Effect of Rice Husk Ash and Stone Dust on Selecting Engineering Properties of Poor Subgrade Soil

Ayush Mittal [1)*]

[1)] Assistant Professor, Rajkiya Engineering College, Ambedkar Nagar, UP, India. PIN-224122, India.
* (Corresponding Author). E-Mail: ayushmittalce0012@gmail.com

ABSTRACT

Roads are one of the major contributing factors for the economic and social enhancement of any country. Its importance further increases if the economy of a country is based on agriculture. From the total land area of India, more than 20% is covered with soils having high swelling and shrinkage potential and low strength. Any type of construction over such soils will not last long due to subsidence and crack formation. So, in order to overcome such situations, some soil stabilization techniques have to be adopted, since removal and replacement will lead to heavy economic burden. This paper presents the effect of adding rice husk ash (RHA) and stone dust on various index and engineering properties of weak soil. Various doses of RHA (5, 10 and 20%) along with 6% cement and stone dust (10, 20, 30 and 40%) are used for stabilization. Tests are carried out to determine consistency limits, specific gravity, differential free swell, compaction characteristics and soaked California Bearing Ratio (CBR). Test results indicated significant reduction in swelling potential and improvement in CBR value of soil, thus decreasing the thickness requirement of pavement and saving costly base and sub-base aggregate materials.

KEYWORDS: Rice husk ash, Stone dust, Subgrade, Expansive soil, Pavement.

INTRODUCTION

Expansive soils are mostly found in the arid and semi-arid regions of the world and are in abundance where average annual evaporation is more than precipitation (Le and Ludwig, 2016). These are residual deposits formed from sedimentary rocks (Pham and Tran, 2019). These soils pose serious problems to highways and structures constructed on them. In India, more than 8 lakh square km land area is covered with such soils, which includes the states of Maharashtra, Bihar, Tamil Nadu, the southern part of Uttar Pradesh, the southern and western parts of Madhya Pradesh, Gujarat, the eastern part of Rajasthan and a few parts of Andhra Pradesh and Chennai (Mittal and Shukla, 2020). Le et al. (2015) studied the effect of adding RHA, lime and gypsum on various properties of marine clay. 5% lime + 20% RHA + 3% gypsum at 28 days of curing were found to be the optimum doses, where an increase of 54% in soaked CBR and a reduction of 30% in swell potential were reported. Sabat (2012) conducted laboratory tests on clayey soil reinforced with RHA and polypropylene fibers in various proportions. Significant improvements in UCS, soaked CBR, hydraulic conductivity and a reduction in swelling pressure were observed up to 1.5% fiber addition. Chouksey et al. (2019) studied the effect of adding potassium chloride (KCI) and RHA on the strength and swelling properties of clayey soil. 1% KCI and 12% RHA content caused maximum improvement, where unconfined compressive strength (UCS) has increased by 515%. Various studies have been conducted on soil samples stabilized with lime, fly ash, bagasse ash, geogrid sheet, pond ash and polypropylene fibers (Subrahmanyam et al., 1981; Jongpradist et al., 2018; Gartner and Macphee, 2011; Ganesan, 2008; Raj et al., 2016; Huang et al., 2017; Dakroury and Gasser, 2008; Akinyele et al., 2015; Van et al., 2011; Kuity and Roy, 2013; Payá et al., 2001; Feng et al., 2005; Fapohunda et al., 2017), while limited literature was available on the use of RHA and stone dust on expansive soil.

Received on 7/5/2020.
Accepted for Publication on 25/12/2020.

The present work focuses on the effect of adding RHA along with cement and stone dust on strength and swelling behaviour of poor subgrade soil.

MATERIALS

Soil

The soil sample used in this study is collected from Darri (25.30°N, 78.48°E), Jhansi district, Uttar Pradesh. The soil is collected by digging trial pits at a depth of 1m below the ground level, as the top soil is likely to contain organic matter and other foreign materials. The area is largely covered with expansive soil having low bearing capacity. The soil is classified as clay of high compressibility (CH) as per Indian standard classification system (IS: 1498-1970). Figure 1 shows the grain size distribution curve of soil. Table 1 shows the various index and engineering properties of CH soil.

