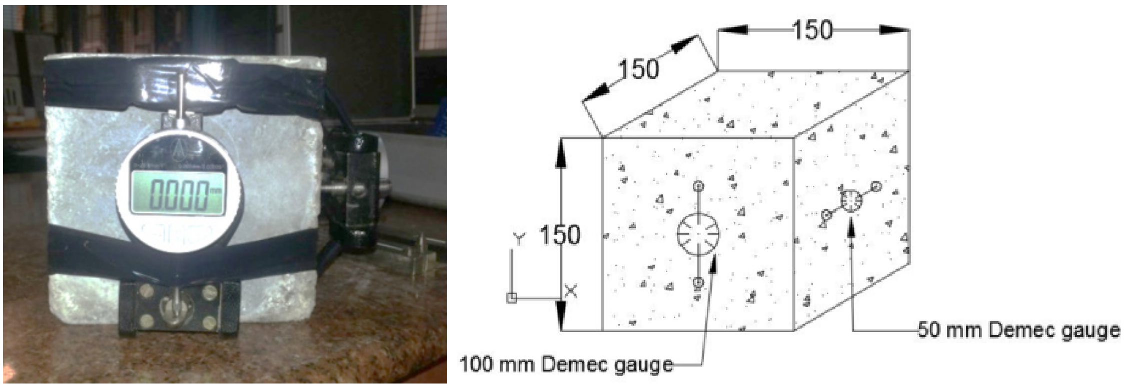

Figure 5. Set up to assess stress-strain relation and Poisson's ratio

Table 8. Properties of Concrete Block Masonry Unit

Block Type	Compressive Strength (MPa)	Modulus of Elasticity (MPa)	Poisson's Ratio (μ)
CB	41.7	37193.8	0.19
25KMSCB	35.10	18092.4	0.2
50KMSCB	32.30	15596.71	0.2
100KMSCB	27.10	10137.85	0.18

