Geotechnical Applications of Construction and Demolition Waste and Future Prospects in Bangladesh - A Comprehensive Review

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DECLARATION

We hereby declare that this thesis is our own work and to the best of our knowledge it contains no materials previously published or written by another person, or has been accepted for the award of any other degree at Sylhet Engineering College (SEC) or any other educational institution, except where due acknowledgement is made. We also declare that the intellectual content of this thesis is the product of our own work and any contribution made to the research by others, with whom we have worked at SEC or elsewhere, is explicitly acknowledged.

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ABSTRACT

The rapid generation rate of construction and demolition waste (CDW) due to urbanization and continued development of infrastructure has become a notable hazard to the environment and economy, including a dearth in landfills and a diminution of natural resources. CDW has become the most common type of waste worldwide, and in recent years, it has gained importance in utilizing and reducing its adverse effects. The use of CDW in geotechnical applications is effective as it provides the benefits of the reuse of waste and lessens the use of excessive natural resources. The paper reviews the different properties of CDW, how it performs with soil and different stabilizers, and analyzes the major findings from published papers. Examining the physical and mechanical properties, it was found that they may show slightly lower quality than NA, but meet the standard for geotechnical applications; stabilizing them with different additives and mixing with soil improves their properties, such as swelling, plasticity, consolidation, bearing capacity, etc. In light of this review, it is aimed to propose the possible geotechnical application of CDW, like pavement, foundation, slope stability, embankment, etc., and to enlighten the economic and environmental feasibility in Bangladesh.

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ABBREVIATIONS

BDM	Building Derived Materials
CB	Crushed Brick
CBR	California Bearing Ratio
CBS	Capillary Barrier System
C_C	Compression Index
CD	Consolidated Drained
CDW	Construction & Demolition Waste
CKD	Cement Kiln Dust
CO_2	Carbon Dioxide
CSA	Crushed Stone Aggregate
C_V	Coefficient of Consolidation
DAP	Dragged Asphalt Pieces
DC	Demolition Concrete
DCB	Dual Capillary Barrier
FA	Fly Ash
FEM	Finite Element Method
GGBS	Ground Granulated Blast-furnace Slag
GHG	Greenhouse Gas
HDPE	High-density Polyethylene
ITS	Indirect Tensile Strength
k	Coefficient of Permeability
LAA	Los Angeles Abrasion

LCA	Life Cycle Assessment
LDPE	Low-density Polyethylene
LKD	Lime Kiln Dust
MDD	Maximum Dry Density
MICP	Microbially Induced Calcite Precipitation
MRA	Mixed Recycled Aggregate
MSE	Mechanically Stabilized Earth
MT	Million Tons
NA	Natural Aggregate
NIR	Near-infrared
OMC	Optimum Moisture Content
OPC	Ordinary Portland Cement
PET	Polyethylene Terephthalate
PSD	Particle Size Distribution
R^2	Coefficient of Determination
RAP	Recycled Asphalt Pavement
RBA	Recycled Brick Aggregate
RCA	Recycled Concrete Aggregate
RCM	Recycled Clay Masonry
RCDW	Recycled Construction & Demolition Waste
RHA	Rice Husk Ash
S	Slag
RLT	Repeated Load Triaxial
UCDW	Unselected Construction & Demolition Waste
UCS	Unconfined Compressive Strength

CHAPTER 1
INTRODUCTION

1.1 Background and Motivations

The materials generated from construction and demolition activities, including the creation, renovation, partial and full demolition of structures, expansion projects, road construction, and maintenance work, are collectively referred to as construction and demolition waste (CDW). It consists of inert and non-inert waste, including hazardous and non-hazardous materials [1]. CDW materials consume a significant portion of total solid waste generated in a year worldwide – approximately 35-40% [2]. Because of rapid urbanization, the civic environment, transportation system and infrastructure are expanding and improving to accommodate the demand of the rising population [3]. The expansion of the construction sector, along with the demolition of old structures to give the buildings a new look, results in a considerable amount of CDW generation [4]. More than 10 billion tons of CDW are generated around the world from construction infrastructure and demolition activities annually [5]. In Hong Kong, 38% of total solid waste is generated from construction and demolition activities per year, while the percentages in Australia, the UK and the USA are 42%, 50% and 30%, respectively [6–8]. However, in the European Union, the amount varies between 25% and 34% [9–11]. Developed and industrialized countries are mainly responsible for generating a large amount of CDW compared to developing countries. China produced around 2.3 billion tons of CDW in 2018 [12]. In the same year, the European Union and the USA produced 835 million tons and 600 million tons, respectively [13,14]. Whereas countries of developing economies like Brazil and Istanbul generated much smaller amounts of CDW at 45 million and 14 million tons per year, respectively [1,15–18]. Natural disasters such as floods, earthquakes, and tsunamis also make a significant contribution to the generation of CDW [19–21].

A good waste management system is required to tackle this waste generation. Among the total CDW generation worldwide, 35% of it is sent to landfills [1]**.** This rate is high for both higher and lower CDW-generating countries. In the European Union, the landfilling rate is 29%, 39%, 43% and 47% in France, Sweden, Cyprus and Slovakia, respectively [22,23]. There is also a significant rate of landfilling in Australia, Brazil and the UK at 35%, 40% and 50%, respectively [1,24]. Due to the landfilling of CDW, many adverse effects on society, economy and environment have been noticed, such as loss of biodiversity, land deterioration, contamination of air, water and soil. Dust pollution, emission of carbon dioxide (CO_2) and methane, asbestos and hazardous chemical contaminations are common problems caused by CDW disposal in landfills [25–27]. It is estimated that each ton of CDW disposal emits 200 pounds of equivalent CO_2 [28]. Moreover, a considerable amount of energy, water, air and raw material resources are being consumed from the earth by construction and demolition activities [29,30].

Many countries are still studying to mitigate this waste generation problem by recycling and reusing it in different ways. Globally, only 20-30% of CDW waste is recovered [31]. The average rate of recovery is 46% in the European Union, while the rate varies from 10-90% among its member countries [32,33]. It is estimated that more than 75% CDW has a residual value and are not currently reused or recycled [24]. In Europe, the transportation infrastructure consumes almost 40% of natural aggregate in unbound layers and the rate is 14 tons per year per capita [34,35]. The demand for construction aggregate is increasing daily. In such cases, several studies have already revealed that CDW can be effectively used to replace natural aggregate in many geotechnical applications, fully or partially[36–41].

1.2 State of Play in Bangladesh

For being a developing country, Bangladesh is experiencing rapid urbanization at present. According to worldometer, the urbanization rate has increased to 42.6% and this rate has increased by 22.8% from 2015 to 2025 [42]. This rapid urbanization is leading to a significant rise in the CDW generation rate, which is increasing every year. In fiscal year 2022-23, the amount of CDW was estimated by using a regression model as 2.590 million tons (MT) in Dhaka city, where 0.3 MT and 2.290 MT of CDW were produced from construction and demolition activities, respectively. In the same fiscal year, the mean waste generation rate of twelve city corporations of Bangladesh was found to be 1626.97 kg/m^2 for demolition activities and 64.68 kg/m^2 for construction activities [43]. Considering an 8% average annual growth rate for the construction sector and using a linear projection, another study estimated that this amount will be

1.69 MT by 2030 [44]. Dhaka city has the highest waste generation rate in Bangladesh, but the recycling rate in Dhaka city is only 2% and a significant portion (85-90%) of CDW is simply dumped or used for landfilling because of a weak infrastructure for CDW management plan in Bangladesh [45–47]. As a result, the emission of greenhouse gas (GHG) is increasing, leading to a rise in temperature and a potential risk to long-term sustainable development [48,49]. CDW has become one of the major solid waste streams in Bangladesh and its disposal has become a serious concern in this country. Lack of public awareness, lack of standards and effective practices, weak law enforcement, lack of public sensitization and use of outdated technologies cause a much higher rate of CDW generation in Bangladesh compared to other developing countries [50].

To counteract the vast amount of CDW, a proper CDW waste management plan is required. However, Bangladesh does not have an adequate waste management strategy. On the other hand, the sources of natural aggregates are depleting rapidly in Bangladesh. These aggregates are generally extracted from rivers and hills. Extraction of natural aggregates from these sources causes several environmental effects, such as increasing flood risk, riverbank degradation and reducing biodiversity [51]. Moreover, the demand for natural aggregates is also met by importing them from India, Bhutan, Nepal, Indonesia, and the Middle East. According to the industry insiders, the country currently needs around seven crore tonnes of aggregates per year, worth around Tk 35,000 crore [52]. Several researchers showed that CDW can be effectively used as an alternative for natural aggregates in various geotechnical applications [36,37,39,41,53]. This study explores the prospects of CDW for various geotechnical applications relevant to the context of Bangladesh. While other review papers have focused mainly on the use of CDW in pavement construction, this paper takes a broader approach to include additional geotechnical applications such as backfill material for retaining walls, soil improvement for shallow foundations, embankment, slope stability and parking lot, tailored to the Bangladesh perspective. This review also provides insight into important physical and mechanical properties of CDW, how these properties can be enhanced through various stabilizers and how CDW behaves with different types of soil when blended. By aligning these findings, this review provides insight for implementing CDW-based sustainable solutions in geotechnical engineering infrastructure in Bangladesh.

1.3 Organization of the thesis

Chapter 1: Introduction and Objective. This chapter provides the background and motivations of the research. The overall objective is described in this chapter.

Chapter 2: Literature Review. This chapter reviews the related works of construction and demolition waste (CDW) with a special focus on its geotechnical applications.

Chapter 3: Properties of CDW. This chapter describes the properties of different types of CDW in detail.

Chapter 4: Prospects of CDW in Bangladesh. This chapter describes the potential geotechnical applications of CDW in Bangladesh.

Chapter 5: Conclusions and Future Work. This chapter summarizes the conclusions and major contributions of this study.

CHAPTER 2

Literature Review

2.1 Application of CDW in different geotechnical applications

Several studies have explored the application of Construction and Demolition Waste (CDW) in geotechnical engineering, highlighting its potential as a substitute for natural materials. Research shows that CDW can be effectively used in pavement base/sub-base layers, improving load-bearing capacity and durability. In soil stabilization, CDW enhances compaction, shear strength, and bearing capacity. It has also been applied in embankments, backfills, and erosion control, demonstrating promising mechanical and environmental performance.

2.1.1 Use of CDW as base and subbase layer of Pavement

CDW aggregate can be used as pavement materials, replacing natural aggregate fully or partially. Multiple investigations have focused on distinct properties of CDW and found its feasibility in this pavement application. To be used in pavement layer, strength and stiffness, along with resistance to rutting, cracking, and abrasion, are the most important properties for aggregate. Recycled construction and demolition waste (RCDW), consisting of concrete, brick, natural stone, terrazzo, tile and ceramic, is usable in subbase layers of pavements, although failed to meet the resilient modulus requirement for base courses [54]. Again, Sultana et al. [55] showed that CDW consists of concrete pieces, brick, timber, steel, tiles, etc., and meets standards for base and subbase layer in flexible pavement despite having slightly lower strength than conventional aggregate. Ok et al. [56] found that CDW meets all technical specifications except water absorption to be used as fill materials in highway base/subbase.

