

The use of fine portions from construction and demolition waste for expansive soil stabilization: A review

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ABSTRACT Construction and demolition waste (CDW) are the largest waste products in the world today and competes as a viable recycled additive material in place of natural aggregates. Due to the increase in compressive strength of different mix proportions of CDW, it is also considered for reuse in concrete and subbase construction. This study shows the effect of CDW in expansive soil stabilization. The chemical and mechanical properties of these materials have shown that they are capable of developing compressive strength properties for replacement of cement with significant reduction in carbon emission. The inherent compositional properties of recycled CDW compared in this review suggests that CDW have good filler properties in highly expansive soils. Mixtures of crushed brick and recycled aggregates characterised based on chemical properties of different replacement ratios suggests that CDW of good-quality aggregates reduces swell potential of expansive soils and increased mechanical strength in pavement construction.

KEYWORDS mixed fine portions, construction and demolition waste, expansive soil, soil stabilization

1 Introduction

Massive urbanisation has boosted up infinite construction activities especially in developed countries and has consistently increased economic and environmental impacts on urban sustainability and environmental safety. One of the many issues encountered in the environment from mass urbanisation is increased landfills caused by materials from building refurbishments. Reducing landfills reduces carbon emissions to the environment and also encourages innovation and sustainability of the environment. Sustainability is achieved by recycling construction and demolition waste (CDW) materials for alternative concrete production and expansive soil stabilization, by enabling materials to have sufficient inherent mechanical properties to make up for mineralogical and chemical compositions that makes soils and concrete works achieve mechanical strength for sustenance of structures.

Expansive soils are categorized as soils that require re-engineering as a result of deformation caused by swelling and shrinkage. Some categories of expansive soils can be highly plastic and cause premature pavement failures during and after saturation, causing low soil bearing capacity before and after saturation [1]. During moisture variation of a saturated soil the shrinking and swelling of the soil leads to reduction in density and strength of its over laying structures. These phenomena cause shearing and deflections within the soil for the overlying layers of pavements and structures; and accelerates deterioration of structural quality capable of maintaining mechanical strength. The effect of deterioration develops from cracks on surfaces and low soil bearing capacity which causes high cost of construction remediation.

In order to remedy the above mentioned common expansive soil defects, several techniques have been used to achieve mechanical strength. For instance, cement in manageable proportions with other cementitious materials such as ground granulated furnace blast slag (GGBS), lime, fly ash, silica fume and other cementitious

by-product materials have been blended in proportions to re-engineer mechanical strength with reference to natural aggregate [2–4]. As a result of blending additives with soil, strength variations have been developed considering chemical substitutes deprived in soil. Several mix compositions have been developed considering strength variations and swell potentials of various soils as well. However, based on the rate of carbon emissions exposed to the environment by cement during stabilization, researchers have discovered that strength variations of mixed CDW proportions as substitute to cement have revealed properties of compressibility to the nearest standard strength of natural aggregate and cement [5]. Other findings have also shown high cement mortar content adhered to the recycled aggregate formed from various mix proportions of both fine and coarse aggregates [6–11]. Studies have also suggested that replacement of recycled aggregate to natural aggregate achieves comparable or higher mechanical strength in concrete mixture proportions and serves as hard-standing settlement in ground engineering [12,13]. Furthermore, through material gradation, researchers have identified significant reduction of plasticity index and swelling potential of blended expansive soils with cementitious materials with major cement reduction and different CDW residue [11]. Blended CDW observed by several researchers suggests that mechanical stabilization can be achieved in expansive soils by partly substituting graded soil after testing unconfined compressive strength (UCS), to achieve satisfactory well graded soils having UCS of 0.8 MPa for subbase and 1.75 MPa for base applications [6–9].

A few researchers have also explored the viability of portions of sand and cement from CDW smaller than 1.18 mm and suggested that a sufficient quantity of these portions causes the packing density of a soil mass to improve and react in the presence of cement for enhanced mechanical properties [11,14]. Similarly, from the basic reference for the Unified Soil Classification System (USCS) and ASTM D 2487, size of fines was defined as particle sizes dimensions from 0.475 to 0.075 mm.

Furthermore, recycled bricks dust and fine concrete materials are widely used construction and building materials reused in geotechnical activities, they are undoubtedly some of the most voluminous portions from waste streams generated considering the rate of rapid urbanisation and infrastructural developments around the world [13–15]. These materials are therefore considered based on characteristics similar to natural aggregates and concrete in mix proportions. Other materials like gypsum, wood, glass, metals, plastic, solvents, asbestos are separated during the recycling process by means of segregation and mechanical crushing using relatively inexpensive and readily available machines such as the jaw crusher and screener for separation from bulk in

stationary or mobile configurations to obtain useful grading of different particle sizes of fines portions (FP) [16]. These methods reduce waste that would otherwise go to landfill to enhance properties of cementitious materials and effectively replace primary raw materials in cement for soil stabilization [14].

