Enhancing the Characteristics of Artificial Stone Utilizing Local Industrial Waste

By

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Abstract

Natural stone is one of the most important construction materials in Palestine. However, the excessive use of this resource has led to its enormous depletion causing devastating impact on environment and biodiversity. On the contrary, the amounts of solid waste, especially industrial by-products are increasing dreadfully due to population growth and increase of economic activities. There is an increasing need to come up with innovative ideas to recycle the generated waste and to use it developing useful materials such as artificial stones. The aim of this project were to identify potential byproducts (waste) from local industries and to test them as additives for development of environment-friendly artificial stones with the internationally requested construction standards, such as high compressive strength and low water absorption ratio. Using 10% non-flocculated stone slurry significantly improved compressive strength of the produced artificial stone, while using 15% fine glass powder improved water absorption. Therefore, we suggest a future work to test several combinations of these two wastes to develop an environment-friendly building stone (EfStone). Using 5% of the fine wood sawdust as an additive produced blocks that have less water absorption, lighter weight, and stronger than locally produced bricks. Therefore, we strongly recommend using this formula to develop environment-friendly bricks (EfBrix). Altogether, our results are very promising indication that there is a strong potential to recycle some of the industrial waste and to use them in a future industry of environment-friendly construction materials.

الإهداء

بسم الله الرحمن الرحيم " وَقَضَىٰ رَبُّكَ أَلَّا تَعْبُدُوا إِلَّا إِيَّاهُ وَبِالْوَالِدَيْنِ إِحْسَانًا" صدق الله العظيم

نهدي هذا العمل المتواضع إلى من وهبونا الحياة والأمل ..إلى أساس النجاح كله .. إليكم والدينا نهدي هذا العمل.

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Research Proposal

1.1 Introduction

Artificial stone is a mixture that contains cement, aggregate, mortar and some additives, manufactured to simulate natural cut stone. It is used as an architectural feature, trim, ornament or facing for buildings or other structures. It can also be used in many domains such as artistic, industrial and construction uses. The idea of producing artificial stone started in the 18th century, and it has been an initial building material for hundreds of year [1].

Prompted by the drain of raw materials, the world has to find new alternatives materials that satisfy the need of natural stone, which be affordable with good quality and price. However, the need of artificial stone in some places is increased because of the privation of natural stone on one hand, and the difficulty of importing natural stone on the other hand so, producing the stone solves the problem in both better and cheaper way.

One of the major drawbacks of using natural stones for construction is the significant batch to batch variations of their visual and physical properties even if they are obtained from the same quarry. This is an inherited feature of most natural stones due to the variable geophysical and geochemical conditions that exist during rock formation process. In contrast, the process of manufacturing artificial stones can be tightly controlled in terms of the ingredients, physical conditions and time. This critical difference is one of the advantages of the virtual stones over the natural stones, especially in construction projects that put restrictions on the margin of visual and physical variations.

Additionally, the current global waste generation levels are approximately 1.3 billion tons per year, and are expected to reach 2.2 billion tons by 2050. With this rapidly generation of waste, the world needs to get rid of it in environmental friendly ways [2].

Hasan Fathy, an Egyptian architectural engineer, who reuses wastes of remnants corn and sugar cane with local substances as mud to produce a new low cost construction material, is one of the examples to dispose waste with an environmental way.

Because of the increase of demand on building materials, the engineers were motivated to reuse the industrial wastes into construction and building materials. Also the increasing accumulation of industrial wastes mostly at the developing countries has resulted negatively on environmental concern[3].

In Palestine, Stone cutting industry generates a huge amount of waste water and solid wastes (dust) in the process of stone quarrying, transportation and production. That causes a serious environmental pollution, which results in several respiratory infections to the workers at the quarry and the surrounding population as well. In addition to that, the dust also adversely affects visibility and decrease the growth of vegetation and hampers aesthetics of the area. Such waste can be utilized in the production of artificial stone and There are other potential industrial wastes that can be added to the artificial stone formula as well[4].

The aim of this project was to utilize local wastes/byproducts materials, such as stone cutting slurry and powder, glass, wood, and marble cutting powder to enhance artificial stone quality and reduce the effects of those wastes.

1.2 Problem Statement

This project answers the following question:

Is it technically feasible to improve the quality of artificial stone by using alternatives and additives from local industries waste?

The following sub-problems will be answered:

1. What is the effect of varying stone cutting slurry or powder percentage on stone compressive strength, water absorption and other required characteristics?
2. What are the potentials of adding admixture (waste/byproducts) on the compressive strength and water absorption?
3. What is the economic feasibility of utilizing industrial wastes in the production of artificial stone?

1.3 Goals and Objectives

Main goal:

The main goal of this project is to exploit byproducts/waste of local industries to produce artificial stone.

Sub-goals:

1. To source and identify potential byproducts from local industries.
2. To prepare artificial stone samples with different alternatives and additives from local industries waste, and test the effects of those alternatives and additives on the formula and characteristics.
3. To evaluate the quality of produced artificial stones based on the compressive strength and water absorption.

1.4 Research Importance

The expansion and development of the industrial sector in Palestine and the persistent need of controlling its environmental impacts later on have raised the interest in industrial waste management. So this project responds to the need of controlling industrial wastes disposal site is based on the concept of utilizing wastes as a resource in the process of producing artificial stone.

1.5 Research Methodology

This research is based mainly on scientific experimental approach which is, in its turn, based on using compressive strength, water absorption ratio and other variables as a tool to investigate the effectiveness of using stone cutting slurry and powder, glass waste, carpentry of wood and marble cutting powder in artificial stone.

The following subsections describe materials and equipment used, and experimental procedure.

1.5.1 Materials

The following materials are used in this project:

1. White cement: white cement type CEM II/B-L 32,5R (br).
2. The by-products/wastes materials:

a) Stone cutting slurry and powder: This collected in an open-air dumpsite, with diameter less than 3 mm.
b) Glass waste powder.
c) Carpentry of wood.
d) Marble cutting powder.

3. Aggregates: two types of coarse aggregate (medium and fine).
4. Concrete admixtures; EPO MFS super plasticizer concrete admixture NO: 15050144.
5. Rotem sand.
6. Tap water.

1.5.2 Equipment

The following apparatus and equipment are used in this project:

1. Grinder to grind the glass waste.
2. Oven to dry samples and materials.
3. Molds to pour the mixture in certain dimensions.
4. Concrete compression machine Hemel Hempstead Herfordshire 1600KN/ England.
5. Slump test equipments (see section 3.4).

1.5.3 Experimental Procedure

In order to achieve the objective of the project, the following steps will be followed:

1) Prepare the wastes/ by-products to reuse in the mixtures.
a) Grind the glass waste into fine powder, wash and dry it.
b) Collect stone cutting slurry and powder.
c) Collect marble cutting powder and carpentry of wood.
2) Test all the material to make sure they conform to ASTM specifications.
3) Perform samples with different ratios of wastes/ by-products with different properties.
4) Test slump, compressive strength, water absorption for the performed samples.
5) Data analysis and ranking in charts and tables.

1.6 Action Plan

This research project will be implementing in two stages. The action plans for the two stages are illustrated in Table 1.1 and in Table 1.2 below.

Table1.1: Action plan for the first semester 2016/2017.

Month / Task	September	October	November	December
Identifying project idea				
Formation of project problem				
Obtaining production formulas				
Sourcing raw materials and preparing it				
Preparing research proposal				
Literature review				
Performing preliminary experiments				
preliminary experiments results analysis				
Documentation				

Table 1.2: Action plan for the second semester 2016/2017.

Task \ Month	January	February	March	April
Investigate the effect of adding glass waste on the formula.				
Investigate the effect of utilizing different wastes on the formula.				
Testing different characteristics for artificial stone				
Data analysis and preparation of chart results and tables				
Documentation				

1.7 Budget

The required budget is estimated at NIS as illustrated in Table 1.3 below.

Table 1.3: The budget required for the research project.

No.	Item	Description	Amount	Cost (NIS)
1	Transportation	Sampling	-	**150**
2	Compressive strength tests	Each test costs 30 NIS	50 test	**1500**
3	Water absorption tests	Each test costs 70	50 test	**3500**
4	Super plasticizers	1 L costs 30 NIS	20 L	**600**
5	Miscellaneous	Bottles, vessels …etc		**250**
	Total			**6000**

Chapter Two

Literature Review

2.1 Introduction

Solid waste produced by industrial, mining, domestic and agricultural activities had increased due to growth of population, urbanization, and the change in standards of living. In 2010, the estimated quantity of waste reached 1.3 billion tons per year, and it is expected to reach ٢.2 billion in 2050[2].

In Palestine, waste is considered as one of the most serious problems; about 1.37 million tons of SW was generated and there is a huge difficulty in dealing with it is. In addition, the increase in population leads to having insufficient waste disposal place sand shortage of sanitary landfills; as municipal solid waste and industrial emissions are considered as the main source of pollution [5]. Figure 2.1 shows the distribution of the generated SW in Palestine for 2010.

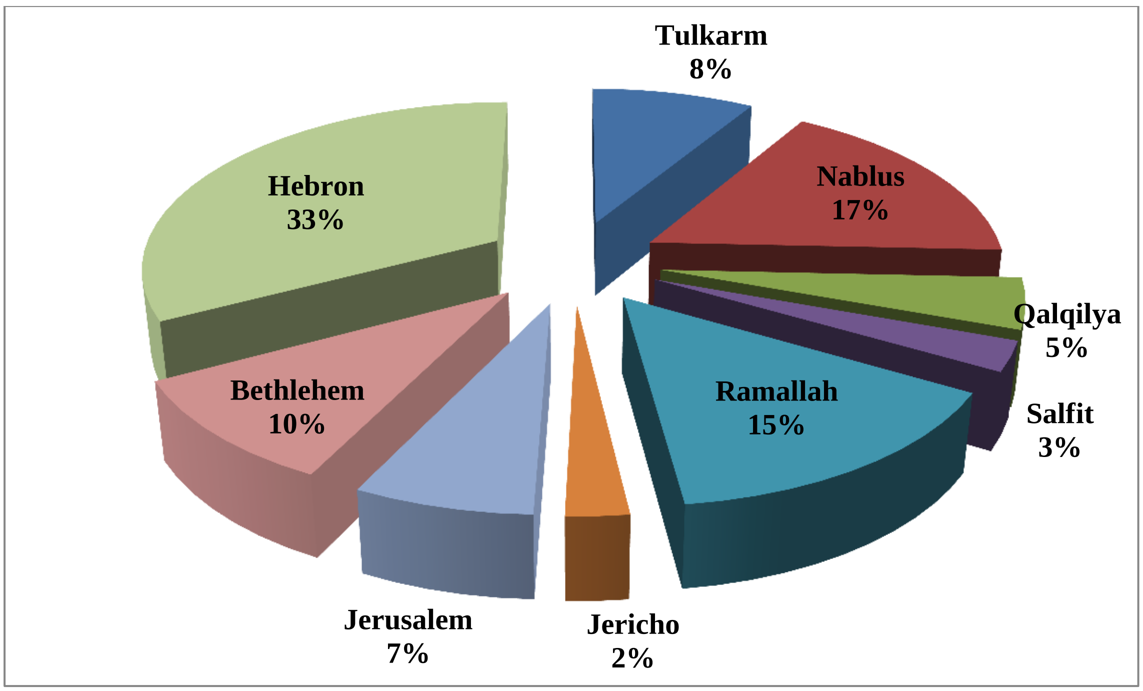

Figure 2.1: Distribution of solid waste generation in the West Bank 2010[5].

Figure2.2 shows current status of solid waste (non-hazardous and hazardous waste) generation from different sources in Palestine.