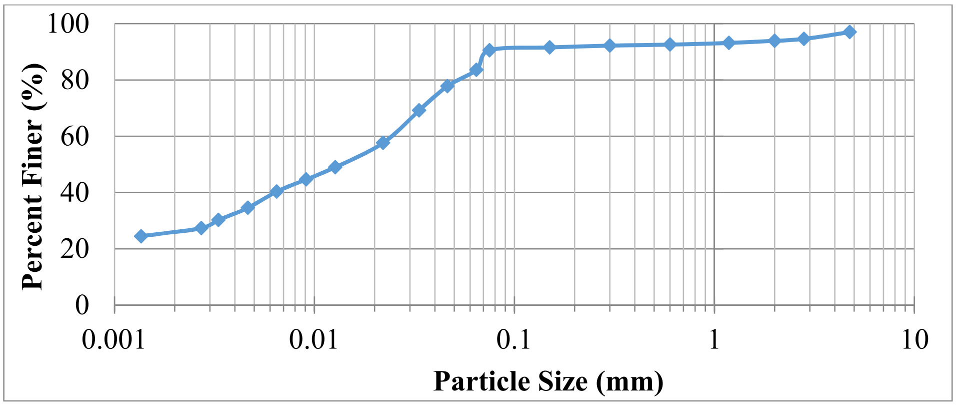

Figure (1): Grain size distribution curve for Jhansi soil

Table 1. Properties of Jhansi soil

Property	Value
Specific Gravity	2.31
Atterberg's Limits	
(a) Liquid Limit (%)	64.41
(b) Plastic Limit (%)	31.67
(c) Plasticity Index (%)	32.74
Grain Size Distribution	
(a) Gravel (%)	0.00
(b) Sand (%)	2.20
(c) Silt (%)	5.30
(d) Clay (%)	92.50
Soil Classification (ISCS)	Clay of High Compressibility (CH)
Water Content (%)	9.39
Differential Free Swell (%)	53.45
pH Value	7.21
Optimum Moisture Content (%)	18.98
Maximum Dry Density (kN/m^3)	17.10
Soaked CBR (%)	2.26

Rice Husk Ash (RHA)

Rice husk is an agricultural waste obtained as a by-product of rice milling. From the 110 million tons of husk produced globally every year, India produces 24 million tons of husk and 4.4 million tons of RHA (Yu et al., 1999). During milling of paddy, around 75% is obtained as rice and bran and the remaining 25% as husk (Ali and Koranne, 2012). Upon burning, 25% husk gets converted into ash and the remainder is a volatile matter (Real et al., 1996). This RHA is a great threat to the environment, as it can damage the surrounding area and land where it is dumped (Memon et al., 2011). It can be used as a pozzolanic material in concrete production, absorbent for oils and chemicals and for soil stabilization (Reddy et al., 2006). Table 2 shows the chemical composition of RHA. Table 3 shows the various physical and index properties of RHA. For the purpose of investigation in this study, RHA is obtained from a rice mill located in Ambedkar Nagar, Uttar Pradesh.

Table 2. Chemical composition of RHA

Constituent	Percentage (%)
Silica (SiO_2)	87.12
Aluminium Oxide (Al_2O_3)	3.27
Ferric Oxide (Fe_2O_3)	1.45
Calcium Oxide (CaO)	2.79
Magnesia (MgO)	0.63
Loss on Ignition	4.50

Source: Subrahmanyam et al. (1981).

Table 3. Physical and index properties of RHA

Particulars	Description
Specific Gravity	2.07
Liquid Limit (%)	Non-plastic
Plastic Limit (%)	Non-plastic
Grain Size Distribution (% Finer than)	
4.75mm	100
2mm	95.45
600µ	89.63
300µ	79.42
75µ	17.90
Optimum Moisture Content (%)	42.20
Maximum Dry Density (kN/m^3)	6.90
CBR (%)	16.12
Color	Grey
Shape Texture	Irregular
Appearance	Very Fine

Stone Dust (SD)

Stone dust (SD) is a solid waste material obtained from crushing of stones at quarry sites (Agarwal, 2015). It contains a little amount of pozzolanic properties and has a high CBR value (Ali and Koranne, 2012). The use of stone dust as a stabilizer is the best method for its disposal (Satyanarayana et al., 2013). For the purpose of investigation in this study, stone dust is obtained from local market in Meerut, Uttar Pradesh. Table 4 shows the various physical properties of stone dust.