Mixed or blended CDW with percentage reduction in cement as binding material are the most commonly used material for subgrade and subbase pavement construction [17]. Other benefits of the reuse of CDW are the inherent strength, ease in construction and low cost of production beneficial for areas of scarce natural aggregates production. The strength required can be enhanced by combining cementitious by-products to enable CDW to form hard-standing settlement during moisture variation, as well as to achieve reduced carbon emission and use of cement [18].

By the current annual rate of generation of CDW, sustainable and green enough recycled aggregate in new concrete production are classified as alternative building materials, resolving the growing disposal cost for landfills in many countries [10,15]. Furthermore, due to greenhouse gas emissions of waste in landfill and production processes of natural aggregate production, over 40 billion tonnes per year of carbon emissions and over 150 billion metric tonnes natural aggregate production between 2007 and 2014 have been recorded [17–22]. Figures 1 and 2 show the gross domestic product of CDW of the circular economy indicating the economic viability of recycled products in construction as alternative materials, and the rate of CDW reuse in tonnes in the circular economy. Table 1 shows the average waste rate of bricks and concrete materials on site in selected countries.

The objective of this study is to assess the mechanical performance of FP of CDW blended with expansive soils. The physico-mechanical properties of mixed proportion are analyzed by discussing the behaviour of chemical characteristics of FP compared to other cementitious materials to a natural expansive soil. Besides the eco-friendly advantages and economic viability of the use the blended CDW, the binding abilities of good quality crushed aggregate are discussed by criteria of chemical properties, particle sizes and compressive strength. Other inherent properties such as optimum moisture content, liquid limit, plastic limit and swell percent of blended expansive soil are also discussed. This study has been developed from various literature, indicating the effect of recycled CDW compared to natural aggregate and it is presented as sustainable blended material for formation of subbases in construction it has demonstrated good field properties which clearly indicates the gap in knowledge and enables geotechnical engineers to better understanding of the response of blended CDW [23]. This is to be achieved by characterising the effect of the above-mentioned properties by swell potential and particle sizes

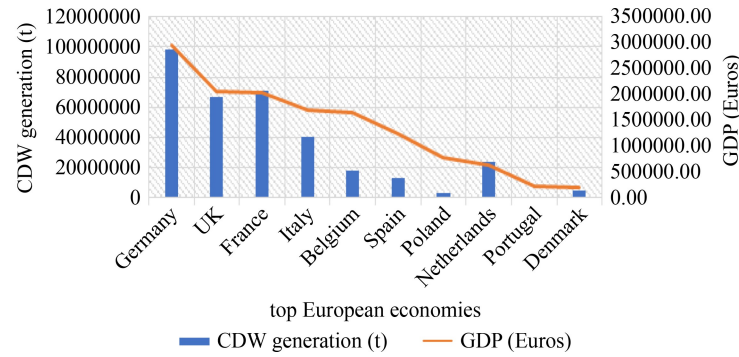


Fig. 1 Gross domestic product of CDW in top European economies.

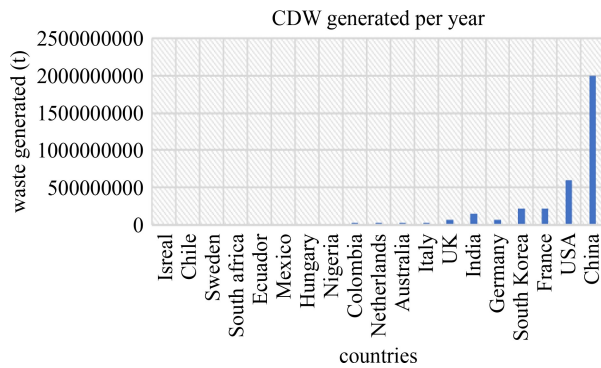


Fig. 2 The reuse of CDW in the circular economy.

Table 1 Average waste rate of bricks and concrete materials on site in selected countries

country	bricks (%)	concrete (%)
USA	3.5	7.5
UK	4.5	2.5
China	2	2.5
South Korea	3	1.5
Brazil	17.5	7

blended with expansive soil [24–26]. In order to understand soil stabilization, cement-based CDW materials are used.

2 Research method

This study presents the characteristics and behaviour of blended CDW with expansive soils. The study focuses on providing geotechnical solutions to expansive soils using blended CDW for base and subbase stabilization. The main objective of this study was to review the physico mechanical and chemical properties of CDW in order to benchmark compressive strength of natural aggregates [27–30]. The review looks into the use of CDW as a means of sustainability to the environment and to encourage use of quality materials in civil engineering, combined to improve strength and stiffness and reduced

swell potentials of expansive soils.