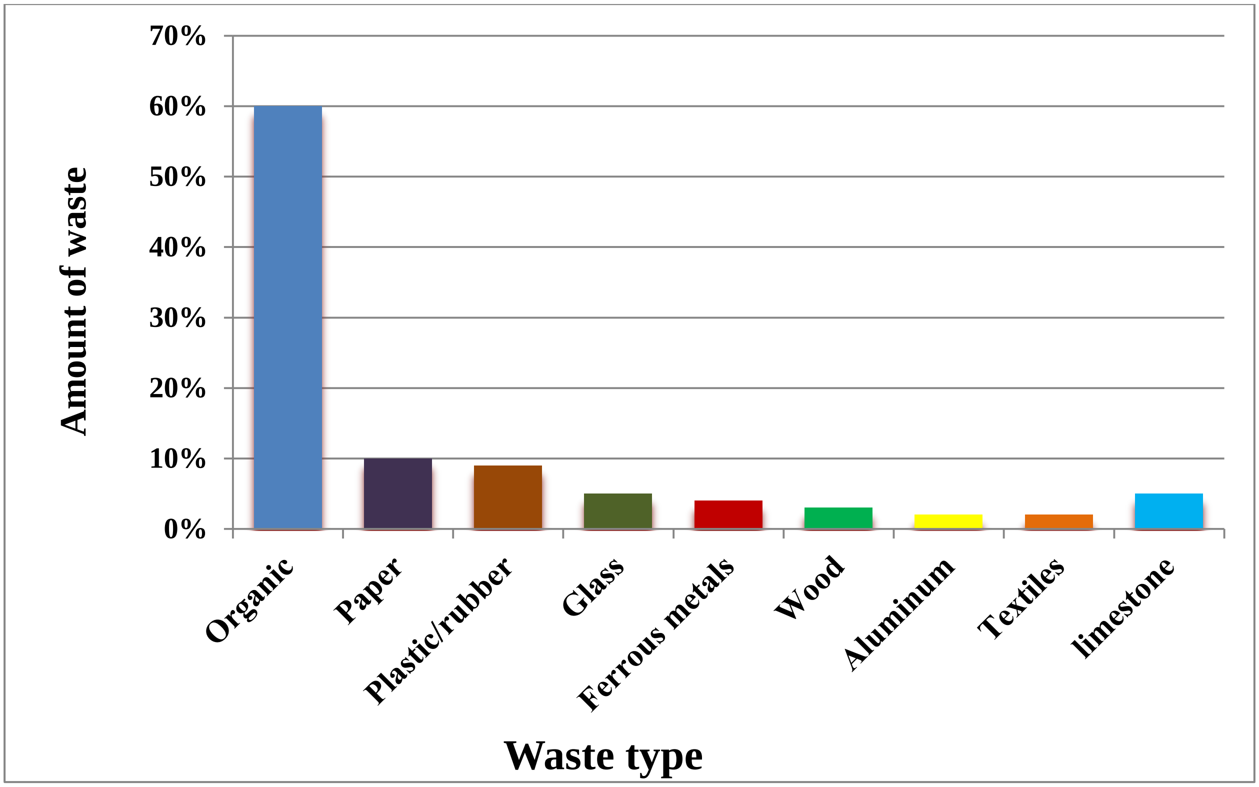

Figure 2.2: Current status of solid waste generation in Palestine[5].

2.2 Solid Waste Management

2.2.1 Introduction

Management of solid waste reduces or eliminates adverse impacts on the environment and human health and supports economic development and improved quality of life. A number of processes are involved in effectively managing waste for a municipality. These include monitoring, collection, transport, processing, recycling and disposal.

Methods of waste reduction, waste reuse and recycling are the preferred options when managing waste. There are many environmental benefits that can be derived from the use of these methods. They reduce or prevent greenhouse gas emissions, reduce the release of pollutants, conserve resources, save energy and reduce the demand for waste treatment technology and landfill space. Therefore it is advisable that these methods be adopted and incorporated as part of the waste management plan [50].

2.2.2 Waste Reduction, Reuse and Recycle

Waste reduction and reuse of products are both methods of waste prevention. They eliminate the production of waste at the source of usual generation and reduce the demands for large scale treatment and disposal facilities. Methods of waste reduction include manufacturing products with less packaging, encouraging customers to bring their own reusable bags for packaging, encouraging the public to choose reusable products such as cloth napkins and reusable plastic and glass containers, backyard composting and sharing and donating any unwanted items rather than discarding them. All of the methods of waste prevention mentioned require public participation.

Recycling refers to the removal of items from the waste stream to be used as raw materials in the manufacture of new products. Thus from this definition recycling occurs in three phases: first the waste is sorted and recyclables collected, the recyclables are used to create raw materials. These raw materials are then used in the production of new products [49].

2.2.3 Waste Collection

Waste is generally collected by local authorities through regular waste collection, or by special collections for recycling.

2.2.4 Treatment and Disposal

Waste treatment techniques seek to transform the waste into a form that is more manageable, reduce the volume or reduce the toxicity of the waste thus making the waste easier to dispose of. Treatment methods are selected based on the composition, quantity, and form of the waste material. Some waste treatment methods being used today include subjecting the waste to extremely high temperatures, dumping on land or land filling and use of biological processes to treat the waste. It should be noted that treatment and disposal options are chosen as a last resort to the previously mentioned management strategies reducing, reusing and recycling of waste[49].

2.2.5 Integrated Solid Waste Management

Integrated Solid Waste Management (ISWM) takes an overall approach to creating sustainable systems that are economically affordable, socially acceptable and environmentally effective. An integrated solid waste management system involves the use of a range of different treatment methods, and key to the functioning of such a system is the collection and sorting of the waste. It is important to note that no one single treatment method can manage all the waste materials in an environmentally effective way. Thus all of the available treatment and disposal options must be evaluated equally and the best combination of the available options suited to the particular community chosen. Effective management schemes therefore need to operate in ways which best meet current social, economic, and environmental conditions [49].

Today there is an increasing interest in developing a simple and economic method to turn waste/byproducts dust into a building product (e.g. artificial stone). Databases available through the Science Direct, Research Gate and Google Scholar were searched for relevant peer-reviewed journal papers dating from 1994 to the present using subject keywords such as, ‘‘quarry dust”, ‘‘limestone dust”, ‘‘cement composites”, ‘‘stone by-products”, ‘‘stone sludge”, ‘‘recycled aggregates”, ‘‘quarry powder wastes” and ‘‘glass wastes”.

2.3 Local Industrial Wastes/byproducts

2.3.1 Stone Cutting Industry

Most of limestone powder wastes (LPW) are cumulated, which cause environmental impacts and health effects [6]. In Palestine, quarrying and stone cutting industry generates a huge amount of stone slurry waste, which is disposed in open areas and sewage network. It causes serious environmental impact to water, air, soil, landscape, biodiversity and human communities. The stone cutting powder could be used in artificial stones production closely to natural stones specifications [7].The removed quarry dust from the aggregates by washing, referred here also as limestone dust. The most important uses of limestone dust are: in agricultural as liming material, in plastics and paper industry as filler, in iron and steel industry as flux, for flue gas desulphurization and for wastes neutralization [8].

2.3.2 Glass

Glass is a unique inert material which could be recycled many times without changing its chemical properties. There is a real need to reuse/recycle glass waste to avoid environmental problems that would be created if they were stockpiled, or sent to landfill [9].

Shaoa, replaced fine particle of glass waste as partial cement in concrete production, the results showed that glass with particle size finer than 38 mm did exhibit a pozzolanic behavior. The compressive strength from lime glass tests exceeded a threshold value of 4.1MPa, as shown in Fig.2.3 [10].

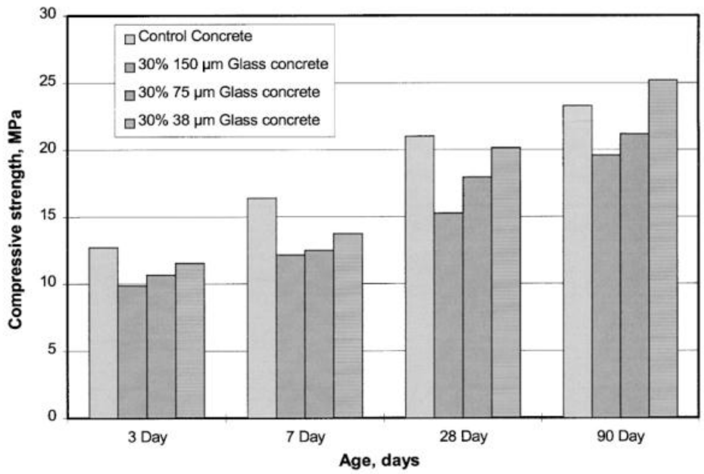

Figure 2.3: Compressive strength of concretes containing 30% ground glass**[10].**

Shayan used 30% fine glass powder (GLP) as cement or aggregate replacement in concrete measured compressive strength 39.9MPa with acceptable strength development properties[9].

Islam studied the chemical analysis of glass and cement sample to produce concrete by using X-Ray fluorescence XRF technique. Minor differences were found in composition between clear and colored glasses. The optimum glass waste content was 20%. The compressive strength was found 2% higher than the control specimen after 90 days. In addition, six tons of glass powder concrete production reduce 1 ton of CO_2 emissions [11].

2.4 Building Materials

2.4.1 Concrete

Concrete is a mixture, which is mainly made up of aggregate, sand, cement and water. Aggregate forms (75%-80%) percentage of the concrete [12]. Based on reviewing 35 papers table 2.1 was prepared, investigate the uses of quarry and stone industry fine wastes for the production of several types of concrete such as self-compacting concrete (SCC), lightweight concrete (LWC) and ordinary concrete products (CP).

Few studies have been done on exploring the feasibility of using crushed fine stone in concrete mixes for example Mahzuz et al. [13]used stone powder as an alternative of sand in concrete production; it was detected that concrete made of stone powder obtained about 15% higher strength than the concrete made of normal sand as the figure 2.4 shows.

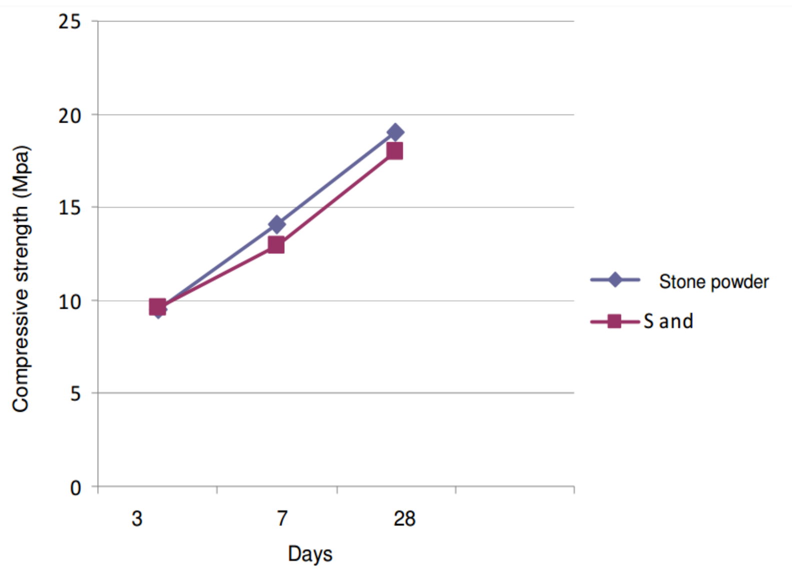

Figure 2.4: Compressive strength vs. duration for concrete[13].

Binici studied the durability of concrete produced with granite and marble as coarse aggregates. The results of this study showed that the marble and granite waste aggregates enhanced the mechanical properties, workability and chemical resistance of the conventional concrete mixtures [14].

Barbhuiya et al. [15].replaced cement by 50% of Fly ash with silica fume. Test results showed that the addition of silica fume improved the early age compressive strength of fly ash concrete exposed to sulfate attack or to decay caused by alkali-aggregate interactions.

The nanotechnology has really spacious applications in different fields, such as cement and concrete mixture, the definitions of nanotechnology, nanoscience and nano-engineering in concrete, and the impact of using this technology in concrete was extensively explained in a review paper [16].

Chahalet al. [17]. Used SporoscarcinaPasteurii bacteria with various cell concentrations to produce concrete mixture with fly ash, the results showed that compressive strength increased by 22%, and water absorption decrease 4 times with 10^5 cells/mL of bacteria. Bouzoubaâ made SCC with high volume of fly ash type F, which ensure the required concrete prosperities, with compressive strength range from 26-48MPa [18]. Becchio replaced natural aggregate with wood waste in mineralized wood concrete MWC production, characterized by high thermal resistance and low weight [19].

