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APPRAISAL OF AN ENVIRONMENT-FRIENDLY GEOPOLYMER FOR CIVIL ENGINEERING APPLICATIONS

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Abstract- The phenomenon of growing urbanization compels planners to think about those regions where soils are problematic. The deficient engineering properties imply the use of conventional stabilizers such as Portland cement (PC) and lime but these cause huge CO2 emissions which impart detrimental effects on the environment. Further, the recycling of waste to produce value-added products is the need of time. Ground granulated blast furnace slag (GGBS) is generated during iron manufacturing as an industrial waste byproduct. The eggshell is food waste. Geopolymer formation utilizing these base precursors in the presence of alkaline activators comprising sodium hydroxide (NaOH) and water glass (Na2SiO3) can prove alternate construction material. Four precursor composites (ESP: GGBS) – 70:30, 50:50, 30:70, and 0:100 were selected to evaluate the influence of growing slag content on the mechanical strengths of composites. Optimum activator content (OAC) and Maximum dry density (MDD) were determined by modified proctor test whereas mechanical properties were examined via unconfined compressive and split tensile strength test. The primary aim of this study is to examine the mechanical strengths of GGBS and eggshell-powder-based geopolymers. All composites have shown significantly greater strength values than achieved via cement stabilized soils required for subgrade and subbase construction. This new geopolymer product offered a cost-effective and eco-friendly solution to the issue of waste disposal and vulnerable soil improvement at the same time.

Keywords: Eggshell powder, GGBS, Geopolymer, Alkali Activation, Cheap geopolymer

1. Introduction

The concept of recycling waste for sustainable development has gained much attention in recent times. The issues related to waste disposal and scarcity of available land for this purpose have motivated experts to think of unconventional yet useable techniques. In countries like Pakistan, municipal waste and industrial waste disposal is a major concern. Poultry waste lies in the category of municipal waste. It may be produced from restaurants, bakeries, fast food centers, hatcheries, and poultry farms [1]. Environmental problems are produced when these wastes are deposited into the landfill. To address this issue, the application of such wastes in the construction industry should be encouraged.

Ground granulated blast furnace slag (GGBS) and eggshells are produced in abundance annually. Their mineralogical composition renders them suitable to utilize as a construction material. Grinding of eggshell waste into suitable particle size eggshell powder (ESP) is not much labor and energy intensive. Since the chemical composition of ESP is quite like cement which makes it apposite to use in construction materials for partial replacement [2] [3].

Ground granulated blast furnace slag (GGBS) is a glazed, granular material that consists of SiO_2, CaO, $Al_2O_3$and MgO. In iron making, the molten blast furnace slag is generated as a byproduct. It is then rapidly cooled by immersing it in water, and then crushed into a fine powder to improve its reactivity. It is often used in concrete for binding purposes due to the high mass percentage of SiO_2, Al_2O_3, and CaO [4].

1.1. Background

Joseph Davidovits introduced the geopolymer technology about 30 years ago [5]. Subsequently, a lot of work has been done in this area. The utilization of geopolymer in mortar and concrete has emerged in the recent past, and currently, considerable work has been carried out on geopolymer concrete and mortar [6] [7]. The concept of geopolymer– soil is relatively novel and still limited work has been done on it [8] [9].

A review study was conducted to appraise the strength enhancement of soft soil by the introduction of industrial by-product-based geopolymers [10] . Different combinations of fly ash (FA) and slag (S) were added to the soil to check the influence on its chemical and engineering properties. UCS of slag-based geopolymer soil was much higher than the fly ash-based geopolymer stabilized soil [11]. Another work was done to check the varying properties of FA-GGBS geopolymer under different combinations of sodium hydroxide (NH) and sodium silicate (NS) solutions [12] . It was detected that NH or NS solution alone resulted in low strength development when used with FA and FA+ GGBS pastes. Better strength was achieved with the NHNS solution. Kumar et al. explored the impact of GGBS on the microstructure, reaction, and mechanical properties of fly ash-based geopolymer. The highest compressive strength was achieved at 80% replacement of slag [13].

