INVESTIGATION ON THE IMPACT OF CURING CONDITIONS ON THE BEHAVIOR OF CONTROLLED LOW-STRENGTH MATERIAL AS BASEMENT OF RURAL ROADS IN THE MEKONG DELTA

Sang Yum Lee[1], Trinh Vo Thi To[2], Tri Ho Minh Le[2]*
[1]Induk University, Seoul 01878, Republic of Korea
[2]Nguyen Tat Thanh University, Ho Chi Minh City 70000, Vietnam

*Corresponding author: lhmtri@ntt.edu.vn

(Received: February 27, 2023; Revised: April 5, 2023; Accepted: April 14, 2023)

Abstract - This study investigates the performance of controlled low-strength material (CLSM) in the challenging Mekong Delta climate, which experiences rapid weather fluctuations, acid rain erosion, uneven mixture gradation, and subpar aggregate quality. Additionally, difficulties in sieving and quality control have led to the disposal of dredged soil in construction sites. The research aims to enhance the practical use of CLSM as a foundation for rural roads in the Mekong Delta by incorporating dredged soil and mineral additives (6% silica fume, 25% bottom ash) under various curing conditions, including normal, acidic, and salted environments. The study assesses CLSM strength through flowability, setting time, and unconfined compressive strength tests. Findings highlight the significant influence of curing conditions on both early and 28-day CLSM strength, with harsh environments compromising cement hydration. Optimizing dredged soil content and mineral components can bolster CLSM strength and promote sustainable use of dredged soil in construction.

Key words - Flowable-fill materials; sustainable development; Mekong Delta; rural roads; curing conditions.

1. Introduction

Controlled low-strength material (CLSM) is a flowable mixture that contains cement, fine aggregates, water, and a small amount of bottom ash or other pozzolanic materials. CLSM is used in construction as a backfill material, for filling underground voids, and for providing structural support to pipelines, utilities, and other infrastructure [1]. The strength of CLSM is influenced by several factors, including the proportions of the mixture components, the curing environment, and the time allowed for the material to cure [2]. In particular, the curing environment can have a significant impact on the strength of CLSM. Proper curing is critical for the development of the strength and durability of CLSM [3]. The curing process involves maintaining the moisture content and temperature of the material within certain ranges to ensure that the cement hydrates and forms a strong bond with the aggregates [4]. If the curing environment is too dry or too cold, the cement may not fully hydrate, and the resulting material may be weaker and less durable [5, 6]. Conversely, if the curing environment is too wet or too hot, the material may shrink, crack, or lose strength. Therefore, it is essential to carefully control the curing environment when working with CLSM to ensure that the material develops the desired strength and properties [7]. Proper curing can also help to minimize the risk of damage to the surrounding infrastructure or the environment [8].

Researchers from several fields have investigated the development of CLSM utilizing by-product material [5,6,9–11]. However, there is a lack of research focus on the incorporation of curing conditions on the strength of this material. In the backfilling of the trench, a limited study fully used a large volume of dredge soil as a replacement for natural construction sand/soil concerning the insufficient bearing capacity. Therefore, the primary goal of this research is to determine the possibility of dredging soil as a full substitution for natural construction sand in the basement of rural roads in the Mekong Delta under various curing conditions.

In order to promote sustainable construction purposes, this research utilizes 0% to 100% dredged soil as fine aggregate. In addition, various mix designs were developed from 3 curing conditions including normal, acid sulphuric (3%), and salted environment in the controlled chamber. Regarding the performance evaluation of proposed mixtures, there were two primary stages to this study: Stage 1 concentrated on the samples' fresh properties; Stage 2 examined the strength gain of hardened specimens under a practical curing process.

2. Materials and methods

2.1. Materials

In this research, the dredged soil was collected from the local area in District 12, Ho Chi Minh city, and the Portland cement type I was provided by a private company. The general properties and gradation distribution of the dredged soil are presented in Table 1 and Figure 1, respectively. Additionally, the dredged soil was found to obtain the liquid and plastic limits of 22.83 and 24.12, respectively. Based on the suggestions from related research and the author’s team trial works, the cement content was fixed at 160 kg/m^3 to acquire the proper strength gain of flowable fill. In order to compare the quality between the conventional natural sand and newly developed material having dredged soil, the construction sand was also incorporated in this research. Besides, the superplasticizer was also used in very small quantities (0.1% by wt. of cement) to minimize the usage of mixing water. Considering the blending of mineral components, silica fume is incorporated to strengthen the qualities of the flowable mixture, particularly its resilience, adhesion, and resistance to wearing. Meanwhile, bottom ash is introduced to the mixture to further investigate the strength of Ash-

CLSM under critical conditions. The overall materials properties are presented in Table 1.

