AMERICAN UNIVERSITY OF BEIRUT

INTEGRATING MICROPLASTIC AND MARINE LITTER INTO SUSTAINABLE CONSTRUCTION MATERIALS

by
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ABSTRACT

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Due to the alarming increase of plastics, especially marine litter, global concern is raised, and attempts are made to repurpose the wastes collected to improve the waste management system. This is because unlike organic waste, plastic wastes need more time to decompose and can harm marine life if washed into the sea. While global attempts are made when it comes to plastic recycling, the percentage of plastics that are eligible for reusing does not cover all. Therefore, it is necessary to include different sectors, and specially the construction sector that is continuously growing, in the attempt of plastic repurposing without the need of further processing.

Incorporating plastic waste and marine litter in concrete can be an effective approach to reuse plastics, avoiding unnecessary processing. This in return creates a construction material that is viable for structural use and may provide an improvement on traditional concrete. More importantly, plastic wastes have shown a potential of being used as a partial replacement for both fine and coarse aggregates in cement and concrete, which can contribute to the preservation of both sand and gravel sources as they are both depletable natural materials. Further, the plastics replacement will lead to the production of a lightweight concrete that would help in

the alleviation of the total cost for materials and handling, and with the reduction of the total self-weight of the building.

This research will investigate the effects of different replacement percentages and sizes of plastics in concrete mixes. Replacement percentages adopted in this research are 10 and 15% for both coarse and fine aggregates, then, based on results, optimal replacement percentage is chosen. Then the effects of different plastic particle sizes, raw and shredded, will be investigated. The physical properties of concrete such as density and weight are observed, as well as the mechanical properties such as compressive, flexural, and tensile strengths, and ductility.

After conducting the experimental program proposed for this research, which evaluated mechanical and physical properties of plastics incorporated in concrete, it was concluded that 10% replacement of natural aggregates is the optimal percentage compared to 15% replacement. Then it was found that 10% replacement of sand with shredded plastics results in better concrete qualities in comparison with 10% replacement of coarse aggregates with raw plastics, and this was attributed to the even distribution of shredded plastic particles.

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CHAPTER 1

INTRODUCTION

The increase of plastic and other wastes debris found on seashores has raised a global concern, since these wastes take 20 to 500 years to decompose and even then, this can be harmful to the environment. The plastics that do not decompose fully harm the marine life by getting stuck on live creatures and cause them to suffocate as they cannot digest them. Further, the plastics that decompose are ingested by marine creatures which in turn can harm us if consumed. Even though the process of recycling plastic and other wastes can reduce the amount of waste, the process of recycling itself causes the accumulation of harmful chemicals specially when used in food packaging. This is besides the high level of carbon footprint that the recycling process produces.

To add to the above, 8 million pieces of plastics get into the sea daily, either from ships but mainly from wastes disposals on seashores and beaches that get washed away by the currents (Godbole et al, 2023). Further, these wastes are producing a carbon footprint of 6kg CO2 per kg (Chuvieco et al, 2021). A comprehensive baseline assessment was conducted by the World Bank (2021) to identify the main sources of marine litter in Lebanon beaches and their quantities, and it was found that marine litter increases by 37% after the summer season as shown in Figure 1. And this is due to waste left behind by beach visitors, increasing the pollution even further.

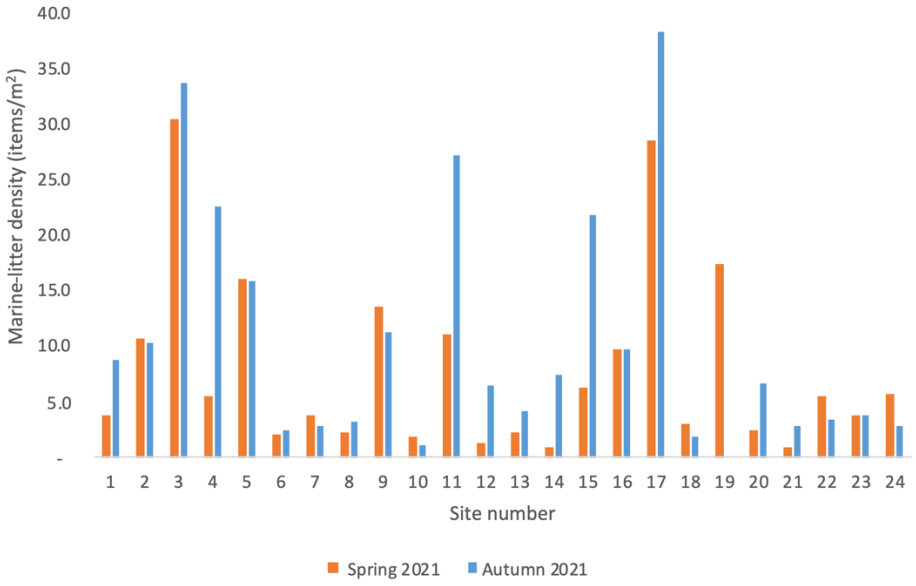

Figure 1: Marine litter before and after summer season (World Bank, 2021)

Yearly, this uncontrolled litter disposal leads to 3.1kg/person leakage into the sea, with 1.1kg/person of it leaking into the city's water system, which approximately totals 3,321 tons per year (Boucher and Bilard, 2020). Considering that 77.7% of these wastes are plastics, according to the previous research, these plastics get washed out into the sea and later broken down naturally into microplastics. These microplastics will either be ingested by marine animals or leaked into the water systems that will become a health hazard. Given the large amount of waste only from the seashore, this has raised global concerns, and researches are pressed to evaluate multiple reuses of these wastes. And here, construction industries are bound to address solutions for repurposing the plastic wastes to produce a viable and sustainable construction material.

Another issue at hand is that demand for natural aggregates increases as the construction industry grows, this being a major concern because natural aggregates are depletable. In a study conducted in 2015, it was reported that the consumption of

natural aggregates had reached 48.3 billion metric tons and is on a constant rise annually by 5% (Saif and Khalid, 2019).

In 2022, sand was considered as the second most exploited natural resource in the world, and its risk of depletion is on the rise, and it is expected to be fully depleted if used at the current rate by the year 2050 (Laguna, 2019). However, the depletion of sand resources is not the only issue, when the act of mining sand on its own causes damages the environment and specially the water resources close to which the sand is mined. When sand is mined, the consolidated layer comes loose and, in many cases, the particles that once were sediments mix into the water that can later get mixed with the city's water system, therefore imposing health risks.

The use of plastic and other wastes in construction materials can be an effective way of dealing with such a critical concern. This can lead to producing construction materials with viable properties, lighter in weight, sustainable, and more environmentally friendly. More importantly, plastic wastes have shown a potential of being used as a partial replacement for both fine and coarse aggregates in cement and concrete, which can contribute to the preservation of both sand and gravel sources as they are both depletable natural materials. Further, the production of a lightweight concrete would help in the alleviation of the total cost for materials and handling, and with the reduction of the total self-weight of the building.

In this research, marine litter from the seashores of Lebanon, namely Ramlet El Bayda beach, that are collected by Cedar For Care (CFC), an environmental development organization, are the subject of investigation as potential replacement of aggregates in cement and concrete mixes. The study will investigate the effects of replacing the aggregates by the collected wastes and other debris from the seashores by considering different replacement percentages and shapes and testing for the

physical and mechanical properties of the new mixes. Sample of wastes received from the seashores are cleaned, sieved, and shredded then incorporated as replacement of fine and coarse aggregates in cement and concrete mixes. At first, the optimal percentage is determined by using different replacement percentages. After finding the optimal percentage, the effect of plastic size is further assessed by keeping the optimal replacement percentage and changing the shape and size of the plastics. The samples are then tested for their compressive and flexural strengths. These tests will determine the optimal percentages and sizes which will result in a construction material that is viable to be used in sustainable construction industry.

Besides the potential advantage of using plastic waste in the construction industry, this research serves the purpose of assessing whether further processing of wastes can be neglected, reducing cost and time of plastic processing. Further, this research is addressing the global concerns regarding marine litter and the increasing amount of waste leakage in Lebanon, potentially decreasing the risk on both marine life and citizens. And the replacement of natural aggregates by plastic wastes and incorporating it in the construction industry will reduce the demand on these materials, hence contributing to preserving nature and producing a viable and sustainable construction material.

In parallel to this research, another research is conducted in AUB investigating the environmental impacts of the use of marine litter from the seashores in concrete mixes. The mentioned research will evaluate the performance of the plastic in the concrete mix and potential risks and benefits from an environmental point of view. Also, the long-term performance under weathering conditions to compare with traditional concrete.

This thesis includes five chapters. This introduction is the first chapter in which background information about plastic wastes and marine litter was outlined and their management was provided. The second chapter includes background research and literature review related to the use of plastic wastes in concrete, while identifying the gaps that this research is intended to fill. The third chapter describes the experimental program, including all tests that were conducted, and the quantities and sizes of samples. Also, the preparation of the wastes received is described along with sieve analysis for both raw and shredded plastics, as well as the properties of all materials used in the mixes, including the plastics. Chapter four presents all the results of the tests conducted along with data analysis. In chapter five, the research is summarized along with the outcomes of the tests, and recommendations are given for future tests and research directions.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

The impact of adding plastic wastes to cement or concrete mixes varies, depending on size, type of plastic, and replacement ratio. The plastic wastes used in this research as a partial replacement for natural aggregates are marine litter from the seashores of Lebanon, that are collected by Cedar For Care (CFC). This is used as partial replacement for sand and coarse aggregates by 10 and 15%, and later shredded to determine the effects of different plastic wastes sizes on concrete properties. In this chapter, research related to repurposing plastic wastes and using them in the construction industry are included and contradictions, similarities, and gaps are explained. For this purpose, various tests such as compressive strength, flexural strength, and split tensile strength are conducted, as detailed below.

