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Recycling of plastic waste as a construction material: An experimental study of low-density polyethylene (LDPE) as partial replacement to coarse aggregates in the concrete mixture

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ABSTRACT

This research paper investigated the potential use of low-density polyethylene (LDPE) plastic bags as a partial replacement for coarse aggregates in concrete. This study aimed to reduce waste plastic accumulation in the environment by utilizing it practically and sustainably as a construction material. The compressive, flexural, and split tensile strength tests were conducted on cylindrical and beam concrete specimens with different concentrations of low-density polyethylene coarse aggregates (LDPECA) (10%, 20%, and 30%). The test results show that the compressive strength of

concrete decreased with an increasing percentage of LDPECA, indicating that it has a negative impact on the strength of concrete. The split tensile strength also decreased with an increasing percentage of LDPECA, but the flexural strength increased with an increasing percentage of LDPECA. In the study, it was shown that LDPE plastic bags as a partial replacement of coarse aggregate in concrete has promising results, but further investigations and experiments are necessary to fully understand the proper application of LDPECA. Further studies could use lower percentages of LDPECA and use admixtures to account for the loss of compressive strength. It may be possible to reduce the amount of plastic waste that builds up in the environment by adding LDPE plastic waste material to concrete. This may also encourage the use of more environmentally friendly materials for construction.

Keywords: *Low-Density Polyethylene (LDPE), Waste Plastic, Low-Density Polyethylene Coarse Aggregates (LDPECA)*

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1. INTRODUCTION

Due to its unique properties, including ease of manufacturing and molding, low cost, and low density, plastic is the most often used artificial material worldwide. It is particularly helpful in a variety of fields, including construction, architecture, and transportation. Unfortunately, waste materials are dumped into nature. Their buildup creates environmental issues because it is everlasting. (Seghiri et al., 2017)

The recycling of waste materials into concrete is gaining attention these days because waste accumulation has become a major issue on a global scale. Delivering waste to landfills is becoming worse day by day, endangering nature in the process. One of the most hazardous materials for disposal is plastic waste. Minimizing or eradicating plastic waste is required if it is not practicable to restrict the production of plastic. Utilizing such materials in concrete is a practical way to reduce the collection of plastic waste (Sivakrishna et al., 2020). It is crucial to take into account various options for producing concrete because billions of tons of it are anticipated to be produced in the upcoming years to meet our infrastructure requirements. These substitutes work best as a partial or complete replacement for cement and aggregates. (Pek et al., 2020)

2. BACKGROUND OF THE STUDY

Tons of carbon and other hazardous substances are discharged into the atmosphere during the production of plastic bags. Only 5% of the one trillion tons of plastic bags used globally get recycled. Landfills receive the remaining materials. Some contaminate soil and streams after being lost in the environment. They also become part of the food chain when they are eaten by animals that have mistakenly taken plastic for food. Consuming plastic can be dangerous and have major negative consequences for human health. A rich soil is created when microorganisms feed on organic matter and break it down into humus during the natural or biological process of decomposition. The majority of plastic bags take time to decompose. This is due to the fact that they are made of petroleum by-products, which microbes cannot consume, rather than organic material. (Soomro, 2021)

Oil is used to make plastics, and they decompose incredibly slowly. Plastics typically decompose in landfills after 1,000 years, plastic bottles after 450 years or more, and plastic bags after 10 to 100 years. The landfill itself and whether or not the bag is exposed to sunlight are two more factors that affect how quickly the bag decomposes (Rinkesh, 2022). New end products can be made using recycled LDPE alone or in combination with virgin LDPE material. For composite timber, architectural, and agricultural applications, as well as other products, recycled LDPE is frequently used to make pipelines, sheets, films, waste bags, and other products. On the other hand, recycled HDPE is typically utilized to make plastic bags and composite timber. (EDL Packaging, 2022)