The search method for this study was done by filtering shown of TITLE-ABS-KEY (“construction and demolition waste”) OR (“recycled portions of concrete and bricks) AND (“sand and cement residue of aggregates”). Only journal articles and review papers published in English were considered in this study. Figure 3 shows articles that has 50% to 70% CDW replacement of natural aggregate with the use of mixed CDW proportions as viable mixtures for remediation in various construction purposes.

Table 2 also shows general applications of CDW for ground improvement and other structural applications. These studies conducted on the application of CDW also shows that 9% of studies considered structure serviceability and building, while lower grade applications were 10%. 23% of studies conducted were on construction of pavement layers and 58% of studies were on aggregate replacement and concrete production. Articles were selected based on results from physico-mechanical and chemical properties of CDW. Some articles explored different replacement ratios of natural aggregate with recycled aggregates identified by using consistent semantic meanings combined into a single word representing the same category including “unconfined compressive strength” and “mechanical strength”.

Finally, in order to analyze the physiochemical properties of CDW, recycled CDW obtained from Bristol Quarry were separated using cone and quartering. The segregated CDW were sieved by an electronic sieve shaker for 10 minutes carried out using a standard nest

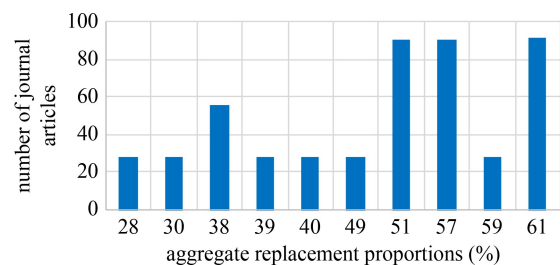


Fig. 3 Replacement ratios of CDW versus journal articles (2019–2022).

Table 2 General knowledge from studies on recycled CDW materials

authors	established prior knowledge	results
Habibzai and Shigeishi [31]	the over-exploitation of natural sand and reuse of waste concrete as a source for aggregates	high-quality fines produced with smaller portions approximately identical to mortar made of virgin sand
Lancellotti et al. [32]	the use of inert materials in debris as in production of bricks and cements	The materials achieved compressive strength and adhesion
Kulisch [33]	the uses of recycled aggregate from concrete waste for base/sub-base infrastructure and structural applications	Crushed concrete waste contains paste/mortar from the original cement mortar which remains attached to the aggregate particles.
Cristelo et al. [34]	the stabilization of the FP of CDW	The presence of cementitious materials improves compression strength and elasticity.
Wu et al. [35]	correcting improper methods of disposal	The bond strength crushed concrete was higher than natural aggregate of reference mortar.
McGinnis et al. [36]	the shortage of raw materials	Replacing portion of natural aggregates with FP achieves proportional strength and stiffness.
Vieira et al. [37]	concrete production and base layers of roadway infrastructures.	Compacted fine-grain recycled CDW exhibit similar shear strength to natural materials.
Sicakova et al. [38]	modification of waste treatment technologies by production of alternative materials	The products prepared using optimized raw materials presented new properties.
Sabai [39]	the recycling of CDW into building materials	85% of the tested concrete specimens from fines achieved compressive strength of 7 N/mm ² .
López Ruiz et al. [40]	reuse and recycling of CDW materials for building refurbishment and construction	promoting new technological solutions of structural and non-structural pre-fabricated elements with high degree of recycled materials from CDW
Saidi et al. [41]	CDW properties measured in the fresh and hardened states	Recycled fines (0/5) had greater mechanical strength compared to mortar.
Alexandridou et al. [42]	a potential alternative for saving natural resources and minimize landfilling	Concrete mixtures containing recycled concrete aggregates had minor deterioration compared to conventional concrete of the same cement quantity.
Alexandridou et al. [43]	recycled materials investigated to supplement natural components of typical building mixes	Long-time water absorption coefficient showed positive effect of fine-grain additives.
Sicakova et al. [44]	the inert portion can be “reused” as a fill material for land reclamation	for recycling low grade recycled aggregates
Kou et al. [45]	a viable way to reuse waste materials to alleviate the demand on public fill capacity	the effects of the use of fine crushed brick and tile aggregate as a replacement of natural sand on the fresh and mechanical properties
Poon and Chan [46]	fast dwindling source of aggregates	compressive and tensile strength of concrete where almost the same as that normal concrete at the 7, 14, 21 and 28 d
Bangwar et al. [47]	the use of recycled fine aggregate made from waste rubble wall to substitute partially for the natural sand for production of cement and sand bricks	The manufacture of bricks containing recycled fine aggregate with good characteristics were similar in physical and mechanical properties to natural aggregate.
Ismail and Yaacob [48]	demolished concrete waste handling and management	The recycled aggregate makes good quality concrete for partial replacement.
Husain and Assas [49]	utilization of recycled waste materials for sustainable consumption and preservation of the environment	Compressive strength of the concrete specimens increased with curing age, clay brick powder and 25% waste glass aggregate.
Olofinnade et al. [50]	relatively low strength in applications	The replacement of fine fraction 0–2 mm in recycled aggregate by natural sand changes to achieve better the properties of recycled concrete.

sieves arranged in descending order of aperture sizes before portions of particle sizes are examined for physico-chemical properties.