*CB: Control Concrete Block with 100% M Sand

*25KMSCB: Concrete Block with 25% KM Soil & 75% M Sand

*50KMSCB: Concrete Block with 50% KM Soil & 50% M Sand

* 100KMSCB: Concrete Block with 100% KM & 0% M Sand

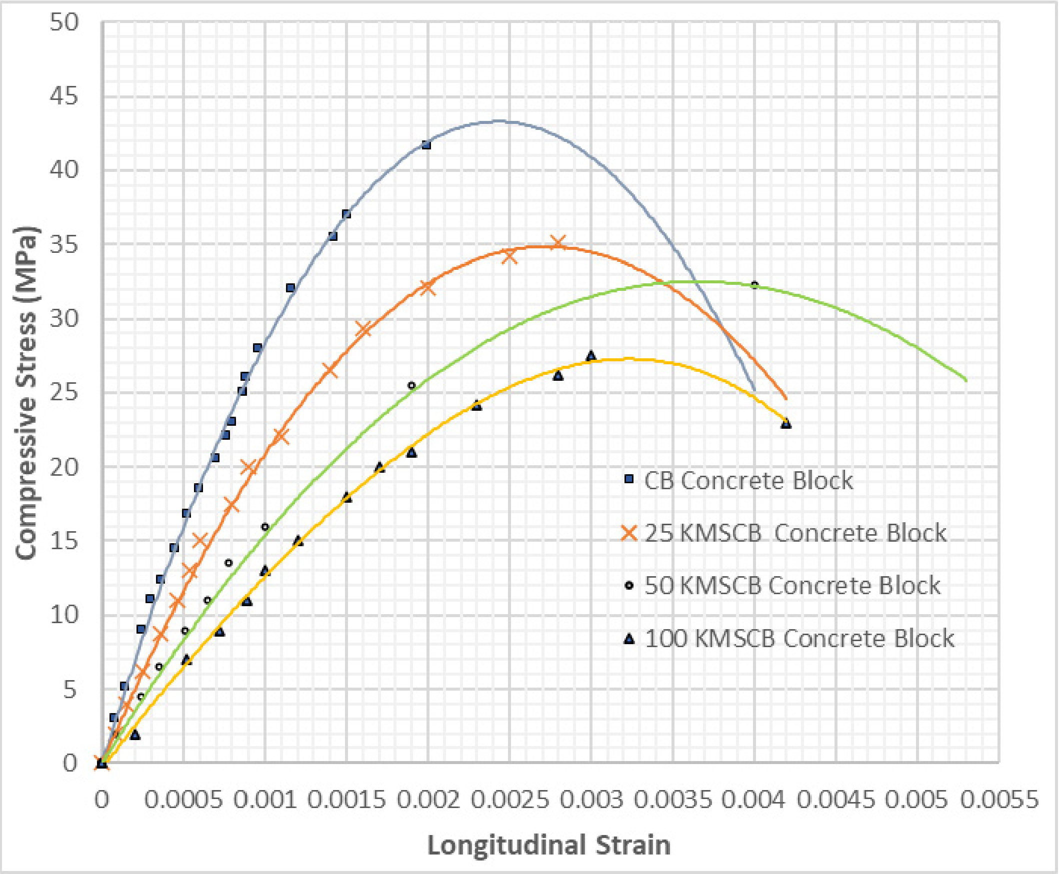

Figure 6. Stress-Strain Curve for various Concrete Block

Table 9. Types of Masonry Prisms

Type of Masonry Prisms	Type of block	Mortar
CB+ 1:3 CMS	CB	1:3 CM
25 KMSCB + 1:3 CMS	25 KMSCB	
50 KMSCB + 1:3 CMS	50 KMSCB	
100 KMSCB + 1:3 CMS	100 KMSCB	
CB + 1:3 CKSM	CB	1:3 CKMSM
25 KMSCB + 1:3 CKMSM	25 KMSCB	
50 KMSCB + 1:3 CKMSM	50 KMSCB	
100 KMSCB + 1:3 CKMSM	100 KMSCB	

*CB: Control Concrete Block with 100% M Sand

*25KMSCB: Concrete Block with 25% KM Soil & 75% M Sand

*50KMSCB: Concrete Block with 50% KM Soil & 50% M Sand

*100KMSCB: Concrete Block with 100% KM & 0% M Sand

*CMS: 1:3 Cement M Sand Mortar; CKMSM: 1:3 Cement KM Soil Mortar

It can be observed that as the percentage of KM clayey soil as a replacement for M Sand increases the compressive strength of the concrete block reduces. From Figure 6, it can be observed that as the percentage of KM soil in the concrete block increases the stress versus strain curve becomes horizontal which represents the ductile behavior.

5. Masonry Strength

Masonry is essentially made up of layers of masonry blocks and mortar between them. As the strength and deformation capabilities of the mortar and block are different, the composite action masonry also varies based on the properties of both block and mortar used in its construction. Henceforth, the properties of stack bond masonry prisms in compression and shear bond are assessed for various combinations of mortar and masonry units shown in Table 9.

5.1. Compressive Strength of Masonry Prism

The procedure and guidelines mentioned in the IS 1905 – 1987 [15] are adopted to assess the compressive strength of the concrete block masonry. According to the guidelines mentioned the minimum height of the prism should be 400 mm and the height to thickness ratio (h/t) should be in the range of 2 to 5. Henceforth, in this experimental work, an h/t ratio of 3.133 is provided by adopting the 3 nos. of concrete blocks of size 150 x 150 x150 mm and the mortar thickness of 10 mm between them. As the h/t ratio is more than 2, the correction factor of 1.2 is multiplied by the experimental result of compressive strength. The masonry prism setup used for the compression test as shown in Figure 7 is cured for 28 days before testing.

Table 10 shows the compressive strength of different prisms and the stress-strain curves are represented in Figures 8 and 9.

