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Sub-grade Characteristics of Flexible Pavements Incorporating Shredded Face Mask in Clayey Soil

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Abstract

Due to disposal concerns, an enormous quantity of personal protective equipment (PPE) waste from the COVID-19 pandemic constituted a severe health and environmental risk. During the pandemic, the usage of protective suits increased dramatically raising concerns about how to dispose of them to safeguard the environment. This research work uses shredded face masks (SFM) to stabilise clayey soil for sub-grade usage. Shredded face masks are added to clayey soil to investigate consistency limits, compaction characteristics, unconfined compressive strength (UCS), and California bearing ratio (CBR). Laboratory experiments demonstrate that clayey soil geo-technical characteristics such differential free swell, consistency limits, UCS, and CBR values have improved. Based on the CBR results, the IITPAVE software is used to design flexible pavement thickness, which was reduced for various commercial vehicles per day for all combinations. Cost analysis is also done to determine the total cost for a 1000-meter stretch. The results show that addition of SFM to clayey soils strengthen the geo-technical properties of clayey soil as the UCS values increase for all curing periods of 3, 7, and 28 days with a maximum improvement of 64% for 28 days curing for 1% SFM content. Also, the CBR value is found to be increased from 1.96% to 6.72%.

1. Introduction

The most vital source of construction is soil in every aspect but it is not necessary that all the soils present in nature are useful for construction purposes [1]. Clayey soils, which are commonly found in arid and semi-arid areas, have a dual shrinkage and swelling behaviour. The fluctuation in water content causes a considerable change in volume in clayey soils, making it difficult to employ as a construction material [2]. The clayey soils contain clay minerals like montmorillonite that shows huge swelling. The clayey soils have various problems like poor shear strength and large shrinkage and expansion in volume with changing seasons [3]. In the past, a variety of approaches such as ground improvement and soil reinforcement were used in order to address the challenging nature of clayey soils and find a solution to the problems that they cause. The best geo-engineering method for enhancing soil's stiffness and strength is soil reinforcement [4]. It is especially effective in regions with soft soil which cannot support any structure or building well. When the soil layers are weak and the soil is sensitive this technique is used. Fibre-reinforced soil is regarded as a successful ground-improvement technique. Soil reinforcement can be achieved by using a variety of methods including geotextiles, soil nailing, and fibre reinforcement. As a result, we may make the soil more durable, stable, and free of settlement with the help of soil reinforcement. A lot of waste materials as a reinforcement to poor soils have been used in the past such as polypropylene, polyester, geo-grid, geotextiles, geo-membranes, natural and artificial fibres, etc. [4-7]. Adding polypropylene fibre reduced the plastic limit by nearly 12%, resulting in increased shear strength, cohesion, and homogeneity, as well as a reduction in soil shrinkage limit [4]. Clayey soil that had polyester fibre added to it had an improvement in its ideal

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moisture content but it had a decrease in its maximum dry density [5]. Adding jute-geotextile and pond ash to sand increases the bearing capacity of sand [6]. Incorporating brick kiln dust along with sisal fibre into clayey soil improves the geo-technical parameters and develop an effective subgrade material [7].

Covid-19, which was identified in China, was affirmed an epidemic by WHO (World Health Organization), and various measures were taken to prevent the virus from spreading further around the world. Since then, governments from numerous countries have tried a variety of measures to restrict the virus's spread. The most effective strategy was lockdown which meant staying at home, and other preventive measures included social distancing, avoiding crowded locations, avoiding travel, maintaining good cleanliness, and wearing surgical face masks. The use of sterilised face mask waste materials is a feasible solution for improving soil properties to reduce Covid-19 generated waste challenges [8]. Few research works have been conducted till now to evaluate Covid-19 produced waste and to find a suitable alternative for its control [1], [9-10]. The Black cotton soil was stabilized using banana fibre and disposable face masks. The work was carried out by adding 0.4% banana fibre and varying percentages of 0.5%, 1%, and 1.5% disposable face masks to enhance strength characteristics [1]. The study revealed that the stabilization of fat clay by adding face masks (0.9%) as fibre reinforcement and silica fume (12%) as the cementitious additives is vital option for increasing strength characteristics [9], [16, 17]. The rutting resistance of the roadway was increased when shredded face masks (also known as SFM) were added to hot mix asphalt. As a result, it was discovered that the mix had excellent rutting resistance. When 1.5% SFM was added to hot mix asphalt, the best mix value was attained. It was also discovered that applying varied quantities of SFM to HMA lowered the rutting depth [10]. Converting and reusing surgical face masks (SFM) into shredded form and mixing it with clayey soil for pavement building is suggested as a new way for decreasing Covid-related trash in the existing study. A variety of tests were undertaken to examine the latent of employing shredded surgical face masks with clayey soil as a material for laying pavement, covering specific gravity, compaction characteristics, unconfined compressive strength (UCS), and California bearing ratio. The findings of this study may be used to create realistic directions for applying face masks to fragments and clay.