3 Results and discussion

Blended FP are known to exhibit mechanical strength in expansive soils as FP closes up pore spaces in the expansive soil after compaction. This technique ensures that blended portions absorb moisture, reduce variation and develop strength and stiffness against deformation of underlying structures [1,32,37]. Similarly, chemical and mineralogical characterization of the main crystalline phases of CDW and soils observed after 3, 7, and 28 d can also be used to determine mechanical strength [50]. Several researchers have also shown that the above-mentioned properties exhibit the best results in terms of

flexural and compressive strength of more concentrated solutions [43–45,50].

3.1 Particle size

Bassani and Tefa [51] observed that CDW adhere well to mixtures with no voids based on high elements of Si, Ca, Mg, and Al, and enhances the composition of the binding phases at optimal mineralogical composition of blended portions of balanced calcium and aluminosilicate phases for strengthening. The aluminosilicate constituents and calcium silicate hydrate (CSH) species inherent in CDW mixtures excites the binder properties required for sustainable improvement of compressive strength. Table 3 presents the effects of inherent oxides in CDW, highlighting chemical properties required for viable replacement of natural aggregates in construction activities. Similarly, an X-ray fluorescence analysis on

CDW by Saiz Martínez et al. [52] showed high silicate content for three types of fines. The calcium and aluminium silicates contents contained higher percentages of Aluminium oxide (Al_2O_3) and Calcium oxide (CaO). These values were also within the ranges found by Angulo et al. [53]. The most unfavourable value of Sulphur trioxide (SO_3) of 3.12% were ceramic fines from CDW, which was also equal to the amount of Sulphur (S) of 1.248%. This value was higher than the limit of 1% established by the UNE-EN 13139:2002 standard “Aggregates for mortar”. High content of this element may provoke gradual loss of mechanical strength and consequently poorer durability in recycled mortar.

Further investigation into the chemical properties of CDW from 3 batches of CDW obtained from UWE Bristol construction site (Batch 1), Bristol quarry (Batch 2) and Batch 3 suggests that SiO_2 as a property also found in cement enhances the compressive strengths and

accelerates hydration process with increasing SiO_2 content. This is major component of a pozzolan that reacts with calcium hydroxide formed from calcium silicate hydration. The rate of the pozzolanic reaction is proportional to the area available for reaction.

In addition, observed result by XRD-EDX (X-ray diffraction and Energy dispersive X-ray) as shown in Fig. 4 shows that contents of SiO_2 behaves not only as a filler to improve microstructure, but also as an activator to promote pozzolanic reaction [57,58]. C4 is the 4th of a set of samples showing Sp1 (spectrum 1), while X8K is the magnification ($\times 8000$) of the image associated with this spectrum.

Properties such as workability, porosity, permeability, strength, degree of compaction and durability of CDW indicate that uniformly graded portions allow greater interaction between particles, compactness and mechanical strength. Particle size distribution of portions

Table 3 Inherent oxides present in CDW

SiO_2	Al_2O_3	CaO	CO_2	Fe_2O_3	MgO	SO_3	K_2O	TiO_2	reference
32.90	6.31	24.80	23.44	4.29	4.93	1.42	1.08	0.43	Bassani et al. [54]
36.51	2.45	32.09	–	1.26	1.05	0.05	0.21	–	Levy and Helene [55]
45.50	10.10	15.70	–	2.44	1.81	3.12	2.31	0.32	Saiz Martínez et al. [52]
63.50	6.57	11.58		1.57	0.61	2.44	2.17	0.17	
67.70	6.48	10.67		1.22	0.54	1.43	2.16	0.15	
8.93	2.85	43.60	–	1.97	0.85	38.30	0.92	–	Patil et al. [56]
15.00	5.72	39.30		3.16	1.02	32.20	1.58		

