Utilization of Rice Straw Ash as Fine Aggregate in Mortar Mixes

Mohit Sehgal\textsuperscript{1,a), Sahil Arora\textsuperscript{2,b)}
\textsuperscript{1}Research Scholar, Department of Civil Engineering, Chandigarh University, Gharuan, India, 140413
\textsuperscript{2}Assistant Professor, Department of Civil Engineering, Chandigarh University, Gharuan, India, 140413

ABSTRACT: This research paper highlights the Rice Straw Ash (RSA) which is an agriculture wastage from rice cultivation and milling processes can be utilized in construction work. Compressive strength is increased due to replacement of rice straw ash up to 12.5% and also 10% cement replacing, it also increases the initial and final settlement time of mortar. By replacing of 10% RSA, the compressive strength is step by step increased and also by replacing the cement ratio the property of mortar (Water permeability) is depended and so as age of mortar. We can simply describe it that, by increasing age and compressive strength of mortar the permeability is decreased. Permeability of RSA mortar depends on the cement substitution percentage of RSA and age of mortar. When the permeability decreases, the compressive strength of mortar also increases.

KEYWORDS: RSA, construction material, wastage, fine aggregate, mortar.

1. Introduction
Rice straw ash is made after heating and burning a massive amount of it. It produces an environmental challenge and sometimes, this loss can be used in agricultural field, to decrease environmental loss, reducing the construction cost and conserve the natural resources, operating local natural loss and by producing materials to rectify the efficiency of construction materials. In the last 20 years in the world wide more country confronted of the consumption of used of natural river sand. Most of the world’s population could not access to good performance and ability construction materials because of high cost. Comparing these high costed materials to rice straw ash, rice straw ash has low cost and also it can be find all over the world. When rice plant starting to grow it has a property that, it absorbs silica from the soil in which it grows and maintains the silica in his body and structure. Yet investigators requirement to focus more on effective usage of inexpensive and locally accessible materials [1–3].

2. Literature review
The performance of cement paste admixed with RSA, Micro silica and RSA- micro silica combination are confident by partly replacing the cement paste with RSA and micro silica which are
waste product from agriculture. Simulated RSA is replaced with six percentages (5%, 10%, 15%, 20%, 25%, 30% and 2.5%, 5%, 7.5%, 10%) of RSA and MS by weight of cement [4–8]. RSA and MS particles are finer than OPC particle their affinity towards moisture increase due to increased specific surface area. Initial and final setting time extend. Because RSA particles are finer as matched to OPC particles thus required more moisture due to increased surface area. The study undertaken to evolve a recycled (RSA) and (WSA) as cement replacement materials in mortar. This paper addresses the use of the agricultural residue materials RSA and WSA to produce Nano Silica from the above waste materials in enhancing the strength properties of mortar. The study involves the replacement of binder with diverse percentages of RSA and WSA. The various mix designs are subjected to the compression test, tensile strength test. The laboratory results show that there is a tremendous improvement in compression strength test and tensile strength with accumulation of RSA and WSA at 15% replacement. The study of useful consumption of dimensional lime stone residue as FA in cement mortar mixes. Using waste dimensional lime stones in diverse proportions with FA. According to the investigation show that utilize of dimensional lime stone waste gradually increase the strength up to 20% substitution level of FA by dimensional lime stone waste [9].

The effects of RSA and micro silica (MS) on durability composition of M40 grade pavement quality concrete. Several tests were performed. This paper presents the study of pavement quality concrete by replacing various percentages of (5%, 10% RSA and 2.5%, 5%, 7.5%, 10% micro silica) the blends were subjected to various tests on mortar with the use of MD as FA in mortar to decrease the uses of natural materials, to reduce the cost of the construction, and have eco-friendly environment. Because the used waste marble powder which is known as waste material and generates from cutting and shipping of marble tiles. The following replacement has been done from (0% to 100%) marble powder to river sand. The marble powder obtained from the marble production [10] and experiment with it by making the concrete by replacing cement. It provides the effective results in concrete and gives economic results [11]. This process also reduces the effects of marble dust on environment. this paper reviewed different methods of sand and cement replacement from the concrete by using marble dust. This work also considers the impact on the environment after using MD in concrete. The analysis of cost is also done to support the utilization of waste and the study shows that it is beneficial and reduces its impact on the environment. Marble dust modified the properties like chemical, mechanical and physical of cement. It showed the protective material result in concrete and no perceptible result in the hydration progression. The results of the proposed method are better when sand is replaced by marble dust. the investigation on six mortar cubes which replaced cement by rice straw ash by 0%, 2%, 4%, 6%, 8%, and 10%. Thus, Compressive strength tests shows that at 2% replacement with RSA at the age of curing after 2, 7, and 28 days was found to be as 15.77, 34.73, and 48.53 N/mm$^2$ and increased with age of curing but decreased at 10% replacement for 7 days (18.06 N/mm$^2$) and 28 days (27.23 N/mm 2) with increase in RSA content for all mixes. It indicates that RSA can be used at 2%, 4%, and 6% to replace cement at the period of 2 to 28 days age of curing, and increase the initial and final setting time when increase rice straw ash.