2. Materials and Methods

2.1. Soil

The soil was collected from Morinda, Punjab (Figure 1), and was found to have specific gravity as 2.66 according to IS 2720-3:1980. To prevent moisture to enter to the soil, it was oven dried in the laboratory and stored in airtight bags and further identified as swelling soil based on the differential free swelling (DFS) which was studied as per IS 2720-40:1977. Also the soil was found as intermediate compressible based on Atterberg's limit according to IS 2720-5:1985. Clayey soil is characterized by a wide variety of distinct physical characteristics, all of which are given in Table 1.

Figure 1. Clayey soil.

Table 1. Geo-technical properties of soil.

Properties	Values
Specific gravity, G	2.66
Optimum moisture content, OMC (%)	18.75
Maximum dry density, MDD (g/cc)	1.69
Liquid limit, LL (%)	43
Plastic limit, PL (%)	24
Plasticity index, PI (%)	19
Differential free swell, DFS (%)	40
UCS (kPa) (28 days)	250
Soaked CBR (%)	1.96

2.2. Face mask

The shredded face mask is made up of various layers; an innermost layer which consists of soft fibres, intermediate layer which consists of melt-blown filter, and an outermost layer which consists of unwoven fibres (hardened fibres), which are able to resist the water from passing through it and are usually coloured [11]. In the soil stabilization procedure, a shredded face mask is introduced as an additive. For testing in laboratory, the face masks were not allowed due to the risk of Covid-19 transmission and laboratory guidelines during pandemic [12]. Thus new surgical face masks were utilized for experimental work in laboratory. These face masks were shredded into small pieces of 0.5 cm width and 2 cm length [13, 14]. The samples were prepared by mixing face mask waste in shredded forming different proportions of 0.5%, 1% and 1.5% (percentage by weight) with dry soil [15]. Figure 2 shows the shredded surgical face masks (SFM) that were used for testing in current study. The various physical properties of shredded face mask are tabulated in Table 2.

Figure 2. Shredded face mask.

Table 2. Physical properties of surgical face masks.

Properties	Values
Specific gravity (G)	0.91
Melting point (°C)	160
Water absorption (%)	8.9
Tensile strength (Mpa)	4.25
Aspect ratio	24
Bulk density (kg/m³)	920

3. Methodology

In order to find the particle size distribution of soil, wet sieve analysis and hydrometer analysis was performed as per IS: 2720 (Part 4) – 1985. For conducting the geotechnical testing, three samples of each specimen were prepared, and the average of those three was taken as final value. The specific gravity testing of soil was carried out in density bottle as per IS: 2720 (part III) 1980. After determining the particle size and specific gravity of soil, the various mixes of soil with shredded face mask were prepared to evaluate the compaction and strength characteristics. During the first stage of laboratory testing, the clay was mixed with shredded face mask in varying percentages of 0.5%, 1%, and 1.5%, respectively. The standard Proctor test was done for compaction in accordance with IS: 2720 Part VIII – 1983. The differential free swell and consistency limit tests were performed as per IS 2720-40:1977 and IS 2720-5:1985, respectively. In the second stage of testing unconfined compressive strength and CBR tests as per IS 2720 (Part 10): 1991 and IS 2720 Part 16, respectively. The UCS testing was carried out after a curing period of 3, 7, and 28 days; the CBR testing was performed after a soaking period of 96 hours.

4. Results and Discussion

4.1. Compaction test

To determine the soil's OMC and MDD, a standard compaction test was performed in the laboratory. The compaction test was used to see how adding different percentages of shredded face masks affects MDD and OMC. The SFM was added in dry soil in different proportions from 0.5% to 1.5% by weight of the clayey soil. The OMC increased as the percentage of face masks increased from 0.5% to 1.5%, whereas the MDD of the soil mixture dropped, as shown in Figure 3. The optimum content of SFM was taken as 1% because there was a minor change in the value of MDD beyond 1% SFM content. The lower specific gravity and density of shredded face masks compared to clayey soil could help in lowering MDD value. Several other researchers have found comparable findings when mixing polyethylene with a low density, polyethylene terephthalate, and polyethylene with a high density to aggregates [11, 16].

