DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

UTILIZATION OF WASTE PLASTICS IN CONCRETE

by
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December, 2017
İZMİR

UTILIZATION OF WASTE PLASTICS IN CONCRETE

A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering, Structure Engineering Program

by
Cihan KARADEMİR

December, 2017
İZMİR

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ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my advisor, Assoc. Prof. Dr. Egemen TEOMETE, for his excellent guidance, caring, patience, and providing me with an excellent atmosphere for doing research. His guidance helped me in all the time throughout research, experimental work and writing period of this thesis.

I would like to thank Batıbeton, Batıçim, Sika, Basf and Narsan companies for their material support.

Finally, I would like to thank my family for their unconditional love and support. And I am grateful to Betül UZ for her priceless help, valuable advices and contributions.

Cihan KARADEMİR

UTILIZATION OF WASTE PLASTICS IN CONCRETE

ABSTRACT

Plastic wastes are a great threat to human and natural health. In 2001, 100 million tons of plastics were consumed in the world. The aim of this experimental study is to gain the plastic wastes back into economy by using them as concrete additives, to develop concrete with improved mechanical properties, to protect human and environmental health.

In this work, waste polyethylene and polypropylene plastic fibers were used in concrete at different volume percentage. 40 mixtures were designed. Flexural and compression tests were performed for each mixture. Flexural strength, flexural toughness, compressive strength and compressive toughness values were determined.

In general, waste plastic fibers decreased compressive strength, did not affect flexural strength, while increased flexural toughness considerably.

The concrete with improved mechanical properties will reduce the structural damages under earthquake and other loads and increase the safety of life and property. The use of concrete with plastic waste additives will prolong the life of structures. The costs of repair, maintenance and renovation of the structures will decrease.

Keywords: Plastic waste, concrete, bending strength, compressive strength

ATIK PLASTİKLERİN BETONDA KULLANIMI

ÖZ

Plastik atıklar, insan ve doğa sağlığına çok büyük tehdit oluşturmaktadır. Dünyada 2001 yılında 100 milyon ton plastik tüketilmiştir. Bu deneysel çalışmanın amacı plastik atıkların, beton içerisinde kullanılarak ekonomiye geri kazandırılması, mekanik özellikleri geliştirilmiş beton elde etmek, insan ve çevre sağlığını korumaktır.

Bu çalışmada, atık polietilen ve polipropilen plastik lifler farklı hacim yüzdesinde betonda kullanılmıştır. 40 karışım hazırlandı. Her bir karışım için eğilme ve basınç testleri yapıldı. Eğilme dayanımı, eğilme tokluğu, basınç dayanımı ve basınç tokluğu değerleri belirlenmiştir.

Genel olarak, atık plastik lifler betonun eğilme tokluğunu önemli ölçüde arttırırken, basınç dayanımını azalttığı, eğilme dayanımına ise etkilemediği saptanmıştır.

Mekanik özellikleri geliştirilmiş beton, deprem ve diğer yükler altında yapısal hasarları azaltacak, can ve mal güvenliğini arttıracaktır. Plastik atık katkılı beton kullanımı yapıların ömrünü uzatacaktır. Yapıların tamir, bakım ve yenileme maliyetleri düşecektir.

Anahtar Kelimeler: Plastik atık, beton, eğilme dayanımı, basınç dayanımı

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CHAPTER ONE
INTRODUCTION

570,493 tons of plastic waste was only released as packaging waste in Turkey in 2010 (Republic of Turkey, Ministry of Science and Technology, 2014). According to the data of the Turkish Statistical Institute (2016) 2014 year, there are 28 million tons of municipal waste annually in Turkey. 2% of municipal solid waste is plastic (Republic of Turkey, Ministry of Science and Technology, 2014), according to which in 2014, municipalities collected 560,000 tons of plastic waste.

In the United States (USA), the amount of plastic waste was 11 million tons in 2003 (Siddique et al., 2008), which was increased to 31 million tons in 2012 (United States Environmental Protection Agency, 2015). In the US, in 2013, 32 million tons of plastic waste came out, of which only 3 million tons were recycled and 29 million tons were waste (United States Environmental Protection Agency, 2013).

In 2001, 100 million tons of plastics were consumed in the world. The amount of plastic waste in the UK in 2001 was 3 million tons. Advantages of plastics can be listed as follows (Siddique et al., 2008); ability to respond to different needs, low weight, packing of food, durability and long use, resistance to chemicals, water and impact, thermal and electrical insulation; low cost, ability to be combined with other materials and esthetics.

Plastic wastes are disposed of as follows (Siddique et al., 2008):

- Filling in the ground: Filling the plastic waste in the soil causes loss of the waste to be used, in addition to environmental pollution.
- Getting energy by burning: Plastic wastes provide energy by giving high heat. Their volume is reduced by 90-95%. However, toxic smoke comes out during combustion. In addition, adding fly ash and base ash (from the boiler) to the soil as a combustion product poses a danger of polluting the groundwater.

Al-Manaseer and Dalal (1997) reported that as the amount of plastic waste aggregate increases, the density of concrete decreases.

As the amount of plastic aggregate replaced with normal aggregate increases, the value of the slump of concrete increases because the plastic aggregate does not absorb water and the amount of free water increases in concrete (Al-Manaseer and Dalal, 1997). Soroushian et al. (2003) stated that the slump value of concrete decreased with the use of waste plastics in concrete. Choi et al. (2005) reported that the use of plastic aggregate at different ratios instead of normal fine aggregates increased the slump value of concrete, the reason for this is that the plastic does not absorb water and smooth. Ankur C. Bhogayata (2017) reported that workability reduced with increased shredded metalized plastic polypropylene fibers content for all test conditions.

Bayasi and Zheng (1993) reported that 19 mm polypropylene fibers did not affect the compressive strength of the concrete but increased energy absorption capacity, while the 12.7 mm long polypropylene fibers increased the compressive strength when it amount was less than 0.5% by volume. Al-Manaseer and Dalal (1997) reported that increasing the ratio of plastic aggregate reduced the compressive strength of the concrete, the tensile strength, the modulus of elasticity, but the fracture was ductile.

Soroushian et al. (2003) reported that the plastic fiber slightly increased the compressive strength of the concrete but the plastic aggregate reduced the compressive strength. Choi et al. (2005) reported that when plastic PET bottles were replaced with fine aggregates at different volumetric ratios (0-25-50-75%), the compressive strength, tensile strength and elasticity modulus of concrete decreased. Batayneh et al. (2007) reported that by changing the fine aggregate with plastic parts at different ratios, the compressive strength decreased with increasing plastic ratio. Marzouk et al. (2007) reported that the compressive and flexural strength would not change if less than 5 mm PET bottle pieces were below 50% volumetric ratio of the fine aggregate.

Rebeiz (1995) produced polymer concrete by combining recycled PET with aggregate using as binder. The strength of polymer concrete decreased with

temperature increase. Byung-Wan et al. (2006) produced polymer-bonded concrete from PET waste, the compressive strength of this concrete was found to be 74 MPa. The tensile strength was 7.9 MPa and the modulus of elasticity was 28 GPa. It was determined that there was a correlation between the compressive strength and other mechanical properties.

Soroushian et al. (2003) showed that air permeability of concrete decreased with different plastic admixtures, while abrasion resistance decreased.

Foti (2011) chopped PET bottles into fiber and ring and added to concrete. In bending tests, the plastic PET layer has increased the energy absorption capacity of the concrete. Ankur C. Bhogayata (2017) reported that the inclusion of plastic fibers in concrete, the crack resistance of concrete improved. plastic fibers caused concrete to become ductile and reduce the propagation of micro cracks of the hardened mass.

Ferreira et al. (2012) investigated the effect of different curing conditions on the mechanical properties of recycled plastic waste added concrete. As different curing conditions, laboratory conditions, curing tank and atmospheric conditions were taken. Increasing the plastic ratio reduces pressure resistance and increases abrasion resistance.

Ismail and Al- Hashmi (2008) substitute aggregate with plastic waste at different ratios. It was reported that as the plastic waste ratio increased, the slump value, density of fresh and hardened concrete compressive strength and flexural strength decreased. Thorneycroft (2018) reported that the substitution of plastics in the concrete mixture is often seen to cause a decrease in compression and tensile strength due to the weak bond between the plastic and the surrounding matrix.

In this study, waste polyethylene and waste polypropylene were used as fibers in concrete. Slump test, compression test and bending test were conducted on waste plastic fiber reinforced concrete. The effects of waste plastic reinforcement on mechanical properties of concrete were determined.

CHAPTER TWO
MATERIALS AND METHOD

2.1 Purpose

The aim of this experimental study is to improve the mechanical properties of concrete using waste plastics in concrete, to use waste plastics reinforced concrete at the value of 20-25 cm slump value in the specific construction industry and to contribute to prevention of environmental pollution by using waste plastics in concrete.

2.2 Scope

This thesis consists of two main steps:

1. In order to investigate the effect of waste plastic on the mechanical properties of concrete, first series of concrete mixtures were determined and this mixture containing 0.2%, 0.5%, 0.8%, 1% and 1.5% of the waste plastic were prepared. For this purpose, 1 reference concrete, 5 different volumetric ratio waste polyethylene reinforced concrete and 5 different volumetric ratio waste polypropylene reinforced concrete were obtained and tested.
2. For use in construction sector for a successful pumping, placing, compaction and workable concrete mixtures are generally preferred. Hence, concrete is desired to have a 20-25 cm slump value. Industrial mixtures were determined and this mixture containing different volumetric ratios of the waste plastic were prepared. For this purpose, 1 reference concrete, 12 different volumetric ratio waste polyethylene reinforced concrete and 16 different volumetric ratio waste polypropylene reinforced concrete were obtained and tested.

2.3 Used materials

The materials used in the concrete, methods of preparing samples, the equipment used in the experiments, the steps followed in the flexural and compression test and the tests details are presented in this chapter

2.3.1 Cement

CEM II B-M (L-W) 42.5 R type cement was used. The cement was taken from the Batıçim Batı Anadolu Çimento Sanayi A.Ş. cement factory. The cement was placed in plastic drums to prevent moisture from the air. The density of the cement is 2.97 gr/cm^3 and the specific surface is 4607 gr/cm^3.