Cheah produced a concrete mixture, some of the cement in the mixture was replaced by wood waste ash. The results were affected by many factors such as combustion temperature of wood biomass and the chemical composition of wood, generally at height level of replacement, the mechanical strength of concrete was reduced but at low level of replacement the strength enhanced. The results recommend that 10% replacement to get acceptable strength properties [20].

Zhuet al. [21] studied the usage of limestone and chalk powder as fillers in self-compacting concrete. The results show that both materials can be used in the mixture with modest adjustment of super plasticizers dosage. Generally higher adjustment in the case of chalk powder, the adjustment affected proportionally with the grid size. The compressive strength was 30-40% grater then the conventional self-compacting concrete.

Lvinvestigated the effect of graphine oxides nano sheet (GOs) in cement on microstructure and mechanical prosperities of concrete composite. GO regulate the formation of flower-like crystals and increase the tensile strength of the corresponding cement composite[22].

Table 2.1: Use of waste/ by-products in production of concrete

Ref. No.	Year of publishing	Uses	Waste / by-products materials	Additives	Tests	Results
[6]	2007	LWC	Limestone powder wastes and wood sawdust wastes	N/A*	Compressive strength tests	7.2MPa strength
[9]	2003	Concrete	Waste glass	Cement, fly ash	compressive strength tests	32MPa strength
[10]	1999	Concrete	Finely ground waste glass	Mineral additives	lime-glass tests, the compressive strength tests, and the mortar bar tests	Compressive strength exceeded 4.1MPa
[11]	2016	Concrete	Waste glass powder	CEM 1 super plasticizer	Compressive strengths	Compressive strength is 30MPa
[12]	2014	Concrete	Crushed Limestone	Portland cement	Slump test. compressive strength	Increased in compressive strength
[13]	2011	Concrete	Stone powder	N/A*	Compressive strength test	Compressive strength is 33.02MPa
[14]	2007	Concrete	Granite and marble	Super plasticizer	Compressive strength splitting-tensile strength	Splitting tensile 3MPa compressive strength 44.3MPa
[15]	2009	Concrete	Fly ash ,silica fume	Water, super plasticizer	Compressive strength test	50MPa strength

[18]	2001	SCC	F fly ash	None	compressive strength and drying shrinkage	compressive strength is 26–48MPa
[19]	2009	LWC	Mineralized wood waste	N/A*	Compressive strength	N/A*
[20]	2011	LWC	Wood waste ash	Portland cement	Compressive, flexural and splitting tensile strength	Decreased
[21]	2005	SCC	Limestone and chalk powders	Super plasticizer	Compressive strength	Increased
[23]	1995	LWC	Textile waste cuttings	Portland cement	Compressive strength tests , water absorption	4.781MPa strength 43.728% water absorption
[24]	2007	Concrete	Waste glass aggregate	N/A*	Compressive, tensile, flexural and strength test	Decreasing tendency along with an increase in the mixing ratio of the waste glass
[25]	2016	Concrete	Waste glass (20-14mm)	Fly ash	Compressive and flexural strength test	Compressive strength reached only about 22MPa
[26]	2008	SCC	Marble dusts	Portland cement	Compressive strength Abrasion resistance	Higher than control specimen
[27]	2007	SCC	Limestone powders	Portland cement	Compressive strength	Compressive strength is 45–50MPa

[28]	2004	High-strength concrete	Palm oil fuel ash	Silica fume	Compressive strengths	79.5MPa

*N/A= No Data Available.

2.4.2 Bricks

Brick is one of the most important building materials that is basically produced from clay, shale or mixture of both, producing mortar and let it sun-dried or burned in kiln, magnifying strength and hardness, table 2.2present the use of some waste/by-products in brick industry [29].

Table 2.2: Use of waste/by-products in brick industry.

Ref. No.	Waste material used for production	Drying time/ temperature	Size of mould (mm)	Firing/curing	Tests	Results
[14]	Plastic fiber, straw polystyrene fabric	N/A*	150 x 150 x 150	Cured using wet gunny bags for 7 days	Compressive strength and water absorption	Compressive strength increased
[30]	Fly ash	For 24 hours at room temperature	95 x 45 x 40	Fired in a oven ,and cured in water	Compressive strength, water absorption	Compressive strength improved by 4 to 5 times

[31]	Crumb rubber waste	For 6 hours at room temperature	105 x 100 x 75	Cured in water for 28 days, dried for 48 hours	Compressive strength, water absorption, flexural strength, UPV test, splitting strength test	Thermal insulation performance is improved
[32]	Cigarette butts	For 24 hours at 105 °C oven	300 x 100 x 50	Fired in a oven	Compressive strength, water absorption, density, flexural strength and thermal conductivity	Density reduced by up to 30 %, thermal conductivity improved by 51 and 58%
[32]	Waste tea	Dried for 72 at 21 °C and then dried at 105 °C in the oven	40 x 70 x 100	Fired at the rate of 2 °C /min until 600°C and then 5 °C /min until 900 °C for 2 h.	Water absorption, compressive strength and density	Compressive strength increased
[33]	Rice husk ash	Dried for 24 hours at 105°C oven	50 x 50 x 50	Fired in a oven at 1000 °C	Water absorption, compressive strength and Density	Compressive strength increased

[34]	Waste paper pulp	At room temperature	2300 x 105 x 80	N/A*	Compressive strength, water absorption and Specific weight	Compressive strength increased

*N/A= No Data Available.

2.4.3 Artificial stone

Many researchers have studied the utilization of some waste/byproducts in order to enhance the characteristics of the produced artificial stone. The main findings of these studies are presented below in table 2.4.

Barani et al[35]. Used the waste stone sludge from the granite and marble stone processing factories to produce artificial stones using vibratory compaction. The compressive strength has resulted more than 90MPa with a density less than 2.68 and water absorption less than 0.64.

Yu Lee et al[36]. Manufactured artificial construction slabs from waste glass powder and fine aggregates, with a compressive strength of 148.4MPa and water absorption less than, 02%.Wangrakdiskul studied the use of by-product of crushing limestone plant for producing non-fired wall tiles. The additive has an effect on the bending strength and water absorption, the bending strength was 2.32MPa and water absorption is 3.20% [37].

Table 2.3: Use of waste/ byproduct in artificial stone production.

Ref. No.	Year	Uses	waste / by-products materials	Additives	Tests	Results	Method of preparation
[8]	2003	Artificial stone	Limestone dust	Portland cement	Compressive strength modulus of elasticity	Compressive strength greater than 7MPa	N/A*
[35]	2015	Lightweight artificial	Waste granite and marble stone sludge	Unsaturated polymer resin (orthophtalic resin)	Compressive strength, flexural strength, water absorption and tensile strength	Water absorption of less than 0.64, a density less than 2.68, a flexure strength of more than 45MPa, a compressive strength of more than 90MPa, and a tensile strength more than 35MPa	Vibratory compaction

[36]	2008	Artificial stone slab	Waste glass powder and fine granite aggregates	Unsaturated polymer resins	Compressive strength, water absorption, flexural strength	Compressive strength of 148.8MPa, water absorption below 0.02% and flexural strength of 51.1MPa	Vibratory compaction

*N/A= No Data Available.

Chapter Three

Experimental Work

3.1 Methodology

This is an experience based project that aims at using wastes/ byproducts to improve functional properties of artificial stone. All materials and tests used in this study comply with ASTM standers. A control samples with (10 ^{x} 10 ^{x} 10) cm dimensions were prepared, slump test was performed on fresh concrete mixture and then left to dry for 24 hours. The compressive strength was measured at (1, 3, 7, 14, and 28 days). Other samples with the same dimensions were prepared with different ratios of stone cutting slurry, both with and without flocculent agent (5, 10, 15 and 20%). Marble waste water, glass waste powder and wood sawdust were utilized as alternative for water, sand and aggregates representatively in artificial stone mixture, compressive strength and water absorption were measured at age 28 days.

3.2 Materials and Equipment

- **Materials**

Materials used in this project include the followings:

Ordinary Portland white cement type CEMII/B-L32, 5R (br), Rotem sand passing sieve 100, two size of angular aggregates (medium and fine gravel), tap water, EPO MFC superplasticizer NO: 15050144, stone cutting slurry with flocculent agent, stone cutting slurry without flocculent agent, glass with various sizes(size I=0.6mm, size II= 1.18mm) and ratios, wood sawdust (fine and coarse) and marble waste water.

- **Equipment**

The following apparatus and equipment are used in this project:

Iron molds to pour the mixture in certain dimensions (10^{x}10^{x}10) cm, concrete mixing tub, tamping rod, slump cone, slump plate, ruler, concrete scoop, concrete compression machine Hemel Hempstead Hertfortshire 1600 KN/ England, oventio dry samples and materials, weight machine and curing tank for concrete specimens.

3.3 Artificial Stone Formula

3.3.1 Addition of Stone Slurry as Alternative of Sand in Artificial Stone production

Two starting production formulas were used in this experimental work. They were obtained from two local manufactures. Then these formulas were modified by adding superplastisizer and different ratios of stone cutting slurry. Table 3.1lists the mixture content for different formulas.

Table 3.1: Mixture content for stone slurry addition.

Formula	Materials quantities	Alternatives/admixtures	Fundamental element
B	2kg white cement. 2.9 kg sand. 9.5kg aggregates [4.75kg medium, 4.75kg fine]. 1200mL tap water.	None	None
A	2.6kg white cement. 2.7 kg sand. 6.5kg aggregates[3.25kg medium, 3.25kg fine]. 1200mL tap water.	None	None
AS	2.6kg white cement. 2.7 kg sand. 6.5kg aggregates[3.25kg medium, 3.25kg fine].	14.5 mL superplastisizer	Water

	950mL tap water.		
ASF	Formula AS	14.5 mL superplastisizer 10% flocculated stone slurry(0.27Kg)	Water and sand
ASP_5	Formula AS	14.5 mL superplastisizer 5% unflocculated stone slurry(0.135Kg)	Water and sand
ASP_{10}	Formula AS	14.5 mL superplastisizer 10% unflocculated stone slurry(0.27Kg)	Water and sand
ASP_{15}	Formula AS	14.5 mL superplastisizer 15% unflocculated stone slurry(0.405Kg)	Water and sand
ASP_{20}	Formula AS	14.5 mL superplastisizer 20% unflocculated stone slurry(0.54Kg)	Water and sand

3.3.2 Addition of Glass Powder as Alternative of Sand in Artificial Stone production

Glass waste powder was added as alternative of sand in artificial stone formula, to enhance the characteristics of the stone. Tables 3.2 illustrate the detailed quantities used in the mixture.

Table 3.2: Mixture content for glass addition in artificial stone formula.

Formula	Materials quantities	Alternatives/admixtures	Fundamental element
ASG_5	3.12 kg white cement. 3.078 kg sand. 7.8 kg aggregates[3.9kg medium, 3.9kg fine]. 1140mL tap water.	17.5 mL superplastisizer 5% glass (0.162 Kg)	Water and sand
ASG_{10}	3.12 kg white cement. 2.916 kg sand. 7.8 kg aggregates[3.9kg medium, 3.9kg fine]. 1140mL tap water.	17.5 mL superplastisizer 10% glass (0.324 Kg)	Water and sand
ASG_{15}	3.12 kg white cement. 2.754 kg sand. 7.8 kg aggregates[3.9kg medium, 3.9kg fine]. 1140mL tap water.	17.5 mL superplastisizer 15% glass (0.486 Kg)	Water and sand

ASG_{20}	3.12 kg white cement. 2.592 kg sand. 7.8 kg aggregates[3.9kg medium, 3.9kg fine]. 1140mL tap water.	17.5 mL superplastisizer 20% glass (0.648 Kg)	Water and sand

3.3.3 Addition of Wood Sawdust as Alternative of Aggregate in Artificial Stone production

Artificial stone mixtures were prepared utilizing wood sawdust as alternative of aggregate. Elaborated mixing ratios were as shown in table 3.3.

Table 3.3: Mixture content for wood addition in artificial stone formula.