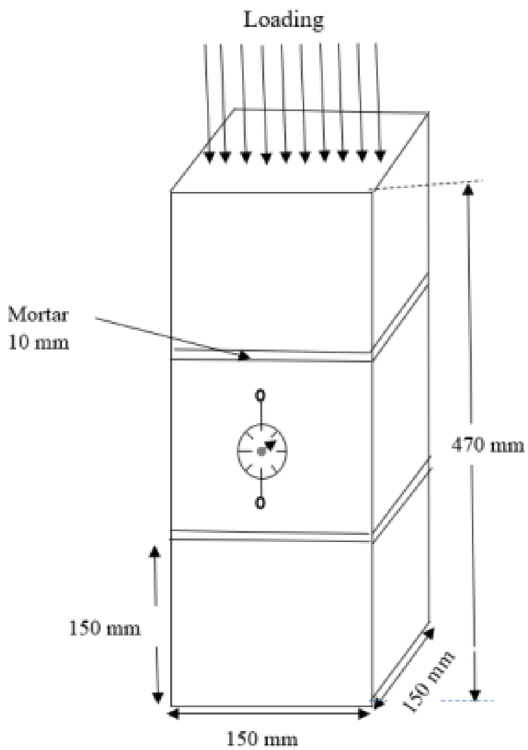

Figure 7. Masonry prism set up for Compression Test

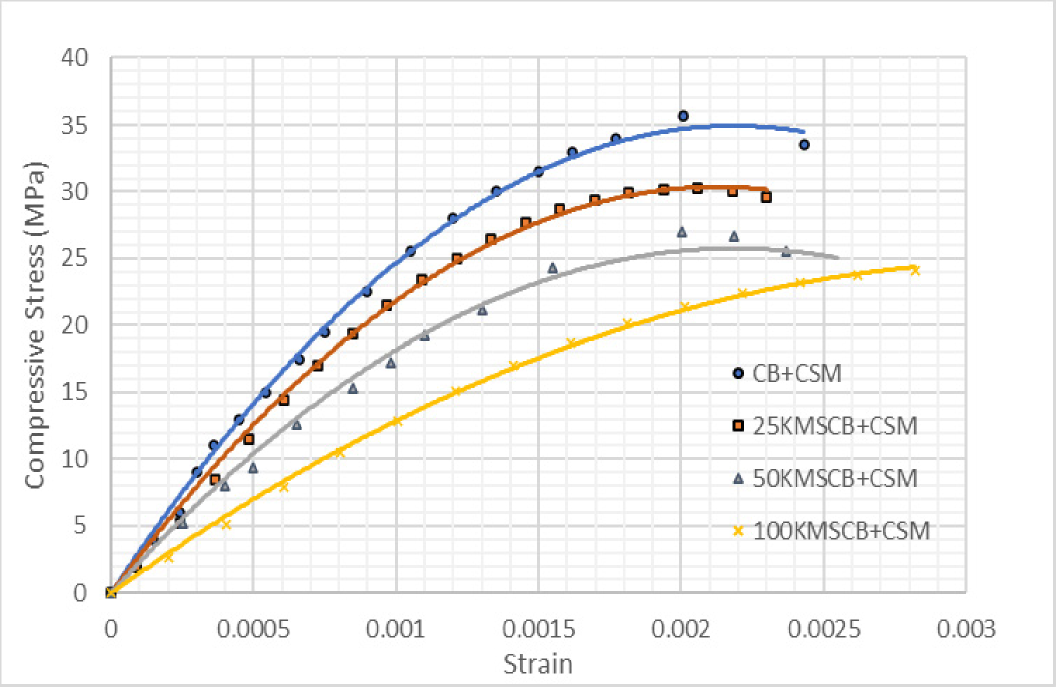

Figure 8. Stress-Strain Curve for Masonry prisms with various concrete blocks and Cement M sand mortar

