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Utilization of concrete waste from demolition sites in pavement subgrade

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A R T I C L E I N F O

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A B S T R A C T

The direct use of recycled waste concrete (RWC) is difficult as the demolished concrete shows large variation of raw materials and higher rate of water absorption due to the porosity of the lumps. Owing to such reasons, the utilization of the RWC is difficult for structural applications; however, it may be interesting to explore the feasibility of using RWC in non-structural applications such as subgrade layer of pavements. In this research work, the demolished concrete has been recycled with nominal crushing treatment in a ball mill and separated as fine powder, small to medium size aggregates. The soil samples have been prepared consisting soft clay (SC) type subgrade soil with all three forms of RWC in equal proportions. The SC has been replaced from 0% to 70% by weight with the blended RWC. Tests for the subgrade characterization namely California Bearing Ratio (CBR) values, dry density, moisture content, and plate load tests have been conducted. Under all test conditions, the addition of the RWC into the SC soil showed improvement at a given fraction of replacement. The work supported the feasibility of the utilization of the RWC for preparing the subgrade layer for the pavements and promoting the sustainability of the waste concrete in the civil engineering applications.

Selection and peer-review under responsibility of the scientific committee of the UKIERI Concrete Congress – Sustainable Concrete Infrastructure.

1. Introduction

Concrete has remained the most common construction materials globally from the past many decades. Though there are several positive reasons for use of concrete as a building material; it imposes many hazardous environmental impacts [1,2]. Moreover, from the quarrying of natural stones to the final placing of concrete nearly all ingredients require high energy for production [3]. On the other hand, with the age, hardened concrete shows degradation and loss of material. Unfortunately, the degraded concrete is apparently not possible for direct reuse as the material is not fit for recycling [4]. During the demolition, the concrete is largely broken into the pieces or lumps and are sent to the landfills as the final disposal option in the absence of the other possibilities for its innovative way for reuse. The fast vanishing natural materials like stone and sand have reached at the alarming stage and it has become necessary to explore the possible ways to reuse the demolished or old concrete [5]. On performing the environmental impact assessment of concrete production and the demolished waste generation, it has been observed that it imposes direct as well as indirect impacts to the environments [6–10]. The demolished concrete is highly heterogeneous material and lac of quality consistency and strength parameters even if received from a single source of supply. No lumps of concrete exhibit acceptable strength characteristics [11]. Additionally, the demolished concrete tends to have a higher rate of water absorption. The aggregates once used in concrete are also difficult to use as the hydrated cement residues are difficult to remove from the surfaces of the aggregates and sand [12]. The removal of the coated layers of cement paste is necessary for the adequate surface binding of the constituents in the new mix being prepared. The researchers have made extensive efforts for the utilization of the demolished concrete. Most commonly, it has been used as the aggregates and to certain limit as sand in the production of the new mixture [13–16]. The crushed concrete is not a suitable replacement of the natural sand and aggregates due to the reason that they are structurally not stable in the impact and compression forces [17,18]. The adhesion of hydrated paste to the surfaces of the constituents raises challenges to formation of the new bonding mechanism within the matrix. These are few of the reasons for restricted use of the recycled concrete into the

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manufacturing of the new concrete for the structural uses [15,19]. On the other hand, there are construction activities where the recycled concrete may be effectively used, namely non-structural applications. Out of these, the improvement of the subgrade soil with addition of the recycled concrete may be an innovative and relatively less explored field of study. Waste recycled concrete (RWC) for pavement subgrade enhancement may be an innovative solution that will reduce the environmental impact of demolished concrete and create a stiffer and stronger base for pavements. In the present study, efforts have been made to utilize the recycled concrete obtained from the demolition sites in the subgrade soil for the pavements and roads.