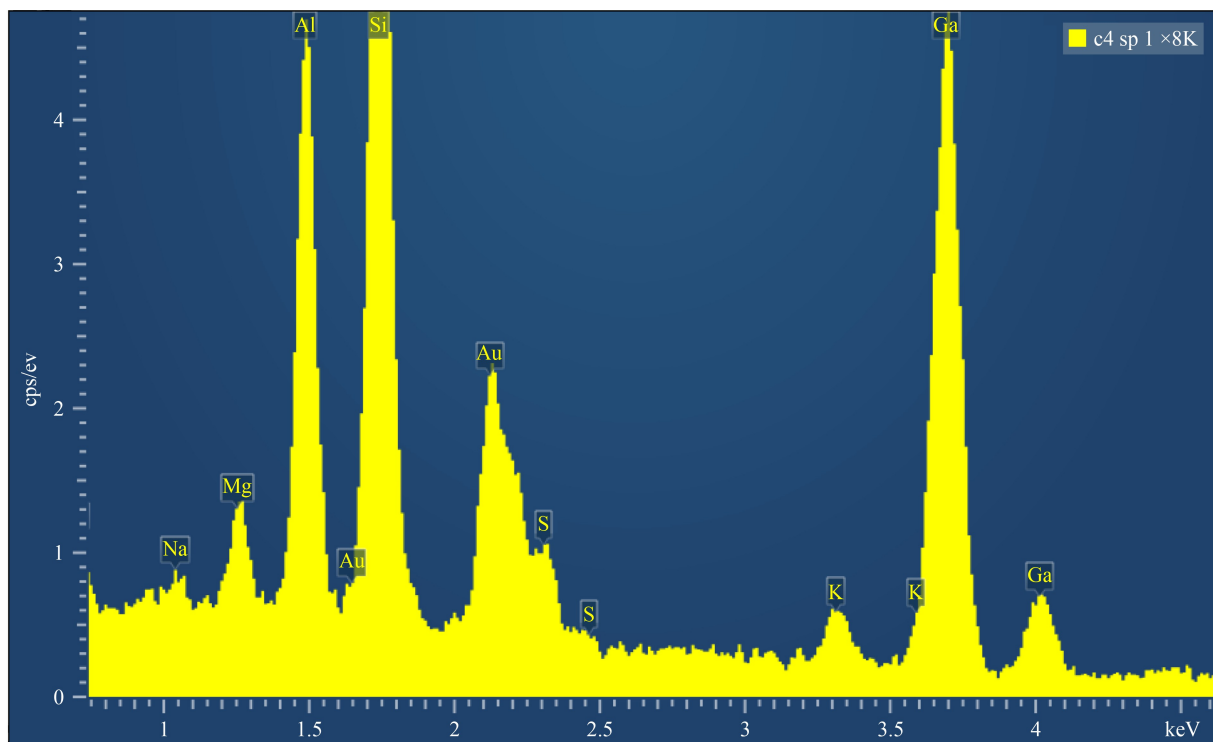


Fig. 4 The effect of SiO_2 in CDW.

the UCS for different proportions submitted in terms of curing periods of 1 and 7 d. The finer fractions less than 0.150 mm presented greater UCS compared to the inherent properties of cement particles after crushing. Some portions exhibited new hydration reactions similar to minerals and chemical compounds found in cement.

3.2 Water absorption

Several researchers have considered water absorption as a major determinant in characterisation of expansive soil and cementitious materials. Wainwright and Cabrera [68] evaluation of water absorption by immersion of blended CDW suggested that damages are more pronounced than natural aggregate. The quality of material sourced also influences porosity of new mixes made of blended materials during moisture variation. Other findings gathered from water absorption tests gathered from various researchers indicate that increases in replacement ratio from 46% fine natural aggregate with fine recycled aggregate compared with reference concrete shows that water absorption varies greatly according to the nature of materials and large occurrences of highly porous materials showed significant increases in water absorption [69].

Crushed brick particles have lesser value of specific gravity (G_s , 1.76) than G_s value of clay grains (2.7), combination of crushed bricks decreases the dry unit weight and water content absorbed by the soil. The density of soil grains with greater water absorption capacity increases based on the quality of recycled crushed concrete combined to the soil for stabilization. This is in order to achieve acceptable levels of compaction dependent on moisture content. The mixture of crushed brick aggregate and expansive soil also reduces the voids filled with air that absorb water and increases the water content of the expansive soil. The addition of a small amount of CDW to an expansive soil also increases the bearing capacity of the soil as a subgrade, which subsequently increases the dry unit weight of the soil especially with mixed crushed concrete paving slab aggregates [70].

Some contents of CDW also possess impurities that influences UCS and self-cementing properties known to adhere to cement paste [30]. At higher moisture content and dry density of an expansive soil, the performance of CDW significantly influence the compressive strength and curing age of the blended FP.