A ton of recycled plastic can save 7,200 kilowatt-hours of electricity, or approximately enough to run a home for seven months, according to research. The most environmentally responsible strategy to cut back on the consumption of fossil fuels is to recycle plastic (Aco Recycling, 2022). By reusing materials that have already been processed and protecting natural resources, recycling plastic lessens the need to mine raw materials. It eliminates the addition of additional waste to landfills and uses less energy than making brand-new virgin polymers. (Buxton, 2022)

3. REVIEW OF RELATED LITERATURES

3.1 Production and Recycling of Plastic

Alexander Parkes invented the first synthetic plastic and officially displayed it at the Great International Exhibition in London in 1862. The material, termed Parkesine, was an organic compound made of cellulose that could be molded once heated and retained its shape when cooled (Bellis, 2020). Plastic has become a material on which we have grown to depend, and it is responsible for many aspects of modern life. Electronics, home insulation, textiles, clothing, plastic wrap, toys, the automotive sector, pipelines, and cables are just a few examples of how plastic has improved our quality of life (Letcher, 2020a). We estimate that virgin plastics have been manufactured in amounts of 8300 million metric tons (Mt) as of today. 6300 metric tons of plastic garbage had been produced as of 2015; 9% of it had been recycled, 12% had been burned, and 79% had ended up in landfills or the environment. (Geyer et al., 2017)

Separating the many forms of plastic is one of the challenges of recycling plastic trash. Symbols on plastic packaging to help with the separation. (Letcher, 2020b)

Table-1: Different forms of plastic.

Form	Symbol	Recycling Rate	Common use
(PET)	1	19.5%	Plastic bottles
(HDPE)	2	10.3%	Gallons
(PVC)	3	>1%	Pipes
(LDPE)	4	5.3%	Plastic bags
(PP)	5	>1%	-
(PS)	6	>1%	Food packaging
Others	7	>1%	-

3.2 Recycled Plastic as a Construction Material

Due to their high rates of production, which seriously impact the environment and its inhabitants, plastic waste is becoming a very serious environmental hazard (Awoyera & Adesina, 2020). Plastics are highly promising if you are seeking construction materials that are effective, long-lasting, and cost-effective. Recycled plastics can be used to make stronger concrete structures (Calovini, 2018). It has important qualities for construction materials, including strength, durability, waterproofness, lightness, ease of molding, and recyclable composition. (Cestari, 2020)

Plastic is a suitable component that can be utilized to create building materials thanks to several qualities. Concrete can be broken down and recycled into fresh concrete for sidewalks, roofing tiles, and driveways. Furthermore, recycled plastic can be used as a filler in concrete to reduce the concrete's weight and carbon footprint (Arqlite, 2022). There are various applications for recycled plastic in the building industry, offering a great chance to stop plastics from entering waste streams for a long time. (Adams, 2021)

3.3 Recycled Coarse Aggregates

Plastic electronic waste is building up due to the world's increasing industrialization, urbanization, and population growth. E-waste is being produced at a rate of 3–4% annually around the world, and by 2025, that rate is anticipated to rise to 55 million tons annually. One of the greatest alternatives is to incorporate waste plastic into the building sector to create green concrete to lessen the negative effects on the environment and conserve natural resources. In this study, artificial plastic coarse aggregate (PCA) made from e-waste is used in concrete as a partial replacement for natural coarse aggregate (NCA). Six different types of concrete samples had 10%, 20%, 30%, 40%, and 50% of NCA (by volume) replaced with PCA. In this study, the impact of produced PCA on the properties of freshly poured and hardened concrete is examined.

The properties of recycled plastic aggregate concrete (RPAC) include dry density, compressive strength, flexural strength, and tensile strength. (Ahmad et al., 2021)

Table-2: Change in the Mechanical Property of Concrete with RPAC.

