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Soil Stabilization Using Construction Demolition Waste: A State of the Art

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A B S T R A C T

Recycling waste materials is a functional approach to reduce the stockpiles of refuse materials while offering significant economic and environmental benefits. Nowadays, construction and demolition waste (CDW) produces large amount of waste throughout the year and competes as a viable reused additive material in place of natural material. Adding these materials into soil grains can improve the geotechnical characteristic of problematic soils, and reduce environmental pollution. Numerous studies are being established for setting up and optimize the potential of reusing construction wastes. Current paper displays some of state-of-the-art studies undertaken on the application of CDW in soil stabilization field as a tool to evaluate the expected influences resulting from the use of substitutional materials. The purpose of the work is to evaluate the improvement degree for resistance factors of mixture soil such as California bearing ratio (CBR). The results collected from the literature show that, the recycle of construction waste (CW) constitutes an essential step towards a more sustainable society by decreasing the environmental impact from poor disposal of this material worldwide. In order to deal with this issue seriously, some recommendations are presented to encourage sustainable waste management solutions such as reuse and recycling. Finally, recycling construction waste from structures that have been torn down as a sub-base material will help reach social, economic, and environmental sustainability.

أحدث التقنيات في تثبيت التربة باستخدام مخلفات البناء والهدم

مريم جابر جمال الشريف منال سالم على

إن إعادة تدوير النفايات هو نهج وظيفى لتقليل مخزوناتها مع تقديم فوائد اقتصادية وبيئية كبيرة، في الوقت الحاضر تنتج مخلفات البناء والهدم (CDW) كمية كبيرة من النفايات على مدار العام وتتنافس كمواد مضافة قابلة لإعادة الاستخدام عوضاً عن المواد الطبيعية، إن إضافة هذه المواد إلى حبيبات التربة بإمكانه تحسين الخصائص الجيوتقنية للتربة التى تعاني من مشاكل كما يقلل من التلوث البيئى، العديد من الدراسات أجريت لإعداد وتحسين امكانية إعادة استخدام مخلفات البناء، الورقة الحالية تعرض بعض الدراسات الحديثة التى أجريت حول تطبيق CDW في مجال تثبيت التربة كأداة لتقييم التأثيرات المتوقعة و الناتجة عن استخدام المواد البديلة، الغرض من العمل يكمن في تقييم درجة التحسن لعوامل مقاومة التربة المختلطة مثل نسبة تحمل كاليفورنيا (CBR)، تظهر النتائج التى تم جمعها من الدراسات السابقة أن إعادة تدوير مخلفات البناء (CW) يشكل خطوة أساسية نحو مجتمع أكثر استدامة من خلال تقليل التأثير البيئى الناجم عن التخلص السيئ من هذه المواد في جميع أنحاء العالم، ولمعالجة هذه القضية بشكل جدي، تم تقديم بعض التوصيات للتشجيع على حلول إدارة النفايات المستدامة مثل إعادة الاستخدام وإعادة التدوير، وأخيرا، فإن إعادة تدوير مخلفات البناء من الهياكل التى تم هدمها كمواد أساسية من شأنه أن يساعد في تحقيق الاستدامة الاجتماعية والاقتصادية والبيئية

INTRODUCTION

Enormous urbanization has boosted up unlimited construction activities principally in developed area and has consistently expanded economic and environmental effects on urban sustainability as well as environmental safety. One of the main problems confronted in the environment from rapidly urbanisation is grew landfills caused by construction refurbishments. Minimizing landfills minimizes carbon emissions to the environment and also motivates innovation and environment sustainability. Consequently, sustainability can be gained by recycling construction and demolition waste (CDW) materials for substitute concrete production and extensive soil improvement, by curing materials to achieve mechanical strength for sustenance (Mgboawaji & Samuel 2022).

Due to the grow development of civil engineering activities, areas characterized by complex weak soils occurrence are being utilized for construction. Therefore, the problematic subsoil must be improved to use as a base for various types of construction. For example, construction on soft clay soils which characterized by low bearing capacity with high compressibility, instability, slip failure and differential settlement is extremely problematic (Vincevica-Gaile et al., 2021). Currently, soil improvement techniques should be focus on a circular economy with solutions that can minimize energy consumption, CO2 emissions and use trash and recycled materials (Gomes Correia et al., 2016). Lately, plenty of proposals on making stabilization of soil more environmentally friendly have been established. Sustainable soil stabilization aims to keep away from conventional methods of soil reinforcement such as deep excavation, cementing and soil replacement and replacing it with modern innovative technologies. Where, it became essential for the engineers to search for modern methods to improve soil other than replacing it at the construction sites.