2.1 Compressive Strength

When it comes to concrete compressive strength, it is generally reported that the replacement of aggregates with plastic wastes will reduce the strength, as the replacement percentage increases, compared to typical aggregates. This is mainly due to the smooth surface of shredded plastics that are impermeable, which in turn weakens the cohesion force between the cementation mix and the aggregates (Babafemi et al, 2018; Belmokaddem et al, 2020). For example, when using polyethylene (PE) or polyethylene terephthalate (PET) plastics, the concrete compressive strength can drop by 21.4% and 52.5% when the natural aggregates is replaced with a high percentage of 40% of PET and PE, respectively (Tayeh el al, 2021). This decrease in strength can be lowered by reducing the replacement percentage, keeping the concrete specimen still viable for traditional uses. For example, a 10% replacement by PET causes only 1.63% decrease in compressive

strength, which can also be attributed to the decrease in bulk density (Tayeh et al, 2021). Another research has shown that when replacing 40% of sand in light weight concrete by recycled PET bottles, the compressive strength reduces by 94%, which is not suitable for any structural uses (Lwin and Oo, 2020). Data found regarding the impact of incorporating plastic waste as partial sand replacement are not consistent, and this is due to the initial mix design, where the lower the mix design strength is, the larger the reduction of compressive strength after partial replacement of natural aggregates. For example, as reported by Tayeh et al (2021), the initial mix design strength was 49MPa and 40% replacement only resulted in 21.4% decrease in strength, while in the case of Lwin and Oo (2020), the control group strength was 20MPa and the same percentage replacement resulted in 94% reduction in compressive strength. This can be attributed to the reduced amount of binding materials, both sand and cement, accentuating the lack of binding due to the smooth surface of plastic wastes. In Figure 2, the poor bond between cement and high-density polyethylene (HPDE) particles is shown, which is the reason to the reduction of mechanical properties. Picture (a) shows the line where the plastic particle and cement paste meet, a close-up is shown in picture (b) and it can be seen that the plastic aggregate and the cement paste are separated, hence the weak bond between them.

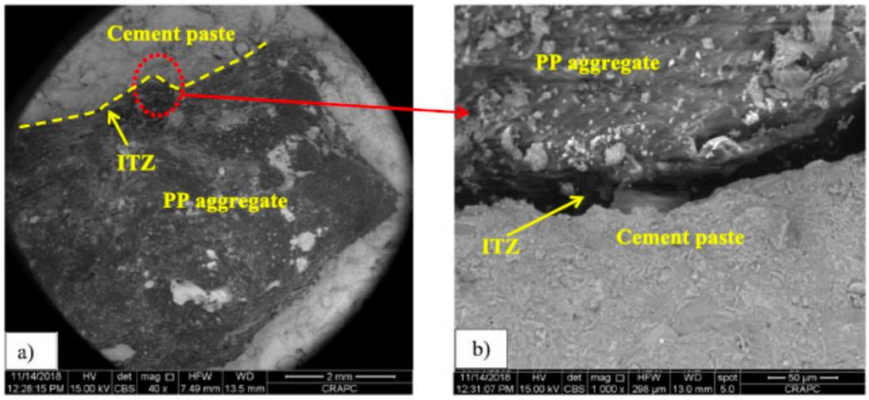

Figure 2: Scan of electronic microscopy plastics waste aggregates, (a) the line on which plastic particle and cement paste meet, (b) close-up of the line to see the bond between them (Belmokaddem et al, 2018)

2.2 Flexural and Split Tensile Strength

The flexural strength improved by approximately 36, 37, and 49% as 10, 20, and 30% of the recycled plastic waste aggregate particles were incorporated, and percentage replacements of 10, 20, and 30% led to an increase in the splitting strength by approximately 4, 9, and 11%, respectively compared to the control group (Radhi et al, 2022). This is because plastics are more ductile when compared with natural aggregates, as they absorb the tensile stress they are subjected to. However, in a different experiment, it was found that incorporating plastic wastes in concrete resulted in a drop of flexural strength from 3.05MPa to 2.61MPa when 10% of sand is replaced by a mix of plastic wastes (Mozumder et al, 2021). The variance between the two research is that different plastic types have been used. In the experiment conducted by Radhi et al (2020), the used plastic was HDPE, which is a high-density plastic that can offer better mechanical properties due to its high ductility and chemical composition. On the other hand, the second research used a mix of plastic waste that contained television sets, electronic boards, and old computer monitors. In another study where mixed plastics are incorporated, the flexural strength decreased from 4.2MPa to 3.1MPa after replacing 10% of sand by plastic wastes that were a mix

of polyethylene terephthalate (PT), low density polyethylene (LDP), E-waste, and polycarbonate (Musa et al, 2025). This confirms that the type of plastics used contributed to the effects on mechanical properties of concrete. Just like flexural strength, the split tensile strength of concrete depends on the type of plastics used. In a research conducted by Mozumder et al. (2023), it was shown that the split tensile strength reduces by 42 and 49% for 10 and 15% replacement of sand by shredded plastic bottles. Data on split tensile and flexural strength is limited as most researches are focused on compressive strength according to Musa et al (2025), only 40% of researches are studying the effects of plastics on concrete while almost 100% have in fact studied their effects on compressive strengths.

2.3 Durability

Unlike the effects on mechanical properties of concrete, using plastic as partial replacement has positive effects on durability of concrete. For example, it was found that incorporating plastic waste in concrete reduced the effects of acid attacks and prevent mass change after 60 days of exposure (Janfeshan et al, 2015).

CHAPTER 3

EXPERIMENTAL PROGRAM AND SETTING

The first step in the current experimental program was to process the plastic wastes to be used in the mixes. The tests experiments are conducted for compressive, flexural, tensile strengths, and tests for finding the stress-strain curves for the concrete specimens were determined.

The mix design chosen is 1:1.5:2.25 with water-cement ratio of 0.45, that is targeting a strength of about 40MPa. This is to assure that, even with of strength reduction due to incorporating plastic wastes, the specimen will still have adequate strength to meet structural qualifications (Koide et al, 2002; Patil, 2014).

The percentage replacement to be investigated in this paper is 10% and 15% replacement of coarse and fine aggregates, while studying the effect of size and shape of the plastic pieces on the mechanical properties and performance of concrete. Workability of the mix was also observed while keeping the water content constant to determine whether adding plastics will cause the mix to need more water or superplasticizer.

3.1 Plastic Processing

The plastics received from the beach that was collected by Cedar for Care (CFC) were already roughly shredded as shown in Figure 3. The wastes received contained sunscreen and water bottles, food packaging, and plastic toys left behind by beach visitors, therefore the density of the sample received was unknown and had to be determined. The first step for the preparation was to wash the plastics with water, to remove any salt or sand carried by the plastics to not let them affect the water absorption of the concrete, and to avoid chips and cracks due to introduction of salt from the sea. Also, because the effect of size and shape of the plastic wastes was to be

studied, they needed to be shredded to be in the range of the size of fine aggregates, as shown in Figure 4. The shredding was done using a special machine, as shown in Figure 5, where the plastics passed through the shredder only once, and then used in replacement of fine aggregates.

Figure 3: Plastic waste as received from CFC

Figure 4: Shredded plastic for fine aggregate replacement

Figure 5: Shredding machine

3.2 Water Displacement Test

To find the density of the plastic wastes received, the water displacement method was used in accordance with ATSM C128-22 (2023) and ASTM 7263-21 (2021). However, it was needed to use a sinker rod because some of the pieces in the mix were floating, affecting the accuracy of the test. The results found were recorded as shown in Table 1, and the density will later be used to determine the quantity of plastic wastes needed in each mix.

Table 1: Water displacement results

Trial	a (g)	w (g)	b (g)
1	308.00	492.70	517.40
2	305.60	490.50	515.50
3	312.50	497.30	526.30
4	300.00	487.60	509.80
5	320.00	496.00	523.60

a = apparent mass of specimen, without sinker in grams

b = apparent mass of specimen, fully immersed with sinker in grams

w = apparent mass of sinker fully immersed in grams

To calculate the average specific gravity:

$$sp\ gr23/23° = \sum \frac{a}{a+w-b} = 1.09$$

$$Density = sp\ gr23/23°C \times 997.5 = 1087.30\ kg/m^3$$

3.3 Sieve Analysis

Plastic samples for both 10% coarse and fine aggregates reduction were analyzed to ensure they are of right size to be used for natural aggregates replacement. Based on the size of the plastic wastes, coarse aggregates of medium size are used to evaluate the effects more accurately. The plastic wastes as received from CFC can be considered as medium-fine aggregate as a 73.28% of the sample was retained on sieve ¾ inch through sieve #4, however they are irregular in shape with sharp edges, flat,

and elongated, sieve analysis data and graph are shown in Table 2 and Figure 6. The shredded plastics were more uniform in shape, and were in the size range of sand, therefore a second pass was not conducted, sieve analysis data and graph are shown in Table 3 and Figure 7.