	Samples					
	0%	10%	20%	30%	40%	50%
Test	Percent Reduction (%)					
Compressive Strength	-	9.95	21.1	32.7	44.4	52.7
Flexural Strength	-	10.9	20.8	27.6	31.7	39.4
Tensile Strength	-	7.8	23.6	27.9	39.1	47.5

It was discovered that the concrete constructed of waste ceramic tile aggregate produced equivalent strength in compression, split tensile, and flexure as normal concrete. This was accomplished by utilizing waste materials. Glass concrete and ceramic insulator concrete cubes' compressive strengths were determined to be 16% and 26.34% lower than those of normal concrete, respectively. Additionally, it was discovered that the findings of the flexural strength and splitting tensile strength tests were comparable to those of the compression strength test. (Sekar et al., 2011)

4. OBJECTIVES OF THE STUDY

4.1 General Objectives

The study aims to determine the effects of LDPECA on concrete by investigating the changes in the strength of the concrete.

4.2 Specific Objectives

1. To identify the effect of recycled LDPECA on the compressive strength of concrete mixtures with 10%, 20%, and 30% LDPECA content.

2. To identify the effect of recycled LDPECA on the flexural strength of concrete mixtures with 10%, 20%, and 30% LDPECA content.

3. To identify the effect of recycled LDPECA on the tensile strength of concrete mixtures with 10%, 20%, and 30% LDPECA content.

4. To identify the rate of change in the density of a concrete mixture with 10%, 20%, and 30% concentrations of LDPECA.

5. SIGNIFICANCE OF THE STUDY

This study will provide information about LDPE plastic bags as coarse aggregates. It will evaluate the mechanical properties and density of concrete with LDPE plastic bags as coarse aggregates. The data gathered will also help future researchers as a guide or reference for their research. Specifically, the findings may benefit the following:

- To the environment and community, the findings of the study may help our environment to reduce plastic waste and lessen the air burning that can result from harmful components being released into the air, which may result in public health risks.
- For the construction industry, the result of the study can help evaluate the potential of concrete mixtures with LDPE compared to conventional concrete mixtures.
- Future or other researchers can use the study as a reference for their research.

6. SCOPE AND LIMITATIONS

The study aims to investigate the effects of using recycled low-density polyethylene (LDPE) as a coarse aggregate by determining the strength of class A concrete with LDPECA. The main limitation of conducting this study is the availability of recycled LDPECA; the researchers will collect plastic bags from their households and around their neighborhood, which makes the collection and processing of LDPE plastic bags challenging and time-consuming. This greatly affects the study due to time constraints during the collection of plastic bags and production of LDPECA; thus, the researchers will be limited and can only produce one set of samples. The other elements that will be used to create the samples are outside the scope of this experiment.

By conducting the study, it will be possible to determine the changes in the strength of concrete with LDPECA. The researchers will produce a control sample along with three samples containing 10%, 20%, and 30% LDPECA. As mentioned, the researchers can produce one set of samples, which will be cured for 28 days, because according to Weru (2018), "Concrete's compressive strength reaches 99% of its final strength within 28 days. As such, engineers typically use the results of the compressive strength test conducted after 28 days to make design calculations, even though the concrete may continue to gain strength over the next 1 to 2 years." Furthermore, the main scope of the study is to determine the strength and density of class A concrete with LDPECA. The researchers will perform four tests: compressive, flexural, tensile, and density tests.

7. METHODOLOY

This chapter describes the process of utilizing low-density polyethylene (LDPE) plastic bags as coarse aggregates in the production of the concrete mixture. The preparation of materials, designs, and instruments that will be used, as well as the location where the study is conducted, will also be discussed.

7.1 Research Design

The researchers used an experimental research approach to provide the data needed to meet the objectives of the study. Specifically, they compared the use of recycled low-density polyethylene (LDPE) bags as coarse aggregates to the use of conventional coarse aggregates in concrete.