Table 4. Physical properties of stone dust

Particulars	Description
Specific Gravity	2.62
Liquid Limit (%)	Non-plastic
Plastic Limit (%)	Non-plastic
Grain Size Distribution	
Coarse Sand (2-4.75mm) %	8.12
Medium Sand (0.425µ-2mm) %	35.90
Fine Sand (0.075µ-0.425µ) %	41.78
Silt (2µ-75µ) %	14.20
Clay (<2µ)	0.00
Optimum Moisture Content (%)	12.10
Maximum Dry Density (kN/m^3)	18.50
CBR (%)	21.67

EXPERIMENTAL DETAILS

Liquid limit, plastic limit, specific gravity, differential free swell (DFS), light compaction and CBR tests are performed on soil samples with and without treatment. Liquid and plastic limit tests are conducted as per IS: 2720 (Part 5)-1985, specific gravity test as per IS: 2720 (Part 3/section 1)-1980, DFS test as per IS: 2720 (Part 40)-1977, light compaction as per IS: 2720 (Part 7)-1980 and CBR test as per IS: 2720 (Part 16)-1987. Three different percentages of RHA (i.e., 5, 10 and 20%) are mixed with soil. To provide adequate cementation property, soil-RHA mix is mixed with 6% cement. Stone dust is mixed in various percentages (i.e., 10, 20, 30 and 40%) by dry weight of soil. The above percentages of RHA and stone dust used are based on rigorous literature review and trial tests; i.e., 15%, 30% and 45% RHA and stone dust each are added in soil samples separately in order to get a rough idea about the optimum ranges depending on un-soaked CBR values.

RESULTS AND DISCUSSION

Atterberg's Limits

The effects of adding RHA along with cement and stone dust on soil properties are shown in Table 5. The liquid limit for virgin soil is 64.41%, which decreases to 55.62%, 52.39% and 49.98%, respectively, for 5%, 10% and 20% RHA addition along with 6% cement in each case. It further changes to 44.40%, 38.54%, 32.67% and 30.23% for 10%, 20%, 30% and 40% addition of stone dust, respectively. Similar trend in values of plastic limit and plasticity index was reported. The plastic limit decreases from 31.67% to 31.20%, 28.08% and 26.75% for various RHA percentages and 24.36%, 22.15%, 19.63% and 17.40% for various stone dust contents, respectively. This reduction in Atterberg's limit of modified soil is due to mechanical or granular stabilization and addition of non-plastic material.

Table 5. Atterberg's limits of soil modified with RHA, cement and stone dust

Property	Percentages of Stabilizers Mixed							
	Virgin Soil	5% RHA + 6% Cement	10% RHA + 6% Cement	20% RHA + 6% Cement	10% Stone Dust	20% Stone Dust	30% Stone Dust	40% Stone Dust
Liquid Limit (%)	64.41	55.62	52.39	49.98	44.40	38.54	32.67	30.23
Plastic Limit (%)	31.67	31.20	28.08	26.75	24.36	22.15	19.63	17.40
Plasticity Index (%)	32.74	24.42	24.31	23.23	20.04	16.39	13.04	12.83

Specific Gravity

The specific gravity for un-modified soil is 2.31, which decreases as RHA content increases in soil (i.e., 2.28, 2.21 and 2.18), indicating that RHA is lighter than soil. On the other hand, as the percentage of stone dust increases, specific gravity also increases (i.e., 2.42, 2.53, 2.67 and 2.78), indicating greater denseness as compared to soil. Figure 2 shows the variation in specific gravity value of soil against admixture contents.