The employment of wastes as additions in soil not only to enhance the soil performance but also to rescue the natural resources by minimizing the disposal issues as well as made ecofriendly and economical products (Wainwright & Cabrera 1994). Other advantages of the recycle of CDW are the enhance durability, construction easily and low cost of production in the areas of scarce natural resources aggregates production. Consequently, the soil strength required can be enhanced by incorporating cementitious by-products to allow CDW to establish hard-standing settlement during moisture variation, as well as to achieve reduced carbon emission and use of cement (Fortová & Pavlu 2018). For instance, in foundation layers of pavement construction, mixed CDW with percentage of cement as bonding material are the most frequently used waste matters as an addition material (Sri Ravindrarajah & Tam 1987).

Since the last few decades, recycling and reuse CDW has been considered and utilized for applied in several countries around the world (Hansen, 1992). Standard technical reports have been published for recycled waste to utilize as raw materials in building and road construction (ACI_555R-01, 2001). This has achieved enormous advantages in terms of environment, engineering as well as economic, aspects. Despite its challenges, several countries have already achieved the goals of recycling CDW as presented in **Table 1**. For instance, countries like Denmark, Estonia, Germany, Ireland, United Kingdom and The Netherlands have already recycled more than 80% of the quantities of CDWs. In fact, there are three main reasons that have prompted and accelerated waste recycling in these countries: lack of raw materials; finding area for landfills is hard; and legal and economic regulations that support recycling. While, due to the availability of natural aggregates of high quality and the default of technical regulations for the reuse of aggregates in Portugal less recycling rates was recorded.

Table (1): quantities of CDWs produced and reused in different countries (EC DG ENV 2011)

Country	Arising (million tonnes)	Recycled %
Austria	6.60	60
Belgium	11.02	68
Czech republic	14.70	23
Denmark	5.27	94
Estonia	1.51	92
Finland	5.21	45
France	85.65	14
Germany	72.40	86
Greece	11.04	5
Hungary	10.12	16
Ireland	2.54	80
Latvia	2.32	46
Lithuania	3.45	60
The Netherlands	23.9	98
Poland	38.19	28
Portugal	11.42	5
Slovenia	2.00	53
Spain	31.34	14
UK	99.10	75

Although, the key to sustainable waste management is by estimating the quantity of C&D waste (Martinez-Lage et al., 2010). However, there is no enough statistics data on daily CDW production in Libya and no legal records on the real amount of waste generation in the whole country (Saleh, 2005). Actually in all Libyan cities, waste disposal is still a problematic where most landfilling based on throw out the waste into large pits located next to vital urban areas. Due to that, serious action has to be taken by constructing engineered landfill sites to reduce the risk of waste impacting the surrounding environment. Whereas, Illegal disposal of CDW can lead in perils to human health and the environment, such as transportation hindering (i.e., CDW on waysides and pavements), which can cause to accidents, air pollution, contamination of soil and groundwater, infrastructure damage (i.e., canals and blocking sewers), and land loss. According to Omran et al., 2011, using landfill is the main common manner of waste disposal of approximately 1.2 million ton of waste yearly in Libya. In 2000, El-Treike considered solid waste management (SWM) in Libya and according to indexes; the problems related to the SWM have been growing seriously. Based on cement consumption, Ashraf et al. 2016 suggested method to estimate the CDW in Libya. The findings revealed that the quantity of C&D waste was approximately 3,050,000 tonnes in 2010.