Table 2: Sieve analysis data for plastic wastes samples, as received from CFC

Sieve no	Sieve diameter (mm)	Retained (g)	Cumulative retained (g)	%retained	%passing
3/4"	19.000	0	0	0	100
1/2"	12.500	4.20	4.2	0.42	99.58
3/8"	9.500	57.30	61.5	6.15	93.85
#4	4.750	671.30	732.8	73.28	26.72
#8	2.360	244.00	976.8	97.68	2.32
#16	1.180	20.50	997.3	99.73	0.27
#30	0.600	1.70	999.0	99.9	0.10
#50	0.300	0.50	999.5	99.95	0.05
#100	0.150	0.30	999.8	99.98	0.02
#200	0.075	0.20	1000	100	0

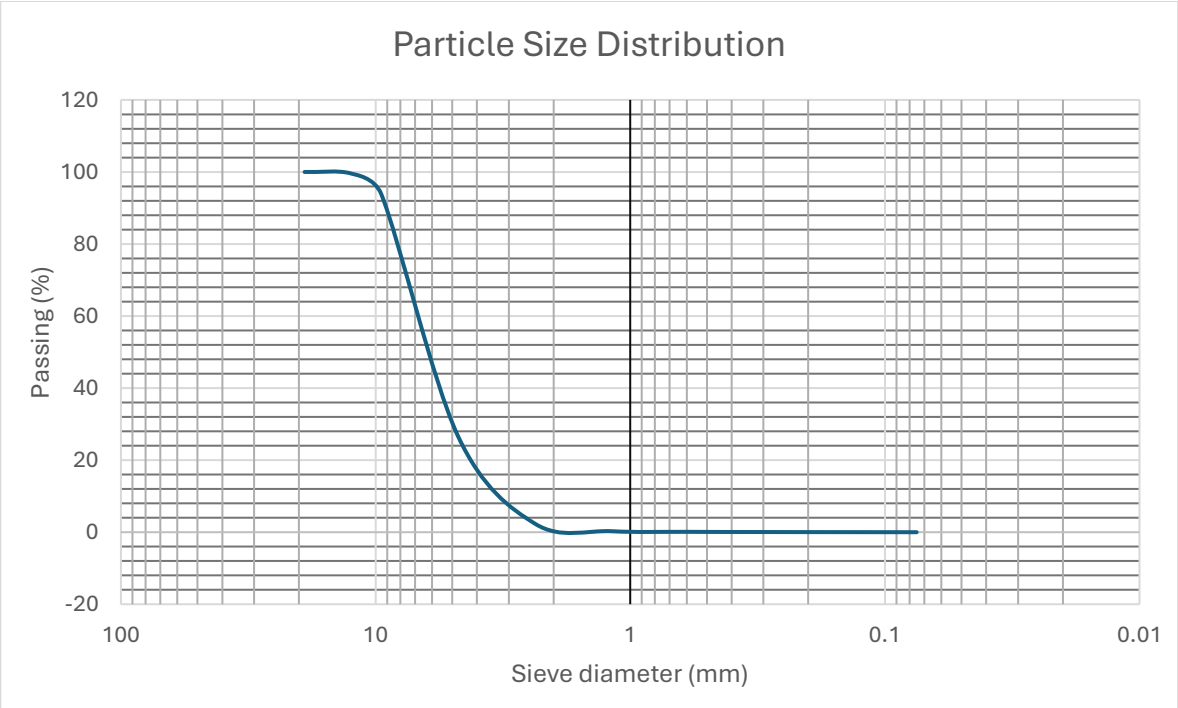

Figure 6: Sieve analysis of plastic wastes samples, as received from CFC

Table 3: Sieve analysis data of shredded plastic wastes

Sieve no	Sieve diameter (mm)	Retained (g)	Cumulative retained (g)	%retained	%passing
3/8"	9.500	0	0	0	100
#4	4.750	29.3	29.3	2.93	97.07
#8	2.360	658	687.3	68.73	31.27
#16	1.180	260.7	948.0	94.8	5.20
#30	0.600	30.3	978.3	97.83	2.17
#50	0.300	8.4	986.7	98.67	1.33
#100	0.150	5.5	992.2	99.22	0.78
#200	0.075	2.4	994.6	99.46	0

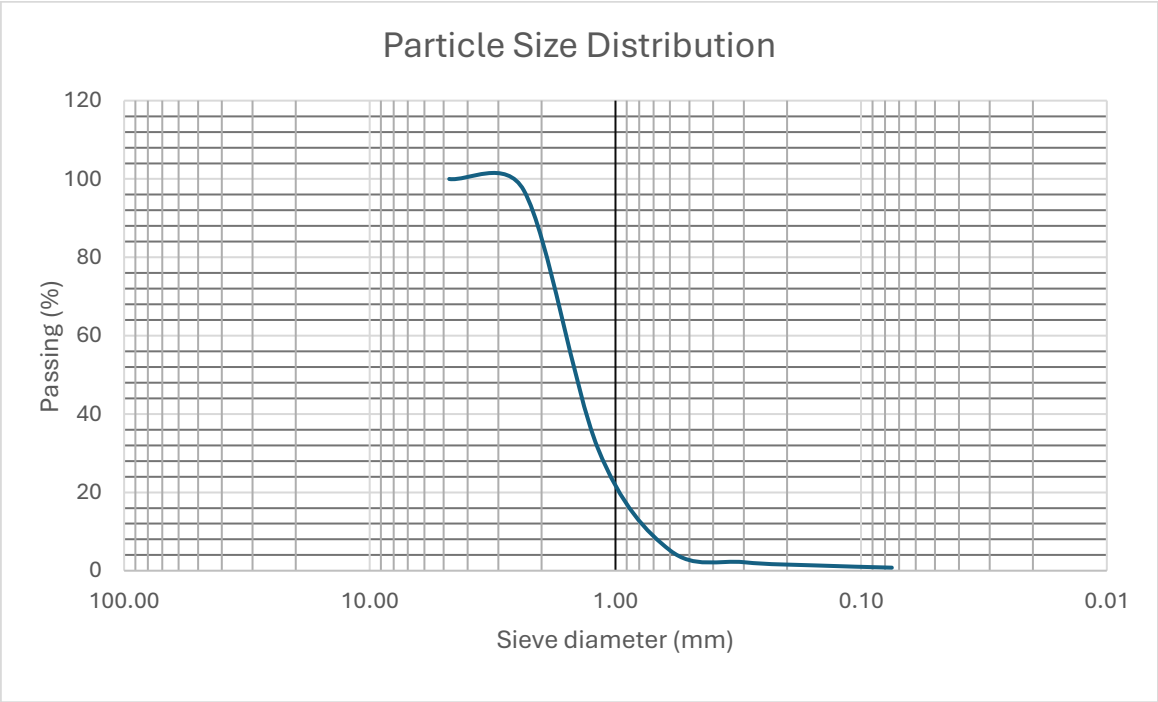

Figure 7: Sieve analysis of shredded plastic wastes

3.4 Mix Design

The mix design used in this research is 1:1.5:2.25 with water content of 0.45 to achieve the strength needed for structural concrete after natural aggregates have been replaced by plastics, where the targeted strength was 45-50MPa. Mixes were adapted with 10 and 15% replacement of natural aggregates, the weight of materials required for the mix in this paper is in Table 4.

Table 4: Materials needed per one cubic meter of concrete

Material (kg)	0PR[1]	15CPR[2]	15FPR[3]	10CPR[4]	10FPR[5]
Cement	360	360	360	360	360
Fine Aggregate	540	540	459	540	486
Coarse Aggregate	810	688.5	810	729	810
Water	162	162	162	162	162
Plastic	0	121.5	81	81	54

[1] Control group, no plastic waste incorporated
[2] 15% coarse aggregate replacement
[3] 15% fine aggregate replacement
[4] 10% coarse aggregate replacement
[5] 10% fine aggregate replacement

2.1.1 Cement:

Cement used for the mix is normal cement (type 1), PA-L 42.5, that is a mix of clinker, limestone, and calcium sulfate, and limestone content is between 6 and 15%.

2.1.2 Sand

The specific gravity and water absorption of the fine aggregates used were determined in accordance with ASTM 128-22 (2023). The specific gravity was found by soaking fine aggregates for 24 hours then drying them to reach saturated surface dry state (SSD) and measure its weight. Then the sample was put in a partially filled pycnometer and filled to the calibration mark, and its submerged weight was measured. Also, the weight of pycnometer filled with water to the calibration mark was measured. Results of the tests for specific gravity and water absorption percentage are presented in Table 5.

Table 5: Specific gravity and water absorption of fine aggregates

Trial No.	1	2
Weight of sample SSD (g)	148.29	151.24
Weight of pycnometer+water (g)	334.92	332.95
Weight of sample+pycnometer+water (g)	426.73	426.78
Weight of sample OD (g)	147.45	150.55
Bulk specific gravity (SSD)	2.63	2.63
Average bulk specific gravity (SSD)	2.63	
Bulk specific gravity (OD)	2.61	2.62
Average bulk specific gravity (OD)	2.62	
Water absorption (%)	0.57	0.46
Average water absorption (%)	0.51	

2.1.3 Coarse aggregate:

The specific gravity and water absorption of the coarse aggregates used tests were determined according to ASTM 127-24 (2022). The specific gravity was found by soaking coarse aggregates in water for 24 hours then patted dry to reach SSD, and their weight was measured in air and in submerged in water. Then samples were oven dried to measure over-dry weight (OD). Results of the tests for specific gravity and water absorption are presented in Table 6.