2. Materials and method of testing

2.1. Recycling concrete waste

The concrete wastes were obtained from the nearby areas of the Rajkot city where the demolition work was in progress. The waste concrete was in form of the large sized boulders or lumps as shown in Fig. 1(a). The lumps were simply washed with the water and left to natural drying for 24 h and placed into the abrasion machine at the laboratory and crushed into the powder, aggregate and small particles as shown in Fig. 1(b) using the sieves. The RWC materials are shown in Fig. 1(c). The Particle Size Distribution curvefor RWC is shown in Fig. 1(d). The curve was utilised to classify the appropriate size of the recycled waste material. Table 1 shows the properties of raw materials, demonstrating the feasibility of the material addition for the development of the new concrete.

2.2. Subgrade soil preparation

The locally available SC soil sample was obtained from the nearby areas to the laboratory. The soil sample was obtained as undisturbed soil sample and utilized to prepare the modified subgrade samples. The RWC with different fractional proportions were added in to the SC samples from 0% to 70% by weight of the SC. The percentage range of the replacement was based on the previous pilot studies and experience of working with the SC during the assessment. Fig. 2(a) and Fig. 2(b) shows samples of raw materials while Fig. 2(c) shows the prepared subgrade sample for the testing. The samples were designated as SCRWC0 to SCRWC70 denoting the fraction of the recycled concrete in the sample from 0% to 70% replacement. Each sample was tested in the laboratory for CBR, dry density and moisture content and for the subgrade reaction the plate load test was conducted on the actual fields from where the SC were sourced. The mixture proportions for each sample are shown in Table 2.

2.3. Methodology for sample preparation and tests

The typical subgrade sample and samples were prepared by following the step wise methodology illustrated in Fig. 3. The SC were obtained as undisturbed samples from the identified marked field under the field conditions. The materials namely RWC and MTS were mixed in dry state with each other and dedicated specimens were made available for the laboratory testing. The CBR test apparatus and sample is shown in Fig. 4(a) and the water absorption test as the moisture content set up has been shown in Fig. 4(b). For the plate load testing, the trench of standard size was prepared and the samples were placed within the confined area of the trench in layered pattern and with necessary compaction of each layer. The subgrade so prepared was assessed for the reaction capacity by the plate load test. The field and laboratory tests were carried out as per the relevant Indian standard codes of practice namely CBR, Dry density, moisture content in terms of porosity calculation, and the plate load test to determine the settlement of soil sample for the reaction calculation were conducted. The test results have been carefully observed and analyzed for the necessary interpretation of the response by the subgrade soil samples. Especially the influence of the addition of RWC on subgrade quality improvement has been studied and presented for the discussion.

Table 1
Preliminary properties of SC and RWC samples.

Property	SC Sample	RWC Sample
Form	Dry mix	Dry mix
Sp. Gravity	2.7	3.11
Moisture contents (%)	<50	<60
Liquid limit	50	–
Plastic limit	40	–
Fineness (mm)	<0.075	0.09–20
Fineness Modules	–	6.11
Impact Strength (%)	–	20–30
Unit Cohesion (kN/m^2)	14.5	–
Angle of Internal Friction (ϕ)	0	36^0 to 42^0

3. Test results and discussion

3.1. CBR test values of SCRWC samples

The samples of subgrade soil were prepared by mixing the RWC containing recycled concrete powder, small and large aggregates in equal proportions mixed into the SC samples. The SCRWC0 was considered as a reference or control mixture. The tests for penetration were carried out. The results of all samples have been shown in Fig. 5. Total of eight samples were prepared and tested. From the result it was evident that the control samples showed a limited range of CBR values for soaked and un-soaked conditions owing to the nature of the soil as sandy clay that is relatively soft in nature. Such soil types have limited resistance to the penetration and shows limited shear resistance capacity also due to the limited internal particle strength in cohesion. Using a filler material like RMC it is possible to increase the adhesion capacity, by improving the internal bonding and adhesion of the particles that can contribute to the improved resistance to the penetration. The powder form of the RWC was the hydrated cement portion of the hardened concrete possessing excellent binding capacity. The RWC powder showed reaction to the moisture present in the soil samples and offered the additional inter molecular friction and holding capac-

Fig. 1. (a) Demolition waste;(b) Pre-treated waste;(c) Constituents of RWC; (d) Particle Size Distribution curve.