Table 1. *The comparison of clustering result*

Portland cement	Type I (3.15 g/cm^3)	
Dredged soil	2.71 g/cm^3 and moisture of 22.08%	0, 25, 75, and 100% replacement of sand (%wt.)
Natural sand	2.67 g/cm^3 and moisture of 5%	
Bottom ash	2.36 g/cm^3, moisture content: 0.1%	25% replacement of cement (%wt.)
Silica fume	2.26 g/cm^3	6% replacement of cement (%wt.)
Air foam liquid	Keratin protein type (liquid, 1.04 g/cm^3) pH (7.1) Salt concentration (1.8%)	

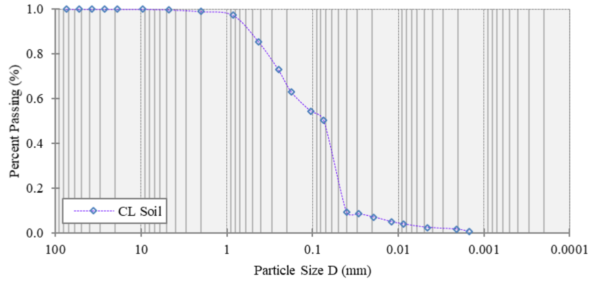

Figure 1. *Gradation distribution of dredged soil used in this research*

2.2. Simulation of harsh curing conditions

Figure 2. *(a) separate specimens before curing, (b) submerged samples, (c) damaged specimens after curing, (d) UCS test*

As regards the first, all mix designs in this research were subjected to normal curing conditions having tap water to develop reference specimens for comparison purposes. To create the harsh condition, the specimens are immersed in sulphuric or a salty setting following the initial seven days of hardening at 20°C and 100% relative humidity (RH), taking into account the sensitive atmosphere. As previously mentioned, the granular base system's resilience may deteriorate due to acid rain from a neighbouring industrial location or polluted water from coastal areas. Consequently, it is crucial to assess how long CLSM will last under these extreme circumstances. In this study, sulfuric acid is diluted with deionized water to a 3% intensity before being added to create an acidic sulfuric environment. A glass rod is subsequently utilized to stir the mixture gradually at a 30rpm rate. The setting of specimens in acid condition and the damaged specimen are presented in Figure 2 b & c, respectively. On the other hand, the preparation of the salted environment is simpler by obtaining used collected seawater from Tien Giang province. The salinity of the studied seawater according to research is from 33 to 35‰. The specimens were cured for 28 days in acidic or salty environment circumstances until the testing day. Before performing the UCS experiment, specimens are wiped with a special cloth and allowed to cure for two hours at a similar temperature and RH.

2.3. Testing process

2.3.1. Mixing process

Considering the blending process, air foam was created by first mixing the foamy ingredient and tap water in a 1:20 ratio. To guarantee homogeneous blending, aggregate, mineral admixtures, and cement was mixed for 2 min with roughly half the required moisture content, accompanied by a 1-minute rest period. The remaining liquid and prepared air foam were then incorporated and blended for an extra 3 minutes after the air foam had been formed in a suitable state [5,6]. For the unconfined compressive strength test, the slurry was blended before being molded into specimens in PVC pipe molds with measurements of 140 mm in height and 70 mm in diameter.

2.3.2. Flowability test

The ASTM D 6103 criteria are used for conducting the flow property experiment [12]. The liquid solution was loaded into the open-end acrylic cylinder in accordance with the instructions. The mean distributing size of the mixture was determined as the mixture's flowability after the mold was raised 5 cm off of the flat metal plate. To achieve the self-leveling objective, the ideal flow rate is anticipated to fall between 180 and 220 mm.