Table 6: Specific gravity and water absorption of coarse aggregate

Trial No.	1	2
Weight of sample SSD (g)	500.71	444.42
Weight of submerged sample (g)	309.17	270.86
Weight of sample OD (g)	487.22	433.02
Bulk specific gravity (SSD)	2.61	2.56
Average bulk specific gravity (SSD)	2.59	
Bulk specific gravity (OD)	2.54	2.49
Average bulk specific gravity (OD)	2.52	
Apparent specific gravity	2.74	2.67
Average apparent specific gravity	2.70	
Water absorption (%)	2.77	2.63
Average water absorption (%)	2.70	

3.5 Experimental Program

The experimental program is divided into two parts. The first part is to compare the effects of two different replacement percentages, 10% and 15%, of both fine and coarse aggregates to determine the optimum replacement percentages. The second part is to determine the effects of the size and shape of plastics on the concrete performance. The first part is to only test for compressive strength of concrete at days 7, 14, and 28 of curing. The second part is to test for compressive strength at 7, 14, and 28 days of curing, and flexure, split tensile with stress-strain curves at 28 days of curing. The number of samples casted, and their shapes and sizes are listed in Table 7.

Table 7: Experimental matrix for part 2

Group - Materials	Test	Number of samples	Sample shape	Sample size
Control group	Compression 7 days	2	Cubes	7x7x7cm
	Compression 14 days	1	Cubes	7x7x7cm
	Compression 28 days	3	Cubes	7x7x7cm
	Flexure	3	Beams	10x10x35cm
	Split tensile	3	Cylinders	15x30cm
	Modulus of elasticity	3	Cylinders	10x20cm
10% coarse aggregate replacement – raw (10%R-CPR)	Compression 7 days	2	Cubes	7x7x7cm
	Compression 14 days	1	Cubes	7x7x7cm
	Compression 28 days	3	Cubes	7x7x7cm
	Flexure	3	Beams	10x10x35cm
	Split tensile	3	Cylinders	15x30cm
	Modulus of elasticity	3	Cylinders	10x20cm
10% fine aggregate replacement – shredded (10%S-FPR)	Compression 7 days	2	Cubes	7x7x7cm
	Compression 14 days	1	Cubes	7x7x7cm
	Compression 28 days	3	Cubes	7x7x7cm
	Flexure	3	Beams	10x10x35cm
	Split tensile	3	Cylinders	15x30cm
	Modulus of elasticity	3	Cylinders	10x20cm

CHAPTER 4

ANALYSIS AND RESULTS

The plastic waste used in this research is marine litter from the beach, and because its properties were unknown in the previous chapter, density of the plastic wastes received from CFC was found, along with the properties of cement, sand, and coarse aggregates that were used in the mixes. After implementing the experimental program that included partial replacement of 10 and 15% of natural aggregates, and 10% replacement of course aggregates by raw plastic waste and 10% replacement of sand by shredded plastic wastes, the collected data are presented in this chapter along with their analysis and results.

4.1 Compressive Strength Test

4.1.1 Effects of different replacement percentages

For the first part of the experiment, the effects of different percentages of natural aggregate replacement were studied to determine the optimal replacement percentage. Percentages tested for were 10 and 15%, replacing sand and coarse aggregates. Compression tests were done on days 7, 14, and 28 of curing, and sample sizes were 7x7x7cm cubes. The results for the compressive strength test are shown in Figure 8.

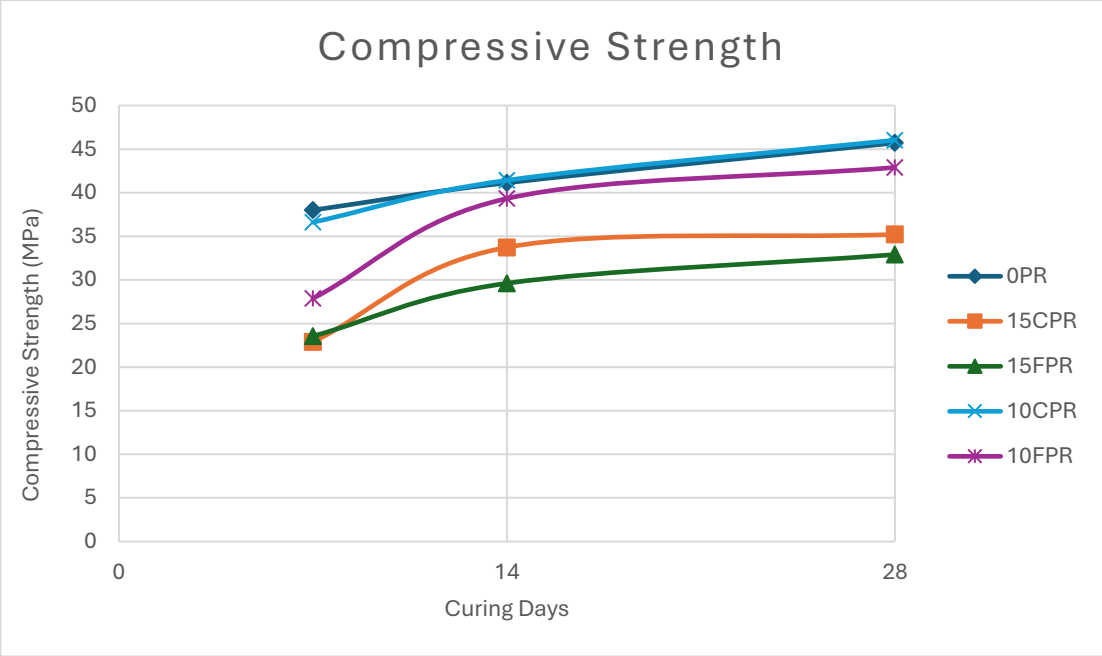

Figure 8: Compressive strength test results for different percentage replacements

The compressive strengths of the control group at 28 days was 45.7MPa, and this strength decreased with the increase of plastic wastes content in the concrete mixes. However, in case of 10% replacement of coarse aggregate by raw plastics, the strength increased slightly, this was but negligible. Compared to 15% replacement of sand and coarse aggregate, the 10% replacement performed better, because 15% replacement of sand and coarse aggregates resulted in 28 and 23% strength reduction, respectively.

The material replaced also affected the compressive strength, where 10% replacement of coarse aggregates causes a slight increase in compressive strength, but when replacing the same percentage of sand, the compressive strength decreased by 1%. This may be due to the fact that sand contributes to the adhesion of other admixtures to the cement particles, and since one of the issues with plastic materials is the smooth surface and lack of binding, decreasing sand decreased the internal bond further. Also, in this part, the plastic is not shredded therefore the size difference does not allow the plastics to imitate the behavior of sand. But when replaced with coarse

aggregates, the plastics give the concrete more ductility while having the sand contribute to the binding process.

4.1.2 Effects of different particle sizes

The second part of testing for compressive strength was to determine the effects of different sizes of plastic particles. Optimum percentage was considered based on the previous part, that was 10% of both sand and coarse aggregates, and in this case the sand was replaced by shredded plastic particles. Curing was for 7, 14, and 28 days, for sample size 7x7x7cm. The results for the compressive strength for this group are shown in Figure 9.

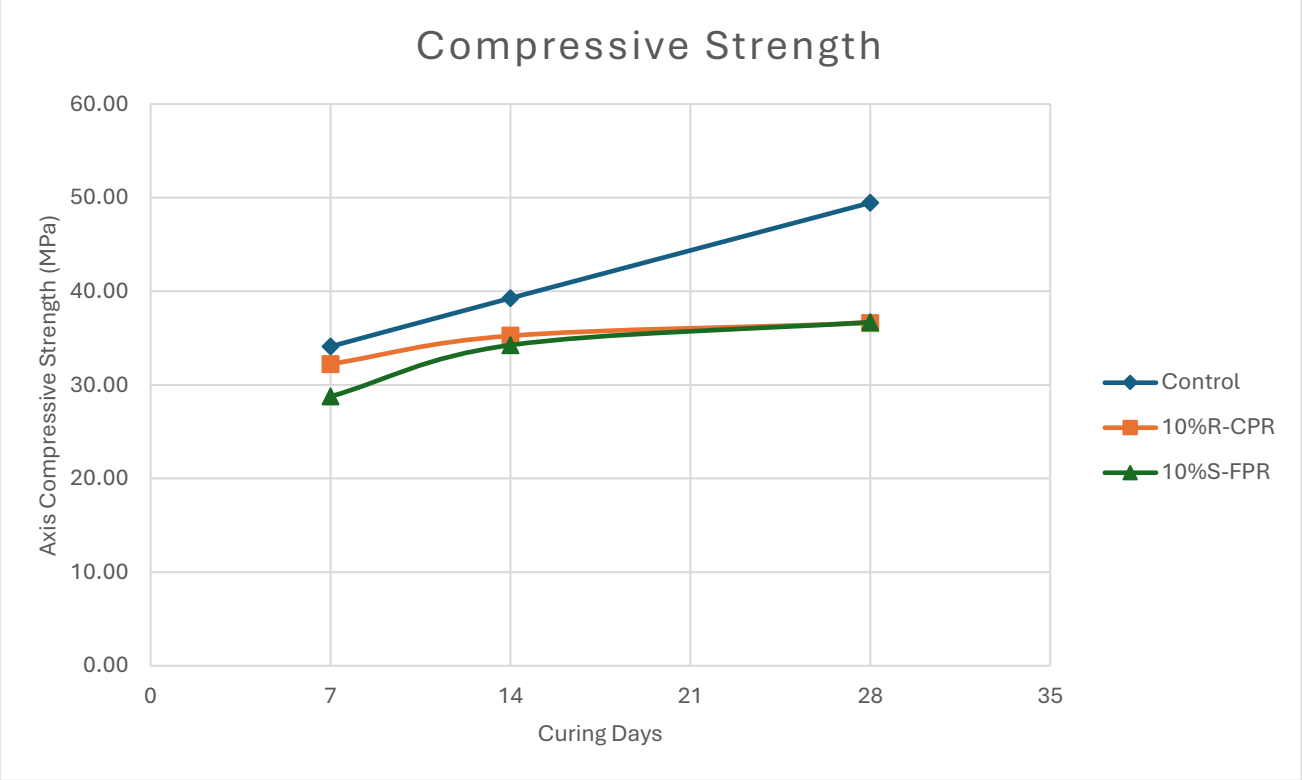

Figure 9: Compressive strength test for different particle sizes of plastic

At 28 days, both raw and shredded plastics resulted in similar compressive strengths that are 36.60 and 36.71MPa, respectively. It is noticed that in the case of 10% replacement of fine aggregate by raw plastic wastes as in the previous part, the strength of fine replacement was lower by about 7%. And the rate of strength gain has

improved when the plastic is shredded for replacement of sand. For raw plastics, at 7 days of curing the sample gained 65% of its final 28-day strength, where in case of shredded plastics it gained 78% of its strength. This can be due to the similarity of size of plastics and sand that can mimic its properties to an extent. However, the compressive strength with respect to the control group has decreased by 25.7% that is in agreement with previous researches.