Table 2.1 CEM II B-M (L-W) 42.5R cement properties (supplied by the manufacturer)

Chemical Properties				
PROPERTY	EXPERIMENT	TS EN 197-1	RESULT	UNIT
Loss of Ignition	TS EN 196-2	-	4.62	%
Chloride (Cl^-)	TS EN 196-2	≤ 0.1	0.0091	%
SO3	TS EN 196-2	≤ 4.0	3.37	%
F.CaO	K.K.T.-53	21 ≥B≤ 35	1.55	%
Total Contribution/L	TS EN 196-4	-	33.53	%
Total Alkali	XRF	-	0.93	%
CaO	XRF	-	53.65	%
SiO_2	XRF	-	23.69	%
Al_2O_3	XRF	-	8.81	%
Fe_2O_3	XRF	-	3.02	%
MgO	XRF	-	1.35	%
Na_2O	XRF	-	0.27	%
K_2O	XRF	-	1.01	%
Physical Properties				
90 µ fineness	TS EN 196-6	-	0.2	%
32 µ fineness	TS EN 196-6	-	12.2	%
Initial setting time	TS EN 196-3	>60	175	min
Final setting time	TS EN 196-3		225	min
Volume expansion	TS EN 196-3	<10	1.5	mm
Compressive Strength of Cement				
2 days	TS EN 196-1	≤ 20	25.2	MPa
28 days	TS EN 196-1	≤ 42.5 ≤ 62.5	52.1	MPa

2.3.2 Fine Aggregate

Crushed fine aggregates (0-3mm) and (0-5mm) were obtained from the Batıbeton A.Ş. Fine aggregate was tested in the Materials of Constructions Laboratory according

to "TS3526 Specific Gravity and Water Absorption Rate Determination in Concrete Aggregates". The moisture content of the fine aggregate (0-3mm) was 1.16%, water absorption and density of SSD fine aggregate (0-3mm) were found to be 1.1% and 2.7 gr/cm^3.The moisture content of the fine aggregate (0-5mm) was 0.98%, the water absorption was 1 % and the density of SSD fine aggregate (0-5mm) was found to be 2.7 gr/cm^3. Sieve analysis test was performed according to "TS 130 Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates". The results of the sieve analysis are shown in Figure 2.1.

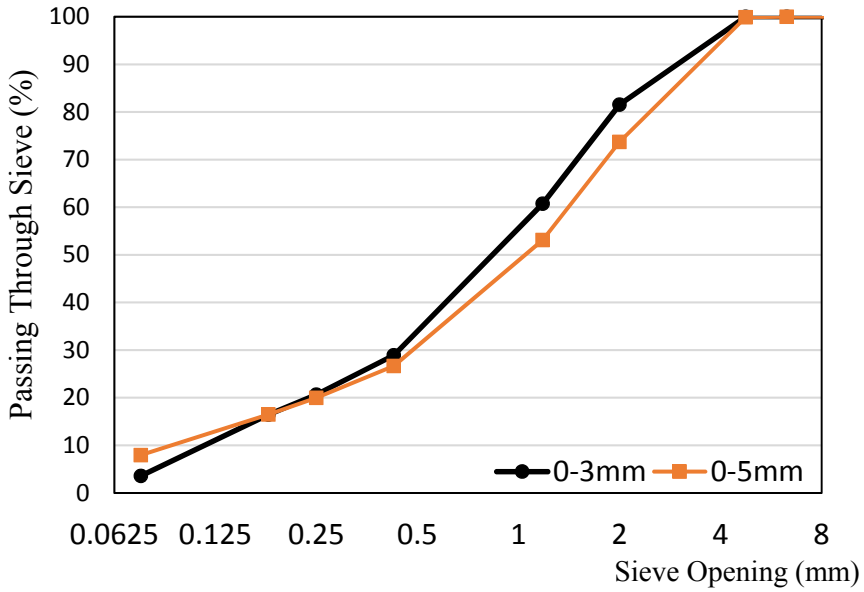


Figure 2.1 Fine aggregate sieve analysis results

2.3.3 Coarse Aggregate

The coarse aggregated (5-15mm) and (15-25mm) used in all mixtures was crushed limestone and obtained from Batıbeton A.Ş. Sieve analysis results are presented in Figure 2.2. The coarse aggregate was tested in the Materials of Constructions Laboratory according to the standard "TS3526 Determination of Specific Gravity and Water Absorption ratio in Concrete Aggregates". The moisture content of the coarse aggregate (5-15mm) was 0.1%, the water absorption ratio was 0.52% and the density of SSD coarse aggregate (5-15mm) was 2.71 gr/cm^3. The moisture content of the

coarse aggregate (15-25mm) was 0.1%, the water absorption rate was 0.52% and the density of SSD coarse aggregate (15-25mm) was 2.71 gr/cm^3.

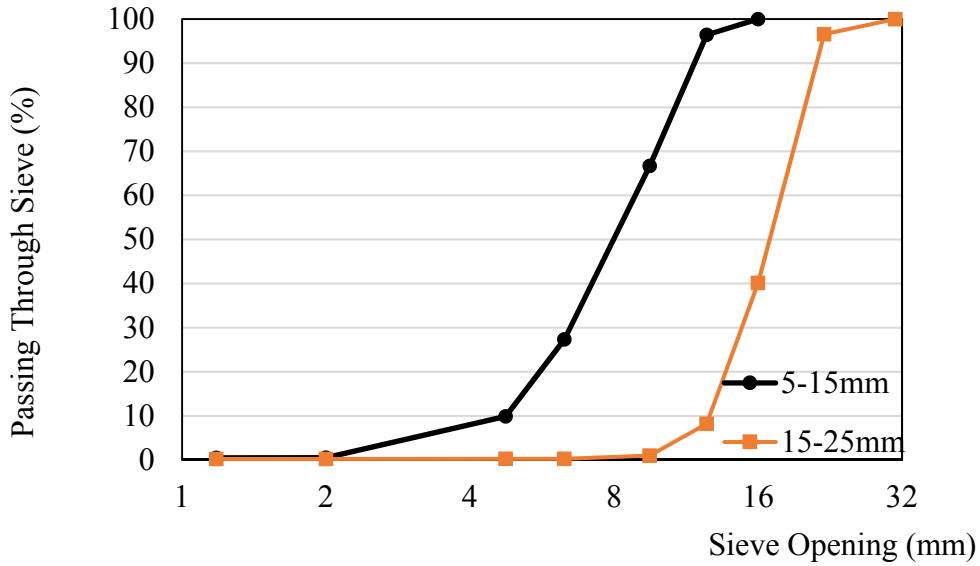


Figure 2.2 Coarse aggregate sieve analysis results

2.3.4 Silica Fume

BASF MasterROC MS 610 silica fume was used. The density of silica fume was 2300 kg/m^3. Chlorine content was below 0.1%. Table 2.2 presents the technical specifications of silica fume.

Table 2.2 Technical specifications of BASF MasterROC MS 610 silica fume (Manufacturer's data)

Items	
Color	Grey
Density	2300 kg/m^3
Chlorine Content (EN 480-10)	<0.1%
Blaine (Fineness)	>15000 m^2/kg
SiO_2	>%85
CaO	<%1
SO3	<%2
% retained on 45 µm sieve	<%40
Activity Index	>%95

An optical microscope photograph of the silica fume was presented in Figure 2.3. Silica fumes which denotes the presence of spherical particles with an average diameter of 0.25 µm



Figure 2.3 BASF MasterROC MS 610 silica fume microscope images 50x (Personal archive, 2016)

2.3.5 Water

In the production of concrete, tap water was used.

2.3.6 Water-Reducing Admixture

Two different plasticizer additives were used. Sika Viscocrete Hi-Tech30 super plasticizer was used in the first approach design mixture. According to the information provided by the manufacturer, density of the admixture is 1.090 kg/lt. It is soluble in water. Equivalent sodium oxide according to TS-EN 934-2 is maximum 4%. The technical specifications of the plasticizer were given in Table 2.3.

Table 2.3 Technical specifications of Sika Viscocrete Hi-Tech30 super plasticizer (manufacturer information)

Chemical structure	Modified polycarboxylate based polymer
Density	1.090 kg/lt at 20 C°
pH	between 3-7
Freezing point	-9 C°
Water-soluble chlorine	< 0.1%
Na_2O	< 4%

The other used plasticizer was Basf MasterGlenium® SKY 608 super plasticizer. The plasticizer was used in the industrial design mixture. Its density was 1.069-1.109 kg/lt. The technical specifications of the plasticizer were given in Table 2.4.

Table 2.4 Technical specifications of the Basf MasterGlenium® SKY 608 super plasticizer (manufacturer information)

Structure of material	Polycarboxylic Ether-Based
Density	1.069-1.109 kg/lt at 20 C°
pH value	between 5-7
Alkali content (%)	≤3.00
Chlorine ion content (%)	≤ 0.1
Corrosion behavior	Only components complying with EN 934-1: 2008, Ek A.1

2.3.7 Waste plastic

Waste plastic was obtained from Narsan Plastic Industry Company. Waste plastics were sorted according to their type in the recycling process and separated plastic wastes were broken down into small pieces and washed. In this way, the plastic waste became suitable for the next recycling stage. These crumbled plastic wastes were melted. Then, these melted waste materials were cut and pelletized to obtain recycled plastic materials. These recycling processes were shown in Figure 2.4.



Figure 2.4 Recycling processes (Personal archive, 2016)

In this experimental study, it is desired to use polyethylene and polypropylene wastes as fiber in concrete after passing through cutting and washing process.