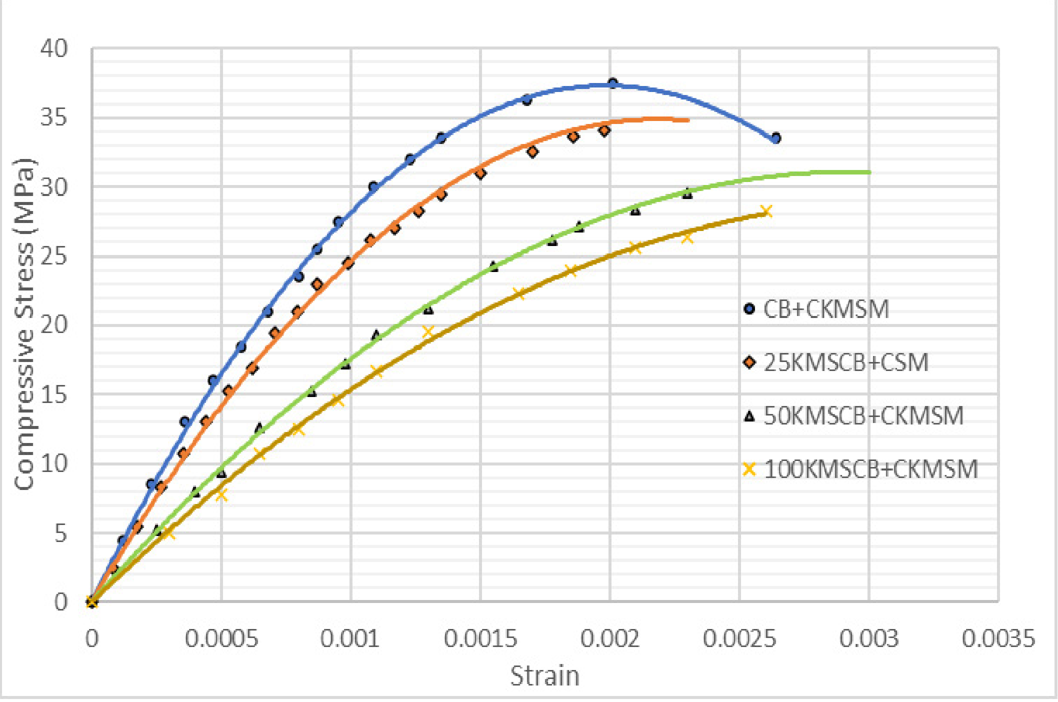

Figure 9. Stress-Strain Curve for Masonry prisms with various concrete blocks and Cement KM soil mortar

Table 10. Compressive Strength & Shear Bond Strength of Concrete Block Masonry Prisms

Type of Concrete Block and Mortar	Compressive Strength of Concrete Block (MPa)	Compressive Strength of Mortar (MPa)	Compressive Strength of Masonry Prism (MPa)	Shear Bond Strength (MPa)	Masonry Efficiency (η)
CB+ 1:3 CMS	41.70	38.5	35.76	0.42	0.71
25 KMSCB + 1:3 CMS	35.10	38.5	30.396	0.43	0.72
50 KMSCB + 1:3 CMS	32.30	38.5	28.727	0.41	0.73
100 KMSCB + 1:3 CMS	27.10	38.5	24.48	0.4	0.75
CB + 1:3 CKSM	41.70	24.14	36.84	0.58	0.74
25 KMSCB + 1:3 CKMSM	35.10	14.42	34.128	0.54	0.81
50 KMSCB + 1:3 CKMSM	32.30	14.42	29.52	0.5	0.76
100 KMSCB + 1:3 CKMSM	27.10	14.42	27.732	0.44	0.85

5.2. Shear Bond Strength of Clay Bricks Triplets in Different Mortars

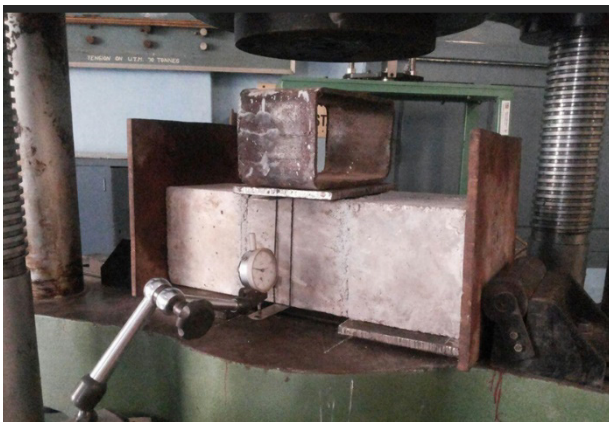

Figure 10. Shear Bond Strength Specimen Set Up

Under compression load the masonry failure is often followed by a bond failure between concrete block and mortar hence in this study the shear bond strength of masonry is assessed through masonry triplets as shown in Figure 10. The triplet block arrangement is made in such a way that the end blocks are restrained from movement whereas the middle block is free to move in the vertical direction thus shearing stress is induced in the mortar and mortar joint. A mortar thickness of 10 mm was maintained throughout and the triplets were cured in water for 28 days. The result of Shear Bond strength is represented in Table 10.