Significant literature is available where GGBS is added in other industrial waste materials' geopolymers to enhance mechanical strengths and reduce the curing age. However, no work has been reported in which combination of ESP and GGBS has been utilized for geopolymer synthesis. Hence, the concept of inserting slag in ESP is innovative.

1.2. Purpose of the study

The current research aimed to evaluate the mechanical strengths of eggshell powder-and GGBS based geopolymers. The effect of curing time and precursor ratio on strength development was also examined. A strength comparison was done between this geopolymer product and conventional cement stabilized soil.

2. Materials and Experimental Methodology

2.1. Materials

Ground granulated blast furnace slag (GGBS) of grade 80 standard ASTM C989 was locally sourced from Dewan cement limited Karachi. Eggshells were collected from a hatchery. The inner organic layer of eggshells was removed by washing and cleaning properly and air-dried for 24 hours. The eggshells after air drying were crushed, and a fine powder of the required particle size was achieved via grinding. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) were procured from the local market. NaOH with 99% purity in flakes form was selected. The activator ratio of (Na_2SiO_3/NaOH) 2 was adopted as the optimum ratio from the previous literature [14]. NaOH flakes were dissolved in water to form a solution and stirred for at least 10 min to ensure complete dissolution of flakes. The solution is then mixed with Na_2SiO_3 in prescribed proportions after cooling to prepare alkaline activators.

The base precursors GGBS and ESP have a specific gravity of 2.81 and 2.14, respectively. The chemical composition of ESP is quite similar to grade 43 OPC which consists of 61% CaO, 20% SiO_2,6%Al_2O_3,4%Fe_2O_3, and 2% MgO. Four precursors' ratios were adopted as- 70ESP:30GGBS, 50ESP:50GGBS, 30ESP:70GGBS and 0ESP:100GGBS to investigate their impact in geopolymerization.

2.2 Experimental Procedure

Eggshell powder and GGBS were mixed in a dry state to form a homogenous mixture. Liquid alkaline activator solution was inserted in this mixture and mixed thoroughly for 3-5 minutes. Modified proctor test was performed on all composite following ASTM D1557 [15]. For all precursor combinations, the activator content was added between 12-40% to identify the optimum activator content (OAC) and maximum dry density (MDD). Samples of diameter 38mm and 76.2mm height were formed via cylindrical split mold for unconfined compressive strengths and split tensile strengths test. Three samples for each curing age were prepared and tested to minimize the margin of error. The samples were kept at room temperature and tested per ASTM D2166 [16]for unconfined compressive strengths. The samples were positioned laterally in the same apparatus to measure split tensile strengths under ASTM C 496 [17].

Table 1: Experimental setup of ESP: GGBS geopolymer

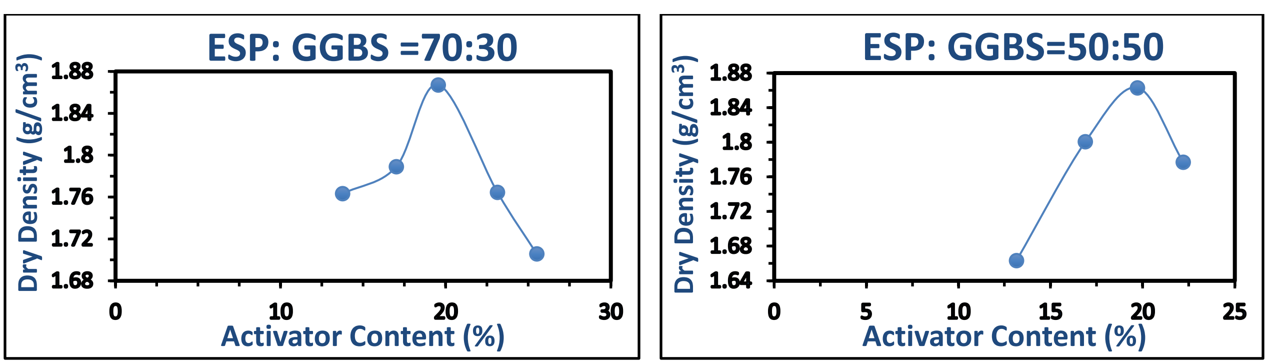
Methodology	Standard followed	ESP: GGBS	Activator percentage (%)	Curing period (Days)
Modified Proctor test	ASTM D1557	(70:30), (50:50), (30:70), (0:100)	12-40	-
Unconfined compressive strength	ASTM D2166	(70:30), (50:50), (30:70), (0:100)	OAC	1,3,7,28
Split tensile strength	ASTM C 496-96	(70:30), (50:50), (30:70), (0:100)	OAC	1,3,7,28