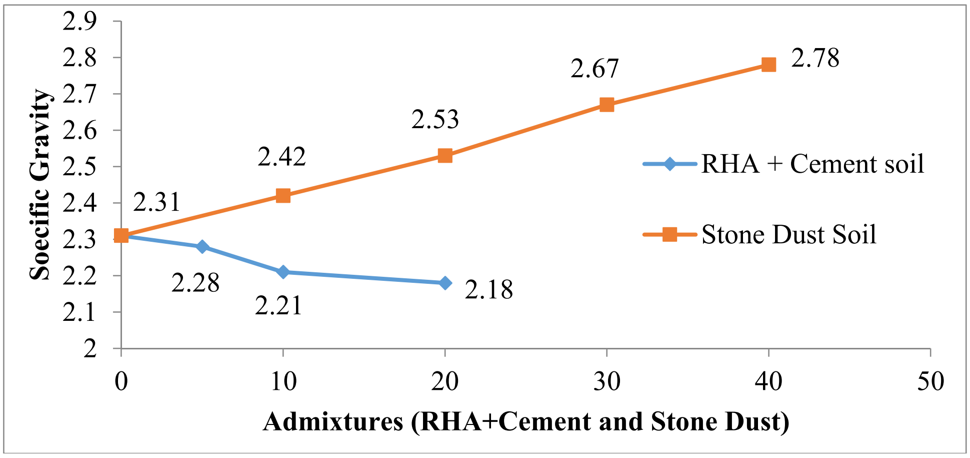

Figure (2): Effect of addition of RHA, cement and stone dust on specific gravity

Differential Free Swell

The addition of RHA and stone dust resulted in significant reduction in free swell of soil. The free swell value for un-modified soil is 53.45%, which decreases to 42.63%, 28.57% and 23.07%, respectively, for soil sample mixed with 5%, 10% and 20% RHA along with 6% cement in each case. DFS further reduces to 40.98%, 32.81%, 25.75% and 20.59% for 10%, 20%, 30% and 40% addition of stone dust in soil, respectively. Degree of expansiveness has changed from very high category to moderate category (below 35%). This behavioral change in soil is due to addition of non-plastic materials, like cement, RHA and stone dust. The cation exchange phenomenon comes into action where sodium ions in soil are replaced by calcium ions present in additives. Figure 3 shows the variation in DFS value of soil against admixture contents.

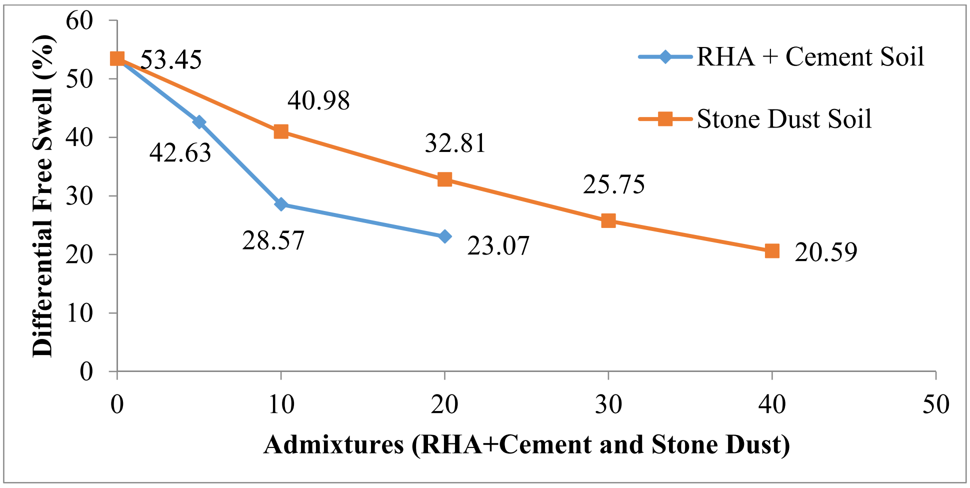

Figure (3): Effect of addition of RHA, cement and stone dust on differential free swell

Compaction Characteristics

The maximum dry density value for un-reinforced soil is 1.71g/cc, which decreases to 1.66g/cc, 1.62g/cc and 1.57g/cc, respectively, for 5%, 10% and 20% RHA addition along with 6% cement in each case. It further changes to 1.74g/cc, 1.78g/cc, 1.82g/cc and 1.85g/cc for 10%, 20%, 30% and 40% addition of stone dust, respectively. This change in MDD is due to the fact that RHA has a lower specific gravity and stone dust has a higher specific gravity as compared to soil; thus, as the percentage of additives increases, MDD decreases for RHA-reinforced soil samples and increases for stone dust-reinforced soil samples. Figure 4 shows the variation in MDD value of soil against admixture contents.

