Investigation of the Mechanical Properties of Concrete by Incorporating P.V.C and Marble Dust Wastes

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ABSTRACT

This research investigates incorporating locally produced wastes which are marble dust waste (MDW) and shredded fibrous plastic wastes (SFPW) on the physical and mechanical properties of normal strength concrete. For this particular reason, testing program that involves 20 different mixtures of concrete is developed. MDW is utilized as a cement's replacement in concrete with the percentages of 0, 5, 10, 15, and 20. On the other hand, SFPW is used as an additive by means of the cement volumes with a proportion of 0, 2,3 and 5%. The influence of these mixtures on the fresh concrete slump, dry unit weight, compressive strength, splitting tensile strength, flexural strength and elastic modulus is examined. Results indicated that physical characteristics such as workability and dry unit weight are affected ever so slightly. On the other hand, the mechanical response does vary where it outperforms the control mixture at some replacement levels and underperform at high replacement levels. It is concluded that the optimal replacement levels of the MDW and SFPW is 5% and 2% respectively.

Keywords: green concrete, marble dust, shredded fibrous plastic wastes, construction waste, PVC.

ÖZ

Bu araştırma, yerel olarak üretilen mermer tozu atığı (MTA) ve ufalanmış lifli plastik atık (ULPA) olan atıkların normal dayanımlı betonun fiziksel ve mekanik özelliklerine dahil edilmesini araştırmaktadır. Bu bağlamda, geliştirilen test programı 20 farklı beton karışım numunelerinden oluşmaktadır. Beton karışımları içeriğinde bulunan çimento oranına ilaveten yüzde 0, 5, 10, 15 ve 20 oranlarında MTA kullanılmaktadır. Buna ek olarak, karışımlardaki çimento hacmine ilaveten yüzde 0, 2.3, ve 5 oranlarında ULPA katkı maddesi kullanılmıştır. Bu çalışmada hazırlanan farklı oranlardaki numunelerin taze beton çökmesi, kuru birim hacim ağırlığı, basınç dayanımı, yarmada çekme dayanımı, eğilme dayanımı ve elastisite modülü üzerindeki etkisi incelenmektedir.. Deneme sonuçları, işlenebilirlik ve kuru birim ağırlık gibi fiziksel özelliklerin çok az etkilendiğini göstermiştir. Öte yandan, mekanik tepki, bazı değiştirme seviyelerinde kontrol karışımından daha iyi performans gösterdiğinde ve yüksek değiştirme seviyelerinde düşük performans gösterdiğinde değişiklik gösterir. MTA ve ULPA'nın en uygun değiştirme seviyelerinin sırasıyla %5 ve %2 olduğu sonucuna varılmıştır.

Anahtar Kelimeler: yeşil beton, mermer tozu, ufalanmış lifli plastik atıklar, inşaat atıkları, PVC.

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INTRODUCTION

1.1 General

Recent reports indicated that, the temperature of the globe is increasing at accelerated rate to score 0.15 degree Celsius per decade [1]. This is mainly due to high production of greenhouse gases such as carbon dioxide, water vapor, methane, nitrous oxide and the ozone gas. This rapid increase in temperature can result in a massive extension crisis and turn our home planet earth into an inhabitable place [2]. For this reason, reducing emission of greenhouse gases is major concerns of various researchers and scientists. Another major concern of nowadays is also sustainable development of urbanized area. This can be achieved by using only materials and energies that have renewable resources with the least amount of waste. Or by reutilizing unavoidable waste in reducing the demand of non-renewable materials.

Concrete is widely used in building material [3]. However, producing one tonnage of concrete can emit a massive quantity of carbon dioxide to the environment. This amount is measured to be 622 kg of carbon dioxide per ton of concrete [4]. This amount is generated mainly by means of converting the calcite rocks ($CaCO_3$) into lime (CaO) that is the major element of cement. Another portion of this amount is related to furnace and heavy machinery which are used in manufacturing cements. It is worth to mention that concrete is not a sustainable material as it exploits non-renewable resources such as aggregate and sands. Hence an alternative for these materials is extremely vital for the future of our planet.

1.2 Problem statements

As of the strategic location of Cyprus and its charming shores, people from all around the world are seeking to possess a real estate in the island. This causes sharp increase in the construction industries all over the island to overcome the massive demand. Most of the construction industries relays on traditional Portland cement concrete which increases the environmental and ecological footprint of the island. Another, material that are extensively used in the construction industry are marble stones and polyvinyl chloride. However, during cutting, molding and polishing large amount of waste is produced which are not recycled and dumped in land fill. Incorporating these two materials in concrete to substitute the cement and its impact on the mechanical characteristics of concrete is rather ambiguous and requires further investigation.

1.3 Objective

The aim of this study is to produce a more environmentally friendly concrete by means of reutilizing largely produced wastes in the Turkish republic of Northern Cyprus. These wastes include marble dust waste and shredded fibrous plastic waste that are largely produced and does not decompose in a short period of time. The targeted mixture should perform better or in similar manner of the traditionally produced concrete.

1.4 Research methodology

The primary objective of this study is generating an environmentally friendly concrete by incorporating two types of wastes that are extensively generated in TRNC. In order to meet this objective, an experimental program is designed to evaluate the optimal ratio of these materials within the concrete mixture. The marble dust waste is incorporated into the concrete by means of replacing the cement mass by 0%, 5%, 10%, 15% and 20%. Meanwhile the shredded fibrous plastic waste is used as an additive since it possesses the shape of fibrous texture. The percentages of the additive are 0%, 2%, 3% and 5% by cement volume. Whereas the produced concrete's mechanical characteristics are evaluated with means of the ASTM standards that involve; compressive strength, splitting tensile strength, flexural strength and elastic modulus.

1.5 Thesis content

This research is subdivided into five cores segment. In the current section back ground information regarding the environmental and ecological footprint of the traditional concrete is presented. Also, the significance of this research is highlighted altogether with the adopted procedure.

The second chapter of this dissertation list essential information presented in the literature. Also presents quotative information regarding the marble dust waste impact and polyvinyl chloride waste on the mechanical characteristics of concrete.

The third chapter of this thesis presents in detailed the designed testing program altogether with the followed experimental and analytical procedures to achieve generated concrete's mechanical characteristics.

The fourth chapter present illustrative figures of the obtained results altogether with critical comments on each figure. Also, the obtained results are compared side to side with the previous study.

The fifth chapter is the conclusion of the thesis where its summaries the finding of this study and highlight the limitation of this research.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter is focused towards highlighting the problems of using traditional concrete in its current form by means of both sustainable and environmental aspects. The chapter discusses also the composition of traditional concrete and more environmentally friendly alternatives. Also, the chapter lists commonly used waste materials by researchers and scientists as suitable substitutes of cement and aggregate around the globe. Since they are the main scope of this study, marble dust and shredded fibrous plastic wastes properties and their incorporation in concrete are discussed in further details.

2.2 Concrete and production phases

Due to its available raw materials and low cost, concrete, that is a combination of coarse aggregate, cement, and water, is the most utilized material in the building sector. Production of cement worldwide is currently at 12 billion tons annually, which equates to approximately 1 m^3 per each individual annually, making it the globe's most utilized natural resources [5] [6]. Concrete offers a number of advantages, but it also has a number of disadvantages. Concrete, for instance, has weak tensile strength, that provoke micro cracks to propagate under applied stresses; this issue is resolved by the implementation of steel and similar additives such as fibers. Similarly, aggregates account for 65 to 85% of concrete’s volume and have a significant impact on its properties.

Tricalcium silicate (C_3S), Dicalcium silicate (C_2S), Tricalcium aluminate (C_3A) and Tetracalcium aluminoferrite (C_4AF) are 4 basic chemicals found in Portland Cement. Every one of those chemicals is involved for some concrete characteristics: C_3S are in charge for initial strengthening, C_2S has relatively slow hardening and after a week the effect on strength start to occur. Nevertheless, C_3S would be the first chemical to demonstrate an impact on the strength, initial hydration, and high temperature production, and the last compound which is C_4AF, is noted for its poor contribution for strength development and quick hydration. After the addition of raw components into the rotary kiln for the Portland cement production, the free, lightly bonded and strongly bonded water disappear at 500^oC, then the reaction of $MgCO_3$ begins at 600^oC to producing $MgCO_2$ and carbon dioxide, then at 800^oC the reaction of $CaCO_3$ begins and starts producing CaO and carbon dioxide, then clay and lime initializes, and lastly, roughly at 1600^oC C_3S, C_2S, C_3A and C_4AF are produced, and clinker is cooled [7] [8].

2.3 Sustainability and environmental aspects of traditional concrete

To help improve living standards across the globe, environmental concerns must be considered in all aspects of life, including construction. According to the experts, the construction sector's primary objective is to participate in the implementation of ecological building structures through the use of technical and functional methods by reducing energy consumption of the construction material sector, minimizing embodied energy, and by reducing cost and environmental potential impact [9]. Researchers stated that it is critical to utilize environmentally sustainable construction materials which can contribute to the quality of the atmosphere within buildings. This is an important health concern that must be addressed [10]. Eco-friendly material production aims to enhance material management, eliminate waste, and produce materials with adequate physical and mechanical characteristics.

One of the frequently used building material is concrete. The usage of cement, which is a crucial element in concrete, accounts for approximately 5% of worldwide CO_2 emissions caused by human activity [11].

2.4 Environmentally friendly cement substitutes

Concrete and cement innovation have resulted in a number of accomplishments. One of these achievements is the usage of waste materials as a filler or an additional material during cement and concrete's production which also had an economic and environmental benefits. These waste products are discovered to have reactive characteristics known as pozzolanas or filling influence in the manufacture of concrete [12] [13]. In the subsequent subsections, we will go in depth about the materials that can be substituted by cement, regardless of whether they have pozzolan behavior or a filler influence on concrete.

2.4.1 Condensed Silica Fume (CSF)

CSF which is also recognized as micro silica is resulted from the manufacture of silicon metal. Smoke which outcomes from the oven during the production of silicon operation is gathered and used as CSF due to its fineness and the high silica proportion [14]. CSF is a highly effective pozzolanic substance utilized in concrete to enhance its characteristics. CSF reduces concrete's permeability attributed to its fineness and the beneficial impact of the pozzolanic reaction which generates denser and more homogenous formations in the matrix. It also aids in the enhancement of its mechanical behavior. Moreover, it contributes substantially to its excellent corrosion resistance to chemical assaults like as nitrates, acids, sulfates, and chlorides [15].

2.4.2 Fly Ash (FA)

FA is a pozzolanic substance consisting aluminous and siliceous elements that has been created in power plants by the combustion of coal. Due to its extremely tiny particles, FA increases the density of the concrete mix. As a result, permeability is decreased and chloride infiltration is lessened [16]. Furthermore, the inclusion of FA in the concrete mix improves the concrete's characteristics, such as increasing strength and boosting resilience to sulfate attack.

2.4.3 Ground Granulated Blast Furnace Slag (GGBFS)

GGBFS is a remnant material of iron extraction from the iron ore retrieved from an industrial iron blast furnace. GGBFS has been utilized for almost 150 years in Europe as a cement material during brick manufacturing. Since the late 1950s, the construction sector employed GGBFS as a replacement material. Slag cement is another name for it [17]. The usage of GGBFS enhances the strength of concrete due to its strong resilience to sulfate. It also reduces the reactivity of alkalis. As a response, by reducing chlorine diffusion and penetration the risk of steel reinforcement corrosion can be decreased [18].

2.4.4 Waste Glass Powder (WGP)

Because of its pozzolana reactivity, WGP is another form of cement replacement material. WGP can improve the hydration rate, mechanical characteristics, and durability of the concrete. To acquire these characteristics, the WGP particles must be processed into a tiny size in to get a decent interaction with cement [19].

2.4.5 Rich Husk Ash (RHA)

RHA is a excess of rice husk’s burning. RHA is mainly amorphous (85-90%) and has a very tiny porous structure, making it appropriate for altering cement via pozzolanic reaction. RHA amorphous silica can respond with calcium hydroxide crystals that develop throughout concrete hydration. RHA can improve the interlocking of the cement paste and fill the space in between cement particles. As a result, the concrete properties can be improved [20].

2.4.6 Metakaolin (MK)

MK is a pozzolanic material that is utilized frequently in mortar and concrete. MK can be retrieved at 500 °C and 800 °C [21]. Because of its pozzolanic and filling capabilities, MK is typically utilized in concrete. MK is also widely recognized for having a substantial impact on the mechanical and durable characteristics of mortar and concrete. Furthermore, due to its aluminum concentration and small particle size, MK enhances the initial strength of concrete, which speeds the hydration rate [22]. MK is also recommended for developing acid resistant concrete. Prior research has shown that using the MK improves chloride permeability and sulphate resistivity [23].

2.5 Sustainable aggregate replacement

Given the economic and environmental benefits, plastic waste material may be utilized, natural and recycled aggregates are evaluated in terms of environmental and economic impact. Considering the strength of concrete, it was discovered that using coarse particles recovered from concrete may considerably minimize environmental effects and costs [24]. In road and pavement construction, insulator or conduit in construction works, or a natural substance for fabric manufacture, plastic is utilized to enhance the strength and longevity of these tasks [9].

Plastic aggregate (PA) and plastic fibers (PF), as mentioned earlier, are two forms of plastic waste that may be utilized in concrete mixes. Plastic aggregate is used as a limited substitute for coarse aggregate (CA) or fine aggregate (FA) in concrete mixes. These plastic aggregates have a lesser density when compared with normal aggregates.