3. Results and discussion

3.1 Modified proctor test (MPT) results of geopolymer mixes

The effect of activator content and precursor ratio on compaction of geopolymer mix was examined. The activator content varied between 12%-40% with an increment of 4% to identify the optimum activator content (OAC) where the maximum dry density (MDD) is attained.

For different combinations of precursors, the compaction curves are plotted in figure 1. The curves revealed that as the MDD of a precursor combination is increased, its OAC is decreased. This behavior is in line with some previous studies [18] [8]. The minimum MDD of 1.684 g/cm3 was achieved for GGBS: ESP=100:0 combination with maximum optimum activator content of 28.6%. It is observed that a decrease in ESP content decreases MDD while increases the OAC. For example, the MDD for 70ESP:30GGBS is 1.867 g/cm3 which decreased to 1.825 g/cm3 for ratio 30ESP:70GGBS. The optimum activator content enhances slightly from 19.2% to 21% for decrement of ESP 70% to 30% but it jumps abruptly for 0ESP.



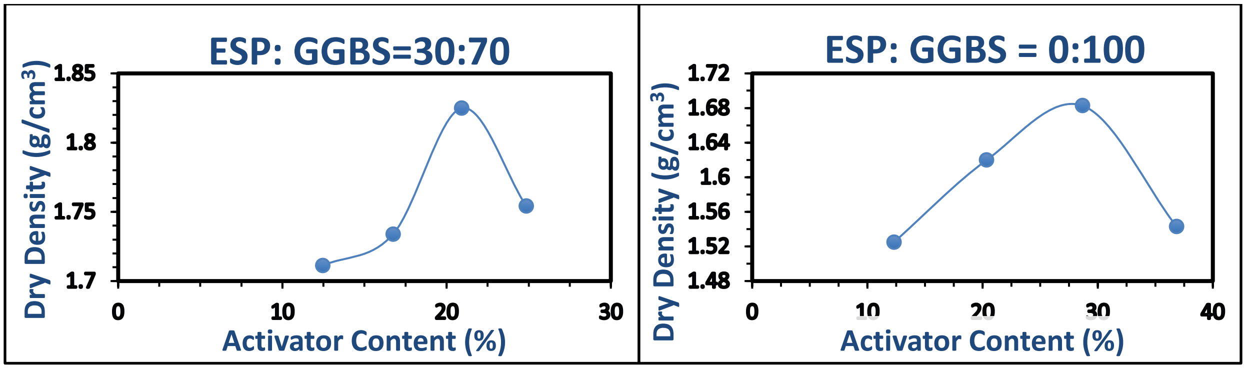
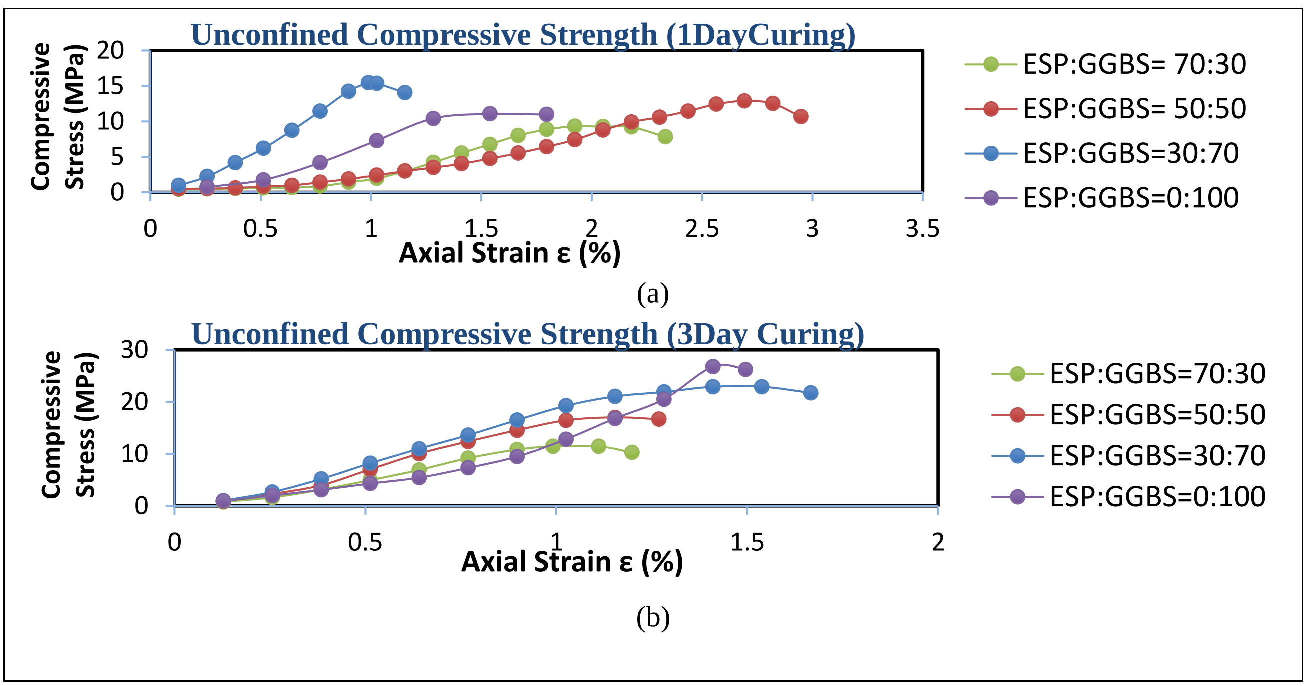
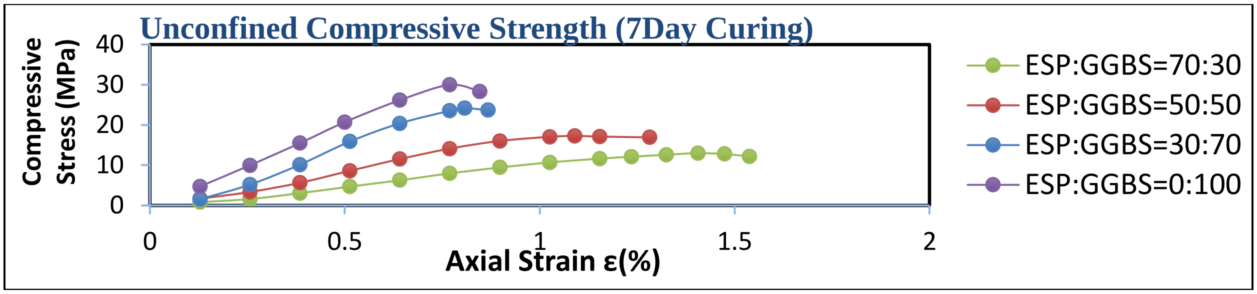