2.3.7.1 Polypropylene

Waste polypropylene (PP) used in the study was supplied by Narsan Plastic. Waste polypropylenes used as sacks, the majority of which were collected to be recycled, were passed through cutting and washing processes. Their length of the polypropylene fibers used ranges between 5 mm and 30 mm and the width varies between 2 mm and 4 mm. The fibers are shown in Figure 2.5 (a). The specific gravity of polypropylene (PP) fibers determined in accordance with ASTM D 1895-96 "Standard Test Methods for Apparent Density, Bulk Factor, and Pourability of Plastic Materials", as shown in Figure 2.5 (b), was found to be 0.904 kg/dm^3.



Figure 2.5 (a) Waste polypropylene fiber (b) Specific gravity test (Personal archive, 2016)

2.3.7.2 Polyethylene

Waste polyethylene (PE) used as a food bag was recycled, as shown in Figure 2.6. The length of waste polyethylene passing through cutting and washing processes was between 5 mm and 40 mm as shown in Figure 2.6. The density of PE fibers was found to be 0.917 kg/dm^3 according to ASTM D 1895-96.

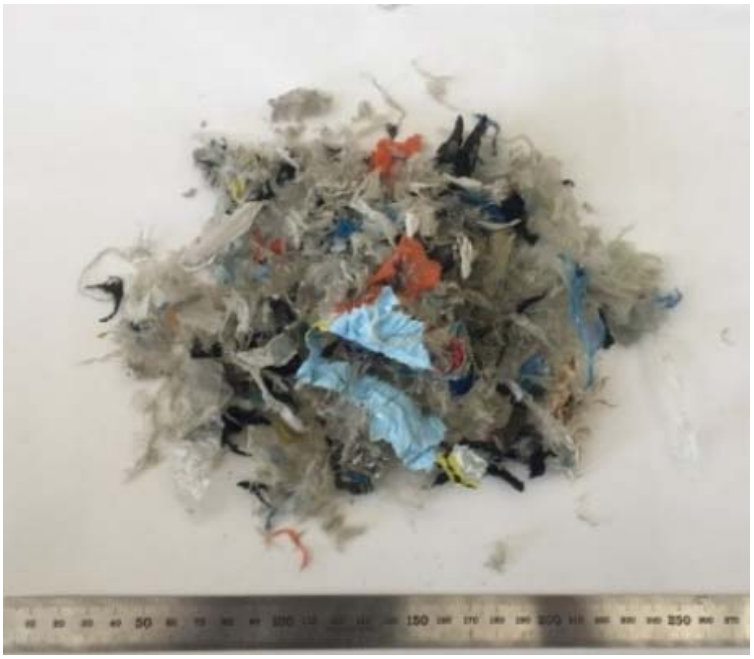


Figure 2.6 Waste polyethylene fiber (Personal archive, 2016)

2.4 Design of Concrete Mixtures

Concrete mixtures containing different amounts of the waste plastics were designed in accordance with the TS 802 standard "Design Concrete Mixes".

2.4.1 First series of Concrete Mixtures

First series of concrete mixtures were designed in order to investigate the effect of waste polyethylene and polypropylene on the mechanical properties of concrete. The following steps were followed while designing the mixtures:

- The target 28. day compressive strength of the non-air entrained concrete was selected to be 30 MPa.
- The water / binder ratio for the non-air entrained concrete with 30 MPa is 0.54.
- The amount of concrete slump was selected as 8 - 10 cm which required a water content of 228 kg/m^3.
- The air content was taken as 2.3% due to largest the aggregate size (15mm) and climatic conditions.
- The plasticizer / binder ratio was taken 1% using the Sika Viscocrete HighTech 30 manufacturer information.
- The water reduction rate of the plasticizer was taken as 10% regarding the recommendations of the manufacturer.
- Silica fume / total binder ratio was taken as 10% as recommended by the manufacturer.
- The coarse aggregate and fine aggregate proportions in the mixtures was 60% fine aggregate (0-5mm) and 40% coarse aggregate (5-15mm).

Table 2.5 The proportions of M0 reference concrete mixture (kg/m^3)

	Cement	Fine Aggregate (SSD)	Course Aggregate (SSD)	Silica Fume	water	Plasticizer
M0	342	986	665	38	224	3

In order to investigate the effect of waste polyethylene and polypropylene on the mechanical properties of concrete, first design mixtures containing 0.2%, 0.5%, 0.8%, 1% and 1.5% of the polyethylene and polypropylene wastes were prepared Waste plastic fiber reinforced concrete in the first approach design were named as in the Table 2.6.

Table 2.6 Designation of waste plastic bearing mixtures

	Fiber type	Fiber Volme	Water/Binder	Water/(kg/m3)	Plasticizer Addtivie	Aggregate (0-5mm)	Aggregate (5-15mm)
M0	-	0%	0.54	228	1%	60%	40%
BPP1	Polypropylene	0.2%	0.54	228	1%	60%	40%
BPP2	Polypropylene	0.5%	0.54	228	1%	60%	40%
BPP3	Polypropylene	0.8%	0.54	228	1%	60%	40%
BPP4	Polypropylene	1%	0.54	228	1%	60%	40%
BPP5	Polypropylene	1.5%	0.54	228	1%	60%	40%
BPE1	Polyethylene	0.2%	0.54	228	1%	60%	40%
BPE2	Polyethylene	0.5%	0.54	228	1%	60%	40%
BPE3	Polyethylene	0.8%	0.54	228	1%	60%	40%
BPE4	Polyethylene	1%	0.54	228	1%	60%	40%
BPE5	Polyethylene	1.5%	0.54	228	1%	60%	40%

2.4.2 Industrial Concrete Design

In ready mix concrete, the desired slump ranges generally between 20-25cm for both initials slump (S_0) and slump at 45 minutes (S_{45}). In the laboratory, the slump at 45 minutes was obtained by mixing concrete 30 second at every 5 minutes until 45 minutes. This is simulating concrete carrying and placing time in ready mixed concrete industry.

- The target compressive strength of the non-air entrained concrete was selected to be 30 MPa.
- The water / binder ratio for the non-air entrained concrete with 30 MPa is 0.55.
- 20-25 cm of slump value concrete was targeted at the S_0 and at the S_{45}.
- The water content of the reference mixture was determined to be 224 kg/m^3 in order to obtain concrete in the desired slump value.

- The air content was taken as 2.3% due to maximum the aggregate size (D_{max}=25mm) and climatic conditions.
- The plasticizer / binder ratio was taken 1% as recommended by the manufacturer (Basf).
- The water reduction rate of the plasticizer was taken as 25% as recommended by the manufacturer.
- The coarse aggregate and the fine aggregate proportions were; 30% (0-3mm), 30% (0-5mm) fine aggregate 20% (5-15mm) and 20% (15-25mm) coarse aggregate for the reference mixture.

Table 2.7 The proportions of C0 reference of industrial concrete mixture (kg/m^3)

	Cement	Fine aggregate (0-3mm) (SSD)	Fine aggregate (0-5mm) (SSD)	Course Aggregate (5-15mm) (SSD)	Course Aggregate (15-25mm) (SSD)	Plasticizer	water
C0	305	574	573	381	381	3	170

It is desirable that the slump value of concrete mixtures is 20-25 cm. There is a decrease in the slump value of concrete during the transportation of the fresh concrete. Therefore, the slump tests were performed both at the time concrete was ready (S_0) and 45 minutes later (S_{45}). As the fiber ratio increases, the slump value of the concrete decreases. If the mixture did not reach the desired slump value, the slump value was taken again after plasticizer was added at 0.1% of the binder. If the slump value was less than 20 cm, 0.1% additional plasticizer was added to the mixture. A maximum of 5 times 0.1% addition was made so that the maximum plasticizer ratio was 1.5%. If the slump value of the mixture was lower than 20 cm, or if the mixture was segregated, then the concrete was re-designed.

Table 2.8 Proportions and designations of waste polypropylene - containing industrial mixture

	Fiber Volume	Water/ Binder	Water (kg/m3)	Water-Reducing Admixture	Aggregate (0-3mm)	Aggregate (0-5mm)	Aggregate (5-15mm)	Aggregate (15-25mm)	S_0 Slump (cm)	S_{45} Slump (cm)
C0	0,0%	0,55	224	%1.0	30%	30%	20%	20%	23,5	21,5
CPP1	0,25%	0,55	233	%1.0 +0.1	30%	30%	20%	20%	19	18,5
CPP2	0,1%	0,55	245	%1.0 +0.1	32%	32%	18%	18%	25	23,5
CPP3	0,2%	0,55	245	%1.0	33%	33%	17%	17%	23,5	22
CPP5	0,3%	0,55	245	%1.0	33%	33%	17%	17%	23,5	23,5
CPP6	0,5%	0,55	245	%1.0	33%	33%	17%	17%	21,5	23,5
CPP7	0,7%	0,55	245	%1.0 +0.1	33%	33%	17%	17%	20	22
CPP8	0,85%	0,55	245	%1.0 +0.5	33%	33%	17%	17%	12	0
CPP8v2	0,85%	0,55	255	%1.0 +0.47	34%	34%	16%	16%	20	19
CPP8v3	0,85%	0,55	270	%1.0	34%	34%	16%	16%	22	21
CPP9	1,0%	0,55	270	%1.0 +0.1	34%	34%	16%	16%	21	20
CPP10	1,1%	0,55	270	%1.0+0.3	34%	34%	16%	16%	21,5	20
CPP11	1,2%	0,55	280	%1.0	35%	35%	15%	15%	20,5	20
CPP12	1,3%	0,55	280	%1.0	35%	35%	15%	15%	20	20
CPP13	1,4%	0,55	280	%1.0	35%	35%	15%	15%	20,5	20
CPP14	1,5%	0,55	280	%1.0+0.3	35%	35%	15%	15%	13,5	11
CPP14v2	1,5%	0,55	300	%1.0 +0.2	35%	35%	15%	15%	18,5	16