This make them an excellent candidate for making lightweight concrete. Moreover, some research have demonstrated that plastic aggregates have a substantial influence on a variety of concrete characteristics, such as fresh, physical, mechanical, thermal, acoustic, and many others [9].

2.6 Local wastes that can be incorporated in concrete

2.6.1 Marble Dust Waste (MDW)

MDW is considered as the main by-product in the building industry that is produced in large quantities in various countries. The large marble blocks are cut to smaller blocks to make the recommended flat figure. While cutting and polishing of marble, approximately 30% of marble is converted into dust, mainly consisting of Al_2O_3, SiO_2, Fe_2O_3 and CaO, with some secondary components such as Mg, K, Mn and Ti oxides. If not effectively treated before disposal, it can cause dangerous damages to the environment, such as pollution of the soil and underground water [25].

2.6.2 Shredded Fibrous Plastic Waste (SFPW)

In the most recent recorded year, 322 million tons of plastic were made worldwide, with Europe solely producing 58 million tons. Average production grew to 335 million tons in 2016, with Europe producing 60 million tons. According to the statistics, 31.1 percent of these excess were reprocess in 2016, 41.6 percent were utilized for energy retrieval, and 27.3 percent were landfilled internationally in 2016. However, by 2035, plastic manufacture is anticipated to triple, and by 2050, it is anticipated to quadruple [9].

2.7 Effect of the local wastes on the fresh properties of concrete

2.7.1 Effect of MDW on workability

The researchers discovered that when concrete comprises 0, 5, 10, 15, and 20% MDW as cement replacement by weight, and at a water/cement ratio of 0.43, MDW has a negative impact on slump. As an outcome, they concluded that as the MDW ratio grows from 0% to 20%, the slump tends to diminish, owing to the refinement of MDW [26]. Another research which is used MDW as partially cement and fine aggregate replacement found at various concrete mixes that as the amount of MDW increases the slump of concrete tend to decrease [27].

Research used MDW as partially cement replacement with percentages 5 and 10, shows a slight increase in the slump value for 5% substitution, however no considerable change was recorded for 10% MDW [28].

2.7.2 Effect of Plastic Waste (PW) on workability

Several concrete characteristics containing plastic aggregate produced with strips were studied, having plastic aggregate substituting sand by 5%, 15%, 30%, 45 %, 65 %, and 85 %. The results reveal that the slump value maintained steady until to 15% substitution, although it fell somewhat at 30% and 45 percent, but this impact was more pronounced at 65 and 85 % of the integration ratio [29].

One research that utilizes fine plastic as a replacement for fine aggregate at 10, 15, and 20% indicates that as the proportion of substitute grows, the slump reduces, with a substantial drop at 20% substitution, which is about 95% when opposed to the reference mix. Additionally, the particle magnitude of plastic aggregates has a substantial influence on concrete’s workability. At 10% and 20% replacements, survey was performed, and the findings revealed that mixes with a greater size of plastic aggregate had a lesser slump value [30].

2.8 Effect of the local wastes on the mechanical properties of concrete

2.8.1 Effect of MDW on compressive strength

Concrete compressive strength is by far the most important element in determining the quality of concrete. Many researches have stated that some aspects may impact the concrete’s compressive that include aggregate shape and size, curing temperature, concrete age, and so on [31].

Numerous researches have analysed and inspect the advantages of utilizing MDW for enhancing the characteristics of concrete. A few of these research looked at whether utilizing MDW as a cement substitute at 0, 10, 15, and 20% in concrete with a water/cement ratio of 0.5 enhanced compressive strength marginally in comparison to a control mix. This small improvement occurred up to 10% cement substitution by MDW, but at 15% and 20% substitution, the trend was negative when compared to the control mix [32].

Other analysis looked at the compressive strength of concrete that included MDW as a partial substitute for cement by weight, as can be seen in Figure 1. The goal of those experiments was to substitute cement for MDW in attempt to create a more sustainable combination. According to the compressive strength data, the optimum ratio for substituting the cement with MDW was around 5% [33] [34]. Nonetheless, in another research, MDW had no influence on compressive strength at 10% and 15% substitution, but at 20% and 25% substitution, there was a decrease as MDW percentage increases [35].

A research was done by using MDW as partially cement replacement with percentages 5 and 10, the results at 28 days curing show as the marble dust content increases the compressive strength decrease for both substitution percentages, where around 18% reduction was recorded at 10% marble substitution [28].

Another research used MDW as cement replacement the substitution percentages were 5, 10, 15, and 20. The results show as the percentage of marble increase the compressive strength value also increase up to 10 marble substitution, however, a dramatical decrease in compressive strength was recorded at percentage 15 and 20 [36].

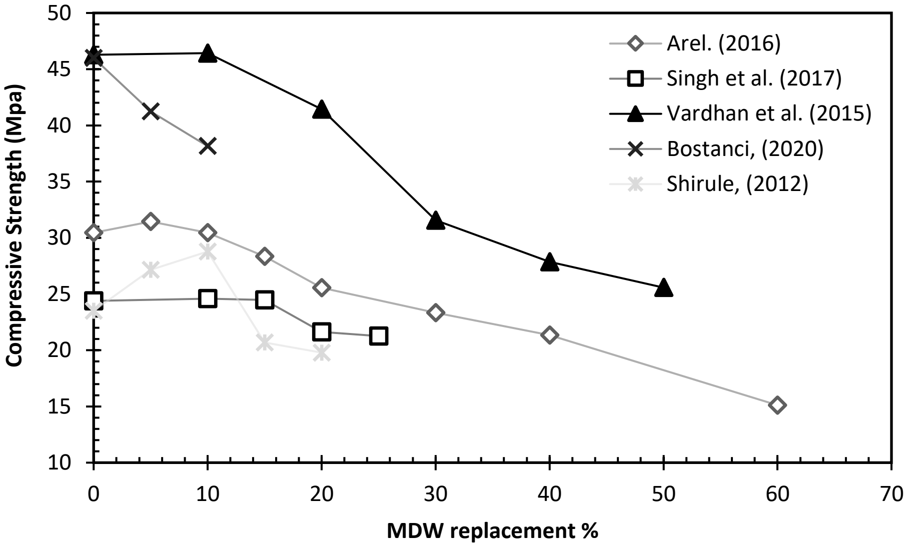

Figure 1: The compressive strength trends versus MDW replacement % related to different researches.

2.8.2 Effect of MDW on flexural strength

Figure 2 illustrates how the researchers explore the flexural property of concrete by replacing different quantities of MDW for cement. According to the flexural strength assessment results given by [37] as the marble dust increases the flexural strength also incceases up to 10% MDW replacement, with an adverse trend at 15% and 20%

replacement. Related research [38] indicated a slight loss in flexural strength equal to 10% MDW substitute compared to the reference sample, but a decline in flexural was identified at 15% afterwards, which maintained to flexural decline as the MDW percentage rose. This might be due to a leak in the delivery of cementitious materials.

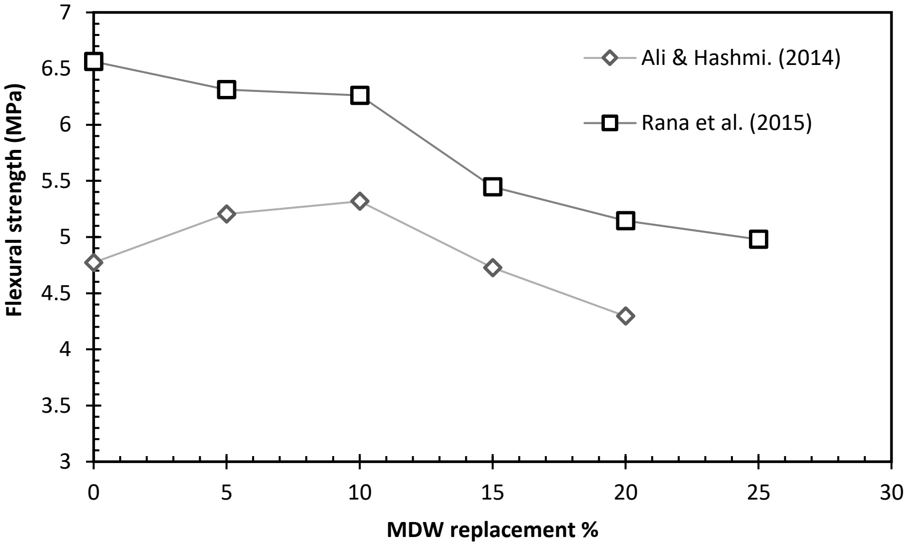

Figure 2: The flexural strength trends versus MDW replacement % related to different researches.

2.8.3 Effect of MDW on splitting tensile strength

In relation to Figure 3, the study conducted by [35] demonstrates that whenever the MDW substitute is 5, the splitting tensile strength rises when in contrast to the reference mix; however, as the MDW substitution exceeds 5%, the splitting tensile strength begins to decline until it reaches 25% substitution. Another investigation found that when the MDW replacement increased, the splitting tensile decreased at 30% as MDW is replaced with cement, the splitting tensile is reduced by more than 20% when compared to the reference mix [39].

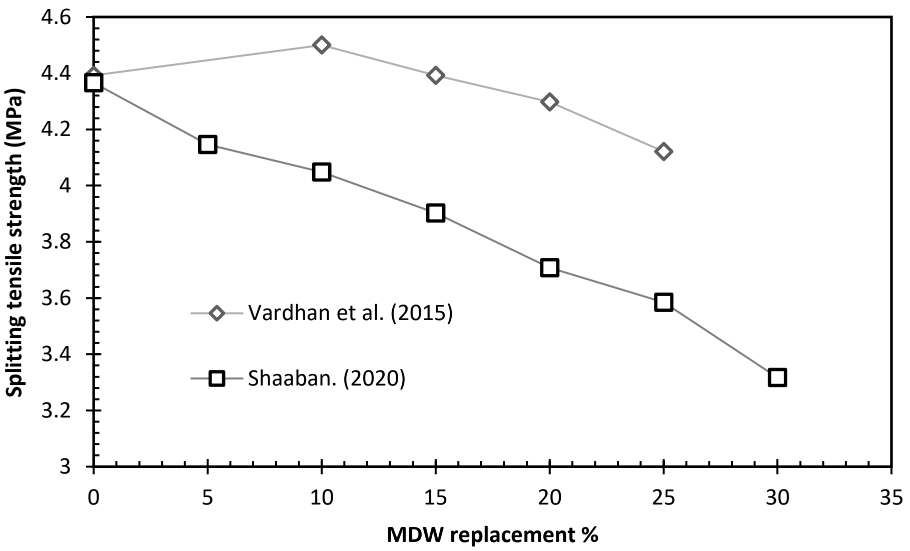

Figure 3: The splitting tensile strength trends versus MDW replacement % related to different researches.

2.8.4 Effect of Plastic Waste on compressive strength

Figure 4 depicts some research that utilize plastic as a substitute for natural aggregate. Research conducted by [29] shows an increment in compressive strength at 5% plastic waste replacement, at 10 and 15% replacement the compressive strength had slight decrease compare by control were at 45% replacement it decreases more than 50% compare by reference. As natural aggregate replacement a study carried by [40] shows a dramatical decrease in the compressive strength at 5% PW replacement, however, a steady decrease at 10, 15 and 20%. Last study which uses electronic plastic as natural aggregate replacement by 10, 20, 30 and 40%, in general the compressive strength decrease as the replacement percentage increases. At 10% replacement the compressive strength decreases, however, a slight enhance was found at 20% were a steady decrease at 30 and 40% replacement [41].

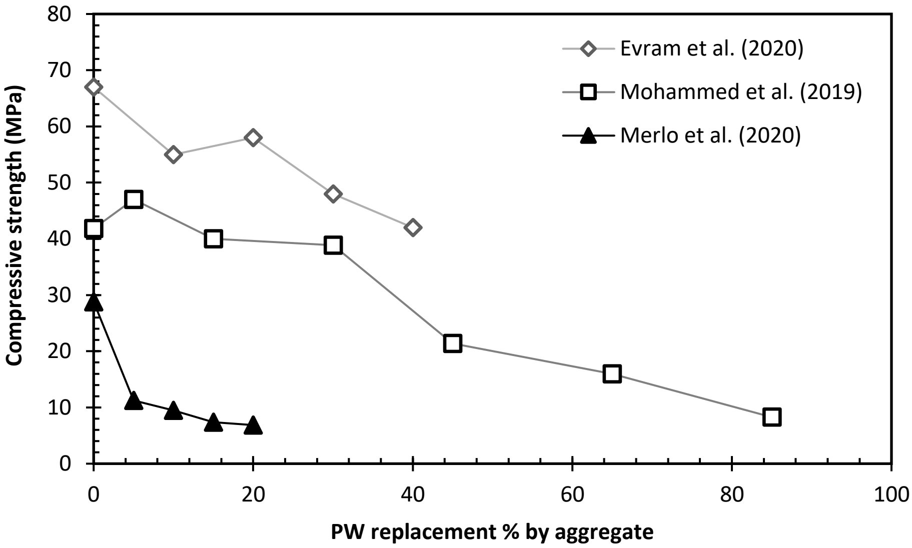

Figure 4: The compressive strength trends versus PW replacement % by aggregate related to different researches.

2.8.5 Effect of PW on flexural strength

As natural aggregate replacement a study carried by [40] shows a sudden drop in the flexural strength at 10% PW replacement, however, a steady decrease in flexural strength was detected at 15% PW substitute as shown in Figure 5. Another study which uses PW powder as natural aggregate replacement was carried by [30] demonstrated that as the PW powder replacement rises the flexural strength decreases, steady decrement in flexural was obtained up to 10% were at 25% replacement more than 15% was lost compare with reference specimen.

