Significance of SEM Analysis in Short-Term and Long-Term Strength of Stabilized Adobes

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Abstract: This study aims to emphasize the importance of scanning electron microscopy (SEM) in explaining the differences in the physical and mechanical behaviours of the short-term (cured for 28 days) and long-term (cured up to 540 days) strength properties of stabilized adobe. The study has been carried out for Stabilized Adobe of 15% and 10% clay content with stabilizers cement, lime and combination of cement-lime. SEM is an essential feature of numerous microstructural analyses, as it allows for the observation of the soil microstructure, which is composed of clay particles and additives. This work discusses the studies based on the microstructural properties of the stabilized adobe with SEM analysis. The conducted research indicates that the inexplicable physical or mechanical behaviour can be elucidated by the microstructural characteristics of clay particles and additives.

Keywords: Stabilized Adobe (SA); Stabilizers, Short-term strength, Long-term strength, cement SA, lime SA, cement-lime SA, microstructural, scanning electron microscopy.

Introduction

The conventional method of using soil for construction has undergone significant modification through time, improving the quality and longevity of the material. Due to its widespread use, low-cost construction technologies have emerged such as stabilized adobe, stabilized mud blocks (SMBs), compressed stabilized earth blocks (CSEBs), rammed earth in construction, and others. The building materials used in modern construction such as burnt clay bricks, cement concrete blocks, and wood derivatives, use energy and have a negative influence on the environment. Additionally, the raw materials might not be produced locally, necessitating their transportation before and after manufacturing to the location where they are to be used. This has led to an increase in the expenditure of energy in one way or another. These alternate materials have a significant amount of embodied energy. Stabilized Adobe is one such material that can be used in buildings, especially in low-cost housing as its production is effective, durable, and energy-efficient.

Globally, architects and civil engineers are struggling with sustainability. The current standard calls for the use of materials that are sustainable and contribute less to environmental pollution and damage. Hence efforts are to be made by using sustainable resources in building thereby leading to a decrease in the effects of global warming. Construction using soil is one such methodology that includes a variety of innovative materials and construction methods.

Scanning Electron Microscopy (SEM)

A concentrated stream of high-energy electrons is employed in scanning electron microscopy to produce a variety of signals at the surface of solid specimens. The majority of SEM microscopy applications include gathering data over a predetermined portion of the sample's surface in order to create a two-dimensional image that shows spatial variations in characteristics, such as the chemical characterization, texture, and orientation of materials. Analysis of specific sample point locations can also be done with the SEM. This method works particularly well for determining crystalline structure, crystal orientations, and chemical compositions in a semi-quantitative or qualitative manner.

SEM is a research tool that helps identify the underlying factors that contribute to different soil types performing differently in different environments. It is a diagnostic tool for various soil issues as well as a development tool for strengthening soils. As a result, the SEM has been a tool for studying the interior of soil mass. In this way, there are a lot of opportunities for researchers and practicing engineers to learn more about soils through the use of electron microscopy. The excellent resolution that the SEM provides for examining bulk objects made of soil is what makes it valuable in geotechnical engineering. Most SEM testing are conducted in labs for material engineering. The expense of a SEM instruments is of high cost. In spite of this, SEM has many uses and provides topographical and detailed imaging. In addition, the SEM instrument's superior technological utilisation makes it easy to use. It is quick to operate and enables digital data creation.

Despite this, SEM has a number of advantages and applications. Consequently, SEM analysis aids in determining the additives' structure of bonding with the clay particles. This discussion has demonstrated the significance of SEM analysis in relation to the stabilised adobe's short- and long-term strength characteristics utilising varying percentages of soil clay content and stabiliser .

Earlier Investigations: Saeed et al. [9] examined the influence of varying curing durations and cement quantities on the strength and compressibility of cement-treated kaolin clay specimens. On clay samples mixed with five and ten percent cement, they performed compaction, unconfined compressive strength, one-dimensional consolidation oedometer tests, XRD analysis, SEM analysis, and pH tests. Strength increased and declined in the compression index in the long-term, as per SEM, the compressibility test, and the unconfined compressive strength test.