Fig. 2. (a) Material samples:(b) Mixing of samples;(c) CBR test in progresses.

Table 2
Dry mixture proportions for the testing of SCRWC samples.

Mixture Designation	SC (% by Weight)	RWC (% by Weight)
SCRWC0	100	0
SCRWC10	90	10
SCRWC20	80	20
SCRWC30	70	30
SCRWC40	60	40
SCRWC50	50	50
SCRWC60	40	60
SCRWC70	30	70

ity. Moreover, the presence of small to medium size aggregates was largely the natural aggregates firmly coated with the cementitious components. Therefore, the RWC played a significant role in the overall strength improvement of the soil samples against the penetration at the given load compared to the untreated soil samples or control samples.

The application of the RWC in soil property enhancement did not show any requirement for the prolonged or special pretreatment and a simple abrasion of the lumps in a ball mill was found sufficient. This is a noticeable part of the study and contributes to the reduction of the unnecessary energy usage required in pre-treatment of the concrete waste to making it useful. With the replacement of natural SC soil up to 50% by combined RWC mixture the CBR value increased from 5% to 56% in soaked conditions and form 10% to 67% in un-soaked conditions. However, with the addition of RWC beyond 50%, the values showed the trend of reduction in the values. Though the reduction was insignificant at 60% and 70% replacement of SC soil in the sample, the reduction was noticed around 9% for the addition of 10% RWC beyond 50% and 16% reduction for the addition of 20% of the RWC beyond 50% addition into the SC soil samples. Therefore, it was observed that addition beyond 50% of RWC did not influenced the improvement of the SC type subgrade soil, however the CBR values were recorded way ahead that of the control samples at this fraction of use of RWC, and therefore, may be employed for the subgrade improvement in a relatively hard soil type with limited sand proportion. The mixed form of finer to coarser particles sizes of the RWC was found responsible for the response to the compaction. Though the response is merely an experience and requires detailed scientific investigation from the geotechnical specialized perspectives, the observation was found important to be mentioned in the technical discussion. There can be a separate set of tests regarding the layer adhesion coefficients; drainage coefficient and elastic modulus are a few examples of possible detailed study on the modified SCRWC samples. The decision of a combined use of the three varying forms of the RWC was found important and useful for the application to the subgrade improvement exercises owing to its multiple advantages including the increased CBR values.

3.2. Dry density of the SCRWC samples

Fig. 6 illustrates the dry density values obtained at the given moisture conditions in the prepared subgrade soil samples. The dry density was obtained as per the guidelines of the IS: 2720-part-8(1983). It is interesting to obtain correlation between the values of soaked and un-soaked CBR values with the MDD values. The values of MDD are expressed in the percentage format indicating the degree of compaction namely heavy and light compaction employed while preparing the samples. As the relationship, values of MDD increase with the increment of the CBR values [20,21]. Similar response was observed during the MDD tests on the samples. The addition of RWC improve the MDD values in the range from 12% to as much as 66% at the 50% addition in the SC soil and beyond that the increment showed reduced trend reached up to 51% improvement. However, that was very well ahead of the control sample values of MDD. The values were of the same trend of increase and decline in the results of the CBR tests. The response of MDD similar to that of the CBR values were confirmed by establishing the relationship of the percentage increase of the CBR values and the MDD values as shown in Fig. 7 the regression R^2 value was found to be 0.98 as the validation of the test results.