Formula	Materials quantities	Alternatives/admixtures	Fundamental element
ASW_5	3.12 kg white cement. 3.24 kg sand. 7.41 kg aggregates[3.705 kg medium, 3.705 kg fine]. 1140mL tap water.	17.5 mL superplastisizer 5% Wood (0.39 Kg)	Water and aggregates

ASW_{10}	3.12 kg white cement. 3.24 kg sand. 7.02 kg aggregates[3.51kg medium, 3.51kg fine]. 1140mL tap water.	17.5 mL superplastisizer 10% Wood (0.78 Kg)	Water and aggregates

3.3.4 Addition of Marble Waste Water as Alternative of Aggregate in Artificial Stone production

As alternative of water, marble waste water was utilized. Table 3.4 clarified the quantities used in artificial stone mixture.

Table 3.4: Mixture content for marble addition in artificial stone formula.

Formula	Materials quantities	Alternatives/Admixtures	Fundamental element
ASM_{20}	3.12 kg white cement. 3.24 kg sand. 7.8 kg aggregates[3.9kg medium, 3.9kg fine]. 912mL tap water.	17.5 mL superplastisizer 20% marble waste water (228 mL)	Water

ASM_{30}	3.12 kg white cement. 3.24 kg sand. 7.8 kg aggregates[3.9kg medium, 3.9kg fine]. 798mL tap water.	17.5 mL superplastisizer 30% marble waste water (342 mL)	Water

3.4 Procedure

In order to achieve the objective of the project, the following steps were followed:

1. Prepare the waste/ byproducts for testing.

a. Grind the glass waste into fine powder, wash and dry it.
b. Collect stone cutting slurry and powder.
c. Collect marble cutting powder and sawdust of wood.

2. Test all the other materials (cement, aggregate and sand) to make sure they conform to ASTM specifications.
3. To perform samples with different ratios of wastes/ by-products, White cement was mixed with sand, aggregate (medium, fines) and tap water for 10 min manually using a trowel. Other components are added according to the selective formula.
4. Test slump, compressive strength, water absorption for the performed samples as detailed below:

a. Slump test was done for the fresh concrete according to ASTM standard (C143). using a standard slump cone, slump plate, tamping rod and a ruler. The slump cone was placed on the slump plate. The cone was filled with fresh concrete in three equal layers. Each layer was tamped for 25 strokes using the tamping rod. The surface was leveled with a trowel. The cone was raised slowly and the slump then was measured with the ruler as the different between the height of the cone and that of specimen.

b. The compressive strength test was performed on the samples at 28 days, using the compressive strength machine and the results were reported according to ASTM standard (C39M).

c. The water absorption test was carried out after 28 days according to ASTM standard tests (C1138M_12) as follows:

   I. The samples were weighted; the mass was recorded as W_1.

   II. The samples were immersed in distilled water for 48 hours.

   III. Using a clean and dry towel, the surface of the sample was dried, the samples were weighed and the mass was recorded as W_2.

Then the percentage water absorption was obtained from the following equation:

$$\text{Percentage water absorption}(100\%) = {(w_2 - w_1)}/{w_1} \times 100\% \qquad (3.1)$$

5. Data analysis and ranking in charts and tables.

Chapter Four

Producing Artificial Stone Utilizing Marble and Stone Cutting Waste

4.1 Introduction

Stone and marble industry is considered one of the main economic resources in most of the Middle Eastern and Mediterranean countries especially in Palestine. This sector contributes widely to the local production, exports and employment capacity[38]. The growth of stone and marble industry is improving in Gaza and West Bank. They provide around 5.5% to gross domestic product, representing 6.12% of the total current industrial production[39], and accepts 15,000 workers. Quarries and stone cutting plants are spread in different areas in Palestine. Sector enterprises can be divided into three main categories depending on their specific activities: quarries, stone and marble factories, and workshops[40].Statistically, there is around 605 stone cutting plants, 252 quarries, 50 crushing plants and 280 small workshops. Based on the number of quarries, Hebron city has 130 quarries putting it on the top of the cities[41].

It can be seen from Figure 4.1 that most of the quarries, factories and small workshops in the field of stone extraction and cutting exist mostly in the southern part of Palestine, namely, Hebron and Bethlehem, Ramallah, Nablus and Jenin have a medium contribution in this sector while the other regions are extremely weak. The biggest automated factories in these cities produce and export a significant amount of their products where they participate in about 40% of the total Palestinian exports[38].

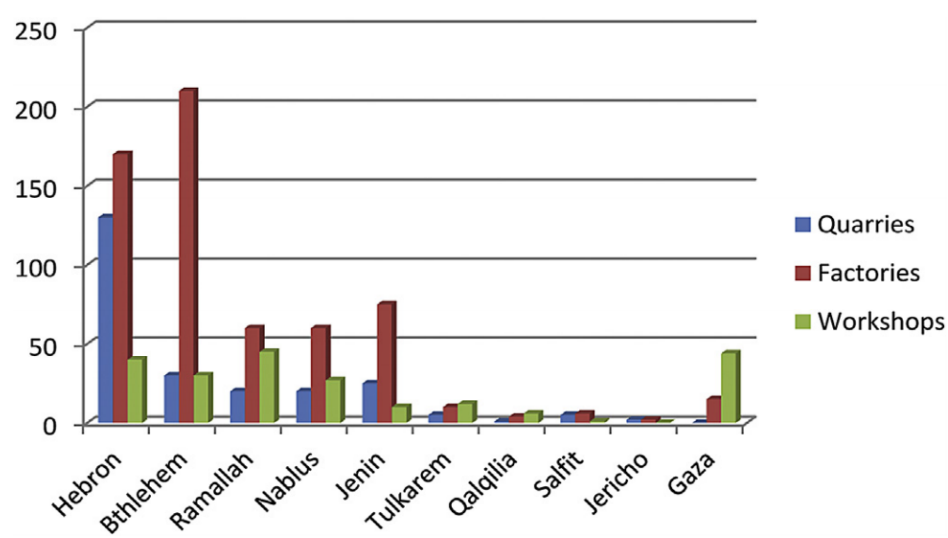

Figure 4.1: Distribution of quarries, cutting factories and workshops amongst the Palestinian governorates[38].

The chemical and physical properties of the "Stone slurry" material resulting from the stone cutting operations is presented in table 4.1[39].

Table 4.1: The chemical and physical properties of "Stone slurry"[38].

Mineralogical	**Chemical**	**Physical**
$CaCO_3$	Cu	Grain size distribution
$CaCO_3 + MgCO_3$	Mg	Oil sorption
Fe_2O	Mn	
Al_2O_3	As	
$Fe_2O + Al_2O_3$	Pb	
SiO_2	Fe	
CaO	P	
	Alkali metals	
	Hg	
	Fl	
	C > 12	
	pH	
	Acids isolable	

This chapter presents the production of artificial stone by using marble and stone cutting waste, using subject keywords such as, ‘‘stone sludge", ‘‘limestone dust", ‘‘marble waste water", ‘‘compressive strength" and ‘‘water absorption".

4.2 Background

4.2.1 Stone manufacturing process[40]

1. **Selection of the right quarry Geologists:**
Check the soil with the latest technology using sonograms, samples and digging to insure that the stone is of the highest quality and that there is sufficient reserve of this specific material. Then experts identify and mark the blocks to be processed.
2. **Cutting the block down into slabs:**
The blocks are brought to processing factories and sliced down into slabs. Slabs with the tiniest defect are rejected on the spot.

3. **Sizing of the slabs:**

   The slabs are sized down and rectified to the required dimensions. The sizes are checked with a digital measuring device to avoid the smallest size difference.

4. **Filling process:**

   Fillers are prepared by color experts to match the natural color of the stone in laboratories.

5. **Final Quality Check and Shade Selection:**

   Teams check every tile by eye for defined shade restrictions. Out-of-shade tiles are carefully eliminated.

4.2.2 Stone waste types

The waste accumulating at quarries, stone cutting plants and open areas is a severe problem facing the stone industry in Palestine. In addition to that, the waste puts the environment at the risk of pollution; it threatens the groundwater, soil, surface water, air, biodiversity and surrounding human communities. In general, the main issues associated with quarrying and stone production are: high impact on air quality, ground water and surface water; increase in pH-value and impact of flora, fauna and soil; consumption of large amounts of fresh water; slurry waste disposal reduces the area of fertile land; heavy metals in stone slurry are not soluble in water; fine suspended solids cause respiration problems[7].Stone waste exists in various forms: powder, fines, aggregates, larger stone pieces and damaged blocks[42]. So we have two types of solid waste as follow:

Quarrying waste types[43]:

1. Defective blocks.
2. Large irregular blocks (≥ 0.2 m^3).
3. Small irregular blocks (dimension < 0.5 m^3).
4. Small particles (splints, chips), and fine size slurry.

Processing waste types:

1. Large to medium size broken pieces called scrap.
2. Medium to small size pieces like splints, flakes, chips.
3. Fine size particles mainly in the form of slurry.

Also, there is a Stone slurry which is semi-liquid substance consisting of particles originated from the sawing and polishing processes and water used to cool and lubricate the sawing and polishing machines[42]. Each operation from quarrying to loading of finished products is associated with stone waste generation Figure 4.2.

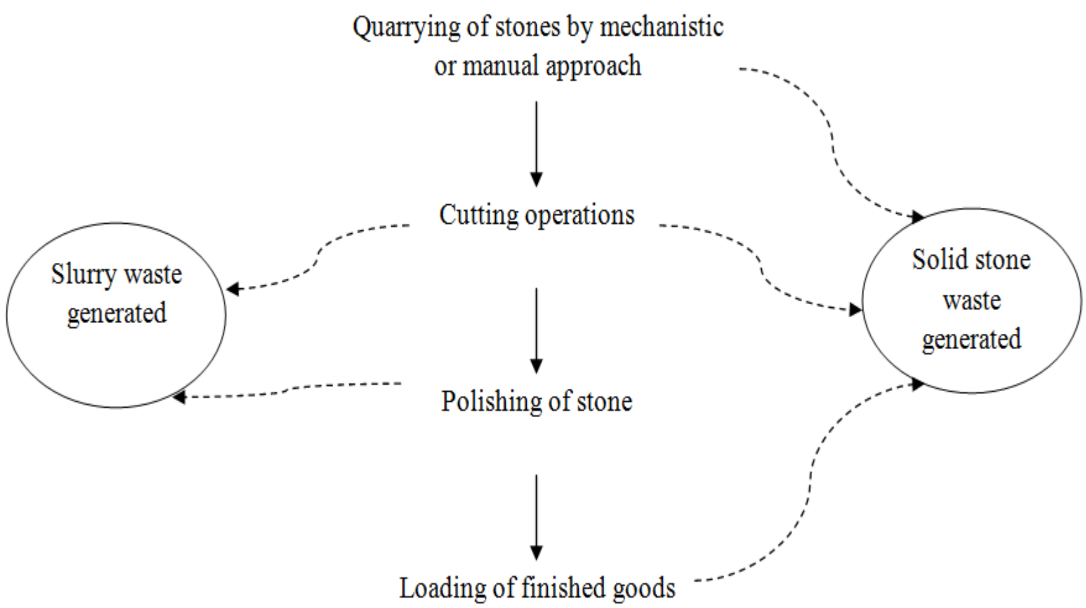

Figure 4.2: Schematic diagram of stone waste generated during various mining and processing operations[44].

4.2.3 Impact of Quarry Waste

In general, this industry is considered to be unfriendly to the environment. It creates different forms of pollution, (solid waste, dust, and noise)[45]**.** Large amount of stone waste generated from natural stone industry, which cause environmental, health and economical drawbacks. Stone slurry destructs the environment. When it disposed in landfills, water dries up and the substance turns into dust, and that causes many negative impacts over the environment. In dry seasons, the stone dust hang up in the air, flies and deposits on the crops. Disposed stone dust on riverbank causes reduction in soil porosity and permeability, which impoverish play the fertility of the soil because of alkalinity increasing[42]. Cutting process is noisy and therefore cutting workshops must be located away from the local community clusters, and noise safety measures should be implemented[38].