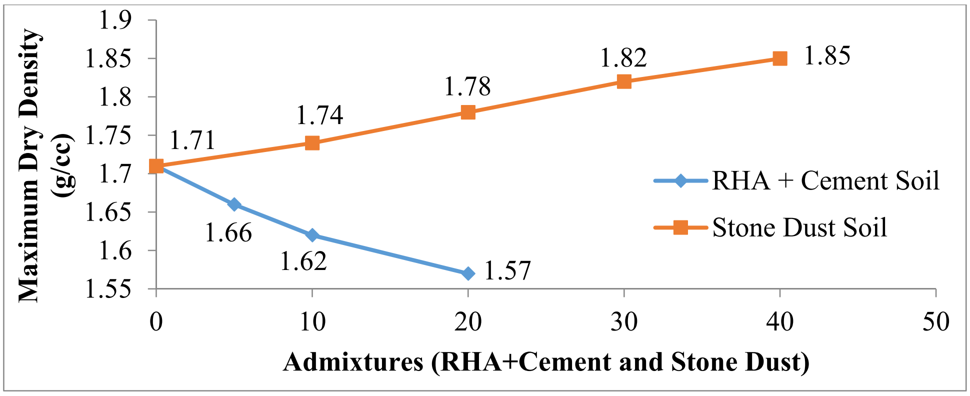

Figure (4): Effect of addition of RHA, cement and stone dust on MDD of soil

The optimum moisture content value for un-reinforced soil is 18.98%, which increases to 21.54%, 21.87% and 24.17%, respectively, for 5%, 10% and 20% RHA addition along with 6% cement in each case. However, reduction in OMC is reported when modified with stone dust having values of 18.04%, 17.63%, 17.06% and 16.32% for 10%, 20%, 30% and 40% addition of stone dust, respectively. This increase in OMC in case of RHA-reinforced soil is due to high water absorption tendency of rice husk. The reasons for reduction in OMC by addition of stone dust are due to proper rearrangement of particles and reduction in surface area of modified soil mass. Figure 5 shows the variation in OMC value of soil against admixture contents.

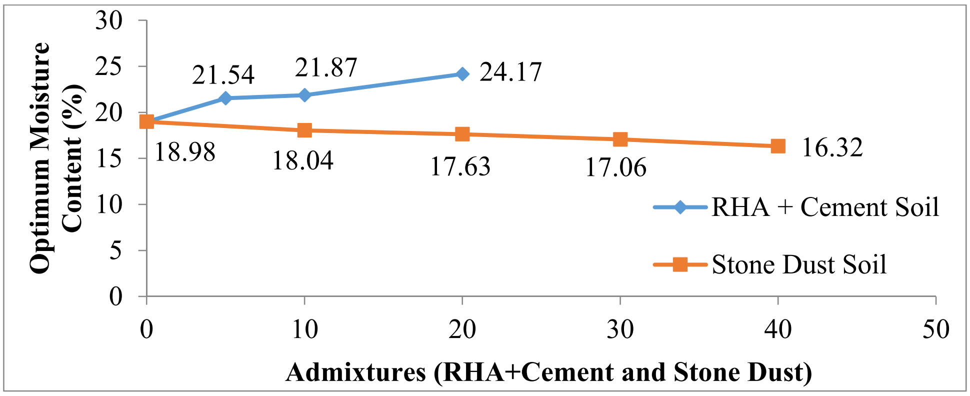

Figure (5): Effect of addition of RHA, cement and stone dust on OMC of soil

California Bearing Ratio

The soaked CBR value of un-reinforced soil is 2.26%, which increases to 3.83%, 5.40% and 4.96%, respectively, for 5%, 10% and 20% RHA addition along with 6% cement in each case. This value further changes to 3.66%, 4.71%, 6.10% and 5.75%, respectively, for 10%, 20%, 30% and 40% addition of stone dust to poor subgrade soil. This increase in CBR is due to proper bonding of additives with expansive soil, thus offering greater resistance to penetration of plunger: Figure 6 shows the variation in CBR value of soil against admixture contents.