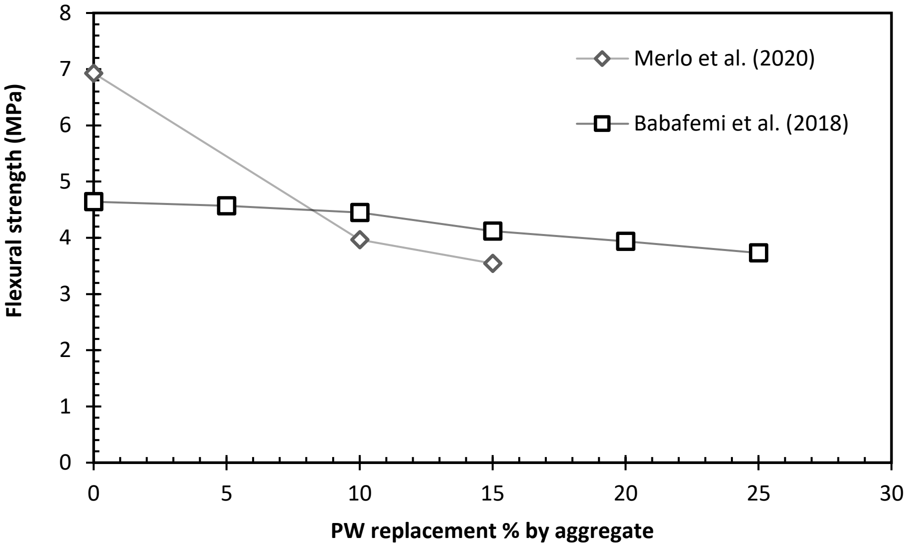

Figure 5: The flexural strength trends versus PW replacement % by aggregate related to different researches.

2.8.6 Effect of Plastic Waste on splitting tensile strength

Figure 6 illustrate the impact of PW replacement by normal aggregate on the splitting tensile strength related to three different studies. One study shows that as the PW powder replacement percentage increases the splitting tensile strength decreases were at 25% replacement approximately 30% loss had observed [30]. Another study was carried out by [41] indicates a significant drop in splitting tensile strength 5% PW substitution, but a continuous decline at 10%, 15%, and 20%. In a previous study that used electronic plastic as a natural aggregate replacement by 10, 20, 30, and 40%, the splitting tensile strength decreased as the quantity of replacement amplified. The splitting tensile strength drops at 10% replacement, although there is a minor increase at 20% substitution and a continuous reduction at 30% and 40% substitute [29].

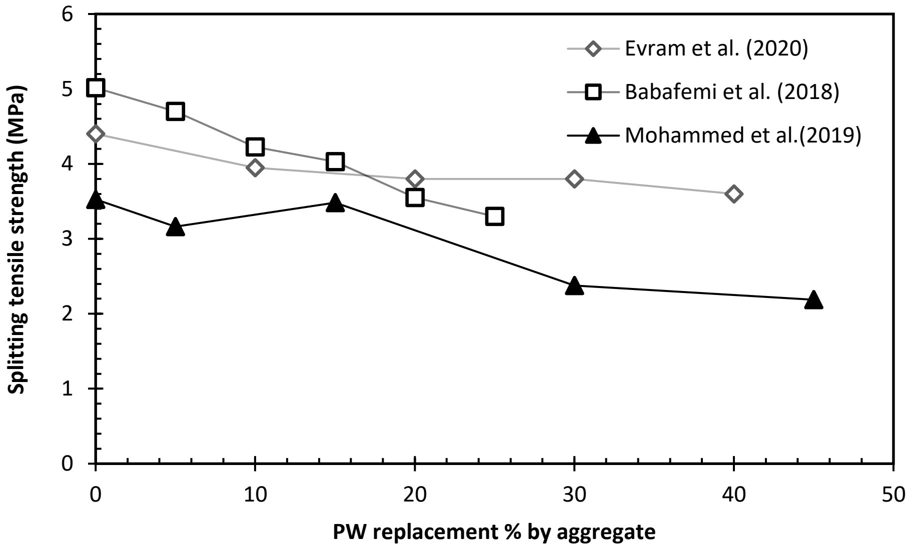

Figure 6: The splitting tensile strength trends versus PW replacement % by aggregate related to different researches.

2.9 Effect of the local wastes on the Modulus of elasticity

The modulus of elasticity, similarly called the elastic modulus or the coefficient of elasticity, is an assessment of a material's resistance to deformation beneath stress and is used to calculate concrete stiffness. A research project that used PW as a natural aggregate replacement discovered a constant decrease in elastic modulus with increasing aggregate PW substitution; additionally, it discovered that coarse aggregate substitution with PW aggregate has a substantial influence on the elastic modulus decline than fine aggregate replacement; and finally, the findings demonstrate that modulus of elasticity follows the similar pattern [29]. Other studies that employed plastic aggregate discovered that the plastic aggregate’s percentage substitution rose, the elastic modulus of concrete decreased linearly [42] [43]. The research which is done by [41] because electronic plastics have a smaller range than natural aggregates, the modulus of elasticity of the concrete dropped as the electronic plastic aggregate substitution ratios rose. The modulus of elasticity of concrete is determined by the modulus of elasticity of its additives, their volumetric proportions, and the bond among both aggregate and matrix. A stronger bond between aggregate and matrix can improve transmission of load among them, leading to higher modulus of elasticity [44]. A research result shows that replacing cement with MDW 5%, 10%, and 15% in concrete enhance its elasticity modulus while substitute cement with MDW 15% in concrete lower its elasticity modulus. Nevertheless, the elasticity modulus of concrete is commonly related to the compressive strength, so increasing compressive strength results in higher elasticity modulus [45]. According to the findings of one study, the application of MDW lead to a decrease in the young's modulus, and this discovery was constant for all data made at whatever phase of hardening [46]. Another research conducted by [41] indicate that the incorporation of MDW had no considerable influence on the concrete modulus of elasticity, with data collected for 5, 10, and 15% MDW substitution by cement weight.

Chapter 3

MATERIALS AND EXPERIMENTAL METHODS

3.1 Introduction

The previous two chapters discussed in detailed manners the introductory part of this dissertation and the available information within the published literature. The goal of this research is to explore the influence of incorporating marble dust and shredded polyvinyl chloride waste materials with fresh concrete mixtures for sustainable measures. In order to meet this objective an experimental program is designed to examine the various aspects of mechanical and engineering properties of the prepared mixes. This chapter goes through the selected materials properties and outline in comprehensive manner the experimental program.

3.2 Selected Materials

3.2.1 Cement

The cement used is type II Portland cement characterized with a normal hardening of 42.5 mega Pascal at 28 days curing (CEM II/B-S 42.5 N, Boğaz Endüstri ve Madencilik Ltd). The probation of the cement clinker is medium in accordance with European standards. The second main composition of the cement used is silica fume, ground granulated blast-furnace slag and pulverized fuel ash. The chemical composition of the cement used is shown in Table 1.

Table 1: Shows the Chemical composition of cement used.

Compounds	Availability in (%)
SiO_2	29.82%
CaO	57.43%
Al_2O_3	5.88%
Fe_2O_3	2.47%
MgO	3.46%
SO_3	2.64%
Free CaO	1.09%

3.2.2 Aggregate

Both coarse and fine aggregate are utilized in developing the concrete mixtures. Aggregate is a crushed limestone obtained from Beşparmak Mountains of Cyprus with a maximum particle diameter of 20 mm. Classification of the used aggregate is conducted in accordance with ASTM C136/C136M − 19 and ASTM C33/C33M – 18. Outcomes are demonstrated in Figure 7 for fine aggregate and Figure 8 for coarse aggregate. As shown both of fine and coarse aggregate are within the recommended limits expect for slight divergence. Additionally, the physical characteristic of fine aggregate and coarse aggregate are evaluated as per ASTM C128-15 and ASTM C127-01 respectively.

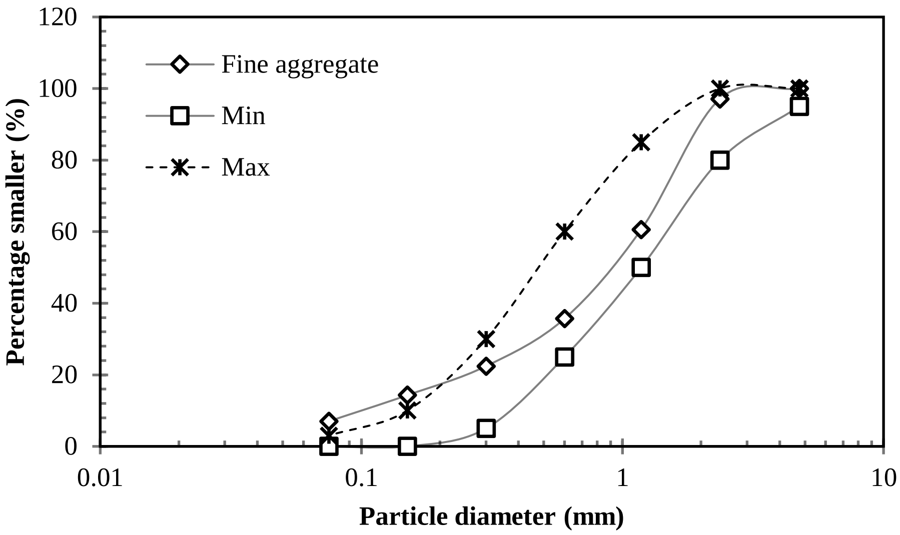

Figure 7: Particle size distribution of fine aggregate used.

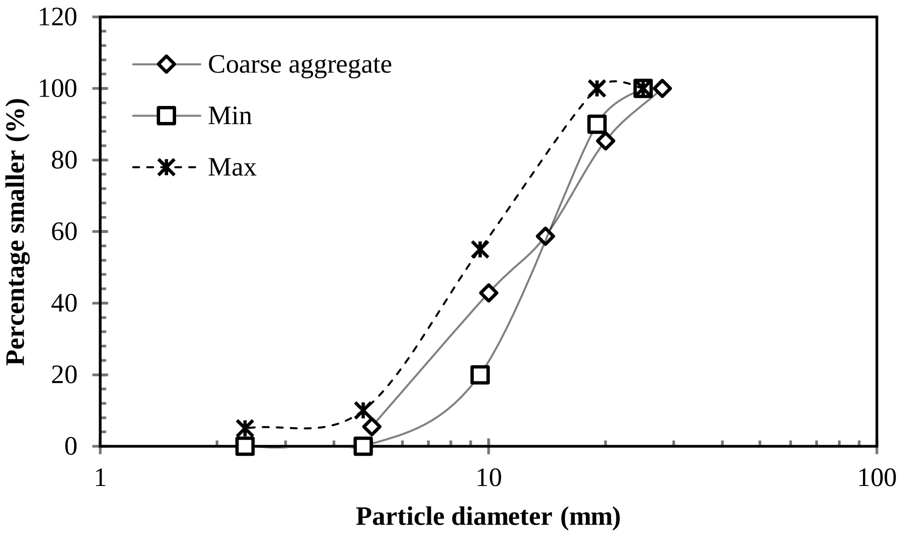

Figure 8: Particle size distribution of coarse aggregate used.

Table 2: Physical properties of the used aggregate.

Physical properties	**Fine aggregate**	**Coarse aggregate**
Relative Density (Saturated surface dry)	2.76	2.74
Relative Density Oven Dry	2.68	2.70
Apparent Relative Density	2.92	2.81
Water absorption	3.09%	1.39%

3.2.3 Mixing water

The water which is used for cement hydration is ordinary tap fresh water. The amount of dissolved salts and pH level are measured using the multiprobe method as per ASTM 2976-71. Results indicate that the amount of dissolved salts is 179.8 part per million and a pH level of 6.91.

3.2.4 Shredded Fibrous Plastic Waste (SFPW)

The SFPW (Figure 9) is obtained from the big industrial region of Famagusta (Gazimağusa büyük sanayi). The waste is generated as scraped material after production of doors and windows to desired sizes.

The SFPW is extremely light in density that it can float on water, alcohol and gasoline. For this reason, available methods for measuring its specific gravity are not adequate as they involve submersing the material in water or any liquid. Thus, new testing methodology is developed to measure the specific gravity of the SFPW material. The test setup is presented in Figure 10. The test setup is composed basically of 1-liter graduated cylinder which is equipped with a detachable wire mesh. The function of the wire mesh is to keep the SFPW submersed under water. The specific gravity is calculated as per Equation 1. The specific gravity is found to be 0.4143.

Figure 9: The shredded fibrous plastic waste.

$$G_s = \frac{m_{SFPW}}{m_{c,w} - (m_{c,SFPW,w} - m_{SPVCW})} \qquad \text{Eq (1)}$$

where, m_{SFPW}: dry mass of the tested SFPW (about 20 gr). $m_{c,w}$: mass of the graduated cylinder with the detachable wire mesh and water. $m_{c,SPVCW,w}$: mass of the graduated cylinder with the detachable wire mesh, with mass of the SPVCW and water.