7.2 Research Setting

The study was conducted in Bacolor, Pampanga, and the City of San Fernando, Pampanga. The researchers produce the LDPECA at Tinajero, Bacolor, Pampanga. Additional tools and materials were obtained from local hardware and construction material suppliers. The researchers produced samples at Filipino Ready-Mix Corporation (FILMIXCO), which is located in Sindalan, San Fernando, Pampanga. The testing of the samples was conducted at ASTEC Materials Testing Corporation and PAR Geotechnical Testing Center, which are both located in the city of San Fernando, Pampanga.

7.3 Preparation of Raw Materials

1. **LDPE Plastic Bags**

   a. Collection and Cleaning

   The researchers will gather LDPE bags both from their households and from the house-to-house collection. The efficiency rate for the collection of plastic bags is 1kg per week. Then clean the plastic bags by removing the contaminants that may alter the properties of the LDPE during the melting process.

   b. Shredding

   The researchers will prepare the plastic bags by shredding or cutting them into ideal sizes for the LDPE to be easily melted on the pan during the melting process.

   c. Melting

   The researchers will use an industrial oven to melt the LDPE plastic bags. Most plastics, including LDPE, usually melt at 130 °C; the oven will be set at 150 °C to melt the plastic. The researchers will be wearing PPE, such as gloves, masks, and goggles, to be protected from possible hazards during the melting process.

   d. Molding

   The researchers will manually mold the melted plastic into size #67 or about 20mm.

2. **Cement**
3. **Sand**
4. **Gravel**

7.4 Proportioning of Materials

The study's objectives require four different samples containing different concentrations of LDPE coarse aggregates per testing procedure. The researchers will use a controlled sample with a cement, sand, and gravel ratio of 1:2:4 (Fajardo M., 1980). Samples will be molded using a beam mold with a dimension of 6"x6"x21" for flexural testing and a cylindrical mold with a dimension of 6"x12" for compressive and tensile testing.

Sample	LDPECA		Cement	Sand	Gravel
	Percentage %	in^3	in^3	in^3	in^3
CS	-	-	108	216	432
S1	10	43.2	108	216	388.8

Table3:

S2	20	86.4	108	216	345.6
S3	30	129.6	108	216	302.4

Concrete mix material ratio with LDPE coarse aggregates.

(Beam Mold)

Sample	LDPECA		Cement in^3	Sand in^3	Gravel in^3
	Percentage %	in^3			
CS	-	-	48.57	97.14	194.285
S1	10	19.428	48.57	97.14	174.857
S2	20	38.857	48.57	97.14	155.428
S3	30	58.285	48.57	97.14	136

(Cylindrical Mold)

The study's objectives require two sets of cylindrical samples and one set of beam samples, which is 12 samples in total. For that number of samples, the researchers need to produce 492.34in3 of LDPECA, which is equivalent to 7kg of plastic. The researchers will collect 10kg of plastic bags to have excess materials to account for errors.

7.5 Making the Samples

With four samples per testing procedure (compressive, flexural, and tensile tests), a total of 12 samples will be made with LDPECA along with the control samples. A detailed procedure is described below:

1. Each molder is brushed with oil to prevent the sample from sticking in the mold.
2. Dry materials will be transferred to a mixing pan and carefully mixed until thoroughly combined. The mixture will be made in batches based on its cement, sand, gravel, water, and LDPE coarse aggregate content.
3. Fill each mold with the mixture and use a tamping rod and mallet to remove voids. After filling the mold with concrete, a piece of paper is attached as a temporary label for the sample.
4. Transfer the samples to a well-ventilated area and let the samples harden for at least 24 hours. Replace the temporary label with a permanent marker.
5. After 24 hours, remove the samples from the mold and let them cure for 28 days.

8. OBSERVATION

8.1 Compressive Strength Test

Compressive strength is the applied load at failure divided by the gauge-cross-sectional section's area. It is the ability of concrete to withstand loads before failing. The compressive strength test is the most crucial of the numerous tests conducted on concrete since it gives information about the material's properties. The samples will be evaluated as per the ASTM C39 standard procedure.

