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MECHANICAL STABILIZATION OF SUBGRADE SOIL USING CERAMIC POWDER

S. Nifana
Former PG Student, Department of Civil Engineering, PSG College of Technology, Coimbatore, India.
Email : nifana10@gmail.com

M. Palanikumar
Professor, Department of Civil Engineering, PSG College of Technology, Coimbatore, India.
Email : mpk.civil@psgtech.ac.in

Abstract

Pavements resting on expansive soil subjected to volumetric change due to moisture content changes, undergo distortion. The thickness of the pavement and the cost will increase when expansive soils are encountered. This study aims in solving the problems faced in road constructions due to expansive soil by stabilizing the soil using ceramic powder. In this study the virgin soil (Liquid Limit of 42%, Plasticity index of 22%, hence classified as CI) is mixed with the ceramic powder (Liquid limit of 27%, Plasticity index of 5%, hence classified as ML) in the proportions of 90:10, 80:20, 70:30 (Soil: Ceramic powder). The test results on the mixes show that the plasticity index value decreases from 22% to 18% and the CBR value increases from 1.7% to 2.2% with replacement of soil with ceramic powder at 30%. Thus, a mix of 70:30 (Soil: Ceramic powder) is considered to be the optimum one. Flexible Pavements are designed as per IRC: 37-2001 for virgin soil and 70:30 mix for traffic intensities of 2 msa and 10 msa. The pavement thickness is reduced around 45% for 2 msa and 41% for 10 msa. For the designed pavements, cost analysis is carried out and the reduction in cost is around 31% to 24%.

Keywords- CBR, OMC, Ceramic powder, Virgin soil.

I. INTRODUCTION

Soil becomes the integral part of any form of construction especially in pavement construction. Roads either in the form of rigid or flexible pavement get affected because of the undesirable properties of soil. One such undesirable property is the swell-shrinkage characteristic of soil. This can be reduced by carrying out soil stabilization. The expansive soils are stabilized in three modes namely:

1. Physical- Physical stabilization is done by making changes to the texture of the soil.
2. Chemical - Chemical stabilization is done by adding chemicals to modify the properties of soil to achieve the desired properties.
3. Mechanical- Mechanical stabilization is done by adding locally available materials thereby improving the gradation of the mix.

In this study, mechanical stabilization is adopted in order to improve the properties of the problematic virgin soil. Moreover, a waste material from an industry is used instead of an expensive locally available material. Use of the waste material also solves the problem of its disposal from the manufacturing sites. Stabilization using dust/powder like waste materials with and without a binder like lime, cement etc. is one of them. Marble dust, Baryte powder, Quarry Dust, Burnt brick dust are some of the prominent dust/powder like waste materials which have been successfully utilized for the stabilization of expansive soil.

Koyuncu H [1] et al found that 40% addition of ceramic tile waste reduced the swelling pressure and swelling potential of a clay by 86% and 57% respectively. Akshya Kumar Sabat [2] in the study on the influence of ceramic powder on an expansive soil found a reduction in liquid limit, plasticity index and swelling pressure on the addition of the powder. An increase in unconfined compressive strength and CBR value was also observed with the increase in the percentage of the powder. Sabat and Bose [3] carried out a study on the combined influence of fly ash, lime and ceramic dust on an expansive soil. Based on the test results, it was concluded that the mix consisting of 10%, 5% and 35% fly ash, lime and ceramic dust respectively produced the best result as far as strength and swelling characteristics were concerned. Ceramic bricks, roof and floor tiles and stoneware industries generate ceramic dust as a waste material. The Indian ceramics industry, which is comprised of sanitary ware, wall and floor tiles, refractory and ceramic materials, bricks and roof tiles for domestic and other use is producing waste about 15 to 30 MT per annum approximately [2]. The disposal of this ceramic waste causes soil, water and air pollution. Cost spent on dumping this waste is high and the land occupied by it could otherwise be utilised effectively for manufacturing processes. The main objective of this study is to stabilize i.e., make a more plastic sub-grade into a less plastic sub-grade by mixing it with the optimum amount of ceramic powder. In this process, if the strength of the subgrade increases, it is an added advantage.