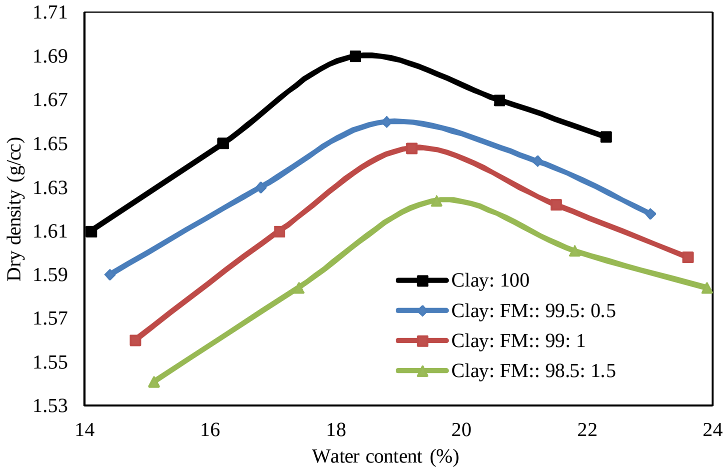

Figure 3. Compaction graph for soil-FM mixes.

4.2. Unconfined compressive strength test

UCS tests were performed in line with IS 2720-10:1991 to determine the strength of the clayey soil. The various stress-strain curves obtained for varying proportions of shredded face mask for curing periods of 3, 7, and 28 days are shown in Figures 4-6, respectively. It was obtained that the UCS value of virgin clayey soil was 56 kN/m^2, 132 kN/m^2, and 250 kN/m^2 after the period of 3, 7, and 28 days, as shown in Figure 7. The face masks were shredded into pieces having dimensions of 0.5 cm width, 2 cm length and then combined with the clayey soil in the proportions of 0.5%, 1%, and 1.5% [12].

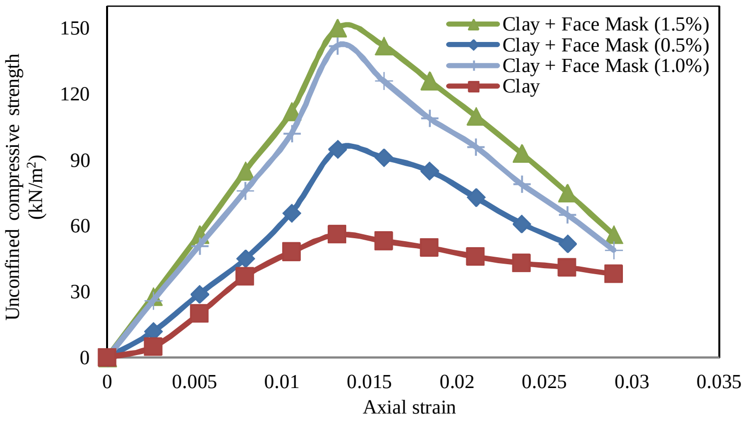

Figure 4. Stress-strain curves for various percentages of face masks mixed in clay after 3 days curing.

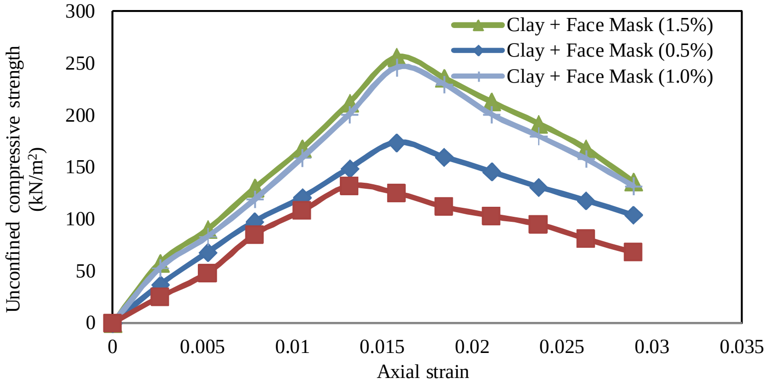

Figure 5. Stress-strain curves for various percentages of face masks mixed in clay after 7 days curing.

