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Using Recycled Aggregates from Construction Waste in Layers of Pavements

Abstract

This paper aims to identify possibility of using recycled aggregate from construction and demolition waste in the layers of the pavements. Qualitative approach was adopted to answer the research question through reviewing the relevant literature and studies. The theoretical review concluded with the possibility of using recycled aggregates from construction and demolition waste in pavements layers within special applications and after conducting experiments and tests that confirm that the properties of these materials are within the recommended specifications. The paper recommends conducting laboratory studies to find treatments capable of improving the properties of recycled aggregates from construction and demolition waste.

Keywords: Recycled Aggregates, Construction and Demolition waste, pavements layers.

1. Introduction

The world is witnessing a great urban development that leads to the consumption of large amounts of natural resources and energy. The buildings and construction sector consumes (40%) of the total energy used in many countries. This sector also produces large amounts of carbon dioxide and waste resulting from the construction, operation, renovation and demolition of buildings, roads, and bridges that affect negatively on the environment. (Busar, Adeyanju, Loto, & Ademola, 2019)

Annually large quantities of construction and demolition waste are produced. (Contreras-Llanes, Romero, Gázquez, & Bolívar, 2021). Globally about 3 billion tons of construction and demolition waste is generated annually (Busar, Adeyanju, Loto, & Ademola, 2019). Construction and demolition waste includes large amounts of materials such as concrete, ceramics, bricks, rocks, metals, plaster, wood, glass, soil and asphalt (Llanes, Pérez, González, & Raya, 2022). Given the large amounts of this waste, many countries of the world have started to recycle this waste to become one of the most important materials recycled on a large scale around the world (Contreras-Llanes, Romero, Gázquez, & Bolívar, 2021)

Recycling reduces the demand for non-renewable resources, diminishes greenhouse gases, reduce air and water pollution and limiting energy consumption (Radosavljević, Đorđević, Vukadinović, & Nikolić, 2018). Recycled aggregate from construction and demolition waste has great importance in reducing the consumption of building materials and reducing the demand for the space needed for landfill (Parshotam, 2019)

Pavement of roads depends on non-renewable resources. Pavements are one of the infrastructure elements that consume the most energy and natural resources. Therefore, the use of recycled aggregates from construction and demolition waste is one of the ideas that can reduce the negative impact of Pavement on the environment (Reis, Quattrone, Ambrós, & Cazacliu, 2021).

When talking about the use of recycled aggregates in the pavement layers, the specialists are concerned about the impact of these materials on the performance of the paving and its ability to withstand the loads imposed on it, especially since the performance of the pavement depends on the properties of the layers materials (Cardoso, Silva, Brito, & Dhir, 2016).

Based on the foregoing, this paper aim to identify the using of recycled aggregates from construction and demolition waste in pavements layers.

1.1 Problem statement

With the increase for waste, voices were raised to recycle this waste to produce aggregate that can be used again in building construction and infrastructure construction (Jiménez, Ayuso, Galvín, López, & Agrela, 2012). Pavement construction is the primary use of this aggregate in the construction industry (Reis, Quattrone, Ambrós, & Cazacliu, 2021). In view of the characteristics of this aggregate, which affect the performance of the pavement (Cardoso, Silva, Brito, & Dhir, 2016), the problem of the study is identify the possibility of using recycled aggregate from construction and demolition waste in the layers of the pavements

1.2 Research question

What is the possibility of using recycled aggregate from construction and demolition waste in the layers of the pavements?

2. Literature review

2.1 Construction and Demolition waste (CDW)

Construction waste, or what is known as Construction and Demolition Waste (CDW), is one of the most important materials recycled on a large scale around the world, which attributed to the large quantities of construction and demolition aggregates (Contreras-Llanes, Romero, Gázquez, & Bolívar, 2021) . For example, approximately 20 million tons of construction and demolition aggregates are produced in the Brazilian state of São Paulo annually (Beja, Motta, & Bernucc, 2020). In addition, this waste constitutes (20-30%) of all waste in the European Union (Jiménez, Ayuso, Galvín, López, & Agrela, 2012).