It is also found that Construction and demolition wastes are applicable in rigid pavement, since Park et al. [57] compared recycled concrete aggregate (RCA) with crushed stone aggregate (CSA) and gravel, finding that RCA can effectively replace CSA in base and subbase layers of rigid pavement, demonstrating comparable stability, shear resistance, and load-bearing capacity. CDW mainly consists of RCA, crushed brick (CB), and recycled asphalt pavement (RAP). Several studies have been done on the different components of CDW separately. A significant number of studies have been carried out to determine the performance of RCA in the sub-base layer of pavement and concluded that this component shows sufficient strength and stiffness properties to serve this application [58–61]. Arulrajah et al. [58,61] found that RCA exhibited equivalent or superior geotechnical properties and produced significantly lower permanent strain and greater modulus than quarry granular materials in pavement subbase. Moreover, RCA exhibits sufficient physical and shear strength properties suitable for use in this application [62]. It is also suitable for the base layer of pavement if the proper gradation of RCA particles can be maintained [63]. Yaghoubi et al. [64] showed RCA and CB give higher resilient modulus and stress-strain performance than natural aggregate (NA). RCA also showed better fatigue and rutting resistance, which makes it usable in base layers. However, the study found that RAP was unable to show sufficient strength and stiffness properties and is not viable for use as base and subbase materials. In another study, RCA showed high Resilient modulus under low deviatoric stress due to the presence of unhydrated cement, and can perform comparably to a fresh base course [65]. Rahman et al. [66] and Arulrajah et al. [67] investigated the geotechnical and hydraulic characteristics of RCA, RAP and CB to use as filter material in a permeable pavement system. They found that all CDW materials (RCA, RAP, and CB) are suitable for permeable pavement, while RAP showed the highest hydraulic conductivity, making it more feasible for use in road pavement systems, embankment fill, and pipe bedding applications than RCA and CB.

The blends of different CDW materials also give satisfactory performances. Replacing RCA with RAP by 50% decreases the California Bearing Ratio (CBR) and cannot meet the standard for the subbase [68–70]. Nevertheless, a 15% RAP blend with RCA met the requirement for resilient modulus and permanent strain for use in the subbase layer of pavement [71]. Correspondingly, according to Jayakody et al. [72], up to 15% RAP with RCA meets the requirements for base layer for high traffic load and 20% RAP is suitable for the subbase layer of low traffic roads. Fine RCA showed the highest shear strength owing to residual suction, while the Coarse RCA and RAP showed higher shear strength due to higher density and particle size [73]. At a given moisture content, matric suction decreases as the recycled clay masonry (RCM) content increases in RCA [74]. Lower RCM content in RCM-RCA blend shows higher resilient modulus and better shear strength, but is more prone to particle breakage. In contrast, higher RCM content shows less strength while showing better shakedown behavior and less breakage [75]. Up to 25% masonry content can be safely added to RCA, MRA and crushed rock blends in pavement sub-base applications in low traffic volume [76–78]. Nguyen et al. [79] suggested that recycled clay brick (RCB) content should not exceed 30% in RCA-RCB blend, since beyond this content CBR value does not meet the standard. Mixed recycled aggregate (MRA) with ceramic content below 35% is technically feasible for unbound pavement application [80].

Generally, natural aggregate exhibits better performance than CDW materials in terms of resilient modulus, permanent deformation, crushing value, impact value, and water absorption. In contrast, according to some studies, RCA shows higher CBR and permeability value than NA [36,37,53]. Construction and Demolition materials can be mixed with natural aggregate with different percentages to meet the standard for use in pavement. A blend of 50% RCA and 50% NA showed satisfactory performance [36,37]. Although having lower density and toughness than NA, RCA and RAA met the key requirements for the base layer. However, washing and compaction monitoring are recommended [38]. RAP showed the best performance when it was crushed rather than milled, and milled RAP required mixing with a natural aggregate in order to improve its properties [39]. Again, Neves et al. [40] observed that a mixture of 70% NA and 30% milled RAP layer seems to have a similar stiffness to the layer consisting of natural limestone aggregate. 100% RCA exhibited the highest stability with the least permanent strain, while 100% RAP showed the highest permanent strain. A 25% RAP/RCA blend with NA matched the properties of the standard material to be used in pavement bases [41].

Due to the crushing of RCA materials, latent cement/pozzolanic particle activates and a self-cementing reaction occurs, resulting in higher CBR and compressive strength than uncrushed RCA [81]. Because of self-cementing properties, the stiffness of RCM and crushed concrete increases significantly over time [82,83]. However, RCM required a proper assessment before use due to moisture susceptibility and variability in materials [84]. Poon et al. [69] investigated the self-cementing properties of fine RCA on the use of unbound subbase. The result found that the self-cementing properties of fine RCA are mainly caused by unhydrated cement in the adhered mortar, particularly in the <0.15 mm and 0.3–0.6 mm fractions, though the effect is minimal if the size fraction is controlled. Recycled concrete and mixed debris aggregates influence water and frost, though it can be used in unpaved rural roads and road shoulders due to high bearing capacity, durability and increased stiffness over time, with no significant environmental risks [85,86]. Again, secondary crushing causes less post-settlement and promotes a dense structure [87]. Frictional resistance reduces due to the particle crushing caused by repeated loading. Careful consideration must be given to the applicability of these materials in civil engineering applications where the loading conditions are intensive and cyclic in nature [88].

CDW with poor physical and mechanical properties are suitable for low-traffic-volume roads. Delongui et al. [89] investigated the CDW parameters for rational pavement design, whereas shear strength parameters and permanent deformation analysis indicated that CDW can be used for bases and subbases as aggregate for low and medium-traffic-volume roads. Tavira et al. [90] observed that recycled mixed aggregates and mixed recycled soil can replace natural aggregates in low-traffic roads. Despite having lower modulus values, their mechanical performance over seven years showed stability and comparable roughness to natural materials. Recycled CDW also showed sufficient resistance to permanent deformation and mechanical behavior under repeated loading compared to NA. However, NA and CDW blends showed better performance under specific stress and moisture conditions [91].

Gupta et al. [92] conducted a finite element analysis (FEM) to experiment the dynamic stability of highway embankments reinforced with CDW. The result shows that incorporating 10% CDW waste into highway embankment improves seismic stability, with brick mix waste performing the best by reducing displacement and acceleration. Using finite element analysis, Akbas et al. [93] showed that RCA pavement significantly reduces liquefaction-induced settlement in sandy soil.

Road construction using CDW for unbound pavement layers is a reliable practice, with long-term performance showing an increase in stiffness due to self-cementing properties and further compaction induced by traffic over time [94]. Li et al. [95] evaluated the long-term behavior of CDW as a subgrade filler. The result indicated that CDW has a much higher CBR value than the subgrade requirement and exhibits stable creep behavior. It was also found that post-construction settlement is influenced by higher loads and environmental conditions. CDW mixture (brick, concrete and mortar slag) exhibits attenuation creep behavior under saturated and dry conditions [96]. Jiménez et al. [85] tested the utilization of CDW materials in unpaved rural road and found that they perform well in compaction, strength and roughness tests over three years, indicating the suitability of these materials in this application. The life cycle assessment proved the benefit of using CDW as subgrade materials over landfilling.

Several researchers made significant improvements in the properties of CDW by mixing different stabilizers. RAP, RCA, and CB, treated by cement (2-4%), exhibit increased strength and stiffness, while RAP shows the highest strength, making it a convenient material for base/subbase applications [97]. Cement (2.5-4%) treatment of RCA and RMA increases unconfined compressive strength (UCS), indirect tensile strength (ITS), and static elastic modulus with lower masonry content and higher compaction [98]. Also, resilient modulus can be increased by treating recycled CDW with 3% cement, and permanent deformation can be limited to Range A (plastic shakedown) for the subbase under heavy traffic [99]. Puppala et al. [100] demonstrated that untreated RAP showed high deformation, demanding stabilization. In addition, cement kiln dust (CKD) showed higher mechanical behavior on CDW than ordinary portland cement (OPC), and gains resilient modulus quickly within 7 days, similar to the value of 28 days. The resilient modulus increases significantly up to 365 days [101]. However, adding more than 10% CKD did not improve strength and could lead to shrinkage. Preventing moisture loss is critical for achieving optimal strength and durability in both stabilized and unstabilized CDW mixtures [101]. Again, Hormozi et al. [102] Dry density and CBR value increased after adding 12% cement with recycled CDW (0-50 mm), but failed to meet standard compressive strength and CBR limits. Cement has a greater effect on fine recycled aggregate than coarse recycled aggregate in terms of UCS, modulus of elasticity, and durability, suggesting the influence of particle size on treatment efficacy [103]. Field and laboratory studies further validate these findings. RCA treated with 3.5% cement in the pavement section shows comparable performance to NA [104]. The UCS value is greatly influenced by cement content, curing duration, and dry density [105]. Hou et al. [106] found that UCS and resilient modulus increased before 60 days of curing and reduced after 90 days. The thickness of pavement can be reduced by up to 22.7% by increasing the CBR value with the inclusion of 2-6% cement and 10-50% fine CDW to clayey soil [107]. RAP, treated by cement up to 3%, improves impermeability and counteracts CBR reductions caused by higher RAP content [108]. In hydraulically bound mixtures, RCA can be used up to 100% without any adverse effect on mechanical properties, reinforcing the role of cement as a reliable stabilizer [109].

The UCS and resilient modulus increased after adding 3% and 5% lime to RCA and CB when cured at 20°C and 40°C for 7 days, which met the subbase requirements [110]. Lime-treated recycled CDW can be suitable for heavy traffic subbase applications, since it enhances resilient modulus and controls permanent deformation [99]. Arulrajah et al. [111] found that CDW with 20% lime kiln dust (LKD) and 10% fly ash shows the best performance among the blends, improving the resilience and durability under cyclic loading.

Sodium hydroxide and sodium silicate improved the mechanical properties of CDW that had not been sorted, screened, or processed and enabled it to meet the subbase standards for cement-stabilized granular mixture by improving UCS, ITS, resilient modulus, and durability [112]. Mohammadinia et al. [113] found materials-specific response by incorporating low-calcium alkali-activated systems with potassium-based activators into RCA and RAP, concluding that the strength of RCA increases most effectively, while RAP shows a negative impact. Again, RAP can be promising for foundation layers by treating with alkali-activated materials [114]. Washed recycled sand blends with microbially induced calcite precipitation (MICP) show improved UCS and stability [115]. The UCS and resilient modulus of RCA, CB, and RAP also increased by treating with fly ash, slag and a combination of both, which met base/subbase requirements [116]. The resilient behavior of these materials can also be enhanced by treating them with 10% fly ash and slag, while slag performed better than fly ash in strength [117]. With the increase of curing time, the UCS of RCA increases when fly ash and rice husk ash (RHA) geopolymer is used as stabilizers in specific ratios, making lightweight bases favorable for low and high traffic volume roads [118]. RCA mixed with ground granulated blast-furnace slag (GGBS) and fly ash can be used in hydraulically bound mixtures without affecting pavement mechanical properties [109]. Curing at 40°C with 8–16% fly ash enhanced the strength and resilient modulus of RCA, RAP and CB significantly; with higher fly ash content resulting in stronger stabilization due to reactive silica and alumina. Overall, geopolymer stabilization improved strength and reduced deformation of CDW materials [119].

Additives like plastic waste and rubber have been explored to enhance CDW performance. The permanent deformation characteristics can be improved by adding up to 3% polyethylene terephthalate (PET) to RCA and CB for base/subbase use, but further increasing the percentages reduces performance [120]. While adding 5% PET with these materials, friction angles and apparent cohesion increased, meeting pavement standards [121]. This blend also showed satisfactory results for RLT and CBR requirements for subbase applications [122]. By NIR (near-infrared) sorting, the environmental impact reduces like sulphate leaching, and the problematic impurities like gypsum and light autoclaved aerated concrete can be removed, which improves the quality of CDW significantly [123]. Adding crushed glass increases the strength and stiffness, while adding crumb rubber reduces the strength and enhances impact absorption and durability [124]. Moreover, using crumb rubber as a stabilizer with RCA reduced maximum dry density (MDD), resilient modulus, and UCS while increasing stiffness by freezing-thawing cycles due to moisture effects [125].