II. OBJECTIVE OF THE STUDY

The following are the objectives of the study:

1. To stabilize a problematic soil by altering its plastic properties by mixing it with the waste material (Ceramic powder).
2. To determine the plasticity properties of the problematic soil and the waste material.
3. To determine the optimum mix of virgin soil and ceramic powder.
4. To design the flexible pavement on virgin soil and the optimum mix.
5. To carry out cost analysis for the flexible pavements designed on virgin soil and on the optimum mix and make a comparison

III. MATERIAL COLLECTION

A. Collection of soil sample and test results

Soil used in the experiments has been collected from Vilankurichi village (Coimbatore). The properties of the virgin soil are given in Table 1.

Table 1: Physical properties of soil

S. No.	Parameters	Results
1.	Fraction finer than 75 microns	67%
2.	Liquid Limit (%)	42
3.	Plastic Limit (%)	20
4.	Plastic Index (%)	22
5.	I.S. Classification	CI
6.	Specific Gravity of solids	2.65

B. Collection of ceramic powder and test results

Ceramic powder used in the experiments has been collected from El-Tech ceramic Industries (Kurichi-Coimbatore). The properties of the ceramic powder are given in Table 2.

Table 2: Physical properties of ceramic powder

S. No.	Parameters	Results
1.	Fraction finer than 75 microns	67%
1.	Liquid Limit (%)	27
2.	Plastic Limit (%)	22
3.	Plastic Index (%)	5
4.	I.S. Classification	ML
5.	Specific Gravity of solids	2.69

IV. METHODOLOGY

The methodology carried out for the study is shown in the form of a flow chart in Fig. 1. The liquid limit and plastic limit tests, Light Compaction tests, California Bearing Ratio(CBR), Differential free swell test have been conducted as per IS:2720[4][5][6][7]. Pavements were designed in accordance with IRC: 37-2001[8].

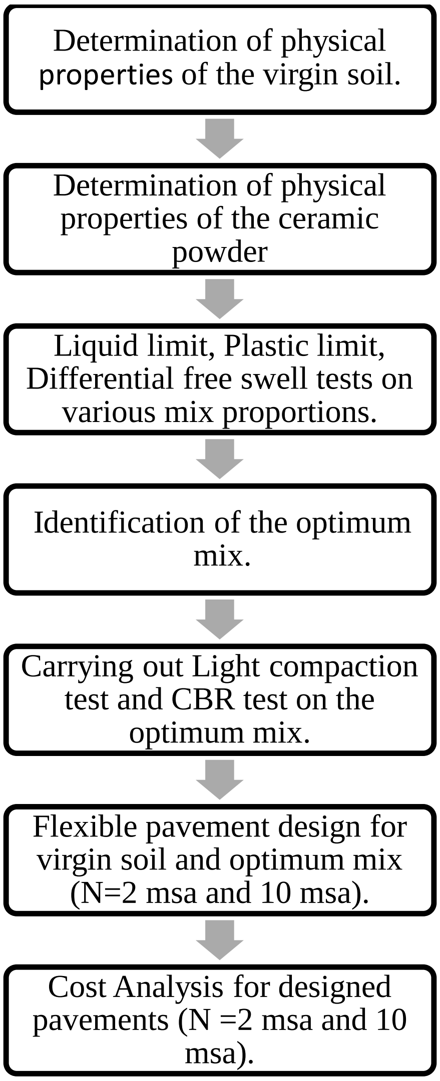


Fig. 1: Methodology of the study

V. TEST RESULTS AND DISCUSSIONS

A. Effect of ceramic powder on the liquid limit and plastic limit

The liquid limit, plastic limit and the plasticity index values of the virgin soil are 42%, 20%, 22% respectively. On replacement of soil with ceramic powder at 10%, 20%, 30%, the plasticity index values reduced to 22%, 18%, 18% respectively. As the liquid limit value reduces below 35% when 30% of ceramic powder is added, the soil classification changes from CI to CL. Thus, 70:30 mix of soil and ceramic powder can be taken as the optimum mix. Fig. 2 shows the influence of ceramic powder on the liquid limit and plastic limit values of the soil.