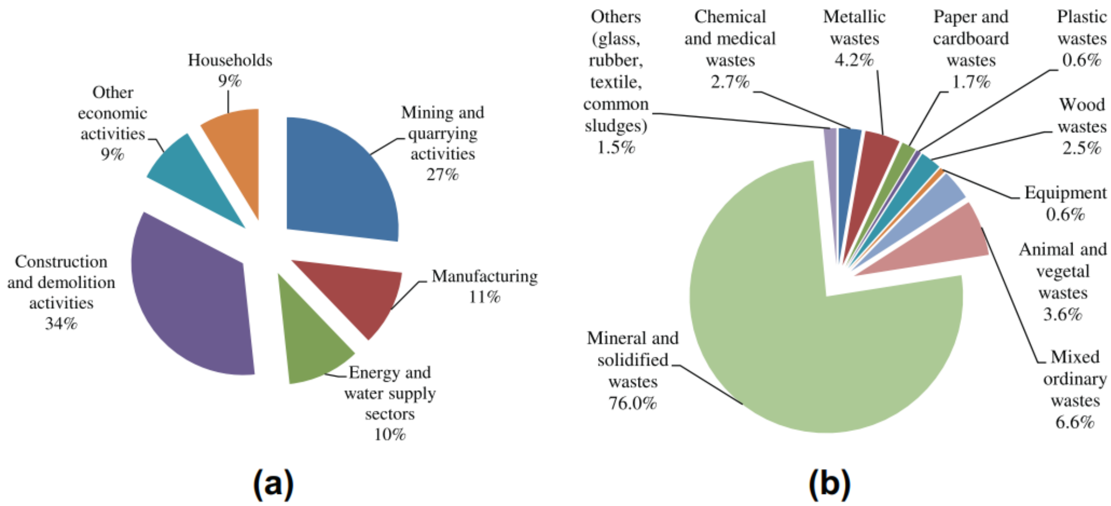

Figure (1): Total waste generated in European Union according to: (a) economic activity; (b) waste category, Reference (Silva, Brito, & Dhir, 2014)

Furthermore, 120 million tons of construction and demolition waste is generated in the UK. In the United States, about (140-534) million tons of it are produced annually, while China produces more than 300 million tons of it. In addition, this waste constitutes (14%) of the total waste in the OECD regions. Globally, about 3 billion tons of construction and demolition waste is generated annually (Busar, Adeyanju, Loto, & Ademola, 2019).

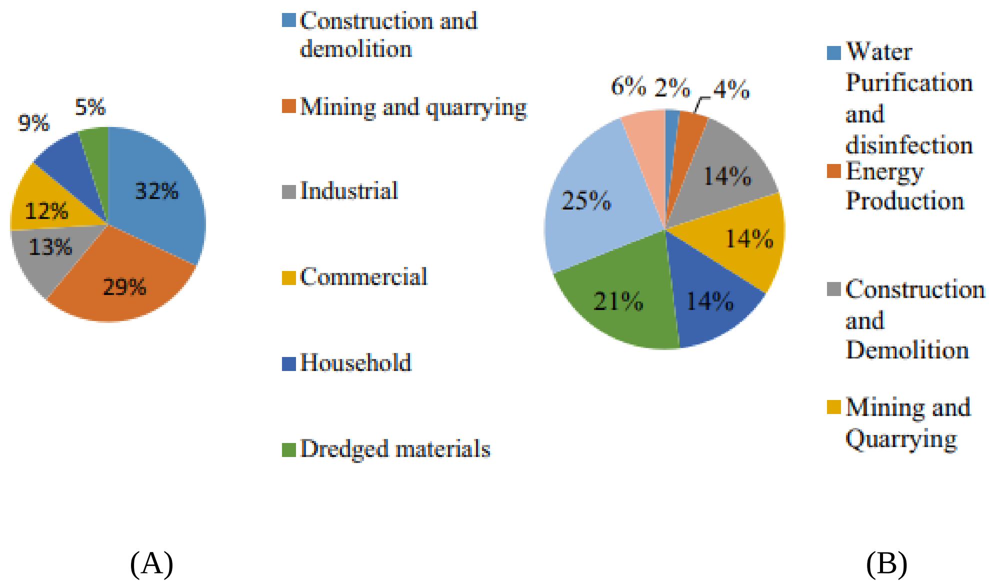

Figure (2): (A) waste generation UK, (B) waste Composition OECD , Reference: (Busar, Adeyanju, Loto, & Ademola, 2019).

Construction and demolition waste refers to the waste, materials and expired items (end of their service life) produced by buildings during the life cycle of buildings, particularly during the demolition phase (Barbudo, Jiménez, Ayuso, Galvín, & Agrela, 2018).

The concept of construction and demolition waste is related to the waste generated from construction, maintenance, renovation and demolition activities of buildings, roads and bridges. (Jain, 2021; Contreras-Llanes, Romero, Gázquez, & Bolívar, 2021).

(Llanes, Pérez, González, & Raya, 2022) indicate that construction and demolition waste includes a variety of materials, including; " concrete, ceramics, brick, rock, metal, plaster, wood, glass, soil and asphalt ". This waste is generated through all the construction stages; Design, purchase, handling, supply, handling, operation, maintenance and demolition.

The rates of construction and demolition waste vary according to the type and size of the project. For example, in Egypt, high-rise buildings is the most projects that generate this waste (Busar, Adeyanju, Loto, & Ademola, 2019).

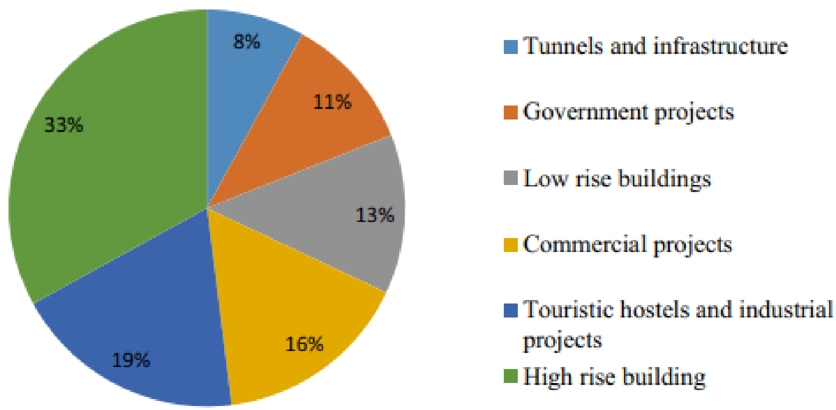

Figure (3): cumulative percentages of projects generating construction waste in Egypt Reference: (Busar, Adeyanju, Loto, & Ademola, 2019).