In term of soil stabilization, a considerable amount of literature has been published on the possibility of using the CDW as additive materials to enhance the performance of foundation soil. Arulrajah et al. (2013) examined the geotechnical and geo-environmental properties of different types of CDW materials which include: recycled concrete aggregate (RCA), crushed brick (CB), waste rock (WR), reclaimed asphalt pavement (RAP) and fine recycled glass (FRG). The study found that geotechnical properties of RCA and WR are comparable to or exceed those of quarry granular sub-base materials. Moreover, the properties of CB, RAP and FRG can be improved by using some additives to enable their usage in pavement construction. Also, Henzinger et al. (2015) investigated the ability of using recycled aggregates obtained from demolition waste in soil enhancement. The study has experimented on two treated fine-grained soils (low plasticity clay- very high plasticity clay). The results indicated that soil improvement was more effective for low plasticity clay. The study also concluded that the improvement ability mainly controlled by water content of the additive materials where strongly recommended using dry material. Recently, Sangeetha et al. 2022 examined the characteristics of black cotton soil and investigated the capability of using recycled aggregates from acquired CDWs in soil improvement. The study focuses on the economical and non-polluting nature of CDWs as an additive for soil improvement. The examinations were done utilizing dissimilar ratios of recycled CDWs in the percentages: 5%, 10%, 15%, 20%, and 25%, to improve the soil stability. The California Bearing Ratio (CBR) and the Optimum Moisture Content (OMC) showed an rise from 2% to 18.09% and from 15% to 18.09% respectively at the same time the Maximum Dry Density (MDD) indicated a reduce from 2.107 g.cc-1 to 1.69 g.cc-1, with the addition of 25% C&D wastes.

Based on the preceding, application of various types of recycled construction and demolition waste materials in geotechnical engineering projects are a critical ground improvement technique which needs to an extensive review. Therefore, this paper aims to provide a thorough review of the advancements in this field. The geotechnical and geo-environmental characteristics of CDWs have been investigated by several investigators which highlighted in this study.

CLASSIFICATION OF CONSTRUCTION AND DEMOLITION MATERIALS

Construction and Demolition (C&D) wastes are typically described as the surplus from the processes of building, rebuilding, extension, modification, maintains and destruction of construction and other infrastructure systems (José et al 2012). Besides, these wastes contain of definite categories of materials, and are a nonhomogeneous surplus that can include any material of construction, infrastructure or any other materials utilized through the construction action. C&D waste alludes to a vast range of materials which can be classified as follow:

- Concrete, bricks, tiles and ceramics;
- Wood, glass and plastic;
- Bituminous mixtures;
- Metals;
- Soil (including excavated soil), stones and dredging spoil;
- Insulation materials; Gypsum; and
- Other construction and demolition material

Figure 1 reveals an inclusive sketch of CDW categorization. Generally, the residue amount and composition of any CDW can be vary widely based on the regions which they are produced in and other main factors such as population, territorial planning, soil properties, topography, construction materials, and technologies, etc. (Menegaki & Damigos (2018) and Monier et al. (2017)).

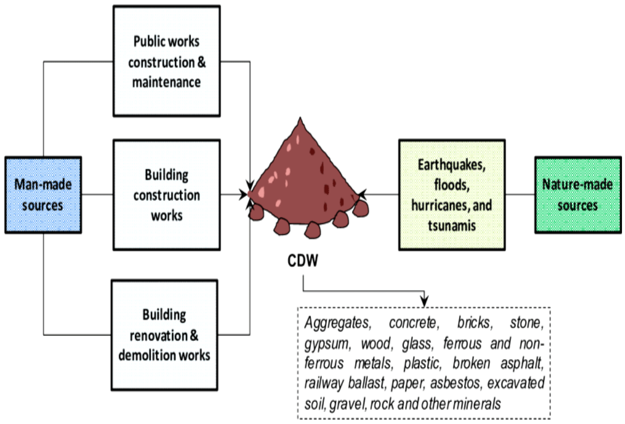

Figure (1): Construction and demolition waste (CDW) classification (Menegaki and Damigos 2018)

Furthermore, separation of CDW materials can be performed at the source during construction or demolition activities by identifying the required materials and take out undesirable one. The in-situ partition of CDW into various parts such as construction, road and pavement materials is critical and pivotal since it smooth the conservation of time and energy as well as help the recognition of waste materials to be modify to functional resource.