Recycled CDW (RCA, CB, RAP) with geogrid showed adequate shear strength for typical construction materials, with RCA performing the best. Geogrid reinforcement generally reduced interface shear strength due to poor interlock and testing limitations. Triaxial geogrids outperformed biaxial ones in strength, though unreinforced materials exhibited higher overall interface strength [126]. Geogrid reinforcement of RCA and CB also improves resilient modulus and permanent deformation significantly, while RCA outperforms CB consistently. Both materials show better performance with uniaxial and triaxial geogrid and exhibit satisfactory results, reinforcing the possibility of using geogrid-reinforced CDW materials in pavement applications [127]. Geocell and geogrid improve load distribution, deformation control, durability, stability, and structural lifespan of CDW materials significantly [128]. Thakur et al. [129] evaluated RAP as a suitable material for geocell-reinforced bases over weak subgrade. It shows stable behavior under cyclic loading, an increase in load-carrying capacity, and a reduction of stress on the subgrade.

The addition of construction and demolition waste increases the UCS and CBR values of clayey soil and reduces the swelling index [130,131]. As a result, the improved CBR values reduce the thickness of pavement subgrade [131]. Hidalgo et al. [132] also showed the improvement of strength and stiffness properties of soil with the increase of CDW content, resulting in the reduction of the thickness of the pavement layer. In a pavement subgrade, the waste ceramic tiles improve CBR and compressibility of soil while reducing UCS [133]. Additionally, the permeability and secant modulus of high plasticity clays also increase with the addition of CDW [134]. Moreover, in high-plasticity clay, CDW is effective in terms of stress-strain characteristics, volumetric behavior, peak deviator stress, stiffness, and shear strength parameter [4]. Modified and intermediate compaction energy gives the best performance of the soil-CDW mixture for the base and subbase layer of pavement, respectively, since CDW undergoes significant grain breakage under compaction [135,136]. Cabalar et al. [137] showed RCA and RAP mixed with clay at a specific content can be used as an alternative to subgrade material.

2.1.2 Soil Stabilization and Strengthening with CDW

CDW, such as recycled aggregate (RCA), crushed brick (CB), recycled asphalt pavement (RAP), building-derived materials (BDM), and other demolished debris, has been explored for improving soil properties. A significant amount of research has been conducted to enhance the properties of clayey and expansive soils because of their swelling behavior and low strength using CDW. Saeed et al. [138] and Karkush et al. [139] blended various types of CDW with expansive soil in different proportions and found an optimum (5-15%) range of CDW mixtures that reduces swelling and compressibility of expansive soil, making it an environmentally sound alternative for soil improvement. CB pieces exhibited the lowest swelling values, whereas dragged asphalt pieces showed the highest swelling values across all mix ratios [140]. Studies carried out by Ma et al. [141] and Ali et al. [142] show that optimal replacement levels varying in the range of 15-25% resulted in significant improvements among different components of CDW mixed with clayey soil. Significant improvement was also noticed in the bearing capacity and compaction characteristics of low plasticity clay compared to high plasticity clay when RCA was blended by 20-50% [143,144]. The addition of 22% CDW to clayey soil individually decreases the differential free swell to zero, while CBR, UCS and pH value increased [145]. Moreover, adding recycled CDW to black cotton soil improved the CBR and optimum moisture content (OMC) while reducing MDD, increasing soil stability and strength [146]. Different types of CDW mixed with clayey soil in different percentages (up to 40%) improved the bearing capacity, internal friction angle, shear strength, consolidation and other geotechnical properties of clayey soil [147–150]. Using CDW columns in triangular and square grid patterns in clayey soil effectively reduces plastic limit, liquid limit, settlement and compression while increasing permeability, consolidation and pre-consolidation pressure, which can be a great solution for the soft soil settlement that occurs under shallow foundations [149]. Up to 30% RCA and triangular patterned RCA columns can be effectively used by mixing them in low-height natural hillocks to solve slope failure issues [150].

The use of CDW in sandy soils has been frequently examined, focusing on improvements in shear strength, bearing capacity, and stability. CDW (up to 50%) and cement (up to 8%) mixed with sandy soil in different percentages, increased strength, stiffness, cohesion and bearing capacity [151,152]. Muktinutalapati et al. [153] and Kumar et al. [154] tested BDM and cement-fly ash stabilized RCA by blending with sand and red soil. Test results achieved peak shear strength at 20% BDM and 30% RC-FA, which outperformed red soil due to better interlocking characteristics. Mixing 17-23% BDM in sandy soil increased shear strength and bearing capacity without excessive settlement and improved performance of foundations, but made it vulnerable to acid attacks [155,156]. Adding 15% RCA increased bearing capacity by 684%, MDD and CBR by up to 125% and reduced settlement by 1.5 times the footing diameter, offering a sustainable alternative to natural aggregates. Another study shows that adding alkali-activated (RC and NaOH) brick dust (optimum – 14%) with sandy and silty soil increased the UCS value by 1.76 times [157]. RCA showed higher stiffness and lower settlement under loading than recycled brick aggregates (RBA) when mixed with sandy soil, proving viable for embankment fill without stabilizers [158]. Mkahal et al. [159] mixed CDW with dredged sediments and natural sand, where CDW proved to be the best granular correctors for various waterways dredged sediments, showing suitable mechanical and geotechnical properties, which can also function as design backfill road materials. Sharma and Shrivastava [160] performed different laboratory tests by mixing RCA and RBA with local sandy soil separately in various proportions, which improved the geotechnical properties of sandy soil and met standard requirements for embankment fill, making them a sustainable alternative to natural soil. Some researchers investigated the use of CDW as a whole or partial replacement for natural aggregate.

Furthermore, CDW can effectively replace natural aggregate in geosynthetic encased stone columns, showing comparable load-bearing capacity, stress distribution, and settlement behavior [161]. Soleimanbeigi et al. [162] found the suitability of RCA for mechanically stabilized earth (MSE) wall systems by examining the mechanical and hydraulic characteristics, showing comparable reinforcement capacity. Adding demolition concrete (DC) and CDW debris into natural aggregate (NA) shows an increase of CBR at 10-15% replacement, reduced plasticity and moisture content, making the soil more stable and less compressible [163,164]. Recycled aggregates can also partially or fully (25-100%) replace NA as backfill in RC retaining walls without compromising seismic performance in all seismic zones [165]. Anita et al. [166] suggested that sand-sized and gravel-sized CDW materials are well-suited for use as backfill material in MSE walls. Well-selected and compacted CDW offers sufficient shear strength compared to natural soil in geosynthetic-reinforced structures [167].

2.2 Summary

This chapter provides a comprehensive overview of previous research and studies focused on the application of CDW in geotechnical engineering, which is organized in two main sections such as use of CDW in base/sub-base layers of pavements, stabilization of soil and strengthening with CDW. In these sections, how CDW materials, particularly recycled concrete aggregates and mixed debris have been effectively used as base and sub-base layers in road pavements and soil stabilization were discussed.

CHAPTER 3
Properties of CDW

3.1 Physical Properties

The physical properties of Construction and Demolition Waste (CDW) play a crucial role in determining its suitability for reuse in geotechnical applications.

3.1.1 Particle Size Distribution

The particle size distribution (PSD) of a material determines the mechanical properties like shear strength, permeability, compaction behavior, and structural behavior. Based on the composition, source, and demolition procedure, the particle size of different types of CDW may vary. The PSD requirement differs based on the application. Fig.1 presents the PSD of different types of CDW with varying sizes and the boundaries of capillary barrier materials and backfill materials such as reinforced soil slopes, MSE walls, and retaining walls. This figure illustrates that, to be viable in these applications, the PSD of the CDW aggregate must fall within the range. A well-graded combination of fines, sand, and gravel is suitable, and it is also acceptable for the materials comprising sand and gravel only. The amount of fines should be less than 50%, the sand should exhibit good gradation, while the size of gravel must remain within 20 mm. Arulrajah et al. [61] presented the suitability of CDW materials in subbase application, finding that the PSD of these aggregates before and after compaction falls within the upper and lower limits of PSD for subbase application.

3.1.2 Specific Gravity

The specific gravity of CDW aggregate varies between 1.9 and 2.85 based on their different particle size and materials types, as shown in Table 1. RCA shows higher specific gravity than CB and RAP because of the lightweight of masonry particles and the presence of bitumen content with low density, respectively [66]. Generally, the coarse particles of RCA exhibit a slightly higher specific gravity than the fine particles, primarily due to their higher density and lower organic content [66,127]. In case of natural materials, commonly used in geotechnical and paving applications, the specific gravity ranges between 2.60 and 2.75, allowing CDW to be used in natural aggregate in this aspect [171].

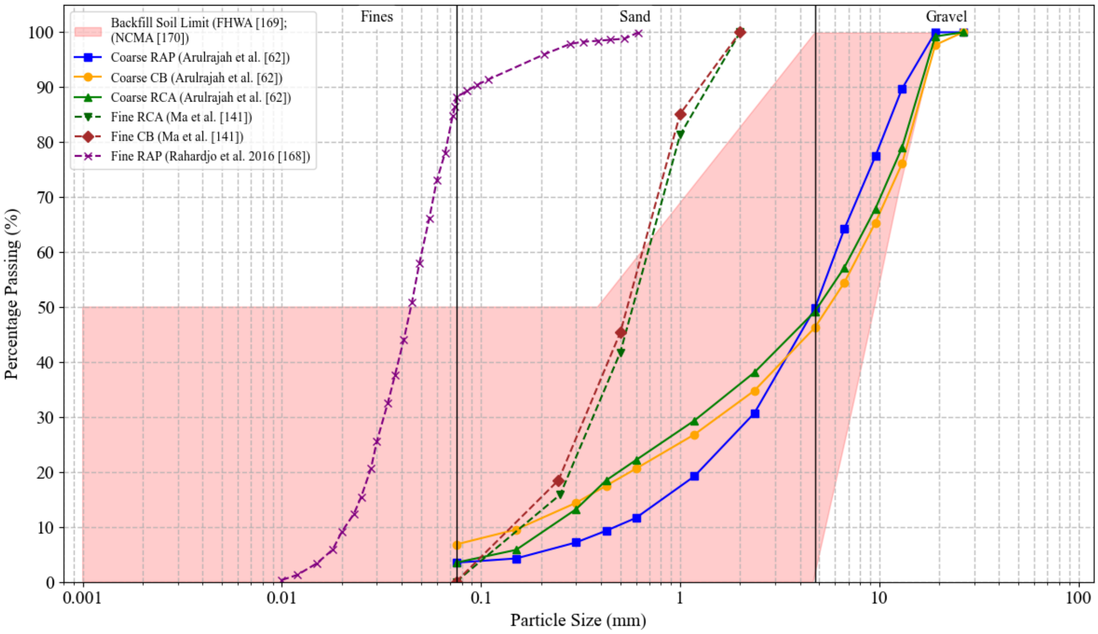

Figure 3-1. Particle size distribution of CDW as a backfill and capillary barrier material [62,141,168–170].

Table 3-1. Physical properties of different types of CDW [34,57,61,77,78,167,172–177].