2.3.3. Setting time test

Following ASTM C 403, a standard penetrating experiment was used to determine the initial setting time. CLSM samples were initially placed in a 150 mm diameter by 150 mm deep cylinder. A tip containing a 16 mm^2 surface area was adopted, and it was pushed into the CLSM specimen until a magnitude of 25 mm was achieved. At various times, the pressures necessary to create the 25 mm penetrating were measured. The observed pressure was divided by the needle's area of contact to get the penetrating resistance. The first setting time was determined to be the interval between the time that cement and water first interacted and when they reached a penetrating resistance of 2.74 MPa.

2.3.4. Unconfined compressive strength test

The unconfined compressive strength test (UCS) was performed by the Universal testing machine according to the ASTM D4832 standard [13] as presented in Figure 2d. Three replicates were used to represent the average value of 1 mixture. The loading rate was controlled at 1mm/min to ensure a precise result.

3. Results and discussions

3.1. Flowability test

Figure 3 presents the flowability test of the dredged soil mixtures under various W/C conditions. Based on the suggestions and recommendations from related works, the flowability value of CLSM should be higher than 200 mm to ensure workability and practical applicability in practice such as void filling and trench reinforcement. The test results indicate a strong impact of W/C ratios on the flow value of the mixture since the higher W/C leads to a clear improvement in the index of this property. However, the flow value varied between dredged soil formulations. It can be observed that the flowability of the W/C of 0.4 conditions ranges from 250 to around 200mm while the flow value of mixture constituted from 100% dredged soil suffered from the great drop to 165.3 and 142.5mm in the W/C =0.35, and 0.3, respectively. It can be explained by the poor distribution of particle size in the dredged soil compared to that of natural construction sand which results in higher friction during the casting of fresh material. As shown in the results, the W/C should be controlled at higher than 0.35 to ensure the flowability of the mixture for actual construction purposes.

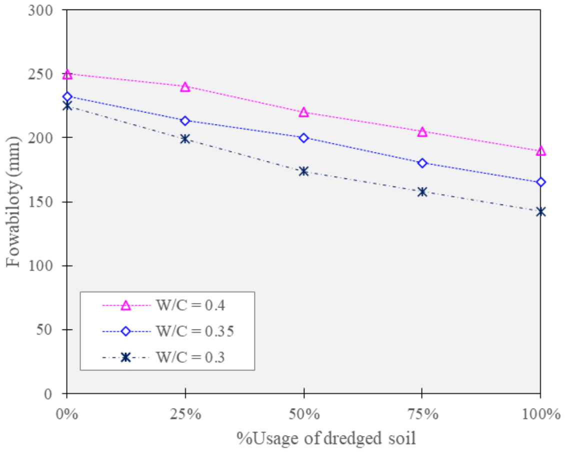

Figure 3. *Flowability test results*

3.2. Setting time test

Regards to road & pavement projects, the setting time of CLSM material should be strictly controlled to ensure rapid construction. Although rural roads in the Mekong delta may be provided a longer time for curing time due to the low volume of traffic, the setting time is expected to reach a standard time for a large-scale application. In general, the fastest setting time belongs to the reference mixture having 100% sand while the mixture containing dredged soil show prolonged setting results (see Figure 4). When a shorter setting time is required, the mixture having lower W/C outperformed the reversed condition in all dredged soil ratios. The excessive usage of mixing water for flowability may impose a negative impact on the strength development of the mixture in the initial phase due to the presence of free water and fewer hydration activities at early ages. Thus, in a CLSM mixture with low cement content, the incorporation of high water for flow objective should be greatly considered. Considering the blending of the high portion of dredged soil, the higher the dredged soil, the greater the setting time of the mixture. For example, at W/C of 0.4, the setting time of mix DS0%, DS25%, DS50%, DS75%, and DS100% is 18.5, 24.5, 25.5, 27.5, and 29 hrs, respectively. It can be attributable to the high adsorption rate of the dredge soil particles which caused the trapped water effects. There may be insufficient water for the hydration process of cement and thereby, contributing to the poor strength gain of dredged soil mixture at an early age. In sum, the usage of dredged soil mixtures should be controlled at lower than 75% to generate the proper setting time of lower than 24hrs for practical applications.