3. Materials and Methods
The test conducted to evaluate the performance of composite mix are as under:
- Compression Test
- Mix Design Calculation
- Mix Design of The Materials
- Compaction Methods
- Curing Samples
- Lab Testing
- Water Absorption Test
4. Results and Discussion

This study enhances the properties of material specimen through partially replacing fine aggregate with Rice Straw Ash. RSA is taken from Kharar, Mohali (Punjab). Percentage of RSA used in this experiment are as; RSA0%, RSA 20%, RSA40%, RSA60%, RSA80% and RSA100%. Casting of specimens were done for 7, 14 and 28 days. After curing various tests were passed out to find out the experimental results of plan work. The results were compared and analyzed with normal design mix specimen [16–20]. The main focus was given or to the utilization of waste material. The results are based on the following tests: Compressive Strength, Water Absorption, The Density and The Porosity of Mortar.

4.1 Density

In Table 10, the values are based on the various mix proportions. In figure 1, It has been observed that, samples deprived of RSA, its density values are relatively much more as matched to specimen consist of RSA as sand, see Table 1.

| Mix ID  | Specimen NO | Weight of Mortar Cubes (kg/m³) | Average Density (kg/m³) | Weight of Mortar Cubes (kg/m³) | Average Density (kg/m³) | Weight of Mortar Cubes (kg/m³) | Average Density (kg/m³) |
|---------|--------------|-------------------------------|-------------------------|-------------------------------|-------------------------|-------------------------------|-------------------------|
| FA      | 100 RSA      | 1.0873                        | 0.816                   | 0.805                         |                         |                               |                         |
|         | A0           | 2.0870                        | 0.822                   | 0.803                         |                         |                               |                         |
|         | 3.0872        | 0.824                         | 2331.43                 | 0.800                         | 2280.3                  |                               |                         |
| FA50RSA | 40           | 1.771                         | 0.770                   | 0.712                         |                         |                               |                         |
|         | 2.769         | 0.770                         | 2206.43                 | 0.704                         | 2010.41                 |                               |                         |
|         | 3.770         | 0.790                         | 2206.43                 | 0.704                         | 2010.41                 |                               |                         |
| FA60RSA | 60           | 1.691                         | 0.730                   | 0.666                         |                         |                               |                         |
|         | 2.689         | 0.702                         | 2043.45                 | 0.662                         | 1882.57                 |                               |                         |
|         | 3.693         | 0.726                         | 2043.45                 | 0.660                         | 1882.57                 |                               |                         |
| FA40RSA | 80           | 1.640                         | 0.644                   | 0.618                         |                         |                               |                         |
|         | 2.642         | 0.634                         | 1818.17                 | 0.617                         | 1755.68                 |                               |                         |
|         | 3.639         | 0.642                         | 1818.17                 | 0.619                         | 1755.68                 |                               |                         |
| FA20RSA | 80           | 1.602                         | 0.594                   | 0.511                         |                         |                               |                         |
|         | 2.600         | 0.590                         | 1683.71                 | 0.530                         |                         |                               |                         |
|         | 3.603         | 0.594                         | 1683.71                 | 0.520                         | 1478.21                 |                               |                         |
4.2 Compression Strength Test

The might properties of mortar through partly replacing fine aggregate with RSA is compared with control mix. This test is commonly performed on harden mortar. The cube sample are examined designed for compression and RSA. The average samples taken which are used for this test, is considered as their final value for 7, 14 and 28-days curing period [22][23], see Table 2.