Figure 1. Compaction Curves for different geopolymer composites

3.2 Unconfined Compressive Strength of geopolymer mixes

The influence of the precursor ratio on the unconfined compressive strength of geopolymer mixes has been evaluated. Figure 2 displays the axial stress-strain behavior of GGBS, and ESP-based geopolymer samples after 1 day,3 days,7 days, and 28 days of air curing. The graphs represented a general trend that the increment of GGBS content enhances the compressive strength linearly. One of the reasons behind this phenomenon is the presence of additional silica in the solution which helps in formulating the C-S-H geopolymer gel. The fineness of GGBS over ESP may be the other controlling factor. The finer particles of GGBS possess a larger surface area than ESP particles resulting in their higher reactivity [14]. Lowering of ESP from 70% to 0% improved the compressive strength. It is also observed that the highest peaks are attained at 28 days curing period.





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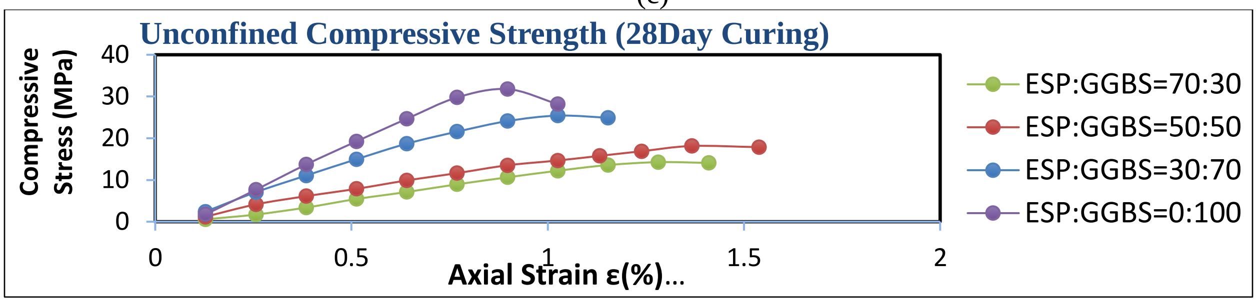


(d)

Figure 2: Axial Stress-Strain behaviour of four precursor combinations at various curing ages (a) 1-day Curing (b) 3 days curing (c) 7 days curing (d) 28 days curing.

Figure.3 compares the unconfined compressive strengths of ESP: GGBS geopolymer. The strength development of geopolymer mix with curing duration is quite similar to Portland cement. For instance, the compressive strength for 30ESP:70GGBS was 15.45MPa at 1-day curing which increased to 25.42MPa after 28 days. It is also deduced from the chart that all composites indicate early strength development. For example, the strength improvement for the 50ESP:50 GGBS composite from 1day to 3 days was 32.04% which diminishes to 4.9% from 7days to 28 days. Due to the high dissolution potential of GGBS and available Ca for geopolymerization, this quick strength gain is more evident [10] [11].

Figure 4 describes the comparison of unconfined compressive strength with the standard given in "General Specifications" of the national highway authority published by the ministry of communications (1998) [19]. According to these specifications, for subgrade construction, the minimum compressive strength at seven days should be 2.94 MPa for cement stabilized soils. Whereas for sub-base the minimum threshold value of laboratory compressive strength is 4.9 MPa. All precursor combinations satisfy this minimum criterion marginally.

