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Assessment of Strength Properties of Clayey Sand Soils Admixed with Marble Powder, GGBS and Geotextile Reinforcement

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Abstract: The use of clayey sand is considered as a low-quality subgrade for pavement construction and presents several challenges. Clayey sand typically has poor engineering properties due to its less strength and high compressibility with moisture changes. This research work is mainly focused on the feasibility of clayey sand to make suitable to use as a subgrade soil when admixed with and ground granulated blast furnace slag (GGBS), which is also termed as Furnace Slag and Marble Powder and reinforced with geotextile. The aim is to evaluating the suitability and find optimum quantities of these additives in improving the soil's engineering parameters. Different tests were conducted on the soil samples such as grain size distribution, Atterberg's limits, compaction, California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) by different amounts of additives. The soaked and unsoaked California Bearing Ratio values of soil reinforced with Geotextile increased to 4.2% and 6.8%, respectively, at 6% of marble powder. A similar trend of increased strength found in case of Furnace Slag admixed with soil reinforced with geotextile and found as 3.6 and 6.8%, respectively. However, it was found that beyond 6%, there is a decline in California Bearing Ratio, indicating that excess Marble Powder and Ground Granulated Blast Furnace Slag negatively impacts soil strength. The use of geotextile reinforcement significantly enhanced Unconfined Compressive Strength values, with the best performance observed at 6% of Furnace Slag and 8% of Marble Powder obtained as 22.6 kPa and 19 kPa, respectively. Based on the results improvements in subgrade soil strength characteristics, the proposed methodology can be adopted for enhancing strength properties of clayey sand subgrades.

Keywords: Clayey Sand, Geotextile, GGBS, Marble Powder, Strength Evaluation, Subgrade.

1. Introduction

Clayey Sand is a general type of low-quality soil that has significant challenges in geotechnical engineering, mainly in the building of subgrade for roads, railroads and other infrastructural projects [1]. Due to the low engineering properties of clayey sand such as low bearing capacity, high compressibility and susceptibility to moisture changes, often require expensive soil stabilization techniques [2]. One way is the stabilization to improve the properties of the soil. This can be attained through different methods such as chemical stabilization (using additives like lime or cement), mechanical stabilization (admixing) or even thermal stabilization [3]. Such stabilization techniques can improve the strength of soil and decrease its susceptibility to moisture changes. Marble powder is a byproduct of marble cutting and crushing processing [4] and the Furnace Slag, produced as a byproduct from iron manufacturing industries [5]. The usage of waste materials such as Marble Powder and Furnace Slag as soil admixtures has increased due to enhancement in soil properties and minimize environmental impact recent years [6]. Eventually, while using Clayey Sand as a subgrade material for pavement construction may not be ideal, with appropriate engineering and construction practices, it is possible to mitigate some of the related challenges and get acceptable results [7]. However, it is crucial to carefully assess the site-specific conditions and consult with geotechnical engineers and pavement specialists to determine the most suitable strategies for the project [8]. This paper investigates the effectiveness of Marble Powder and Furnace Slag in enhancing the strength characteristics of clayey sand, particularly in the context of constructing geotextile reinforced subgrades.

The damages in the pavements are getting severe attention across the world due to various reasons such as improper work and also due to over loading. But out of all these reasons, the pavements are being built on unsuitable (inferior) soil could be one of the main reasons for failure of structures [9]. It is possible to prevent the failures of pavements by improving the strength of subgrade soil with recommend and suitable stabilizations [10]. The Clayey Sand mainly contains the clay and more moisture content within the soils such as due to rains, floods and due to water seepage [11]. When the pavements are being built on these soil subgrades there is a chance of loss of strength of soils thus leads to failure of pavement [12].