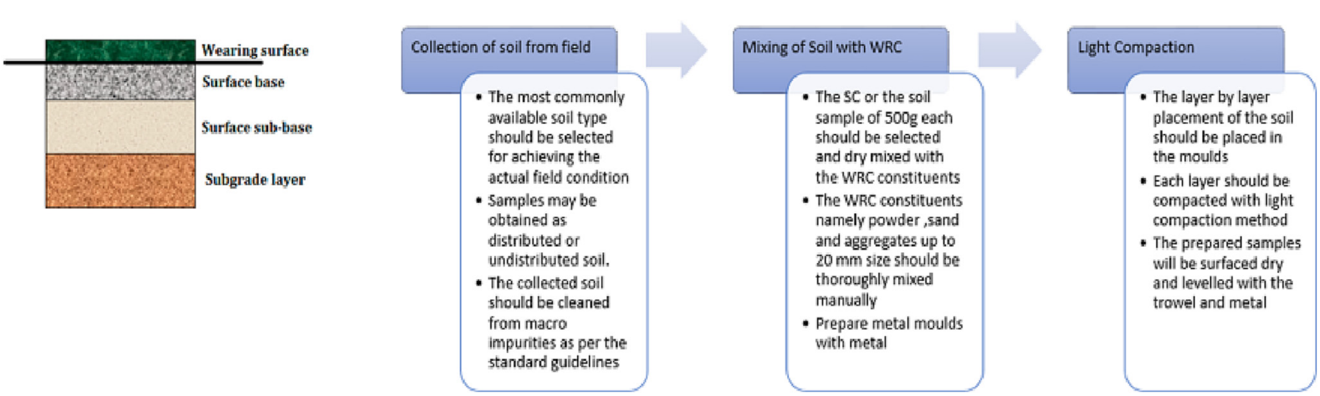

Fig. 3. Typical Cross section of Subgrade &Methodology.

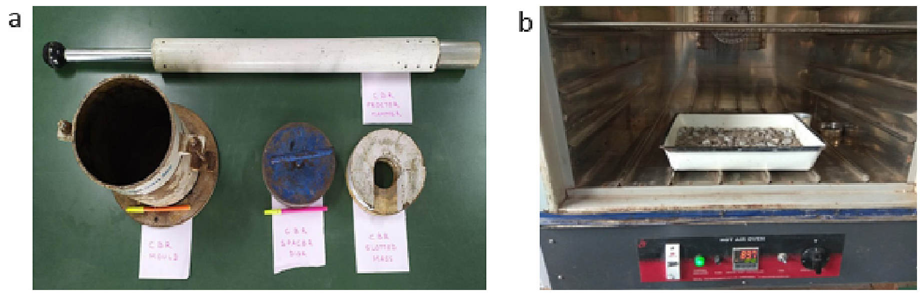

Fig. 4. (a) CBR Apparatus:(b) Sample in oven.

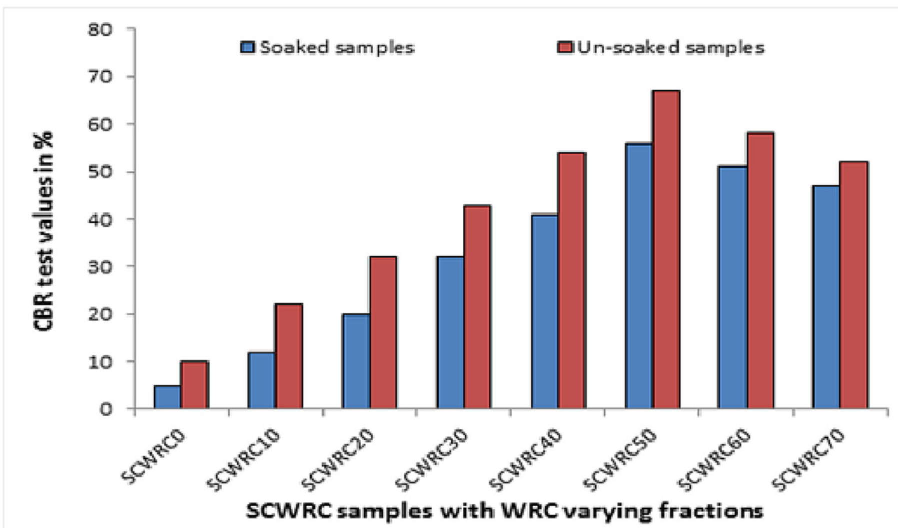

Fig. 5. Effect of RWC on the property enhancement of subgrade soil.