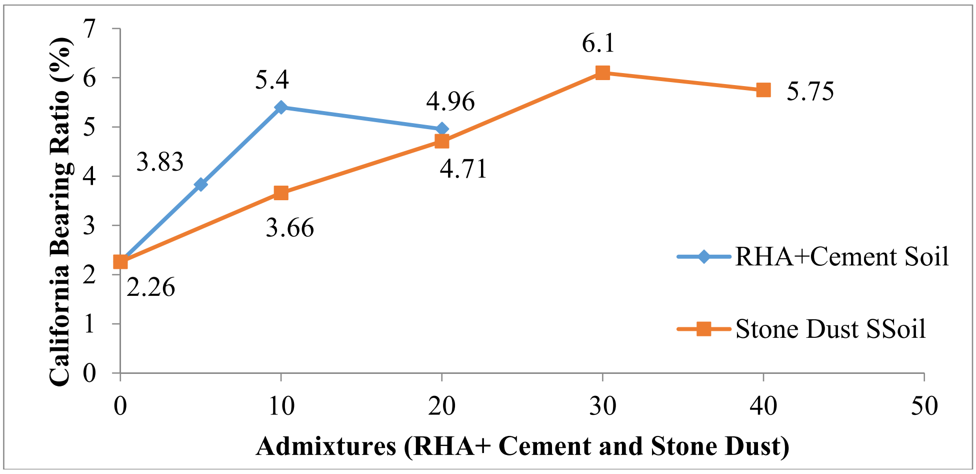

Figure (6): Effect of addition of RHA, cement and stone dust on CBR of soil

CONCLUSIONS

Based on the experimental results and discussion made, the following conclusions are drawn:

1. As the percentage of additives increases, reductions in liquid limit, plastic limit, plasticity index and differential free swell values are reported. Such reductions are due to addition of non-expansive/non-plastic materials in soil.
2. The MDD value decreases for all RHA-reinforced samples. The value has changed from 1.71g/cc for virgin soil to 1.57g/cc for (20% RHA + 6% cement)-modified sample. However, all stone dust-modified soil samples have greater MDD (maximum of 1.85g/cc for 40% stone dust) as compared to virgin soil.
3. The OMC values for all RHA- and stone dust-reinforced samples are more and less, respectively, as compared to OMC value of virgin soil. The value has changed from 18.98% for virgin soil to 24.17% for (20% RHA + 6% cement)-modified sample and to 16.32% for 40% stone dust addition.
4. This behavioral change in MDD and OMC values is due to difference in specific gravity and water

absorption tendency of soil, RHA and stone dust.

5. Maximum increase of 138% and 170% in CBR, respectively, is reported for soil samples reinforced with (10% RHA + 6% cement) and 30% stone dust, thus changing the subgrade class from very poor to fair category.
6. This increase in CBR will cause 32% reduction in pavement thickness as per IRC:SP:72-2015 design catalogues of flexible pavements for low-volume rural roads, leading to a cost reduction of 12%.
7. It is recommended to use 30% stone dust treatment to clayey soil when considered on the basis of strength improvement and thickness and cost reduction.
8. These conclusions can be effectively used in various Civil Engineering applications, such as embankment construction, backfilling and pavement on soft soils. The effective use of rice husk ash and stone dust will significantly reduce waste disposal problems and lead to better environmental conditions. It will also pave a way for developing new and improved stabilization techniques. However, more research is required to fully understand the working mechanism of additives in poor subgrade soils. Hence, it's time to support more and more use of agricultural waste like rice husk ash and industrial waste like stone dust.

Acknowledgements

The author wishes to acknowledge Rajkiya Engineering College Ambedkar Nagar, India for providing all the facilities for carrying out this work.