6. Discussions on Masonry Test Results

Figure 11 shows the variation of compressive strength of masonry prism for various combinations of mortar and masonry block. It can be observed that the masonry produced with Cement mortar with KM soil as a replacement for M Sand had better compressive strength when compared with the masonry produced with Cement mortar with M Sand. The property of the clayey soil to stiffen during the evaporation of mixing water might have had a positive implication on the bonding of the mortars produced with KM soil with concrete block. According to G. Sarangapani et al. [16], the bond strength has a proportional implication on the compressive strength of masonry. The test results of shear bond strength (Figure 12) also show that the masonry prepared with KM Soil mortar possessed a better bond than the mortar prepared with M Sand thus improving the compressive strength. Hence it can be concluded that the replacement of KM soil with M sand in cement mortar will improve the bond strength thus improving the compressive strength of masonry.

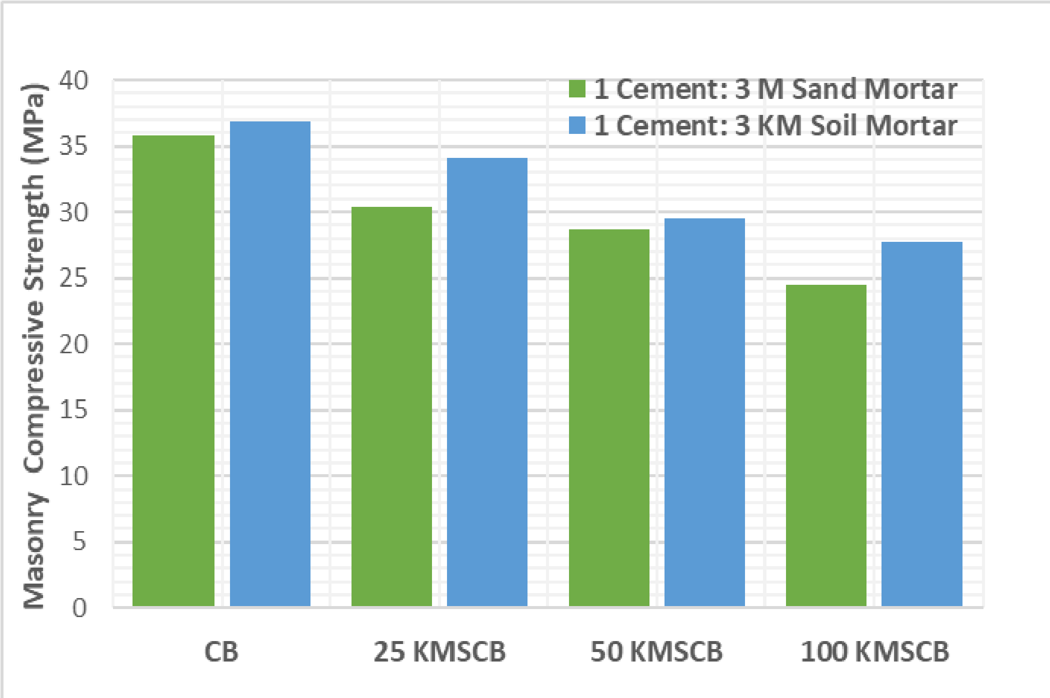

Figure 11. Variation of Masonry prism Compressive strength

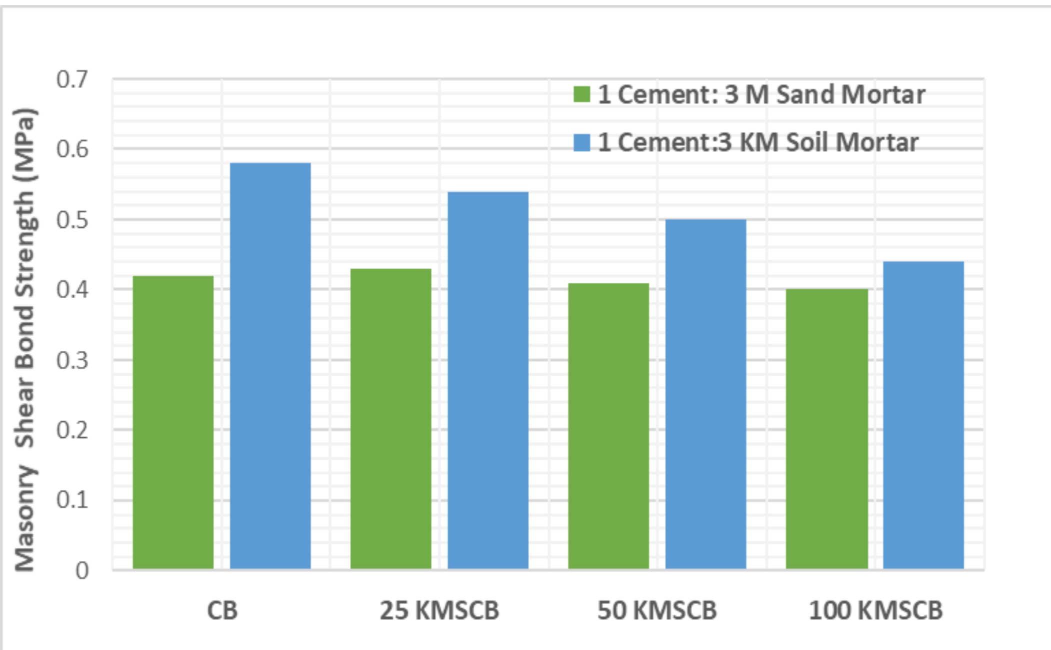

Figure 12. Variation of Masonry prism Shear Bond strength

7. Summary and Conclusion

The experimental work mainly focused on assessing the feasibility of replacing the M Sand with the clayey soil which has Kaolinitic Montmorillonite (KM) as the dominant clay mineral in the cement mortar and concrete block preparation. The effect of the replacement of M Sand with KM soil in mortar and concrete block on the performance of masonry was also studied.

The following conclusion is arrived on the basis of the study:

1. As the KM soil adopted in the study requires 20.9 percent of water by its weight to reach a plastic state, the water demand in the mortar and concrete mix increases as the percentage of replacement of KM Soil for M Sand in the mix increases. This may be due

to the reason formation as KM soil has a double-layered formation structure there exists a tendency to imbibe more water hence some quantity of mixing water is also utilized by the clay particles to reach a workable state.
