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STRENGTH BEHAVIOR OF SUBGRADE SOIL MIXED WITH SAND MANUFACTURING DUST AND FIBER

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ABSTRACT

This paper introduces the potential of sand manufacturing dust (SMD), generated during the production of manufactured sand, in pavement applications. An attempt has been done to improve the subgrade properties of weak soil, with the addition of SMD and along with polyvinyl alcohol (PVA) fibers. The introduction of new materials, the design of experiments, further analysis and interpretation from the research content of this manuscript. The optimum percentage of SMD and the PVA fiber to be added to the soil for better performance of subgrade is estimated and their suitability for use in pavement construction has been demonstrated. It was observed that addition of 10% of SMD to the soil performed better in terms of California bearing ratio (CBR). A series of tests were conducted with 10% SMD, 3% cement and varying percentages of fiber (0, 0.5%, 1%, and 1.5%). The performance has been evaluated in terms of CBR, unconfined compression strength (UCS) tests, split tensile tests and cyclic triaxial test. The test results indicated that the soil stabilized with SMD and PVA fibers performs better under both static and dynamic loadings. The improvement in strength with suggested modifications was found to be very significant (up to 50-fold increase).

Key words: Subgrade, polyvinyl alcohol fiber (PVA), sand manufacturing dust, California bearing ratio, cyclic loading.

1. INTRODUCTION

The subgrade is an important component in pavements as it acts as a supporting layer for the vehicular loads. Since all the loads are finally to be carried by the subgrade, the subgrade layer should have sufficient stability when subjected to repeated loadings and should perform better under severe climatic conditions. Most of the highway agencies consider soil subgrade properties in the design of pavement. The subgrade soil should be adequate enough to provide a stable platform to construct the track, limit progressive settlement from repeated traffic loading, and prevent massive slope failure (Li 2004). Due to rise in population and infrastructure, laying of roads in regions with poor subgrade soil properties has become inevitable. Therefore, it is necessary to improve the subgrade properties for improving the pavement performance.

Several studies were conducted in the past on the utilization of wastes on stabilization of soils. Amadi (2014) studied the effect of curing time on strength development in the black cotton soil — Quarry fines composite stabilized with cement kiln dust (CKD). Their findings indicated a general increase in UCS values with increasing CKD content as well as the curing time for soil mixtures. The suitability of fibers in soil reinforcement has been established by various researchers in the past (Gray and Ohashi 1983; Shewbridge and Sitar 1989; Bauer and Fatani 1991; Santoni *et al*. 2001). Kumar and Gupta (2016) studied the effect of the addition of rice husk ash, pond ash, cement and fiber on the compaction, and strength behavior of clay. They observed that inclusion of fiber to the soil caused an increase in the unconfined compressive strength and split tensile strength. Chauhan *et al*. (2008) investigated the suitability of subgrade soil modified with fiber (coir fiber and synthetic fiber) by considering strength as the major criterion. They reported that the permanent as well as the resilient strains reduced with the decrease in confining pressure while it increased with increase in the deviator stress and number of load cycles. Lekha *et al*. (2015) studied the effect of randomly spread areca nut fiber in the properties of subgrade soil and concluded that the areca nut fiber reinforced cement soil mix can be used for low volume roads (traffic ≤ 1 million standard axles). Yetimoglu (2003) studied the effect of the addition of randomly distributed fibers on the shear strength property of sand. The test results revealed that the addition of fiber reinforcement had a negligible effect on the initial stiffness and the peak shear strength of the sand. However, fiber reinforcement helped in reducing the soil brittleness as a result of which the post-peak shear strength was slightly reduced. Ranjan *et al*. (1994) observed that the stress and deformation behavior of sand reinforced with randomly distributed fiber depends mainly on the fiber properties and the friction developed on the fiber-sand interface. They found that the samples made by the composition of sand and fibers failed at critical confining stress and the shear strength increased with increase in fiber content. Cai *et al*. (2006) investigated the effect of lime and polypropylene fiber in the soil for reducing the brittleness of soil. They found that the UCS and direct shear results increase with an increase in the lime and fiber percentage. Several other studies established the suitability of using fly ash and bottom ash in subgrade soil with fibers (Kumar and Singh 2008; Kumar *et al.* 2007; Karthikeyan *et al*. 2018; Sudhakaran *et al*. 2018).