3.3 Compaction

Mechanical compaction is an effective means of increasing strength of materials and stabilising soils. This a method of field control test to ensure that compacted fills meet prescribed design specifications. The design specification determines the water content and for most

engineering properties, strength and resistance to shrinkage. Several authors have suggested that blended crushed brick with other recycled aggregates improves the performance of subbase application [66,67]. These researchers discovered that grading limits of crushed brick compared before and after compaction and CBR (California bearing ratio) of upper and lower bounds were effective pavement subbase material, because density of brick mixtures are independent of curing time and of good compaction behaviour with progressive loss of water [68–70]. A compaction process conducted by da Conceição Leite [71] showed that material composition and compactive effort influences the physical characteristics of blended brick material, contributing to the densification of fine aggregates and improvement of the soil bearing capacity. The result showed that the recycled FP can be utilized as subbase layer for low-volume roads. However, these materials alone between in a range of particle sizes differs in compaction behaviour and therefore vary in porosity, thereby altering the influence of resistance to permanent load with a slight reduction in permanent deformation when materials are compacted at higher energy.

Furthermore, some researchers have stated that compacted mixtures of CDW possess strength in mixtures of blended fine grains for high, medium or low strength replacement [72,73]. The strength of blended fines to reference concrete have also been comparable at 100% replacement, provided the water and cement residue in the CDW is higher [74]. As water–cement ratio reduces, mechanical strength retains about 75% of the reference mix and the optimum moisture content also appears to affect the compressive strength [75]. CDW between ranges of particle sizes differs in compaction behaviour and also shows difference in resistance to permanent load with a slight reduction in permanent deformation. Compacted 100% bricks and concrete fines as subbase materials are considered as minimum strength requirement for most regions and the recorded percentage swells for all subbases are less than 0.13% which can be considered negligible [76].

3.4 Unconfined compressive strength

There is a general trend of reduction of UCS values for CDW. However, the trend also shows that increase fine particles provide more durable arrangement between the grains and voids and encourages higher values of UCS [76,77]. Table 8 shows replacement ratios of CDW for the replacement of cement based on particles reducing the void and increasing the strength. The variation in compressive strength over time were known to cause increase in strength over time. This indicates that fines composed exclusively of waste material showed increased strength, for 28 to 90 d. Figures 5 and 6 also show changes in mechanical and physical properties of

Table 8 Compressive strength properties of blended FP over time

No.	replacement ratio (%)	density (kg/m ³)	compressive strength (MPa)	days of curing	slump (mm)	stiffness (kN/m)	w/c ratio	water absorption (%)	particle size (mm)	reference
1	30, 100	2100	27	1, 2, 28	195	2.69	0.65	10.7	0–6	[81]
2	10, 30, 50, 100	2298	61.65	14, 28, 91	125	–	0.52	7.09	0–4	[82]
3	50	2450	58	7, 28	50-90	18	0.68	8.0	–	[83]
4	10, 50, 100	–	39.5	9, 24, 28	–	–	0.55	13.8	0.5	[84]
5	10, 20, 30	1469.8	54.2	3, 7, 28	–	–	–	–	–	[85]
6	10, 30, 50, 100	2010	37.3	7, 28, 56	120	–	0.55	10.9	0–4	[86]
7	20	–	42.1	28	122	–	–	7.2	0–36	[87]
8	30, 50, 60, 100	–	40	3, 7, 28	8	–	–	0.71	–	[88]
9	30, 100	1913	59.3	7, 28	70	2.38	0.41	13.1	0–38.1	[89]
10	50, 100	1430	–	1, 3, 7, 28	120	2.7	0.46-0.74	–	–	[90]
11	25, 50, 75, 100	2310	–	3, 7, 28, 90	–	3.18	0.53	2.38	–	[91]
12	25, 50, 75, 100	2190	56.5	4, 7, 28, 90	76	2.11	0.53	2.84	0–5	[92]
13	25, 50, 75, 100	1671	30	7, 14, 28	–	3.3	–	–	0–5	[93]
14	20, 50, 100	2338	40	7, 28	170	3.6	0.5	–	0–10	[94]
15	–	2150	31.1	7, 14, 28, 56	–	–	0.4	10	0–10	[95]
16	30, 50, 100	–	45.9	7, 28, 56, 91	140	3.09	0.64	0.76–2.7	5	[96]
17	30	1913	61.3	7, 28, 56	80	2.38	0.45	13.1	0–1	[97]
18	25, 50, 100	2450	–	3, 7, 28	–	–	0.55	1.65	0–20	[98]
19	25, 50	2492	–	4	–	–	–	3.51	0–5	[99]
20	25, 50, 100	2050	51.1	1, 7, 28, 90	190	3.0	0.5	14.75	0–4	[100]
21	–	1356	52.5	7, 28	–	–	0.53	5.5	–	[101]
22	–	2160	–	1, 3, 27, 28	50	3.78	0.65	12.0	0–6	[102]
23	–	2205	35.4	3, 28	90	3.78	0.66	12	0–6	[103]
24	8	2460	60	3, 7, 28	–	17.2	–	–	0–2	[104]

expansive soil as the inherent soil mechanical properties changes in plastic limit and swell potential, as well as changes in liquid limit and optimum moisture content of the mixtures due to inherent moisture variation of expansive soils. Some researchers have not considered the importance of UCS enough for structures on expansive soils irrespective of different moisture variations and swelling potentials [78]. All discrepancies in CDW also show inconsistencies that challenges the prediction of the strength properties of mixtures due to varying swell potentials and swell pressures of the expansive soils using different methods of experimentation [79].