Concrete cylinder samples are tested at ASTEC Materials Testing Corporation at Unit A, Genesis Building, Mc Arthur Highway, Brgy. San Isidro, City of San Fernando, Pampanga All samples are tested and certified as correct by Genesis Ian A. Esteban, Laboratory Supervisor.

Sample	Curing Days	Dimensions		Area (mm^2)	Machine Reading	Compressive Strength		Type of Fracture
		D (mm)	L (mm)			MPa	psi	
CS (0%)	28	152.3	304.8	18217.54	268.804	14.58	2110	CS – TYPE 3
S1	28	151.7	304.8	18074.28	174.141	9.64	1400	CS – TYPE 3

(10%)								
S2 (20%)	28	153.9	304.8	18602.32	167.537	9.01	1310	CS – TYPE 3
S3 (30%)	28	152.7	304.8	18313.36	159.254	8.70	1260	CS – TYPE 3

Table-4: Test Results on Compressive Strength

The results of the compressive strength test of cylindrical concrete samples (ASTM C-39) with 28 days of curing the control sample (CS) has a diameter of 152.3mm and 304.8mm in length, with an area of 18217.54 mm2. The control sample (CS) has a machine reading of 268.804 KN, a compressive strength of 14.58 MPa, which is equivalent to 2110 psi, and a Type 3 fracture. Sample 1 (S1) has a diameter of 151.7mm and 304.8mm in length, with an area of 18074.28 mm2. Sample 1 (S1) has a machine reading of 174.141 KN, a compressive strength of 9.64 MPa, which is equivalent to 1400 psi, and a Type 3 fracture. Sample 2 (S2) has a diameter of 153.9mm and 304.8mm in length, with an area of 18602.32 mm2. Sample 2 (S2) has a machine reading of 167.537 KN, a compressive strength of 9.01 MPa, which is equivalent to 1310 psi, and a Type 3 fracture. Sample 3 (S3) has a diameter of 152.7mm and 304.8mm in length, with an area of 18313.36 mm2. Sample 3 (S3) has a machine reading of 159.254 KN, a compressive strength of 8.70 MPa, which is equivalent to 1260 psi, and a Type 3 fracture.

8.2 Flexural Strength Test

Flexural strength is the measure of how much pressure and force a plain concrete slab or beam can withstand until failure. Flexural strength also referred to as modulus of rupture, is a tensile strength measure for concrete slabs or beams. Flexural testing is performed to determine the flex or bending property of a material. The samples will be evaluated as per ASTM C78 standard procedure.

Concrete beam samples are tested at ASTEC Materials Testing Corporation at Unit A, Genesis Building, Mc Arthur Highway, Brgy. San Isidro, City of San Fernando, Pampanga All samples are tested and certified as correct by Genesis Ian A. Esteban, Laboratory Supervisor.

Table-5: Test Results on Flexural Strength

Sample	Curing Days	Dimensions			Area (mm^2)	Machine Reading	Flexural Strength	
		Length (mm)	Depth (mm)	Base (mm)			MPa	psi
CS (0%)	28	450	153.9	156.7	18217.54	17.766	2.15	310
S1 (10%)	28	450	155.9	157.0	18074.28	25.834	3.05	440
S2 (20%)	28	450	158.9	155.1	18602.32	23.440	2.69	390
S3 (30%)	28	450	157.9	155.2	18313.36	25.677	2.99	435

Table 3.2 represents the test results on the flexural strength of all samples after 28 days of curing. The control sample (CS) has a machine reading of 17.766 kN and a flexural strength of 2.15 MPa, which is equivalent to 310 psi. Sample 1 (S1) has a machine reading of 25.834 kN and a flexural strength of 3.05 MPa, which is equivalent to 440 psi. Sample 2 (S2) has a machine reading of 23.440 kN and a flexural strength of 2.69 MPa, which is equivalent to 390 psi. Sample 3 (S3) has a machine reading of 25.677 kN and a flexural strength of 2.99 MPa, which is equivalent to 435 psi.