REFERENCES

Agarwal, N. (2015). "Effect of stone dust on some geotechnical properties of soil". IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 12 (1), 61-64.

Akinyele, J.O., Salim, R.W., Oikelome, K.O., and Olateju, O.T. (2015). "The use of rice husk ash as a stabilizing agent in lateritic clay soil." International Journal of Civil and Environmental Engineering, 9, 1418-1422.

Ali, M.S., and Koranne, S.S. (2012). "Performance analysis of expansive soil treated with stone dust and fly ash." Electronic Journal of Geotechnical Engineering, 16, 973-982.

Anupam, A.K., Kumar, P., and Ransinchung, G.D. (2013). "Use of various agricultural and industrial waste materials in road construction." (2nd CTRG), Procedia-Social and Behavioral Sciences, ELSEVIER, 264-273.

Bureau of Indian Standards (BIS), New Delhi. (Second Reprint, t September 1994).

Chouksey, A., Dev, N., and Kumari, S. (2019). "Review paper on utilization potential of rice husk ash as a supplementary cementitious material." In: Das, B.B. & Neithalath, N. (eds.), Sustainable Construction and Building Materials, Lecture Notes in Civil Engineering, vol. 25. Springer, Singapore. https://doi.org/10.1007/978-981-13-3317-0_60

Dakroury, A.E., and Gasser, M.S. (2008). "Rice husk ash (RHA) as cement admixture for immobilization of liquid radioactive waste at different temperatures." Journal of Nuclear Materials, 381 (3), 271-277.

Fapohunda, C., Akinbile, B., and Shittu, A. (2017). "Structure and properties of mortar and concrete with rice husk ash as partial replacement of ordinary Portland cement: A review." International Journal of Sustainable Built Environment, 6, 675-692.

Feng, Q., Sugita, S., Shoya, M., and Yamamichi, H. (2005). "Study on the pozzolanic properties of rice husk ash by hydrochloric acid pretreatment." Cement and Concrete Research, 35 (5), 1018-1019.

Ganesan, E.K., Rajagopal, K., and Thangavel, K. (2008). "Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete." Construction and Building Materials, 22, 1675-1683.

Gartner, E.M., and Macphee, D.E. (2011). "A physico-chemical basis for novel cementitious binders." Cement and Concrete Research. Journal of Cement and Concrete, 41 (7), 736-749. https://doi.org/10.1016/j.cemconres.2011.03.006

Huang, H., Gao, X., Wang, H., and Ye, H. (2017). "Influence of rice husk ash on strength and permeability of ultrahigh- performance concrete." Construction and Building Materials, 149, 621-628.

IS: 1498-1970. "Classification and identification of soils for general engineering purposes (first revision)". Bureau of Indian Standards (BIS), New Delhi. (Eighth Reprint, June 2000).

IS: 2720 (Part 16)-1987. "Methods of test for soils: Determination of California bearing ratio (second revision)". Bureau of Indian Standards (BIS), New Delhi.

IS: 2720 (Part 3/Sec 1)-1980. "Methods of test for soils: Determination of specific gravity, Section 1: Fine grained soils (first revision)". Bureau of Indian Standards (BIS), New Delhi. (First Reprint, April 1989).

IS: 2720 (Part 4)-1985. "Methods of test for soils: Grain size analysis (second revision)".

IS: 2720 (Part 40)-1977. "Methods of test for soils: Determination of free swell index of soils". Bureau of Indian Standards (BIS), New Delhi. (Third Reprint, August 1997).

IS: 2720 (Part 5)-1985. "Methods of test for soils: Determination of liquid and plastic limit (second revision)". Bureau of Indian Standards (BIS), New Delhi.

IS: 2720 (Part 7)-1980. "Methods of test for soils: Determination of water content-dry density relation using light compaction (second revision)". Bureau of Indian Standards (BIS), New Delhi. (Fifth Reprint, August 1997).

Islam, S., Hoque, N., Uddin, M., and Chowdhury, M. (2018). "Strength development in clay soil stabilized with fly ash." Jordan Journal of Civil Engineering, 12 (2), 188-201.