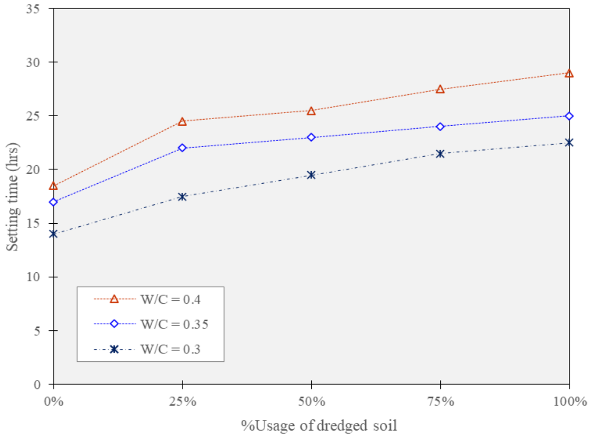

Figure 4. *Setting time test results*

3.3. Unconfined compressive strength test

Representing the featured findings of this research, the impacts of the curing environment on the strength gain of CLSM mixtures is shown in the following Figure 5. As regards the first, the compressive strength of CLSM specimens is strongly correlated to the application of dredged soil. As briefly mentioned in the fresh stage of samples, the 28-day UCS of dredged soil-modified CLSM mixture presents a reduced value compared to that of the reference mixture containing 100% natural construction sand. For example, in the normal curing condition, the 28-day UCS values of mix DS0%, DS25%, DS50%, DS75%, and DS100% are around 0.6, 0.52, 0.47, 0.45, and 0.42 MPa, respectively. Considering the normal conditions, although there is a sharp reduction from the original mixture, the improvement in the dredged soil content may not greatly interfere with the bearing capacity of the mixture. However, the usage of high-volume dredged soil suffered critically from the harsh curing condition. This may be explained by the poor structure formation of dredged soil specimens which allowed the penetration of damaged substances such as acid and salt. The test results reveal that DS100% mixtures displayed a great drop of 35.7% from 0.42 to 0.27 MPa when Acid 3% conditions were applied. Meanwhile, this value of the DS50% was 21%, indicating the potential usage of less than 50% dredged soil in the CLSM mixture. Additionally, considering the practical strength of CLSM material for rural basement construction, it should be noted that almost all mixtures passed the threshold of 0.3MPa which is very factor for the following construction of the next layers.

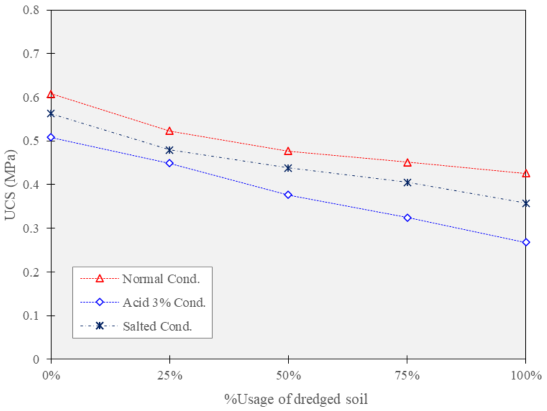

Figure 5. *28-day UCS results of CLSM mixture subjecting to harsh curing conditions*

3.3.1. Effect of silica fume

In addition to the usage of only dredged soil as the core aggregate of the CLSM mixture, this research also incorporates a small portion of silica fume and bottom ash intending to enhance the insufficient strength gain of the proposed dredged soil mixture. As presented in the following Figure 6, the reinforcement of silica fume is very promising since the use of these mineral components significantly improves the 28-day UCS of CLSM under harsh curing conditions. The SF containing results in the increased 28-day UCS through all conditions. Especially, because of the stronger structure formation, all CLSM show greater durability under acid curing conditions which mitigate the infiltration of acid solutions into the internal structure of specimens. This finding is verified by the improved gap between the normal and acid 3% conditions. For example, the increased value of DS100% mixture in normal conditions is 6.7% while this value measured in an Acid 3% environment is up to 21%, showing a clear acid resistance effect.

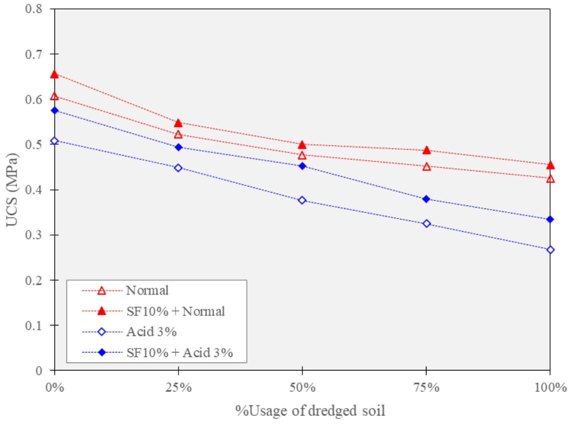

Figure 6. *Effect of silica fume in the strength gain of CLSM mixture under acid curing conditions*