After determining the reference mixture, it was desired to reach the maximum fiber ratio at the desired slump value. Water / binder ratio was the same for all mixtures. Mix design changes were shown with thick lines in the Table 2.7. The water content of CPP1 (0.25%) mixture was determined to be 233 kg/m^3. The coarse aggregate and the fine aggregate distribution were 30% (0-3mm) and 30% (0-5mm) fine aggregate 20% (5-15mm) and 20% (15-25mm) coarse aggregate for CPP1 (0.25%). However, since the slump value was less than 20 cm, the water content was increased and the CPP2 (0.1%) mixture was redesigned. The water content of the CPP2 (0.1%) mixture was increased from 233 kg/m^3 to 245 kg/m^3. The coarse aggregate and the fine aggregate proportions for CPP2 (0.1%) were changed to 32% (0-3mm) and 32% (0-5mm) fine aggregate 18% (5-15mm) and 18% (15-25mm) coarse aggregate. The S_0 slump value of CPP2 (0.1%) was found to be 25 cm by adding 0.1% additional plasticizer and S_{45} slump value was found to be 23.5 cm. The coarse aggregate and the fine aggregate proportions for CPP3 (0.2%) were changed to 33% (0-3mm) and 33% (0-5mm) fine aggregate 17% (5-15mm) and 17% (15-25mm) coarse aggregate and this mixture ratio was kept constant up to 0.85% polypropylene fiber content. However, the mixture was redesigned because the S0 and S45 slump values in the CPP8 (0.85%) mixture was less than 20 cm. The water content of CPP8v2 (0.85%) was 255 kg/m^3, the fine aggregate ratios were increased by 1%, meanwhile the water content was increased to 270 kg/m^3 for CPP8v3 (0.85%) since the desired slump value was not

achieved. and this mixture ratio was kept constant up to 1.1% polypropylene fiber content at 20-25 cm slump. In CPP11 (1.2%) water content was increased to 280 kg/m^3. The coarse aggregate and the fine aggregate proportions were determined 35% (0-3mm) and 35% (0-5mm) fine aggregate 15% (5-15mm) and 15% (15-25mm) coarse aggregate for CPP11 (1.2%). At this mixture ratio, maximum 1.4% waste polypropylene fiber ratio value was achieved at 20-25cm slump value. The slump value of CPP14 (1.5%) and CPP14v2 (1.5%) were less than 20 cm. The maximum fiber ratio at the desired slump value was obtained with the CPP13 (1.4%) mixture with the gradual increments of water and fine aggregate.

Similar procedures were made in polyethylene fiber mixtures. Mixture design changes are shown with thick lines in the Table 2.8. The water content of CPE1 (0.2%) mixture was determined to be 245 kg/m3. The coarse aggregate and the fine aggregate distribution were 33% (0-3mm) and 33% (0-5mm) fine aggregate 17% (5-15mm) and 17% (15-25mm) coarse aggregate for CPE1 (0.2%). The ratio of this mixture reached 0.85% polyethylene fiber. Changes in water content and aggregate ratio were conducted as necessary to obtain slump higher than 20cm.

Table 2.9 Proportions and designations of waste polyethylene - containing industrial mixture

	Fiber volume	Water/ Binder	Water (kg/m3)	Water-Reducing Admixture	Aggregate (0-3)mm	Aggregate (0-5mm)	Aggregate (5-15mm)	Aggregate (15-25mm)	S_0 Slump (cm)	S_{45} Slump (cm)
C0	0,0%	0,55	224	%1.0	30%	30%	20%	20%	23,5	21,5
CPE1	0,2%	0,55	245	%1.0	33%	33%	17%	17%	21	23,5
CPE2	0,3%	0,55	245	%1.0	33%	33%	17%	17%	21,5	22
CPE3	0,5%	0,55	245	%1.0	33%	33%	17%	17%	21	22
CPE4	0,7%	0,55	245	%1.0 +0.1	33%	33%	17%	17%	20	20,5
CPE5	0,85%	0,55	245	%1.0+0.3	33%	33%	17%	17%	15	18
CPE5v2	0,85%	0,55	270	%1.0 +0.1	34%	34%	16%	16%	20	20
CPE6	1,0%	0,55	270	%1.0 +0.1	34%	34%	16%	16%	20	20
CPE7	1,1%	0,55	270	%1.0 +0.2	34%	34%	16%	16%	19	18
CPE7v2	1,1%	0,55	280	%1.0 +0.1	35%	35%	15%	15%	21	20
CPE8	1,2%	0,55	280	%1.0	35%	35%	15%	15%	20	21
CPE9	1,3%	0,55	280	%1.0 +0.1	35%	35%	15%	15%	20	20
CPE10	1,4%	0,55	280	%1.0	35%	35%	15%	15%	18	12

2.5 Preparation of Concrete Mixtures

2.5.1 First Series of the Mixture

7.5cm x 7.5cm x 30.5cm steel mold used. As seen in Figure 2.7, the molds were lubricated to leave a thin oil film layer before concrete casting.



Figure 2.7 The steel mold (Personal archive, 2016)

The materials to be mixed were weighed with the use of a precision scale. The cement, silica fume, water, fine aggregate and coarse aggregate were discharged to 125lt tilting revolving portable concrete mixer respectively shown in Figure 2.8.



Figure 2.8 The mixer (Personal archive, 2016)

To prepare the mixture, the cement and silica fume were first poured. The mixture of water and the plasticizer was mixed. After cement and silica fume casting, water was added in three stages in to the mixture and mixed for 30 second. Afterwards fine aggregate (0-5mm) was added to the mixture in three stages and mixed for 30 second for each mixture. After adding fine aggregate, coarse aggregate (5-15mm) was added in three stages and mixed for one and a half minutes. The plastic fibers were then gradually added to the mixture. All mixture materials were added; they were mixed for a total of 5 minutes.

Each mixture was cast into steel mold in Figure 2.9. Each sample was left in the mold for one day and after demolding it was kept in water at 20° C for 28 days. The samples were then left in the laboratory condition for 7 days. For each mix, three prismatic samples 7.5cm x 7.5cm x 30.5cm were prepared. All specimens were subjected to flexural strength test on the 36^{th} day, and compressive strength tests were performed on both sides of the sample from the flexural strength test with the aid of a 7.5cm x 7.5cm iron plate.

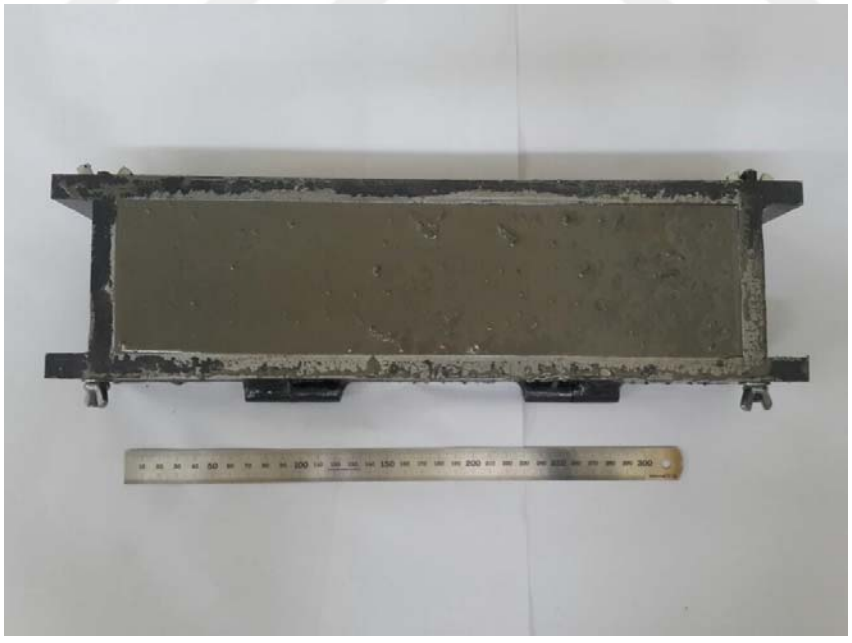


Figure 2.9 The casting mold (Personal archive, 2016)

2.5.2 Industrial Design Mixture

In the industrial concrete design approach, the following operations were applied when making the concrete mixture.

First, 15-25mm coarse aggregate was placed in the concrete mixer, then 5-15mm coarse aggregate and then 0-5 fine aggregate. It was mixed with trowel every time. Cement, 0-3 mm fine aggregate and fibers were all distributed and deposited in order. Dry mixing was performed in the mixer for 30 seconds. All water was added to the mixer and mixed for 5 min.

Both initials slump(S_0) and slump at 45 minutes(S_{45}) tests were conducted for industrial concrete mixtures according to TS EN 12350-2 after mixing the fresh concrete in Figure 2.10.a. If the slump values were below 20cm, the experiment was repeated by adding 0.1% of plasticizer. This experiment was carried out to see how much consistency was lost after 45 minutes. In construction sector for a successful pumping, placing, compaction and workable concrete mixtures are generally preferred.

7.5cm x 7.5cm x 30.5cm steel mold and 10cmx 10cm x 10 cm cube plastic mold (shown in Figure 2.10 b). The entire surfaces of the molds were lubricated before casting. 6 cube samples and 3 prismatic samples were cast from every mixture.



Figure 2.10 (a) Slump experiment (b) The plastic mold (Personal archive, 2016)

Concrete specimens were removed from the mold without damage to the specimens after 24 hours. Once the specimens were removed from the mold. The roughness caused by the mold surface was cleaned.

The samples were cured in water tank at 20 °C as shown in Figure 2.11. After the completion of the cure period, samples were removed from water. The cube specimens were tested in compression test at 7^{th} day and 28^{th} day ages. Three-point bending test was applied to the 28^{th} day age prismatic specimens.



Figure 2.11 The curing tank (Personal archive, 2016)

2.6 Mechanical Tests

2.6.1 Flexural Tests

In the flexural strength tests, Shimadzu universal testing machine was used. Figure 2.12 shows the test device used.

Its main features were as follows:

- It has a high data transmission frequency. It has a data rate of 1000 data per second.
- It is equipped with the TRAPEZIUMX® software, which provides creation and application of various tests easily.
- Both flexural and compressive tests can be performed by changing heads.
- The maximum load capacity of the device is 300kN.