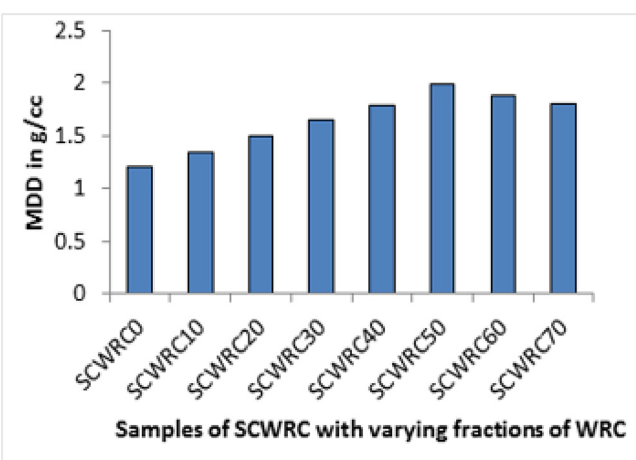

Fig. 6. Results of MDD tests.

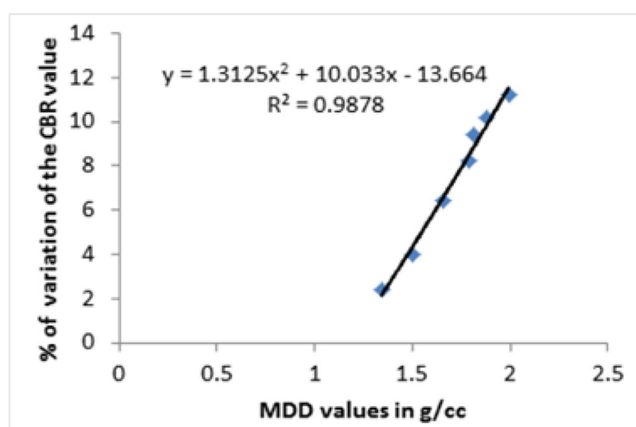

Fig. 7. Relationship of MDD and CBR values.

3.3. Moisture content of sample

The moisture content characteristics of the SCRWC samples have been obtained using the guidelines of IS: 2720-Part-2 (1973) and as per the oven dry method. The prepared samples were oven dried at 110 °C for 24 h. The results are shown in the Fig. 8. The objective was to determine the impact of presence of the RWC constituents on the moisture content on mixing with the SC. As per the nature of the SC soil, the experiments carried out in the literature has shown that the inclusion of the non-soil materials have contributed to the reduced water absorption of the samples [22–24].

The similar results to an extent were observed in the case of the SCRWC samples containing varying fractions of the RWC. In the other terms, the moisture ingress of the SCRWC samples with 10 to 70% of the RWC was significantly lower as compared to the reference mix. The optimum value of the reduction was noticed in the samples containing 50% and 60% replacement of the SC soil. Beyond the 60% addition of the waste did not affect the reduction