3.3.2. Effect of bottom ash

Regards to the addition of thermal ash in CLSM mixture having dredged soil, it can be easily observed that CLSM mixture containing low cement content and 25% substitution of thermal ash may not be useful for short-term application. As shown in the test results (see Figure 7), the 28-day UCS of all mixtures experienced a clear drop from 2% to more than 30%. This phenomenon can be explained by the low reactivity of bottom ash at an early age. However, the long-term reactivity of bottom ash may compensate for the strength gap. Regards to the curing condition impact, the strength test showed that adding thermal ash may not be feasible for dredged soil mixture for CLSM production in high acid concentration conditions since this component may reduce the protection of CLSM mixtures to acid flow. Under this condition, many mixtures cannot meet the strength gain of higher than 0.3MPa. As a result, the combination of thermal ash and dredged soil for the utilization of by-product material in green construction should be avoided in the high acid environment to ensure the durability of the mixture.

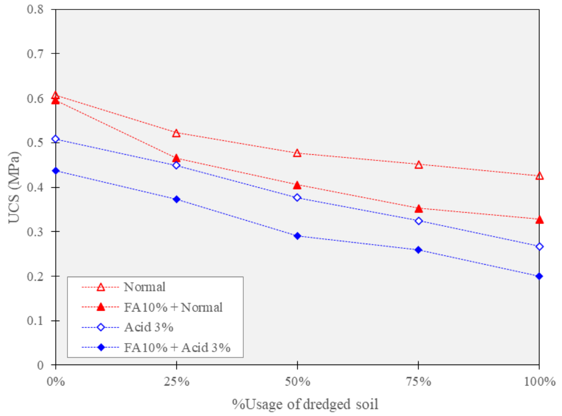

Figure 7. *The effect of bottom ash on the strength gain of CLSM mixture under acid curing conditions*

4. Conclusion

This study aims to investigate the behavior of CLSM containing dredged soil under harsh curing conditions in the Mekong Delta region to promote its practical use as a base material for rural roads. Various CLSM mixtures were prepared using different dredged soil content as a replacement for construction sand (0, 25, 50, 75, 100%). The specimens were subjected to simulated curing conditions, including acid and salted environments. Additionally, a proper silica fume (6%) and bottom ash (25%) were respectively added to the mixture to improve the durability of the mixture under damage factors. The performance of the CLSM mixture was evaluated through the flowability, setting time, and unconfined compressive strength tests. The following conclusions can be drawn from the research:

▪ It can be observed that the flowability of the mixtures having W/C of 0.4 ranges from 250 to around 200mm while the flow value of mixture constituted from 100% dredged soil suffered from a great drop to 165.3 and 142.5mm in the W/C of 0.35, and 0.3, respectively. It can be explained by the poor distribution of particle size in the dredged soil compared to that of natural construction sand which results in higher friction during the casting of fresh material.

- In general, the fastest setting time belongs to the reference mixture having 100% sand while the mixture containing dredged soil show prolonged setting results. When a shorter setting time is required, the mixture having lower W/C outperformed the reversed condition in all dredged soil ratios.

- The 28-day UCS of dredged soil modified CLSM mixture presents reduced value compared to that of reference mixture containing 100% natural construction sand. For example, in the normal curing condition, the 28-day UCS values of mix DS0%, DS25%, DS50%, DS75%, and DS100% are around 0.6, 0.52, 0.47, 0.45, and 0.42 MPa, respectively.

- The results indicate that curing conditions are crucial in determining the early and 28-day strength of CLSM specimens. CLSM is vulnerable to harsh environments, as chemical substances can infiltrate the air-void system in the specimens, thereby disrupting weak cement hydration production at an early age.

- However, the usage of high-volume dredged soil suffered critically from the harsh curing condition. This may be explained by the poor structure formation of dredged soil specimens which allowed the penetration of damaged substances such as acid and salt. The test results reveal that DS100% mixtures displayed a great drop of 35.7% from 0.42 to 0.27 MPa when Acid 3% conditions were applied.