Figure 2.12 Shimadzu mechanical testing machine (Personal archive, 2016)

Flexural strength tests were performed according to ASTM 1609. Three-point bending test was performed with the test apparatus as in Figure 2.13. The test loading rate was 0.1mm / min and the mid span was 263mm. The experiment was terminated when the center displacement of the sample was 1.8 mm. For each mixture, three samples were tested for flexural strength.

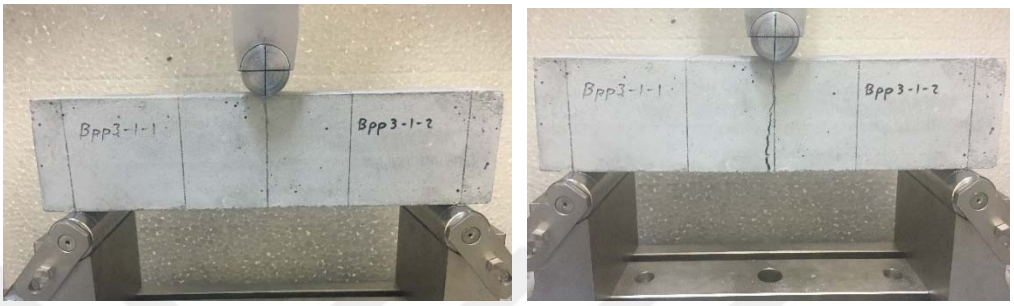


Figure 2.13 Three-point bending test (Personal archive, 2016)

The flexural toughness is found by calculating the area under the force-displacement curve as much as the value at which the beam mid-point displaces 1.8 mm in the flexural test as shown in Figure 2.14.

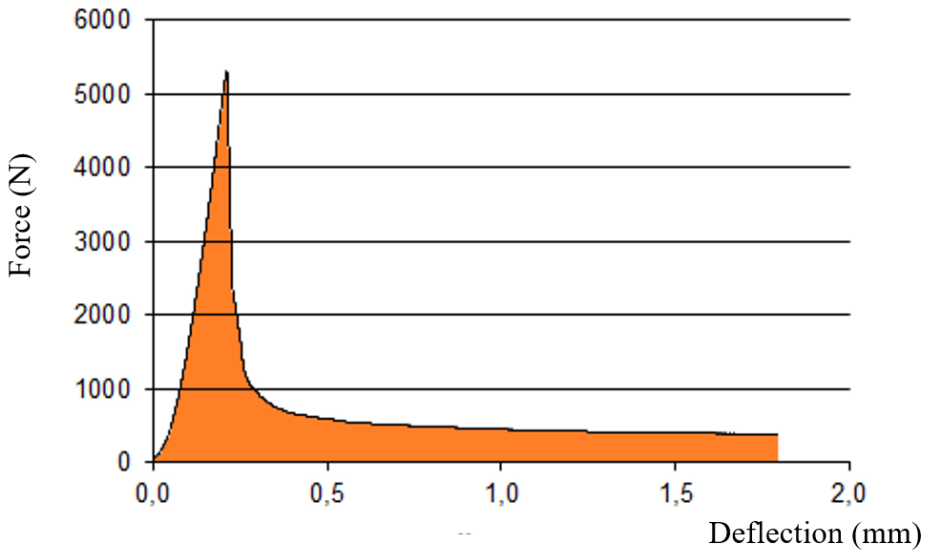


Figure 2.14 Force-deflection diagrams of concrete for flexural test

2.6.2 Compression Test

In the compressive strength tests, Shimadzu universal testing machine and Elepress testing machine were used.

Compression tests were performed on broken portions of the samples obtained from the flexural test by Shimadzu mechanical testing machine as shown in Figure 2.15. After the flexural strength test with the aid of a 7.5 cm x 7.5 cm plates, the samples were subjected to compression test. The loading speed was taken as 0.5 mm / min. The experiment was stopped when the load dropped to 50% of the maximum load.

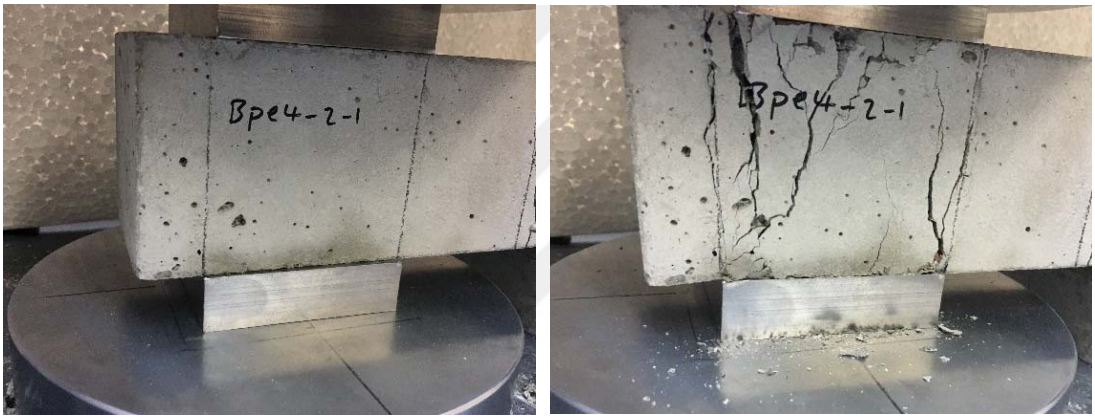


Figure 2.15 Compressive strength test (Personal archive, 2016)

In this study, the compressive toughness was found by calculating the area under the load-displacement curve up to the maximum load as shown in Figure 2.16.

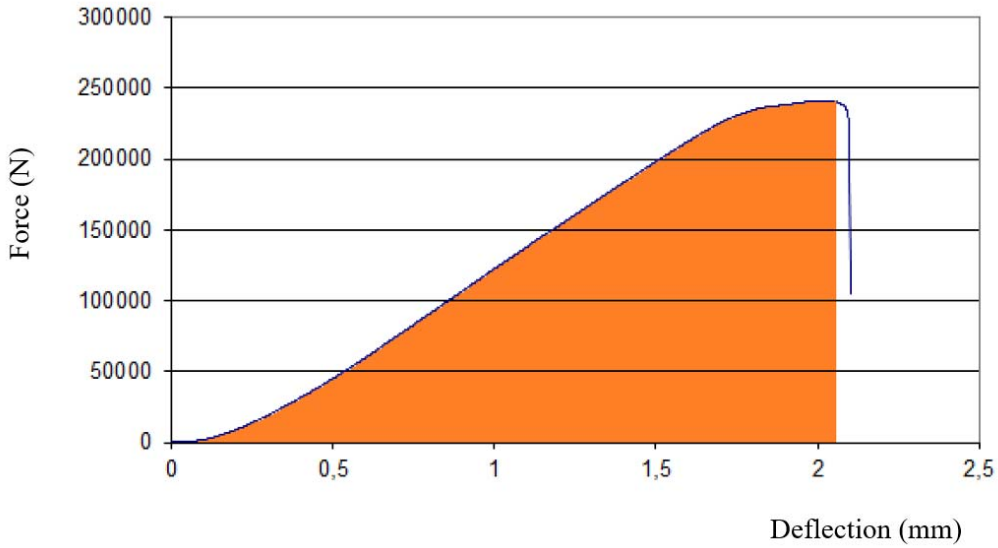


Figure 2.16 Force-deflection diagrams of concrete for compression test

Compression test were applied to 10 cm cube samples by Elepress test machine was shown in Figure 2.17 (a) which has 300 ton capacity. 10 cm cube samples were tested at a rate of 6 kN / sec as shown in Figure 2.17 (b). Test stopped at the maximum force.



Figure 2.17 (a) Elepress Machine (b) Compressive strength test (Personal archive, 2017)

CHAPTER THREE
RESULT AND DISCUSSION

3.1 Results of Concrete Slump Tests

The slump test results were given in Figure 3.1 and Figure 3.2 Slump value range was required to be between 20-25cm for industrial concrete. If the slump value was below 20 cm, additional plasticizers were added to the mixtures. It was determined how much the slump value was lost by taking the concrete slump value again after 45 minutes from the time cement and water was mixed. As seen in Figure 3.1 and Figure 3.2, the slump value decreased as the waste plastic fiber ratio increased. To compensate for these reductions, keeping water / cement ratio constant, both cement and water contents were increased. At the desired slump value in the study, the maximum values of waste plastic volume percent were 1.4% for polypropylene and 1.3% for polyethylene. However, as the fiber content increased, more water and cement were used to maintain the slump value of the concrete, which in turn made the concrete more costly.

