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Recycling Construction Waste Materials to Reduce the Environmental Pollutants

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***Abstract*—**There have recently been many studies and investments in developed and developing countries regarding the possibility of recycling construction waste, which are still ongoing. Since the term 'construction waste' covers a vast spectrum of materials in constructing buildings, roads and etc., many investigations are required to measure their technical performance in use as well as their time and place of use. Concrete is among the major and fundamental materials used in current construction industry. Along with the rise of population in developing countries, it is desperately required to meet the people's primary need in construction industry and on the other hand, dispose existing wastes for reducing the amount of environmental pollutants. Restrictions of natural resources and environmental pollution are the most important problems encountered by civil engineers. Reusing construction waste is an important and economic approach that not only assists the preservation of environment but also, provides us with primary raw materials. In line with consistent municipal development in disposal and reuse of construction waste, several approaches including, management of construction waste and materials, materials recycling and innovation and new inventions in materials have been predicted. This article has accordingly attempted to study the activities related to recycling of construction wastes and then, stated the economic, quantitative, qualitative and environmental results obtained.

***Keywords*—**Civil engineering, environment, recycling, construction waste.

I. Introduction

THERE are several reasons to reuse construction materials, due to the limitation of natural resources and environmental protection, reusing and recycling of construction materials has recently been turned into an inevitable act. One of major approaches for reducing the amount of environmental pollutants, especially carbon dioxide as the main factor of global warming, is reusing and recycling of construction materials. Among the most significant problems recently faced by developing or developed countries of the world is the aggregation of construction wastes due to urban developments and replacement of old buildings with new constructions. Attention to such important fact might be due to some reasons as, waste disposal sites, shortage of raw materials, environmental problems, improper landscape and political and social issues [1].

Recycling of waste has not a long history in third world countries whereas, in many developed countries like, German, Holland, Belgium and Norway there have been many studies in that regard the result of which has been the creation of certain standards for employment of such materials. Several wide experiments including physical, chemical and mechanical has been performed on construction wastes. Concrete is one of the most important materials used in construction projects. Issues related to its recycle will be considered in the following sections.

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II. Amount of Wastes from Building Demolition

Due to the fast urban developments, landfills are mostly rare and insufficient. In one hand, allocation of certain sites for land filling these materials requires land ownership and money and on the other hand, due to the placement of landfills far from urban areas, transportation costs will be included too. In addition, disposal of such a large volume of materials is not acceptable, given the high price of raw materials. The amount of construction wastes depends on various factors the most important of which are as followed [1]:

- Population growth and growing need for new residential areas
- Immigration rate from rural to urban regions
- Texture of existing buildings
- Architecture of existing buildings and needs of current generation.

Moreover, cities might be damaged due to natural disasters such as earthquake, flood, thunder, etc. and thus, leave high amount of waste that should definitely be considered for reuse. For instance, in the earthquake happened in Taiwan in 1999, about 53,000 residential units were completely destroyed and around 45,000 ones were also partially damaged and produced a large amount of debris [2].

Construction and demolition (C&D) waste materials are generally produced during the construction, renovation or demolition of buildings, roads and other structures. Among these construction wastes are: wood, glass, concrete, walls, copper wires, insulation, flooring, pebble and in general, all the materials used in construction [3]. Studies all around the world indicate that the amount of construction building wastes among other dumps is between 13-29% [2].

Appropriate materials are those with the possibility of more than 90% recycling as well as cheap recycling costs. One of the most important features of using C&D materials is economic benefits. Amongst these advantages are their replacement for construction materials and also their reuse without need to recycle according to Quality Control Procedures including, ASTM Subcommittee E 06.55. Materials with less than 90% recycling capacity and expensive

recycling process are considered as impure and mixed materials. This kind of material is the most important factor for the presence of construction wastes and debris. They include, brick, concrete, stone facades, tiles, candles and etc.

The rate of C&D materials produced every day is considerable. According to Bosnic and Browers (1996), the estimated amount of wastes produced in one year in Holland is 14,000,000 tons and its share in total waste production of the country is 26% [4]. Other studies in different countries also confirm this. According to Crown et al. (1993), production of C&D materials in Australia is about 20 to 30% of its total waste production [5] and 20% of the total solid waste of United States [6]. But this amount is less in German or Finland with respectively, 19% [7] and 13-15% [8] waste production rate.