Depending on their availability and cost-effectiveness, it may be worthwhile to explore alternative subgrade materials that offer better engineering properties [13]. This could include importing suitable fill materials or using recycled materials such as crushed concrete, asphalt, Furnace Slag, Fly ash, Marble Dust and Wollastonite. Previous studies have explored the use of various additives, including lime, fly ash and cement, for stabilizing clayey soils [14]. However, limited research has been conducted on the utilization of marble powder and Furnace Slag as soil stabilizers, especially in combination with geotextiles. Some studies have shown that marble powder improved mechanical properties of soil by filling voids and enhancing particle packing [15]. Similarly, Furnace Slag , a waste product from industries, has been found to exhibit pozzolanic properties, contributing to the pozzolanic action and thus cause to form cementitious compounds in soil [16]. The utilization of geotextiles in the layers of pavements provides two basic contributions such as separation and reinforcement [17]. Geotextile reinforcement reduces rutting and hence maintenance cost could be reduced [18]. In most instances, the inclusion of nonwoven geotextile in subgrade-geotextile-base system has shown improved performance while compensating the weakness of soil mass [19].

In this paper, the strength of Clayey Sand is evaluated when admixed with Marble Powder [20] and/or Furnace Slag [21]. The suitability of these additives in increasing the strength properties of the soil, particularly for the construction of geotextile reinforced subgrade is assessed [22]. Various laboratory tests including compaction, California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) tests were conducted on the soil samples with varying proportions of these additives. The results indicated promising improvements in the strength of the soil, suggesting the potential application of these admixtures in the subgrade construction of pavements.

2. Materials

The following materials were used in the present study and their properties have been described herewith.

2.1 Clayey Sand

In this study, locally available soil has been selected for experimental work. The properties of soil have been given in Table 1. The soil was classified – Unified Soil Classification System (IS:1498-1970) as Clayey Sand (SC) [23] and considered as a low quality soil viz., as it is unsuitable for subgrade construction.

Table 1. The properties of untreated Clayey Sand

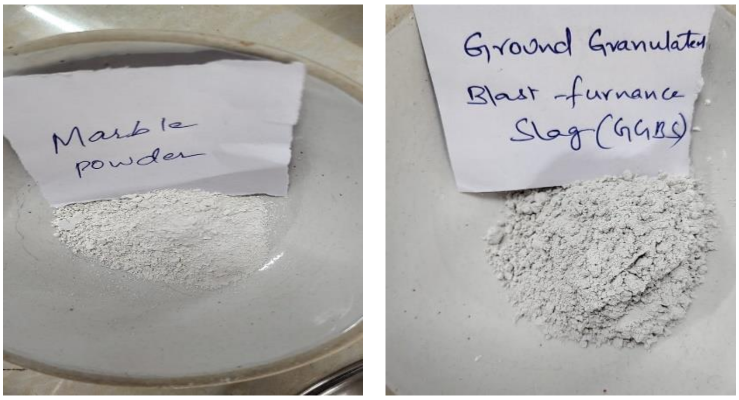
Property of the Soil	Value
Specific Gravity	2.51
Grain size Distribution (GSD) (%)	
Gravel	10
Sand	54
Silt	17
Clay	19
Atterberg Limits (%)	
Liquid limit	41
Plastic limit	23
Compaction Properties	
Optimum Moisture Content (OMC) (%)	18
Maximum Dry Density (MDD) (g/cm^3)	1.85
Shear Strength Parameters	
Unconsolidated undrained condition	
Cohesion (kPa)	49
Angle of internal friction	19^0
Consolidated drained condition	
Cohesion (kPa)	13
Angle of internal friction	32^0
Unsoaked California Bearing Ratio (%)	5
Soaked California Bearing Ratio (%)	2
Coefficient of Permeability (cm/sec)	6.01×10^{-5}

2.2 Marble Powder

Marble Powder is a waste material obtained from the process of reducing and sharpening of marble stones. The main constituent of marble powder is calcium carbonate [24] (nearly 90%) which would be admixed in the stabilization process of the proposed Clayey Sand. The materials used in the present study are presented in Figure 1.

2.3 Ground granulated blast slag

The furnace slag is by-product that produced during the manufacture of iron. It mainly contains alumina, lime and silicate. There is a similarity between Furnace Slag and ordinary Portland cement in oxides types but not the percentage.



Marble Powder Furnace Slag Powder

Figure 1. The materials used in the present study

Table 2. The chemical composition of Furnace Slag used in this study

Compound	CaO	SiO	Al_2O_3	MgO	Fe_2O_3	SO_3	K_2O	TiO_2	pH
Furnace Slag	41	39	5	4	0.03	0.01	0.92	0.85	8.5

During the process of production of Furnace Slag , its cementitious characteristics would be enhanced because molten slag chills rapidly after coming out of the furnace [25]. The process of rapid chilling leads to reduction in the crystallization and converts the molten slag into a glassy material. The chemical composition of Furnace Slag utilized in this research is given in Table 2.