REPERCUSSION OF CONSTRUCTION AND DEMOLITION WASTE

Currently, in many countries including Libya, most CDW is disposed by entombed in neighboring areas without any treatment (Disfani *et al.2011)*. Consequently, disposing of waste in this manner will lead to cover a large area of land and also cause serious environmental effect due to waste infiltration, dust during the storing up and transferring. In short, the specific impacts of CDWs can be summarized as follows (AECOM 2018):

- Land loss: for 10,000 ton of CDW with 5m height stockpile, 0.167 ha land is wanted.
- Water pollution: in CDWs dispose sites contains a vast quantity of calcium silicate hydrate, calcium hydroxide, sulphate and heavy metal ions. Hence, surface and underground water will be contaminated due to the leachate flows into water runs and without accepted treatment.
- Air pollution: The CDW wastes may carry sulphate ions, which could be mutate to hydrogen sulphide in anaerobic states as in landfills. In the same conditions,

lignin and tannin may be furtherly converted to volatile fatty acids (VFA). These kinds of materials lead to pollute the air.
- Soil pollution. The risky components of CDW will cause soil pollution by changing of physical and chemical soil properties in additional to effect on micro-organisms activities in soil.

The above environmental effects resulted by CDW has not get enough attention from the governments and the public in most countries. Consequently, in the viewpoint of urban development and people's livelihood, there is a crucial require to apply the management of CDW recycling. Therefore, this review aims to evaluate accumulated knowledge on the subject and pinpoint areas where additional research is needed.

The following section will summarize the main themes that emerged in term of using of recycled construction and demolition waste materials in geotechnical applications.

APPLICATIONS OF CDW MATERIALS IN GEOTECHNICAL ENGINEERING

With the growing use of repurposed C&D materials in civil engineering applications, a comprehensive understanding of their behaviour and properties is needed to allow their utilization in these engineering uses. Consequently, numerous researchers have tried to assessed the sustainability of C&D waste materials in diverse civil engineering applications such as soil stabilization, embankment, pipe-bedding and concrete applications (Bossink et al.1996, Townsend et al. 1999, Horpibulsuk et al.2008, etc).

1. DEMOLISHED CONCRETE AGGREGATE DCA

DCA is a by-product generated from the construction and demolition of concrete structures. The concrete is crushed into aggregates of varying sizes depending on the intended application. Numerous investigators have documented the geotechnical characteristic of recycled concrete aggregate for use in geotechnical and pavement sub-base applications (Arulrajah et al., 2013, Rahman et al., 2014). Moreover, coarse or fine recycled aggregates of CDWs can be utilized in different constructions as backfill materials, sub-base material in road and pavement construction, landfill liners, canal lining, fills in land reclamation and drainage projects. In addition, it can be used in a new concrete production (Hemalatha et al. 2008).

According to the experimental study done by Tong et al. (2013) to examine the capability of utilizing CDW as stable materials in base and subgrade layers of roads, the CDW was utilized instead of natural aggregates. The investigation concentrated on the effect of cement content with different CDW sources on subgrade properties. The authors reported that without any additive of cement, recycled CDW of concrete and masonry can be used for all layers of road foundation. Moreover, in lower base layers, using recycled fine aggregate (RFA) it should be strengthen by adding 7.5% and 10.5% of cement for RFA produced from concrete and masonry debris respectively. Likewise, using RFA for top layers, it should be strengthen by adding 10.5% and 12.5% of cement for RFA produced from concrete and masonry debris respectively.

The study by Ibrahim et al. (2018) has investigated the impact of crushed waste concrete CWC on the physical properties of soils. The study considered organic and cohesive soils and the results show increase in the maximum dry density MDD with rising CWC content (by a maximum of 25%), while the optimum water content OWC reduces (by a maximum of 40%). In the same framework, Karkush and Yassin (2019) outlined that soil with 5% additive of CWC results the lowest maximum dry density, which is even less than dry density of untreated soil. The MDD parameter was achieved with a 15% of CWC content. The OWC was obtained at 10% of CWC content, while it was the lowest when CWC content was 15%. Recently, Kanniyappan et al. (2019) examined the possibility of reusing recycled concrete aggregate as restricted substitution for soil in soil stabilization. These experiments illustrate that utilizing recycled concrete aggregate led to increase CBR value and decrease the pavement thickness which minimize the construction cost. Further, using CDW to stabilize the soil properly will increases environmental utility.