It is important to note that mixture of samples with smaller grain sizes than 0.42 mm confirms Poon et al. [67] observation on the self-cementing property of waste material governed by the fine fractions. Due to the composition of the fraction and reactive phases, high UCS results indicated a fairly significant increase in strength over time. This is indicative of samples of CDW composition having incremental mechanical strength over time [80]. Table 8 presents the physico mechanical properties of various mixture proportions of CDW.

Furthermore, Figs. 5 and 6 present normalised importance charts from Statistical package for social sciences (SPSS) showing the sensitivity analysis of each predictor from existing data generated from stabilised expansive soils. The sensitivity analysis is a computation of the weights of each predictor of the training and testing samples to determine the importance of each predictor for soil stabilization with blended CDW and cementitious by-products. SPSS was used to investigate and benchmark the inherent properties of stabilised expansive soils with blended CDW and cementitious materials by pattern recognition and classification. This method was investigated to bridge the gap between blended expansive soil proportions of CDW and cementitious materials.

3.5 Carbonation

Expansion, cracking and weakening of materials made of concrete are some of the known effect of concrete carbonation [35,41]. These leads to permanent sequestration of CO₂, which directly affect porosity of a mixture. This implies that with CDW mix proportions,

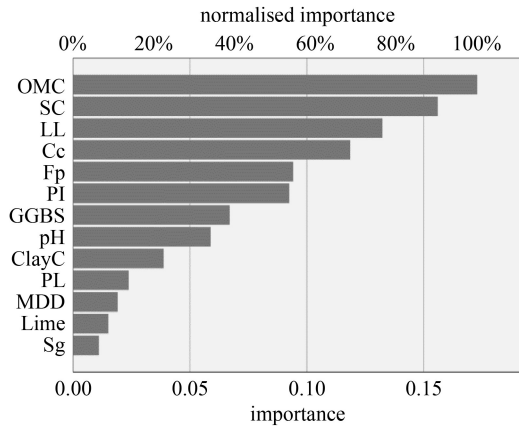


Fig. 5 Normalised importance chart of 2 hidden layers and 10 hidden units of stabilised soil models.

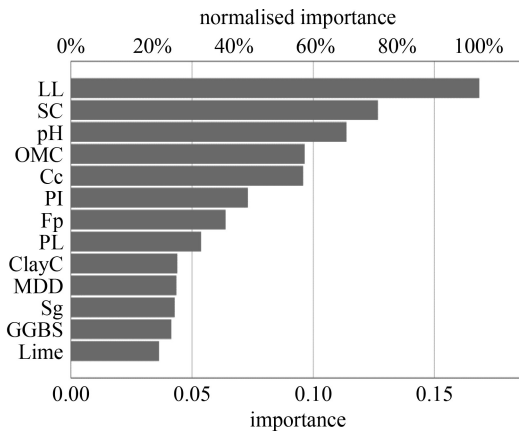


Fig. 6 Normalised importance chart of 1 hidden layer and 10 hidden units of stabilised soil models.

less permeable microstructure has less carbonation [36]. Furthermore, generating changes in pore structure of CDW mix also increases the density of pore structure and the strength of mixture. Similarly, Etxeberria et al. [28] study on the impact of recycled concrete obtained slightly lower carbonation depths than its reference mix after introducing more cement to CDW to achieve standard strength and improved mixture. Corinaldesi and Moriconi [99] discovery using linear relationship between CDW carbonation depth and the square root of time was similar to conventional concrete. This suggested that the use of blended CDW does not cause significant increase in carbonation depth even though the mixture seemed to more porous. In summary, researchers discovered that alkaline reserved within the CDW portions served as barrier to the progression of CO₂ molecules. The carbonation depth measured by Evangelista and de Brito [101] in concrete mixes of 100% CDW was around 110% higher than in an equivalent conventional concrete, while value for mixes with 30% replacement fell to 40%. Zega and di Maio [105] analyzed concrete mixes containing CDW and fly ash cementitious by-product material

showed that the carbonation of the mixes with 0, 20%, and 30% replacement of natural fine aggregate by recycled CDW fines were similar. This was associated with the recycled fines absorbing mixing water, leading to lower water-cement ratios [88,89].