2.4 Geotextile

The use of geotextiles in construction and pavement applications has long been recognized as a cost saving technique and performance enhancing solution over traditional construction techniques. In many engineering applications a geotextile fulfils as stabilization technique or reinforcement function [26]. In this process, the geotextile provides the soil to take up higher loads and thus supports the soil in providing tensile strength when subject to vertical loads.

There are three distinct mechanisms by which a geotextile can stabilize the soil subgrade and improve its resistance to permanent deformation under repetitive traffic loading viz., Restraint+ Confinement, Membrane mechanism and Local Reinforcement. Using geotextiles as a separation layer between the subgrade and the pavement layers can also help to prevent mixing of the subgrade material with the overlying layer [27]. This can reduce the potential for deformations and improve the overall stability of the pavement structure.

In the present study a non-woven geotextile, trade name is being DuPont Typar SF56 was used. This geotextile was so selected such that it acts as only reinforcement without contributing in providing extra strength during compression. The properties were given in Table 3.

Table 3. Properties of DuPont Typar SF 56

Property	**Value**
Mass per unit area	0.02 g/cm^2
Thickness	0.06 cm
Tensile Strength [28]	13000 N/m
Elongation at maximum load	55/100
Dynamic Perforation Resistance	2.2 cm
Resistance to Static Puncture	1850 N
Opening Size O_{90}	8e-5 m
Permeability [29]	303 m/day

3. Methodology

Experiments in laboratory were carried out to evaluate the strength properties of Clayey Sand admixed with varying percentages of Marble Powder and/or Furnace Slag. The soil samples were prepared by mixing predetermined quantities of additives with the clayey sand using a mechanical mixer. For Clayey Sand, modifications are necessary to account for the strength component. This could involve adjusting the moisture content range tested and hence it is necessary to perform liquid limit tests. Compaction tests were performed to determine the optimum moisture content and maximum dry density of the soil mixtures. Proper compaction is crucial for enhancing the strength properties of the subgrade. Even though Clayey Sand might not have ideal properties, achieving maximum compaction can still enhance its performance to some extent. Compaction should be done in layers, with adequate moisture control to ensure optimal density. California Bearing Ratio (CBR) testing was done on the prepared specimens following IS 2720- Part 16-1987 [30] or relevant standards. The test involves subjecting the specimen to increment in the vertical loads and measuring the penetration resistance using a penetration piston. These tests were conducted to assess the bearing strength and compressive strength, respectively [31]. In this research, the California Bearing Ratio test results would provide valuable insights into how the addition of Marble Powder and/or Furnace Slag affects the strength properties of the Clayey Sand.

Unconfined compressive strength tests were conducted on the prepared specimens as per IS 2720-Part 10-1991 [32] standards. The test involves applying a compressive load to the specimen at a constant rate while measuring the stress applied and the corresponding strain or deformation until failure occurs. The maximum stress of failure is noted as the Unconfined Compressive Strength value. A greater strength and resistance to compression specifies higher Unconfined Compressive Strength values whereas lower value proposes weaker soil behavior. The load-bearing capacity of the subgrade and its ability to support pavement loads both can be evaluated using Unconfined Compressive Strength values. While Clayey Sand present encounters for subgrade buildings, California Bearing Ratio and Unconfined Compressive Strength testing can help in evaluating its suitability and guide efforts to advance its performance for pavement applications.

4. Results and Discussion

The outcomes of the laboratory tests show necessary improvements in the engineering properties of the soil with the addition of Marble Powder and Furnace Slag. The maximum dry density improved, representing better compaction characteristics, while the optimum moisture content found with slight differences depending on the proportion of additives. Moreover, both California Bearing Ratio and Unconfined Compressive Strength values exhibited prominent improvements with increasing percentages of marble powder and Furnace Slag. When marble powder and Furnace Slag were added together resulted in synergistic effects, leading to advanced strength improvements compared to using them as separate additives.