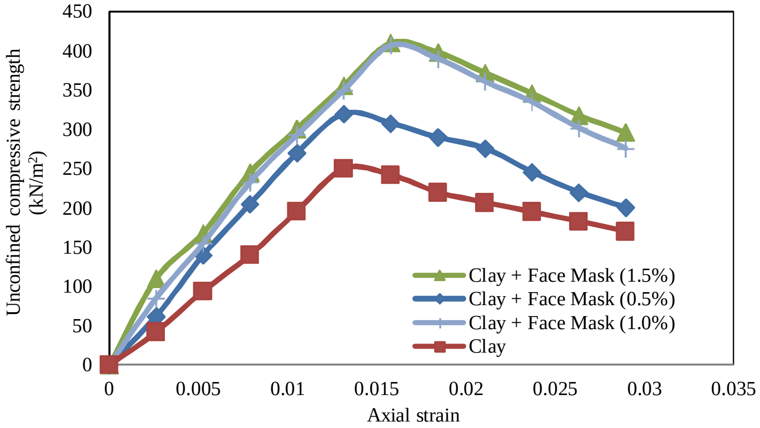

Figure 6. Stress-strain curves for various percentages of face masks mixed in clay after 28 days curing.

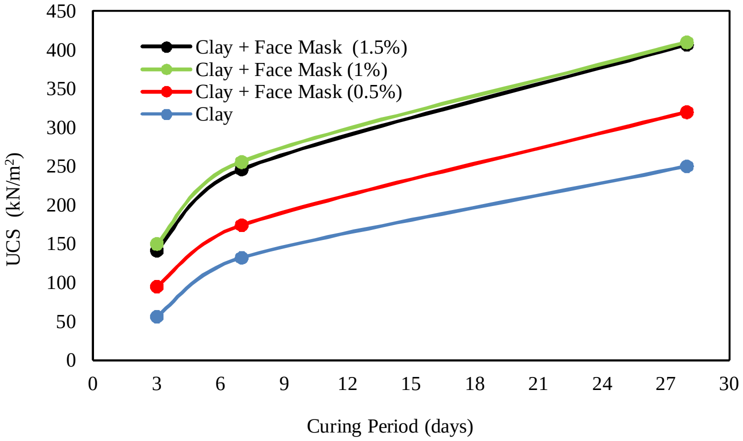

Figure 7. UCS graphs for various percentages of face masks mixed in clay.

4.3. California bearing ratio (CBR) test

The CBR test was used to determine the strength of clayey soil by mixing various quantities of SFM (0.5%, 1%, and 1.5%) with the soil according to ASTM D1883-05, and the various stress-strain curves are shown in Figure 8. The clayey soil's soaked CBR value was 1.96 %, indicating that it cannot be used for subgrade construction (Figure 9). There is a need to stabilize the soil for using it in pavement subgrade. To improve the CBR value of mix, the shredded face mask was added to the clayey soil and it showed satisfactory results. On adding 0.5% SFM, the value of CBR was obtained as 3.81% and on adding 1% SFM the value obtained was 6.72%. On further addition of 1.5% SFM the value increases up to 7.34%. Thus the CBR value for 1%can be taken as optimum as after this there is very small increment in the value of

CBR [11, 13]. This could be because water consumption increases during the soaking time as strength decreases, resulting in a decreased CBR value [16]. As a result, according to IS requirements, this value can be utilized as a sub-base layer for roads with very heavy traffic.

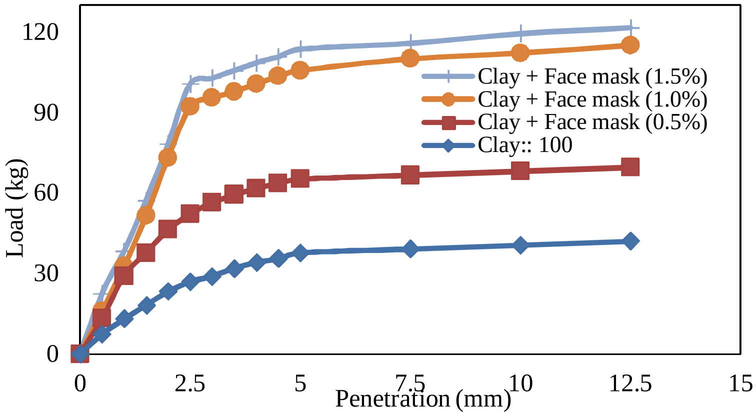

Figure 8. Stress-strain curves for various percentages of face masks mixed in clay after 4 days soaking period.