Properties	RCA	RAP	CB	MRA
Specific Gravity				
Fine	2.4-2.7	2.2-2.4	2.4-2.6	-
Coarse	2.05-2.85	1.9-2.5	2.3-2.5	1.92-2.62
Flakiness index (%)	6-21	5-23	14	5.9-40
Particle density - kN/m^3				
Fine	22.65-26	23.4	20.03-25.8	12.85-25.99
Coarse	24.39-27.1	23.5	18.79-26.2	20.89-27.75
Water absorption (%)				
Fine	6.5-10.3	13.1-14.8	9.5-30.9	4.2-15.2
Coarse	1.43-7.5	11.5-12.7	13-19.5	1.2-12.5
pH	10.2-11.5	7.1-7.3	9.2-9.7	7.8-8.9
Organic content (%)	1.7-2.3	3.3-5.1	1.8-2.5	0.2-0.95

3.1.3 Flakiness index

Flakiness index is measured by the likelihood of breaking down the particles during their service period under the vehicle load and during compaction. The ability of particles to withstand breakage and flaking controls some mechanical properties like load-bearing capacity and stability against permanent deformation[171]. The ranges of different CDW materials are presented in Table 1. CDW materials, such as RCA, CB and RAP, satisfy the limit of flakiness index to use in pavements [61]. The presence of ceramic rubble in the CDW can increase the flakiness index, as Vegas et al. [80] found that ceramic rubble has flat and elongated particles and a flakiness index of around 40. The compaction and crushing stages influenced the flaky behavior of CDW. After modified and intermediate compaction, flat and elongated particles convert into cubic particles [70]. After two or more crushing stages, recycled materials generally result in rounder and less sharp particles, whereas RCA usually shows a higher sharpness and flakiness index than natural aggregate after initial crushing [11].

3.1.4 Particle Density

The particle density of the coarse fraction of the CDW aggregate is slightly higher than that of the fine particles and RCA shows greater density than CB and RAP, as shown in Table 1. However, CDW shows lower density than natural aggregate due to the presence of mortar in the vicinity of the surface of the concrete, which has high pores and low apparent density [178]. Higher density can be achieved by increasing the processing level. The applications where strength and stiffness are required, aggregates with higher density values typically provide better performance [179]. The density of mixed recycled aggregate declines with the increase of the proportion of low-density aggregate, like brick, mortar, etc.

3.1.5 Water absorption

CDW shows greater water absorption than natural aggregate, resulting from the presence of adhered mortar in it, which leads to form cracks and high porosity due to being subjected to degradation in nature [178]. The water absorption of fine and coarse CDW aggregates is presented in Table 1. Fine portion of CDW has a broader specific surface area and absorbs more water than coarse aggregate [61]. The water absorption value for NA is limited to 3% [78]. CDW should be used in such geotechnical applications where water absorption doesn't create any major issues, such as in pavement, parking facilities, embankment protection, etc.

3.1.6 pH

Table 1 presents the range of pH values for different components of CDW materials, demonstrating that the CDW materials are alkaline in nature. Due to the presence of dry mortar pastes and gypsum products on the surface, CDW materials show alkalinity behavior. RCA showed the highest pH value due to the formation of soluble calcium hydroxide during the hydration reaction from the residual cement present in the RCA [71].

3.1.7 Organic content

According to Table 1, the organic content is higher for RAP than for other CDW materials. RAP is rich in carbon due to the presence of bituminous materials [61]. The organic content influences the geotechnical and mechanical properties of an aggregate. The presence of organic content in CDW materials is generally higher than natural aggregates due to the presence of organic impurities adjacent to the surface of CDW materials and the chemical reactions that they have undergone in their lifetime [61].

3.1.8 Swelling

When soil absorbs water or moisture, it tends to expand and puts upward pressure on anything above it. This swelling behavior damages the building foundations, roads, pavements and underground facilities and greatly reduces soil strength and bearing capacity. In this aspect, CDW exhibits effective filler properties in highly expansive soils, which can effectively reduce the swelling potential of expansive soils and increase mechanical strength [181]. Prior studies found that after mixing CDW with clayey soil, the differential free swell decreased (DFS) continuously and attained a zero value at 22-24% CDW proportion [134,145]. This is because the coarser particles of CDW substitute for the finer particles of clayey soil, which leads to a decrease in surface activity. Cabalar et al. [137] showed that blending RCA and dragged asphalt pieces (DAP) with clay by 10-50% reduced the swelling percentage of clay by 0.1-1.1% and suggested using them for road pavement subgrades. Another study found that crushed concrete paving slab (5-20%) outperforms dragged asphalt and crushed brick, which reduced the swelling percentage of clayey soil from 2.5% to 0.58%, while dragged asphalt showed the lowest decrement from 3.01% to 1.32% in swelling percentage because of its high elastic properties [131]. This study also demonstrated the relationship between moisture content and swelling percentage, showing that the swelling percentage decreased with the increase of moisture content.

The swelling behavior of soil also depends on the curing period of the mixture. An optimum mixing percentage of 12% CDW was found in a study after 28 days of curing, which improved the swelling pressure by up to 55% of soil+CDW blends. The swelling pressure dropped below 150 kPa from 330 kPa in 28 days after adding the CDW up to 24% [138]. Another study noted a gradual decrease in the free swell index of treated samples by more than 50% after mixing CDW up to 25% with expansive soil while observing the mixture from 0-60 days of curing period. The samples showed the greatest decrement in swelling pressure after 60 days of curing. The fine sand residue in the mixture might be the main reason for such a decrement in swelling because it obstructs the voids by taking water and reduces the interparticle attraction between clay particles [130].

3.1.9 Hydraulic Conductivity

Pavement layer retains water due to lower hydraulic conductivity (*k*), and pore pressure may be generated under repeated dynamic load, which reduces shear strength and stiffness. Coarse materials with less than 10% fines are generally used to ensure sufficient hydraulic conductivity. CDW shows sufficient hydraulic conductivity to be used as a pavement material. The *k*-value of RCA and RBA can be higher or lower than that of natural aggregate, depending on various factors like gradation, percent of fines, etc. Poorly graded materials show a higher *k*-value due to the higher void ratio and less interlocking between particles [160]. Again, a greater number of fines fills the voids and reduces hydraulic conductivity. Fig.2 illustrates the wide range of variability of *k*-values for CDW materials found in different literature. Bennert and Maher [182] showed that the addition of natural aggregate with a higher *k*-value can significantly increase the permeability of RCA in different mixing proportions. Toka and Olgun [36] explained that the reason for the higher hydraulic conductivity of RCA than NA as the fines portion of RCA is non-plastic and doesn't show swelling behavior. However, Poon et al. [69] showed that the self-cementing properties of fine RCA is the reason due to good quality drainage. Again, RCM bricks showed higher hydraulic conductivity than RCA due to a large pore size and lower density. However, the blend of 55/45%

RCA/RCM exhibited lower hydraulic conductivity than RCA particles [74]. This may be due to producing more fines while compaction, since the fine RCM fills the voids of RCA, which leads to the self-cementing phenomenon [69]. Arulrajah et al. [76] showed that, *k*-value increased in the CB-RCA blend with the increase of RCA in the blend. However, Sharma et al. [183] showed that the inclusion of RCA does not affect the hydraulic conductivity much. Again, RAP material decreases the hydraulic conductivity of the blend because of the presence of impervious bituminous particles and aggregation due to compaction. The asphalt particles may create a bond between particles, resulting in the reduction of hydraulic conductivity [108].

The hydraulic conductivity of soil can be increased by the addition of CDW due to the increase in coarse particles having a higher coefficient of permeability [149]. Abdulnafaa et al. [184] explained that the *k*-value increases due to the increase of granular and non-cohesive materials, which accelerates the flow of water through the soil. However, the addition of CDW into cohesionless soil does not show any significant variation in it.

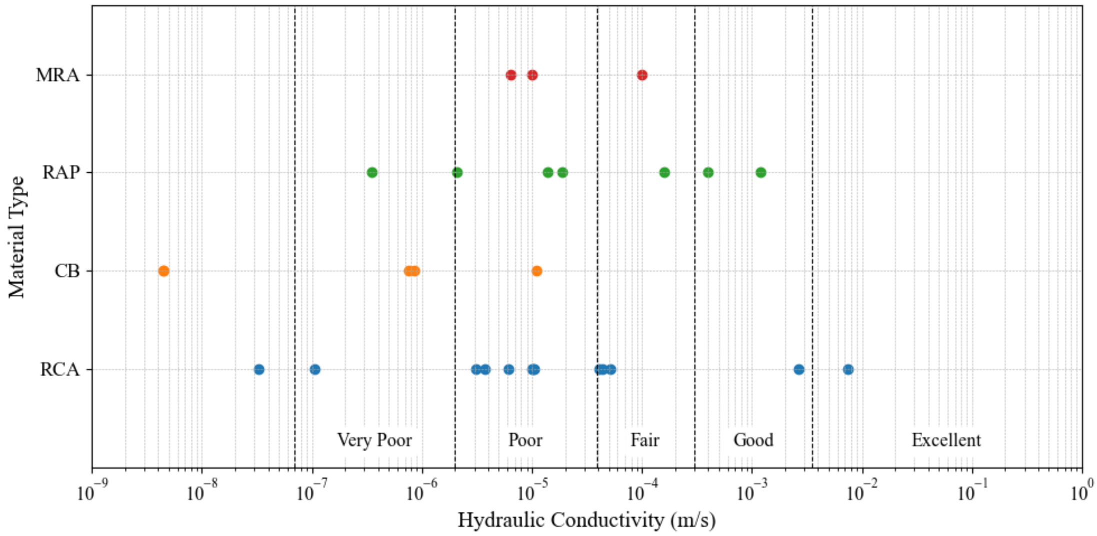

Figure 3-2. Hydraulic conductivity of CDW aggregate and drainage quality according to AASHTO [36,67,69,73,76,108,162,185–191].

3.2 Mechanical Properties

The mechanical properties of CDW like California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), Loss Angeles Abrasion Values (LAA), Shear Strength, Modulus of Elasticity, etc., are vital in assessing its structural performance and durability when used in geotechnical applications.

3.2.1 California Bearing Ratio (CBR)

California bearing ratio is one of the common properties for road pavement design. The thickness of the base, subbase and subgrade layers is determined from the CBR data. Construction and demolition waste shows a sufficient CBR value to be used in pavement. Table 2 shows the CBR values of different components of CDW found from different literature, indicating that the soaked CBR values are always marginally smaller than the unsoaked value. This is because the presence of water reduces the inter-particle bonding, weakens the shear strength and demotes the load-bearing capacity [63,72,108,192]. Among the CDW materials, RCA exhibits the highest value in the CBR test and meets all the standards to be utilized in the base and subbase layer of pavement [36,59,61,63,68,69,72,192–195]. Mixed recycled aggregate gives a lower CBR value than RCA because of lower intrinsic particle strength, since it consists of various components such as brick, mortar, ceramic, etc. [59]. Generally, the CBR value of RCA decreases with the addition of fine clay brick content. This may be because of the poorer interlocking system of clay brick with RCA [78]. Inclusion of RAP in RCA also decreases the CBR value since the bitumen-coated RAP particles have poor interlocking characteristics, lowering the stiffness and load-bearing capacity [72,108]. The curing period also influences the performance of CDW. Jayakody et al. [192] showed that the compacted particles gain maximum friction between interlocking particles within the first 4 days. CDW shows approximately 60% higher CBR value when compacted with modified effort compared to intermediate effort [70].

