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Reinforcing Expansive Soils through Medical Waste Valorization: A Critical Review of Nitrile and Latex Glove–based Stabilization Techniques

Ku Pragati Damke[1] and Abhijit Kundu[2]
[1-2]GH Raisoni University, Amravati India
Email: gati48damke@gmail.com

***Abstract*— The behaviour of expansive soils has always been a critical issue in geotechnical engineering, because of the large degree of shrink–swell which causes serious distress to pavements, structures and light-weight construction. Traditional stabilizers like lime and cement have proven to be efficient stabilizers, but they are quite costly with environmental issues often restricting the cost and energy intensive manufacturing process. Lately, the idea of sustainable geotechnics has driven the development of new materials obtained from waste streams to control soil behaviour with minimum environmental footprint.**

The volume of waste generated particularly nitrile and latex gloves has significantly increased as a result of international health emergencies, unprecedented interest has arisen to valorize them into civil engineering applications. Shredded nitrile gloves and shredded latex gloves have been identified as potential reinforcement fibers for expansive-stabilized soil because of their tensile strength, flexibility—and resistance to moisture degradation. When integrated within a soil, the polymer Fiber provide improved mechanical properties and greater control of volume changes.

The present review systematically presents available experimental and analytical literature on the use of waste nitrile gloves and latex gloves for treatment of expansive soil. Nevertheless, there is still dearth in long-term durability characterization, large-scale field validation, environmental risk assessment and standard mix design guidance. Further investigations should remedy these shortcomings to allow for secure, cost-effective and regulatory-compliant integration of glove stabilization methods into geotechnical construction practice.

***Keywords*— Expansive soil, medical waste valorization, nitrile gloves, latex gloves, fibers reinforcement, sustainable geotechnics.**

I. INTRODUCTION

Problematic geomaterials, which are so called expansive soils, have large variations in volume regarding moisture. These soils usually have a high content of clay minerals, such as montmorillonite with layered type crystal structure that can adsorb water among interlayers expanding or releasing water during moistening and drying periods causing swelling and shrinkage [1]. The cyclic shrink–swell behaviour introduces uncertain and differential ground movements that are difficult to predict and control, especially in semi-arid and tropical environments.

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Expansive soils are extensively found in countries, such as India, the United States and Australia as well as in many places of Africa and their highly destructive engineering behaviour is magnified when the several times change throughout a year [2]. The extent of swelling behaviour is a function of mineralogy, plasticity index, soil fabric, stress history and environmental exposure; thus, expansive soils are considered one of the problematic subgrades for civil engineering infrastructure [5].

During the COVID-19 pandemic there was a dramatic increase in the use of PPE, such as single-use nitrile and latex gloves, not previously experienced in healthcare, industrial or public sectors. Critical for preventing the spread of respiratory illnesses, disposable gloves have also created a significant disposal issue [6]. Disposal of medical gloves in the wrong ways represents an environmental risk (e.g., landfills overfull, emissions from incineration, microplastic pollution). According to studies, the pollution of soil and water due to non-biodegradable PPE made up of polymer material such as plastics is on the rise [7]. Consequently, there is increasing interest worldwide in finding safe and profitable reuse applications for medical glove waste—for instance ones in non-structural or geotechnical end-use areas with limited human contact [8].

II. Literature Review

The literature review aim is to provide a critical discussion of the potential use of nitrile and latex glove waste as reinforcement material in stabilizing expansive soil. This review extracts studies related to the material properties, reinforcement principles, experimental performance, and sustainability effect of glove-stabilizing techniques. Additional aims are to investigate the influence of glove nature on strength, bearing capacity and swelling effect; compare nitrile vs. latex gloves; and establish dosage ranges for both. In addition, the paper summarises environmental gains, implementation barriers and knowledge deficit associated with long term performance and field applicability. Thematically, the paper is organized with an introduction of expansive soil behaviour and stabilization techniques, then medical waste valorization, experimental results, comparative study and sustainability potential. Suggestions for the application of the reviewed methods in sustainable geotechnical engineering, as well as those needed for future work are made