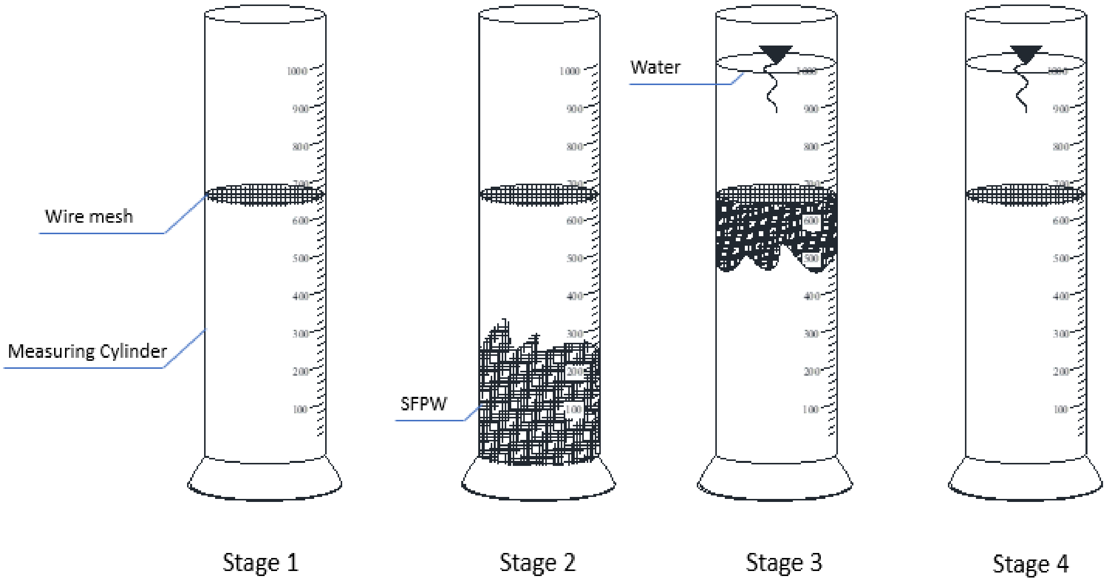

Figure 10: Developed test setup to measure the specific gravity of the SFPW.

3.2.5 Marble dust waste (MDW)

The marble dust waste is obtained also from the big industrial region of Famagusta (Gazimağusa büyük sanayi). The waste is generated in sludge form as results of cutting and polishing the marble stones to make statues, decorative elements and grave monuments. Particle size distribution of MDW is conducted in accordance with ASTM C136/C136M – 19. Results of the sieve analysis is shown in Figure 11. The specific gravity of marble dust waste is evaluated using density bottle method (pycnometer) as per ASTM C110 where ethyl alcohol is used instead of water in 500 ml pycnometer.

This is done, in order to prevent any reactions between the MDW and water from taking place. Results indicated that the specific gravity of the MDW is 2.64.

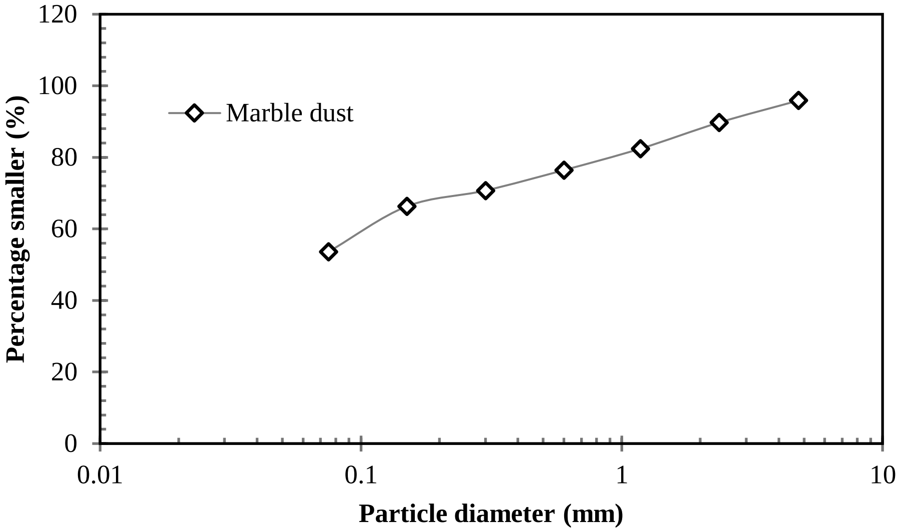

Figure 11: Particle size distribution of the marble dust waste.

3.3 Experimental program

In order to study the impact of introducing MDW and SFPW materials with fresh concrete mixtures for sustainable measures. Focused experimental program is designed to inspect different characteristics of the mechanical and engineering properties of the obtained environmentally friendly concrete mix. Figure 12 presents flow chart of the adopted test procedure. The testing strategy is basically composed of 5 replacement percentages of the marble dust waste by means of the cement mass. These percentages are 0,5,10,15, and 20%. Also, the SFPW is introduced to the mix as an additive with an amount of 0, 2, 3, and 5% of the cement volume in the mix. casted sample are then cured for periods of 7, 28 and 56 days to evaluate the specimen’s compressive strength. However, For the splitting tensile strength, flexural strength and elasticity modulus samples are cured for 28 days.

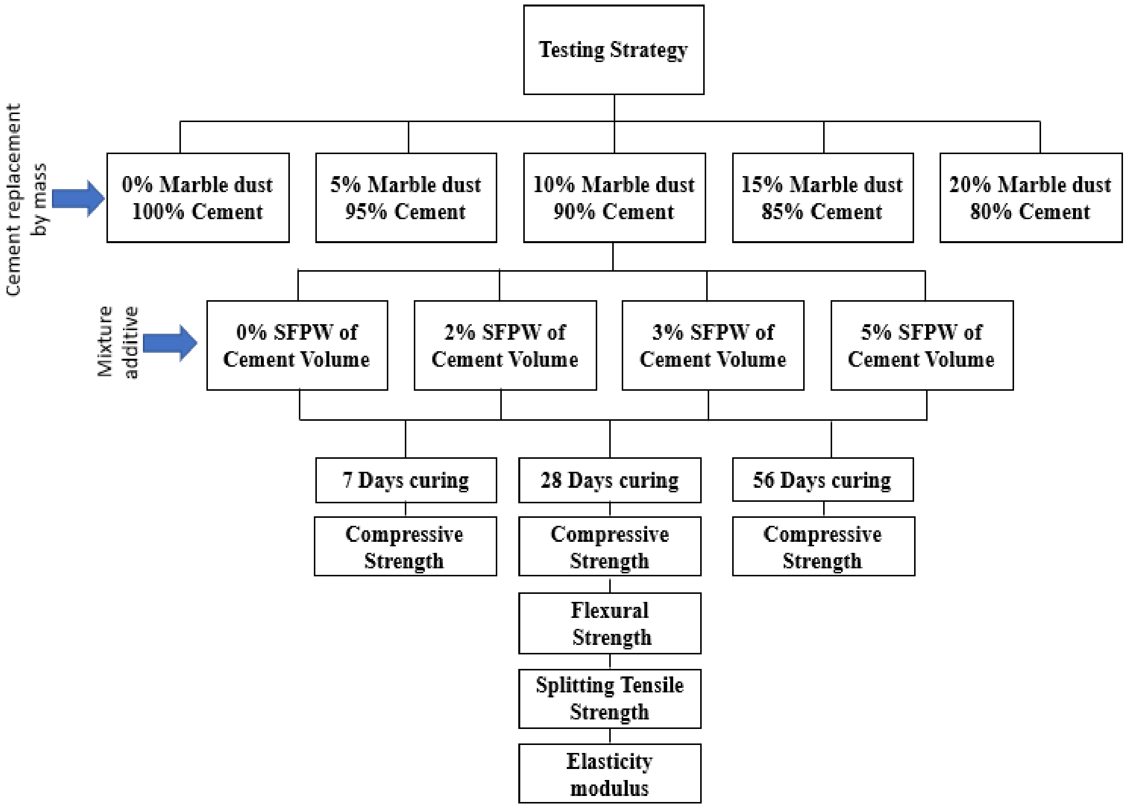

Figure 12: Adopted testing strategy.

3.4 Testing Samples preparation

For any given concrete mix the required amount of cement, aggregate (coarse and fine), water, marble dust waste, and SFPW are determined by means of their mass. Then the concrete components are fed to a vertical shaft concrete mixer. The mixer is then switched on until a homogenous mixture is obtained. Then the concrete mix slump is measured as per ASTM C143 / C143M – 20.

3.4.1 Compressive strength and splitting tensile samples

Cubic plastic molds with a side dimension of 150mm are initially greased with oil. Then the concrete mix is supplied to the molds in three layers. Every layer is compacted with a manual rammer for 25 blows across the surface of the sample. This is done to drive out any air void within the mix.

3.4.2 Flexural strength samples

Prismatic steel mold with a length of 500 mm, width of 100 mm and height of 100 mm. Similarly with the compressive strength samples, the concrete mix is supplied to the molds in three layers. Every layer is compacted with a manual rammer across the surface of the sample until the air void are dissipated from the mix.

3.4.3 Elastic modulus sample

Cylindrical steel mold with a diameter of 75 mm and height of 150 mm. Likewise, with the compressive strength samples, the concrete mix is supplied to the molds in three layers. Every layer is tapped with a tapping steel rod for 25 rams across the surface of the specimen. This is done to annihilate any air void within the mix.

3.4.4 Sample curing

Immediately after casting the samples, they are shipped to curing room. Samples are kept in the curing room for an overnight period. Then, the samples are discharged from their mold into a curing tank that is filled with fresh water. Samples are kept in the curing tanks until the desired testing period is reached. upon that date, samples are removed from the tank and set aside prior to testing. Figure 13 shows the used water tank to cure the casted samples. It is worth to mention that the temperature of the water tank and the humidity of the laboratory were checked weekly as shown in Table 3.

Figure 13: Curing water tank.

Table 3: Temperature and relative humidity measurements during testing.

Week	Time	Water Tank 1		Water Tank 2		Water Tank 3	
		Temperature	RH%	Temperature	RH%	Temperature	RH%
Week 1	15:19	23.2	32.5	-	-	-	-
Week 2	16:22	25	25.7	-	-	-	-
Week 3	16:50	23.5	17.2	24.6	17.2	-	-
Week 4	11:50	24.3	32.4	24.3	32.4	24.7	32.4
Week 5	15:21	24.3	13.2	24.9	13.2	24.2	13.2
Week 6	13:01	25.3	30.2	25.5	30.2	25.5	30.2
Week 7	12:03	28.4	32.1	28.2	32.1	28.6	32.1
Week 8	10:32	27.5	31.9	27.5	31.9	27.5	31.9
Week 9	13:05	28.7	21.5	28.8	21.5	28.9	21.5
Week 10	19:21	-	-	29.2	15.9	28.9	15.9
Week 11	10:30	-	-	28.2	15.5	28.3	15.5
Week 12	20:30	-	-	28.1	14.9	27.9	14.9

3.4.5 Concrete mix design

The mix design is prepared using calculation sheets of provided by the Building Research Establishment (BRE). The characteristic compressive strength is selected to be 30 MPa at 28 days as it covers wide range of site application (foundations, columns, and beams). Defective percentage of 10% is selected and the target strength was found to be 40 MPa. The cement water ratio is fixed as 0.5 and cement content was 330 Kg/m^3. So, based on these assumptions mix design table is generated which is shown in Table 4.

Table 4: The adopted testing mix design.

Mixture	Cement (Kg)	MDW (Kg)	SFPW (g)	Adjusted Water Content (Kg)	Natural aggregate (Kg)			
					0 – 5 (mm)	5 – 10 (mm)	10 15 (mm)	15 -20 (mm)
S 0 M 0	330.0	0.0	0.0	205.0	925.0	350.0	350.0	350.0
S 0 M 5	313.5	16.5	0.0	205.0	925.0	350.0	350.0	350.0
S 0 M 10	297.0	33.0	0.0	205.0	925.0	350.0	350.0	350.0
S 0 M 15	280.5	49.5	0.0	205.0	925.0	350.0	350.0	350.0
S 0 M 20	264.0	66.0	0.0	205.0	925.0	350.0	350.0	350.0
S 2 M 0	330.0	0.0	882.0	205.0	925.0	350.0	350.0	350.0
S 2 M 5	313.5	16.5	882.0	205.0	925.0	350.0	350.0	350.0
S 2 M 10	297.0	33.0	882.0	205.0	925.0	350.0	350.0	350.0
S 2 M 15	280.5	49.5	882.0	205.0	925.0	350.0	350.0	350.0
S 2 M 20	264.0	66.0	882.0	205.0	925.0	350.0	350.0	350.0
S 3 M 0	330.0	0.0	1323.0	205.0	925.0	350.0	350.0	350.0
S 3 M 5	313.5	16.5	1323.0	205.0	925.0	350.0	350.0	350.0
S 3 M 10	297.0	33.0	1323.0	205.0	925.0	350.0	350.0	350.0
S 3 M 15	280.5	49.5	1323.0	205.0	925.0	350.0	350.0	350.0
S 3 M 20	264.0	66.0	1323.0	205.0	925.0	350.0	350.0	350.0
S 5 M 0	330.0	0.0	2205.1	205.0	925.0	350.0	350.0	350.0
S 5 M 5	313.5	16.5	2205.1	205.0	925.0	350.0	350.0	350.0
S 5 M 10	297.0	33.0	2205.1	205.0	925.0	350.0	350.0	350.0
S 5 M 15	280.5	49.5	2205.1	205.0	925.0	350.0	350.0	350.0
S 5 M 20	264.0	66.0	2205.1	205.0	925.0	350.0	350.0	350.0

where; S= SFPW, and M= MDW.

3.5 Testing procedures

All the tests within this study are conducted in the Material of construction laboratory in the civil engineering department at Eastern Mediterranean university. Testing procedures are conducted with the ASTM standards.