Jongpradist, P., Homtragoon, W., Sukkarak, R., Kongkitkul, W., and Jamsawang, P. (2018). "Efficiency of rice husk ash as cementitious material in high-strength cement-admixed clay." Advances in Civil Engineering, 1-11. https://doi.org/10.1155/2018/8346319

Karkush, M.O., Al-Murshedi, M.O., and Karim, H.H. (2020). "Investigation of the impacts of nano-clay on the collapse potential and geotechnical properties of gypseous soils." Jordan Journal of Civil Engineering, 14 (4), 537-547.

Khan, R.A., and Sharma, R. (2018). "Strength and durability characteristics of rice husk ash concrete reinforced with polypropylene fibres." Jordan Journal of Civil Engineering, 12 (4): 653-668.

Kuity, A., and Roy, T.K. (2013). "Utilization of geogrid mesh for improving the soft subgrade layer with waste material mix compositions." (2nd CTRG), Procedia-Social and Behavioral Sciences, ELSEVIER, 255-263.

Le, H. T., and Ludwig, H. M. (2016). "Effect of rice husk ash and other mineral admixtures on properties of self-compacting high-performance concrete." Materials & Design, 89, 156-166.

Le, H. T., Siewert, K., and Ludwig, H. M. (2015). "Alkali silica reaction in mortar formulated from self-compacting high-performance concrete containing rice husk ash." Construction and Building Materials, 88, 10-19.

Memon, S. A., Shaikh, M. A., and Akbar, H. (2011). "Utilization of rice husk ash as viscosity-modifying agent in self-compacting concrete." Construction and Building Materials, 25, 1044-1048.

Mittal, A., and Shukla, S. (2020). "Effect of random inclusion of kenaf fibres on strength behaviour of poor subgrade soils." Jordan Journal of Civil Engineering, 14 (1), 43-56.

Payá, J., Monzó, J., Borrachero, M., Mellado, A., and Ordoñez, L. (2001). "Determination of amorphous silica in rice husk ash by a rapid analytical method." Cement and Concrete Research, 31, 227–231.

Pham, V.P., and Tran, V.T. (2019). "Rice husk ash burnt in simple conditions for soil stabilization." In: Long, P.D. & Dung, N.T. (eds.), Geotechnics for Sustainable Infrastructure Development, Lecture Notes in Civil Engineering, vol. 62. Springer, Singapore. https://doi.org/10.1007/978-981-15-2184-3

Raj, R.R., Banupriya, S., and Dharani, R. (2016). "Stabilization of soil using rice husk ash." International Journal of Computational Engineering Research, 6, 43-50.

Real, C., Alcalá, M.D., and Criado, J.M. (1996). "Preparation of silica from rice husks." Journal of the American Ceramic Society, 79 (8), 2012-2016.

Reddy, O.E., Gopinath, E., Shrinivasan, K.S., and Poornima, C.A. (2006). "Effect of quarry dust on compaction properties of clay". Proceedings of National Conference on Corrective Engineering Practices in Troublesome Soils, 31-34.

Sabat, A.K. (2012). "Effect of polypropylene fibre on engineering properties of rice husk ash-lime-stabilized expansive soil." Electronic Journal of Geotechnical Engineering, 17, 651-660.

Satyanarayana, P.V.V., Raghu, P., Kumar, R.A., and Pradeep, N. (2013). "Performance of crusher dust in highly plastic gravel soils as road construction material." IOSR Journal of Mechanical and Civil Engineering, 10 (3), 01-05.

Subrahmanyam, M.S., Cheran L.L., and Cheran, L.S. (1981). "Use of rice husk ash for soil stabilization." GSM Geotechnical Engineering Seminar, Geol. Soc. Malaysia Bulletin, 14, 143-151.

Van, T.N., Ye, G., van Breugel, K., and Copuroglu, O. (2011). "Hydration and microstructure of ultrahigh-performance concrete incorporating rice husk ash." Cement and Concrete Research, 41, 1104-1111.

Yu, Q., Sawayama, K., Sugita, S., Shoya, M., and Isojima, Y. (1999). "The reaction between rice husk ash and $Ca(OH)_2$ solution and the nature of its product." Cement and Concrete Research, 29 (1), 37-43.