4.2.4 Waste disposal methods

Waste from quarries and stone saws is disposed in many ways, such as dumped in abounded quarries, breakers or random dumps. There are two types of waste: liquid and solid waste. Liquid waste produced by the cooling process in the saws, called “stone slurry”, may be stored in a sedimentation ponds, where the solids are deposit, and the water reused in the cooling process, the remaining material discharged to a special tanks and then transported to abandoned quarries or random dumps, this material hazard to the environment and soil, it forms an insulating layer and prevents soil ventilation. On the other hand, solid waste produced by quarries is in a large amounts of broken rock is more difficult to be reused in the industry.

Therefore, the waste is also deposited in random dump[46]. It was also found that some saws get rid of the liquid waste through the piston, this method considered as the newest in liquid waste disposal methods, it does not result any environmental damage or other side effects. In this way, the “stone slurry” compressed and produce solid waste which can used in bricks and ceramic industry.

4.3 Experimental Methodology

The detailed experimental methodology was presented in chapter three: adding stone slurry as alternative of sand, with flocculent and without for various dosages (5%, 10%, 15% and 20%) for each type. Another sample was prepared in a similar scheme of artificial stone, adding marble waste water as an alternative of water in two different ratios (20% and 30%). The compressive strength was measured at 28 days, water absorption was measured after 28 days according to ASTM standards. Then all the samples were coated with imperplast and water absorption ratio was measured.

4.4 Results and Discussions

The results for utilizing stone slurry and marble waste in artificial stone production were obtained, discussed and presented in the following figures that show the effect of using each waste on compressive strength and water absorption.

4.4.1 Utilizing Stone Slurry in Artificial Stone Production

This section represents the results obtained for using stone slurry in artificial stone production. Compressive strength and water absorption ratio were discussed and presented.

- **Effect of Stone Slurry on Compressive Strength and Water Absorption**

The compressive strength of the artificial stone samples was measured by concrete compression machine (Hemel Hempstead Hertfordshire 1600 KN/ England). Obtained compressive strength curves for artificial stone samples formula A and formula B are shown in figure 4.3 (see section 3.3.1). Clearly, formula A samples had higher compressive strength than B. Thus, it was adopted as a base formula for the subsequent experiments. In addition, the compressive strength test results for formula A samples after adding (14.5mL) of superplasticizer compared with formula A samples with concrete 300 is shown in figure4.4. The obtained results indicate that adding superplasticizer to the formula increases the compressive strength values. This is attributed to the fact that superplasticizer must decrease the water ratio, therefore, compressive strength increases.

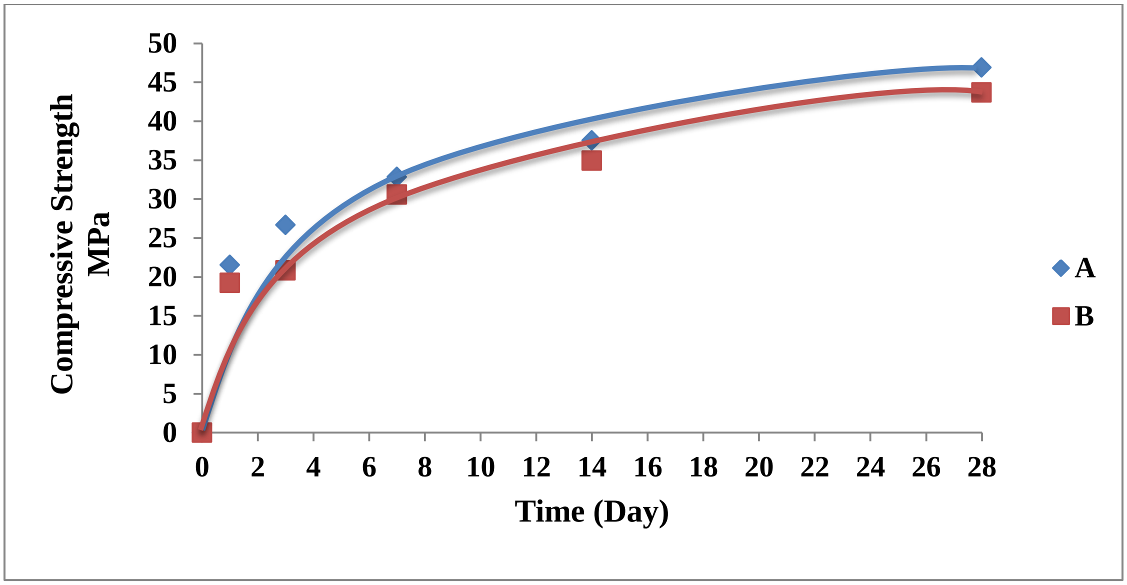

Figure 4.3: The measured compressive strength versus time for formula A and B. (see section 3.3)

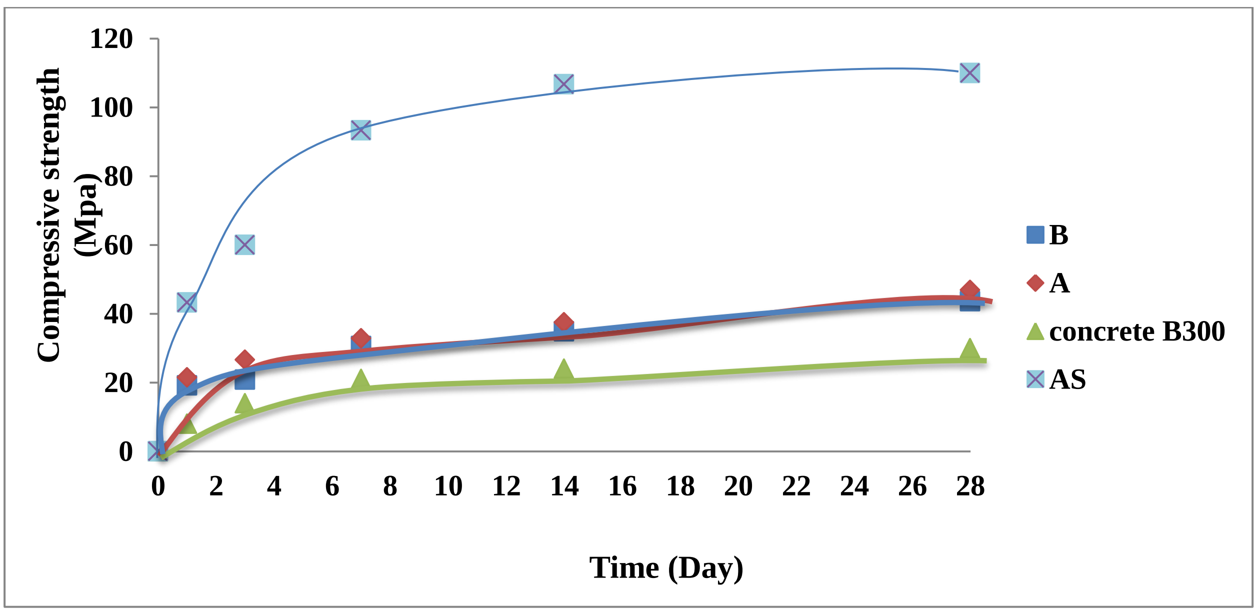

Figure 4.4: The measured compressive strength versus time for A, B, AS formulas and concrete B300. (See section 3.3)

The following table 4.2 shows the result of compressive strength and water absorption after adding stone slurry waste comparing two sources: non flocculated slurry (P) and flocculated slurry (F).

Table 4.2: The effect of percentage adding of stone slurry to artificial stone formula on compressive strength and water absorption.

Type of stone slurry	Percentage of stone slurry addition	Compressive strength	Water absorption
Non flocculated slurry (P)	5%	73.7	2.67
	10%	84	2.45
	15%	62.4	2.8
	20%	54	2.98
Flocculated slurry (F)	10%	60	2.9

Table 4.2 lists compressive strength and water absorption results for various ratios of stone cutting slurry with and without flocculent agent (5, 10, 15 and 20%). In general, adding stone slurry decreases compressive strength. From the results obtained of various stone slurry ratios we conclude that compressive strength increases until reach a critical point (10%) then it declines. Same as in water absorption it decline until it reaches (10%) then it increases.

Compressive strength was measured at 1, 3, 7, 14, and 28 days according to ASTM standard, figure 4.5 represents the result of compressive strength of various ratios of stone slurry added to A formula.

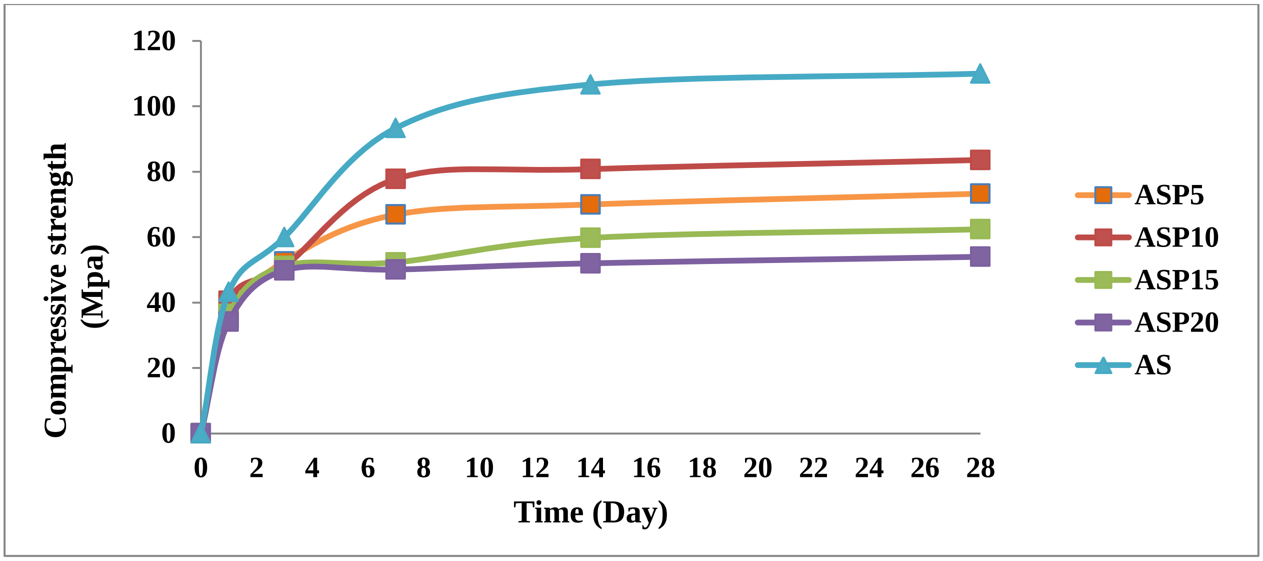

Figure 4.5: Experimental curve of Compressive strength for various percentages of stone slurry(non flocculated). (See section 3.3)

The figure 4.5 illustrate the compressive strength result, and show that the optimum value of stone slurry ratio was 10% gave the best compressive strength at day 28, which equals 84Mpa. In other words, we state that 10 % is the optimum ratio for stone slurry.

- **The Effect of Imperplast in Artificial Stone Production on Water Absorption**

Water absorption measured after 28 days according to ASTM standard (section 3.4), it was measured before and after coated artificial stone with imperplast. Figures 4.6 and 4.7 show the results of water absorption when adding stone slurry: with flocculent (F) and without flocculent (P) and the effect of imperplast on water absorption.