3.5.1 Compressive strength

The compressive strength of the concrete specimen is conducted in accordance with C109/C109M − 20b. Three samples from each mix at each curing period are evaluated and the average is noted to be the compressive strength. The test is conducted by means of constant rate of loading that is 0.5 MPa/s.

3.5.2 Splitting tensile strength

This test is conducted in order to evaluate the tensile strength of concrete mixture indirectly. Similarly, with the compressive strength, the evaluation is conducted on three specimens and the average is taken as the tensile strength of the samples. The test is conducted at controlled strain rate of 0.04%.

3.5.3 Flexural strength

The flexural strength is obtained as provisioned by ASTM C1609 / C1609M - 19a using 3 identical samples. The average of these samples is the flexural strength. The test is conducted in constant rate of loading manner of 0.05 MPa/s.

3.5.4 Elasticity modulus

The elastic modulus is evaluated as per ASTMC469/C469M-14. It represents the initial slope of the stress strain curve. And it is evaluated between the strain levels of 0.00005 (ε_1) and the strain at which 40% of the ultimate strength is reached (σ_{max}). As illustrated in Figure 14.

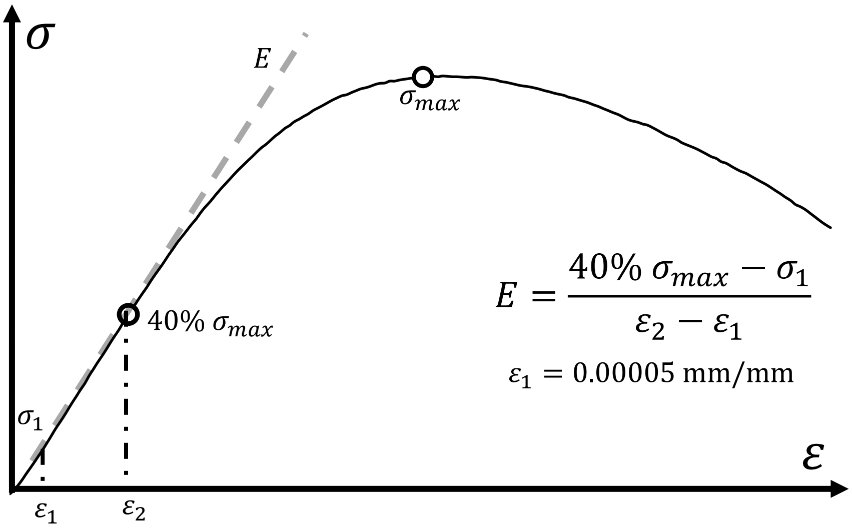

Figure 14: calculation of the elasticity modulus.

Chapter 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter presents the obtained outcomes regarding incorporating locally found construction wastes into green concrete production. The results are depicted by means of illustrative figures altogether with comprehensive comments that present explanation regarding the physical and mechanical behavior of the obtained materials.

4.2 Workability of the fresh mix

Workability is extremely an essential property of the fresh concrete mixture especially when heavily reinforced structural element is casted onsite. Or while preparing pumpable concrete. Workability is estimated usually by means of the slump test. Hence, slump of each of the mixtures are evaluated to analyze the serviceability of the produced material. The results are depicted in Figure 15. As shown the slump of the fresh concrete mix significantly dropped upon incorporating both MDW and SFPW. It is worth to mention that the relationship between slump level and the MDW replacement percentage is inversely proportional where replacement level of MDW of 20% resulted in reducing the slump to roughly 70% of the controlled mix slump, where a similar outcome obtained by [26] [27] . This can be related to the high surface area that the MDW possesses in addition to its high-water absorption capacity. Similarly, the SFPW percentage also negatively influenced the workability of the control mix where even 2% addition of SFPW resulted in reducing the slump to roughly 67% of the controlled mix slump. This can be attributed to the fact that SFPW acts as fibrous additive which usually reduces the slump of the concrete mixture.

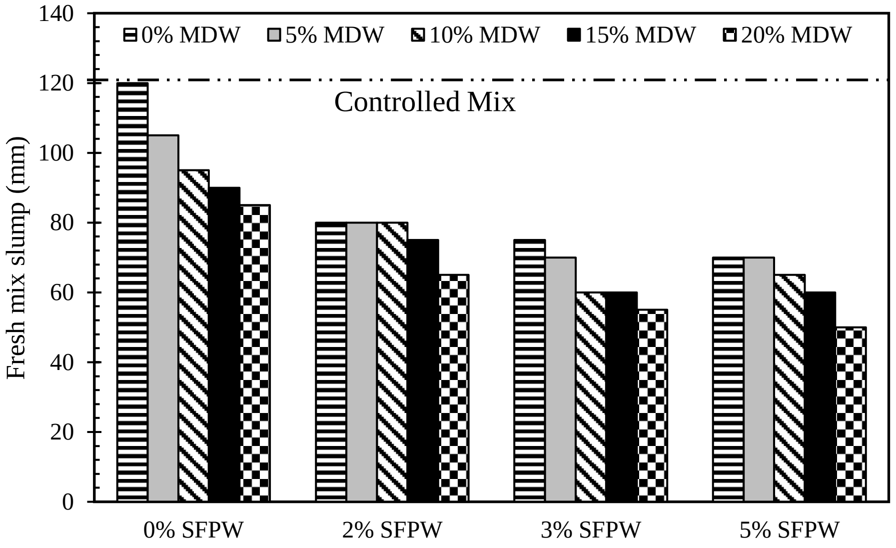

Figure 15: Slump values of the fresh concrete mixtures.

4.3 Dry unit weight

The unit weight of the produced green concrete is extremely important as it is one of the most essential parameters needed in designing any structural element. For this purpose, measurements regarding the dry unit weight of each of the aforementioned concrete mixtures are recorded after 28 days of curing. Outcomes of these measurements are presented in Figure 16. As shown the proportion of the wastes added to the concrete has almost no effect in regards with the controlled mix. Whereas all of the mixtures have roughly a unit weight of 2440 (±15) kg/m^3 and hence all the produced concrete are normal weight concrete.

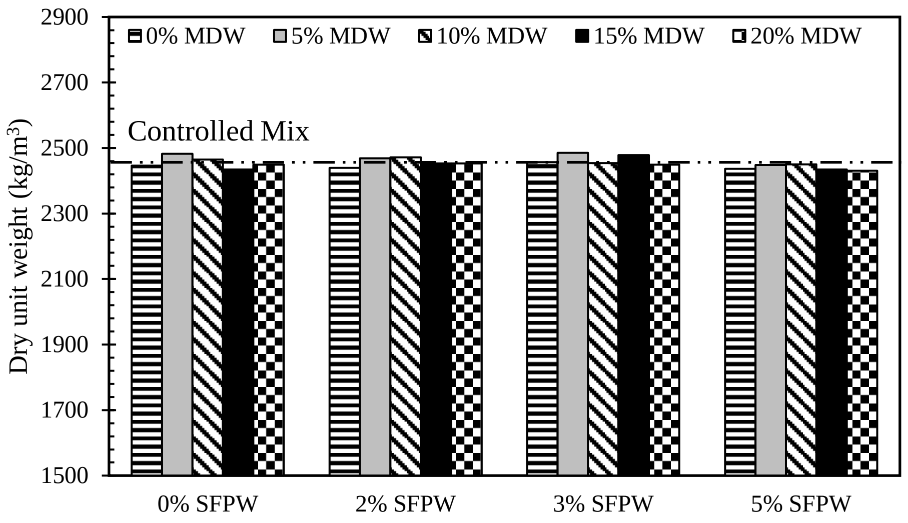

Figure 16: Dry unit weight of the mixtures at 28 days.

4.4 Compressive strength

The early development of strength upon one weak of curing is evaluated for every single mixture. The compressive strength results are presented in Figure 17. As illustrated the compressive strength at 7 days curing period is inversely proportional with the MDW replacement levels. For instance, 20% addition of marble dust resulted in a compressive strength that is roughly 27% lower when compared with reference, this is also obtained in previous study which done by [32] [33] [35]. It might be linked to the fact that, MDW does not possesses any pozzolanic activity and is rather an inert material which acts as filler only. However, including the SFPW indeed resulted in improving the compressive strength slightly (by 1.5%) at 2% SFPW addition with 5% MDW. Also, statistical summary of the results is shown in Table 5. As presented, it can be clearly observed that the samples of a given mixture are almost identical as their standard deviation varied between 0.32 and 1.96 MPa.

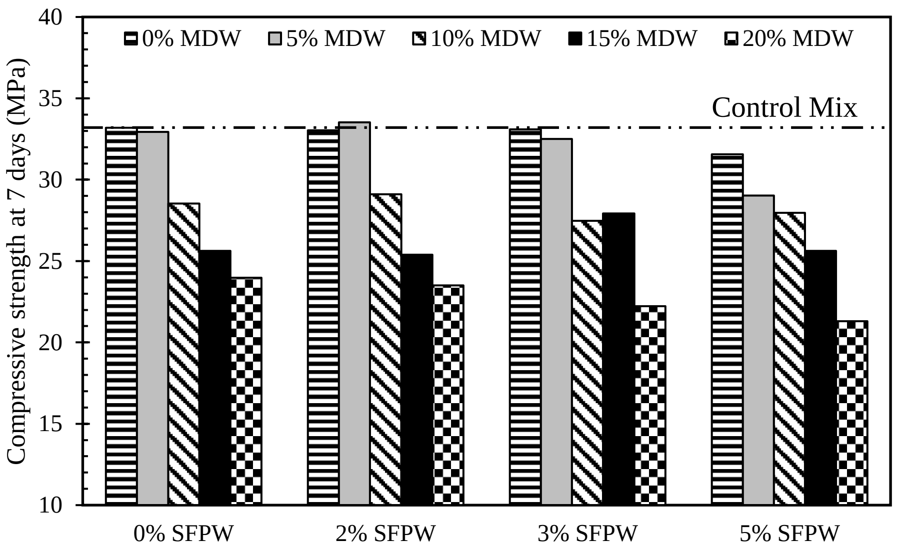

Figure 17: Compressive strength at 7 days of curing.

Table 5: Statistical description of the compressive strength at 7 days curing.

Cement (%)	**MDW (%)**	**SFPW (%)**	**1st Sample (MPa)**	**2nd Sample (MPa)**	**3rd Sample (MPa)**	**Average (MPa)**	**Standard deviation (MPa)**	**Rate of change (%)**
100	0	0	32.3	33.3	34	33.2	0.85	0.00
95	5	0	33.3	32.8	32.7	32.9	0.32	-0.80
90	10	0	28.5	28	29.1	28.5	0.55	-14.06
85	15	0	26.2	26	24.7	25.6	0.81	-22.79
80	20	0	23.6	24.7	23.6	24.0	0.64	-27.81
100	0	2	32.9	32.7	33.5	33.0	0.42	-0.50
95	5	2	33.6	33.9	33.1	33.5	0.40	1.00
90	10	2	29.7	28.9	28.7	29.1	0.53	-12.35
85	15	2	26.9	23.5	25.8	25.4	1.73	-23.49
80	20	2	25	23.4	22.1	23.5	1.45	-29.22
100	0	3	33.4	32.9	33	33.1	0.26	-0.30
95	5	3	31.8	31.9	33.8	32.5	1.13	-2.11
90	10	3	27.2	28	27.2	27.5	0.46	-17.27
85	15	3	27.9	28.3	27.6	27.9	0.35	-15.86
80	20	3	22.5	23	21.2	22.2	0.93	-33.03
100	0	5	29.4	32.1	33.2	31.6	1.96	-4.92
95	5	5	30.9	27.2	29	29.0	1.85	-12.55
90	10	5	28.8	26.6	28.5	28.0	1.19	-15.76
85	15	5	27.7	24.9	24.3	25.6	1.81	-22.79
80	20	5	21.1	20.8	22	21.3	0.62	-35.84

The samples that were crushed after 28 days of curing resulted in similar behavior with the samples cured after 7 days. This can be observed in Figure 18 which present the testing outcomes in a bar chart form. As illustrated as the MDW percentage increases beyond 5% dramatic reduction in the compressive strength is attained, where replacing the cement by 20% MDW resulted in a compressive strength that is roughly 20% lower than the control sample, moreover, same results was discovered by previous studied which is done by [33] [34]. On the contrary, SFPW percentage has almost no significant effect on the compressive strength where the rate of change did not exceed ±2%. For the composite mixtures that includes both of MDW and SFPW it gives an optimal performance with 5% MDW and 2% SFPW replacement levels where the compressive strength improved by 4%. Further statistical details of the testing outcomes are illustrated in Table 6.

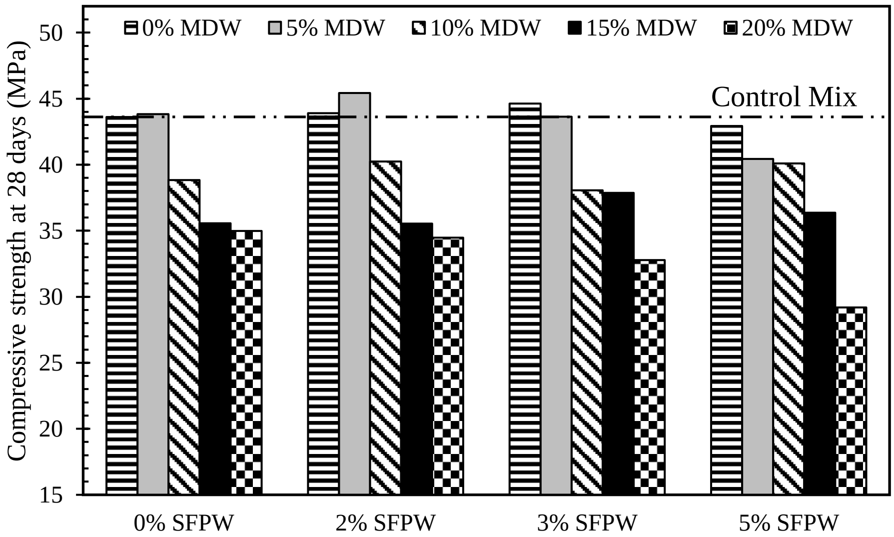

Figure 18: Compressive strength at 28 days of curing.