2. The compressive strength and modulus of elasticity of the mortar and concrete mix decrease with an increase in the percentage of KM Soil in the mix. This may be due to the reason that the composition of the soil may not contribute to the hydration of the cement particles.
3. Though, the compressive strength of the mortar and concrete block prepared with KM soil as fine aggregate is inferior in comparison with the one prepared with M Sand its performance in masonry in composite action is better.
4. The cohesive nature of KM Soil has a positive influence on the bond between mortar and block, thus the performance like compression and shear bond strength of masonry prepared with the concrete block and mortar consisting of KM soil is better than the masonry prepared with conventional M Sand cement mortar and concrete block.
5. The efficiency of the masonry prepared with KM Soil as a replacement to the M Sand in mortar and concrete block is better than the one prepared with the M Sand.
6. The KM soil can be used as an alternative for M Sand in preparation of cement mortar and concrete block which can be effectively used in masonry without compromising on the performance and efficiency of the masonry. Wherein, 25 percentage replacement of KM Soil with M Sand in the concrete block preparation is found to be optimum.

8. Scope for Future Research

The experimental study and conclusion of this study pave the way for the following future research scopes:

1. The nonlinear analysis on the masonry constructed with concrete block and mortar with KM soil can be attempted to understand the behavior of the masonry beyond the elastic limit of the stress strain curve.
2. The parameters obtained in the study can be considered to analyze the lateral and shearing stress the masonry by stimulating the stack bonded masonry prism through Finite Element Analysis software tool.
3. An attempt can be made to establish the effectiveness of the masonry constructed with concrete block and mortar with KM soil in real world application by testing the masonry wallet for compression loading with a loading frame setup.

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