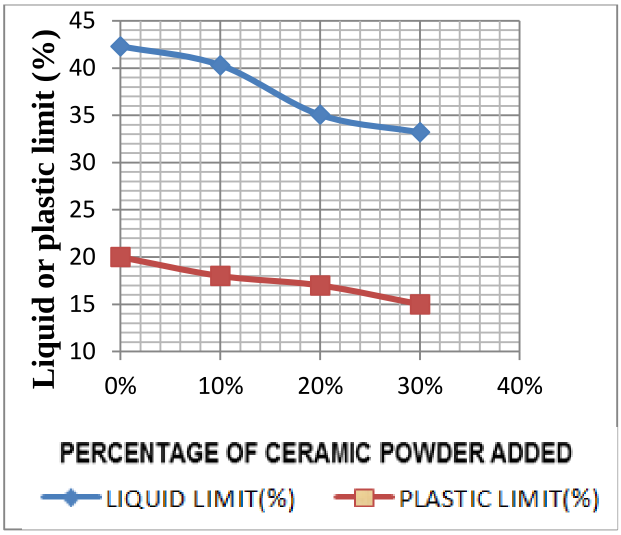


Fig. 2: Effect of ceramic powder on Atterberg's limits of expansive soil

B. Effect of ceramic powder on the swelling potential of the expansive soil

The differential free swell tests are conducted on the soil and the mixes to observe the swelling potential. It is also used as a confirmatory test to identify the optimum mix proportion. Fig. 3 gives the results of differential free swell tests for the virgin soil and various mixes. From the results, it is observed that the swelling potential of the expansive soil reduces by 60% when 30% of ceramic powder is added to it.

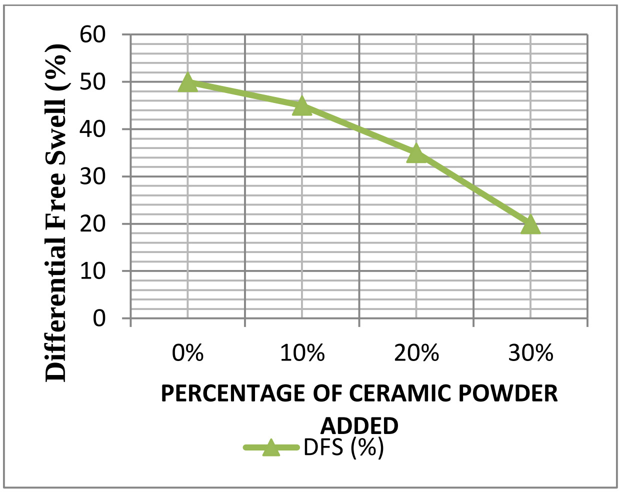


Fig. 3: Effect of ceramic powder on the swelling potential of the expansive soil

C. Effect of ceramic powder on the strength of soil

From the light compaction and the CBR tests, the OMC and the CBR value of the virgin soil are determined to be 20.5% and 1.7% respectively. When the same was conducted on the optimum mix (70:30), the OMC value decreases to 18% and the CBR value increases to 2.2%. Fig. 4 and Fig. 5 show the influence of ceramic powder on the OMC, dry density and the CBR value of the soil. The addition of ceramic powder not only makes the soil less plastic but also increases the CBR value beyond 2%. This eliminates not only the buffer layer (recommended on expansive subgrade) but also the capping layer (recommended on weak subgrade having CBR less than 2%).