Table 6: Statistical description of the compressive strength at 28 days curing.

Cement (%)	**MDW (%)**	**SFPW (%)**	**1st Sample (MPa)**	**2nd Sample (MPa)**	**3rd Sample (MPa)**	**Average (MPa)**	**Standard deviation (MPa)**	**Rate of change (%)**
100	0	0	44.4	44.5	41.9	43.6	1.47	0.00
95	5	0	42.6	45.6	43.3	43.8	1.57	0.54
90	10	0	37.5	40.2	38.8	38.8	1.35	-10.93
85	15	0	36.2	36.7	33.8	35.6	1.55	-18.43
80	20	0	34.6	34.5	35.8	35.0	0.72	-19.80
100	0	2	44.2	43.5	44	43.9	0.36	0.69
95	5	2	45.2	44.3	46.8	45.4	1.27	4.20
90	10	2	39.1	40.5	41.1	40.2	1.03	-7.72
85	15	2	36.3	35.7	34.6	35.5	0.86	-18.50
80	20	2	34	35	34.4	34.5	0.50	-20.95
100	0	3	47.4	42.9	43.6	44.6	2.42	2.37
95	5	3	44.1	43.3	43.3	43.6	0.46	-0.08
90	10	3	37.2	38.8	38.2	38.1	0.81	-12.69
85	15	3	39.3	36.1	38.2	37.9	1.63	-13.15
80	20	3	32.3	33.9	32.1	32.8	0.99	-24.85
100	0	5	41.3	43.6	43.9	42.9	1.42	-1.53
95	5	5	39.7	41.1	40.5	40.4	0.70	-7.26
90	10	5	39.6	38.6	42.1	40.1	1.80	-8.03
85	15	5	36.9	35.9	36.3	36.4	0.50	-16.59
80	20	5	29	28.5	30.1	29.2	0.82	-33.03

56 days of cured samples resulted performed in similar manner with the samples crushed after 7 and 28 days. This can be noticed in the bar chart of Figure 19. As depicted the compressive strength of the cured samples reduces as the MDW percentage increases beyond 5%, for instance, 20% MDW that was used as substitute of the cement resulted in a compressive strength that is roughly 22% lower than the reference sample, similarly was recorded by a study which done by [33]. Alternatively, the effect of SFPW percentage is almost insignificant regarding the compressive strength where the rate of change did not exceed ±2%. Ultimately, optimal performance for mixtures including both of MDW and SFPW is achieved at 5% MDW

and 2% SFPW replacement levels where the compressive strength increased by 2.37%. More detailed statistical data of the testing results are projected in Table 7.

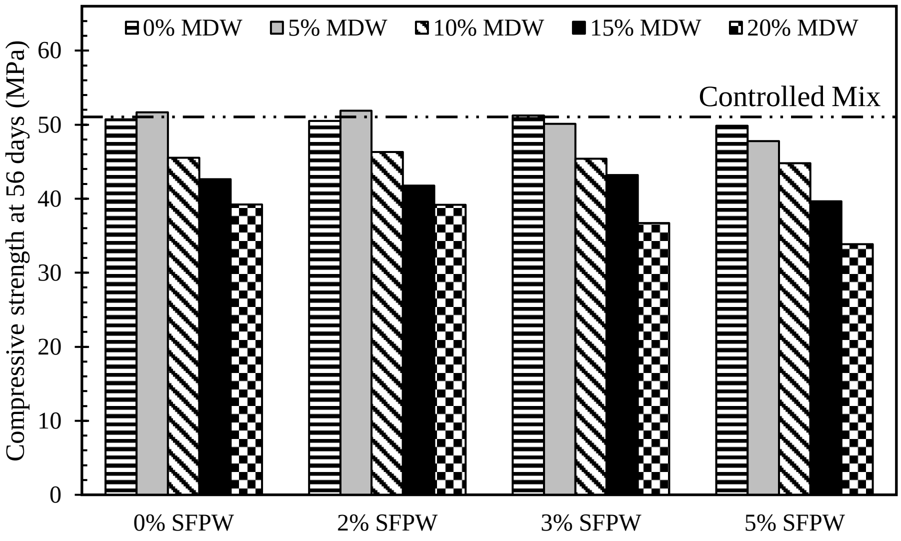

Figure 19: Compressive strength at 56 days of curing.

Table 7: Statistical description of the compressive strength at 56 days curing.

Cement (%)	MDW (%)	SFPW (%)	1st Sample (MPa)	2nd Sample (MPa)	3rd Sample (MPa)	Average (MPa)	Standard deviation (MPa)	Rate of change (%)
100	0	0	49.1	51.1	51.9	50.7	1.44	0.00
95	5	0	51.4	51.1	52.5	51.7	0.74	1.91
90	10	0	44.4	43.6	48.6	45.5	2.69	-10.19
85	15	0	44.4	40.8	42.7	42.6	1.80	-15.91
80	20	0	37.9	38.9	40.8	39.2	1.47	-22.68
100	0	2	50.9	49.9	50.7	50.5	0.53	-0.39
95	5	2	51.8	51.5	52.4	51.9	0.46	2.37
90	10	2	47.2	45.4	46.4	46.3	0.90	-8.61
85	15	2	41.1	43.2	41	41.8	1.24	-17.62
80	20	2	39.8	38.7	39	39.2	0.57	-22.75
100	0	3	51	52.8	49.9	51.2	1.46	1.05
95	5	3	50.2	50.1	50.1	50.1	0.06	-1.12
90	10	3	45.5	44.6	46.1	45.4	0.75	-10.45
85	15	3	44.8	40	44.8	43.2	2.77	-14.79
80	20	3	35.9	36	38.3	36.7	1.36	-27.55
100	0	5	49.85	46.7	53	49.9	3.15	-1.68

95	5	5	47.9	47.9	47.6	47.8	0.17	-5.72
90	10	5	44.3	45.3	44.8	44.8	0.50	-11.64
85	15	5	39.6	40.1	39.2	39.6	0.45	-21.83
80	20	5	33.6	33.5	34.5	33.9	0.55	-33.20

4.5 Tensile strength

The tensile strength of the produced materials is evaluated indirectly by means of the splitting tensile strength test. Results of which are shown in Figure 20. It is observed that SFPW has no influence on the splitting tensile strength. Unlike the MDW which generally reduces the splitting tensile strength for replacement levels larger than 5%, this is also reported by the previous studies which done by [35] [39]. However, incorporating both wastes lead to dramatic decrease of the splitting tensile strength. Where 20% MDW with 5% SFPW resulted a splitting tensile strength that is 36% less than the reference mix. This can be linked to the information that both of MDW and SFPW lack any cementitious materials. Additional statistical descriptive information is presented in Table 8.

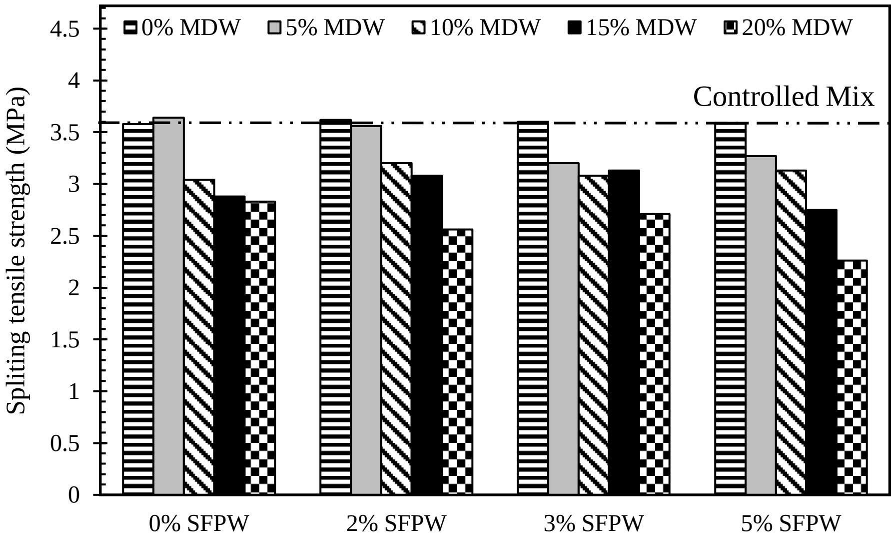

Figure 20: Splitting tensile strength at 28 days of curing.

Table 8: Statistical description of the indirect tensile strength at 28 days curing.

Cement (%)	**MDW (%)**	**SFPW (%)**	**1st Sample (MPa)**	**2nd Sample (MPa)**	**3rd Sample (MPa)**	**Average (MPa)**	**Standard deviation (MPa)**	**Rate of change (%)**
100	0	0	3.52	3.61	3.60	3.58	0.048	0.00
95	5	0	3.69	3.64	3.58	3.64	0.052	1.63
90	10	0	3.11	3.01	2.99	3.04	0.062	-15.14
85	15	0	2.85	2.86	2.91	2.88	0.032	-19.63
80	20	0	2.88	2.80	2.81	2.83	0.042	-20.93
100	0	2	3.68	3.61	3.59	3.62	0.047	1.32
95	5	2	3.59	3.50	3.59	3.56	0.053	-0.51
90	10	2	3.19	3.21	3.19	3.20	0.009	-10.60
85	15	2	3.09	3.05	3.10	3.08	0.027	-13.86
80	20	2	2.57	2.54	2.57	2.56	0.017	-28.51
100	0	3	3.61	3.60	3.60	3.60	0.007	0.75
95	5	3	3.05	3.22	3.32	3.20	0.140	-10.66
90	10	3	3.09	3.05	3.09	3.08	0.023	-13.93
85	15	3	2.96	3.00	3.42	3.13	0.258	-12.62
80	20	3	2.70	2.72	2.71	2.71	0.012	-24.21
100	0	5	3.57	3.59	3.62	3.59	0.028	0.45
95	5	5	3.29	3.25	3.27	3.27	0.022	-8.69
90	10	5	3.25	2.97	3.16	3.13	0.139	-12.62
85	15	5	2.63	2.93	2.69	2.75	0.159	-23.05
80	20	5	2.29	2.22	2.28	2.26	0.035	-36.73

4.6 Flexural strength

Flexural strength is an essential property as it measures the resistance of a material to deformation by means of modulus of rapture. Outcomes of flexural strength are displayed in Figure 21. As shown the Flexural strength of concrete significantly improved upon adding SFPW, where 5% of SFPW has flexural strength 13% larger than the control mix. On the other hand, MDW tends to reduce the flexural strength for replacement levels larger than 5% as MDW does not initiate any pozzolanic activities, additionally, similar results for 5% MDW substitution was reported by [38]. On the contrary, considering both of MDW and SFPW it is found that the optimum mixture is 5%MDW and 2% SFPW increased the flexural strength by roughly 10% in comparison with the controlled mix. More illustrative statistical information is displayed in Table 9.

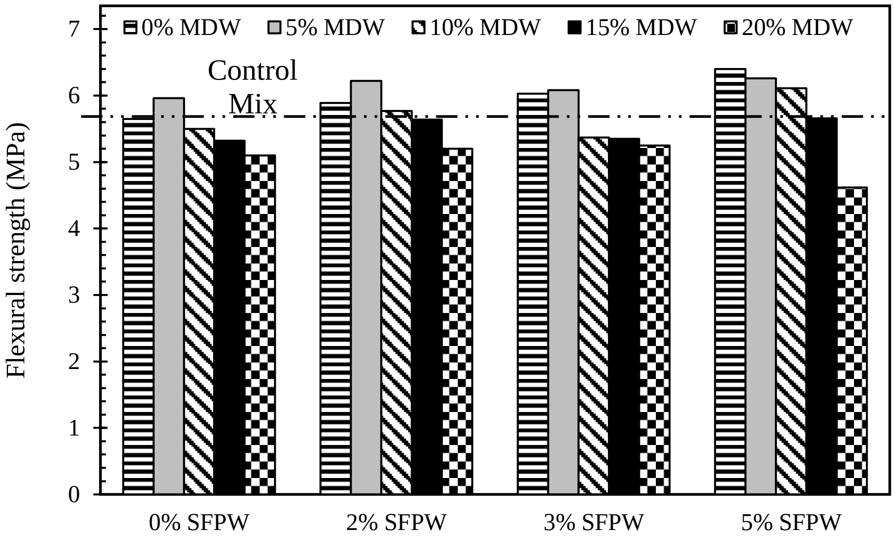

Figure 21: Flexural strength at 28 days of curing.

Table 9: Statistical description of the Flexural strength at 28 days curing.