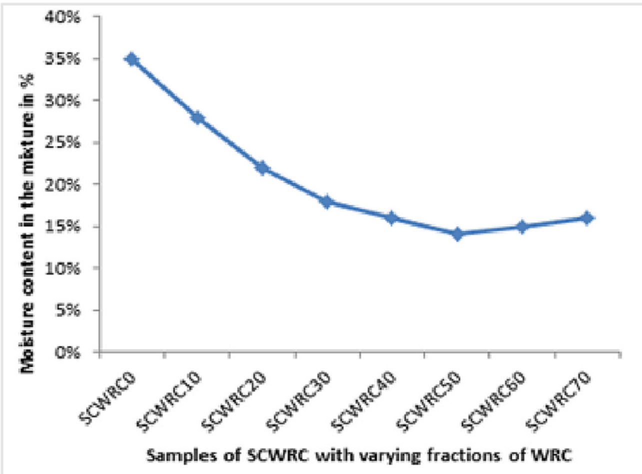

Fig. 8. Water absorption of SCRWC samples and impact of RWC.

of moisture content of the mix significantly. This is due to the reason that the moisture content is regarded as the function of the overall internal pore structures and air voids present randomly in the mix, and therefore with the addition of the all sizes of RWC ingredients entered during the compaction of the mixture.

3.4. Plate load test of samples

The plate load test has been conducted at the fields from where the SC soil sample has been collected and utilized. As per the reference of the IS:1888-1982 code, the test pit and pressure gauges along with the loading assembly have been followed. The load test was the laboratory plate load test with the apparatus shown in Fig. 9 and the results are shown in Fig. 10. The test results clearly indicated the positive influence of addition of the RWC on the load carrying capacity enhancement and resistance to the settlement. The reason is due to the presence of the varying sizes of the RWC components as powder, sand like and aggregates like particles. The higher compressive stress intensity requires denser subgrade for uniform and effective distribution within the mass. By having the stronger intermolecular bonding of the SC particles with the RWC particles, it became possible to resist the forces more effectively. This response was evidently appeared from the subgrade samples containing the RWC in varying fractions up to 70%. A careful observation showed that with the increase of the RWC fraction in the mix the settlement values declined and at the given load in each sample, the overall subgrade settlement was reduced. This response established and encouraged the authors to reach to a conclusion that the addition of the RWC in the SC soil subgrades improves the load resisting capacity of the soil.

4. Advantages of RWC for the field applications

The experimental results encouraged the authors for the utilization of the waste concrete in a sustainable perspective for subgrade improvement. The structural applications of the recycled concrete may require a few energy intensive pre-treatments. The previous studies and results suggest that there are several challenges to overcome for making the waste concrete reusable. Therefore, it may be an innovative and less energy intensive approach to use the waste concrete in the upgradation of the soil properties for subgrade of pavements. Fig. 11 shows the flow of development of the modified subgrade for pavement using the RWC. The figure indicates P as the pollution, E as the energy included and S as the sustainability aspect of the process. It may be noted that there are several stages indicating the substantial amount of energy usage in the conventional method of subgrade improvements however, the inclusion of RWC in the specific soil type shows a clear advantage and benefits. The area of the present study may be explored more scientifically with the added attributes of the environmental impact analysis aspects. The present study focused on the feasibility of the subgrade strengthening with the RWC constituents and it was observed that the inclusion of the RWC influences all primary properties of a subgrade and may be potentially applied as the secondary or filler material for the subgrade improvement as well as alternate way of managing the waste concrete or demolished concrete effectively.

5. Conclusions

The waste concrete obtained from the actual site after the demolition process have been pre-treated with the simple abrasive process to separate the hardened constituents of the concrete mix.

Fig. 9. Plate load test.