8.3 Splitting Tensile Test

The tensile strength of concrete is a crucial factor that is taken into account during the design process. Due to the fact that it accounts for 10% of the concrete's compressive strength, it can significantly affect the other structural elements' strengths in flexure. The samples will be evaluated as per the ASTM C496 standard procedure.

Concrete cylinder samples are tested in the PAR geotechnical testing center at Unit G, commercial space, km 78, McArthur Hi-way, Saguin, City of San Fernando, Pampanga. All samples were tested by M. Manlutac and A. Takebayashi, laboratory technicians, and certified as correct by Christopher H. Almero, the laboratory supervisor.

Table-6: Test Results on Tensile Strength

Sample	Curing Days	Dimensions		Area (mm^2)	Machine Reading	Tensile Strength		Type of Fracture
		D (mm)	L (mm)			MPa	psi	
CS (0%)	28	154.16	300.05	18665.27	198.35	2.73	395.85	CP
S1 (10%)	28	154.52	300.03	18752.55	157.45	2.162	313.49	CP
S2 (20%)	28	153.13	300.02	18416.69	148.51	2.058	298.41	CP
S3 (30%)	28	154.93	300	18852.20	139.41	1.910	276.95	CP

The results of the split tensile strength test of cylindrical concrete specimens (ASTM C-496) with 28 days of curing. The control sample has a diameter of 154.16 mm, 300.05 mm in length, and an area of 18665.27 mm2. The control sample has a machine reading of 198.35 kN, a tensile strength of 2.730 MPa, which is equivalent to 395.85 psi, and a CP type of fracture. On the other hand, Sample 1 (S1) has a diameter of 154.93 mm, 300.00 mm in length, and an area of 18752.55 mm2. Sample 1 (S1) has a machine reading of 157.45 kN, a tensile strength of 2.162 MPa, which is equivalent to 313.49 psi, and a CP type of fracture. Sample 2 (S2) has a diameter of 153.13 mm, 300.02 mm in length, and an area of 18416.69 mm2. Moreover, Sample 2 (S2) has a machine reading of 148.51 kN, a tensile strength of 2.058 MPa, which is equivalent to 298.41 psi, and a CP type of fracture. Sample 3 (S3) has a diameter of 154.93 mm, 300.00 mm in length, and an area of 18852.20 mm2. Finally, Sample 3 (S3) has a machine reading of 139.41 kN, a tensile strength of 1.910 MPa, which is equivalent to 278.95 psi, and a CP type of fracture.

8.4 Density Test

A density test is a measure of the weight per unit volume of solid or liquid samples. A density test will be performed to determine the effect of the partial replacement of LDPECA on the density of concrete. The researchers will perform three (3) trials of manual computation to determine the density of samples.

Table-7: Results of the Density Test

Sample	Type	Mass (kg)	Diameter (m)	Length (m)	Depth (m)	Base (m)	Volume (m^3)	Density (kg/m^3)
CS (10%)	Beam	30.99	-	0.45	0.1539	0.1567	0.010852	2699.6
	Cylinder	14.18	0.1523	0.3048	-	-	0.005553	
	Cylinder	14.235	0.15416	0.30005	-	-	0.005601	
	-	59.405	-	-	-	-	0.022005	
S1 (10%)	Beam	29.87	-	0.45	0.1559	0.1570	0.011014	2511.9
	Cylinder	12.74	0.1517	0.3048	-	-	0.005509	
	Cylinder	13.029	0.15452	0.30003	-	-	0.005626	
	-	55.639	-	-	-	-	0.02215	
S2 (20%)	Beam	29.2	-	0.45	0.1589	0.1551	0.01109	2417.0
	Cylinder	12.53	0.1539	0.3048	-	-	0.00567	
	Cylinder	12.136	0.15313	0.30002	-	-	0.005525	
	-	53.866	-	-	-	-	0.022286	
S3 (30%)	Beam	27.56	-	0.45	0.1579	0.1552	0.011028	2319.4
	Cylinder	12.04	0.1527	0.3048	-	-	0.005582	
	Cylinder	12.043	0.15493	0.3	-	-	0.005656	
	-	51.643	-	-	-	-	0.022265	