4.2 Split Tensile Test

To test for the tensile strength of the samples, the standard Brazilian split tensile test was conducted following ASTM C496 (2017). Cylinders were 10dx20h cm and cured for 28 days and tested for tensile strength by applying a diametral compressive force along the length of a cylindrical concrete specimen. This will indirectly induce tensile failure by keeping the samples under triaxial compressive strength. Results for the test are presented in Table 8. The strength value for 0%PR sample 3 is not included in the average strength as the sample failed in compression, and failure was not along the length.

Table 8: Tensile strength test results for different plastic particle sizes

Group	Sample	Height	Diameter	Area=πhd	Load	Tensile Strength	Average
Designations		mm	mm	mm2	N	MPa	MPa
0%PR	1	203.61	96.00	61376.20	68515.00	2.23	2.34
	2	202.70	96.70	61547.42	99562.00*	3.24	
	3	204.80	95.57	61458.39	74939.00	2.44	
10%R-CPR	1	201.70	95.81	60680.11	81710.00	2.69	2.48
	2	202.87	94.71	60331.39	73624.00	2.44	
	3	203.00	94.38	60159.70	69707.00	2.32	
10%S-FPR	1	202.21	95.32	60522.42	78742.00	2.60	2.71
	2	203.42	95.48	60986.78	87734.00	2.88	
	3	203.50	95.32	60908.53	81039.00	2.66	

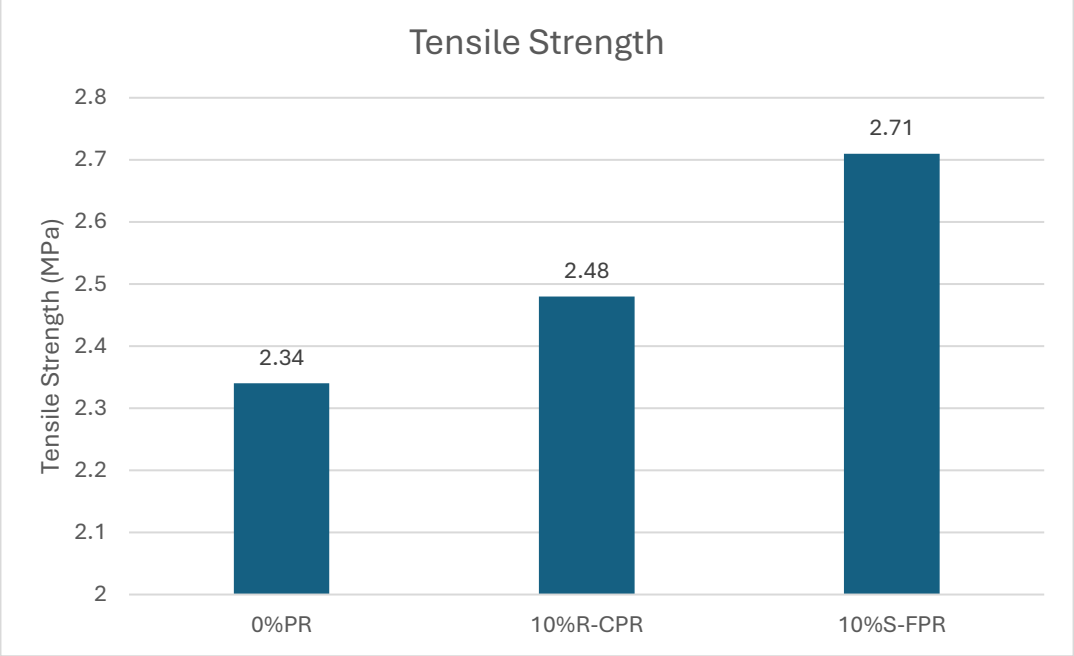

Figure 10: comparison of tensile strengths

Opposite to the compressive strength, and as shown in Figure 10, the replacement of natural aggregates resulted in an increase in the concrete tensile strength. The tensile strength for the control group was 2.34. However, when 10% of coarse aggregates is replaced by raw plastic wastes, the tensile strength increased by 6% that was 2.48MPa, and in case of 10% fine aggregates replacement by shredded plastic waste the increase is 15.8%, that was 2.71MPa. It is important to notice that all samples with plastic replacements did not split in half when they reached failure, as shown in Figures 11 and 12, where samples had to be hit by a hammer to be split in half to observe plastic particle distribution. This is unlike the control group that failed completely after reaching maximum load. This can be attributed to the ductile properties of plastics in comparison to natural aggregated, as coarse aggregate is highly brittle. The use of shredded plastics contributed to a higher increase in tensile strength when compared to raw plastics, which is mainly due to the distribution and shape of the plastic particles. As shown in Figures 13 and 14, raw plastics are unevenly distributed in the sample and they are irregular in shapes, where some are

flat and elongated therefore do not provide the same strengths. Shredded plastics however are more evenly distributed within the sample and their shapes are regular and consistent.

Figure 11: Tensile failure behavior for sample with 10% coarse aggregates replaced with raw plastic waste

Figure 12: Tensile failure behavior for sample with 10% sand replaced with shredded plastic waste

Figure 13: Raw plastic distribution in cylinder samples

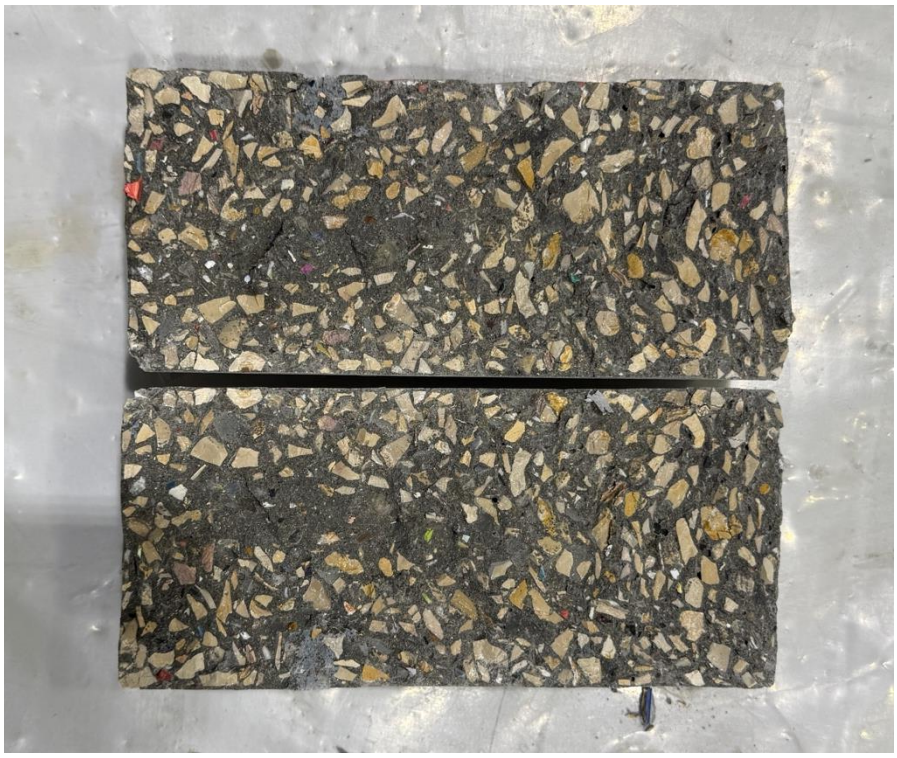

Figure 14: Shredded plastic distribution in cylinder samples

4.3 Flexural Strength Test

To test for the modulus of rupture in this paper, samples are prepared and tested in accordance with ASTM C293 (2025). Samples were cured for 28 days, the size of the samples was 10x10x35cm beams. The test conducted was center-point loading, making failure occur mainly in the middle. The results of the tests are shown in Table 9.