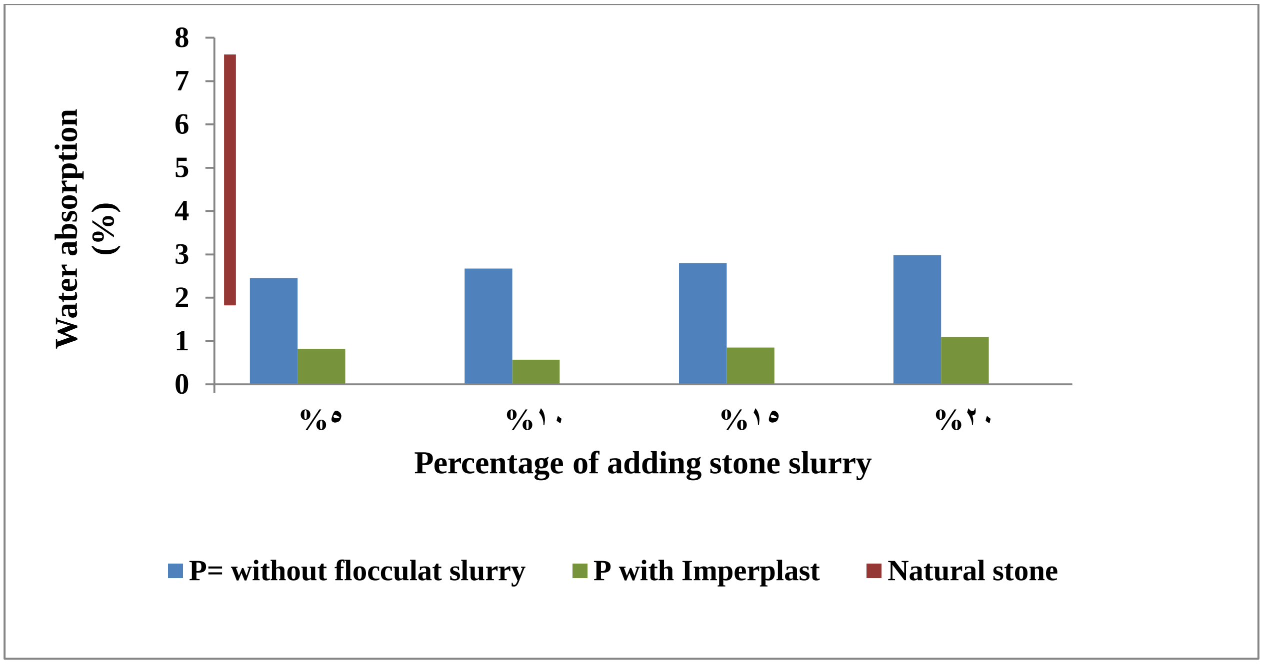

Figure 4.6: Effect of imperplast on Water absorption for no flocculated stone slurry.

Clearly, as show in figure 4.6 impreplast extremely decrease the water absorption ratio for the various ratios of stone slurry in artificial stone formula.

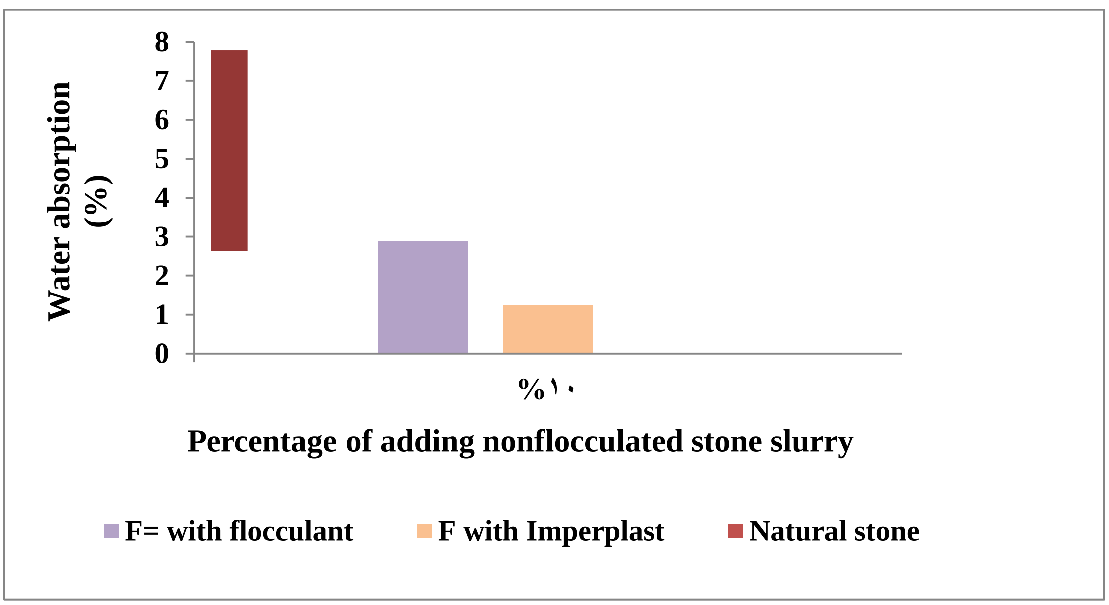

Figure 4.7: Effect of imperplast on Water absorption for flocculated stone slurry.

Same as, for artificial stone with non-flocculated stone slurry, water absorption reaches 1.5 after it was 2.9 as we see in figure 4.7, that within the range of natural stone's water absorption.

4.4.2 Utilizing Marble Waste Water for Artificial Stone Production

- **Effect Marble on Compressive Strength and Water Absorption**

Figures 4.8 and 4.9 represent compressive strength and water absorption results respectively for using marble waste water as alternative of water in artificial stone production.

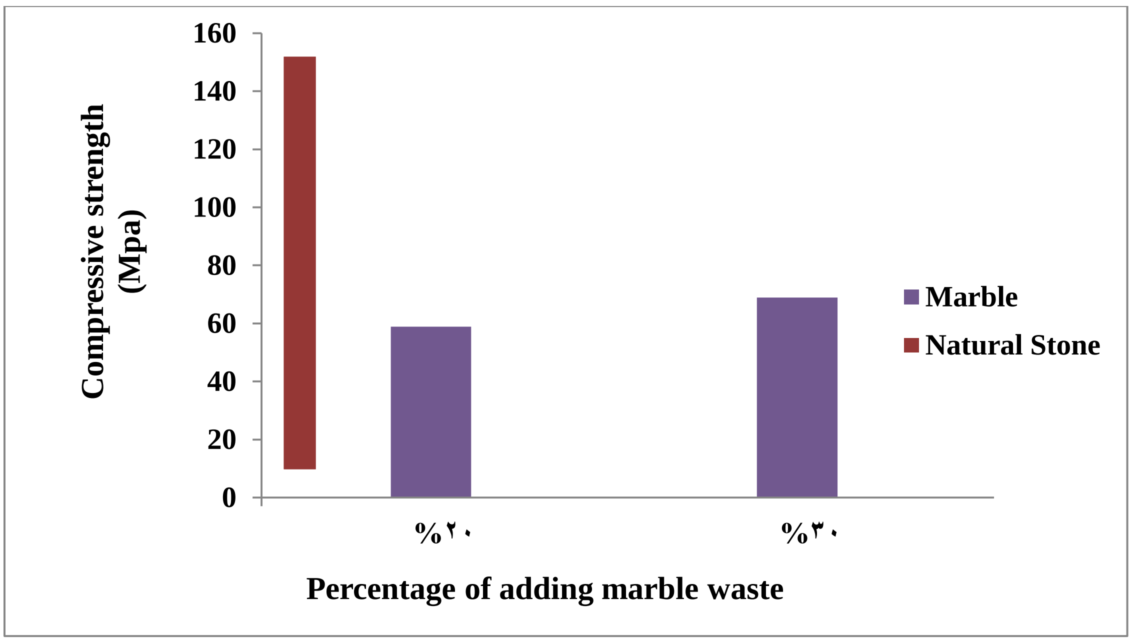

Figure 4.8: The effect of percentage added of marble waste water to artificial stone formula on compressive strength.

Compressive strength for adding marble waste water in artificial stone production as are shown in figure 4.8. It will increase by increasing the percentage of marble. As well, the result of compressive strength within the range for natural stone.

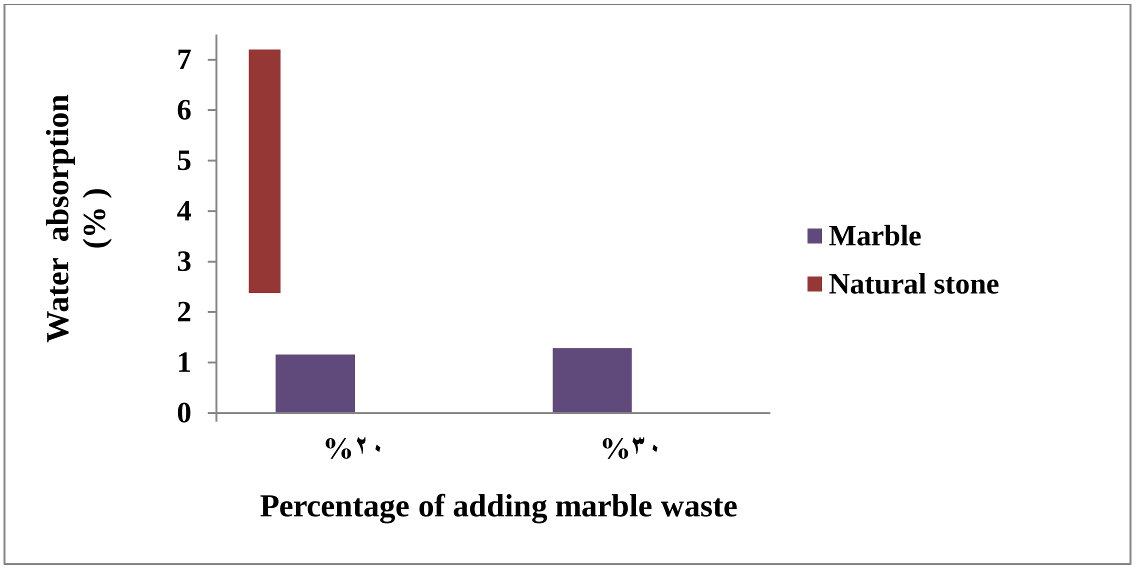

Figure 4.9: The effect of percentage added of marble waste water to artificial stone formula on water absorption.

Figure 4.9 illustrate water absorption result for marble addition. Water absorption increases when the percentage of marble waste water increases, but it still in the desired range of natural stone water absorption.

- **The Effect of Imperplast in Artificial Stone Production on Water Absorption**

Imperplast reduces the water absorption for artificial stone, the result of water absorption obtained is shown in figure 4.10

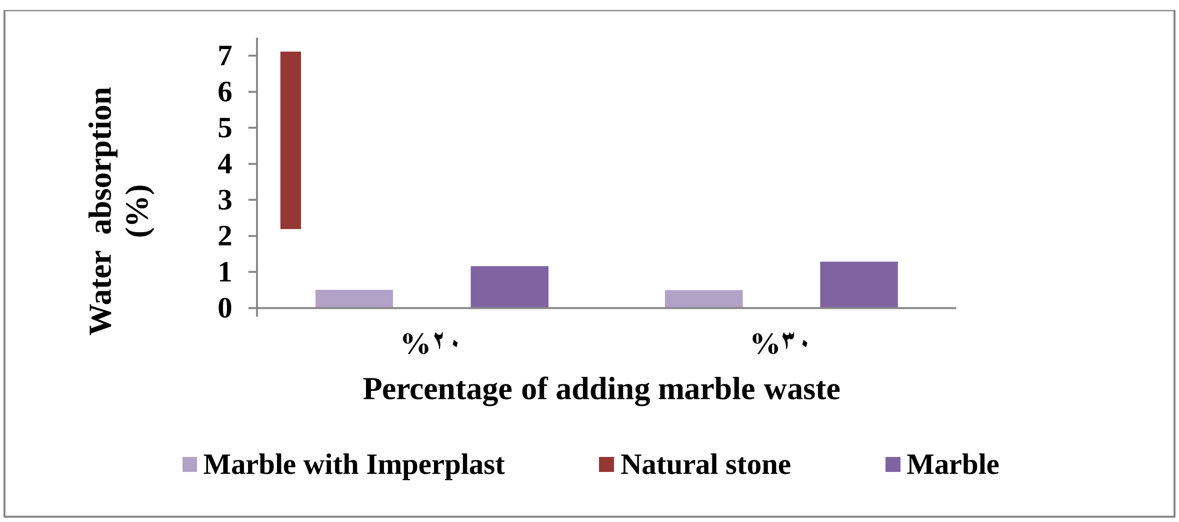

Figure 4.10: Effect of imperplast on Water absorption for marble.