Ural [11] examined the relationship between compacted clayey silts' pore-size distribution and geotechnical index characteristics. The combinations were created by substituting silt for two distinct clays (three distinct percentages of clay). Mixtures were subjected to Atterberg's limit tests, standard compaction tests, mercury intrusion porosimetry, XRD, SEM examination, and particular surface analyses. Dispersed structure for compacted silt samples was seen from SEM images. The addition of clay has improved flocculation in the soil structure.

Wang et al. study [12] examined the impact of aggregate size on modifications to the microstructure and mineralogical compositions of compacted soils treated with lime. Three soil powders with varying maximum aggregate sizes were made for this purpose and treated with 2% lime before being used. Subsequently, untreated and treated samples at different curing periods were analysed using XRD, environmental SEM combined with chemical analysis using energy dispersive X-ray spectrometry (EDX), and mercury intrusion porosimetry (MIP). After a year of curing, crystallised C-S-H was found in the soil treated with lime and prepared with big aggregates. A noticeable rise in nanopores smaller than 0.1 μm C-S-H was also noted as a result of the formation of C-S-H 34.

Granulated blast furnace slag (GBFS) and cement are used to stabilise lithomarge clay, according to research by Sekhar and Nayak [13] utilising SEM and XRD. Mixtures were subjected to XRD, SEM-EDS, physical, and strength tests. Natural soil was seen to have a smooth texture, wavy structure, and observably greater void regions in the SEM pictures. The replacement soil with GBFS produced agglomerations, as shown by the SEM pictures, which led to the observation that the pore or air gaps were reduced and the particles had flocculated. Large pores were eliminated by bonding particle sand flocculent particle arrangements, resulting in high strength and stiffness. Cement, according to researchers, produces hydration products during longer curing times, which aid in the filling of pores and voids by cementitious products.

Material Characterisation and Methodology

The results of the laboratory tests carried out to study the properties of the materials such as Soil, Manufactured-Sand (M-Sand), Cement and Lime used in the casting of SA have been listed. To explore the impact of material variation on the qualities of SA, it is essential to proportion the different materials used for casting it. These test findings provide significant information regarding the properties of the materials as well as their compliance with established standards like those set forth by the BIS (Bureau of Indian Standards).

Table 1: Physical Characteristics of Natural Soil and Reconstituted Soil

Parameters tested	Natural Soil	Reconstituted Soil	
		reconstituted soil of 15% clay content (C15)	reconstituted soil of 10% clay content (C10)
Sand content, (%)	43	56.61	70.32
Silt content, (%)	37.42	28.38	19.37
Clay content, %)	19.58	15.07	10.31
Liquid limit (%)	41	31	26.8
Plastic limit (%)	20.33	18.56	17
Plasticity index (%)	20.67	12.44	9.8
Free Swell Index (%)	11.4	10.7	10.1

M-Sand used in the present study confirms zone - II as per IS 383:2016 [6] and the specific gravity is 2.6. The procured lime is quick lime and it is slaked. The Ordinary Portland Cement of 53-grade cement confirming IS 12269:2015 [9] has been used in the study having specific gravity of 3.12.

For the preparation of SA, as per IS 1725(2013) [1], the clay content in the soil should be less than 18%. In the present study, the procured soil clay content is 19.58%. Reconstituting the soil by adding M-Sand, clay content has been reduced to 15% and 10%. To stabilize the soil 8% cement alone, 8% lime alone and a combination of 6% cement and 3% lime has been added. The compressive strength properties of SA of 15% and 10% clay content (C15 and C10) with different stabilizers (cement and lime) and curing periods (28 days, 90 days, 180days, 360days and 540 days) have been studied. Designation of Stabilized Adobes Considered in the Study are presented in the Table 2.