Table 9: Flexure strength test results

Group	Sample	Width	Depth	Span Length	Load	Modulus of Rupture	Average
Designations		mm	mm	mm	N	MPa	MPa
0%PR	1	100	100	350	13450	7.06	7.26
	2	100	100	350	13710	7.20	
	3	100	100	350	14283	7.50	
10%R-CPR	1	100	100	350	10384	5.45	5.32
	2	100	100	350	10216	5.36	
	3	100	100	350	9782	5.14	
10%S-FPR	1	100	100	350	10629	5.58	5.23
	2	100	100	350	10003	5.25	
	3	100	100	350	9205	4.83	

The average flexural strength of the control group was 7.26MPa, which is higher than the average strength for structural concrete. The flexural strength of concrete containing plastic wastes was 5.32MPa for raw plastics and 5.23MPa for shredded plastics, which accounts for almost the same loss of strength. This can be due to smooth surface of the plastic particles when compared to natural aggregates that are not adhesive to the cement particles. However, similar to failure under tensile strength, the behavior of the samples was different in comparison with the control group. While the control samples cracks ran through the sample and split it in half, as shown in Figure 15, the samples with plastic particles did not split into two, as shown in Figure 16. Instead, the sample would crack but this was invisible until more load was applied to make the cracks more visible. After removing the samples from the

machine and placing them on a different surface the samples stayed intact as shown in Figures 17 and 18.

Figure 15: Control sample after failure

Figure 16: Sample with 10% replacement of coarse aggregate with raw plastic wastes after failure

Figure 17: Sample with 10% replacement of coarse aggregate with raw plastic wastes after failure with no visible cracks

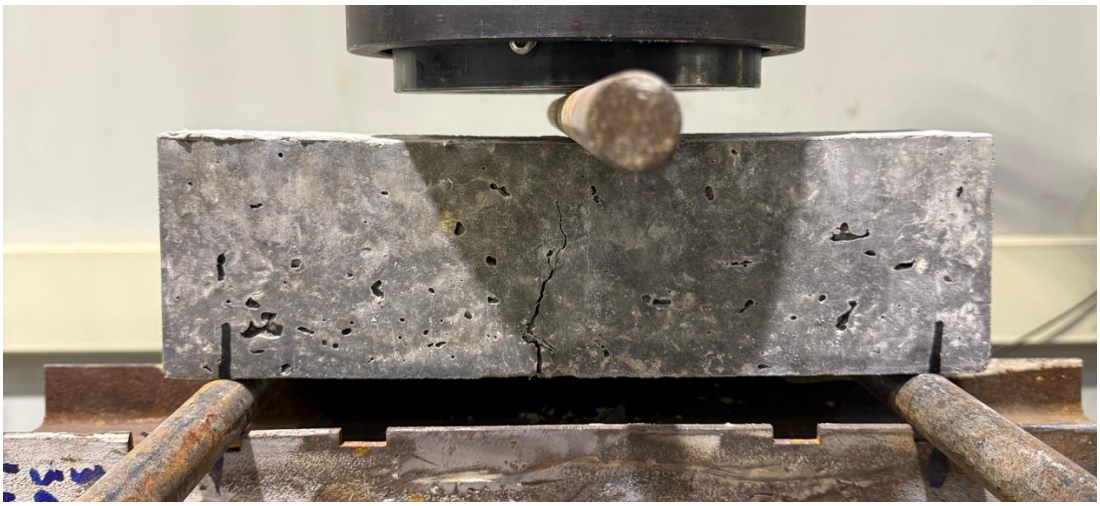

Figure 18: Sample after applying load further to show crack

This failure behavior can be attributed to ductility of the plastic particles, especially in the case of coarse aggregates replacement. Coarse aggregates, regardless of their strength, are brittle and crack upon failure, giving little time as a warning before complete failure. In this case, when plastic wastes are used as a replacement for coarse aggregates, the sample becomes more ductile, not splitting even after failure. This behavior was noticed as well in the samples with 10% replacement of sand by shredded plastics, but cracks were less visible in comparison to coarse aggregates replacement, as shown in Figure 19.

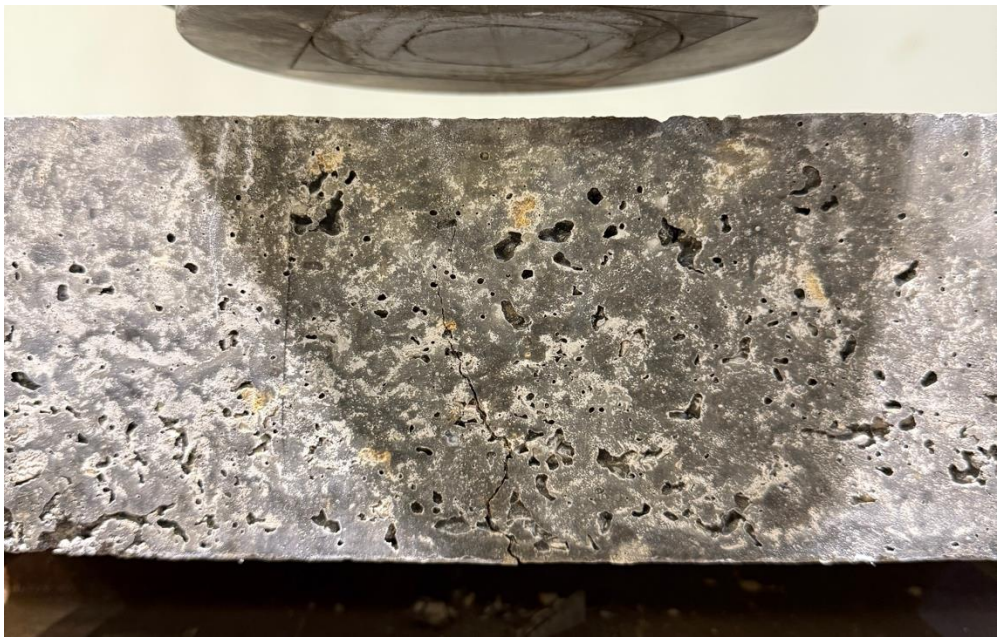

Figure 19: Sample with 10% replacement of fine aggregate with shredded plastic wastes after failure with no further load applied

4.4 Modulus of Elasticity

To obtain the stress-strain curve and obtain, direct compression tests were conducted on 15x30cm cylinders after 28 days of curing. Four sensory gauges were placed to measure the displacement of the sample under stress at each point. The test configuration is shown in Figure 20, with CVDT 1 and 2 in back and front, and CVDT 3 and 4 on left and right. Each sensor measured displacement, then their average was taken to calculate strain. Then average stress-strain curves for the groups are plotted in Figures 21, 22, and 23, and all three curves are plotted in Figure 24 for comparison of sample ductility under stress. Then the moduli of elasticity of the samples are calculated using the linear portion of the graphs.