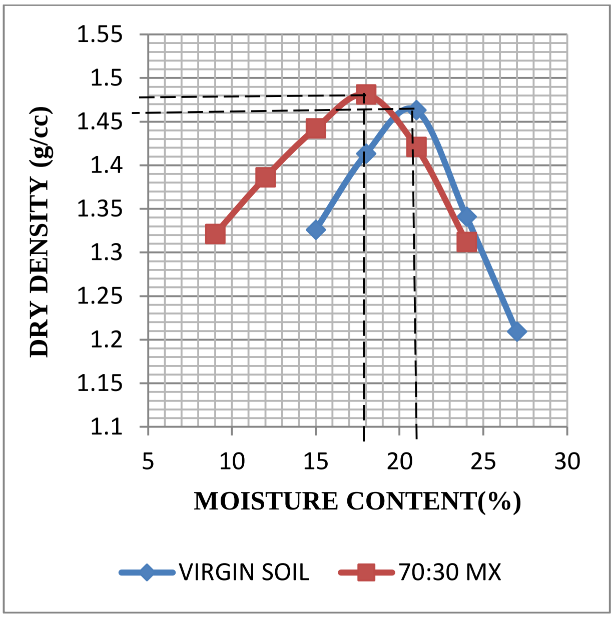


Fig 4: Effect of ceramic powder on the OMC and dry density of soil

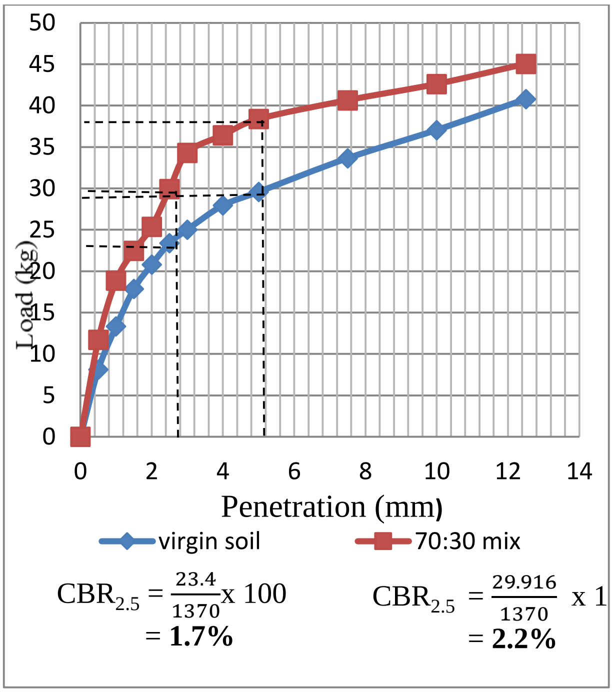


Fig 5: Effect of ceramic powder on the strength of soil

VI. DESIGN OF FLEXIBLE PAVEMENT

Flexible pavement is designed as per IRC-37:2001[8]. The design of the pavement is based on the CBR value of the subgrade and the traffic intensity measured in terms of million standard axles (msa). The pavement is designed for traffic intensities of 2 msa and 10 msa. Fig. 6(a) and 6(b) show the pavement structure for a traffic intensity of 2 msa on virgin soil and the stabilized (70:30 mix) soil respectively.

The pavement structures for a traffic intensity of 10 msa are presented in Fig. 7(a) and 7(b) respectively.

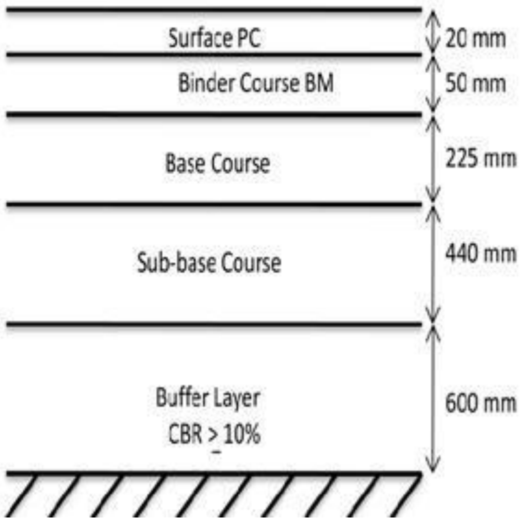
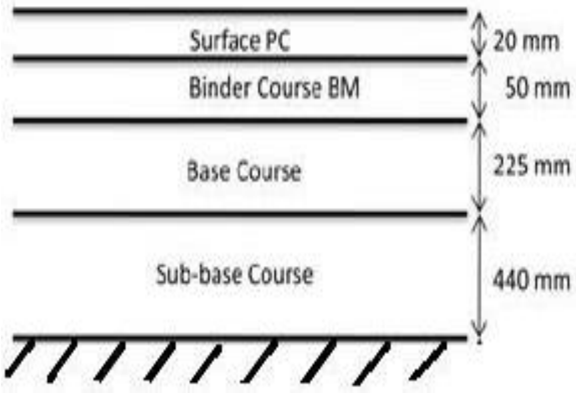