(Contreras-Llanes, Romero, Gázquez, & Bolívar, 2021) indicate that the Construction and demolition waste consist of s inert and inert materials, hazardous and non-hazardous materials, such as cement, concrete, glass, bricks, plastics, metals, solvents. In addition, excavated materials such as soil, gravel, rocks, clay, and plants.

In most cases, most construction and demolition waste consists of non-inert, non-hazardous and non-biodegradable materials such as sand, gravel, concrete, metal, plastic, glass, etc. Inert components make up between 40 - 85% of the total volume of this waste (Reis, Quattrone, Ambrós, & Cazacliu, 2021).

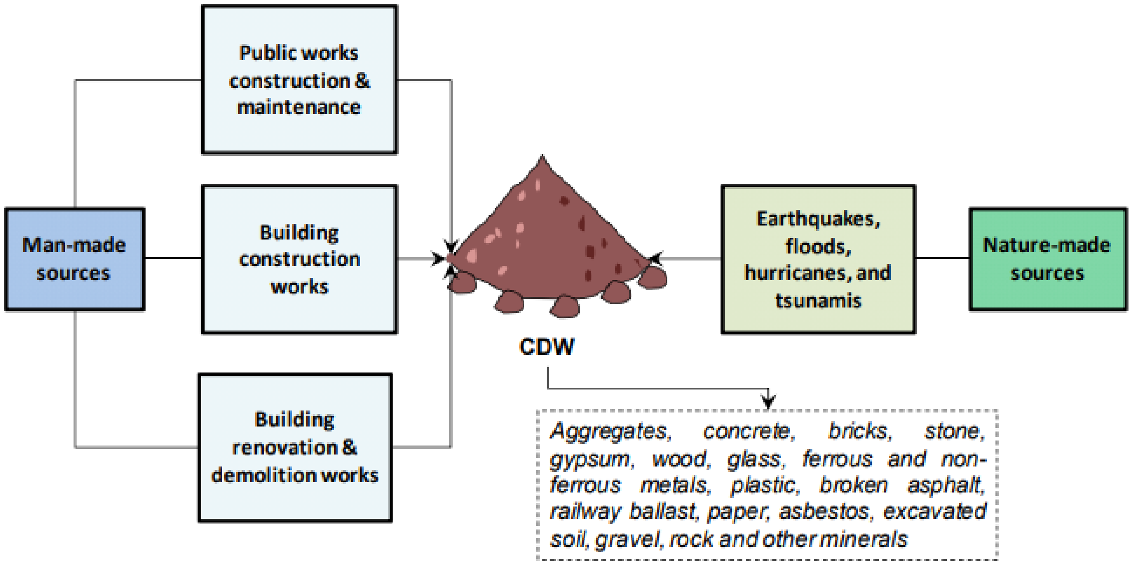

Figure (4): Classification of construction and demolition waste based on to the source of origin, Reference: (Reis, Quattrone, Ambrós, & Cazacliu, 2021)

2.2 Recycled Aggregates (RA)

Recycling refers to the transformation of waste and expired materials into new materials or objects of value. Recycling is one of the most important sustainable strategies, works to reduce greenhouse gas emissions, preserve natural resources from depletion, reduce energy use and reduce air and water pollution. A large number of materials can be recycled such as glass, cardboard, paper, metals, plastics, textiles, electronics...etc (Radosavljević, Đorđević, Vukadinović, & Nikolić, 2018).

Aggregates are considered, as major constituents in the composition of concrete. It is one of the materials that can be recycled (Kessal, Belagraa, Noui, Maafi, & Bouzid, 2020). Aggregates are classified into three categories; Natural aggregates that are produced from mineral sources, secondary aggregates which are produced in an industrial way and recycled aggregates which are aggregates produced by processing materials previously used in construction processes. (Pepe, 2015).

Recycled Aggregates are defined as "aggregate composed of recycled materials" (Sorato, 2016). The use of recycled aggregates has a significant interest from the economic and environmental epacts (Kessal, Belagraa, Noui, Maafi, & Bouzid, 2020). Furthermore, it is important step towards sustainability (Cardoso, Silva, Brito, & Dhir, 2016), because it creates environmentally friendly building materials and reduces the consumption of natural resources and landfill spaces (Parshotam, 2019).