Irrespective of natural disasters, this amount of materials is still too much. For instance, the volume of construction wastes from renovation and rebuilding of roads in America is about 90 million tons [9].

In the State of California, about 12% of landfills are filled with debris that forms about 25% of total portion of waste. The average amount of produced construction wastes in this State is more than 4 million tons per year [10].

About 12 million tons concrete waste from construction and demolition projects are yearly produced in England that due to their low quality, a large portion of them are used in base course and embankment or transported to landfills. Less than 3 million tons of these materials are recycled. Meanwhile, more than 250 million tons of aggregates are yearly used in this country which about 70 million tons of them are employed in concrete production [11].

Demolition and construction waste materials produced in Germany are respectively 22,600,000 and 10,000,000 tons per year. According to Kohler and Kirsch (1993), two years later these rates reached 30,000,000 and 14,000,000 million tons for demolition and construction waste materials, respectively [12].

More than 3 million tons of building construction wastes (containing mostly of concrete) are yearly produced in Australia. Half of these materials are used in recycled concrete as aggregates and the rest is sent to landfills. Before 1994, about 200,000 tons of waste materials were being recycled, while this rate is more than 1 million tons in Victoria. Despite many enhancements in the field of recovery, this country still needs to increase the level of recycled materials. The main purpose of recovery is preventing the environmental destruction and also restriction of landfills in urban areas [13]. Therefore, considering the high level of waste production, environmental problems for land filling those materials and also growing cost of primary raw materials, recycling is increasingly required.

A study conducted in Brazil reveals that the rate of construction waste production is 20 to 30% of construction materials [14]. Hamusky and Netto (1994) concluded that 25% of materials change into wastes during construction process in the south of Brazil [15]. Moreover, studies conducted by Formoso et al. (1993) indicate that 20% of employed materials in a construction site turn into construction waste materials [16]. Although it is not possible to compare studies conducted in Brazil with other countries because of their own specific construction techniques and procedures, it is yet possible to note that the production rate of construction waste materials in other countries is almost similar to numbers just provided.

This huge level of construction and demolition waste materials in the world cannot be simply be overlooked. For instance, Soybelman et al. (1994), concluded that the real level of C&D waste production is 0.85 to 8 times more than what has been estimated [17]. Although some construction waste materials cannot be prevented, effective waste management and recycling can significantly decrease the level of their production.

There have been quite many studies regarding the reduction of construction waste materials. Even though the level of construction waste materials is less than those of demolition, their management is also of great importance [18]. Because:

- Due to their high level of pollution and assimilation, recycling construction waste materials is difficult.
- Preventing production of construction waste materials is preferred to recycling demolition waste materials.
- Construction waste materials contain a high level of chemical wastes.
- Reducing construction waste materials is cheaper than recycling demolition waste materials.

III. Recycling Construction Waste and Materials

Recycling is a process in which reduced materials are processed again and turned into new materials for reuse. The first important problem in recycling is separation of materials. There are generally two types of separation in recycling of construction waste materials: initial separation and commingled separation [19]. Both types of recycling have advantages and disadvantages. Initially-separated waste materials are technically preferred to commingled waste materials. Initially-separated waste materials with more than 90% recycling rate are more economical than recycling of commingled materials or land filling of wastes. Due to space limitation and economic benefits, commingled recycling materials are mixed. On the other hand, capital resources and equipment of a recycling process can obey the following rules [18]:

- Workshop recycling (reducing transportation)
- Onsite recycling with sorting and preparation
- Offsite recycling in a central station
- Offsite recycling in a distant unit (more than 200 ml)

There are several methods for reusing and recovering C&D waste materials that have requirements, advantages and disadvantages. The most prominent barrier against a successful recycling is generally the resource of recyclers. Recycling of building construction waste materials depends on the following elements:

- Different mixture of waste materials
- Extension of construction and demolition activities
- Presence of different rules for construction waste

management

- Presence of alternatives in land filling of waste materials
- Different costs for land filling through waste aggregation

Some construction waste materials and debris exist on construction sites that can be reused and recovered up to 95%. Some waste materials like bars have not been mixed with other materials and thus, can be separated and cleaned. Some recyclable materials include, concrete, metals, brick and block, asphalt and wood.