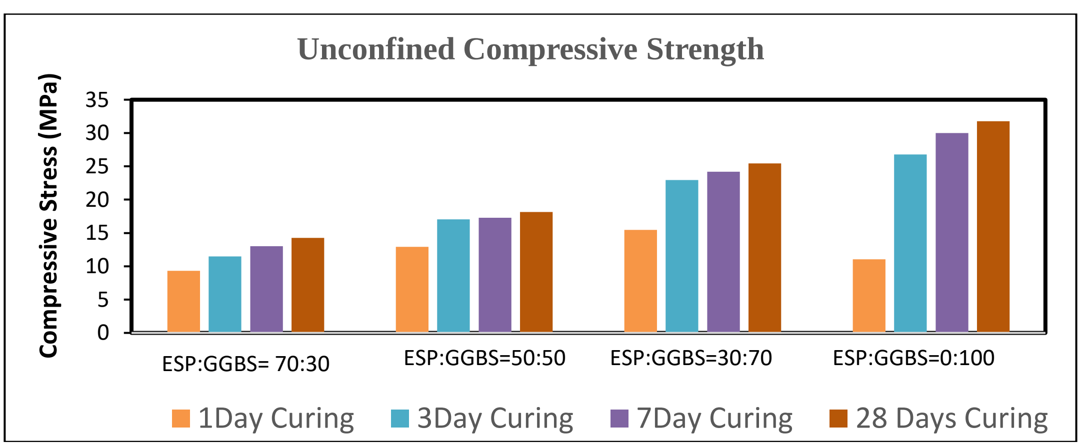


Figure 3: The strength development pattern of different precursor composite at varying curing periods

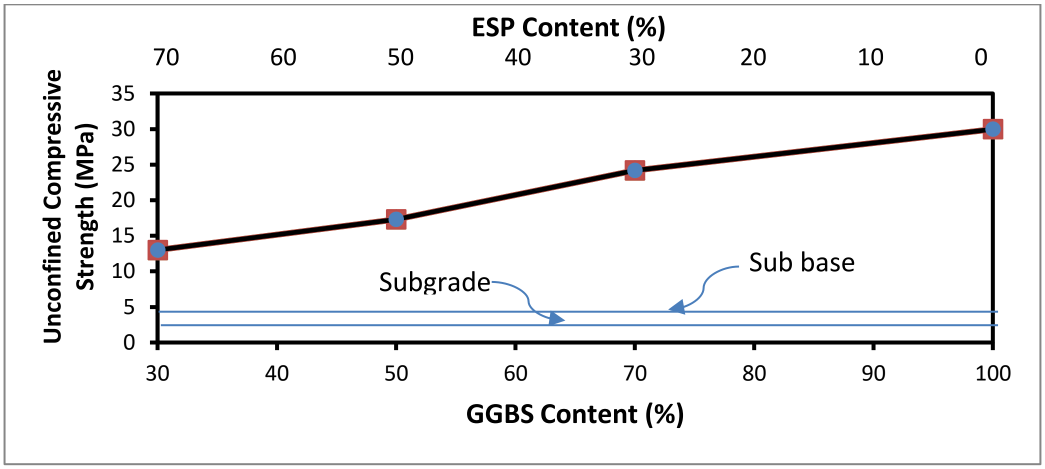
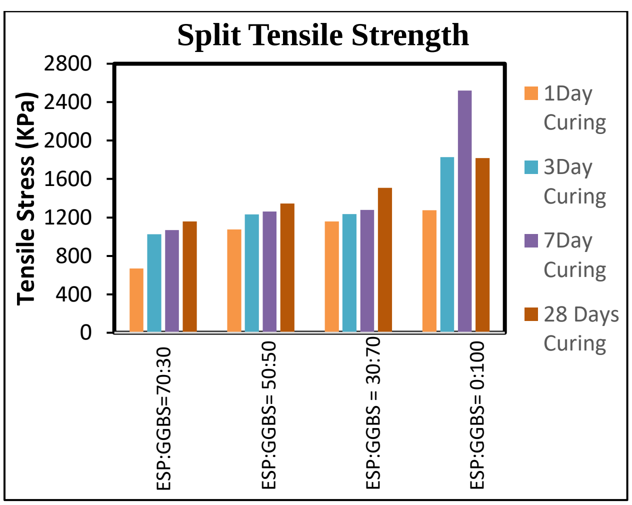