Cement (%)	**MDW (%)**	**SFPW (%)**	**1st Sample (MPa)**	**2nd Sample (MPa)**	**3rd Sample (MPa)**	**Average (MPa)**	**Standard deviation (MPa)**	**Rate of change (%)**
100	0	0	6.21	5.04	5.69	5.65	0.586	0.00
95	5	0	6.06	5.93	5.90	5.96	0.085	5.61
90	10	0	5.42	5.62	5.47	5.50	0.104	-2.54
85	15	0	5.38	5.22	5.35	5.32	0.085	-5.84
80	20	0	5.11	5.18	5.01	5.10	0.085	-9.68
100	0	2	5.88	5.85	5.93	5.89	0.040	4.25
95	5	2	6.29	6.25	6.13	6.22	0.083	10.21
90	10	2	5.69	5.83	5.79	5.77	0.072	2.18
85	15	2	5.59	5.63	5.70	5.64	0.056	-0.12
80	20	2	5.27	5.20	5.12	5.20	0.075	-7.97
100	0	3	6.12	6.02	5.95	6.03	0.085	6.79
95	5	3	6.10	6.01	6.13	6.08	0.062	7.67
90	10	3	5.22	5.51	5.39	5.37	0.146	-4.84
85	15	3	5.42	5.84	4.80	5.35	0.523	-5.19
80	20	3	5.15	5.24	5.35	5.25	0.100	-7.08

100	0	5	6.19	6.47	6.53	6.40	0.181	13.28
95	5	5	6.40	6.22	6.17	6.26	0.121	10.92
90	10	5	6.19	6.08	6.05	6.11	0.074	8.15
85	15	5	5.81	5.56	5.60	5.66	0.134	0.18
80	20	5	4.56	4.49	4.80	4.62	0.163	-18.24

4.7 Elasticity modulus

The elasticity modulus represents the relation between the applied stress and resulted deformation. It is obtained by means of the initial slope of the stress strain curve. Results of the elasticity modulus are presented in Figure 22. As illustrated the MDW increased the modulus of elasticity until an optimal value of 5 % is reached. Beyond that any addition in the MDW resulted in significant reduction in comparison with the controlled mix, moreover, similar outcomes were obtained by [45]. On the other hand, SFPW percentage has an optimal value of 3%, where it resulted in roughly 4% higher modulus of elasticity in comparison with the reference mix. Ultimately, the optimal replacement levels of both MDW and SFPW is found to be 5% MDW and 3% SFPW, and 5% MDW and 5% SFPW.

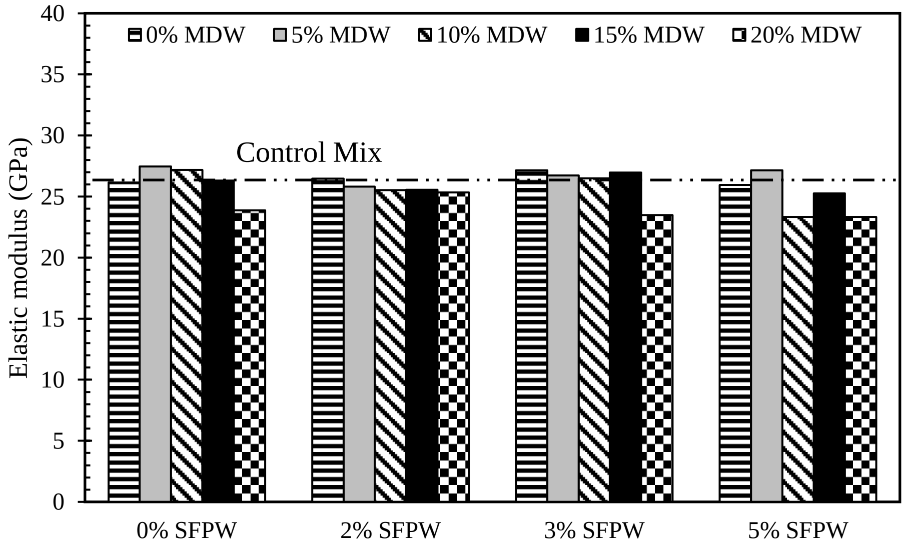

Figure 22: elastic modulus at 28 days of curing.

4.8 Compressive strength relationships

Colorations between the compressive strength and other mechanical properties are extremely important. As it might reduce the amount experimental work. These relations are obtained by means of regression analysis. Multiple regression analyses are conducted including; linear, logarithmic, power and exponential regressions. However, regression relations with higher coefficient of determination (R^2) are adopted.

4.8.1 Compressive strength and splitting tensile strength

The linear regression analysis exhibited a solid linear relationship exists among the compressive strength and the splitting tensile strength. The relationship is presented in Eq (2), where it has a coefficient of determination (R^2) equivalent to 0.89. Application of the developed formulation in comparison with the measured data are presented in figure 23.

$$STS = 0.082\sigma_c - 0.073 \qquad \text{Eq (2)}$$

Where; STS: splitting tensile strength, and σ_c: compressive strength.

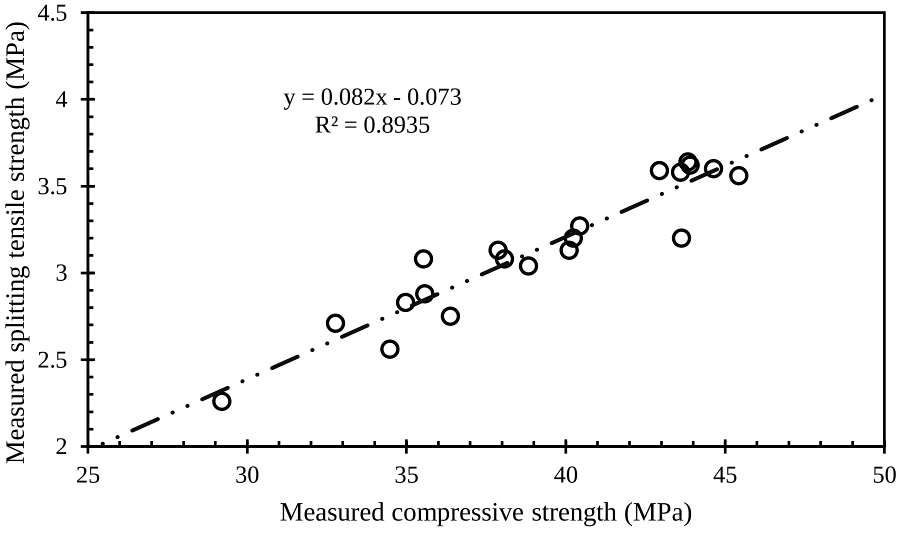

Figure 23: Relationship between compressive strength and splitting tensile strength.

4.8.2 Compressive strength and flexural strength

Regression analysis indicated a moderate logarithmic relationship is existed among the compressive strength and the flexural strength. The relationship is presented in Eq (3), where it has a coefficient of determination (R^2) equivalent to 0.7386. utilization of the developed formulation in comparison with the measured data are presented in figure 24.

$$FS = 3.2976 \ln \sigma_c - 6.4 \qquad \text{Eq (3)}$$

Where; FS: flexural strength, and σ_c: compressive strength.

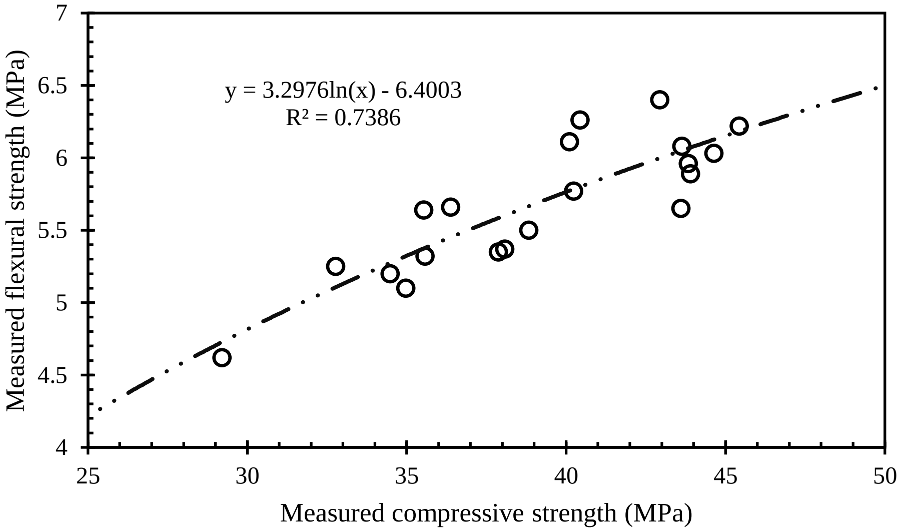

Figure 24: Relationship between compressive strength and flexural strength.

4.8.3 Compressive strength and elastic modulus

Regression analysis indicated a moderate logarithmic relationship is existed among the compressive strength and the elasticity modulus. The relationship is presented in Eq (4), where it has a coefficient of determination (R^2) equivalent to 0.755. employment of the developed formulation in comparison with the measured data are presented in figure 25.

Where; E: Elastic modulus (GPa), and σ_c: compressive strength.

$$E = 9.8649 \ln \sigma_c - 10.991 \qquad \text{Eq (4)}$$

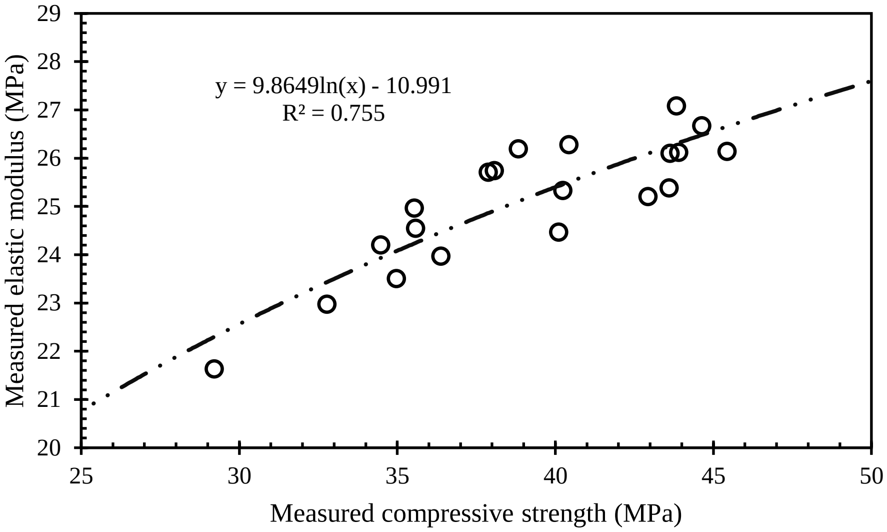

Figure 25: Relationship between compressive strength and elastic modulus.

Chapter 5

CONCLUSIONS

5.1 Conclusion

The aim of this study is to a more environmentally friendly concrete by incorporating locally produced wastes which are the MDW and SFPW. In order to meet this objective, a comprehensive research program is designed in order to capture the optimal percentages, where the MDW is replacing the cement content by mass and the SFPW is used as an additive by means of the cement volume. The outcomes of this research are summarized in the following bullet points:

1. The slump of the mixture dropped from high to medium workability. The most crucial element on the workability is replacing the cement by the marble dust as it has very large surface area and requires more water to cover its particles surfaces.
2. The proportions of MDW and SFPW did not influence the dry unit weight of concrete, where all of the mixture achieved a dry unit weight of 2440 (±15) kg/m^3.
3. The compressive strength is evaluated over three periods of curing which are: 7, 28 and 56 days. However, the behavior with respect to the control samples remained similar regardless of the curing periods. The optimal percentage of using the MDW and SFPW is found to be 5% and 2% respectively. This proportion achieved higher compressive strength in comparison with the controlled mix.

4. Regarding the indirect tensile strength, the MDW replacement levels significantly reduced the tensile strength. In contrast, the addition of SFPW has no significant effect. The optimal mix that causes no decrease in the indirect tensile strength using the MDW and SFPW is found to be 5% and 2% respectively.
5. Flexural strength is impacted significantly by means of the MDW replacement levels. However, the SFPW enhanced the flexural strength so slightly. The optimal probation of the MDW and SFPW is found to be 5% and 2-5% respectively.
6. The modulus of elasticity is not influenced dramatically by the addition of MDW and SFPW. However, the optimal percentage of using the MDW and SFPW is found to be 5% and 3-5% respectively.
7. There is strong linear connection between the compressive strength and the indirect tensile strength. and moderate logarithmic relation among the compressive strength, flexural strength and the elastic modulus.

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APPENDIX

Mix Design

1)

1.1 Characteristic strength Specified ....30............. N/mm2 at..........28...........days

Proportion defective ……....10.............%

1.2 Standard deviation ………………………………8……….......................N/mm2

1.3 Margin C1 (k=....1.28........) ....1.28.........*.......8...........=..........10.24........N/mm2

1.4 Target mean strength C2 ....30............+.........10..........=..........40.........N/mm2

1.5 Cement strength class Specified …………………42.5……………. 42.5/52.5

1.6 Aggregate type: coarse ………………crushed………………. Crushed/Uncrushed

Aggregate type: fine …………………crushed ……………… Crushed/Uncrushed

1.7 Free-water/cement ratio (Fig. 26, Fig. 27) ....0.57................... kg/m3

1.8 Max. Free water/cement ratio Specified ……………….......0.5................................

Using the lower value which is ………………………0.5……………................