Table I: Quantitative Performance

Year	Name of author	Title of paper	Material used	Findings
2024	Ponnusamy, et al	Sustainable Reuse of shredded face mask in Biopolymer Treated Expansive soil.	Shredded face masks chip and various dosages of xanthan *GUM and Guar GUM (2%inlusion)	UCS, CBR, FSI, splitting tensile test, swelling pressure, swelling potential test.
2024	WU, et al	DFM modelling of granular soils reinforced by disposable face mask chip.	Disposable face mask chip (%by wt of soil)	Enhance the mechanical behaviour of granular soil under varying confining pressures.
2023	Chandan, et a1	Sub grade characteristics incorporating shredded face mask in clayey soil.	Shredded faceEnhance the mechanical behaviour of granular soil under varying confining pressures.	UCS, CBR, FSI, consistency limit UCS values increase for all curing period of 3. 7 and 28 days.
2023	Kumar, et a1	Influence of SLG Addition on concrete	SLG (%by wt of soil) + 0.3% silica fume + 10% replacement of cement. (SLG 0.1% and 0.3%)	Workability durability, mechanical properties, compressing, strength.
2022	Lynch, et al	Application of COVID-19 single use SNG in study from concrete case study from Australia.	SNG % by wt of soil (5 to 10 mm)	Workability, durability test
2022	Zhu et al	Reusing COVID-19 Disposable nitril gloves to improve mechanical properties of expansive clay subgrade an innovation metical waste solution	SNG not specific dimensions (1 to 5%)	CBR, UCS, MDD, OMC
2022	Ghadr et al	Mechanical behaviour of sand reinforced with shredded face masks	1. FM: 0.5* 1cm 2. Fm: 0.5*2cm (Upto 0.5%)	Undrained shear strength of soil
2021	Gamily et al	Assessment of the reuse of covid-19 heathy personal protective materials in enhancing materials in enhancing geotechnical properties Numerical & experimental study	HPPM (up to 0.5%)	UCS, CBR

2021	Saberian et al	Repurposing of COID-19 single use face masks for pavement base/subbase.	SFM (% by wt of soil)	Aggregate crushing value loss Angeles's abrasion, flakiness OMC, MDD, UCS.
2021	Shobana et al	Soil stabilization using banana fibre and disposable face mask	Banana fibre.FM (0.5 to 1.15%)	OMC, MDD, UCS.
2021	Rehman et al	Optimization of COVID-19 face mask waste fibres and silica fume as a balance, mechanical clay using response surface methodology.	FM	Qu and CBR
2021	Tadele, et al	Surgical face masks as a potential source for microplastic pollution in the COVID 19 scenario.	Surgical face masks	Yes

III. CONCLUSIONS

This study presented an appraisal of expansive soil reinforcement project with waste-based nitrile and latex gloves with respect to material characteristics, behaviour, mechanisms of improvement, experimental findings, sustainability issues and utilization complexities. Overall, the current body of work has shown that in general expansive soil which happens to be unstable materials could effectively be reinforced with shredded polymeric glove fibers. In laboratory experiments, glove reinforcement always induces decreases in plasticity and swelling characteristics as well as increases in unconfined compressive strength and California Bearing τ Ratio and confers enhanced ductility and post-peak behaviour. These results verify that the key performance controlling factors are mechanical based (fibre–soil friction, crack bridging, tensile resistance and confinement against volumetric expansion) [3].

From a technical feasibility standpoint, both nitrile and latex gloves have been demonstrated to operate adequately as individual fibers in an encapsulated form when incorporated at low to intermediate levels. They generally are used with a gain in strength improvement and durability (high significant increase) for nitrile gloves by the fact that they consist of synthetic polymer materials while one use it contributes on increasing elasticity and crack resistance even under cyclic moisture conditions only in which spells may be different [4].

Experimental evidences indicate that there is an optimal glove content, usually in the range of 0.5–2.0% by dry mass soil content, beyond which compaction effectiveness and strength gain decrease [9]. When nitrile or latex glove fibres are combined with expansive soils, they decrease the clay fraction and destroy the continuity of the clay matrix causing a reducing in soil adherence for water [10]. This is mainly a mechanical effect and not chemical, as glove fibres do not contribute to cation exchange or pozzolanic reactions. Something that is evident from the modified Atterberg limits of the expansive soils is that reinforcement by gloves enhance the consistency properties of the expansive soils without disturbing their mineralogical constitution [11].

The increase of OMC is due to the need for extra water content necessary for proper lubrication and uniform distribution of Fibers during compaction process, The decrease in MDD is related to lesser specific gravity the polymeric Fibers compared with that of soil solids. Latex particles, though less effective in peak strength enhancement than Fibers do due to low stiffness and weak bonding, lead to better ductility and post-peak behaviour so as to eliminate the sudden failure [12]. Above the optimal fiber content, UCS values plateaus or decreases due to lower compaction efficiency and clustering of fibres [13]. These results underline the need for Fiber dosage optimization to allow the combination of improvement in both strength and workability [14]. The improved UCS behaviour would warrant the use of glove reinforced soils for subgrade and foundation applications under light to moderate traffic loadings [15]. Elasticity of latex considerably contributes to better cushioning swelling strains without tearing, and elevated swelling pressure resistance by nitrile gives better reinforcement to it [16]. These findings illustrate the potential of glove-based stabilization in long-term regulation of expansive soil [17].

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