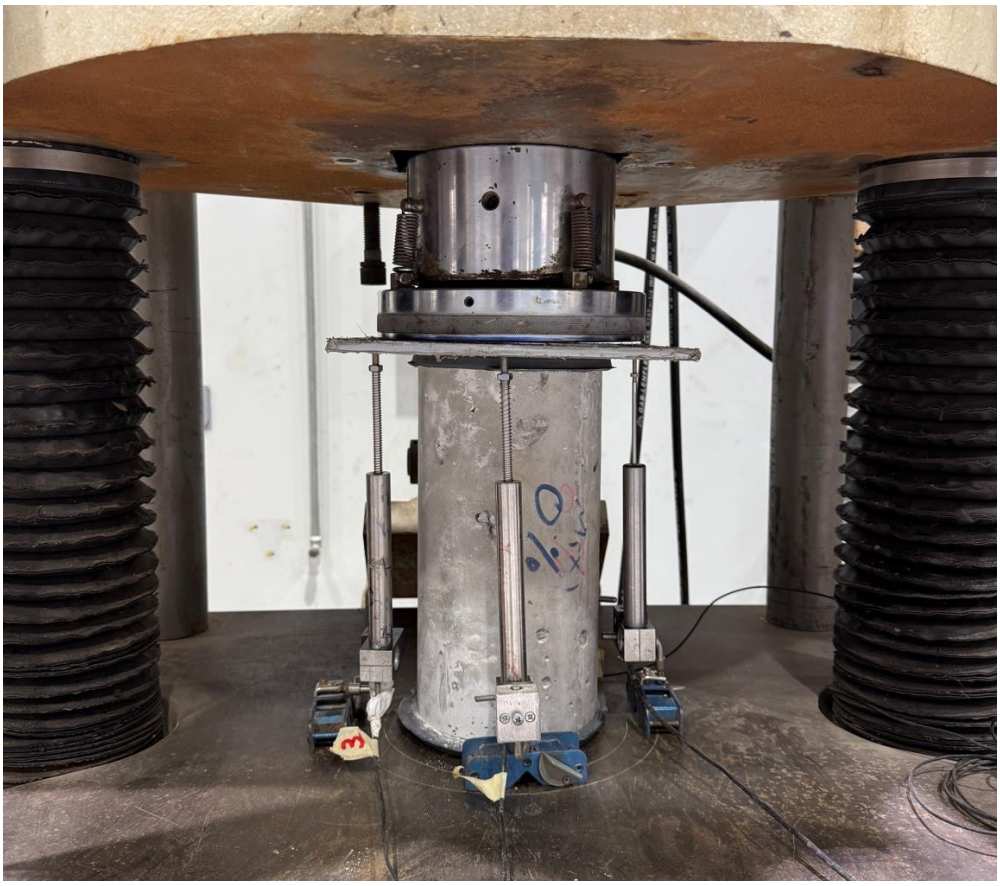

Figure 20: Stress-strain test set-up

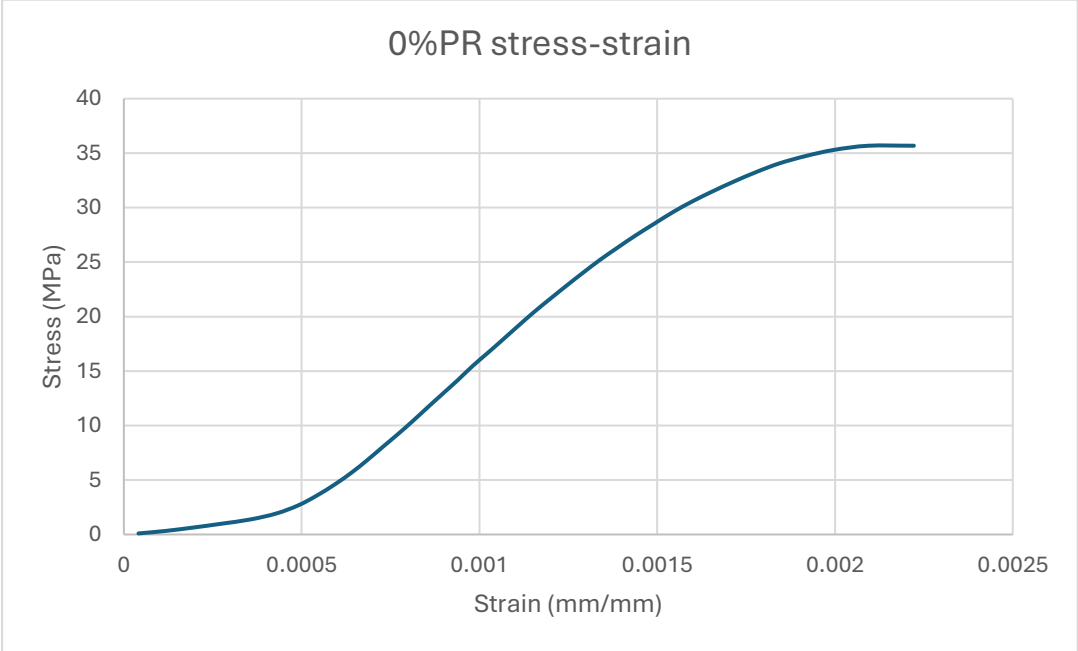

Figure 21: Stress-strain curve for control group

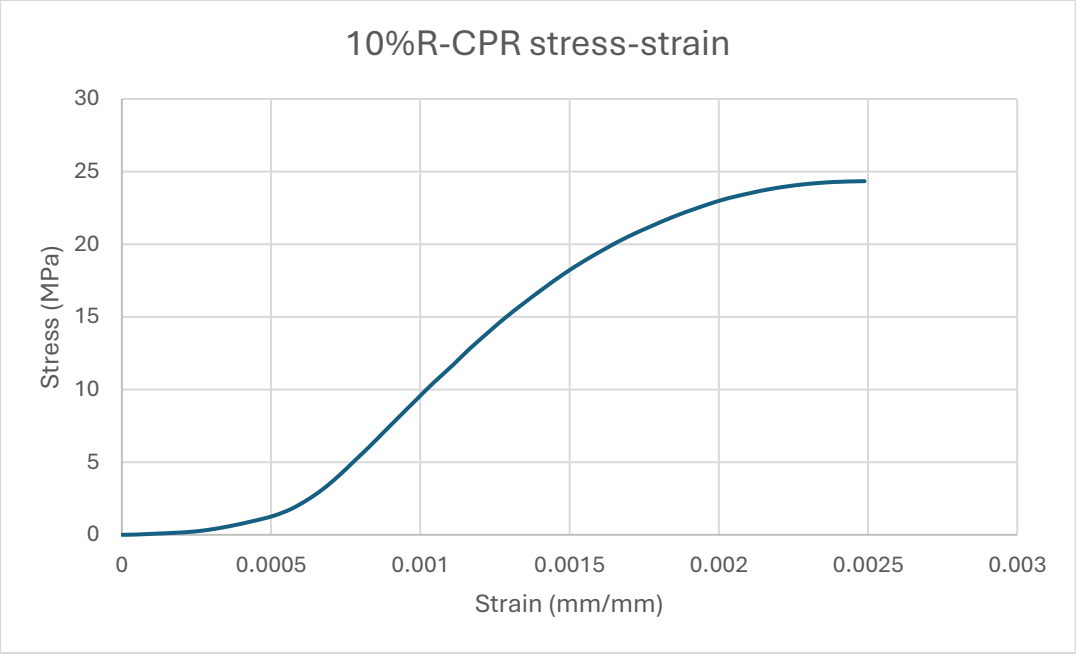

Figure 22: Stress-strain curve for 10% replacement of coarse aggregate by raw plastics