**Table 2. Compressive strength test results of Mortar.**

| Percentage of RSA | Ratio 1:2 |          |          | Ratio 1:3 |          |          | Ratio 1:4 |          |
|-------------------|----------|----------|----------|----------|----------|----------|----------|----------|
|                   | Average Compressive Strength of Cube (N/mm²) | Average Compressive Strength of Cube (N/mm²) | Average Compressive Strength of Cube (N/mm²) | Average Compressive Strength of Cube (N/mm²) |
|                   | 7 days   | 14 days  | 28 days  | 7 days   | 14 days  | 28 days  | 7 days   | 14 days  | 28 days  |
| FA0RSA0           | 21.63    | 25.08    | 28.54    | 18.38    | 21.85    | 25.32    | 18.38    | 20.21    | 22.04    |
| FA80RSA20         | 23.34    | 27.5     | 32.25    | 16.96    | 19.55    | 22.14    | 13       | 16.15    | 20       |
| FA60RSA40         | 13.44    | 18.15    | 23.04    | 13.44    | 16.90    | 22.14    | 12.25    | 15.20    | 18.15    |
| FA40RSA60         | 9.42     | 15.83    | 22.85    | 8.41     | 12.77    | 20.37    | 9.98     | 12.90    | 15.83    |
4.3 Compressive strength of mortar mixes after 7 days of curing

The mix is calculated as per (IS-2250-1981) and value of compressive strength showed graphically in fig.2. After 7 days is as; the mix of (1:2) compressive strength of conventional mortar or M-1 (100% FA and 0% RSA) is 21.63 MPa. Whereas, the compressive strength of M-2 (80% FA and 20% RSA) is 23.34 MPa. It increases by 7.9% in comparison to the conventional mix, M-3 (60% FA and 40%RSA) is 13.44 MPa. It has reduction of 37.86%. M- 4 (40% FA and 60% RSA) is 9.42 MPa it has reduction of 56.45%. M-5 (20% FA and 80% RSA) is 7.73 MPa it has reduction of 64.26% and M- 6 (0% FA and 100% RSA) is 5.70 MPa it has the reduction of 73.64% as compared to conventional mortar at 7 days. And mix of (1:3) is as followed, M-1 (100% FA and 0% RSA) is 18.38 MPa. Whereas, the compressive strength of M-2 (80% FA and 20% RSA) is 16.96 MPa it has reduction of 7.72%, M-3 (60% FA and 40% RSA) is 13.44 MPa it has reduction of 73.12, M-4 (40% FA and 60% RSA) is 8.41 MPa it has reduction of 54.24%, M-5 (20% FA and 80% RSA) is 6.05 MPa it has reduction of 67.08% and M-6 (0% FA and 100% RSA) is 5.70 MPa it has the reduction of 68.98% as compared to conventional mortar at 7 days. And mix of (1:4) is as; M-1 (100% FA and 0% RSA) is 18.38 MPa. Whereas, the compressive strength of M-2 (80% FA and 20% RSA) is 13 MPa it has reduction of 29.27%. M-3 (60% FA and 40% RSA) is 12.25 MPa it has reduction of 33.35, M-4 (40% FA and 60% RSA) is 9.98 MPa it has reduction of 45.70%, M-5 (20% FA and 80% RSA) is 7.73 MPa it has reduction of 57.94% and M-6 (0% FA and 100% RSA) is 5.70 MPa it has the reduction of 68.98% as compared to conventional mortar. Result of 7 days reveals mix (1:2) up to 20% of replacement rice straw ash works fine, because it increase compressive strength by 7.9% and for all other mixes compressive is decreased.
Figure 2. Effect of RSA contents on compressive strength after 7 days of curing

4.4 Compressive strength of mortar mixes after 14 days of curing

The mix calculated by (IS-2250-1981) and value of compressive strength showed graphically in figure 3. The compressive strength at age 14 days as follow:

The conventional mortar or M-1 (100% FA and 0% RSA) is 25.08 MPa. Whereas, the compressive strength of M-2 (80% FA and 20% RSA) is 27.5 MPa. It increases by 10.16% as compared to conventional mix. M-3 (60% FA and 40% RSA) is 18.15 MPa it has reduction of 27.63%, M-4 (40% FA and 60% RSA) is 15.83 MPa it has reduction of 36.88%. M-5 (20% FA and 80% RSA) is 13.07 MPa it has reduction of 47.88% and M-6 (0% FA and 100% RSA) is 12.25 MPa it has the reduction of 51.15% as compared to conventional mortar and for mix (1:3) is as followed, M-1 (100% FA and 0% RSA) is 21.85 MPa [24][25][26]. Whereas, the compressive strength of M-2 (80% FA and 20% RSA) is 19.55MPa it has reduction of 10.52%, M-3 (60% FA and 40%RSA) is 16.90 MPa it has reduction of 22.65, M-4 (40% FA and 60% RSA) is 12.77 MPa it has reduction of 41.55%, M-5 (20% FA and 80% RSA) is 9.52 MPa it has reduction of 56.43% and M-6 (0% FA and 100% RSA) is 7.75 MPa it has reduction of 62.34% as compared to conventional mortar.

Result of 14 days reveals mix (1:2) up to 20% of replacement Rice Straw Ash works fine, because it
increases Compressive Strength by 10.16% and for all other mixes compressive strength is decreased. Effect of RSA on Compressive Strength curing after 14 days is shown below.

Figure 3. Effect of RSA on compressive strength after 14 days of curing.

4.5 Compressive strength of mortar mixes after 28 days of curing

The mix calculated as per (IS-2250-1981). The result after 28 days as follow for the mix of (1:2) compressive strength of conventional mortar or M-1 (100% FA and 0% RSA) is 28.54 MPa. Whereas, the compressive strength of M-2 (80% FA and 20% RSA) is 22.85 MPa it has reduction of 19.93%, M-3 (60% FA and 40% RSA) is 22.33 MPa it has reduction of 22.10%, M-4 (40% FA and 60% RSA) is 18.41 MPa it has reduction of 35.49% and M-5 (20% FA and 80% RSA) is 15.2 MPa it has reduction of 54.09% as compared to conventional mortar and mix of (1:3) is as followed, M-1 (100% FA and 0% RSA) is 25.32 MPa. Whereas, the compressive strength of M-2 (80% FA and 20% RSA) is 22.14 MPa it has reduction of 12.55%, M-3 (60% FA and 40% RSA) is 20.37 MPa it has reduction of 19.54%, M-4 (40% FA and 60% RSA) is 17.14 MPa it has reduction
of 32.30%, M-5 (20% FA and 80% RSA) is 13 MPa it has reduction of 48.65% and M-6 (0% FA and 100% RSA) is 9.81 MPa it have the reduction of 61.25% as compared to conventional mortar and mix (1:4) is as followed, M-1 (100% FA and 0% RSA) is 22.04 MPa. Whereas, the compressive strength of M-2 (80% FA and 20% RSA) is 20 MPa it has reduction of 9.25%, M-3 (60% FA and 40% RSA) is 18.15 MPa it has reduction of 17.64%, M-4 (40% FA and 60% RSA) is 15.83 MPa it has reduction of 28.17%, M-5 (20% FA and 80% RSA) is 12.25 MPa it has reduction of 44.41% and M-6 (0% FA and 100% RSA) is 9.52 MPa it has the reduction of 56.80% as compared to conventional mortar. Result of 28 days reveals mix (1:2) up to 20% of replacement Rice Straw Ash works fine, because it increases Compressive Strength by 11.50%, see figure 4.

![Figure 4. Effect of RSA on compressive strength after 28 days of curing](image)

4.6 Water Absorption
The values for water absorption are relatively less as matched to specimens that have addition of RSA to replace fine aggregates in mortar. However, 20% substitution of sand with RSA displayed the decrease in water absorption. There is an increasing trend of water absorption beyond 20% replacement of sand with RSA as shown in Figure 5 and Table 3.

