Laboratory evaluation of curing period for stabilized expansive soil by a new paper/timber industry waste based cementing material

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Abstract. In order to minimize the geological disaster triggered by expansive soil, and promote environmentally sustainable utilization of industrial-waste, a new composite cementing material was proposed for the expansive soil stabilization based on paper/timber industry waste. In this article, laboratory evaluation is conducted to establish the effect of curing-period for the stabilized expansive soil with newly proposed composite cementing admixture (CCA) and compared it with lignosulphonate (LS) alone, in perspective of various engineering properties, i.e., volume change behaviour, hydraulic-conductivity and strength parameters. Results showed that the curing-period has a notable impact on the performance of CCA. For the soil stabilized with CCA, swelling potential was completely eradicated after seven days of curing; whereas, the strength parameters exhibited improvement till twenty-eight day of curing with some variation in hydraulic-conductivity. Conversely, LS treated expansive soil remained prone to potential swelling after seven days of curing. Further, LS exhibited an insignificant amelioration of hydraulic-conductivity and strength parameters with the curing-period. Based on the test results, it is concluded that the CCA stabilization method is far superior than LS stabilization. Moreover, based on laboratory evaluation, twenty-eight days of time is recognized as the optimum curing-period for CCA treated soil to achieve better engineering properties.

1. Introduction
Expansive/swelling soil is regarded as a problematic material for various Civil Engineering projects because of its volumetric change behaviour owing to the presence of montmorillonite, an expansive clay mineral. The disastrous behaviour of expansive soil is usually triggered by varying wet-dry environmental conditions. Such kind of soils causes extreme distress and severe damages to various Civil Engineering structures e.g., embankment failure, sub-grade subsidence, differential settlement of flooring, distress to buried pipe lines etc., and causes billions of dollars of damages all over the world [1, 2]. Due to its high occurrence around the globe, more specifically in China, where one third of the country falls under expansive soil region, and economic constraints, it is not pragmatic to bypass such material or to replace it with some borrowed material [3, 4]. Among different techniques to deal with
such kind of problematic soils, soil stabilization is one of the cost-effective methods. Several traditional stabilizers such as hydrated lime (LM), Portland cement, etc., have been incorporated to stabilize such kind of soils [5-7]. Hydrated lime is a well-known stabilizer to deal with such problematic soil and has been extensively used in the past years. LM reacts with clay minerals through pozzolanic reaction and results in the formation of cementations material, i.e., calcium silicate hydrate and calcium aluminate hydrate, which are responsible for the long-term strength gain with curing period [8]. However, the extensive use of such stabilizers not only considerably enhances the construction budget, but also escalates the natural resource consumption [9]. Therefore, it is inevitable to find a low cost as well as a comprehensive stabilizer other than traditional ones [10].

Moreover, striking growth in urbanization and industrialization in recent years has resulted in millions of tons of different kinds of industrial wastes; which are posing serious environmental and economic issues. Therefore, the sustainable use of such wastes is a key research area now a days. Lignosulphonate (LS) is a paper/timber industrial waste, and it is extensively generated around the globe (50 Mt/annum) due to ever increasing demand for paper and timber utilities. It requires serious attention for disposal due to its abundance, especially in China, as China is leading the world in paper/board production [11-14]. Therefore, the potential use of LS as an expansive soil stabilizer could provide a cost-effective and sustainable solution for construction as well as the waste management field.

Limited studies have been conducted on the utilization of LS as an expansive stabilizer, which have shown moderate improvement in few engineering properties of expansive soil, e.g., volumetric change behaviour, plasticity, etc., [15]. Whereas, an insignificant effect has been reported on shrinkage and strength characteristics [16, 17]. Moreover, the LS stabilization is based on intermolecular interaction, instead of a chemical reaction as in LM stabilization [18]. Besides, there is a literature scarcity on the improvement of LS as a stabilizer for expansive soils, despite the highly anticipated economic benefits for the construction and waste management fields. Keeping in view the performance of LS as an expansive soil stabilizer, authors propose that LS can turn into a more effective stabilizer by compositing it with some reactive additive, i.e. LM.

This study is focused on the performance of newly proposed cementing material by using paper/timber industry waste at various curing periods and suggests an optimum curing period for practical implementations. For this purpose, different engineering characteristics, i.e. volume change behaviour, hydraulic conductivity, and strength parameters, were evaluated, accounting different curing periods. Afterwards, based on the laboratory evaluation, an optimum curing period was selected at which adequate stabilization was achieved, keeping in view the aforementioned engineering properties. Moreover, a comparison was also carried out between CCA and LS at various curing period to highlight the utility of newly proposed CCA.

2. Materials and methods

2.1. Materials
The expansive soil was procured from Nanyang, China. The soil exhibited a high liquid limit of 61.9% with a plasticity index (PI) of 39.6%. The particle size distribution showed that 9% of the soil particles fall under the range of sand, while the remaining 91% was fine-grained size particles, i.e. silt/clay. As per USCS, the soil is designated as fat clay (CH). The soil also exhibited a high activity of 1.82; based on the aforementioned engineering properties, the subjected soil was found to be potentially expansive.

The hydrated lime and lignosulphonate were purchased locally. The hydrated lime comprised of 83% Ca(OH)₂, while LS was amorphous in nature.