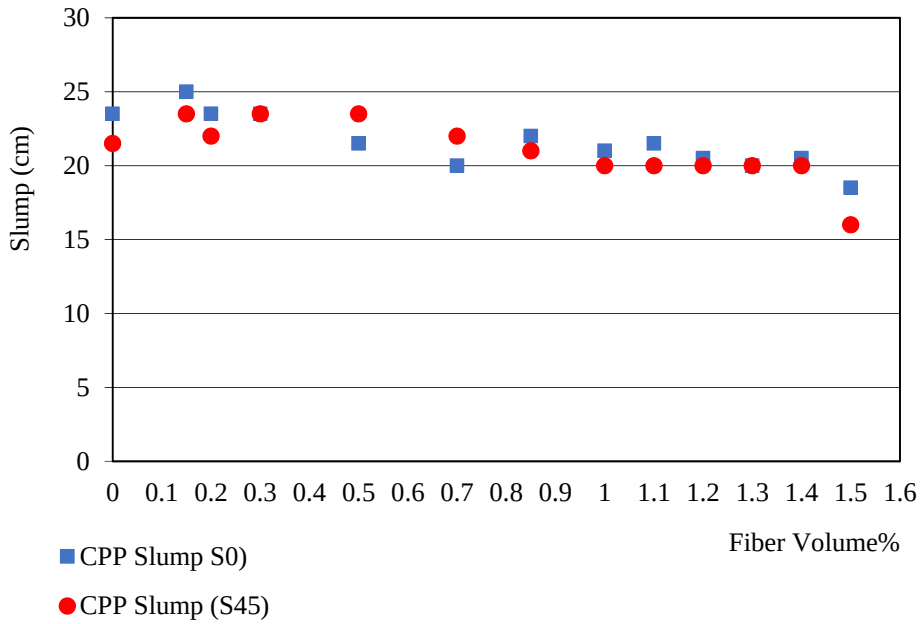


Figure 3.1 Relationship between slump and polypropylene to fiber content of concrete mixture

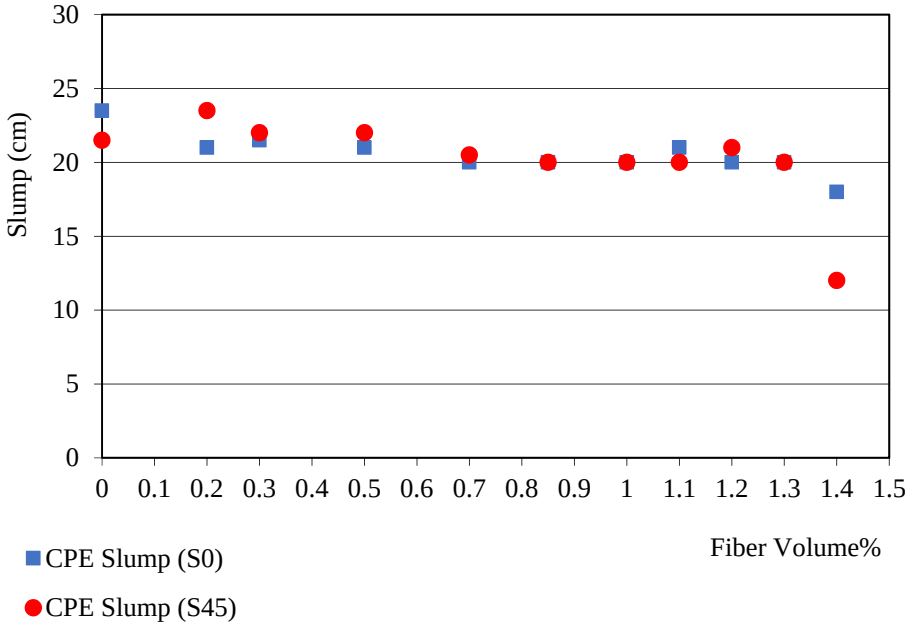


Figure 3.2 Relationship between slump and polyethylene to fiber content of concrete mixture to

3.2 Flexural Test Results

3.2.1 Flexural Test Results of First Concrete Series

The results of flexural strength tests of waste polypropylene and polyethylene bearing concrete mixtures are shown in Figure 3.3. The waste polypropylene fibers did not affect flexural strength, while waste polyethylene fibers decreased the flexural strength.

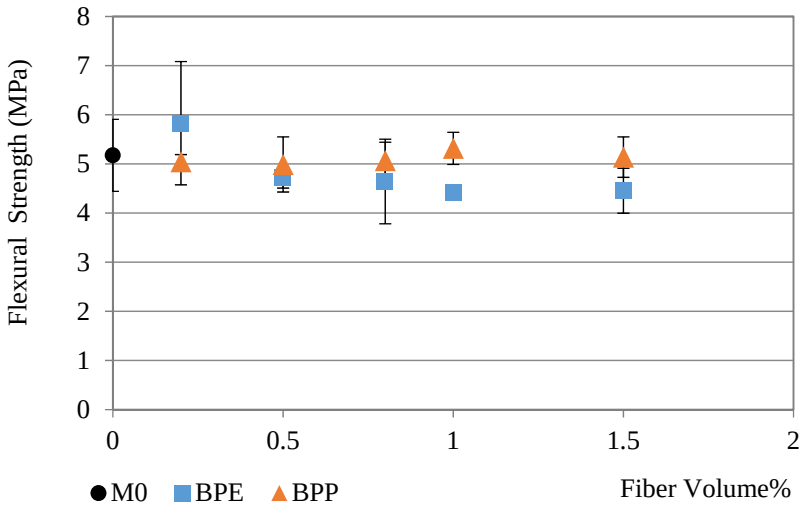


Figure 3.3 Relation of flexural strength to fiber volume ratio

The flexural toughness of the first series mixtures containing either polypropylene or polyethylene fibers, obtained by three-point bending test are shown in Figure 3.4. The flexural toughness is found by calculating the area under the force-deflection curve as much as the value at which the beam mid-point displaces 1.8 mm in the flexural test. Both of the fibers increased the flexural toughness: The fact was more pronounced at higher fiber contents. Flexural toughness of BPP5 (1.5%) was 6.3 times higher than the flexural toughness of M0 reference concrete. The flexural toughness of BPE5 (1.5%) was 2.77 times higher than that of the M0 reference concrete. The flexural toughness of waste polypropylene fiber reinforced concretes was higher than that of waste polyethylene fiber concretes.

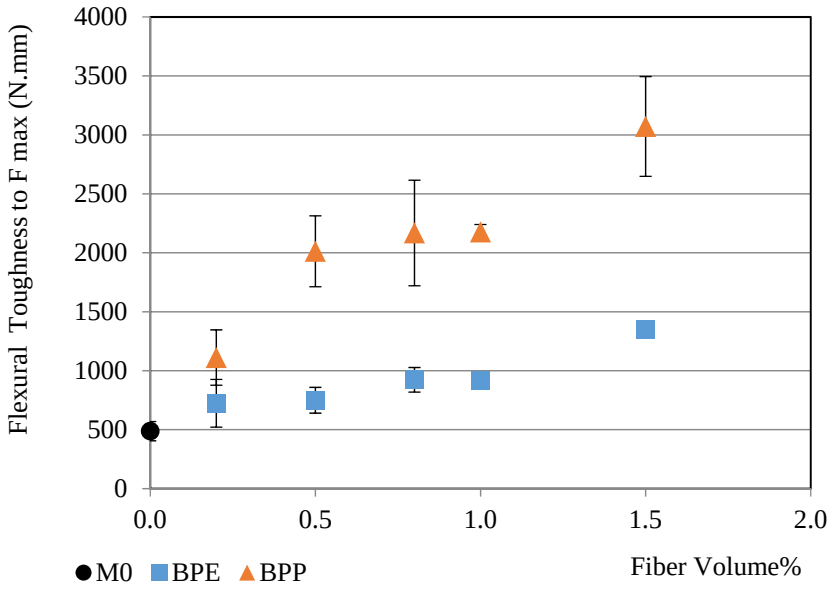


Figure 3.4 Relation of flexural toughness to fiber volume ratio

The load-displacement graphs of waste polypropylene and polyethylene fiber concrete are given in Figure 3.5. After the first crack was formed in the bending test, the plastic fibers in the concrete carried the load with the bridging effect and prevented crack propagation. This resulted in further energy absorption by fiber reinforced mixtures after first cracking. In addition, as the fiber ratio increased, it was observed that the plastic fiber reinforced concrete absorbed more energy. This was evident when BPP5 (1.5%) was compared with other samples. Polypropylene fibers carried more

load than polyethylene fibers. It could be explained by similar behavior in flexural toughness. Waste plastic fibers increased the flexural toughness of the concrete.

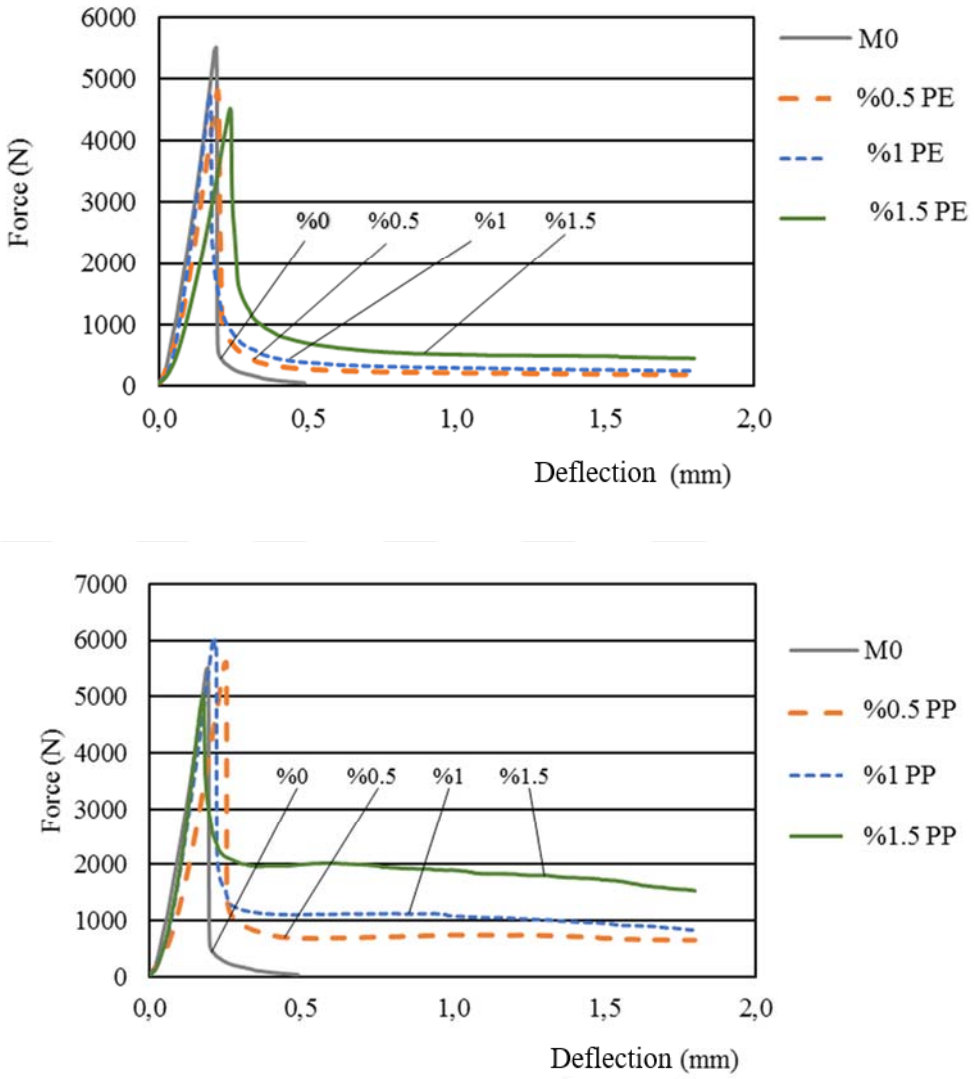


Figure 3.5 Bending Force- deflection diagrams of (a) PE concrete (b) PP concrete

3.2.2 Flexural Test Results of Industrial Concrete

As the fiber ratio increased, a decrease in the bending strength value was observed in Figure 3.6. Polyethylene fiber reinforced concrete at higher fiber ratios had lower bending strength than polypropylene fiber reinforced concretes. In the first design concrete series, there was no significant change in the flexural strength of concrete upon waste polypropylene fiber inclusion. However, polypropylene fiber addition reduced the flexural strength in industrial concrete. The decrease in industrial concrete

was due to the changes made to obtain the desired slump value of concrete. In concrete, increasing water, cement and fine aggregate contents reduced the course aggregate content consequently. Thus, the flexural strength of the mixtures decreased.