The use of recycled aggregate is not very common compared to natural aggregate (Cardoso, Silva, Brito, & Dhir, 2016), the following figure are illustrates that:

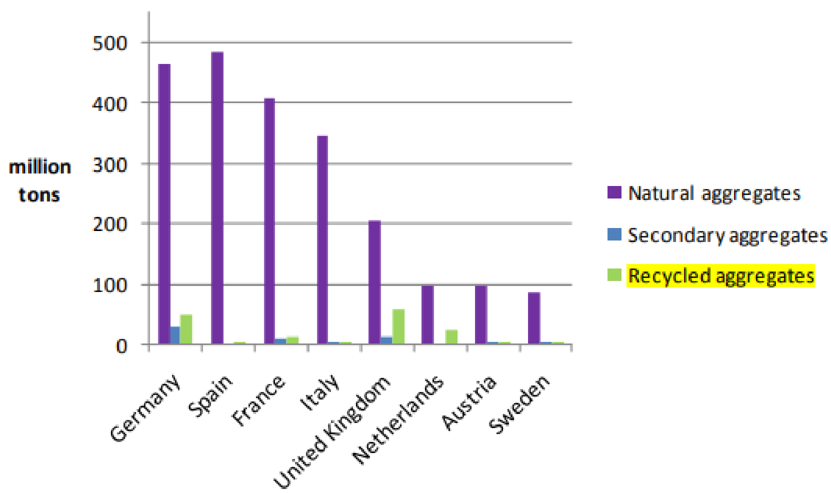

Figure (5): Aggregates production in Europe, Reference: (Pepe, 2015)

2.3 Recycled Aggregates (RA) from Construction and Demolition waste (CDW)

2.3.1 Classification

There are three main types of material derived from most construction and demolition waste (CDW): crushed concrete; crushed masonry and mixed demolition debris (Silva, 2015). The following figure are illustrates that:

(A) (B) (C)

Figure (6): Main types of RA sourced from CDW, (A) : crushed concrete, (B): crushed masonry, (C) d mixed recycled aggregates, Reference: (Cardoso, Silva, Brito, & Dhir, 2016)

After crushing and undergoing beneficiation in certified recycling plants, the resulting aggregates may be assigned to one of the four following categories

1) **Recycled Concrete Aggregates (RCA):** Construction and aggregate waste includes large amounts of concrete because it is the most used construction material. The organizations concerned with specifications for construction materials have agreed that recycled concrete aggregate comprises at least (90%) of its total mass on Portland cement and natural aggregate fragments. This type also includes mortar and concrete masonry units (Silva, 2015).
2) **Recycled masonry aggregates (RMA):** The classification of masonry rubble refers to all building materials born out of the construction, operation, renovation, and demolition of buildings, bridges, roads or any other structures. In addition, mud-filled

materials and burnt mud materials such as tiles, roofs, and wooden panels. These materials constitute of (90%) of the building aggregate mass. Recycled aggregate, which contains a high percentage of recycled bricks, are distinguished by its manufacturing in which a lot of effort is spent to separate concrete and asphalt to other stockpiles (Silva, 2015).

3) **Mixed Recycled Aggregates (MRA)**: mixed recycled aggregate consists of crushed concrete aggregate with graded granules. It is a mixture of two main components, produced from the process of beneficiation construction and demolition waste. Portland cement and natural aggregates constitute less than (90%) of its total mass, which means that it contains other construction and demolition waste, such as ceramics and lightweight concrete (Cardoso, Silva, Brito, & Dhir, 2016).

4) Construction and Demolition Recycled Aggregates (CDRA): (Silva, Brito, & Dhir, 2014) indicate that the literature contains a limited amount of information regarding the origin and composition of the aggregates. Therefore, where the recycled aggregates could not be fully classified, they were considered as recycled aggregates for construction and demolition. In other instances. The recycled aggregate contains high levels of impurity such as asphalt, glass, plastic and wood. Due to its incompatibility with other categories (RCA, RMA, MRA) , it has been classified into a new category (CDRA) (Silva, Brito, & Dhir, 2014).

Recycled aggregate from crushed concrete and recycled concrete aggregate are used in the production of new concrete and high-performance pavements, while materials from crushed masonry, recycled masonry aggregates and mixed recycled aggregates are used in the construction of pavements that do not require high strength, Where safety and risks are less important compared to structural concrete. Because Construction and Demolition Recycled Aggregates contains various contaminant that may affect the specifications of the final products, analyses process must be carried out to determine the economic feasibility of the recycling process. Recycling factories usually reduce pollutants (asphalt, wood, soil, glass, metal and plastic) through processing techniques (Cardoso, Silva, Brito, & Dhir, 2016)

2.3.2 Contaminants

The variety of Contaminants that can be found in aggregates recycled from construction and demolition waste leads to poor strength of concrete that is made of. These impurities include; Asphalt, gypsum, metal, rubber, plastic, soil, and wood (Silva R. V., 2015).

1) Asphalt: Asphalt consists of bituminous materials that have a negative effect on strength. Adding (30%) to the volume of asphalt reduces the compressive strength by about (30%). Others noted that adding (64%) of asphalt reduces the compressive strength by (75%). International standards allow the presence of bituminous materials at a rate of (10%) only in the recycled aggregates. In general, manufacturers aim to have recycled aggregates that meeting rigorous limits of (5%) or (1%) by mass (Silva, Brito, & Dhir, 2014).
2) **Glass**: When buildings demolishing, the glass panes are removed. In countries that encourage recycling, recycling is carried out on a large scale, so glass is often not found in construction and demolition waste and recycled aggregates. This pre-sorting is vital due to its analogous density to stone’s and brick’s, which makes it difficult to separate

glass from other heavyweight materials. In addition, due to the fragility of glass, it contains particulate after crushing operations in factories, so recycled sand contains a high percentage of contaminated glass. Specifications allow for a percentage not exceeding (1%) of the glass (Silva R. V., 2015).