The CBR value of soil can also be increased by the addition of CDW. Some research showed that CDW increased the CBR value of sandy and silty soil [132,158,160]. A significant increase in the CBR values of black cotton soil with the consequent increase in the proportions of recycled CDW was observed by Sangeetha et al. [146]. Fig.3 illustrates the relation of the increment of CBR value with the addition of CDW at various percentages in expansive soil. The percentage increment of CBR is linear up to 30% CDW addition; beyond that, the CBR value increases drastically. By the addition of cement, fly ash and lime with RCA, the CBR value of clayey soil increases to a great extent [135,196,197]. The polyurethane content increases the CBR value of CDW by squeezing continuously. It also creates bonding with the adjacent particles during manufacturing, which increases the particle rearrangement significantly [198].

Seferoğlu et al. [108] showed that RAP with 0- 3% cement increases CBR value from 30% to 138%.

Table 3-2. CBR values of CDW aggregate at soaked and unsoaked conditions with different compaction efforts.

Materials	CBR (%)				Reference
	Standard		Modified		
	Unsoaked	Soaked	Unsoaked	Soaked	
RCA	-	-	-	97 - 138	[59]
MD	-	-	-	62 - 94	
RCA	81	75	-	-	[192]
RCA+CB+RAP	58-77	47-76	-	-	
UCDW	-	-	-	60.1-159.9	[199]
RCA	101-176	92-159	-	-	[72]
RAC + RAP	82-170	75-145	-	-	
MRA	-	-	75.97–136.87	47.78-100.31	[200]
RCA	-	-	-	118-160	[61]
CB	-	-	-	123-138	
WR	-	-	-	121-204	
RAP	-	-	-	30-35	
RCDW	-	-	-	117	[70]
MRA	-	-	-	12.4-197.5	[80]
RCA	-	-	-	172	[187]
CB	-	-	-	135	
RAP	-	-	-	39	
RCA	-	-	-	118	[71]
RAP	-	-	-	30-35	
RCA+RAP	-	-	-	39-66	

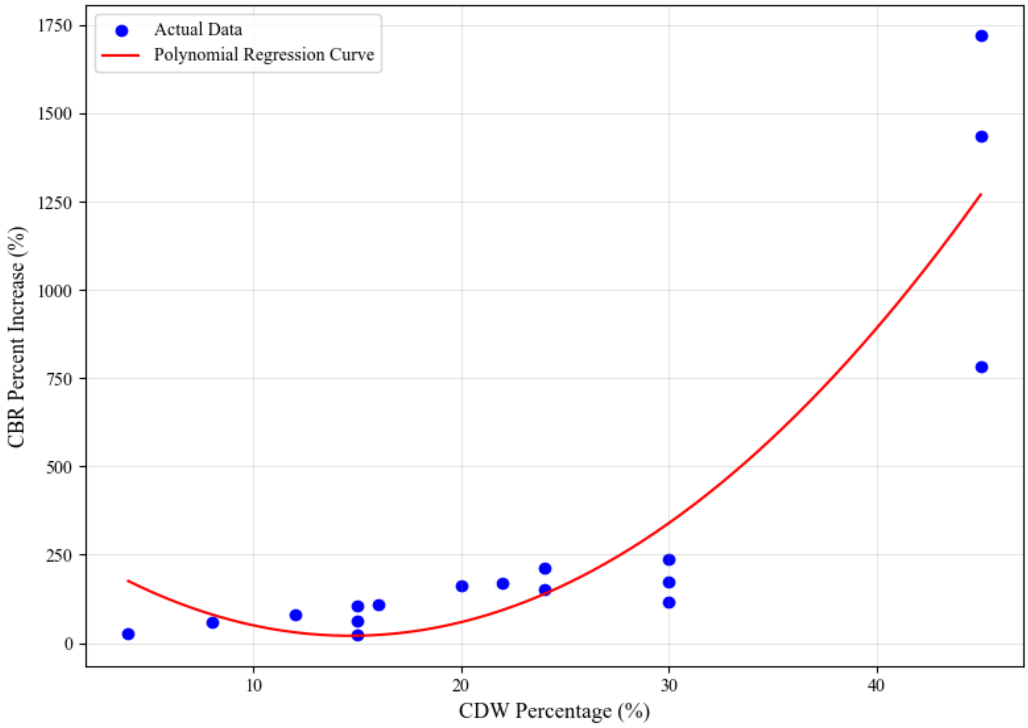

Figure 3-3. Percent increase of CBR value of expansive soil with various CDW content [134,141,145,196].

3.2.2 Unconfined Compression Strength (UCS)

The unconfined compressive strength (UCS) is used as a vital parameter in geotechnical design at unconfined conditions. Generally, RCA exhibits higher compressive strength than other CB, RAP, and MRA [62,84]. In contrast, Mohammadinia et al. [97,113] found that RAP showed greater UCS than RCA due to asphalt bonding. Jayakody et al. [72] mixed RAP in RCA up to 20% and demonstrated that the UCS value decreases as the percentage of RAP increases. This is due to the decrease in residual cement content of RCA with the increase of RAP. The strength of CDW materials significantly increases with various additives. Table 3 presents the effect of different stabilizers on CDW aggregates in various curing days. Cement, lime, fly ash-slag geopolymer enhances the compressive strength of CDW aggregates substantially with increased curing periods. As shown in Table 3, Cementitious-treated CDW materials provide satisfactory performance, which meets the VicRoads (2013) [201] standards of 4 MPa to serve as base/subbase materials. Curing periods have a great impact on the value of UCS since the aggregate creates strong bonding through the hydration process that increases over time. However, the rate of gaining strength reduces with time [97]. The addition of cement leads to a higher increment of UCS due to the increased inter-particle bonding [97]. However, the UCS value reduces with the addition of PET, LDPE, and HDPE plastic. These additive materials have lower surface roughness, which causes a decrease in the UCS of the CDW aggregate [202,203]. Mohammadinia et al. found the optimum range for using fly ash in CB and RAP as 15 – 20%, and further increase of fly ash content reduces the UCS value [204].

Incorporating CDW into the soil enhances the UCS, especially in applications for subgrade and subbase. An optimum range of 22 – 24% mixed CDW exhibits the highest improvement in the UCS value of clayey soil [134,145,147]. A similar finding was observed by Cabalar et al. [137], incorporating RCA into clayey soil. This author explained that the reason for such strength development is the pozzolanic reaction between soil and CDW and the self-cementing properties of CDW.

Table 3-3. UCS values of different types of non-treated and treated CDW.

CDW Materials	Curing period (Days)	UCS (MPa)	References
RCA	1, 7, 28	0.5	[97]
RCA + cement (2-4%)		1.4 – 4.1	
CB		0.3	
CB + cement (2-4%)		1.5 – 4	
RAP		1.1	
RAP + cement (2-4%)		2.75 – 5.4	
MRA	0, 7, 28, 365	0.2 – 1.9	[101]
MRA + CKD (10-20%)		1.6 – 7.2	
MRA + cement (2-4%)		1.4 – 5.3	
MRA	7	0.42	[99]
MRA + Cement (3%)		4.6	
MRA + Lime (3%)		3.6	
RCA	3, 7, 14, 28	0.55	[113]
RCA + FA		0.9 – 2.2	
RCA + S		2.0 – 5.2	
RCA + FA + S		1.5 – 4.0	
CB		0.34	
CB + FA		0.45 – 1.0	
CB + S		0.55 – 2.0	
CB + FA + S		0.5 – 1.4	
RAP		0.73	
RAP + FA		0.6 – 0.95	
RAP + S		1.2 – 3.0	
RAP + FA + S		1.0 – 2.05	
RCA	-	0.44	[203]
RCA + LDPE plastics (3-5%)		0.22 – 0.25	
RCA + HDPE plastics (3-5%)		0.26 – 0.3	
RCA	7, 28	3.8 – 4.48	[202]
RCA + PET (3-5%) + cement (3%)		1.2 – 2.14	
CB		4.7 – 5.49	
CB + PET (3-5%) + cement (3%)		1.3 – 3.13	

3.2.3 Compaction behavior

The rearranging and repacking of the particles of aggregates reduces the voids in the geomaterial due to compaction. As a result, some engineering properties like shear strength, internal friction and water drainage improves [171]. However, compaction also leads to particle breakage and crushing, increasing fine percentages. CDW produces more fines than NA since the material with lower crushing strength tends to undergo more particle breakage. Compacting by impact produces more fines, whereas standard and modified efforts in compaction tests don’t show significant differences. In contrast, compacting by vibration increases less fine percentage and the effect of vibration is almost similar for all types of aggregate [11]. Degree of compaction has the most significant impact on the mechanical behavior of recycled unbound aggregate [205]. Leite et al. [70] also discussed the impact of the degree of compaction and CDW composition on their mechanical behavior. The research concluded that particle size decreased as the compaction energy increased. Fig.4 shows the average OMC and MDD values of CDW materials and natural aggregate. Natural aggregates exhibit higher MDD values and lower OMC values than all types of CDW materials. Among the CDW materials, RAP shows a lower OMC value, while the MDD values are almost similar for all CDW materials. Cardoso et al. [11] found similar behavior, concluding that the MDD values are generally higher for natural aggregate than for various CDW aggregates. The researcher also found that, RCA and MRA show higher OMC than natural aggregate, while RAP shows lower OMC due to water absorption properties.

The OMC of soil decreases with the increase of CDW content in soil since CDW absorbs less water than soil because of its non-plastic behavior. On the other hand, MDD increases because of having a greater particle density than the soil [149,184].

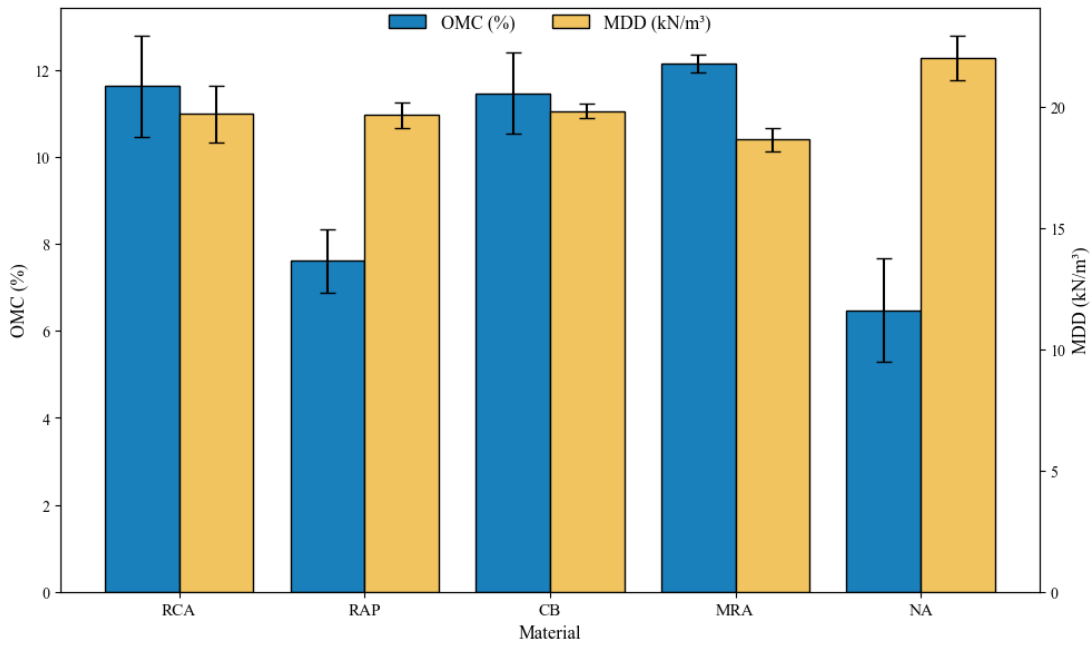

Figure 3-4. Comparison of OMC and MDD values of different CDW materials [11,54,57,60–62,66,76,97,99,110,112,131,193,195,199,206].