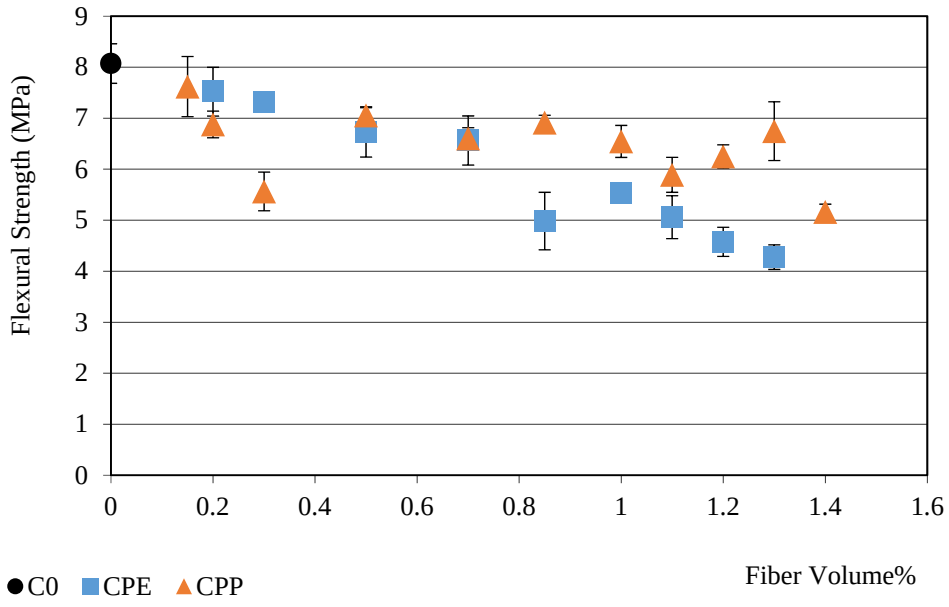


Figure 3.6 Relation of flexural strength of industrial concrete to fiber volume ratio

The flexural toughness values of industrial concrete are given in the Figure 3.7. In this experimental study, the flexural toughness values of the concrete mixtures were obtained from the force-deflection graphs. As the fiber ratio increased, there was a clear increase in the flexural toughness of the concrete. The flexural toughness of CPP13 (1.4%) concrete increased about 3.5 times and that of CPE7 (1.1%) increased about 2 times with respect to the flexural toughness of reference concrete. Polypropylene fiber concretes had more toughness than polyethylene fiber concretes.

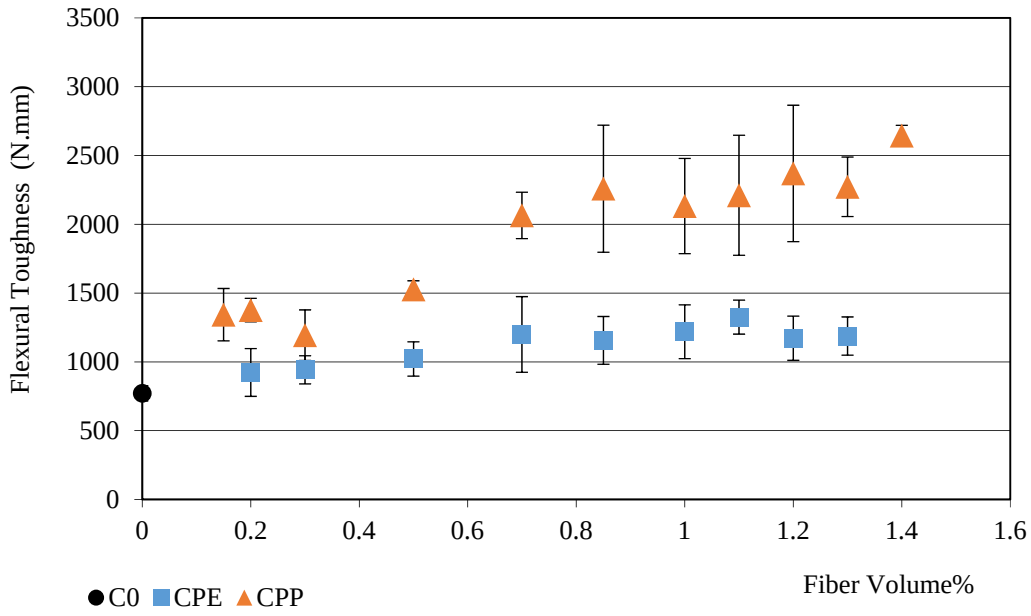


Figure 3.7 Relation of flexural toughness to fiber volume ratio

The load-deflection graph of waste polypropylene and polyethylene fiber industrial concrete was given in Figure 3.8.a and Figure 3.8.b. After the first crack was formed in the flexural test, the waste fibers in the concrete continued to carry the load by bridging cracks. As the fiber ratio of the concrete increased, flexural toughness increased. According to the test results, polypropylene fiber reinforced concretes had more flexural toughness than polyethylene fiber reinforced concretes.

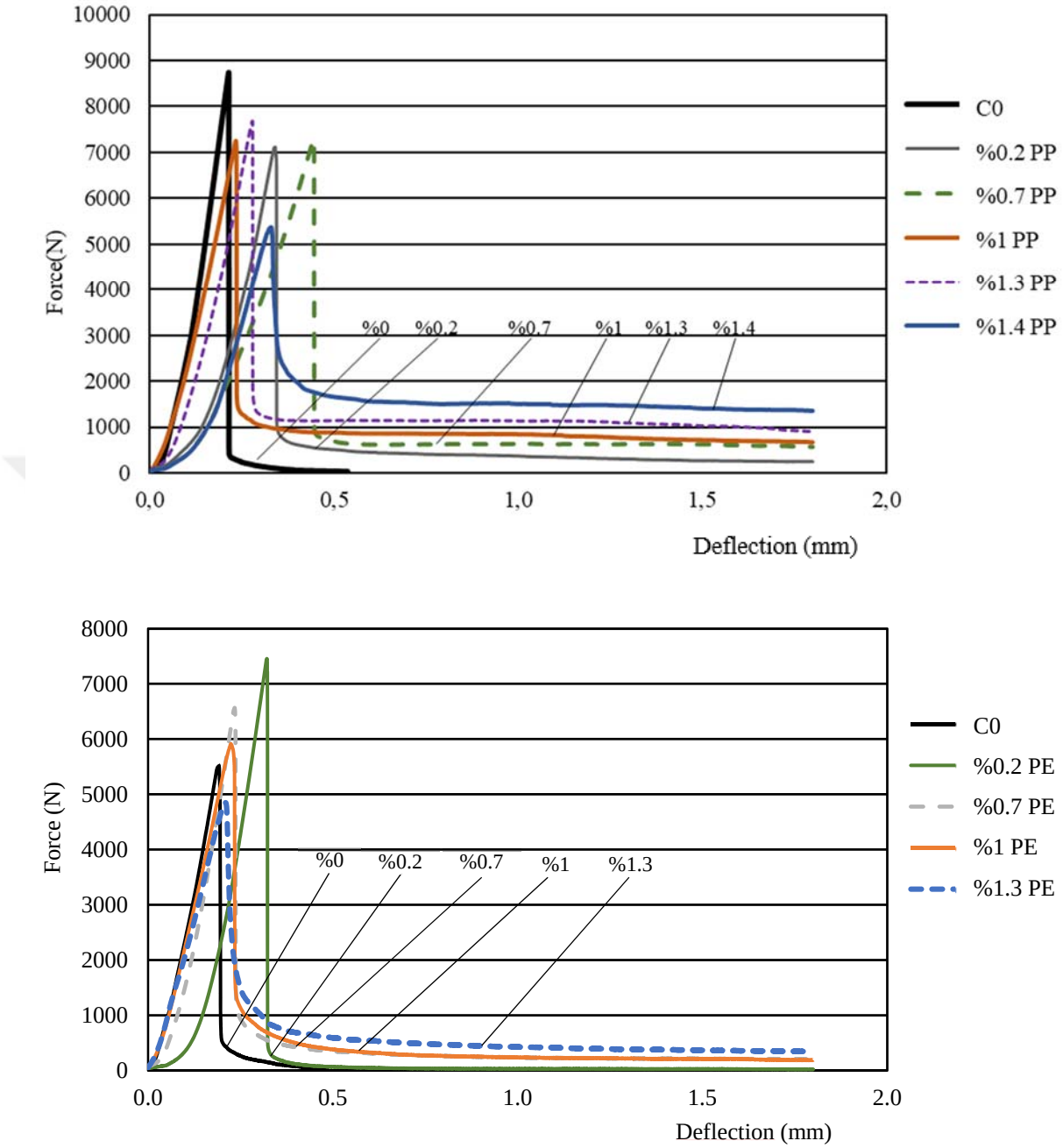


Figure 3.8 Force-deflection diagrams of (a) PP industrial concrete (b) PE industrial concrete

3.3 Compression Test Results

3.3.1 Compression Test Result of First Concrete Series

The results of the compressive strength tests of the plastic waste fiber reinforced concretes are shown in Figure 3.9. The compressive strength of the samples containing

waste fibers decreased as the fiber ratio increased. Fibers acted as voids and reduced the strength. Waste polyethylene fibers caused more strength loss than waste polypropylene fibers.