IV. Recycling of Construction Waste Materials with Respect to Qualitative, Technical, Economic and Environmental Features

One of initial steps taken in recycling process of construction waste materials is their separation. As mentioned before, in case of initial separation, recycling procedure would be more efficient and practical. Moreover, recycling costs would fall.

After introduction and classification of construction waste materials, Joodaki (2009) investigated each class' potential for being recycled. Then he studied how they can be managed through (1) disposal and land filling, and (2) reusing and recycling. After comparing the costs of these two approaches, he provided some suggestions for better management of such construction waste materials [20]. If recycling is more expensive than land filling, there would be always one good reason for not recycling. But in case the cost of recycling is the same as or less than land filling, recycling would always come first.

International experience has proven that during the reconstruction and cleaning operations in disaster-stricken areas including, earthquake, flood and etc., a major portion of demolition waste materials can be reused or recycled to not only save economically, but also prevent the delivery of wastes to limited landfills and accordingly, many environmental issues.

In 2008, Shafa-Baakhsh and Rezaian investigated different methods for promoting recycling systems of solid waste materials [21]. They compared the initially-separated and commingled materials for recycling and concluded that the former is technically much preferred to the latter. They also discussed advantages and disadvantages of these two approaches. In general, preventing the loss of materials, recycling and reducing production and land filling costs would decrease the total cost of projects. In their study, Shafa-Baakhsh and Rezaian provided a table in which advantages and disadvantages of different management methods of construction waste materials are illustrated. It should be noticed that each factor in this table has its own requirements, advantages and disadvantages that must be considered before performing a waste management program. In addition, methods mentioned in that table cannot be applied to or implemented in every workshop and should be adapted to the present circumstances of each workshop [1].

In a study conducted in 2011, Mortezaee investigated the behavior of aggregates and concrete resulting from recycling materials as well as their physical and chemical properties [22]. Aggregates are needed for construction projects and are usually defined as rubbles that are employed either in natural form or after being mechanically crushed, washed and sized. Aggregate can be naturally sand, gravel or rubble. Thus, by replacing natural aggregates with recycled aggregates, environmental damages would decrease.

Employing C&D waste materials in buildings' facades using new implementation methods are increasing. Among them are recycled glass and plastic facades and also recycled concrete façade.

Recycled glass façade: glass wastes are newly used in the buildings' facades. In recycled glass facades, glass wastes are firstly accumulated from different places and then turned into granules in specific sites. Glass granules are then turned into dough to which aluminum, plastic or other substances are added for better formation. After cooling process, aggregate glass granules with different colors are resulted that can be combined with concrete and create a beautiful façade resistant to erosion and corrosion.

Recycled plastic façade (plastic panels): plastic panels are a new type of modern facades made of polyolefin plastics. High strength and high resistance to weather, UV ray and erosion are among the features of these panels.

Recycled concrete façade: recycled concrete façade is an innovative plan for using C&D waste materials, especially those from concrete structures, in new-made facades [23]. Concrete wastes currently form the main portion of construction waste materials. Only a small part of them are reused in concrete aggregates and a significant portion is disposed as useless waste materials. However, it should be noted that waste concrete particles are also used as aggregates in concrete which is nothing, compared to its large level of disposal.

In a study conducted by Meisam Arji and Parsa Mohajeri in 2012, a new façade made of recycled concrete wastes was introduced considering proposed approaches used in the buildings' façades and its resulting waste materials. This façade with code number of 72468 was registered as a patent in the State Organization for Registration of Deeds and Properties in Iran. In this design, it has been attempted to create a beautiful façade with different applications by using concrete and other construction materials with economic justification [18] (Fig. 1).

Fig. 1 Recycled concrete facade with different designs [18]

Recycled concrete façade made of C&D waste materials was firstly used as an approach for reducing and recycling

construction waste materials. The main materials used in recycled concrete façade are concrete, sand mortar and cement. Other C&D waste materials like, brick, tile, stucco and even asphalt can also be used in creating recycled façades. Given the growing rate of construction in developed countries, it is expected that recycled concrete façade not only can decrease waste materials but also be a new approach for reusing and recycling those materials in interior facades with acceptable features. Although more studies on other construction materials are required, performed examinations have proven the use of such facades in buildings [18].

Moreover, there have been several researches with respect to qualitative and technical features of recycling materials which are briefly counted. In 2007, Raw and Zha studied the possibility of using construction waste materials in concrete and evaluated different problems of C&D waste materials, their recycling and reusing in concrete form different aspects.