4.1 Liquid Limit

The Atterberg limit test was performed on natural Clayey Sand samples and clayey sand samples admixed with different percentages of Marble Powder/Furnace Slag. The liquid limit test was also performed in accordance with IS: 2720 (part: 5) – 1985 [33]. The test findings of liquid limit of the clayey sand samples admixed in different proportions of Marble Powder/Furnace Slag are shown in Table 4.

The liquid limit initially decreases as the percentage of marble Powder increases from 0% to 6%, reaching its lowest at 31%. However, beyond 6%, the liquid limit starts to increase, reaching 38% at 10% marble powder. This behavior suggests that low percentages of marble powder contributes to a reduction in soil plasticity [34]. The addition of Furnace Slag reduces the plasticity of the soil, as seen by the liquid limit decreasing from 41% at 0% Furnace Slag to 30% at 10% Furnace Slag. The reduction in liquid limit indicates that Furnace Slag may be effective in improving soil stability by decreasing its moisture sensitivity. The trend of reduction was also found by previous studies [35].

4.2. Compaction

Compaction testing is a significant component of evaluating the engineering qualities of soil, particularly in the situation of subgrade building where achieving sufficient compaction is necessary for ensuring stability and load-bearing capacity [36].

4.2.1. Optimal Moisture Content and Maximum Dry Density

Admixing of the marble powder and/or Furnace Slag influences the compaction performance of the soil compared to the untreated Clayey Sand. Table 5 gives the results of the compaction test.

Table 4. Liquid Limit Testing with various Combinations

% of Marble Powder/Furnace Slag	Liquid Limit (%)	
	Marble Powder	Furnace Slag
0	41	41
2	40	38
4	35	32
6	32	31
8	34	32
10	38	30

Table 5. Optimum Moisture Content and Maximum Dry Density with different combinations of admixtures

% of Marble Powder / Furnace Slag	Marble Powder		Furnace Slag	
	Optimum Moisture Content (%)	Maximum Dry Density (g/cm³)	Optimum Moisture Content (%)	Maximum Dry Density (g/cm³)
0	18	1.85	18	1.85
2	16	1.89	17	1.88
4	15	1.95	16	1.97
6	14	1.99	17	1.90
8	16	1.90	19	1.80
10	19	1.85	21	1.70

4.2.2. Effect of Additives on Compaction Characteristics

The data for marble powder indicates an initial decrease in the Optimum Moisture Content from 18% to 14% as the percentage increases up to 6%, with a corresponding increase in Maximum Dry Density to 1.99 g/cm³, suggesting enhanced compaction. However, as the marble powder percentage increases further to 10%, OMC rises back to 19%, and MDD decreases to 1.85 g/cm³. This suggests that lower percentages of marble powder contribute to denser compaction, while higher amounts may hinder compaction efficiency by requiring additional moisture for optimal mixing. As the percentage of Furnace Slag increases, the Optimum Moisture Content (OMC) shows a generally increasing trend, rising from 18% at 0% Furnace Slag to 21% at 10% Furnace Slag. Meanwhile, the Maximum Dry Density (MDD) follows a decreasing trend, with the highest density observed at 4% Furnace Slag (1.97 g/cm³), which gradually declines to 1.70 g/cm³ at 10% Furnace Slag. Overall, the compaction test results provides valuable insights into the influence of Marble Powder [15] and/or Furnace Slag [25] as admixtures on the compaction characteristics of Clayey Sand, thereby contributing to the advancement in engineering practices for subgrade construction.

4.3. California Bearing Ratio

Typically, very weak California Bearing Ratio values for subgrade of soil indicates 2% or less indicates, whereas values above 10% are consider as appropriate for pavement construction without significant stabilization.

The addition of Marble Powder improves the California Bearing Ratio values of clayey soil, with optimal results observed at 6% of Marble Powder content. Beyond this range, further addition reduced the soil strength. Geotextile reinforcement significantly enhanced the California Bearing Ratio values, especially in soaked conditions, with the best improvement found at 4% Marble Powder. Therefore, for optimal soil performance, 4% Marble Powder with geotextile reinforcement is recommended for both soaked and unsoaked conditions. Such increase and decrease of strength properties was also found in previous study [37].