As shown in figure 4.10, water absorption after paint artificial stone with impereplast decreases and promote the best value of water absorption. In addition, the two percent of marble waste water gave the same water absorption.

Chapter Five

Investigating the Technical Feasibility of Utilizing Glass and Wood Sawdust Waste

5.1 Introduction

The amount of solid waste is increasing hurriedly due to the rapid increase of population, rabid economic growth and the rise of living standards. Statistics showed that the waste from the household sector reach to 2.7 thousand tons per day in West bank and Gaza, where the industrial sector Produce 84.7 thousand tons monthly [48], these exponentially growing amounts of solid waste are raising a serious alarm that have to be noticed.

Improper solid waste management causes mischievous effects on the environment followed by all types of pollution (air, water and soil) and it may affects human health, therefore these huge amounts of solid waste and its harmful effects on the environment promote the importance of managing it in environmental friendly ways to decrease it effects. All the above mentioned reasons create real challenge in managing waste especially for developing countries as Palestine.

5.2 Classification of Solid Waste

Solid waste can be classified in three categories depending on their source, Municipal solid waste (MSW), Construction industry and demolition waste (CDW) and Medical waste. In this project we are interested in using glass waste and sawdust (wood) as alternatives on the artificial stone mixtures, both glass and sawdust waste are considered as municipal solid waste (MSW) outputs, for that we are interested in municipal solid waste statics.

٥.٢.١ Municipal solid waste (MSW) :

This type basically is residues from homes, restaurants, hotels and commercial sources, this waste is mainly heterogeneous on both physical and chemical composition, the size of municipal waste can vary from small dust to big items such as furniture, in between these we found thousands materials as plastic, papers, organics, cans, textile and glass. Municipal waste occupies the first place among waste types in terms of quantities produced as statics showed. Unfortunately, because of the special political situation in Palestine, the restrictions and conditions imposed by the occupation on the Palestinian statistical institutions, there is no available modern statistics for the quantities produced[47]. However, table 5.١ present the monthly estimated quantity of solid waste produced in the economic establishments in the Palestinian Territory by the year 2004[48].

Table 5.1: The monthly estimated quantity of solid waste produced in the economic establishments in the Palestinian Territory by region 2004.

Region	Estimated Quantity of Solid Waste	
	Quantity (tons)	Quantity (m^3)
Palestinian territories	84.7326	5817.0
West Bank	75.1568	5138.3
North of the West Bank	26.9721	2325.5
Central West Bank	41.3285	2487.8
South of the West Bank	6.8562	325.0
Gaza strip	9.5758	678.7

This immense variation and amounts creates enormous problems and challenges on the authorities in managing municipal waste.

٥.٢.١.1 Glass Solid Waste

The term glass is often used to refer to silicate glass, which is familiar in uses as glass bottles and windows. Silicate glass was named based on the chemical compound(silica) or quarts, which is the primary constituent of sand.

Glass (silicate glass) is widespread use due to its physical properties such as transparency, its ability to transmit light without scattering it, ease of shaping, resilient to chemical attack and its durability. All those properties give it a preference for a lot of other materials. This huge demand on glass increases the environmental pressure to reduce it and to recycle as much as possible. The construction materials industry adopted several methods to achieve this goal such as reusing glass waste in concrete and bricks.

٥.٢.١.2 Wood Solid Waste

Sawdust or wood dust is a fine particles of wood that produced by cutting and pulverizing wood as a by-product . It is also the by-product of certain animals, birds and insects which live in wood, such as the woodpecker and carpenter ant. The accumulations of sawdust present various health and safety problems.

5.3 Experimental Methodology

The detailed experimental method was presented in chapter three: adding glass powder as alternative of sand, with two particle sizes and various dosages (5, 10, 15 and 20%) for each size. Another samples were prepared in a similar Scheme of artificial stone, adding sawdust (wood dust) in two different sizes and ratios (5and 10%) for each size as alternative for aggregates. The compressive strength was measured at 28 days; water absorption was measured after 28 days according to ASTM standards. All samples were coated with imperplast and water absorption ratio was measured.

5.4 Results and Discussion

The Results for utilizing glass waste and sawdust of wood in artificial stone production were obtained, the effect of adding each waste on compressive strength values and water absorption ratios were plotted and discussed in figures.

5.4.1 Utilizing Glass Waste powder in Artificial Stone Production

In this section we will present and discuss the obtained compressive strength values and water absorption ratios for the samples utilizing glass waste powder.

- **Effect of Glass Waste Powder on Compressive Strength**

The compressive strength of the artificial stone samples was measured using concrete compression machine (300 KN motorized from Matest). Compressive strength for glass waste powder samples was measured and obtained as in figure 5.1, the figure presents the tested compressive strength results for Utilizing glass waste powder in various percentages and two deferent particles size.

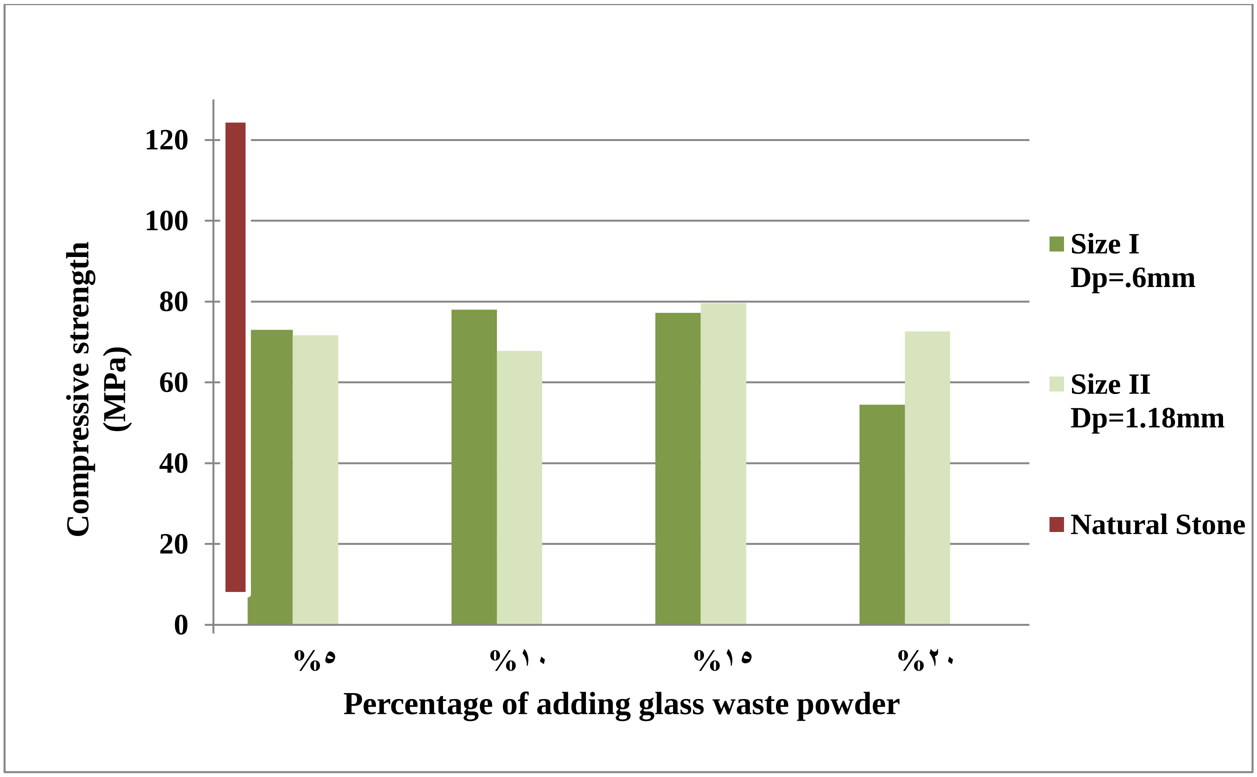

Figure 5.1: Comparison of compressive strength for two sizes of glass waste powder (1.18mm and 0.6mm) with four different ratios.

As figure 5.1 shows the obtained compressive strength measures for glass waste powder were in the acceptable range (the range of the natural stone). The best obtained compressive strength was by using 15% of size two (1.18 mm) glass waste powders.

- **Effect of Glass Waste Powder on water absorption ratio**

Water absorption ratio was measured according to ASTM standards as illustrated in chapter three (see section 3.4), chart 5.2 illustrate the water absorption ratios that were obtained from tests for samples utilizing glass waste powder in various percentages.

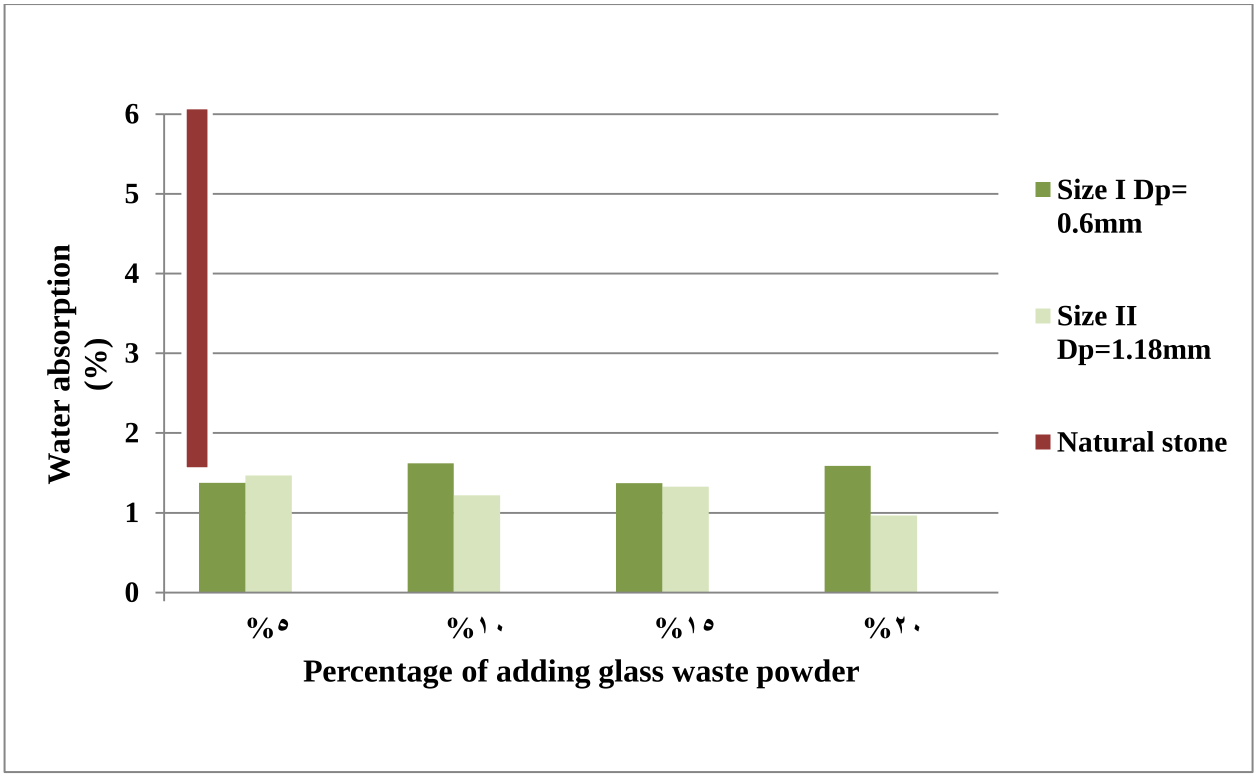

Figure 5. 2: Comparison of water absorption ratio for two sizes of glass (1.18mm and .6mm) powder whit four different ratios.

As figure 5.2 illustrate the utilizing of glass waste powder was positively effective on the water absorption ratios on all samples , all the results were better than the acceptable range (the range of the natural stone), samples with 20% of glass waste powder size two (Dp=1.18mm) shows the best results on water absorption as its clear in the chart.

5.4.2 Utilizing wood sawdust Waste in Artificial Stone Production

In this section we illustrate the effect of utilizing wood sawdust on both compressive strength and water absorption ratios.

- **Effect of wood sawdust waste on Compressive Strength**

The effect of adding wood sawdust (fine and coarse) on compressive strength was presented in figure 5.23 in same scheme as figure 5.1.