The optimum percentages of lignosulphonate (OLS) and proposed composite cementing admixture (OCCA) for expansive soil treatment were experimentally determined on the basis of the plasticity index (PI) value; considering that PI is a good indicator of swell-shrinkage behavior [19]. The basic soil properties of untreated and treated soil with OLS and OCCA are tabulated in Table 1.
Table 1. Basic soil properties of untreated and treated soil.

| Properties          | UTS\(^{a}\) | OLS\(^{b}\) | OCCA\(^{c}\) |
|---------------------|-------------|-------------|-------------|
| PI (%)              | 39.6        | 27.9        | 23.5        |
| 95% of MDD (g/cc)   | 1.54        | 1.52        | 1.53        |
| OMC (%)             | 22.2        | 22.5        | 22.8        |

\(^{a}\) Untreated soil.
\(^{b}\) Optimum lignosulphonate treated soil.
\(^{c}\) Optimum composite cementing admixture treated soil.

2.2. Methods

The laboratory tests included 1-D swelling tests [20], constant volume swell pressure test [21], falling head permeability tests [22], and direct shear tests [23]. All the soil samples were compacted at 95% of the maximum dry density (MDD) and optimum moisture content (OMC) by using static compaction. In the direct shear test, the shear rate of 0.01 mm/min was employed for all the soil samples. After compacting the soil samples as per moisture-density relationship, the soil samples were cured by sealing it in plastic bags and placing it in a glass desiccator jar to avoid any moisture loss during the course of curing. After achieving the desired period of curing, the soil samples were subjected to the aforementioned tests.

3. Results and discussion

3.1. Swell potential and swell pressure

Results of percentage swell and swell pressure test of untreated and treated soil accounting the effect of curing are presented in Figures 1 and 2.

Figure 1. Effect of the optimum percentage of LS and CCA on the swell percentage of untreated soil at 28th day of curing.

The results exhibit the amelioration in swelling potential and swell pressure along with the curing period with the addition of admixture. The newly proposed OCCA exhibited the complete eradication of the swelling potential and swell pressure of the expansive soil on the seventh day of curing. Conversely, the expansive soil treated with OLS admixture was still prone to considerable swelling and swell pressure. Moreover, OLS admixture was found to be ineffective in curtailting the swelling potential and swell pressure of expansive soil with extended curing period, i.e., the swell potential and
swell pressure almost nearly remained constant after seventh days of curing. Thus, it is inferred from the above discussion that the proposed OCCA works superiorly in comparison with OLS treated samples, and seven days of curing period are enough to eradicate the swelling potential and swell pressure by using CCA.

![Graph a)](image1.png)

![Graph b)](image2.png)

**Figure 2.** Effect of OLS and OCCA treatment on volume change behavior of expansive soil; a) swell (%) versus curing period; b) swell pressure (kPa) versus curing period.

### 3.2. Hydraulic conductivity

Figure 3 presents the hydraulic conductivity of untreated and treated expansive soil with OLS and OCCA, accounting for the effect of different duration of curing period. The results exhibited a marginal increase in saturated hydraulic conductivity with the addition of admixture. At 28th day of curing the OLS and OCCA treated samples were 0.74 and 0.70 times more pervious than untreated soil. In addition to this, the OCCA treated soil samples at first exhibited an increase in saturated
hydraulic conductivity, i.e., on 3rd day of curing, the saturated hydraulic conductivity was increased by 2.0 times, which further started to decrease with curing period, and then remained constant after 28 days of curing. This can be attributed to the development of a more regular structure with an extended curing period triggered by a chemical reaction of LM and intermolecular interaction of LS with clay minerals.

![Graph of hydraulic conductivity vs curing period](image1)

**Figure 3.** Effect of OLS and OCCA treatment on hydraulic conductivity of expansive soil accounting different curing periods.

3.3. Shear strength parameters

Figure 4 presents the variation in shear strength parameters of expansive soil with OLS and OCCA addition, along with an extended curing period.

![Graph of shear strength parameters vs curing period](image2)

**Figure 4.** Effect of OLS and OCCA treatment on shear strength parameters of expansive soil accounting for the effect of the curing period.

The results showed that OLS addition had an insignificant effect on the shear strength parameters of the expansive soil along with an extended curing period, owing to the inefficiency of the LS admixture.
Conversely, the OCCA admixture exhibited tremendous improvement in shear strength parameters. The cohesion has been improved by 69% on the 28th day of curing, while the angle of internal friction was improved by 25%. It is pertinent to mention that OCCA treated expansive soil underwent an increase in shear strength until 28 days of curing; on further increase in the curing period, there is a slight variation. Owing to the notable effect of the curing period on shear strength, it is deduced that 28 days of curing is critically important from a strength point of view, which is the most important engineering parameter that governs the stability of the structure.

4. Conclusions
It is concluded that the new paper/timber industry based cementing material addition implants superior engineering characteristics in expansive soil in comparison with LS alone. The swell potential is completely eradicated on the seventh day of curing and remains constant afterwards. Conversely, LS treated soil still remains prone to substantial swelling after seven days of curing and exhibits no reduction in swelling potential with an extended curing period. The proposed cementing material tremendously improves the strength parameters until twenty-eight days of curing and then remains constant; while LS treated soil have an insignificant effect on the strength parameters with the curing period. Both CCA and LS have an insignificant effect on hydraulic conductivity and exhibit slight variation with the curing period. Based on the test results, it is concluded that twenty-eight days of curing is the optimum curing period keeping in view the strength parameters.

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