The results for density of beam and cylindrical concrete with 28 days of curing the control sample for beam concrete has a width of 156.7 mm, a depth of 153.9 mm, and a length of 450 mm, with a volume of 0.010852 m3 and a mass of 30.99 kg. Cylindrical concrete in compressive form has a diameter of 152.3 mm, 304.8 mm in length, a volume of 0.005553 m3 and a mass of 14.18 kg. Cylindrical concrete in split tensile has a diameter of 154.16 mm, a length of 300.05 mm, a volume of 0.005601 m3, and a mass of 14.235 kg. All the control samples have a total mass of 59.405 kg and a total volume of 0.022005 m3. They all have a density of 2699.557 kg/m3.

On the other hand, Sample 1 (S1) for beam concrete has a width of 157 mm, a depth of 155.9 mm, a length of 450 mm, a volume of 0.011014 m3, and a mass of 29.87 kg. Cylindrical concrete in compressive form has a diameter of 151.7 mm, 304.8 mm in length, a volume of 0.005509 m3 and a mass of 12.74 kg. For cylindrical concrete in split tensile, it has a diameter of 154.52 mm, a length of 300.03 mm, a volume of 0.005626 m3, and a mass of 13.029 kg. All the control samples have a total mass of 55.639 kg and a total volume of 0.02215 m3. They all have a density of 2511.954 kg/m3.

However, the results for Sample 2 (S2) for beam concrete have a width of 155.1 mm, a depth of 158.9 mm, a length of 450 mm, a volume of 0.01109 m3, and a mass of 29.2 kg. Cylindrical concrete in compressive form has a diameter of 153.9 mm and a length of 304.8 mm, with a volume of 0.005567 m3 and a mass of 12.53 kg. Cylindrical concrete in split tensile has a diameter of 153.13 mm and a length of 300.02 mm, with a volume of 0.005525 m3 and a mass of 12.136 kg. All the control samples have a total mass of 53.866 kg and a total volume of 0.022286 m3. They all have a density of 2417.058 kg/m3.

Finally, the results for Sample 3 (S3) for beam concrete have a width of 155.2 mm, 157.9 mm in depth, 450 mm in length, a volume of 0.011028 m3, and a mass of 27.56 kg. Cylindrical concrete in compressive form has a diameter of 152.7 mm and a length of 304.8 mm, with a volume of 0.005582 m3 and a mass of 12.04 kg. Cylindrical concrete in split tensile has a diameter of 154.93 mm, 300 mm in length, a volume of 0.005656 m3, and a mass of 12.043 kg. All the control samples have a total mass of 51.643 kg and a total volume of 0.022265 m3. They all have a density of 2319.44 kg/m3.

9. CONCLUSION

The test results on compressive, flexural, and tensile strengths of concrete samples after 28 days of curing have been presented. The compressive and flexural strength tests were conducted at ASTEC Materials Testing Corporation, while the tensile strength tests were performed at PAR Geotechnical Testing Center. The results show that the control sample (CS) has the highest values of compressive and tensile strengths, followed by samples S1, S2, and S3. Sample 1 (S1) with 10% LDPECA has the highest flexural strength among all the samples, followed by sample 2 (S2) and sample 3 (S3). The results of the density test indicate that the density values of S1, S2, and S3 are significantly lower than the density of the control sample.

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