**Table 3.** Effect of RSA in water absorption.

| Percentage of RSA | Ratio 1:2 | Ratio 1:3 | Ratio 1:4 |
|-------------------|----------|----------|----------|
|                   | Dry weight of specimen (W1) | Submerge weight of specimen (W2) | Average water Absorption (%) | Dry weight of specimen (W1) | Submerge weight of specimen (W2) | Average water Absorption (%) | Dry weight of specimen (W1) | Submerge weight of specimen (W2) | Average water Absorption (%) |
| FA100RS A0        | 0.751    | 0.827    | 10.11    | 0.762    | 0.828    | 8.60    | 0.720    | 0.805    | 10.6 |
|                   | 0.753    | 0.830    |          | 0.764    | 0.830    |          | 0.730    | 0.803    |          |
|                   | 0.750    | 0.825    |          | 0.762    | 0.828    |          | 0.727    | 0.800    |          |
| FA80RS A20        | 0.714    | 0.760    | 6.44     | 0.702    | 0.761    | 7.24    | 0.670    | 0.712    | 6.75 |
|                   | 0.712    | 0.763    |          | 0.686    | 0.730    |          | 0.669    | 0.704    |          |
|                   | 0.710    | 0.761    |          | 0.692    | 0.740    |          | 0.650    | 0.707    |          |
|                   | 0.621    | 0.661    | 6.56     | 0.630    | 0.702    | 11.85   | 0.585    | 0.666    | 14.3 |
| FA60RS A40        | 0.625    | 0.665    |          | 0.610    | 0.690    |          | 0.570    | 0.662    |          |
|                   | 0.620    | 0.662    |          | 0.626    | 0.695    |          | 0.583    | 0.660    |          |
|                   | 0.548    | 0.629    | 14.15    | 0.530    | 0.610    | 14.77   | 0.550    | 0.618    | 15.5 |
| FA40RS A60        | 0.549    | 0.630    |          | 0.532    | 0.615    |          | 0.530    | 0.617    |          |
|                   | 0.546    | 0.627    |          | 0.526    | 0.598    |          | 0.525    | 0.619    |          |
|                   | 0.505    | 0.593    | 16.14    | 0.485    | 0.583    | 20.79   | 0.440    | 0.511    | 17.3 |
| FA20RS A80        | 0.508    | 0.590    |          | 0.480    | 0.580    |          | 0.455    | 0.536    |          |
|                   | 0.503    | 0.592    |          | 0.482    | 0.585    |          | 0.445    | 0.525    |          |
|                   | 0.563    | 0.547    | 18.14    | 0.410    | 0.505    | 23.79   | 0.390    | 0.456    | 16.7 |
| FA0RS A100        | 0.465    | 0.549    |          | 0.408    | 0.509    |          | 0.400    | 0.467    |          |
|                   | 0.460    | 0.546    |          | 0.409    | 0.505    |          | 0.395    | 0.460    |          |
4.7 Porosity
The Porosity test has been carried out for mix proportion after 28 days. Intended for conducting of porosity test specimen with cube size 70.6 mm * 70.6 mm * 70.6 mm have been used. The results of the porosity test of the conventional mortar and mortar with addition of RSA are shown in figure 6. The porosity test value of mortars that contain 0%, 40%, 60%, 80% and 100% of RSA is higher than that of the conventional mortar and only there is reduction in porosity when 20% of rice straw ash was used to replace fine aggregate at all mixes after 28 days.

5. Conclusion
It would be a great choice to substitute natural materials of mortar which is fine aggregate. Consumption of RSA as fine aggregate in mortar with diverse proportions i.e. 1:2, 1:3, 1:4 were tested for compressive strengtdensity, porosity and water absorption. The result is concluded as following for each of mentioned tests:

- Compressive strength of M-2 (1:2) mortar mix was increased by 12.9 % as compared to conventional mortar and further increase in RSA beyond 20 % decreases the compressive strength of.
the mortar mix at all curing ages. Compressive strength of all other mixes i.e. 1:3 and 1:4 reduces with the addition of RSA. Compressive strength reduces when w/c ratio increases also when w/c ratio increases therefore porosity will increase due to it, compressive strength is decreased.

- Density of mortar with addition of rice straw ash decreases with increase in its % age content as compared to conventional mortar thus making it a light weight mortar. Density is reduced when increases w/c ratio also when volume is constant and mass reduces then density is reduced.

- Water absorption was found to decrease by 36.3 % with replacement of 20 % of rice straw ash with fine aggregate in 1:2 mortar mixes. However, further increase in rice straw ash content beyond 40 % in mortar mix increases its water absorption as compared to conventional mortar.

- 20 % fine aggregate replacement with RSA resulted in fall in porosity of mortar cube by 8 % for 1:2 mix, 12 % for 1:3 mix and 19 % for 1:4 mix.

- Utilization of rice straw ash up to 20 % replacement with fine aggregate in 1:2 mortar gives appreciable results for compressive strength, lighter mortar, lower water absorption and porosity values. Hence it is recommended to use 20 % RSA content in mortar for various construction applications.