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Traditionally, stabilizers and additive are proven technology to improve the engineering properties of the soil. In the present study, a new stabilizing material is introduced which is available as a byproduct from sand manufacturing units. The manufactured sand is produced by a series of processes which includes crushing of rocks in crushers, removal of the very fine particles and dust that can cause cracks in concrete. A large quantity of these dust left after production of manufactured sand is stockpiled in sand manufacturing units. This material can be utilized as a stabilizer to soil, which will reduce the disposal problems arising out due to the stockpiling of these waste materials. We term this dust produced during production of manufactured sand, as sand manufacturing dust (SMD). Polyvinyl alcohol (PVA) fiber is a synthetic fiber which performs better than other fibers such as polypropylene fiber, polyester *etc*. with respect to tensile strength, weather resistance, and chemical resistance.

This paper investigates the suitability of using SMD and polyvinyl alcohol (PVA) fibers in subgrade soil to improve the strength characteristics under static and dynamic loading. A fixed quantity of cement (3%) was used as a binding agent. PVA fibers of 6 mm cut length were varied in quantity from 0.5% to 1.5%. Test specimens were cured for 28 days after which they were subjected to California bearing ratio (CBR) tests, unconfined compression strength tests (UCS), split tensile tests and cyclic triaxial tests. This paper presents the details of experimental investigations and the results obtained of a typical subgrade section.

2. EXPERIMENTAL INVESTIGATIONS

2.1 Materials

2.1.1 Soil

Soil sample investigated was collected from Ettimdai region, Coimbatore. The properties of the soil and their grain size distribution are shown in Table 1. Indian Standards (IS): 2720 for 'Method of Test for Soils' published under separate parts for various determinations have been followed for the characterization of soil sample. The soil can be classified as SC (Clayey Sand) as per Unified Soil Classification System (USCS).

Table 1 Properties of soil and SMD

Properties	Soil	SMD
Liquid limit	36%	Non-plastic
Plastic limit	28%	Non-plastic
Specific gravity	2.7	2.2
Optimum moisture content	12%	–
Maximum dry density	2,050 kg/m^3	–
Gravel content (> 4.75 mm)	1.2%	–
Sand content (4.75 ~ 0.075 mm)	59%	2%
Silt + clay (< 0.075 mm)	39.8%	98%

2.1.2 Stabilizer: Sand Manufacturing Dust (SMD)

The soil stabilizer used in this study was obtained from a local sand manufacturing unit located in Thodupuzha, Kerala, India. This material is generated while producing manufactured sand which is used as an alternative to river sand in Kerala. The specific gravity of the SMD was found to be 2.2. Manufactured sand is produced by crushing of rocks in crushers. Then screening is done to get sand particles of the desired size and the obtained aggregates are washed to eliminate very fine particles which are undesirable for concrete. The properties of SMD are presented in Table 1 (as per IS: 2720).

2.1.3 Fibers

Polyvinyl alcohol fibers (Fig. 1) were used as reinforcing material throughout the study. The fiber diameter was 2.2 dtex. The cut length of the fiber used in this study was kept as 6 mm. The tensile strength and modulus of elasticity of the fiber was 13cN/dtex and 280 cN/dtex. The specific gravity of the fiber was specified as 1.3.

Fig. 1 Polyvinyl alcohol fibers

2.1.4 Cement

The pozzolanic Portland cement (PPC) manufactured by ACC Ltd. was used in this present study. Grade of PPC cement as per IS 1489 is equivalent to grade of OPC-33.

2.2 Experimental Program

A series of laboratory tests were conducted on the soil modified with different percentages of SMD and fiber with a fixed quantity (3%) of cement. The test performed includes compaction tests, CBR tests, UCS tests, and split tensile tests. The fiber content was varied in different percentages (0.5%, 1%, and 1.5%) by dry weight of the soil. The specimens were prepared at optimum moisture content (OMC) and were tested after curing it for 28 days.

2.2.1 Compaction Tests

Standard Proctor tests were conducted on soil-SMD mixtures to determine the OMC and maximum dry density (MDD). The tests were performed according to Indian Standard specifications for a modified Proctor compaction test IS: 2720 (Part V11)-1980. The OMC of the mixtures was found to be 10.5%, 8.3%, 9% and 10% for 0%, 10%, 20% and 30% of SMD content, respectively. The corresponding MDD was found to be 2070, 2220, 2090 and 2070 in kg/m^3. It is to be noted that there is negligible change in OMC with addition of varying percentage of SMD whereas the MDD was found to be maximum for 10% SMD content.