Table 2: Designation of Stabilized Adobes Considered in the Study

Sl No	Designation of C15 and C10 series SA		Composition of clay and stabilizer
1	C15 Series SA	C15A	Reconstituted Soil with15% clay (C15) + 8% cement (A)
2		C15B	Reconstituted Soil with15% clay (C15) + 8%lime(B)
3		C15C	Reconstituted Soil with 15% clay (C15) + (6% cement + 3% (Lime) (C)
4	C10 Series SA	C10A	Reconstituted Soil with 10% clay (C10) + 8% cement (A)
5		C10B	Reconstituted Soil with 10% clay (C10) + 8% lime (B)
6		C10C	Reconstituted Soil with 10% clay (C10) + (6% cement - 3% Lime) (C)

In the present study, stabilized adobes are casted by manual pugging of wet soil mix (soil+ M-Sand + Stabilizers) with adequate amount of water. A special five-sided iron mould which was developed by Subhas Basu [4] is used to cast the stabilized adobes. The size of the five-sided iron mould is 230mmX190mmX100mm.

Strength Properties of Stabilized Adobe

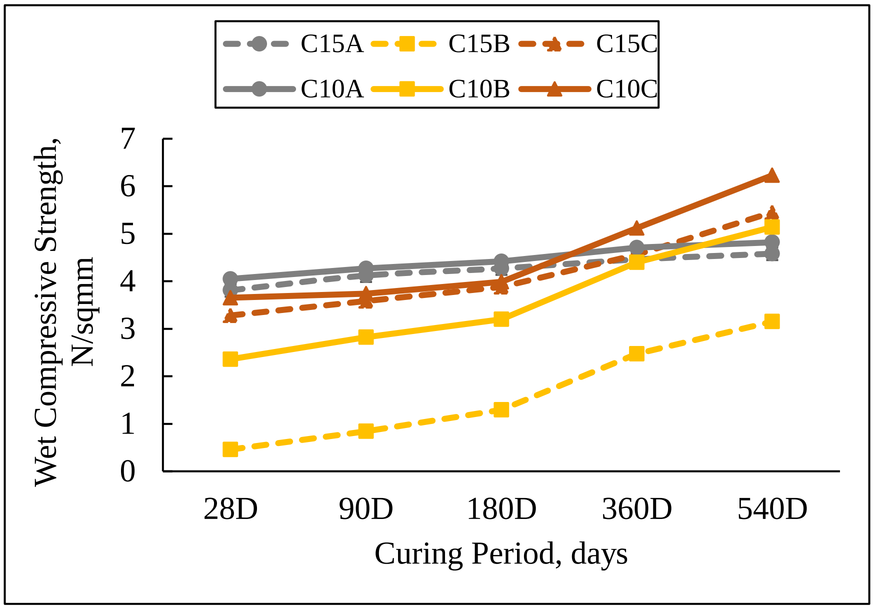


Fig 1: Variation in Wet Compressive Strength of Stabilized Adobe of C15 and C10 Series w.r.t Ageing

Fig 1 presents variation of Wet Compressive Strength of Stabilized Adobe of C15 and C10 Series. The rate of gain of Strength is gradual in cement SA up to 180 days and after 180 days it remains almost constant, the increase is about 20% and 19% in C15A and C10Awith an increase in the curing period from 28 days to 540 days. The lime SA (particularly in C15B) shows a steep and continuous increase in the rate of gain of Strength till 540 days of curing [10]. The WCS of lime SA with 10% clay content (C10B) almost reaches the same strength as the SA with cement alone. The rate of gain of WCS of SA with an increase in curing period, with lime stabilizer increases at a very high rate of about 6 times in C15B and 2 times in C10B respectively. For both 10% and 15% clay content, the WCS of SA with a combination of cement-lime stabilizer increases gradually up to 180 days of the curing period, on further increase in curing the Wet compressive strength increases at a higher rate (at 540 days of ageing the wet compressor strength is highest) than SA with cement alone and lime alone as a stabilizer. C15C and C10C increase by 66% and 70% with an increase in curing period from 28 days to 540 days.