3.2.4 Los Angels Abrasion (LAA)

The Los Angeles Abrasion (LAA) is an indicator of the abrasion and toughness characteristics of aggregate, which is measured by the ability to withstand mechanical degradation caused by impact, abrasion, and wear [56]. CDW must meet the LAA value within the standard limit to be used in pavement infrastructure. Generally, CDW materials have less resistance to abrasion than NA. According to Ok et al. [56], the LAA loss is 44% higher than that of virgin aggregate. This is due to the chemical reactions, crushing, and recycling processes of CDW materials that materials have experienced [56,127]. Fig.4 illustrates the dispersion of LAA values of different CDW materials. The figure indicates that RCA shows the least LAA value among the CDW materials, while RAP possesses the highest, which makes it the most vulnerable material against abrasion. Again, MRA shows significant variation in the LAA values due to the presence of different CDW materials in various proportions. However, the LAA value of RAP does not differ much among various studies, except for Mohammadinia et al. [116], who found the LAA value of RAP to be 20.81%. Diagne et al. [200] and Barbudo et al. [84] presented the resistance of mixed CDW against abrasion and found that the resistance decreases with the increase of CB content in RCA, and the value of all mixes is higher compared to natural aggregate. Again, Jiménez et al. [59] found the correlation between LAA loss and concluded that the greater the mean particle size of RCA, the higher the LAA value. Again, de Juan and Gutiérrez [201] found the relationship between LAA value and attached mortar, assuming that all mortar presented in CDW becomes powdered.

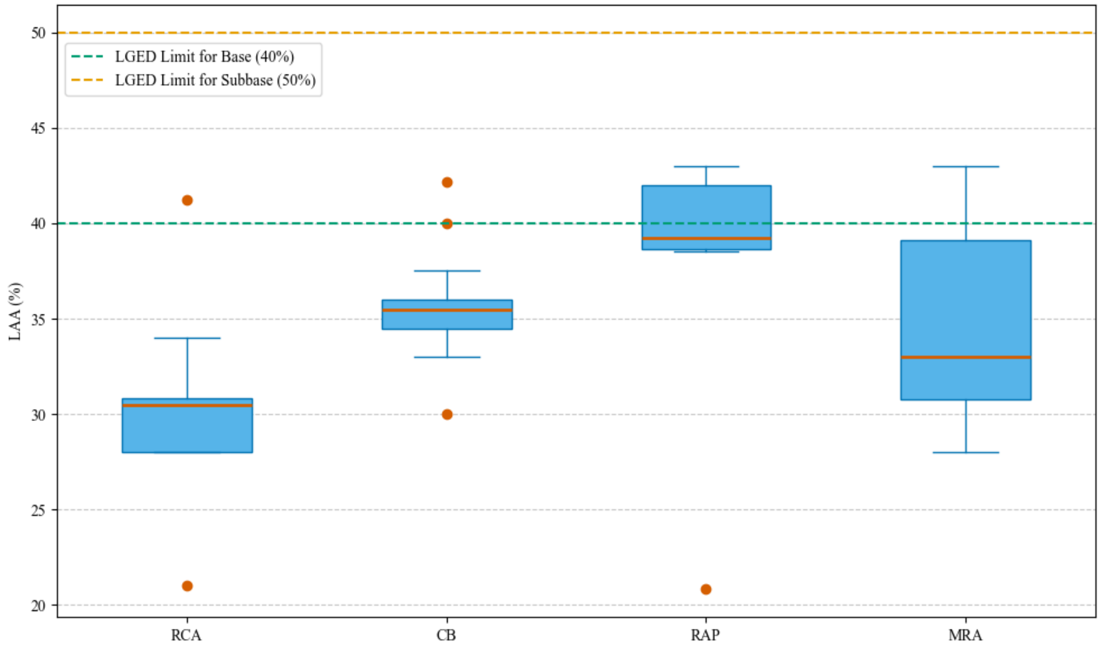

Figure 3-5. Dispersion of LAA value of CDW aggregate [60, 61,67,74,89,91,97,99,116,122,126,127,155,165,180,183,185,187,199,200,206,209].

3.2.5 Shear strength properties

In assessing the stability of geotechnical infrastructure, shear strength is the most important unsaturated parameter since slope stability, lateral earth pressures, bearing capacity, etc., are dependent on the shear strength [210]. Pereira and Vieira [34] presented the range of cohesion and angle of friction for various CDW materials found in different literature. Arulrajah et al. [62] conducted direct shear tests and consolidated drained (CD) triaxial tests and presented the apparent cohesion and friction angle in critical and peak states for various CDW materials. The cohesion value ranges from 0 to 284 kPa while the friction angle ranges from 39° to 56°. For the direct shear test, the apparent cohesion at the peak states is significantly higher than that of the critical state, while the difference for the friction angle is small. For the CD triaxial test, it is obvious that the effective cohesions are zero for both peak and critical state. However, in the saturated state, it is consistent for cohesionless materials. Arulrajah et al. [60] tested the CD triaxial test on CB-crushed rock (CR) and CB-RCA blend of various proportions and found no clear trend in the variation of cohesion and angle of friction. This may be due to the non-homogeneous nature of the CDW aggregate.

Jayatheja et al. [211] improved the shear strength properties of cohesionless soil by replacing the soil with 20% building-derived materials (BDM), with an increase of angle of friction from 28.10 to 40. The cohesion and friction angle of sandy soil can be increased significantly by the addition of cement and CDW [151]. On the other hand, with the mixing of CDW with clayey soil, cohesion decreases, and the angle of friction increases [4,149,212]. In contrast, Kianimehr et al. [213] found the increase of both cohesion and angle of friction with the addition of CDW with clayey soil.

3.2.6 Repeated load triaxial test

Particle size distribution, composition of aggregate, stress state, matric suction, and moisture content have a significant role in the value of modulus of resilience [214]. The resilient modulus of the CDW aggregate can be lower or higher than NA. Lower resilient modulus of CDW can be attributed to the lower elastic modulus, adhered residual coatings, presence of microcracks, and weak interfacial transition zone [178]. Higher resilient modulus may be found due to the higher interlocking properties from particle shape and enhanced gradation through processing. Resilient modulus has a positive correlation with moisture content [209,214,215]. Gupta et al. [214] found the relation of resilient modulus with moisture content in a certain confining pressure and deviatoric stress for various combinations of RAP, RCA and NA. Among them, 100% CDW mixture showed the highest resilient modulus. The internal friction of RAP is large in high confining stress, resulting in a lesser effect of deviatoric stress in high confining stress on the resilient modulus and a significant increase in resilient modulus observed at 50-75% RAP content in blends [100,216]. Again, Bennert et al. [41] investigated that 100% RAP showed the highest permanent strain, while 100% RCA showed the lowest. This may be attributed to the breakage of the asphalt binder under high loading in the permanent strain test. Again, resilient modulus decreases with increased masonry content in the CDW mixture [74,215]. Matric suction also has a great influence on the resilient modulus [209,214]. Masonry particle reduces matric suction, resulting in a decrease of the Resilient modulus [74]. Permanent deformation can be reduced from 10 % to 20% with higher compaction effort [70].

Various models are used to estimate the resilient modulus and its dependency on various factors. These models can effectively capture the non-linear stress-dependent behavior under varying field conditions. These models incorporate key stress variables such as confining stress and bulk stress, which allows to predict the resilient modulus more accurately. Table 4 presents the value of model parameter constants of the Bulk stress model and Three-parameter model for different CDW materials, and the changes of these values before and after treatment with various stabilizers such as cement, lime, fly ash, slag geopolymer, and after reinforcing with biaxial and triaxial geogrid. This indicates that these hydraulic binders provide stiffness and reduce the effect of stress. The shear resistance of RCA and RAP increases after adding these stabilizers, while a decline in this property is shown for CB after the addition of fly ash and slag geopolymer, as shown in Table 4. After reinforcement with biaxial and triaxial geogrid, stiffness and shear strength increased. Rahman et al. [127] and Arulrajah et al. [126] found that geogrid-reinforced CDW materials showed lower permanent deformation compared to unreinforced materials. The authors concluded that triaxial geogrid showed better performance than biaxial in terms of both resilient modulus and permanent deformation. Again, the resilient modulus increases and permanent deformation reduces over time with the addition of 3% cement and 3% lime, which indicates the gain of stiffness [99]. Mohammadinia et al. [110] also found that the resilient modulus was enhanced with the addition of lime and the effect was more in RCA than RAP.

Table 3-4. Resilient modulus model parameters (Bulk and Three-Parameter Models) for various Treated CDW materials.

Model	Materials	k_1	k_2	k_3	R^2	Reference
Bulk-stress model	RCDW– 7 days	502.3	0.664	-	0.98	[99]
	RCDW– 28 days	540.8	0.596	-	0.97	
	RCDW– 60 days	660.5	0.593	-	0.99	
	RCDW + lime- 7 days	2731.4	0.517	-	0.99	
	RCDW + lime– 28 days	3845.3	0.338	-	0.98	
	RCDW + lime– 60 days	4406.7	0.343	-	0.99	
	RCDW + cement– 7 days	3032.1	0.484	-	0.97	
	RCDW + cement– 28 days	4763.8	0.318	-	0.99	
	RCDW + cement– 60 days	4948.0	0.264	-	0.98	
Three-parameter model	CB	2290.87	0.22	0.27	0.97	[116]
	CB + 4% FA	2754.23	0.14	0.20	0.80	
	CB + 4% S	3467.37	0.22	0.21	0.96	
	RCA	5011.87	0.30	0.14	0.98	
	RCA + 4% FA	5248.07	0.05	0.34	0.98	
	RCA + 4% S	9120.11	0.21	0.31	0.98	
	RAP	10233.96	0.30	0.10	0.98	
	RAP + 4% FA	11484.93	0.25	0.14	0.94	
	RAP + 4% S	12022.64	0.19	0.20	0.96	
Three-parameter model	RCA	0.81	0.69	0.12	0.98	[127]
	RCA + biaxial	0.96	0.73	0.14	0.99	
	RCA + triaxial	1.10	0.70	0.15	0.99	
	CB	0.75	0.35	0.08	0.99	
	CB + biaxial	0.88	0.37	0.10	0.98	
	CB + triaxial	1.04	0.38	0.10	0.99	

*Note: k_1, k_2, and k_3 are model parameter constants representing the stiffness magnitude, stress dependency, and stress hardening, respectively

3.2.7 Consolidation

Consolidation is one of the core properties because it denotes the settlement, coefficient of permeability (*k*) and pre-consolidation pressure of saturated soil. Coefficient of consolidation (c_v) and the compression index (*Cc*) are the two main parameters determined from consolidation test results. Islam et al. [149] reported that mixing CDW with clayey soil by up to 40% can greatly improve the consolidation property of clayey soil, which is depicted in Fig.7. The gradual decrease of *Cc* and increase of c_v in the mixed samples means that the compressibility and consolidation settlement have decreased due to the presence of CDW, improving the resistance to load of clayey soil [134,217]. Due to this improvement, excess pore water dissipates faster and quickens settlement, making CDW a viable stabilizer for building foundations, embankments and pavement subgrades.