Form of aggregates affects the properties of both fresh and hard concrete. Aggregate particles should be ideally in the form of cubic. In case the number of flat and long aggregates increases, the concrete's efficiency would decrease and the amount of water needed for obtaining the expected slump would increase. The crushing process of concrete should be closely monitored. Recycling aggregates are materials 100% crushed and are highly angled. While this shape assists the mixture's resistance, it reduces the concrete's efficiency.

Recycled aggregates do not basically affect the concrete's compressive and tensile strengths when large natural aggregated are replaced with large recycled aggregates. When natural granules are replaced with recycled ones, the concrete's strength is decreased about 35 to 50%. If the concrete is made of 100% recycled aggregates, there is no significant difference between the former and a concrete containing natural granules regarding their resistance to melting and freezing [1].

Pon et al. studied the creation of paving blocks using recycled concrete materials and crushed clay brick [24]. Due to the shortage of space for land filling of materials in Hong Kong, they decided to use recycled materials for production of paving blocks. Results revealed that due to high water absorbance of clay particles, using clay brick in these paving decreased their density, compressive and tensile strengths. Therefore, replacing clay brick with fly ash with the same ratio increased the blocks' compressive strength. Paving blocks made of 50% crushed clay brick and 50% recycled concrete materials are able to satisfy the minimum requirements of pavements [24], [25].

Martin Morales and Zamorana (2010) investigated the characteristics of recycled aggregates [26]. They used four types of recycled rubbles. Sample 001 contained particles obtained from breaking before shaking of sieves and samples 002, 003 and 004 were recycled aggregates with particle sizes of 10-50 mm, 6-10 mm and 0-6 mm, respectively.

Findings indicated that geometrical, physical-mechanical and chemical characteristics of aggregates affected the properties of recycled aggregates. Chemical compounds of recycled aggregates had the most negative impact, because recycled materials had high concentrations of sulfate and chloride. The quality of recycled aggregates can be modified by combining them with natural aggregates or soaking them in water to reduce chloride.

Moghimi and Berenjyaan (2006) examined the effect of crushed concrete as aggregates in recycling concrete [27]. Concretes with certain strengths were selected for recycling. Water absorption, density and bulk specific weight tests were performed on the waste concrete after being crushed and the results were compared with natural aggregates. Finally, compressive and tensile strengths, elasticity module and shrinkage of recycled and normal concretes were compared.

Results illustrated that in most cases, using recycled aggregates will lead to a recycled concrete with less compressive and tensile strength than normal concrete. Replacing recycled granules with natural gravel do not yield a significant change in compressive and tensile strengths of recycled concrete. Additionally, recycled concrete has more shrinkage compared to the normal concrete.

V. Conclusion

One of the most significant problems recently faced by developing or developed countries of the world is the aggregation of construction waste materials due to urban developments and replacement of old buildings with new constructions or unexpected natural disasters such as earthquake and flood. Thus, recycling waste materials is a vital task theta needs to be examined form different economic, technical, qualitative and environmental aspects. Reusing waste materials as primary raw materials introduces beneficial and economic approaches that not only help preserving environment, but also solve the shortage of primary raw materials to some extent. In line with ongoing urban developments, recycling materials can be used in park designing, slope leveling, landscaping, road-constructions and foundations. The main purpose of this study is to first classify the existing data in the field and then to create some policies for reusing construction materials (including waste materials) by recycling them into some other elements useful in construction. Indeed, this fact seeks a more important goal which is to prevent the accumulation of materials in mass and their occupation of useful spaces and also, to prevent environmental pollution.

It should be noted that having accurate information about the quality and amount of waste materials, place of recycling materials and markets for used materials are amongst the most important issues for a successful plan of recycling. Constant change in compounds of construction materials due to presence of different types of material with different qualities are among the problems in recycling construction waste materials.

More experimental studies are needed to balance the buildings' demolition, reconstruction and renovation activities and also to create approaches for reusing and recycling of construction debris in order to decrease environmental impacts and pollutions. Several studies were considered in the present article. Results indicate that recycling of waste materials is an efficient act from an environmental aspect. However, the type

of waste material and required equipment determine the efficiency of this issue from technical, economic and qualitative aspects.

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