Overall, depended on the recycled concrete quality that used for soil stabilization the soil density increases with higher water absorption capacity. Besides, adding a small amount of CDW like crushed concrete paving slab-aggregates to an expansive soil lead to enhance the bearing capacity of subgrade soil, which consequently increase the soil dry unit weight (Eckert and Oliveira (2017)). Recent cases reported by Ok et al 2020 also support the hypothesis that construction and demolition materials can serve as a viable alternative to virgin aggregate utilized in the padding provided that it is taken quantify versus high water absorption value.

2. CRASHED BRICK

Due to demolition activities, plenty of brick waste is generated. The best manner to dispose of this waste without harming the environment is to recycle it in proper way and used as a new material. Typically, this kind of wastes is utilized as construction materials in buildings, infrastructure projects and also in ground improvement as a result of its stationary nature. Despite its challenges, recycled bricks dust and fine concrete materials are vastly utilized as construction materials in geotechnical activities. As a result of the rate of quick urbanization and infrastructural developments around the world, bricks and concrete materials wastes are certainly the most enormous portions in waste masses generated (Delongui et al. (2018), Robayo-Salazar et al. (2020)).

Numerous studies have examined the using of mixed crushed brick with other reclaimed aggregates to enhance the performance of sub-base application (Aboutalebi (2020), Poon et al. (2006)). These authors observed that grading limits of smashed brick before and after compaction and CBR (California bearing ratio) of upper and lower sides were successful sub-base pavement material. The researchers explained that because: brick mixtures density is separate of treatment time and of good compaction behaviour with gradual loss of water (Wainwright and Cabrera (1994), Eckert and Oliveira (2017)). Besides, less specific gravity of (Gs=1.76) have been noted for crushed brick particles than Gs value of clay soil (2.7), crushed bricks combination reduces the dry unit weight as well as water content absorbed by the soil (Eckert and Oliveira (2017)).

Various experiments were performed by Anand et al 2014 to outline the benefits of using demolished brick waste (DBW) as a stabilizer to improve the cohesive soil strength utilized in construction of sub grades in pavements. The main findings indicate that California Bearing Ratio (CBR) values significantly increased to over 400 % with 40 % DBW mixed with cohesive soil. Also, the results concluded that the optimum demolished brick waste content is approximately 40% which should be added to cohesive soil for stabilization. In addition, the study is noted that the optimum moisture content value reduced with increase the DBW content.

According to the experimental study done by Kumar et al 2019, the brick dust shows significant potential as a soil stabilizer, enhancing the geotechnical properties of soil. Its low specific gravity, ease of compaction, and ability to alter moisture content contribute positively to the geotechnical characteristics of clay soil.

In the same framework, Shivaprasad and Suresh (2022) evaluated the engineering properties of building related recycled brick materials in road embankment. This laboratory study focused on a single source of CDW with one particular gradation as it can obviously change the properties and the criteria for suitability. The findings showed that compared to traditional fill materials in embankment, recycled brick waste have better properties and strongly represented the substitution of recycled demolition wastes for conventional embankment materials fill.

3. CRASHED CERAMIC

Because of the rapid renaissance in construction around the world, ceramic waste consists of a crucial segment of building wastes which need sizeable space of land to disposal it. The utilization of crashed ceramic waste as additive materials for soil stabilization is one of sustainable and eco-friendly alternative.

Binici (2007) reported that the ceramic waste causes major critical ecological issues which about 30% of ceramic industry production is wasted and not recycled for any goal. Nonetheless, numerous researchers have tried to investigate the utilization of waste ceramic in soil improvement and concrete for diverse establishment sites. Chen and Idusuyi (2015) investigated the impact of ceramic dust on soil engineering characteristics. The findings revealed that soil indexes like plastic limit, plasticity index, liquid limit and optimum moisture content reduced with increase in ceramic dust content. Whereas, california bearing ratio (CBR), unconfined compressive strength (UCS) and the maximum dry density (MDD) increased with increasing ceramic dust content. These findings were in agreement with the studies done by Sabat (2012) and James and Pandian (2015) as they noticed the 30% as the optimum value of ceramic dust. Other studies have also highlighted the benefits of adding ceramic tile dust waste to the soil and its effect on the MDD, CBR values and angle of internal friction thereby yielding a composite with improved properties (Ameta et al. (2013), Sabat (2012) and Cabalar et al. (2017)).