2.2.2 California Bearing Ratio Tests

The tests were conducted according to Indian Standard Specification for laboratory determination for CBR, IS 2720 (Part 16)-1987. The CBR tests were conducted for various percentages of SMD, soil, cement and fiber mixtures. The specimen was heavy compacted at optimum moisture content and was cured for 28 days in the standard CBR mold. CBR values of untreated soil and modified soil with different percentage of stabilizers (SMD) were found by performing California bearing ratio tests. With the optimum percentage of stabilizer and soil, the fiber percentage was varied with and without the inclusion of a fixed quantity of cement and its effect was studied.

2.2.3 Unconfined Compressive Strength Tests

Unconfined compressive strength (UCS) tests were carried out on cylindrical specimens of 39 mm diameter and 78 mm long as per IS 2720, Part 10 (1991). Three samples were prepared for each test considering the MDD and OMC of the mix obtained from the compaction tests mentioned above. The soil-SMD mixture was mixed properly in dry state and then required amount of water was added and mixed again. Proper care was given to arrive at a uniform mix. The prepared mixes were then placed inside the mold, compacted and then extracted. The soil samples with 10% SMD, 3% cement and varying percentages of fiber (0%, 0.5%, 1%, and 1.5%), were compacted at optimum moisture content and maximum dry density. All the samples were tested according to IS: 2720 (Part 10)-1991. Three specimens for each mix proportion were tested, and the average of the three values was taken as the UCS.

2.2.4 Split Tensile Strength Test

Evaluation of tensile strength is also important since the pavement can be subjected to tensile stresses due to wheel load, seasonal variations, alternate wetting and drying cycle and shrinkage. Addition of polyvinyl alcohol fibers in the subgrades can improve the tensile strength of the subgrades. The mix proportion and size of samples used for split tensile tests were similar to that of UCS sample as discussed. The split tensile strength is calculated according to IS 5816:1999, as below:

$$T = \frac{2P_{\max}}{\pi\, dL} \tag{1}$$

where T is the split tensile strength; $P_{\max}$ is the maximum applied load; L and d are length and diameter of the specimen respectively.

2.2.5 Cyclic Triaxial Compression Test

The dynamic loading on the pavement can be generated due to movement of traffic, earthquake or vibrations induced by heavy equipment operating nearby. Hence it is necessary to study the behavior of subgrade soil when it is subjected to cyclic loading. The samples with different mix proportions were subjected to cyclic loading and their effect with respect to time as well as their behavior in terms of deflection was studied. Cylindrical specimens of 50 mm diameter and height 100 mm prepared at optimum moisture content. Cyclic triaxial compression tests were conducted according to ASTM-D3999/D3999M, under confining pressure of 100 kPa and loading frequency of 1 Hz. The cyclic triaxial compression test was conducted under unconsolidated undrained (UU) condition.

2.3 Results and Discussions

2.3.1 California Bearing Ratio Tests

The CBR values of soil sample with varying percentage (0%, 10%, 20%, 30%) of SMD are shown in Fig. 2. It is evident that the soil mixed with 10% stabilizer (SMD) shows better performance in terms of CBR and hence the quantity of SMD for further investigations was fixed as 10%. This may be due to the maximum dried density of compacted samples of soil and SMD mixtures at 10% SMD. The significant increase shown in the CBR values ensures that the subgrade performance can be increased with the addition of 10 percent of SMD. Amadi (2014) in his studies with the addition of 10 percent quarry fines obtained similar results. In a study by Nagraj and McManis (1997), the addition of fiber in the sand and clay mixtures have resulted in significant increase of CBR.