C10 series SA are found to have a higher WCS than those with C15 series SA. In terms of stabilizers, cement SA (C15A & C10A) has a higher WCS than a combination of cement-lime SA, (C15C & C10C) followed by lime alone (C15B & C10B).

SEM Analysis

Following fig 2 and fig 3 presents the SEM images of C15 and C10 Series Stabilized Adobe Cured at 28 days and 540 days.

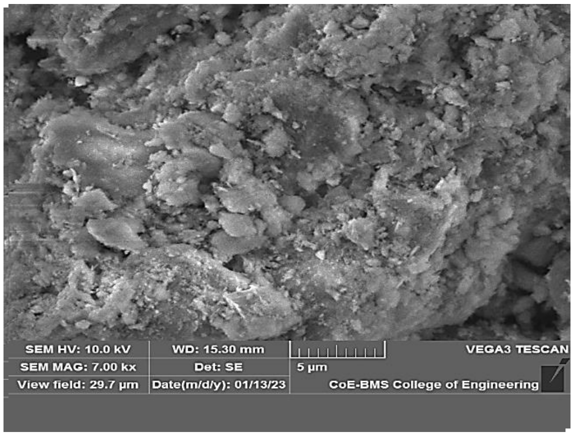


Fig a) C15A Cured at 28 days

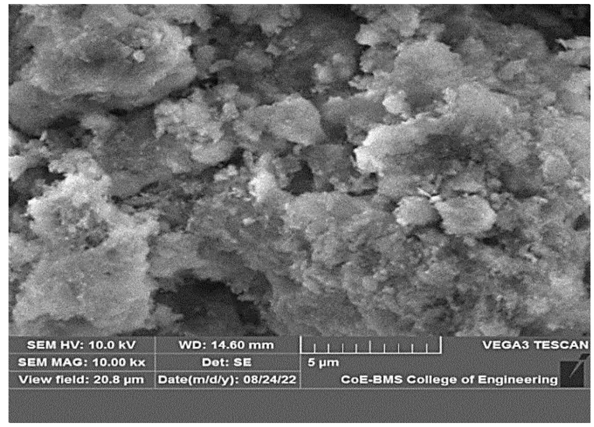


Fig b) C15A Cured at 540 days

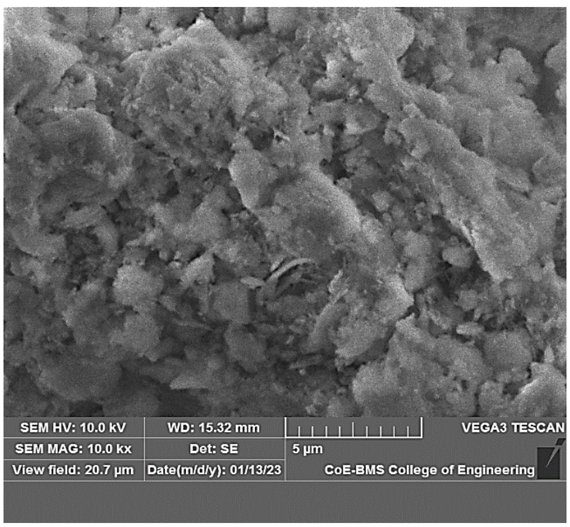


Fig c) C15B Cured at 28 days

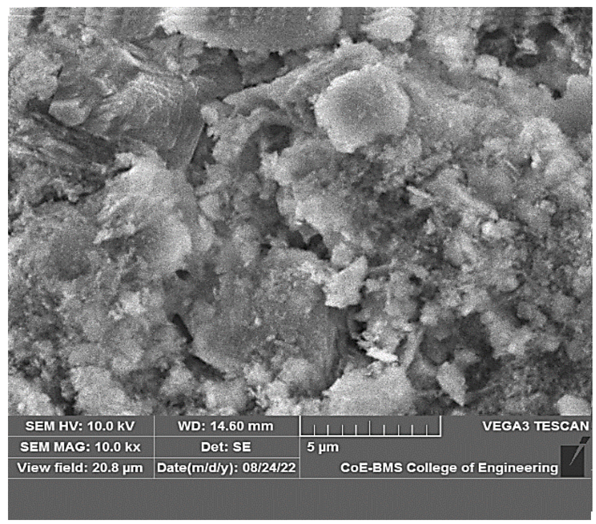


Fig d) C15B Cured at 540 days

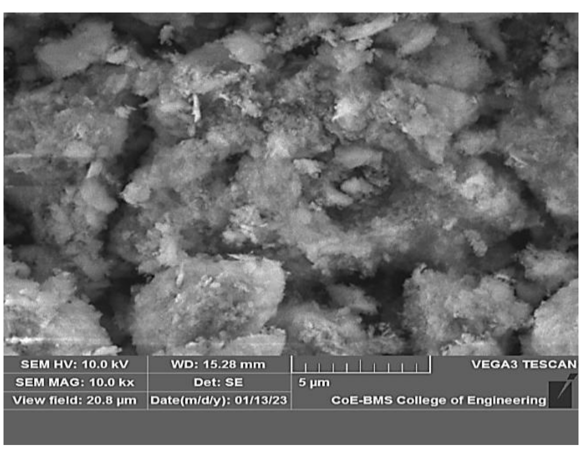


Fig e) C15C Cured at 28 days

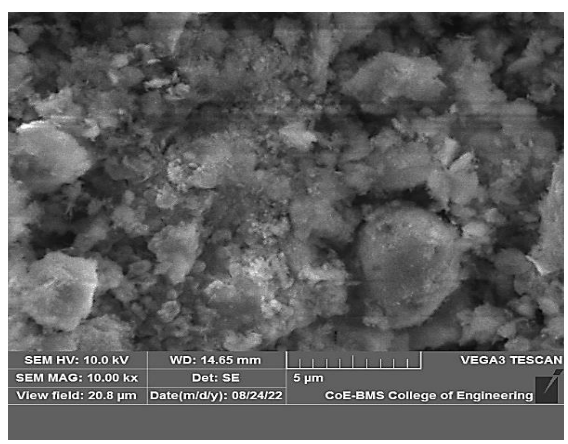
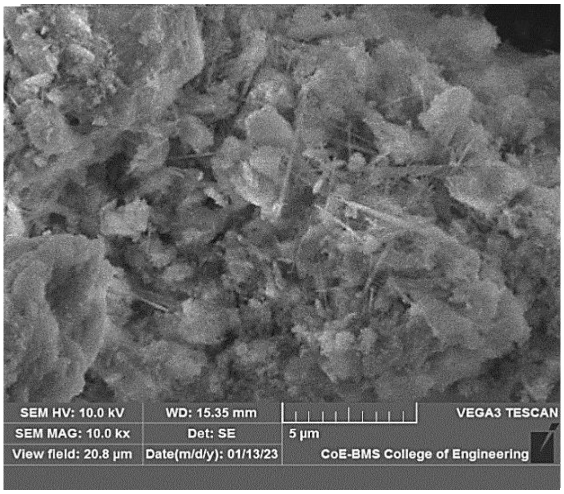