Fig. 6(a) Pavement structure on virgin soil for 2 msa

Fig. 6(b) Pavement structure on 70:30 mix for 2 msa



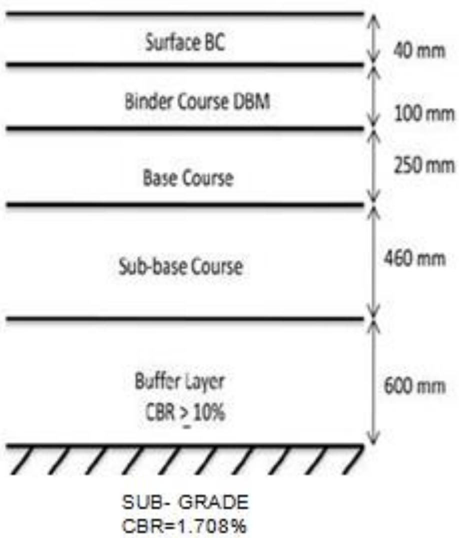


Fig. 7(a) Pavement structure on virgin soil for 10 msa

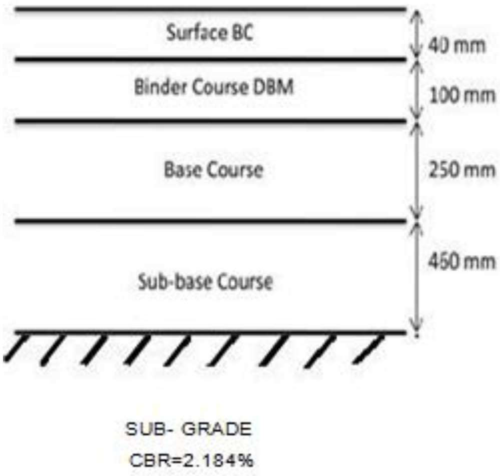


Fig. 7(b) Pavement structure on 70:30 mix for 10 msa.

IRC: 37 suggests introduction of a buffer layer of thickness ranging from 0.6 m to 1.0 m between the expansive subgrade and subbase. Since, the subgrade soil considered for the present study is moderately expansive, a buffer layer of thickness 0.6 m has been provided. It is observed that, the pavement thickness is reduced from 1335 mm to 735 mm for optimum mix at 2 msa and from 1450 mm to 850 mm for optimum mix at 10 msa respectively.

VII. COST ESTIMATION AND COMPARISON

The rates for various components of flexible pavement are collected from Highways Department, Coimbatore, Tamil Nadu, India. Cost estimation is carried out for 1 m^2 area of the designed pavements. The details of the cost estimation for all the cases are presented Tables 3, 4, 5 and 6.

Table 3 Cost estimation of flexible pavement on virgin soil for 2 msa

Component	Quantity	Unit	Rate /unit	Amount (Rs)
Buffer layer	0.6	m^3	1000	600
Sub- base	0.44	m^3	1300	572
Base	0.225	m^3	1500	338
BM	0.05	m^3	5400	270
PC	1.0	m^2	180	180
Total cost				1960

Table 4 Cost estimation of flexible pavement on 70:30 mix for 2 msa

Component	Quantity	Unit	Rate /unit	Amount (Rs)
Sub- base	0.44	m^3	1300	572
Base	0.225	m^3	1500	338
BM	0.05	m^3	5400	270
PC	1.0	m^2	180	180
Total cost				1360

Table 5 Cost estimation of flexible pavement on virgin soil for 10 msa

Component	Quantity	Unit	Rate /unit	Amount (Rs)
Buffer layer	0.6	m^3	1000	600
Sub- base	0.46	m^3	1300	598
Base	0.25	m^3	1500	375
BM	0.1	m^3	6500	650
PC	0.04	m^3	7300	292
Total cost				2515

Table 6 Cost estimation of flexible pavement on 70:30 mix for 10 msa

Component	Quantity	Unit	Rate /unit	Amount (Rs)
Sub- base	0.46	m^3	1300	598
Base	0.25	m^3	1500	375
BM	0.1	m^3	6500	650
PC	0.04	m^3	7300	292
Total cost				1915

Table 3 and 4 show that the saving in the total cost of the pavement designed for 2 msa is 31%. From Table 5 and 6, it is concluded that the saving is 24% when 70:30 is used as subgrade rather than the virgin soil. However, this conclusion is valid only for the soil selected.

VIII. CONCLUSIONS

In this work, a comparative study has been carried out between the unsterilized expansive soil and the soil stabilized with ceramic powder for its plasticity, compaction, swelling and strength characteristics. Flexible pavements are designed on the virgin soil and the stabilized soil. Based on the test results, design and cost estimation, the following conclusions are made.

1) The expansive nature of the sub-grade can be reduced by adding a non-plastic or a less plastic waste material (ceramic powder).