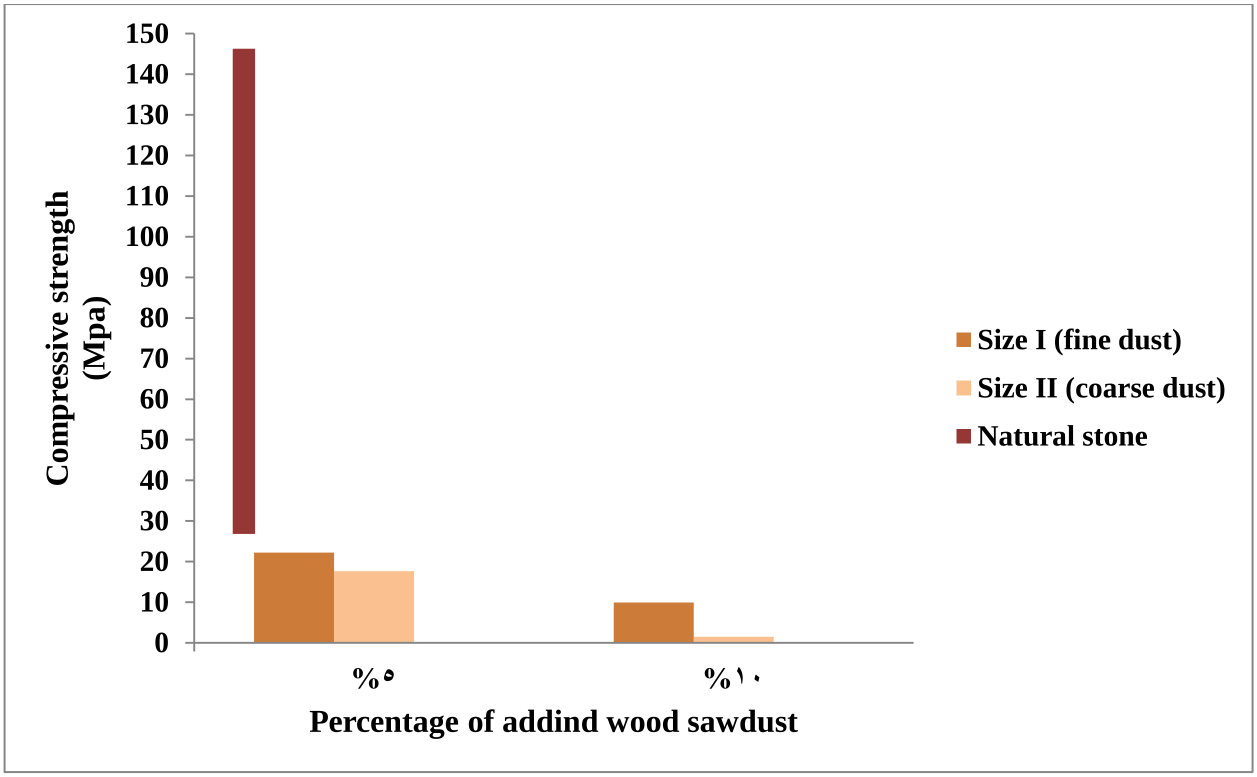

Figure 5.3: Comparison of compressive strength for two sizes of wood sawdust (fine and coarse) with two different ratios.

As figure 5.3 shows, the addition of wood sawdust gave a relatively low compressive strength comparing with height quality natural stone and other additives. The values were in the acceptable range (the range of the natural stone) except the 10% added of coarse sawdust.

- **Effect of Wood Sawdust Waste on Water Absorption.**

In the same approach that was used in water absorption for glass waste powder samples, samples with adding wood sawdust were tested. Figure 5.4 present the effect of adding wood sawdust on the water absorption ratio.

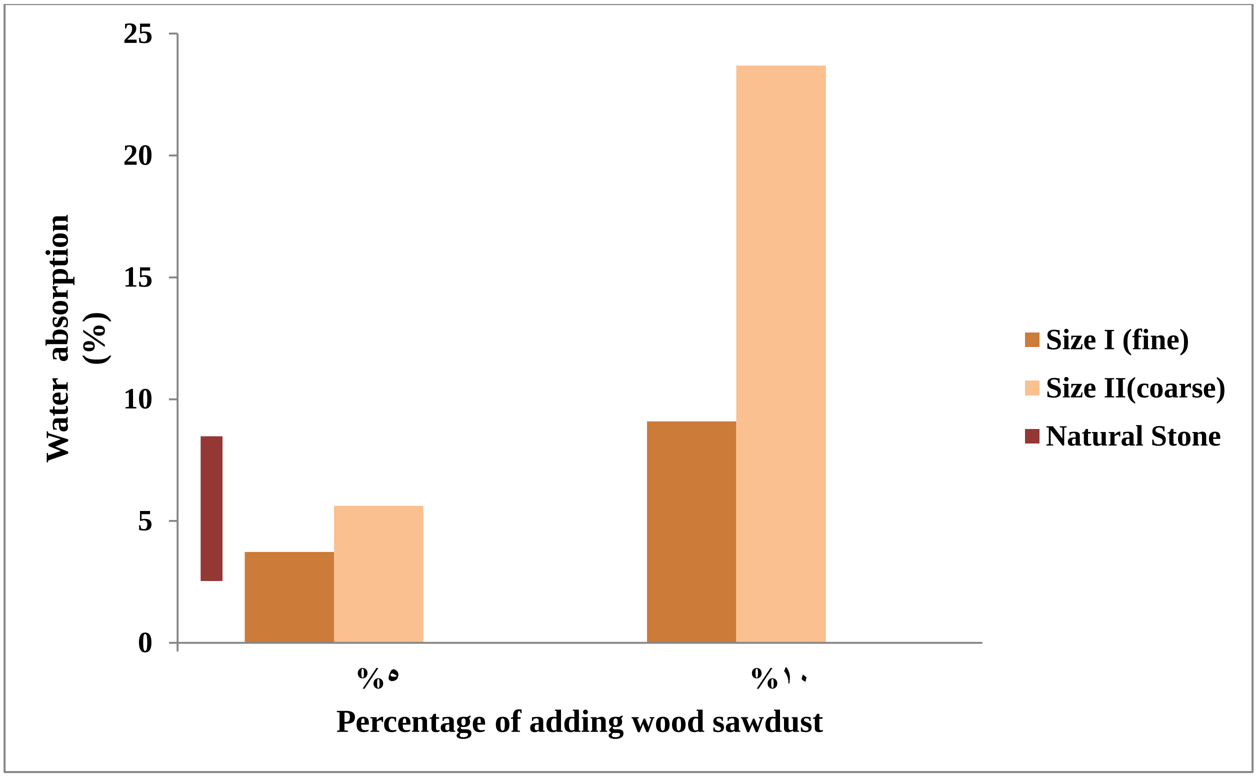

Figure 5. 4: Comparison of water absorption ratio for two sizes of wood sawdust (fine and coarse) whit two different ratios.

As shown in figure 5.4, wood sawdust increased the water absorption ratio for more than the permissible percentage, and this is logical as wood is known to act as good water absorbent.

5.4.3 The Effect of Imperplast in Artificial Stone Production on Water Absorption

In order to enhance water absorption ratio, we coated all the samples with imperplast (a colorless impregnating silicon) as explained in chapter three (see section 3.4), figure 5.5 present the effect of coating all samples that contains various percentage of size one and two(0.6mm and 1.18mm) glass waste powder with imperplast.

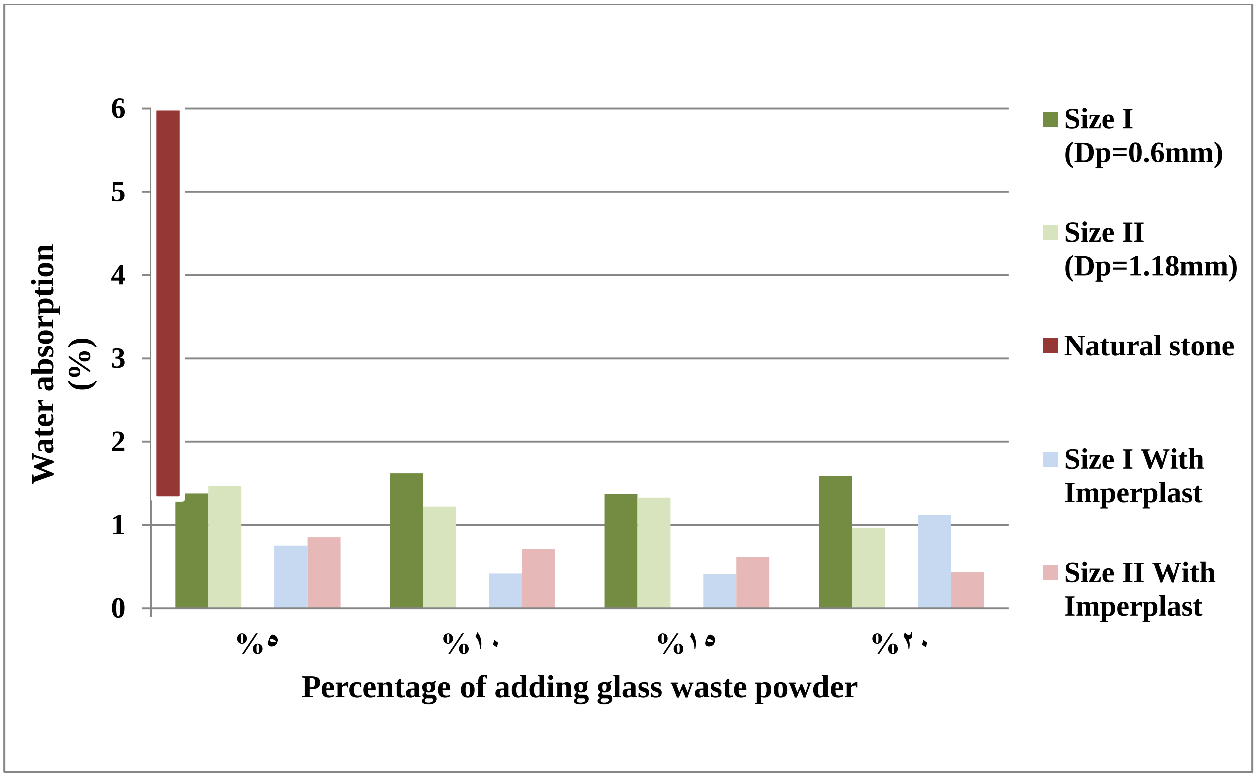

Figure 5.5: Comparison of water absorption ratio for two sizes of glass powder whit four different ratios, before and after painting imperplast.

As can be seen in Figure 5.5, the addition of imperplast substantially reduced water absorption especially when coating blocks that contain.

Conclusion

Our results all together showed strong evidence that waste/ byproducts from local industries can be potential additions in producing environmental friendly construction stone. Comparison of compressive strength results shown in the previous chapters, indicate that the optimum value was 84Mpa when utilizing 10% of non-flocculated stone slurry as alternative of sand, then 15% of size II from glass waste powder samples, 80Mpa. Followed by 30 % of marble waste water, which give 69Mpa.

In addition to our results, glass size II with 20% had the optimum value of water absorption .9%, followed by marble waste water both ratios with 1.2%, then non flocculated stone slurry10% , water absorption was 2.4%.

What should be noted, that imperplast effect on water absorption that decreased it significantly.

Our study shows promising results of using local waste to enhance the compressive strength as well as to reduce the water absorption ratios. These results are still preliminary and we look forward, by using more sophisticated measuring methods, to achieve better results that can be finally translated into a commercial product. This project will open a new approach for investees to give more attention on local industrial waste as available resources instead of conception of it as serious problem.

Recommendation

1. Using wood sawdust produced blocks that have less water absorption, lighter weight, and stronger than locally produced bricks. Therefore, we strongly recommend using this formula to develop environment-friendly bricks (EfBrix).

2. Using stone slurry significantly improved compressive strength, while using glass powder improved water absorption. Therefore, we suggest a future work to test several combinations of these two wastes to develop an environment-friendly building stone (EfStone).

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