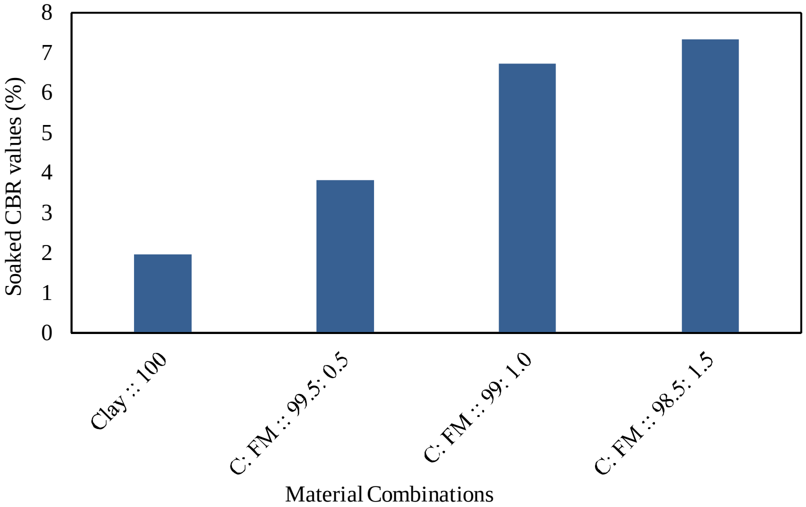

Figure 9. Effect on CBR value on addition of shredded face mask to soil.

5. Pavement Design

The pavement actions are analysed using the mechanistic-empirical software IIT-PAVE. The multi-layer theory is used in IIT-PAVEs for the analysis of flexible pavement. The carriageway width, road classification, growth rate, terrain, design life, construction period, and other variables are used as input into the IIT-PAVE software.

Table 3. Assumed values for designing flexible pavement.

Input names	Values
Carriageway width after construction	Single and double lane
Classification of road	Major district road (MDR)
Design life	15 year
Growth rate	5%
Terrain	Hilly
Construction period	1 year

Table 4. Allowable and actual strain for all optimum combinations calculated using IIT-PAVE.

Optimum combination	Design CBR (%)	CVPD (both side)	Design traffic		Layer thickness (mm)	Allowable strain (in micro strain)		Actual strain (in micro strain)	
			15 years (msa)	5 years (msa)		Tensile strain at the bottom of the bitumen layers	Vertical compressive strain at the top of subgrade	Tensile strain at the bottom of the bitumen layers	Vertical compressive strain at the top of subgrade
S:SFM::99:1 (Single Lane)	6.72	1000	14.77	6.30	630	367	618	195	301
		3000	72.95	31.13	640	201	342	148	259
		5000	121.58	51.89	640	176	306	148	259
S:SFM::99:1 (Double Lane)	6.72	1000	7.38	3.15	580	438	720	202	340
		3000	36.48	15.57	630	291	398	195	301
		5000	60.79	25.94	630	211	356	157	273

6. Cost Analysis

The length of the road was assumed to be 1000 meters for this study and also the pavement was planned for a single subgrade soil. Tables 5-7 show the cost estimation of the subgrade layer in Indian rupees. The construction cost of the subgrade layer was computed based on subgrade thickness and its composition and the price of the material used for the subgrade layer per meter cube as per materials. The price of constructing different layers including a sub-grade layer comprised of a clayey soil is listed in Tables 5-7 for 1000, 3000, and 5000 CVPD, respectively.

Table 5. Cost of building different layers including a clayey soil subgrade layer for 1000 CVPD.

Sr. No.	Pavement components (1000)	Top width (assumed)	Bottom width (assumed)	Height (m)	Volume (m^3)	Rate per m^3 (INR)	Cost (INR)	Total cost
1.	Bituminous course	3.50	3.75	0.03	108.75	5254.05	571377.9	71,05,496
2.	DBM course	3.75	4.50	0.05	206.25	6549.48	1350830	
3.	WBM course	4.50	5.50	0.250	1250	1685.51	2106888	
4.	Sub-base course	5.50	7.50	0.200	1300	1353	1758900	
5.	Sub-grade	7.50	9.50	0.500	4250	310	1317500	

Table 6. Cost of building different layers, including a clayey soil subgrade layer for 3000 CVPD.