Further CBR tests were conducted on soil-SMD mixture with different percentages of fiber (0.5%, 1%, and 1.5%) with and without cement (3% by dry weight of soil). The variation of CBR value of soil-SMD mixtures with different percentage of fiber without cement is presented in Fig. 3. It is observed that the addition of fiber leads to the increase in CBR of soil-SMD mixture. As CBR is the resistance to penetration, increase in CBR with increase in fiber content may be attributed to increase

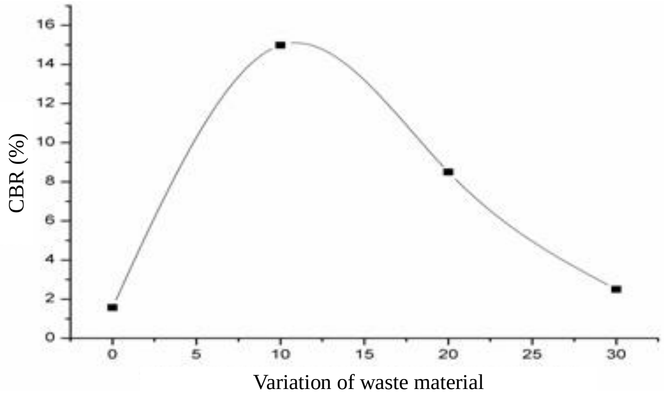

Fig. 2 Plot for finding optimum quantity of SMD to be used from CBR values

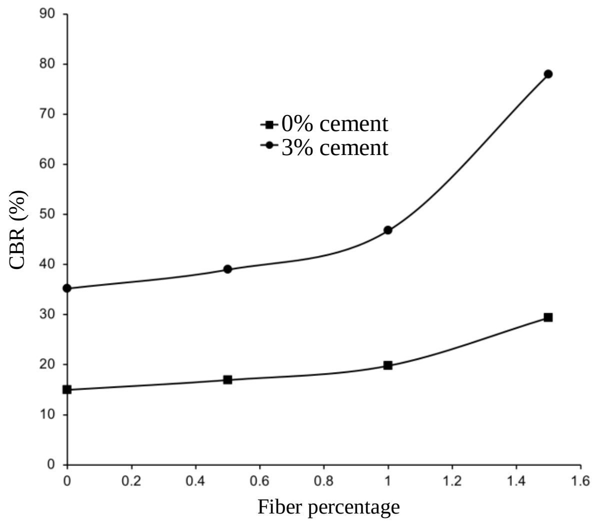

Fig. 3 Variation of CBR values with respect to increase in fiber percentage, with and without cement

in frictional interaction between fiber and soil particles (Sarbaz *et al*. 2014). Increase in friction between soil and fiber reduces the ability of the soil particles to change their position around fibers (Nagraj and McManis 1997). The CBR results obtained by addition of PVA fibers and SMD in the present study is found to be higher than that obtained by addition of fly ash and PP fibers as reported by Kumar and Singh (2008).

Further CBR tests on soil-SMD-fiber mixtures were done with addition of 3% cement after curing for 28 days. Since cement was introduced, curing was required to achieve strength due to pozzolanic and hydration reactions. These results are also presented in Fig. 3. It is found that the CBR value had a significant increase of 150% with addition of cement. This may be due to the hydration reaction of cement with soil leading to the improved strength of soil-SMD mixtures. IRC 37 (2012) recommends a minimum CBR value of 8 percent for the subgrade soil of roads having traffic of 450 commercial vehicles per day or higher. The CBR value which initially was 1.57% for untreated soil increased to 77.94% with addition of 10% SMD, 3% cement and 1.5% fiber. Hence it is evident that the suggested modification can effectively improve the soil subgrade for road pavements with high traffic loads.

2.3.2 Unconfined Compression Strength Tests

UCS tests were performed on untreated soil sample as well as soil samples with 10% of SMD, 3% cement and different percentages of fibers (0%, 0.5%, 1%, and 1.5%). The samples specimens were prepared at optimum moisture content and cured for 28 days. Figure 4 shows the stress-strain plot for soil sample with 10% SMD, 3% cement and different percentages of fiber.

Figure 5 shows the variation of UCS of soil-SMD mixture with respect to fiber content. UCS value increased to 1326.8 kPa from 23 kPa (untreated soil sample) after the suggested modifications for samples made of 1.5% fiber. From the obtained results it is clear that with the inclusion of fiber the UCS values of the soil sample were considerably increased. Similar studies were carried out by Chauhan *et al.* (2008) in performance evaluation of silty sand modified with fly ash and fiber (coir fiber and synthetic fiber). Compared to the present study the increase was slightly lower when fly ash was used as a stabilizer in place of SMD. Tang *et al*. (2007) reported that the fiber reinforcement within soil increases the UCS value and axial strain at failure.