2)

2.1 Slump or VeBe time (Specified) Slump ....60-180.........mm or VeBe time.... /.... s

2.2 Max. Aggregate size (Specified) …………………20…..........................mm

2.3 Free-water content (Fig. 28) ....225............................kg/m3

3)

3.1 Cement content C3 ....225........... / ....0.5............. = ...450....... kg/m3

3.2 Maximum Cement content Specified ....330.......................kg/m3

3.3 Minimum Cement content Specified ..../..........................kg/m3

Do not use less than 3.3 or more than 3.2 ....330.................... kg/m3

3.4 Modified free-water/cement ratio ....330.......... / ....0.5......=.......165.......kg/m3.

4)

4.1 Relative density of aggregate (SSD) ....2.7.................. known/assumed

4.2 Concrete density (Fig. 29) ....2460...................................... kg/m3

4.3 Total aggregate content (C4) ....2460....... - ....330.... - ...165.... = ...1965.... kg/m3

5)

5.1 Grading of fine aggregate Percentage passing 600-micron sieve...........35.7............%

5.2 Proportion of fine aggregate (Fig. 30) ....47..............................%

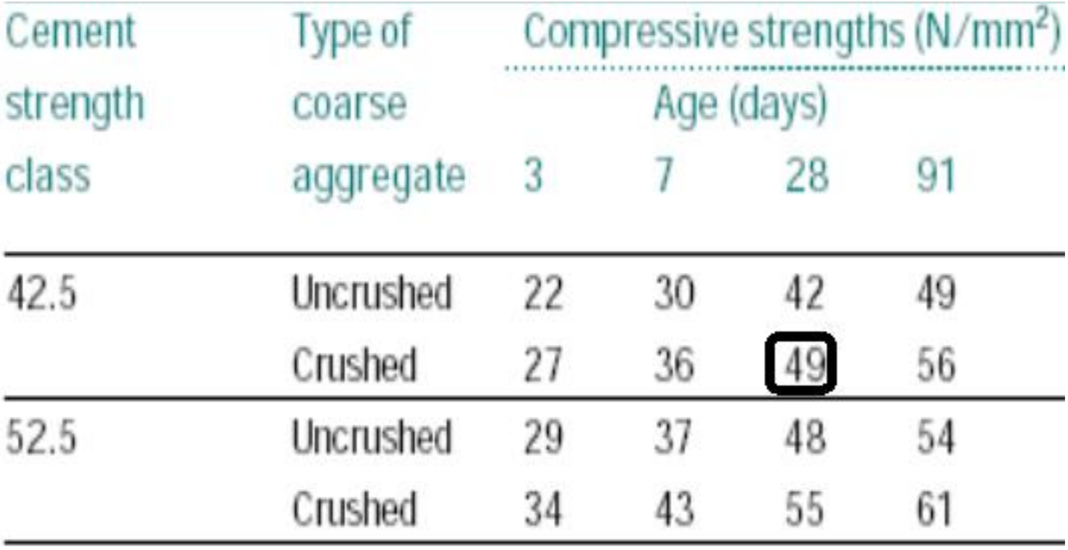
5.3 Fine aggregate content C5.......1965........... **x** ....0.47............. = ...925.......kg/m3

5.4 Coarse aggregate content ......1965......... **-**. ....925......... = ...1040............kg/m3

Table 10: Shows the material quantities for $1m^3$.

Cement (Kg)	Water (Kg)	Fine (Kg)	Coarse (Kg)		
			5 – 10 mm	10 – 15 mm	15 – 20 mm

330	165	925	345	345	345



Cement strength class	Type of coarse aggregate	Compressive strengths (N/mm²) Age (days) 3	7	28	91
42.5	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
52.5	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Figure 26: Approximate compressive strength of concrete with w/c ratio 0.5

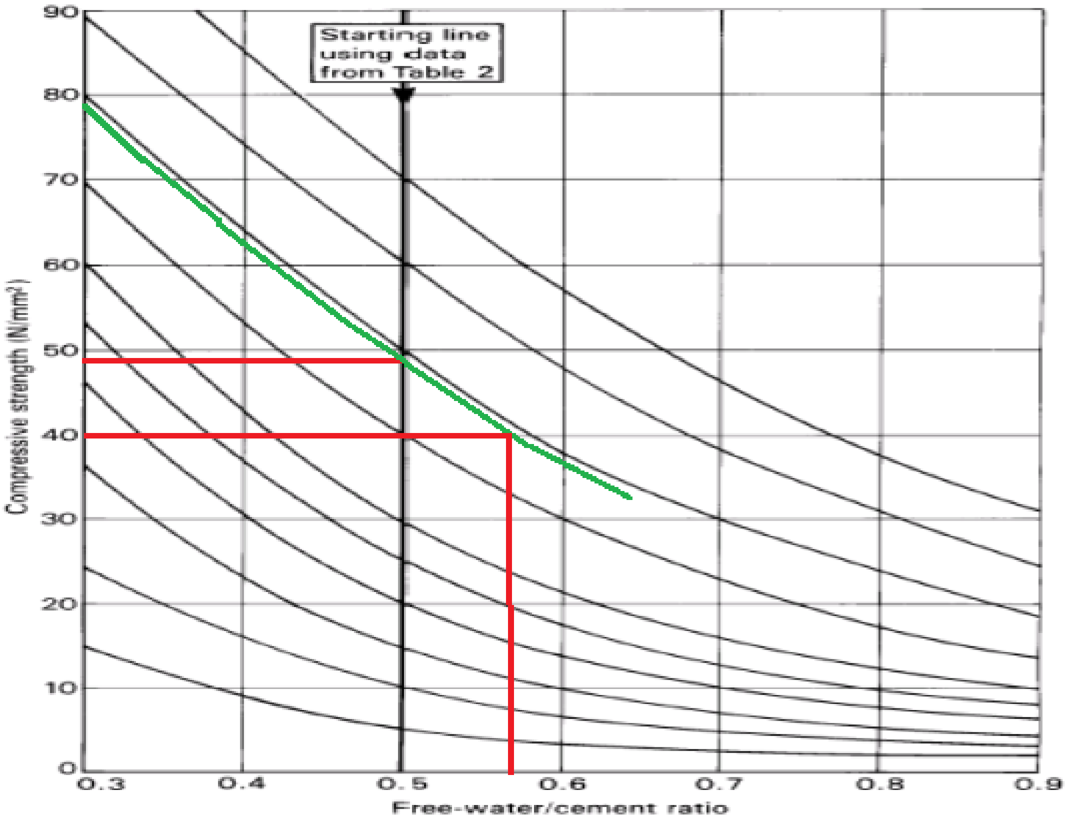
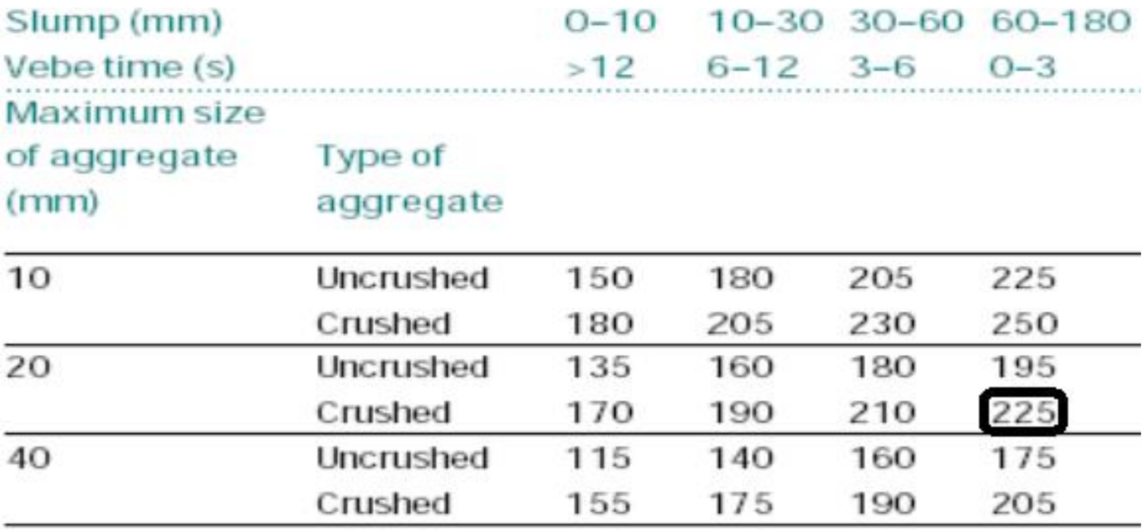


Figure 27: Relation between compressive strength and free water / cement ratio.



Slump (mm)		0–10	10–30	30–60	60–180
Vebe time (s)		>12	6–12	3–6	0–3
Maximum size of aggregate (mm)	Type of aggregate				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	$\boxed{225}$
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Figure 28: Approximate free water content for various workability levels.

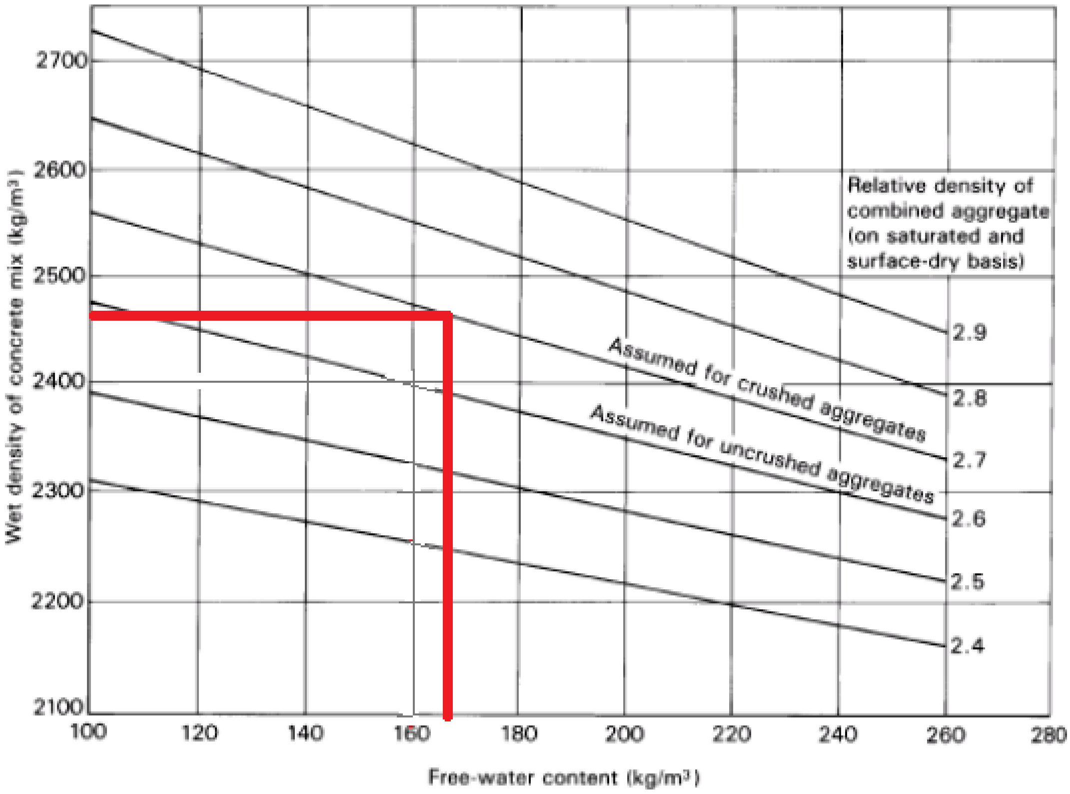


Figure 29: Estimated wet density of fully compacted concrete.

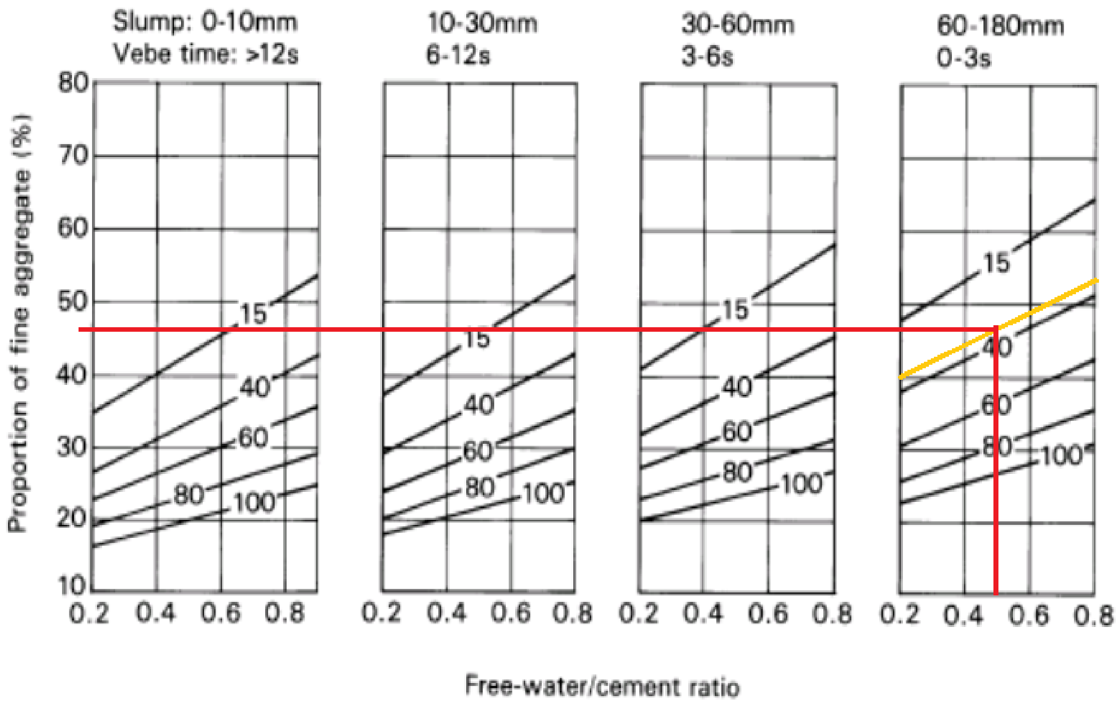


Figure 30: Recommended proportion of fine aggregate for maximum size 20mm.