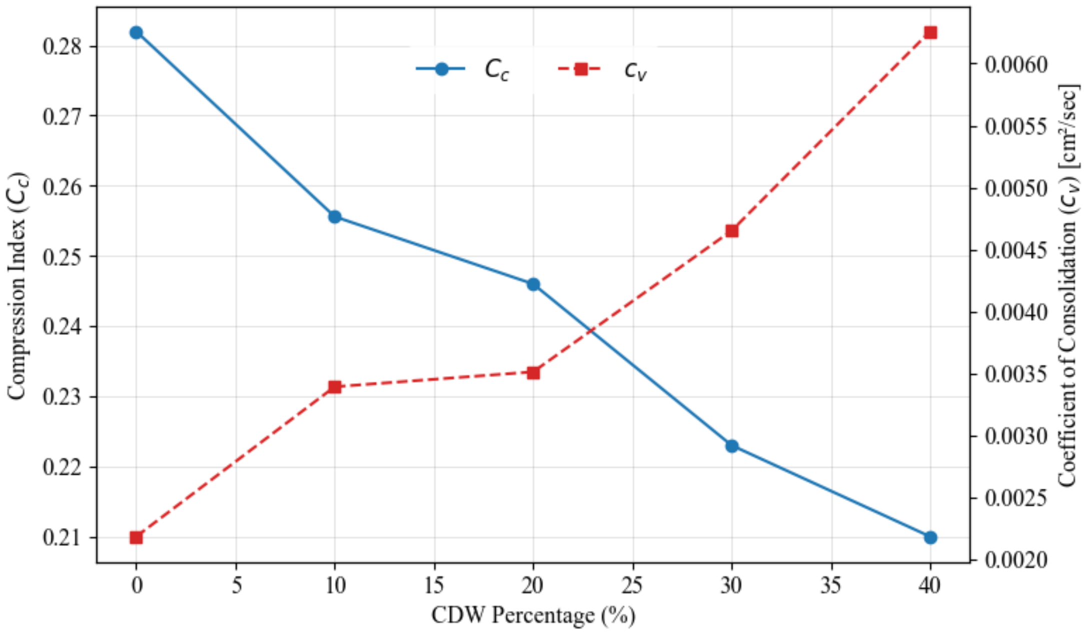

Figure 3-6. Variation of *Cc* and c_v with the variation of CDW content [149].

3.3 Summary

This chapter focused on the physical and mechanical properties of CDW and evaluated how these characteristics influence its potential use in geotechnical engineering. It highlights key physical properties like particle size, density, and water absorption, as well as mechanical properties such as compressive strength, abrasion resistance, and bearing capacity. These properties influence how CDW behaves when used in sub-base layers, soil stabilization, and backfilling. With proper processing, CDW can provide adequate strength and durability, making it a sustainable alternative to natural materials in geotechnical engineering.

CHAPTER 4

Prospects of CDW in Bangladesh

4.1 Potential Applications of CDW

Bangladesh, like many developing countries, is experiencing rapid urban growth, infrastructure expansion, and increased construction activities—leading to a significant rise in Construction and Demolition Waste (CDW). Despite its volume, much of this waste remains underutilized, often disposed of without proper recycling or reuse. However, CDW holds great potential as an alternative material in various construction and geotechnical applications. This section explores how CDW can be effectively used in Bangladesh to reduce environmental impact, lower construction costs, and promote sustainable development in the built environment.

4.1.1 Pavement:

According to LGED 2025 [218]Bangladesh's total road network spans roughly 411,137.03 km, of which 249,814.67 km is unpaved and 161,322.35 km is paved as of February 2025. For light-traffic rural roads in Bangladesh, crushed brick, stone and gravel are mainly used on a granular sub-base. As for national highways, bituminous bound bases and cement stabilization are common. For subgrade material, natural in-situ soils and sand/granular fill are mainly used [219]. Bangladesh is currently facing a scarcity of materials used for base, sub-base, and subgrade layers for road construction. Such materials are mainly imported from India, Bhutan, Nepal, Indonesia, and the Middle East [52]. Such materials are mainly imported from Southeast Asia, South Asia, and the Middle East. All these materials are costly and environmentally harmful. The most up-to-date data shows that about Tk 3,218 crore/yr is spent for base/sub-base construction & reconstruction and Tk 6,261 crore/yr is spent for surface maintenance (periodic + routine) in the year 2023-24 [220]. On the other hand, rapid urbanization and infrastructure development are increasing CDW generation while depleting the natural resources in this country. In this aspect, using CDW as base, sub-base and subgrade material to replace natural aggregates will greatly impact the economy and environment of Bangladesh in a positive way.

Numerous studies indicated that CDW materials (RAP, RCA, and CB) have high potential for use in pavement base and subbase layers, either directly or mixed with stabilizers. CDW exhibits sufficient strength and stiffness properties to function as a construction material in roads [4,54,60–62,67,76,90,95,132,221]. Again, CDW materials, treated with stabilizers such as cement, lime, and fly ash, exhibit improved UCS, CBR, and resilient modulus to serve this application [97–100,102–105,109,110,118,190,197,222]. Silva et al. [223] presented various case studies of pavement projects around the world using CDW materials, including subbase layers at Lisbon International Airport in Portugal, a 140-meter-long base course for a test road in Singapore and the use of cement-treated mixed recycled aggregates in road construction in Spain. Such applications may lead to a reduction of pavement thickness and construction costs in Bangladesh, where durable pavements are needed to support growing traffic loads. Again, urban flooding is one of the most pressing matters in most of the cities in Bangladesh, especially in Dhaka. This problem can be mitigated to some extent by using permeable pavements in low-traffic load areas. Research suggests that CDW such as RCA and CB are suitable alternatives for permeable pavement subbase, while the performance of RAP needs more research [66,206,224].

4.1.2 Shallow Foundation:

Shallow foundations are widely used for medium to low-rise buildings, lightweight infrastructure, etc., in rural and semi-urban areas of Bangladesh for their ease of construction and cost effectiveness. Generally, Bangladesh consists of various types of soil, which vary from place to place [225]. The majority of the soil in the sub-surface of Dhaka city is soft soil, which is prone to excessive settlement and exhibits low bearing capacity [226]. Various ground improvement techniques are used to overcome this issue. One of the effective techniques is mixing various types of admixtures into soil in different mixing ratios. Incorporating fine-grained CDW improves the geotechnical properties of weak soil under shallow foundation by increasing permeability, CBR, UCS and undrained shear strength, and decreasing consolidation settlement, swelling potential, compressibility [139,149]. Moreover, sand column and stone column are also being used to improve the bearing capacity and reduce the settlement issue of soil, but such natural aggregates are expensive [227,228]. With the depletion of natural resources and the limitation of sand mining in Bangladesh, a vast amount of sand is imported from other countries, resulting in an increase in the unit price. Islam et al. [149] investigated the suitability of using powder CDW column in square and triangular grid patterns in soil and found that it can be used as a replacement for sand column, reducing the overall use of sand in Bangladesh.

Sandy soils are also present in many areas of Bangladesh, like Dhaka, Manikgonj, Gazipur, Narayangonj, Norshindhi, etc [225]. This type of soil shows low cohesion and shear strength and is susceptible to liquefaction. Poorly graded sand mixed with building-derived materials can enhance the load-bearing capacity of soil without excessive settlement and can be used in the foundation bed of the substructure [155]. Sandy soil treated with alkali-activated CDW shows higher UCS, stiffness, durability and load bearing capacity and less deformation [151]. The bearing capacity of loose sand under circular footing can be increased up to 4.96 times, and the settlement can be decreased up to 5.03 times, providing different CDW layers with various relative densities [229].

Despite having promising potential, using CDW in soil to construct shallow foundations in Bangladesh is still unexplored since there is no well-published implementation in field trials. Further research and pilot projects are required to utilize these wastes as resources.

4.1.3 Slope Stability:

Eight out of 64 districts in Bangladesh were exposed to landslide episodes and five were recognized as profoundly affected, with Chittagong Hill Tracts being the hot spot area during monsoon seasons. Since 2000, landslides have resulted in over 700 deaths and over 1000 injuries in the southeast part of Bangladesh. A single landslide in 2017 in Rangamati district alone cost USD 223 million, damaging 40,000 houses and affecting infrastructures like roads, telecommunication systems, and agricultural fields [230–234].

Blending up to 30% cement-fly ash stabilized RCA with soil meets shear strength requirements for slopes, which can be a beneficial use of CDW to reduce the landslide risks of such hilly areas [154]. Even without any stabilizer, RCA can be used up to 30% by inserting RCA columns in hillock soils of Bangladesh hill tracts, which increases permeability significantly and reduces compression index, cohesion and consolidation settlement, mitigating the landslide occurrences during heavy rainfall [150]. This type of unique solution can be applied to stabilize the slopes along riverbanks and control river erosion in Bangladesh. Moreover, CDW can also be used as cover material in a capillary barrier system (CBS). In a few studies, CDW has been employed as a cover material for shallow slope stabilization, which minimizes rainwater infiltration and reduces the probability of rainfall-induced slope failure [168,235–238].

4.1.4 Riverbank Erosion:

Bangladesh is a land of rivers, with more than 700 rivers, their tributaries, and distributaries, forming a network of river systems throughout the country. Riverbank erosion is a significant issue in this country where the major rivers like Padma (The Ganges), Jamuna and Meghna erode several thousand hectares of floodplain, making a great portion of people landless and homeless every year. Along with the 2400 kilometers of bank line, there are 283 locations, 85 towns and growth centers that are vulnerable to erosion [239]. Due to heavy rainfall in the monsoon period and flooding issues, rivers get eroded. Water percolates to the soil of the bank and increases pore water pressure, decreasing shear strength and resulting in the erosion of the bank of the river. The probability of slope failure that is induced by rainfall can be minimized by using the Capillary Barrier System (CBS) [237]. Using capillary barrier on the bank of the river can be effective to protect the riverbank by minimizing water infiltration. This reduces pore pressure and keeps the soil near the surface drier and stronger during rainfall. Generally, natural aggregates like sand, gravel are used in the two-layer capillary barrier systems. However, several researchers found the effectiveness of using CDW as an alternative to natural aggregates in CBS. Dual Capillary Barrier (DCB) made with fine and coarse CDW reduces rainwater infiltration [168]. Laboratory tests and finite element seepage analyses demonstrated that the DCB effectively minimizes rainwater infiltration, thereby reducing leachate generation and maintaining slope stability during rainfall events [168]. Furthermore, stone riprap can also be used as one of the riverbank protection methods. CDW materials, especially RCA and CB, possess high durability and resistance to weathering. Moreover, the angular shape of these materials enhances their interlocking properties, which provides greater stability and resistance to displacement under the forces of flowing water, making CDW an ideal alternative to natural materials in riprap. Bangladesh generates more than enough CDW that can be used in this application. Using these waste materials to protect the riverbanks can be a sustainable solution.

4.1.5 Embankment Stability:

Embankments are used to protect roads, railways, and residential areas from flooding and soil erosion. Since Bangladesh is known as the “Land of Rivers,” and it has a low-lying geography, embankment construction has become a major priority because of frequent flooding and the need for elevated roads and railways (e.g., Padma Bridge Rail Link). Embankments are typically built using natural resources like sand, clay, and crushed stone. Because of the increasing demand for construction material, along with the rising cost, there has been a scarcity of high-quality natural aggregates, which generates a challenge for sustainable embankment construction. Transporting these materials to remote or rural areas further increased the cost and logistical issues. That is why scientists observe the exploration of alternative materials such as CDW, which can provide cost-effective and environmentally friendly solutions to these problems.