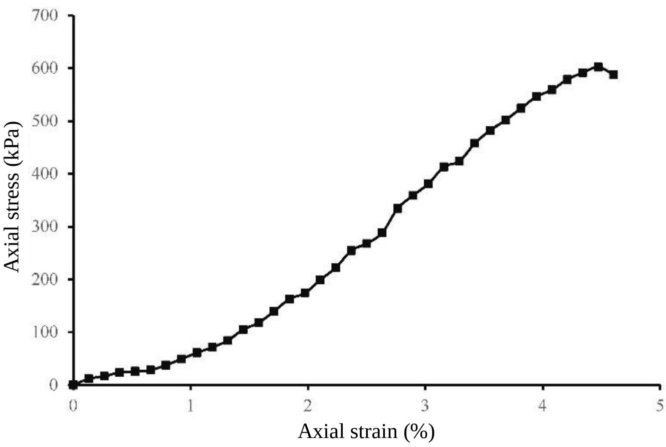

Fig. 4 Stress-strain relationship for UCS soil sample with 10% SMD, 3% cement and 0.5% fiber

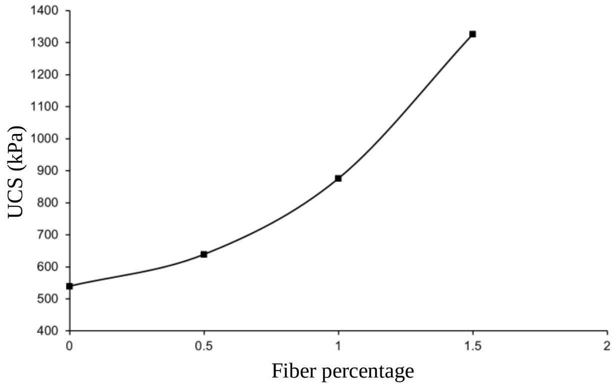

Fig. 5 Effect of fiber on soil samples with 10% SMD, 3% cement and different percentage of fibers

2.3.3 Split Tensile Tests

The setup for split tensile test is shown in Fig. 6. The average split tensile values obtained for samples with 10% SMD, 3% cement and different percentages of fiber are shown in Fig. 7. It can be seen that the tensile strength increased with increase in the amount of fiber. This indicates that PVA fibers could efficiently take up the tensile load acting on the soil sample. Split tensile value increased to 214 kPa from 63.1 kPa after the suggested modifications of samples with 1.5% fiber. The fibers act as bridging agents to hold the soil particles together which enables the soil to carry higher tensile stress. The increase in split tensile strength of soil modified with SMD and fiber reflects its ability to carry the tensile stress developed in the subgrade due to vehicular movement.

Fig. 6 Split tensile test setup

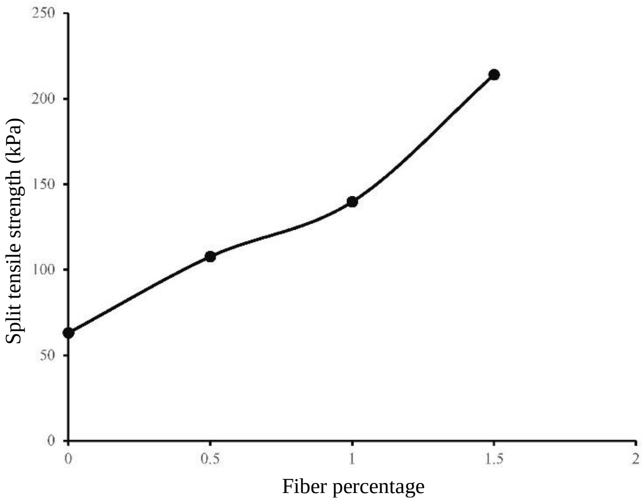

Fig. 7 Effect of fiber on soil samples with 10% SMD, 3% cement and different percentage of fibers

2.3.4 Cyclic Triaxial Tests

Cyclic triaxial tests were performed on soil samples with 10% SMD, 3% cement and different percentages of fibers after curing for 28 days. The variation of deviatoric stress versus axial strain; displacement versus time in seconds and displacement versus the number of cycles were studied for different mix proportions for twenty loading and unloading cycles. The variation of deviatoric stress versus axial strain for a typical sample with 0.5% fiber and 10% SMD is shown in Fig. 8.