3) **Other constituents**: It is difficult to separate organic materials such as wood and plastic from the content of construction and demolition waste before they are crushed, some of these materials can be separated or using air blowers, and treatment through the property of buoyancy. Wood, paper, plastic, etc. are transformed into “other constituent". Although soil and clay particles are less than 4 mm, they stick to stones and bricks. Clay negatively affects the properties of concrete; therefore, the recycled aggregate should be treated with water before using it to remove dust and mud, which are classified as “other constituents. (Silva R. V., 2015)” Moreover, ferrous and non-ferrous metals are “other constituents.” After the crushing process, ferrous metals should be removed from aggregate waste using magnets, while non-ferrous metals are removed using eddy currents or manually. In addition, Gypsum expands the sulfate, so it is also "Other constituents", which must be removed by washing the waste with water (Silva, Brito, & Dhir, 2014).

2.3.3 Chemical composition

The chemical composition of the recycled aggregate affects the properties of concrete; therefore, it is important to know the chemical composition of the recycled aggregate. The chemical composition, such as the proportions of sulfates, chlorides, and alkali, must be known and consistent with the permissible percentages.

1) **Sulphate content**: Recycled aggregate contains water-soluble sulfate. The source of this material is gypsum plaster, which consists from demolition aggregate for gypsum work. The existence of gypsum is a negative indicator of the properties of recycled aggregate due to its poor bearing capacity, low hardness and density. The level of soluble sulfate is related to the percentage of gypsum and crushed clay bricks w, as well as the percentage of pollutants. On the other hand, recycled concrete aggregate contains more sulfate than natural one due to the mortar. The specification specifies that the permissible percentage of sulfur in the recycled aggregate should not exceed (0.8%-1.0%) by mass (Silva R. V., 2015).
2) Chloride content: Chloride corrodes the reinforcing bars, so recycled aggregate containing large amounts of chloride is unusable and deteriorates rapidly. Marine environments contain high levels of soluble chloride; therefore, the use of concrete exposed to these environments to obtain recycled aggregate is not feasible spicaly in the manufacture of steel reinforced concrete. Soaking the recycled aggregate in water reduces the percentage of chloride contamination. Thus, Washing or soaking in water for two weeks reduces the amount of chlorides in a way that allows the recycled aggregate to be used to produce concrete, prestressed concrete and even reinforced concrete. Specify the quantity (Silva R. V., 2015).
3) **Alkali content**: The cement and the reactive silica present in the aggregates are a source of alkalis, which cause alkaline reactions. The existence of alkali in values greater than the recommended limit (3.5 kg/m^3) (Silva R. V., 2015) leads to alkaline reactions that

cause expansion of concrete, and it becomes more susceptible to cracking (Hajighasemali, Ramezanianpour, & Kashefizadeh, 2014).

2.3.4 Size and shape

The shape and size of the aggregate affect the effectiveness of concrete and its workability. The shape and size of the recycled aggregate are determined according to the type of devices that crush construction and demolition waste. The crushing process goes through several stages; Primary and secondary. Jaw crushers are used in the primary crushing stage. This type of equipment contributes to the best grain size distribution of recycled aggregate for concrete production. While secondary crushing makes the grains more rounder and less sharp, therefore relying on the primary crushing stage only, produces relatively flat and sharp grains. On the other hand, cone crushers are used for the secondary crushing stae (Ferreira, Brito, & Barra, 2011; Fonsecaa, Brito, & L.Evangelista, 2011), which produces granules with a maximum size of (200 mm) with spherical shape for the recycled aggregate. Impact crushers are also used for secondary crushing and give good grain size distribution with less flake (Silva, Brito, & Dhir, 2014).

2.3.5 Density

Aggregates are classified according to their specific gravity, which refers to normal weight, lightweight, and heavy weight. The largest category of aggregate is natural weight aggregate comprising natural sand, gravel, and crushed rock (eg granite, dolerite, basalt, limestone, and sandstone). Manufactured aggregate (eg; vitreous aggregate) and recycled aggregate belong to this category. The density of the recycled aggregate is determined based on the recycling procedure, the quality and size of the original material

1. **Recycling procedure**: Moreover, the number of crushing stages determines the degree of its density, the density of the recycled aggregate increases as the number of crushing stages increases. This attributable to "the cumulative crushing of cement paste adhered to the surface of the recycled coarse concrete aggregate". The density of cement is also affected by the processing and sorting techniques and its quality (Silva, Brito, & Dhir, 2014).
2. **Quality of the original material**: the type of original material affects the density of recycled aggregate. Because of the porosity, the density of recycled masonry aggregates is lower than the density of recycled concrete aggregate (Debieb & Kenaib, 2008). Regarding the particle density of the recycled mixed aggregate, it can be estimated by the density of the original materials. Mixed recycled aggregate shows a decrease in density with increasing content of recycled aggregate (Gokce, Nagataki, Saeki, & M.Hisadad, 2011). For recycled concrete aggregate, the strength of the original concrete has an effect on the density of the aggregate produced. On the other hand, the density of the recycled masonry aggregates is affected by the compressive strength of the original bricks (Silva R. V., 2015).
3. **Size**: The size of the recycled aggregate has a clear correlation with its density. In a study conducted to investigate the effect of the content of the attached mortar on the properties of the recycled concrete aggregates , it was found that the content of the attached mortar increases with the decreasing size of the fracture (Juan & Gutiérrezb,