Fig f) C15C Cured at 540 days

Fig 2: SEM Analysis of C15 Series Stabilized Adobe Cured at 28 days and 540 days



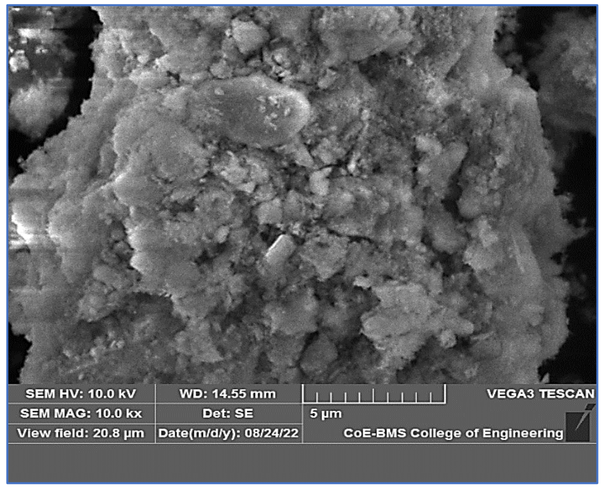
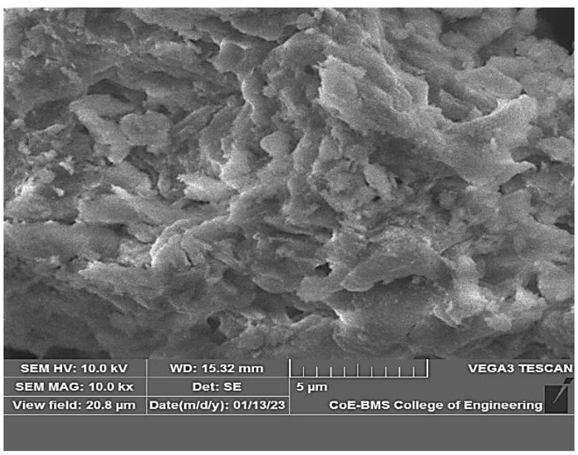


Fig a) C10A Cured at 28 days

Fig b) C10A Cured at 540 days



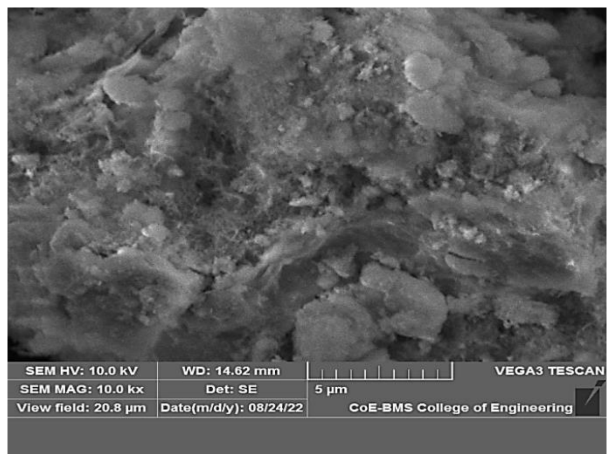
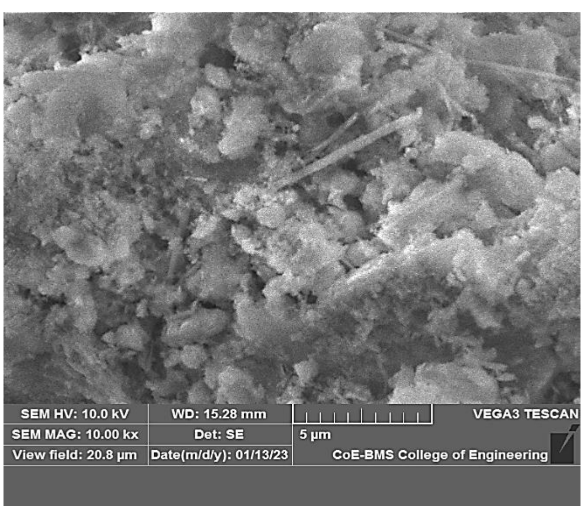