The study done by Koyuncu (2004) investigated the ability of adding ceramic tile wastes to Na-bentonite and its effect on swelling pressure and swelling potential. The author outlined that, by adding 40% of ceramic tile waste, swelling pressure and swelling potential decreased by 86% and 57% respectively. Likewise, Panwar and Ameta (2016) reported that using ceramic tile waste to stabilize fine sand is suitable for the embankment construction since it leads to improve the strength characteristics notably.

More recently, Deboucha et. al 2020 examined the effects of adding ceramic tile waste (CW), marble dust (MD) with the cement on the performance of soil characteristics. The findings revealed that CW and MD mixed with cement could use as additive materials for soil stabilization in sub-base layers of road. Moreover, the study concluded to the possibility of enhancing the sub-base layer of constructions through better resource utilization of eco-friendly materials to achieve considerable economic and environmental sustainability. In the same framework of recycle ceramic waste, Sharma, R. K. (2020) stated that using waste ceramic and fly ash with poor sand for soil stabilization of clay led to noticeable decrease the maximum dry density (MDD) and increase the optimum moisture content (OMC) and the CBR as well. In addition to the fact that this composite formed upgrades soil properties, its use in road construction leads to disposal the wastes safely too.

Similarly, Arias-Trujillo et al 2023 presented an experimental study to investigate the impact of using ceramic brick waste aggregates as additive materials on geotechnical characteristics of aeolian sand. Three different percentages of replacement 15%, 30% and 45% have been considered and the main findings indicated an enhancement of the inclusive geotechnical properties of soil after blending. For the two higher replacements, the CBR derived is about 33 % and the ideal replacement of 30 % has been recognized which this result is consistent with other studies done by (Sabat (2012) and James and Pandian (2015)). As a result, this stabilization technique can be considered achievable and environmentally satisfactory.

In summary, it can be confirmed that ceramic tile waste can be utilized to enhance the properties of poor soils and adapt them for better use in construction environments. Besides, using ceramic tile wastes in construction works leads to reduce the potential risk impacts on the environment as well as considerable savings in terms of raw material.

CONCLUSIONS

This study set out to gain a better understanding of the significant importance of utilizing recycled CDW in soil stabilization field towards sustainable social, economic and environmental benefits. In light of this, the following conclusions were reached:

i. Nowadays, recycling and repurposing construction and demolition waste (CDW), which is often either sent to landfills or discarded improperly, can significantly reduce the strain on expensive land resources.
ii. Since there are no rules or systems dominating the management of construction and demolition waste thus, Deterioration of environment is a vital concern due to the unlawful construction and demolition waste disposing.
iii. with right management and recycling strategies of construction and demolition (C&D) wastes were executed, an optimal exploitation of natural resources could be performed, along with minimizing the environmental effects resulting from their extraction.
iv. The use of waste materials as additives presents a cost-effective and environmentally friendly approach to soil stabilization. This method not only reduces material expenses but also addresses the challenges associated with waste disposal, which can often be expensive and problematic.
v. With the employ of C&D wastes as a soil stabilizer, a significant improvement in soil engineering characteristics is noted and many of poor soil issues in construction addressed too.

Based on the preceding, the increasing troubles produced by the enormous C&D wastes generation such as water pollution, green areas, public spaces, and the exhaustion of limited landfill spaces can be curbed. Furthermore, incorporating construction and demolition (C&D) waste in soil stabilization field will enhance the engineering characteristics of the soil while minimizing overall project costs. This approach will also have a beneficial impact on the environment, promoting a more sustainable construction practice.

RECOMMENDATIONS

i. Strict and particular regulations must be established for construction demolition and demolition waste dumping.
ii. Recycling of construction and demolition waste must be stimulated by government agencies in order to encourage its use, this is can be through a procedure of conduct a public awareness campaign to promote better understanding and implementation of construction and demolition waste recycling.
iii. To improve the sustainability of the construction, both the government and customers must pay more attention to construction waste management and move beyond the status quo of disposal waste in open areas. Moreover, extreme efforts should be made to recycle and reuse these waste materials so that waste is transformed into wealth for sustainable development" Social and economic benefits".

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