2009), this be attributable to the recycling processes , when the aggregate is subjected to many stages of mechanical processing, the amount of slurry sticking to the coarse aggregate is reduced, and as it is gradually crushed, the cement paste accumulates in the fine part of the recycled aggregate (Gokce, Nagataki, Saeki, & M.Hisadad, 2011). Therefore, the density of the fine recycled aggregate is lower than that of the coarse recycled aggregate from the same origin (Silva R. V., 2015).

2.3.6 Water absorption (WA)

Water absorption affects the strength of materials and their resistance to natural and unnatural factors. The water absorption indicates permeability (the ability of fluids to penetrate their structures). Materials with high permeability allow water and ions molecules to penetrate inside, which leads to interaction with the cement paste and destroying the chemical stability. Conversely, the low permeability contributes to an increase in the resistance of the material as it protects it from decomposing agents (Zhang & Panesar, 2018; Eckert & Oliveira, 2017). The permeability value of the natural aggregate ranges between (0.5% - 1.5%). As for the recycled aggregate, it has a higher permeability of (12%), its high porosity is due to the presence of attached mortar (Belin, Habert, Thiery, & Roussel, 2013; Quattrone, Cazacliu, Angulo, Hamard, & Cothenet, 2016), which enhances the porosity of the aggregate and affects the amounts of water available for mixing. Consequently, concrete loses its operational ability and becomes less durable in the long term (García-González, Rodríguez-Robles, Juan-Valdés, Pozo, & Guerra-Romero, 2014).

The use of recycled aggregates from construction and demolition waste is of environmental and economic importance. From an environmental point of view, this aggregate helps reduce the consumption of non-renewable resources, reduces the demand for land for landfill waste, and reduces carbon dioxide emissions, which reduces the negative impact of buildings and structures on the environment. From an economic point of view, the process of recycling construction waste Demolition is economically feasible if simple processing is used to create low-energy recycled materials (Jiménez, Ayuso, Galvín, López, & Agrela, 2012).

Engineers allow the replacement of natural aggregates with recycled aggregates from construction and demolition waste, when the required specifications are achieved. To enhance its quality, aggregate sources must be separated from hazardous materials (such as solvents or asbestos) and other components that are considered constituents (such as gypsum, wood, glass, metal, plastic and excavated soil) should be removed (Coelho & Brito, 2011).

Aggregate recycled from construction and demolition waste has physical, mechanical, and chemical properties that make it different from natural aggregates. Recycled aggregate has lower density, higher water absorption, lower compressive strength, higher content of sulfur compounds and soluble salts. In some countries, the use of recycled aggregates from construction and demolition waste is refused because it does not meet the required specifications (Barbudo, Jiménez, Ayuso, Galvín, & Agrela, 2018). Specialists prefer to use natural aggregates instead of using recycled aggregates from construction and demolition waste. This can be explained by the following reasons (Cardoso, Silva, Brito, & Dhir, 2016):

- From an economic standpoint, in general, the use of natural aggregates is more economical than the use of recycled aggregates due to the high transportation costs between construction sites and recycling factories.
- Recycled aggregate requires costly long time procedures to select it according to specific and strict criteria due to the different composition of construction and demolition waste compared to natural aggregates
- Compaction of recycled aggregate can change its properties, therefore use it for specific applications requires multiple pilot tests to verify its operational capability.
- In the case of using recycled aggregates from construction and demolition waste for pavement and bridges, are required higher number of trial tests, compared to natural aggregates.
- Some countries refuse to use recycled aggregates.
- Mixing recycled aggregates from construction and demolition waste with natural aggregates may have negatively effect on soil stiffness and strength.
- It is difficult to change the traditional mindset of designers and contractors who are highly experienced with natural aggregates, which is still abundant.

2.4 Layers of Pavements

The efficiency of the road system depends on high quality pavements (Kivi, 2013). The Pavement is defend as "the structure which supports the wheels loads imposed on it from traffic moving on it. It is designed to resist the stresses imposed on it and to distribute the loads on the subgrade" Pavements are designed by finding a combination between the thickness and quality of materials that allow them to withstand the traffic loads imposed on them (Makki, Ahmed, Gergis, & Abu-ALGasim, 2015). The performance of pavement is the change in its condition during its operational life. It determined by its ability to carry the loads resulting from traffic during the design life, both functionally and structurally (Sreedevi, 2014).

There are three main types of pavement: Block Pavement, Rigid Pavement and Flexible Pavement. Rigid pavements (consists of concrete slab -Slab PCC.) have sufficient beam strength to beat local subgrade failures. When the subgrade drifts under the rigid pavement, the concrete slab, due to its structural ability, can bridge localized malfunctions and areas of insufficient support. Flexible Pavement (asphalt pavement) consist of several layers. The strength of these pavements depends on the strength of the subgrade, when the subgrade drifts, the elastic pavement is deformed. Block pavements (Composite Pavements) combine rigid pavements and flexible pavements(Asphalt and concrete layers) , as they provide a more solid surface than the bituminous materials found in flexible pavements, but they are not as rigid as concrete (Makki, Ahmed, Gergis, & Abu-ALGasim, 2015).