The behavior of samples with different percentages of fiber with respect to time is shown in Fig. 9. It is observed that for the same number of cycles the samples made of 1% fiber performed better in terms of displacement. The cyclic test results show that the modified soil subgrade can perform better when it is subjected to repeated loading. The performance under repeated loading is important in pavements since it is always subjected to moving traffic.

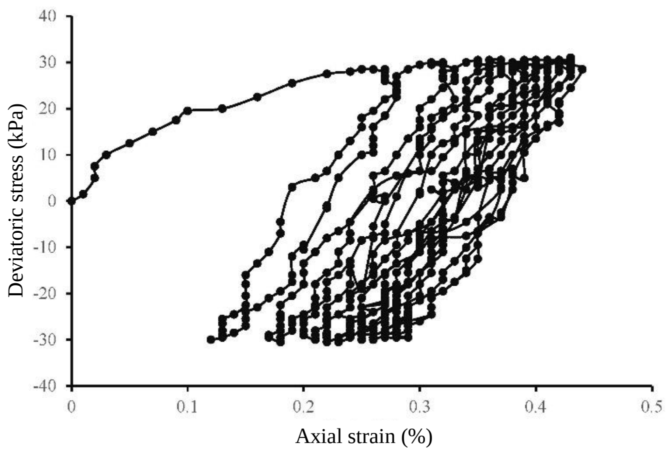

Fig. 8 Variation of deviatoric stress versus strain on soil samples with 10% SMD, 3% cement, and 0.5% fiber

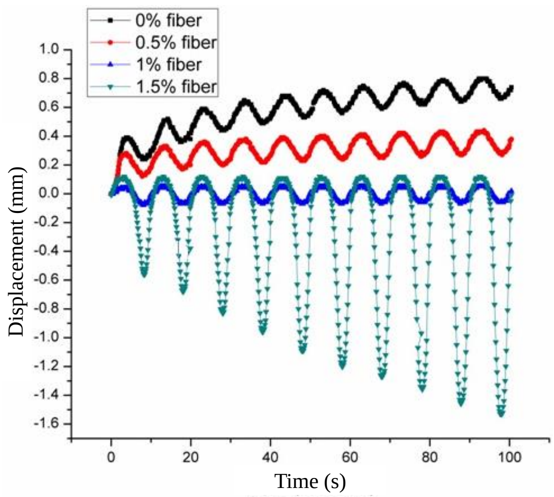

Fig. 9 Variation of displacement versus time for soil samples with 10% SMD, 3% cement, and different percentages (0, 0.5%, 1%, and 1.5%) of fibers

3. CONCLUSIONS

In the present study, the suitability of SMD obtained from the production of manufactured sand and PVA fiber in improving the subgrade performance was studied. Based on the test results of CBR, UCS Tests, split tensile tests, cyclic triaxial tests, following conclusions were derived from the present study.

1. Addition of 10% SMD to the soil gave better CBR value whereas further addition of SMD decreased CBR value considerably.
2. With addition of 10% SMD, 3% cement and 1.5% fiber, there was a 50-fold increase in the CBR value compared to that of untreated soil. This highlights the fact that SMD-cement-fiber combination has the ability to increase the CBR value of soil subgrade significantly.
3. Similarly, 58-fold increase in UCS value was observed with the suggested modifications of soil sample with 10% SMD, 3% cement and 1.5% fiber.
4. The average split tensile strength was found to increase by 250% approximately. with the addition of 1.5% fiber which highlights the efficacy of PVA fibers in carrying the tensile load acting on the soil.
5. From the cyclic triaxial results, it was seen that the soil samples made of 1% fiber, 10% SMD and 3% cement performed better under repeated loading.

The CBR, UCS values, as well as the split tensile values, increased with the suggested modifications which highlight efficacy of SMD and PVA fiber in enhancing the strength behavior of soil subgrade.

At present, many countries are paying attention towards recycling of natural resource and manufactured sand is becoming an alternative choice for engineering construction. As a result, the number sand manufacturing units are considerably increasing which may lead to availability of sand manufacturing dust (SMD) in abundance. The present study is first of its kind in demonstrating the possible application of SMD in geotechnical engineering. The results are quite promising and imply that SMD can be effectively used as a stabilizing agent in subgrade soil. Further investigations are recommended to explore the potential utilization of SMD in other geotechnical applications.

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