Figure 4: Comparison of UCS values with cement stabilized subgrade and subbase courses

3.3 Split Tensile Strength (STS) of geopolymer mixes

Figure 5 represents the split tensile strengths of four precursor ratios at 1,3,7 and 28 days of air curing at ambient temperature. Generally, higher ESP content lowers the STS whereas higher GGBS content improves the tensile strength. For precursor combination 70ESP:30GGBS, STS values are 1026.37 KPa, 1070 KPa, 1158.33 KPa while for geopolymer mix 30ESP:70GGBS, STS achieved as 1235.97KPa, 1277.36 KPa and1509.55 KPa for 3,7 and 28 days of curing, respectively. This increasing fashion of tensile strengths with growing slag percentage is due to the same reason as discussed previously in compressive strengths results. Significant SiO2 available in slag augments the reaction kinetics. The development of tension cracks at higher strains not only split the samples into two halves but also indicate their brittle nature as can be observed by a sudden loss of tensile strength after peak attained (Figure 6).



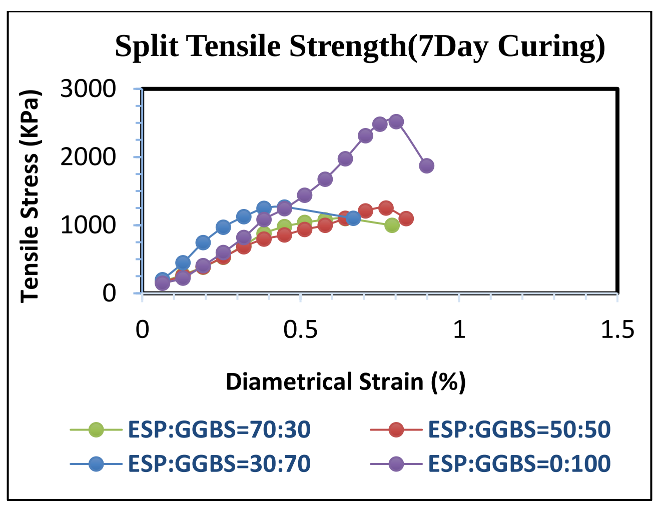


Figure 5: Effect of curing duration on Split tensile strengths (STS) *Figure 6: Tensile stress vs diametrical strain (%) behaviour*

The pavement construction through problematic regions where weak soils are encountered and need to be stabilized for subgrade and subbase formation, the geopolymer formed can be a suitable alternative to place as subbase and subgrade layers. The strength requirements are fulfilled as established in the previous section. The optimum combination of geopolymer proves to be a cost-effective alternative to the soil stabilized with any conventional stabilizer.

4. Conclusion

The current study is an assessment to examine the suitability of the new geopolymer mix in engineering applications. The mechanical strength of GGBS and ESP-based geopolymer was appraised to check the appropriateness of geopolymer composites to replace the usage of traditional stabilizers for problematic soils. Following are the principal conclusions of this work:

- The findings of this study reveal that the geopolymer mixture formed by reusing waste shown reasonably good strength as compared to the soils improved via conventional stabilizers.
- Increasing slag content in the combination increases the overall composite strength.
- It is deduced from the results that all precursor combinations fulfill the minimum criterion threshold for subbase and subgrade compressive strengths. However, the 50ESP: 50GGBS composite can be identified as optimum because the eggshell powder is much cheaper than GGBS.
- This geopolymer product suggested an eco-friendly way out of the problem of discarding these wastes and divert their utility in construction.

References

[1] P. Pliya and D. Cree, "Limestone derived eggshell powder as a replacement in Portland cement mortar," Construction and Building Materials, no. 95, pp. 1-9, 2015.

[2] W. G. A. J. M. L. S. Kamaruddin, "Chemical and fresh state properties of foamed concrete incorporating palm oil fuel ash and eggshell ash as cement replacement," Int. J. Eng. Technol, pp. 350-354, 2018.