2.4.1 Flexible pavements

Flexible pavements consist of successive layers of natural soil that are covered with an asphalt surface (Sotiriadis, 2016). Surface layer of flexible pavements consists of bituminous concrete, while the layers of the foundation and the sub-base can be of crushed gravel or sand-gravel mixtures or from materials treated with one of the bituminous bonds. Flexible pavement is characterized by that its resistance to bending is very weak and the deformations that may occur in the soil of the track or any other layer may be reflected across the layers until reaching the surface layer. Flexible pavements transfer loads to deeper layers by transferring grain to grain through the contact points of the pavement structure. Three styles of flexible pavement are used; conventional super imposed flexible pavement, full-depth asphalt pavement, contained rock asphalt mats (Babu, 2016).

Flexible paving consists of four basic layers (Makki, Ahmed, Gergis, & Abu-ALGasim, 2015):

1. **Subgrade course**: It forms the base of the flexible paving and consists of natural soil that is prepared to receive the paving layers. This soil is prepared by treating it to become a homogeneous surface. If the resistance of this soil is not good, it should be treated and fixed with bituminous or chemical materials.
2. **Subbase course**: It is a layer located between subgrade and the base course. This layer consists of compact granular material. it can be dispensed if the subgrade soil characteristics are excellent or the traffic density is weak. During the construction process, this layer acts as a protection for the substrate from the mechanisms on the site. In addition, it helps reduce frost damage, prevent free water build-up within or below the pavement structure, and prevent penetration of fine-grained soils into the underlying layers.
3. **Base Course:** It is located directly under the surface layer. It consists of aggregates such as crushed stone, crushed slag, gravel and sand, or a combination of these materials. This layer requires higher specifications than those of the sub-base layer such as strength, stability and hardness. This layer distributes the transferred loads, this layer

is designed to resist thermal and climatic conditions and protect the surface layer from capillary rise of water.

4. **Surface Course:** the main objective of this layer is providing a safe, stable, smooth surface and able to withstand the stresses resulting from traffic movement and friction between the tires and the surface. This layer must resist thermal stresses and climatic factors, also it should limit the amount of surface water that penetrates the pavement. On the other hand, the mechanical, physical and chemical properties used in this layer must be of high specifications.

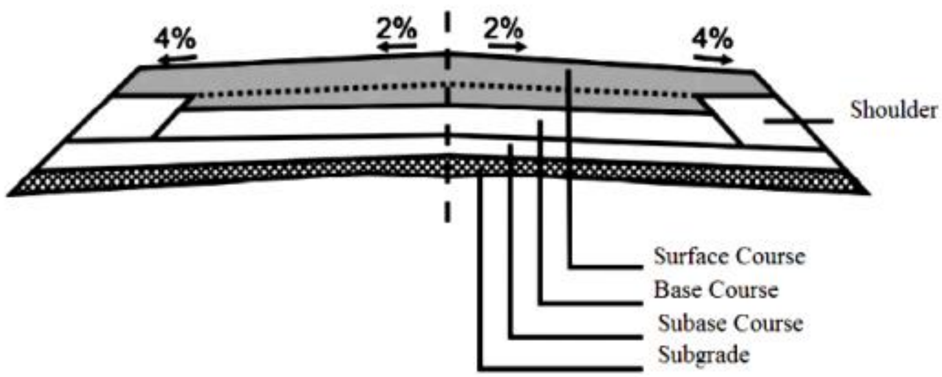

Figure (7): Cross Section of Typical Flexible Pavements, reference: (Hadiwardoyo, Sumabrata, & Berawi, 2012)

2.4.2 Ridge Pavement (Concrete Pavement)

Flexible asphalt Pavement is used in the roads, but some highways and industrial roads require another type of paving which able withstand heavy loads and heavy traffic movement. Ridge Pavement (concrete pavement) is the most suitable system for this type of road (M, Reddy, Dana, & Mahantesh, 2018). There are three types of concrete pavements are mostly used in highway applications: Jointed Plain Concrete Pavements (JPCP), Jointed Reinforced

Concrete Pavements (JRCP) and Continuously Reinforced Concrete Pavements (CRCP) (Kivi, 2013).

Jointed Plain Concrete Pavements (JPCP) are the most common concrete pavements, it is consisting of concrete slabs with a thickness ranging between (150-300 mm). These Pavements use regularly spaced contraction joints to control cracking .Also, it does not use any reinforcing steel. As for the Jointed Reinforced Concrete Pavements (JRCP), they are similar to the previous type in terms of using contraction joints but they use a grid of reinforcing steel. Continuously Reinforced Concrete Pavement (CRCP) does not use contraction joints. Transverse slits are formed but it are fixed with continuous rebar. The steel is installed in the middle of the depth of the concrete slab and the amount of steel required for this type is (0.6%) of the pavement area (Kivi, 2013).