Fig c) C10B Cured at 28 days

Fig d) C10B Cured at 540 days



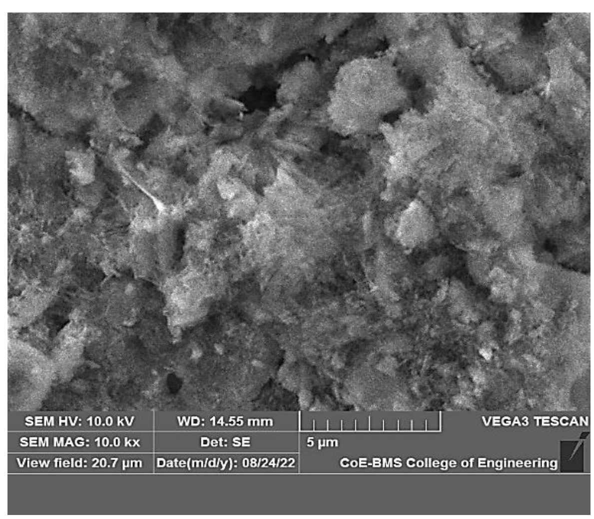


Fig e) C10C Cured at 28 days

Fig f) C10C Cured at 540 days

Fig 3: SEM Analysis of C10 Series Stabilized Adobe Cured at 28 days and 540 days

At the beginning of ageing (28 days), as seen in Figure 2.a and Figure 2.e, i.e. C15A and C15C SEM pictures, the particle size is small; as ageing time advances, the particle size steadily increases. The particle size continues to grow still 540 days of ageing (fig. 2.b and fig. 2.f). Fine clay particles and CSH-aggregates mass are encased in calcified crystals and silicates, which then bond the small particles to create stable, bound, big particles. Between the particles, there is a clear agglomeration action that creates a dense mass, boosting mechanical strength.

From fig 2.c, the space between the grains is been seen in C15B is more at 28 days, which may reduce the specimen's density and strength. As the age of curing period increases, the increasing hydration level, more hydration products and compact micro-morphology could be seen in 540 days of aging. The hydration of lime in the usual curing environment, the specimen's micro-morphology became more compact at 540 days. The C-S-H gel in the shape of a foil and other hydration products filled the spaces between the grains. In the long-term, some ettringite combined with free gypsum to produce mono sulphate, a hexagonal plate-like reaction product [14] is illustrated in Fig 3.d. As these reaction products formed and grew, the stabilized soil structures became denser and more durable, increasing the strength.

Figures 3. a and 3.e shows that cementitious products like CSH and ettringite are abundantly generated in the early stages of the process of hydration of cement [6]. With longer curing times, reaction products might be seen to expand significantly. C-S-H materials and ettringite hardened on the surface of the stabilized soil, as seen in Fig. 3.b and Fig. 3.f. While relatively fewer white patches are visible, the photos demonstrate the binding and covering of aggregated soil particles, forming a densely packed and compacted structure. This relative lack of white patches is due to the cementitious gel's consumption in binding and filling voids, which significantly increases strength [7,8].

The soil-lime particles in C10B (fig. 3.c) shows the formation of C-S-H as flocculation layers after 28 days of curing [5]. Figure 3.d further demonstrated that an ettringite net has been built between soil particles and hydration products, which significantly improved the mechanical properties as the curing period increased [15]. This resulted in more hydrated crystals and C-S-H gels found in the specimen's microscopic pores creating the dense masses.

Conclusion

Using cement as a stabiliser causes a marginal increase in the rate of strength gain in SA. This may be due to the quick hydration process of cement forming cementitious compounds that result in an early gain of strength, because of the lime's gradual reaction, which becomes stronger with longer curing. When lime is used as a stabiliser, long-term curing in the SA is more effective. At 540 days of curing, the strength increased by SA using a combination of cement and lime stabiliser is more than that of SA using cement and lime alone, demonstrating the combined action of cement and lime. 10% clay percentage in SA has demonstrated greater wet compressive strength than 15% clay content, irrespective of stabilizers.

Material science laboratories have carried out SEM tests. SEM pictures consequently show reaction products, variations in microstructures, and micro- macro pores for all types of stabilised adobes. SEM analysis can be applied to examine the effects of the additives, curing time, % of the additive, and other factors in detail. As a result, the strength characteristics of stabilised adobe can be used to better understand and interpret by the SEM pictures.

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