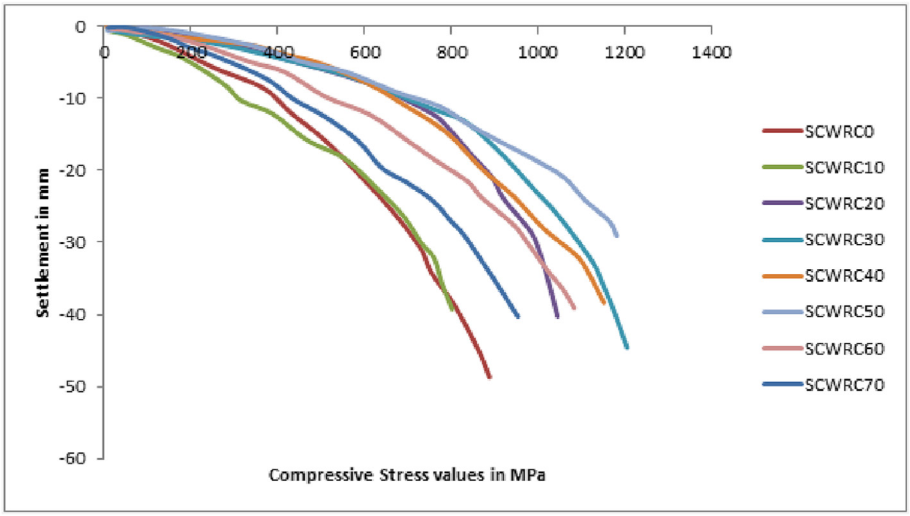

Fig. 10. Plate load test results.

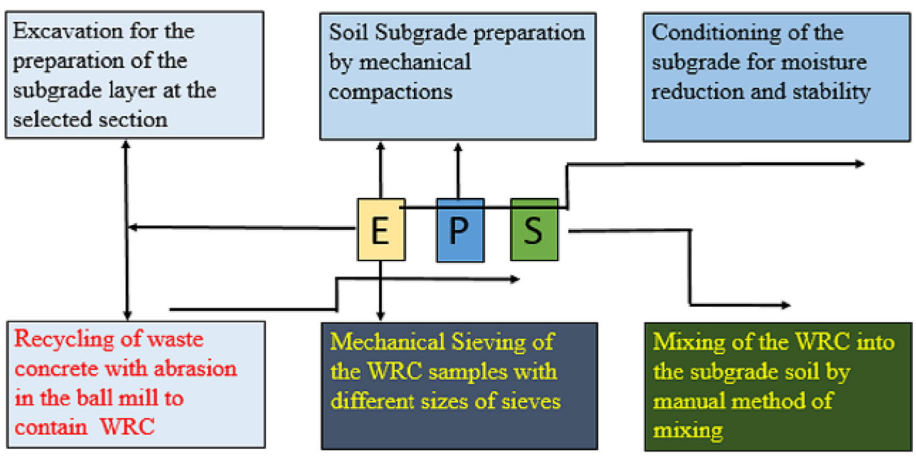

Fig. 11. Sustainability attributes of the subgrade modification with RWC.

The recycled concrete so obtained has been utilized to enhance the load carrying capacity and stability of the subgrade of pavement by examining the samples under various test conditions and criteria. Following are the important findings obtained as the conclusion of the present study;

- The addition of the RWC in the SC type soil for subgrade by replacement of SC up to 50% by weight, showed excellent improvement in CRB values, MDD values, reduced moisture ingress at the given room conditions.
- The constituents of recycled concrete namely powder, small sized and medium sized aggregates performed as well graded particles and enhanced the intermolecular adhesion with the SC soil particles by improving the internal friction and thereby producing a denser subgrade capable of resisting the higher amount of load for a given settlement value. Moreover, the compaction capability was increased in terms of MDD values due to the presence of all size particles in the test samples. The test results promoted the combined use of all three varying types of the waste concrete in the subgrade strengthening mechanism.
- The study revealed that without employing the significant energy and efforts in recycling of the waste concrete, it is possible to take advantage of the RWC for the ground or soil improvement techniques and to achieve improved strength and load carrying capacity. The study also established that rather allowing the RWC to be disposed of into the landfills, a more sustainable option is to make a use of it in more environment friendly way for sustainable construction practices.

CRediT authorship contribution statement

Mihir Baldania: Resources, Methodology, Investigation, Formal analysis, Data curation. **Ankur Bhogayata:** .

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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