The coefficient of permeability, angle of friction, and cohesion are important factors for embankment stability [224]. CDW materials, such as RCA, RBA, and their blend, etc. have the potential to improve the stability of earthen structures like embankments [240]. They offer several geotechnical advantages and give satisfactory performances, including adequate permeability, improvements in shear strength properties, compaction characteristics, etc. [183]. RCA and RBA blended with sandy soil as fill materials in embankment enhance compaction and strength characteristics, making them suitable for this application [160]. CDW is also effective in expansive soil since crushed CDW increases embankment stability by improving the stress-strain characteristics and volumetric behavior remarkably [4]. Recycled CDW shows higher resilient moduli and lower permanent deformation compared to the clay soil, which demonstrates the improved rutting damage and structural capacity in highway embankment [241]. Again, a common cause of failure of embankments is the build-up of pore water pressure. The permeability of materials, like RCA, crushed brick, allows for better water flow through the embankment, mitigating this problem [183].

Bangladesh is situated in a seismically active zone; the embankments of this country must withstand dynamic loading and have long-term structural stability. Moreover, highway embankment often faces dynamic loads like vibration or weaving from vehicles or trains [224]. Gupta et al. [92] investigated stability and the dynamic response of highway embankment incorporating CDW by the finite element method

(FEM), and found that brick mix enhances the stability and seismic performance. Using a reasonable proportion of CDW shows stable creep behavior and reduces deformation, indicating the long-term performance in highway embankments.

4.1.6 Parking Lot:

The demand for parking spaces in urban areas of Bangladesh, particularly divisional cities like Dhaka, Chittagong, Sylhet, etc., is increasing, which has placed appreciable pressure on the construction industry to provide suitable infrastructure for vehicle storage. Those areas could benefit from CDW-based permeable pavements. Parking areas are prone to water accumulation that leads to erosion and poor drainage systems. CDW offers improved drainage properties, as materials like RCA have good permeability and porosity, allowing water to pass through them easily. RCA and CB mixtures show high hydraulic conductivity, which can reduce surface runoff and mitigate urban flooding, making them suitable for permeable pavement systems [66]. This can also result in creating low-cost permeable parking surfaces and accommodating heavy vehicles.

Urban areas often face parking shortages because of the soft, waterlogged soils. For unbound base layers, the strength and stiffness properties of soft soils can be enhanced by using CDW, making it ideal for parking lots [67,132]. For the long-term performance of a parking surface, treating CDW with cement or lime is effective as it enhances the durability for high-traffic areas near commercial hubs or markets [110].

4.2 Economic and Environmental Sustainability of CDW

4.2.1 Economic:

In Bangladesh, increasing construction activities and rapid urbanization have resulted in the generation of a significant amount of construction and demolition waste. These wastes have good recycling potential throughout the world. Many developed countries are benefiting economically by recycling these wastes, with a good recycling rate [24]. However, Bangladesh has a lower recycling rate compared to the other countries [242]. By recycling these large amounts of waste, the economic sector of a country can benefit in many ways.

Recycled concrete aggregate, recycled crushed brick and recycled mortar aggregate, the major components of construction and demolition waste, have good recycling potential and can be used as an alternative to natural aggregate in many applications. Concrete and brick have a recycling potential of 75% each and mortar has a recycling potential of 5% [43]. According to the market price of virgin construction materials and recycled materials, approximately 30-50% profit can be made if the CDW is sourced properly [43,48]. Based on the waste generation rate and recycling potential of Bangladesh, Haque et al. [44] measured the potential economic benefit that can be gained from CDW in Dhaka city in a fiscal year. Considering the expansion of the construction and demolition activities, by 2025, 32,245 BDT and 11,666 BDT can be benefited by using concrete waste as aggregate, and the amount will be 47,379 BDT and 17,142 BDT by 2030. By recycling brick aggregate, a total amount of 66,510 BDT can be benefited by 2025 [44].

Another study shows that Savar has the highest economic potential among the eight districts of the Greater Dhaka region, which is estimated to reach 2319.54 million USD for demolition and 1287.71 million USD for construction by 2030 [243]. There are a lot of rural roads that are yet to be paved and recycled brick can be used in this application. In fiscal year 2016-2017, a budget of approximately 58.80 million USD was issued for rural road construction [244]. According to the economic output of recycled bricks in Dhaka city, a potential to save 13.96% of this budget was estimated [242].

The more CDW is recycled, the demand of natural aggregate will be less. Recycling CDW can contribute significantly to the economic sector by reducing the consumption of natural aggregates.

4.2.2 Environmental:

The environmental sustainability of construction and demolition waste (CDW) in Bangladesh is a major concern due to rapid urbanization and a booming construction infrastructure. The CDW management in this country is heavily dependent on landfilling and illegal dumping [45,46], which leads to significant environmental effects. Soil is being contaminated by CDW due to the presence of alkaline matter in it. The disposal of CDW is worsening the air quality and heat waves by directly affecting the phenomena of global warming and increasing energy consumption for transportation [245]. Depletion of natural resources is one of the most urgent environmental concerns in Bangladesh. As a result, river sands and crushed stones are extensively mined and transported at a high ecological cost. Uncontrolled and unplanned sand mining leads to riverbank erosion, destruction of habitats, and changes in geomorphology in many parts of the country. Sustainable practices like reusing and recycling CDW offer substantial benefits by reducing the demand for virgin materials, reducing energy consumption, and alleviating landfill pressures, leading to the release of significant pressure on the natural ecosystem. Primary energy consumption for virgin materials is 35% higher than for recycled materials [246]. By recycling CDW, the accumulated energy of waste materials can be saved, as it is the driving force behind reducing emissions [247]. Moreover, Coelho and De brito [246] investigated that, CO_2 emission rate is 16% higher for virgin raw materials compared to recycled materials. Burciaga et al. [248] showed that natural aggregate generates more CO_2 due to the fuel consumption required for transforming construction materials, and by replacing 68% of it with CDW, CO_2 emissions can be reduced by 53%. Bangladesh is facing droughts, deforestation, and extreme weather events due to the negative effects of global climate change [242].

The environmental benefit of reusing CDW also extends to reducing greenhouse gas (GHG) emissions. A life cycle assessment (LCA) approach indicates that CDW recycling, compared to virgin material production, can reduce GHG emissions by 40–60%, depending on the application and distance of transport [248].

4.3 Potential Challenges and Barriers in Bangladesh:

To execute the suggested applications of construction and demolition waste (CDW) in Bangladesh successfully, it is important to recycle it in a controlled and systematic way. Hasan et al. [249] identified that the four main barriers hindering efficient CDW management are ‘Poor supervision’, ‘Negligence and carefree attitude of workers’, ‘Lack of space for onsite storage’, and ‘Inadequate workers’ skills’. Due to the heterogeneous nature of CDW, its different components—such as concrete, bricks and mortar must be segregated and sorted properly before reuse. Engineering behaviors of these waste materials are significantly reliant on the particle composition, size, source, etc. For example, grading size of the aggregate greatly influences its permeability, strength, compaction and other geotechnical characteristics, which are crucial for various applications, indicating the importance of quality control. Therefore, proper processing should be ensured before use. However, there are no dedicated CDW recycling facilities in Bangladesh that are capable of making quality-controlled materials broadly. Landfilling, illegal dumping and unauthorized placing are the main methods of regulating CDW [45,46]. Only 2% of CDW's are recycled through unregulated recyclers and local scrap dealers, which are not ideal for use in geotechnical infrastructure [242]. Bangladesh also lacks of comprehensive regulatory framework and standardized guidelines for CDW management and reuse. Authorities like RAJUK, LGED, or PWD have no clear policies or codes about the collection, processing or reusing method of CDW in geotechnical works. The Government of Bangladesh does not have specific policies and regulations for using CDW, particularly. However, Bangladesh has created some policies like "National 3R Strategy for Waste Management", aimed at promoting waste recycling, resource recovery, and resource conservation [250]. Moreover, there is a significant knowledge gap pertaining to the potential application of CDW in engineering due to the extremely limited research on the reuse of CDW. Most professionals and stakeholders are not aware of recycling and how to utilize it effectively. Consequently, the utilization of CDW remains unaddressed, despite its great potential to be reused.

To contribute to the sustainable development and resource efficiency in this country by using CDW, a national regulatory and policy must be formed to provide technical guidance for engineers that defines the standards to use these recycled materials in these potential applications. Recycled plant and facilities should also be formed to get a consistent supply of well-sorted and quality-controlled CDW-based aggregates. Research work on the reuse and utilization of CDW at the university level should be encouraged. Additionally, training programs and seminars can be arranged in this matter.

4.4 Summary

This chapter highlighted the potential use of Construction and Demolition Waste (CDW) in various geotechnical applications across Bangladesh. It discussed how CDW can be used in pavements, shallow foundations, embankments, parking lots, and riverbank erosion control. These applications show that CDW can serve as a sustainable and cost-effective alternative to natural materials. Proper utilization of CDW can help reduce environmental impact and support resource-efficient construction in the country.

CHAPTER 5
Conclusion

5.1 Conclusions

This study aimed to review the geotechnical properties of CDW, the enhancement of properties after mixing with different stabilizers, and the influence of CDW on soil in the context of Bangladesh. Additionally, this study explored the prospects in the geotechnical field of the country, where rapid urbanization, growing construction materials demand, and waste generation pose serious challenges. The use of Construction and demolition waste in place of typical construction materials in different geotechnical applications gives a sustainable solution for the increasing amount of waste material, coupled with the scarcity of natural aggregates. The reuse of CDW also offers environmental and economic benefits by reducing carbon dioxide and GHG emissions, lowering construction costs, and supporting sustainability goals.

The properties of CDW are influenced by various factors such as source, type, and manufacturing processes of these materials. CDW is mainly made of concrete, masonry, asphalt pavement, and other impurities. The presence of impurities and unwanted materials largely affects the strength of CDW. Other factors like particle size distribution, pH, specific gravity, water absorption, and amount of organic content also play an important role in influencing the strength and stiffness properties of CDW. RCA exhibits the best result among the CDW materials compared to NA, overall. CB and RAP can also be used with RCA and NA when blended. However, the percentage of CB and RAP should be controlled in mixed CDW to maintain standard performance. Some studies showed that CDW materials do not meet the standard in all aspects. Standard laboratory tests are recommended to evaluate the properties of these materials before using them. Nevertheless, their performance can be enhanced through mixing them with various stabilizers such as cement, lime, fly ash, etc., at different ratios. These stabilizer increases the strength, stiffness, and durability properties of CDW significantly to make CDW materials suitable for different geotechnical applications such as pavement construction, backfill material, etc.

Again, the several properties of soil, such as consolidation properties, shear strength, load-bearing capacity, hydraulic conductivity, swelling properties, etc., can be improved by mixing fine CDW in a certain content. The enhancement of these properties makes it possible to construct shallow foundations on weak soil. CDW also shows sufficient drainage facilities and reinforcement to replace traditional sand and stone columns in soft soil improvement. Moreover, CDW materials can be used as a capillary barrier system to prevent water percolation in riverbank, embankment, etc. Beyond this, the use of CDW in geosynthetic-reinforced structures such as retaining walls, embankments, and reinforced soil beds offers sufficient load distribution and settlement behavior.

Overall, this review concludes that CDW has great feasibility to be used in different geotechnical applications in Bangladesh, such as rural and low-volume road construction, soil improvement for shallow foundation, slope stabilization, controlling riverbank erosion, parking lot development, etc. Appropriate processing and application of these materials can make the transition of a country towards more resilient geotechnical infrastructure.

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