The addition of Furnace Slag enhances the California Bearing Ratio values of soil, with the best performance observed at 4–6% Furnace Slag. Beyond this percentage, the California Bearing Ratio values decrease, indicating diminishing strength with excess Furnace Slag. Geotextile reinforcement further improves the California Bearing Ratio values, particularly in soaked conditions, with the optimal Furnace Slag content at 4%. Therefore, the most effective combination for improving soil strength found at 4% of Furnace Slag with geotextile reinforcement for both soaked and unsoaked conditions, which also indicates a similar trend of results observed in previous study [13].

4.3.1. Optimum Mix Proportion

An optimum mix proportion of marble powder and/or Furnace Slag that outcome is the highest California Bearing Ratio value is found. This was recognized by conducting the California Bearing Ratio tests for various mix proportions and identifying the mix that yields the maximum strength. California Bearing Ratio values got from the research with relevant standards or specifications for subgrade soils. The results and their comparison can help in determining whether the treated soil meets the required strength criteria for subgrade construction [38]. The improved strength characteristics of the treated Clayey Sand that may affect the overall performance and durability of the road infrastructure, and the engineering implications of the California Bearing Ratio results for geotextile reinforced subgrade construction.

Table 6. California Bearing Ratio with varying percentages of Marble Powder and geotextile reinforcement

% of Marble Powder	California Bearing Ratio Values (without Geotextile reinforcement)		California Bearing Ratio Values (with Geotextile reinforcement)	
	Soaked	Unsoaked	Soaked	Unsoaked
0	2	5	3.5	7
2	2.5	5.2	3.8	7.2
4	2.9	5.4	4.2	7.3
6	3.2	5.6	3.6	6.8
8	3	4.8	3.2	6.5
10	2.5	4	3	6.2

Table 7. California Bearing Ratio values with varying percentages of Furnace Slag and geotextile reinforcement

% of Furnace Slag	California Bearing Ratio Values (without Geotextile reinforcement)		California Bearing Ratio Values (with Geotextile reinforcement)	
	Soaked	Unsoaked	Soaked	Unsoaked
0	2	5	3.5	7
2	2.5	5.2	3.8	7.2
4	2.8	5.3	4.2	7.5
6	3	5.8	3.6	6.8
8	2.4	4.3	3.2	6.2
10	2.2	4.1	3	6

In general, the California Bearing Ratio test results provided a comprehensive understanding of how the admixing of marble powder and/or Furnace Slag affects the strength properties of clayey sand soil and its suitability for geotextile reinforced subgrade construction.

4.4. Unconfined Compression Strength (UCS)

The Unconfined Compression Strength (UCS) test results play an important role in evaluating the strength properties of soil, mainly in the view of subgrade construction. Testing the sample in Unconfined Compressive Strength machine is presented in Figure 2. In this research work the Unconfined Compressive Strength test results provided valuable insights into how the addition of marble powder and/or Furnace Slag affects the strength characteristics of the clayey sand soil. Figure 2 shows the Unconfined Compressive Strength (kPa) of plain clayey soil/admixed with Marble Powder/Furnace Slag without/with geotextile.

Figure 2. Testing the sample in The Unconfined Compression Strength (UCS) machine

Table 8. Unconfined Compressive Strength (kPa) test details

Marble Powder/Furnace Slag (%)	Without Geotextile		With Geotextile (Typar SF 56)	
	Marble Powder	Furnace Slag	Marble Powder	Furnace Slag
0	12	14	14	18
2	13.8	15.5	15	19
4	15.5	16	16	19.8
6	18.9	17	17.5	22.6
8	16	17.4	19	17.5
10	9	13	11.5	15