Sr. No.	Pavement components (1000)	Top width (assumed)	Bottom width (assumed)	Height (m)	Volume (m^3)	Rate per m^3 (INR)	Cost (INR)	Total cost
1.	Bituminous course	3.50	3.75	0.04	145	5254.05	761837.25	72,95,954.95
2.	DBM course	3.75	4.50	0.05	206.25	6549.48	1350830.25	
3.	WBM course	4.50	5.50	0.250	1250	1685.51	2106887.5	
4.	Sub-base course	5.50	7.50	0.200	1300	1353	1758900	
5.	Sub-grade	7.50	9.50	0.500	4250	310	1317500	

Table 7. Cost of building different layers, including a clayey soil subgrade layer for 5000 CVPD.

Sr. No.	Pavement components (1000)	Top width (assumed)	Bottom width (assumed)	Height (m)	Volume (m^3)	Rate per m^3 (INR)	Cost (INR)	Total cost
1.	Bituminous course	3.50	3.75	0.040	145	5254.05	761837.3	72,95,955
2.	DBM course	3.75	4.50	0.050	206.25	6549.48	1350830	
3.	WBM course	4.50	5.50	0.250	1250	1685.51	2106888	
4.	Sub-base course	5.50	7.50	0.200	1300	1353	1758900	
5.	Sub-grade	7.50	9.50	0.500	4250	310	1317500	

7. Conclusions

On the basis of geo-technical experimental testing, the main findings of this study are as follows:

1. On varying amounts of shredded face masks into virgin soil, the maximum dry density reduces because clayey soil has a larger specific surface area and density than virgin soil does. On the other hand, the optimal moisture content increases because clayey soil has more fibre fragments, which require more water.
2. The maximum unconfined compressive strength is reached when 1% of shredded face masks are added to the virgin soil; more inclusion of shredded face mask to clayey soil decreases the maximum UCS value.
3. On adding 1% of shredded face masks to clayey soil results in the best California bearing ratio, which is 6.72%. This ratio is appropriate for the subgrade construction since it is adequate for carrying heavy loads.
4. Based on the optimum California bearing ratio values, the flexible pavement's subgrade thickness is designed. An optimum mixture of

shredded face masks and clayey soil keeps the strain values in limit.

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ویژگی‌های زیر درجه روسازی‌های انعطاف پذیر با ماسک صورت خرد شده در خاک رسی

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ارسال 2023/03/24، پذیرش 2023/05/21

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چکیده:

با توجه به نگرانی‌های مربوط به دفع، مقدار زیادی ضایعات تجهیزات حفاظت فردی (PPE) ناشی از همه‌گیری COVID-19 یک خطر جدی برای سلامتی و محیط زیست است. در طول همه‌گیری، استفاده از لباس‌های محافظ به‌طور چشمگیری افزایش یافت و نگرانی‌هایی را در مورد نحوه دفع آن‌ها برای حفاظت از محیط زیست ایجاد کرد. این کار تحقیقاتی از ماسک‌های صورت خرد شده (SFM) برای تثبیت خاک رسی برای استفاده در زیرگرم استفاده می‌کند. ماسک های صورت خرد شده برای بررسی محدودیت‌های قوام، ویژگی‌های تراکم، مقاومت فشاری نامحدود (UCS) و نسبت باربری کالیفرنیا (CBR) به خاک رسی اضافه می‌شوند. آزمایش‌های آزمایشگاهی نشان می‌دهند که ویژگی‌های ژئوتکنیکی خاک رسی مانند تورم بدون تفاوت، محدودیت‌های قوام، مقادیر UCS و CBR بهبود یافته‌اند. بر اساس نتایج CBR، نرم افزار IITPAVE برای طراحی ضخامت روسازی انعطاف‌پذیر استفاده می‌شود که برای وسایل نقلیه تجاری مختلف در روز برای همه ترکیب‌ها کاهش می‌یابد. تجزیه و تحلیل هزینه نیز برای تعیین هزینه کل برای یک کشش 1000 متری انجام می‌شود. نتایج نشان می‌دهد که افزودن SFM به خاک‌های رسی، خواص ژئوتکنیکی خاک رسی را تقویت می‌کند، زیرا مقادیر UCS برای تمام دوره‌های پخت 3، 7 و 28 روز با حداکثر بهبود 64 درصد برای 28 روز پخت برای 1 درصد افزایش می‌یابد. محتوای SFM همچنین، مقدار CBR از 1,96٪ به 6,72٪ افزایش یافته است.

کلمات کلیدی: کووید-19، ماسک صورت خرد شده، ویژگی های قدرت، مدیریت ضایعات.