2.5 Recycled Aggregates from Construction and Demolition waste in Layers of Pavements

The construction of Pavements is one of the most energy-intensive infrastructure that based on non-renewable resources, therefore the use of recycled aggregates from construction and demolition waste in Pavements construction is one of the effective sustainable ideas. Currently, Pavements construction is the primary use of recycled aggregate from construction and demolition waste (Reis, Quattrone, Ambrós, & Cazacliu, 2021).

Recycled aggregate from construction and demolition waste can be used for flexible pavement and Ridge pavement. The characteristics of the recycled aggregate used in flexible and rigid pavements depend on the main function of the layer in which it will be employed. These properties include "Grading curve, shear strength, stiffness, permeability and freeze–

thaw resistance". Therefore, the selection depends on the characteristics of the aggregates that affect the layer performance. The different behavior of pressed materials made from recycled aggregates or natural aggregates can be explained by changes in the properties of the aggregates. Incorporating recycled aggregates has negatively effects on durability, shear strength and stiffness, because the physical properties of the recycled aggregates is worse than natural aggregates (Cardoso, Silva, Brito, & Dhir, 2016).

Recycled aggregate from construction and demolition waste is used in pavements layers especially in the structural and sub-Course (Agrela, et al., 2012). The properties of recycled aggregate from construction and demolition waste vary depending on the material it is made, so the physical, chemical and mechanical properties of pavements applications should be examined (Beja, Motta, & Bernucc, 2020). (Arulrajah, Piratheepan, Disfani, & Bo, 2013) indicates the possibility of using construction aggregates recycled from construction and demolition waste in paving layers, provided that making an evaluation process for the permanent deformation coefficient and flexibility are determined through laboratory tests.

The pavements are subjected to stress, cracking, deformation and subsidence. These problems are attributed to the poor performance of the base and sub-base layers. Aggregate properties such as strength, stiffness, weight, and grain gradation affected the performance of the pavement layers. Because of the heterogeneous properties of recycled aggregate from construction and demolition waste, its use in paving roads with high loads may affect its operational efficiency (Cardoso, Silva, Brito, & Dhir, 2016).

On the other hand, (Leite, Motta, Vasconcelos, & Bernucci, 2011) pointed out the importance of examination the compressive stress of this aggregate because it affects the stiffness of the aggregate (higher compressive effort means higher modulus of elasticity). In addition, the pozzolanic reactions resulting from the presence of non-aqueous cement and ceramic tiles lead to the formation of hydraulic bonds that significantly increase the stiffness (Vegas, Ibañez, Lisbona, Cortazar, & Fríasc, 2011). Furthermore, aggregates recycled from construction and demolition waste may contain silicic and carbonate components (such as calcite, hydroxides, and quartz) that react with the remaining components to produce a non-granular material (Contreras, et al., 2016). It is worth noting that the studies that evaluated the use of recycled aggregates from construction and demolition waste in pavements layers were applied to rural and low-traffic roads, which it makes their use on highways and heavy traffic risky. However, adding hydraulic couplings may result in reduced variance and increased mechanical strength, which requires practical investigations in the field (Beja, Motta, & Bernucc, 2020).

(Barbudo, Jiménez, Ayuso, Galvín, & Agrela, 2018) indicates that aggregates recycled from construction and demolition waste can be used in urban roads, pedestrian roads, bike paths and roads with low traffic density that require lower structural and functional specifications than highways. In Spain, relevant stakeholders have worked to develop the "Catalogue of road pavements with recycled aggregates (CRA-2017)" which provides models for the use of recycled aggregates in pavement layers such as paving of road works with a traffic density of less than 800 heavy vehicles/day, rural roads, pedestrian roads and cyclists' sidewalks.

(Reis, Quattrone, Ambrós, & Cazacliu, 2021) pointed out the possibility of using recycled aggregates from construction and demolition waste in reclaimed asphalt pavement

(RAP), which is a widespread pavement system in Egypt, Japan, the United States of America, China and other countries. (Vidal, Moliner, Martínez, & Rubio, 2013) Showed that incorporating (15%) of reclaimed asphalt pavement reduces energy consumption, limits climate change and reduces fossil fuel use by (13-14%). With regard to the amount of this material allowed to be used, studies have found the possibility of using up to 60% of the reclaimed asphalt pavement in the sub-base course and 20% in the construction of the base course (Mousa, azaam, El-Shabrawy, & El-Badawy, 2017). The scholars indicate that the mechanical performance of a sub-base course built using reclaimed asphalt pavement is better than that made of limestone. In addition, this material does not have any negative effect when used as a paving material for highways (Reis, Quattrone, Ambrós, & Cazacliu, 2021).

4. Conclusion

Recycled aggregate from construction and demolition waste can be used for flexible and rigid pavements layers. Based on the unclear characteristics of the recycled aggregate from construction and demolition waste, the use of this aggregate in the pavements layers should be accompanied by many studies and experiments in order to verify its efficiency for use, especially in the base and sub-base course. On the other hand, it is recommended to use this type of aggregate in pavements roads with light loads such as pedestrian roads, bicycle paths, rural roads, and roads with low traffic density. It is possible to use recycled aggregate from construction and demolition waste to produce reclaimed asphalt pavement and combine it with the sub-base and the base course.

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