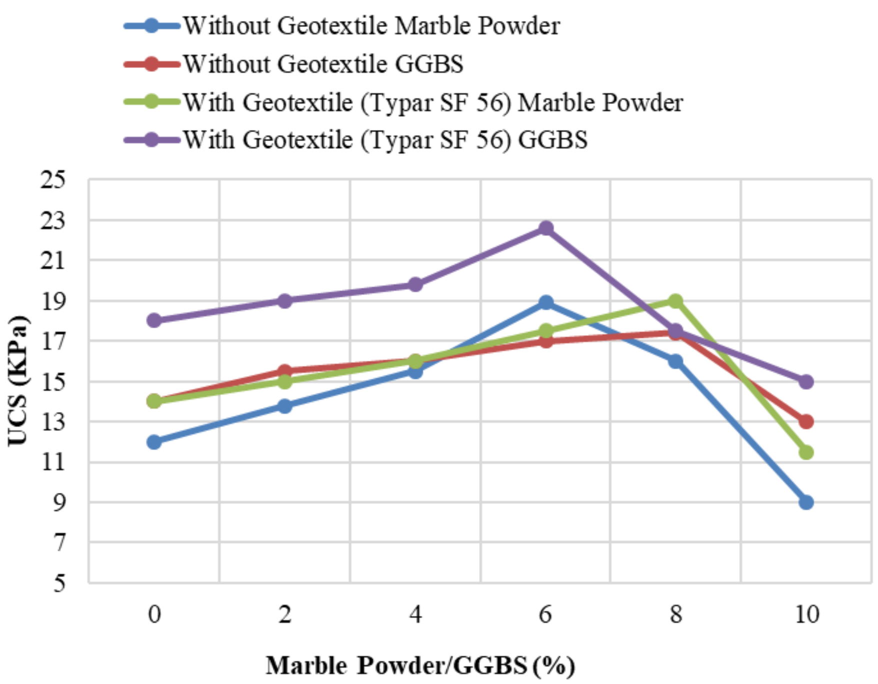


Figure 3. Unconfined Compressive Strength (kPa) of plain clayey soil/admixed with Marble Powder/Furnace Slag without/with geotextile

The addition of both Marble Powder and Furnace Slag improves the Unconfined Compressive Strength of clayey soil up to an optimum percentage of around 6%. Beyond 6%, particularly at 10%, there is a fall in Unconfined Compressive Strength values, indicating that excess Marble Powder or Furnace Slag negatively impacts soil strength. The use of geotextile reinforcement (Typar SF 56) significantly enhanced Unconfined Compressive Strength values, with the best performance seen at 6% of Furnace Slag and 8% of Marble Powder found as 22.6 kPa and 19 kPa, respectively, and indicating a beneficial interaction between the soil, additives, and geotextile. Similar to studies were also revealed that unconfined compressive strength (UCS) on geotextile reinforced soils with varying percentages of marble powder and Furnace Slag enhanced the strength [39].

5. Conclusion

This study highlights the potential of Marble Powder and Furnace Slag as sustainable and effective admixtures for enhancing the strength properties of clayey sand, a commonly used but lower-strength soil type in construction. By incorporating these industrial by-products, clayey sand can be transformed into a more stable and load-resistant material, suitable for applications such as geotextile-reinforced subgrades in transportation infrastructure. The addition of Marble Powder at 6% of optimum content improved the unsoaked California Bearing Ratio values of clayey soil to 5.6% and 6.2% with geotextile. The addition of both Marble Powder and Furnace Slag each at 6% of optimum contents improved the Unconfined Compressive Strength of clayey soil to 18.9 kPa and 17 kPa without geotextile and 17.5 kPa and 22.6 kPa with geotextile, respectively.

This approach not only addresses the soil's limitations in compressive strength and load-bearing capacity but also supports environmentally conscious construction practices by repurposing waste materials. The improvements in soil stability and resistance to settling and deformation under applied loads ensure longer-lasting infrastructure with reduced maintenance costs, particularly beneficial for roads, railways, and embankments. Overall, the integration of Marble Powder and Furnace Slag in soil stabilization offers a viable solution that enhances both structural integrity and sustainability in construction.

6. Future Scope

Based on the above research findings, it has been recommended for future scope as to develop regression and AI models to estimate subgrade soil strength using UCS, CBR and elastic modulus values with micro-structural analysis by XRD and SEM tests.

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Authors Contribution Statement

D. Bharath Naik: Conceptualization, Implementation, Methodology, Experimental Result Finding, Writing Draft Paper and Editing, Review of Existing Literature and Paper Formatting. R. Srinivasa Kumar: Supervision, Data Interpretation, Final Editing and Proof Reading. All the authors read and approved the final version of the manuscript.

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Data Availability

The data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

Has this article screened for similarity?

Yes

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