6. References
[1] Thind P S, Sareen A, Singh D D, Singh S and John S 2021 Compromising situation of India’s bio-medical waste incineration units during pandemic outbreak of COVID-19: Associated environmental-health impacts and mitigation measures Environ. Pollut. 276
[2] Sidhu B S, Sharda R and Singh S 2021 An assessment of water footprint for irrigated rice in punjab J. Agrometeoral. 23 21–9
[3] Chohan J S, Mittal N, Kumar R, Singh S, Sharma S, Singh J, Rao K V, Mia M, Pimenov D Y and Dwivedi S P 2020 Mechanical Strength Enhancement of 3D Printed Acrylonitrile Butadiene Styrene Polymer Components Using Neural Network Optimization Algorithm Polymers (Basel). 12 2250
[4] Kumar S, Kumar M and Handa A 2018 Combating hot corrosion of boiler tubes – A study Eng. Fail. Anal. 94 379–95
[5] Gairola P, Gairola S P, Kumar V, Singh K and Dhawan S K 2016 Barium ferrite and graphite integrated with polyaniline as effective shield against electromagnetic interference Synth. Met. 221 326–31
[6] Khan A M, Jamil M, Mia M, Pimenov D Y, Gasiyarov V R, Gupta M K and He N 2018 Multi-objective optimization for grinding of AISI D2 steel with Al2O3 wheel under MQL Materials (Basel). 11
[7] Singh D, Kumar V and Kaur M 2019 Single image dehazing using gradient channel prior Appl. Intell. 49 4276–93
[8] Singh U and Rattan M 2014 Design of linear and circular antenna arrays using cuckoo optimization algorithm Prog. Electromagn. Res. C 46 1–11
[9] Kim I S, Choi Y S, Choi S Y and Yang E I 2019 Evaluation of durability and radiation shielding property of heavyweight filling material for application in radioactive disposal facilities Ann. Nucl. Energy 133 750–61
[10] Anon 2018 IOP Conference Series: Materials Science and Engineering IOP Conference Series: Materials Science and Engineering vol 413 (Institute of Physics Publishing)
[11] Gao Z-X, Guo P and Li J 2018 Experimental on molding process for chip-sprinkling cement concrete pavement 植石水泥混凝土路面成型工艺试验 Chang. Daxue Xuebao (Ziran Kexue Ban)/Journal Chang. Univ. (Natural Sci. Ed. 38 34–42
[12] Al-Fakih A, Wahab M M A, Mohammed B S, Liew M S, Wan Abdullah Zawawi N A and As’ad S 2020 Experimental study on axial compressive behavior of rubberized interlocking masonry walls J. Build. Eng. 29
[13] Vandanapu S and Muthumani K 2020 Heat of Hydration and Alkali-Silicate Reaction in Oil Palm Shell Structural Lightweight Concrete Silicon 12 1043–9
[14] Konduru H, Rangaraju P and Amer O 2020 Reliability of Miniature Concrete Prism Test in Assessing Alkali-Silica Reactivity of Moderately Reactive Aggregates Transp. Res. Rec. 2674 23–9
[15] Abraham S M and Ransinchung G D R N 2020 Laboratory research on reclaimed asphalt pavement-inclusive cementitious mixtures ACI Mater. J. 117 193–204
[16] Xu W, Wen X, Wei J, Xu P, Zhang B, Yu Q and Ma H 2018 Feasibility of kaolin tailing sand to be as an environmentally friendly alternative to river sand in construction applications J. Clean. Prod. 205 1114–26
[17] Nikravan M, Ramezanianpnoor A A and Maknoon R 2018 Technological and environmental behavior of petrochemical incineration bottom ash (PI-BA) in cement-based using nano-SiO2 and silica fume (SF) Constr. Build. Mater. 191 1042–52
[18] Long W-J, Li H-D, Wei J-J, Xing F and Han N 2018 Sustainable use of recycled crumb rubbers in eco-friendly alkali activated slag mortar: Dynamic mechanical properties J. Clean. Prod. 204 1004–15
[19] Wang W, Cheng Y, Tan G and Tao J 2018 Analysis of aggregate morphological characteristics for viscoelastic properties of asphalt mixes using simplex lattice design Materials (Basel). 11
[20] Priyadharshini P, Ramamurthy K and Robinson R G 2018 Reuse potential of stabilized excavation soil as fine aggregate in cement mortar Constr. Build. Mater. 192 141–52