[3] A. A. G. W. I. M. K. H. S. S. &. B. I. A. Jhatial, " Green and sustainable concrete–the potential utilization of rice husk ash and egg shells," Civil Engineering Journal, pp. 74-81, 2019.

[4] B. B. Serdar Aydın, "Effect of activator type and content on properties of alkali-activated slag mortars," Composites Part B: Engineering, vol. 57, pp. 166-172, 2014.

[5] J. Davidovits, "Geopolymers: inorganic polymeric new materials," Journal of Thermal Analysis and calorimetry, pp. 1633-1656, 1991.

[6] G. D. L. J. D. E. &. R. N. Habert, "An environmental evaluation of geopolymer based concrete production: reviewing current research trends," Journal of cleaner production, pp. 1229-1238, 2011.

[7] D. W. S. E. S. D. M. &. R. B. V. Hardjito, "Fly ash-based geopolymer concrete," Australian Journal of Structural Engineering,, pp. 77-86, 2005.

[8] S. H. C. S. A. C. A. A. M. M. D. Chayakrit Phetchuay, "Calcium carbide residue: Alkaline activator for clay–fly ash geopolymer," Construction and Building Materials, vol. 69, pp. 285-294, 2014.

[9] N. G. S. F. L. &. P. A. T. Cristelo, "Effect of calcium content on soil stabilisation with alkaline activation," Construction and Building Materials, pp. 167-174, 2012.

[10] M. j. Yaghoubi, A. Arulrajah and M. M. Disfani, "Effects of industrial by-product based geopolymers on the strength development of a soft soil," Soils and Foundations, no. 58, pp. 716-728, 2018.

[11] B. Singhi, A. I. Laskar and M. A. Ahmed, "Investigation on Soil–Geopolymer with Slag, Fly Ash and their blending," Arabian Journal for Science and Engineering, vol. 41, pp. 393-400, 2016.

[12] T. Phoo-ngernkham, A. Maegawa and N. Mishima, "Effects of sodium hydroxide and sodium silicate solutions on compressive and shear bond strengths of FA–GBFS geopolymer," Construction and Building Materials, no. 91, pp. 1-8, 2015.

[13] S. Kumar, R. Kumar and S. P. Mehrotra, "Influence of granulated blast furnace slag on the reaction, structure

and properties of fly ash based geopolymer," Journal of Materials Science, vol. 45, pp. 607-615, 2010.

[14] P. Shekhawat, G. Sharma and R. M. Singh, "Strength behavior of alkaline activated eggshell powder and flyash geopolymer cured at ambient temperature," Construction and Building Materials, no. 223, pp. 1112-1122, 2019.

[15] "ASTM D1557-12e1, Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft3 (2,700 kN-m/m3))," ASTM International, West Conshohocken, PA, 2012.

[16] "ASTM D2166 / D2166M-16, Standard Test Method for Unconfined Compressive Strength of Cohesive Soil," ASTM International, West Conshohocken, PA, 2016.

[17] "ASTM C496 / C496M-17, Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," ASTM International, West Conshohocken, PA, 2017.

[18] S. H. S.-L. S. Patimapon Sukmak, "Strength development in clay–fly ash geopolymer," Construction and Building Materials, vol. 40, pp. 566-574, 2013.

[19] N. H. Authority, "General Specifications," Ministry of communications Government of Pakistan, 1998.

[20] A. &. Y. A. P. K. Parkash, "A review study of egg shell powder as a cement replacing material in concrete," international journal of latest research in engineering and computing (IJLREC), 2017.

[21] J. Davidovits.Washington, DC:U.S Patent 4,349,386, 1982.

[22] C. H. S. S. C. C. A. A. A. &. D. M. M. Phetchuay, "Calcium carbide residue: Alkaline activator for clay–fly ash geopolymer," Construction and Building Materials, pp. 285-294, 2014.