- The silica fume addition results in increased 28-day UCS through all conditions. Especially, because of the stronger structure formation, all CLSM show greater durability under acid curing conditions which mitigate the infiltration of acid solutions into the internal structure of specimens. This finding is verified by the improved gap between the normal and acid 3% conditions. For example, the increased value of the DS100% mixture in normal conditions is 6.7% while this value measured in the Acid 3% environment is up to 21%, showing a clear acid resistance effect.

- Considering the addition of ash, the 28-day UCS of all mixtures experienced a clear drop from 2% to more than 30%. This phenomenon can be explained by the low reactivity of bottom ash at an early age. However, the long-term reactivity of bottom ash may compensate for the strength gap.

- In general, the proper use of dredged soil and silica fume can contribute to stronger strength gains in CLSM mixtures while promoting sustainable construction.

Acknowledgments: The author’s team would like to thank Nguyen Tat Thanh University, Ho Chi Minh City, Vietnam for the support of time and facilities for this scientific research.

REFERENCES

[1] T M Do and Y. S. Kim, “Engineering properties of controlled low strength material (CLSM) incorporating red mud”, *Int. J. Geo-Engineering*, vol. 7, no. 7, pp.17, 2016, DOI 10.1186/s40703-016-0022-y.

[2] T. Q. Tran, Y. S. Kim, G. O. Kang, B. H. Dinh, and T. M. Do, “Feasibility of Reusing Marine Dredged Clay Stabilized by a Combination of By-Products in Coastal Road Construction”, *Transp. Res. Rec.*, vol. 2673, no. 12, pp. 519–528, 2019.

[3] G. O. Kang, Y. S. Kim, T. Q. Tran, and N. A. Dan, “Strength monitoring of dredged marine clay stabilized with basic oxygen furnace steel slag using non-destructive method”, *Proc. Int. Offshore Polar Eng. Conf.*, vol. 2, 2409–2414, 2019.

[4] D.-W. Park, H. V. Vo, and Y. Lim, “Recycling of Dredged Soil Waste Using Air-foam Stabilization Method as Highway Construction Material”, *Innovative and Sustainable Use of Geomaterials and Geosystems*, 2014, pp. 41–48, DOI:10.1061/9780784478455.006.

[5] T. H. M. Le, D. W. Park, J. W., Seo, J. W. Lee, and K. J. Kim, “Applicability evaluation of ponded Ash as a sustainable backfill material using air foam”, *Fourth International Conference on Sustainable Construction Materials and Technologies, Las Vegas* USA, 2016.

[6] T. H. M. Le, D. W. Park, T. W. Lee, and J. W. Seo, “Feasibility study of locally excavated soil in foamed cement mixture as backfill material for abutments of railway bridges”, *J. Test. Eval.*, vol. 50, no. 6, p. 21, 2021, DOI:10.1520/JTE20210169.

[7] T. M. Do, Y. S. Kim, and M. Q. Dang, “Influence of curing conditions on engineering properties of controlled low strength material made with cementless binder”, *KSCE J. Civ. Eng.*, vol. 21, pp. 1774–1782, 2017.

[8] K. J. Folliard, L. Du, and D. Trejo, “Effects of curing conditions on strength development of controlled low-strength material”, *ACI Mater. J.*, vol. 100, no. 1, pp. 79–86, 2003.

[9] T. M. Do, Y. S. Kim, G. O. Kang, M. Q. Dang, and T. Q. Tran, “Thermal conductivity of controlled low strength material (CLSM) made entirely from by-products”, *Key Eng. Mater.*, vol. 773, pp. 244–248, 2018.

[10] C. L. Hwang and T. P. Huynh, “Characteristics of alkali-activated controlled low-strength material derived from red mud-slag blends”, *Key Eng. Mater.*, vol. 753, pp. 343–348, 2017.

[11] M. C. Nataraja and Y. Nalanda, “Performance of industrial by-products in controlled low-strength materials (CLSM)”, *Waste Manag.*, vol. 28, no. 7, pp. 1168–1181, 2008.

[12] ASTM Int., *“ASTM D 6103-04 Standard Test Method for Flow Consistency of Controlled Low Strength Material”*, pp. 1–4, 2004.

[13] ASTM Int., “*ASTM D4832–02 Standard Test Method for Preparation and Testing of Controlled Low Strength Material*”, pp. 1–5, 2002.