2) Replacement of soil with ceramic powder at optimum percentage reduces the plasticity and increases the strength of sub-grade.

a. At 70:30 mix of soil and ceramic powder, the liquid limit reduces from 42% to 33% and the sub-grade soil is deduced from CI to CL.

b. At 70:30 mix of soil and ceramic powder, the CBR value increases from 1.7% to 2.2%.

3) The partial replacement of the expansive subgrade by the ceramic powder not only reduces the liquid limit value below 35%, but also increases the CBR value more than 2%, thereby eliminating not only the buffer layer (meant for expansive soils) but also the capping layer (meant for weak soils of CBR less than 2%). Thus, the addition of ceramic powder to the expansive soil at optimum percentage reduces the overall thickness of flexible pavement.

4) A cost reduction of 31% is observed for flexible pavement designed for 2 msa on virgin soil and stabilized soil.

5) Similarly, for flexible pavement designed for 10 msa on virgin soil and stabilized soil, a cost reduction of 24% is observed.

However, these conclusions are applicable only for the subgrade and waste material chosen.

REFERENCES

[1] KOYUNCU, H., GUNEY, Y., YILMAZ, G., KOYUNCU, S., AND BAKIS, R. (2004) "Utilization of Ceramic Wastes in the Construction Sector," Key Engineering Materials, pp 2509-2512.

[2] AKSHYA KUMAR SABAT (2012) "Stabilization of expansive soil using waste ceramic dust", Electronic journal of Geotechnical engineering, Volume 17, pp 654- 662.

[3] SABAT, A.K. AND BOSE. B (2014), "Strength, swelling and durability characteristics of fly-lime stabilized expansive soil-ceramic dust mixes", International Journal of Earth Sciences and Engineering, 7(3), pp 1210-1215

[4] LAVANYA PRABHA, S., GOPALAKRISHNAN, M., NEELAMEGAM, M.: Development of high-strength nano-cementitious composites using copper slag, ACI Materials Journal, 2020, 117(4), pp. 37–46.

[5] SUNDARABALAN, BALASUBRAMANIAN, SHANMUGAM, P., & AHN, Y. H.: Modeling the underwater light field fluctuations in coastal oceanic waters: Validation with experimental data. Ocean Science Journal. https://doi.org/10.1007/s12601-016-0007-y

[6] MOHAN, A , VIJAYAN, D.S. , REVATHY, J., PARTHIBAN, D., VARATHARAJAN, R.: Evaluation of the impact of thermal performance on various building bricks and blocks: A review, Environmental Technology and Innovation, 2021, 23, 101577(2021)

[7] M. THOLKAPIYAN, A.MOHAN, VIJAYAN.D.S: A survey of recent studies on chlorophyll variation in Indian coastal waters, IOP Conf. Series: Materials Science and Engineering 993 (2020) 012041, 1-6.

[8] GOPALAKRISHNAN, R., MOHAN, A., SANKAR, L. P., & VIJAYAN, D. S. (2020). Characterisation On Toughness Property Of Self-Compacting Fibre Reinforced Concrete. In Journal of Environmental Protection and Ecology (Vol. 21, Issue 6, pp. 2153–2163).

[9] LAVANYA PRABHA, S., DATTATREYA, J.K., NEELAMEGAM, M., SESHAGIRI RAO, M.V., Investigation of bolted RPC plate under direct tension, Journal of Structural Engineering (Madras), 2009, 36(5), pp. 333–341

[10] MOHAN, A., TABISH HAYAT, M.: Characterization of mechanical properties by preferential supplant of cement with GGBS and silica fume in concrete, Materials Today: Proceedings, 2020, 43, pp. 1179–1189.

[11] DHARMAR, S., GOPALAKRISHNAN, R., MOHAN, A.: Environmental effect of denitrification of structural glass by coating TiO2, Materials Today: Proceedings, 2020, 45, pp. 6454–6458

[12] KIRUTHIKA, C., LAVANYA PRABHA, S., NEELAMEGAM, M.: Different aspects of polyester polymer concrete for sustainable construction Materials Today: Proceedings, 2020, 43, pp. 1622–1625

[13] PRABHA, S.L., SURENDAR, M., NEELAMEGAM, M.: Experimental investigation of eco-friendly mortar using industrial wastes ,Journal of Green Engineering, 2019, 9(4), pp. 626–637