4 Benchmarking the properties of construction and demolition waste

Fractions of significant amount of cementitious by-product of silica and alumina enhances mechanical properties in recycled CDW. This suggests that the cement residue in CDW hydrates and enhances the performance of CDW mixture [105]. Very fine particles react as pozzolanic materials and mineral fillers in mixed proportions achieve mechanical strength viable for road construction materials. Furthermore, components of calcium oxide present in CDW reacts to attribute to the presence of calcium-rich aggregate and residual cement [106]. These contents also possess impurities that influences UCS and self-cementing properties known to adhere to cement paste; as higher moisture content and dry density of an expansive soil extends the performance of recycled portion as well as the water and cement ratio that significantly influence the compressive strength and curing age of the blended FP.

According to Bassani et al. [54], chemical characterisation of FP identifies the crystalline phases and ascertain the presence of aluminosilicates needed for activation of FP, which shows how fine portions react positively in a basic environment, showing increases in mechanical strength. The hardened paste of an undivided fine aggregate exhibits results in terms of compressive strength with more concentrated solution of inherent alkaline additives. Table 9 presents the main chemical combination and physical properties of cementitious additives such as silica fume, having a high content of amorphous SiO₂ and extreme fineness. Elevated CaO gives class C fly ash unique self-hardening characteristics which can densify the cement matrix by filling pores, leading to improvement of mechanical strength. Ground granulated blast furnace slag is a constituent for cement and a mineral admixture for making high performance concrete and possesses high reactivity due to its

Table 9 Main chemical combination and physical properties of cementitious additives [87,84,101,108,109]

chemical analysis	CaO (%)	SiO ₂ (%)	Al ₂ O ₃ (%)	Fe ₂ O ₃ (%)
Portland cement	62.3–62.58	20.25–21.96	4.73–5.31	3.68–4.04
fly ash	2.86–4.24	53.33–56.2	20.17–27.65	6.04–6.69
silica fume	0.45	90.36–92.3	0.71	1.31
GGBS	34.12–40.38	32.35–36.41	10.39–11.36	1.48–0.69
limestone filler	52.9–55.6	0.13–1.84	0.09–1.37	0.24–0.47

ultra-fineness. Limestone filler contains a high degree of calcium carbonate (CaCO_3). Substitution of limestone fillers in concrete has grown due to it is actually cheaper and well-adapted and can present several advantages over ordinary cements. Nano-silica (nano- SiO_2) has attracted considerable scientific interest in concrete technology due to its enhancing effect in workability, strength and durability. Its microstructure is effective for filling up the pores and further promote cement hydration due to the high pozzolanic activity, leading to considerably improvement in mechanical strength.

According to Velay-Lizancos et al. [107], the internal curing effect of recycled concrete and its final compressive strength at different replacement ratios are determined by different curing ages derived from varying recycled material compositions. Expansive soils are also affected by engineering properties derived from widely varying heterogeneity in soil composition based on different micro and macro deposits and physico chemical reactions between the soil and stabilisers.

5 Conclusions

This study analyzed the properties and composition of CDW for use in soil stabilization and has led the authors to propose its use on its based inherent properties and eco-friendly impact to the construction sector. The study also indicates the viability of enhancing expansive soil's inherent properties using CDW for stabilization by benchmarking the physico chemical properties of natural aggregates and cement. This is in order to encourage the recycling of large volumes of CDW blended with cementitious materials. The treatment of expansive soils is analyzed to ensure the long-term equilibrium of the soil and the its reaction to CDW and cementitious by-product materials from different replacement ratios capable of enhancing the physico mechanical properties of expansive soils during moisture variations.

In conclusion, CDW possesses viable recycled additive material properties and has led to the increase in compressive strength of different mix proportions blended with expansive soil. The physico chemical and mechanical properties have also shown increased compressive strength properties and reduced swell potentials for replacement of cement with significant reduction in carbon emission. The physical, chemical and mechanical properties highlighted are suggested as good filler materials for reduced swell potential and increased mechanical strength for subbase construction. The strength of blended CDW and reference concrete are not yet comparable to 100% replacement of cement yet but appears to influence the compressive strength positively. As CDW material between ranges of particle sizes differs in compaction behaviour, bricks and concrete fines

applied in subbase materials have shown reduced swell potentials that can be achieved in subgrade construction with minimum strength for percentage swell.

The strength and stiffness of recycled CDW preceded by laboratory formulations for the assessment of physico-mechanical properties and estimation of their actual service life aims at achieving the long-term performance considering the effect of periodic infiltration of moisture. However, the stiffness of recycled aggregates varies with moisture content, curing age, method of compaction and ratio of cementitious materials combined.

The classification of the inherent properties of mixed recycled aggregates is also traceable to the quality of strength and stiffness expected as a mechanical response to severe dynamic loads. Although these methods have been successful in filling and embankment construction applications for the UCS using recycled aggregate and environmental impacts, expansive soils are also affected by the same engineering properties derived from widely varying heterogeneity in soil composition.

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