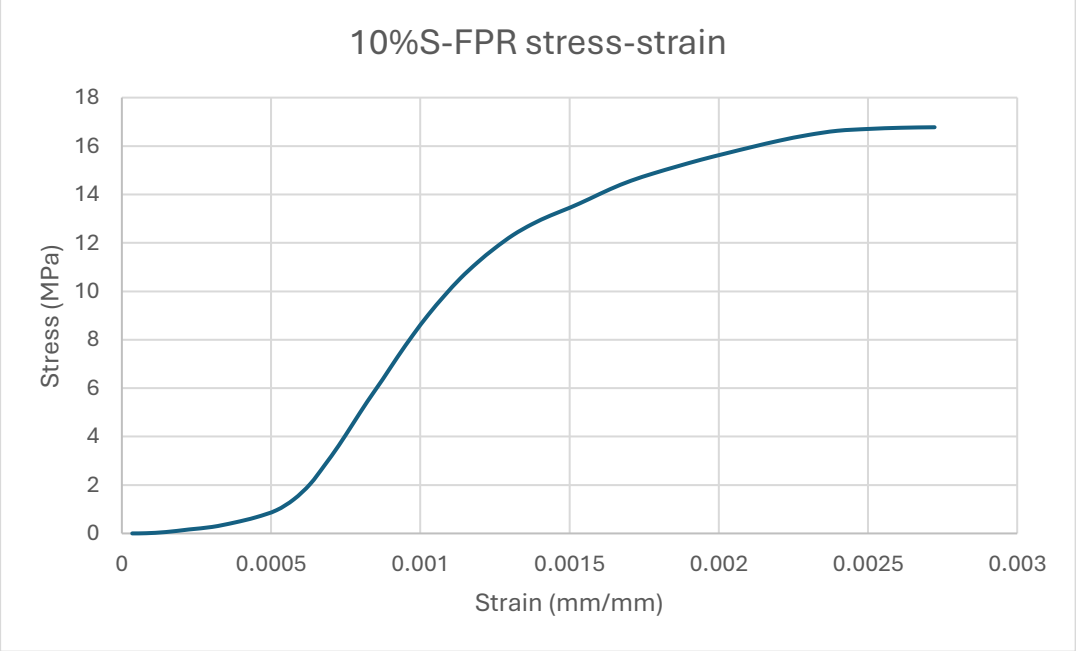

Figure 23: Stress-strain curve for 10% replacement of sand by shredded plastics

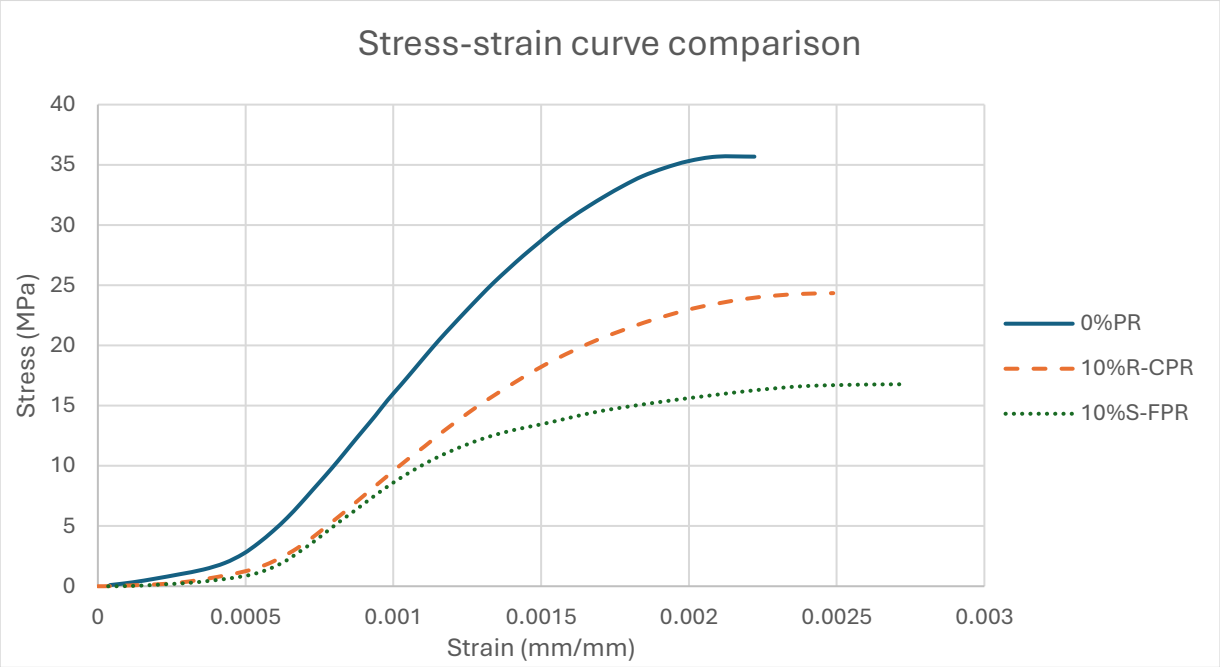

Figure 24: Stress-strain curve of all groups

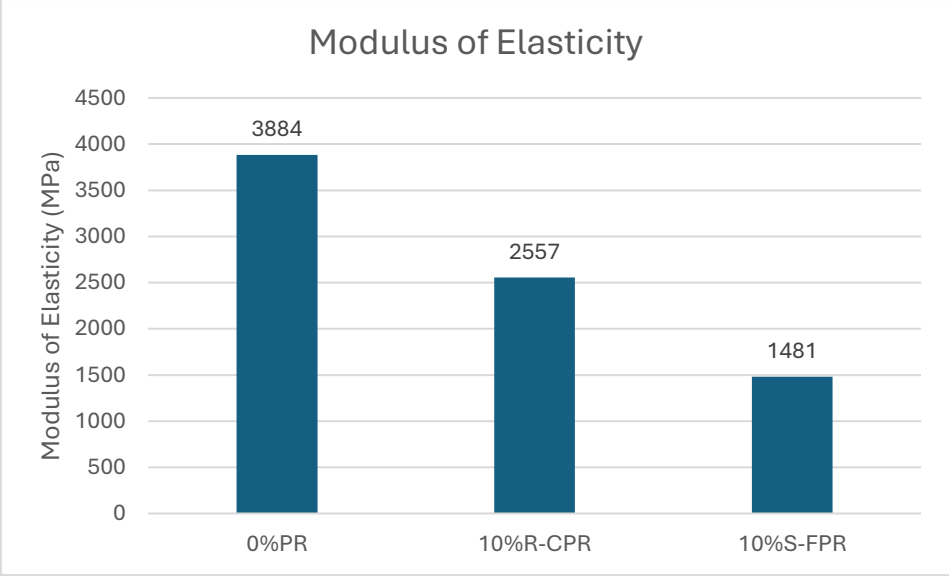

Figure 25: Modulus of elasticity of control, 10%R-CPR, and 10%S-FPR groups

Compared to the control group, the modulus of elasticity of 10%R-CPR decreased from 3884MPa to 2557MPa, and the modulus of elasticity of 10%S-FPR decreased from 3884MPa to 1481MPa, that is a total of 34.2% and 61.9%, respectively. This explains the ductile behavior of the samples during the previous tests and their failure behavior. It is noticed that in case of replacement of sand, the modulus of elasticity has significantly decreased, which is because the shredded plastic particles are more evenly distributed in

the sample. Both samples were able to withstand slightly more deformations, indicating a slight improvement in ductility.

4.5 Density

The density of cubes that were casted for compressive strength tests was measured before crushing, and their density values are plotted in Figure 26. In agreement with previous research, the density of the samples with plastic replacements decreased with respect to the control group. This is due to the nature of plastics that have lower density and are lighter in weight as discussed in Chapter 3 where density of the plastic waste mixes were calculated. For the mix of plastic wastes that was received in raw form resulted in 5.6% decrease in density, and when shredded, it resulted in 4.3% decrease. The difference is due to the difference in replacement, and while both are 10%, the weight of coarse aggregate replaced is more than sand, hence less shredded plastic is used in the groups with sand replacements.

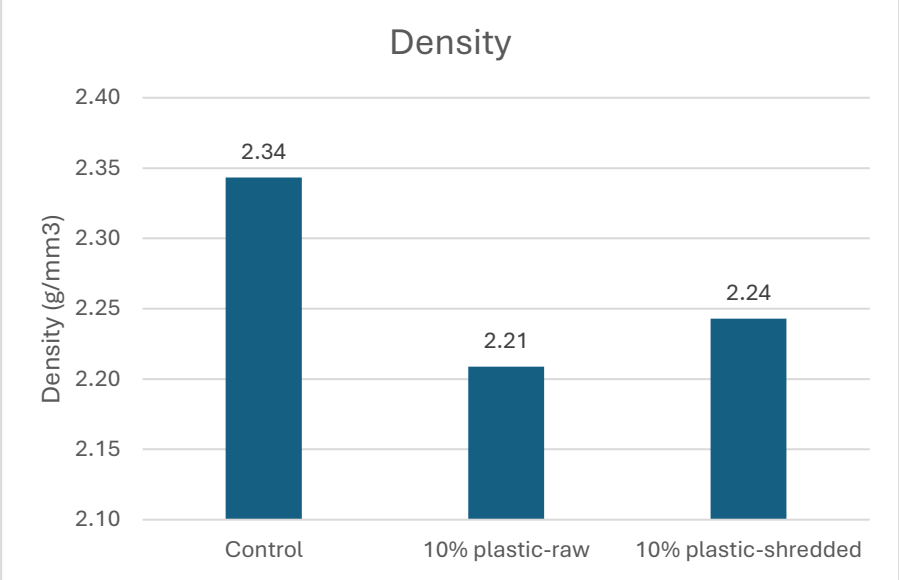

Figure 26: Density of control, 10%R-CPR, and 10%S-FPR groups

CHAPTER 5

SUMMARY, RECOMMENDATIONS, AND CONCLUSIONS

In this research the marine litter collected by Cedar for Care (CFC) from the seashores of Lebanon was used as a partial replacement of natural aggregates. The purpose of this replacement was to reduce the amount of plastic leakage into the sea and to better manage the disposal of plastic wastes in general. While plastic recycling has been adopted to reduce the environmental impacts of plastic wastes, the process of recycling results in CO_2 emission, therefore this is an attempt to reuse plastic wastes while minimizing the overall processing procedure. Besides the environmental factor, this partial replacement will lead to a lower the high demand on natural aggregates that are depletable.

The effects of different replacement percentages of both fine and coarse aggregates with 10 and 15% were investigated. After determining the optimal replacement percentage, the effects of raw and shredded plastics were investigated to determine the effects of plastic particle sizes. After implementing the experimental program that includes compressive strength, split tensile, flexural, stress-strain test, and evaluating the density of the different groups, conclusions below are summarized:

5.1 Summary of Results

- Compressive strength decreases as replacement percentages of plastic wastes increases. In this case, 10% replacement of coarse aggregates resulted in a slight increase of strength, but when replacement percentage increased to 15%, the decrease of strength was 23%. And when raw plastics was replaced with 10% of sand, it had an opposite effect of coarse aggregates replacement and caused a 1% decrease. However, when the effect of particle size was investigated, it was noticed that 10% replacement

of both natural aggregates resulted in similar strengths, because the shredding process helped the plastics to behave more like fine sand.

- In case of tensile strength, the replacement of natural aggregates by plastic wastes had a positive impact on the tensile strength of concrete. Tensile strength increased by 6% in case of 10% replacement of coarse aggregates by raw plastic wastes, and 16% when the same percentage of sand is replaced by shredded plastics. And the improvement in the case of sand replacement is attributed to the even distribution and size of particles.
- Flexural strength however decreased when plastic wastes were introduced to the concrete mixes. Strengths were 5.32 and 5.23MPa for 10% replacement of coarse aggregates by raw plastics and sand by shredded plastics, respectively. The effects were similar to that on compressive strength, where both replacements resulted in similar reduction, therefore size and shape difference did not affect the strength.
- Modulus of elasticity of concrete decreased when plastic wastes were introduced. Modulus of elasticity was decreased by 34.2% when 10% of coarse aggregate was replaced by raw plastics, and by 61.9% when 10% of sand was replaced by shredded plastics. These results justified the failure pattern noticed in split tensile and flexural strengths. The incorporation of plastic wastes resulted in a less brittle failure. In all control groups, for both tensile and flexural tests, the samples failed and split in two parts when samples reached the maximum load capacity; however, in case plastic incorporated concrete, none of the samples split in two until extra load was applied to make cracks more visible.
- Overall, 10% replacement of sand by shredded plastics was found to be the optimal for strength and ductility of concrete. When compared to 10% replacement of coarse aggregate by raw plastics, shredded plastics resulted in minimal cracking after failure

and were more compact. Also, samples with shredded plastics withstood more elastic deformation in comparison to other groups.

5.2 Recommendations

Fundamental mechanical tests were conducted in this research to observe the effects of different replacement percentages and sizes. It is recommended that further research be done to explore the effects of incorporating plastic wastes on impact resistance of concrete, thermal and acoustic insulation, and its effect when included in reinforced concrete to evaluate how plastics react with steel bar reinforcements. Also, this research can be extended into practical applications, where plastic wastes can be incorporated into masonry blockwork and partition walls, as well as in pre-cast panels, as then validated for use in the sustainable construction industry. Also, further study is needed regarding the environmental impacts of using plastic wastes in concrete, and this is currently being investigated in parallel in AUB. This is to study the long term behavior of the plastics in concrete and its reaction under weathering condition.

5.3 Conclusions

This research was a starting ground for repurposing marine litter to create a viable and sustainable construction material. This is a response to the alarming rate of marine litter found in the seashores that are poorly managed and leak into the sea and after decomposing can leak into the water system of the city and impose health hazards on the citizens. Also, to find a viable replacement for natural aggregates that face the risk of depletion due to the continuous demand because of the construction sector. The plastics used were from the seashores of Lebanon, as an attempt to reduce from the waste accumulating, and used while avoiding unnecessary processing to reduce CO_2 emission to zero.

After conducting several mechanical tests and evaluating the physical properties of plastic incorporated concrete, it was concluded that 10% replacement of natural aggregates is the optimal percentage compared to 15% replacement. Then it was determined that 10% replacement of sand with shredded plastics results in better concrete qualities in comparison with 10% replacement of coarse aggregates with raw plastics. Which is because of the size and shape of the particles, in the case of as received plastic wastes, the irregular shape resulted in an uneven distribution, therefore uneven resistance to applied load from the plastics.

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