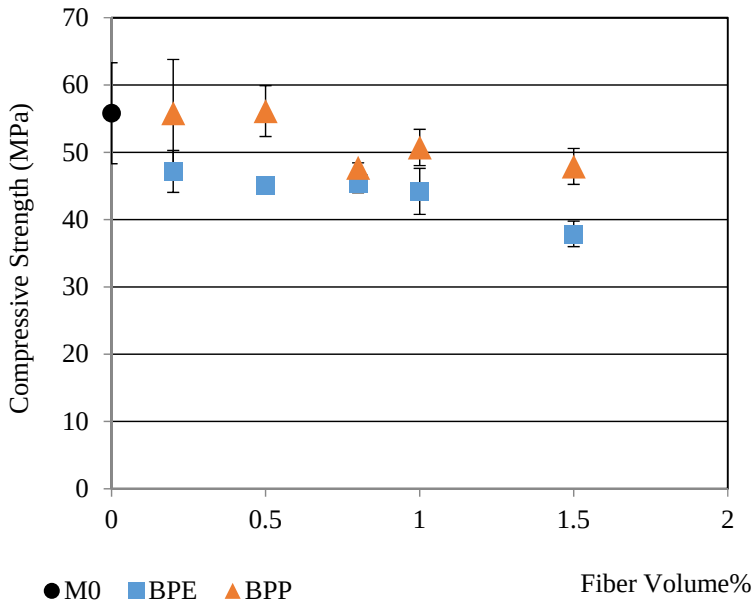


Figure 3.9 Relation of compressive strength to fiber volume ratio

The compressive toughness was found by calculating the area under the load-deflection curve up to the maximum force. The results of the compressive toughness are given in Figure 3.10. As the compressive toughness was measured at maximum load, it had similar behavior with the compressive strength. The compressive toughness of waste plastic fiber concretes decreased as the fiber ratio increased.

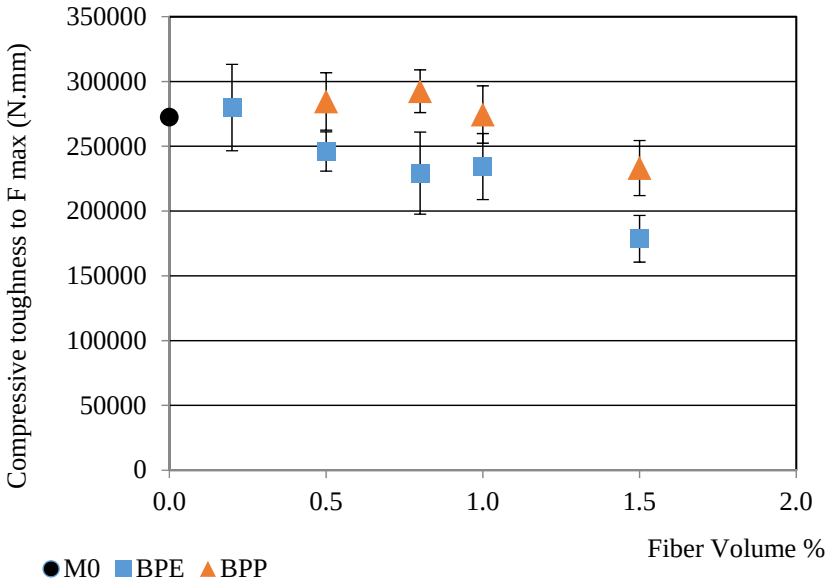


Figure 3.10 Relation of compressive toughness to fiber volume ratio

3.3.2 Compression Test Results of Industrial Concrete

The values of 7th day and 28th day compressive strength of 10cm cube waste fiber concrete specimens are given in Figure 3.11 and Figure 3.12. At low waste fiber ratios, the compressive strength did not show a significant change with respect to that of the reference mixture. As the fiber ratio increased, decreases in compressive strength were observed. The reason for this decrease was that the fibers acted as voids in the concrete and weakened the concrete. The decrease in the polyethylene fiber concretes was higher than that of the concrete containing polypropylene fibers.

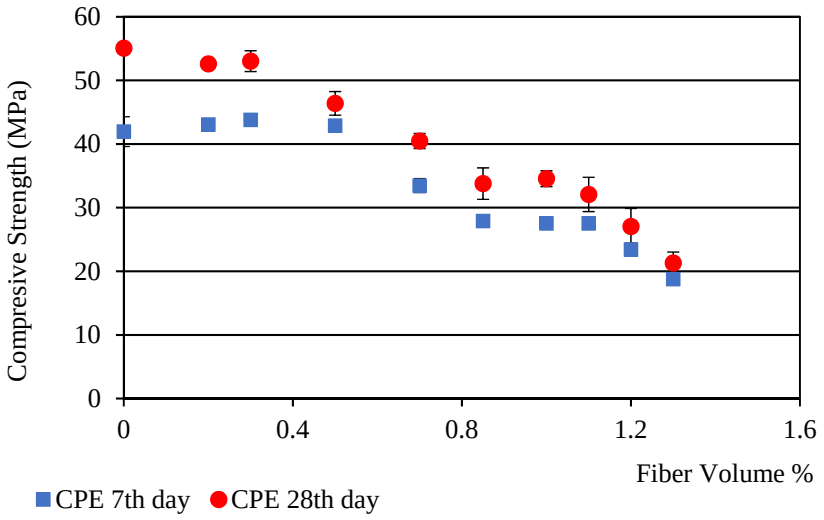


Figure 3.11 Relation of compressive strength to polyethylene fiber volume ratio

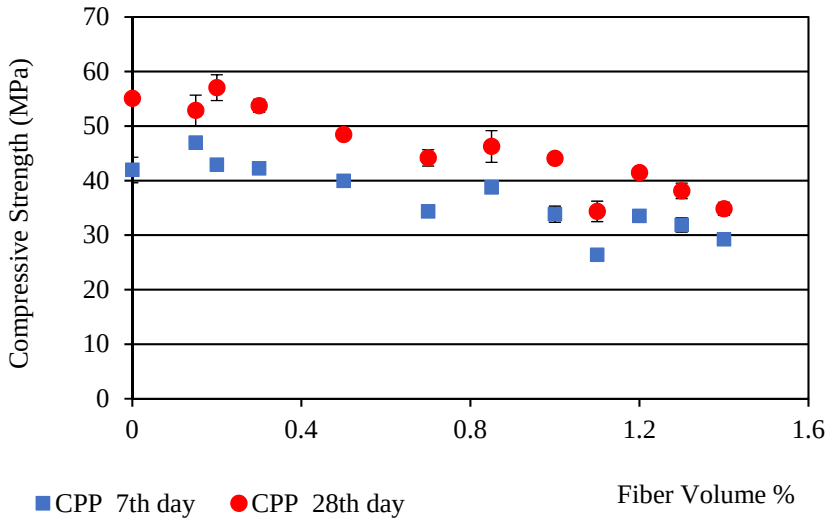


Figure 3.12 Relation of compressive strength to polypropylene fiber volume ratio

The 28th day compressive strength test results of 7.5 modified cubes conducted on broken portions of flexural test specimen are given in Figure 3.13. For polypropylene fiber concretes, there was a slight increase in compressive strength at low fiber ratios. At low fiber ratios, polyethylene fiber concrete had similar results to that of the reference concrete. As the fiber ratio increased, the compressive strength reduced gradually. The loss of strength of waste polythene concrete was higher than waste polypropylene concrete.

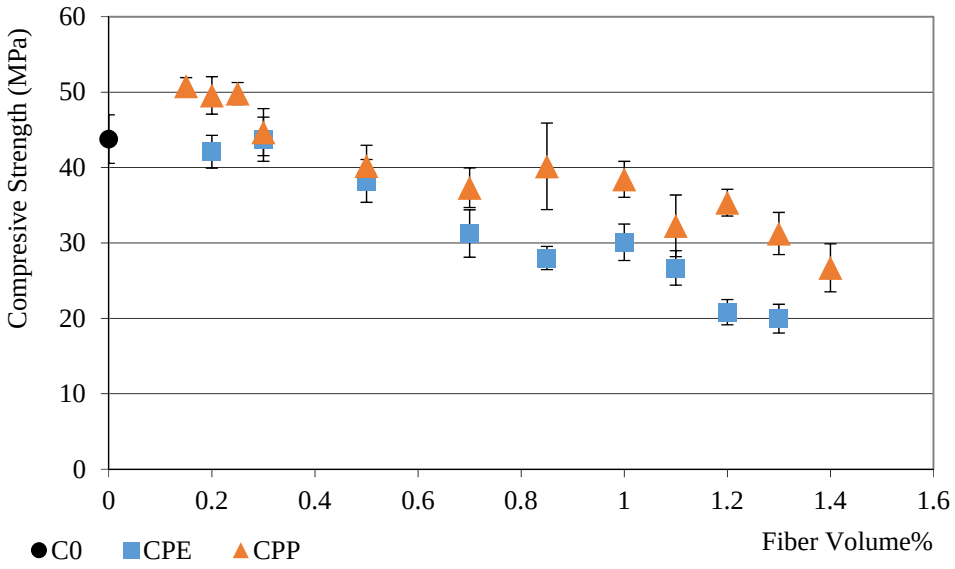


Figure 3.13 Relation of compressive strength to fiber volume ratio

The compressive toughness was found by calculating the area under the force-displacement curve up to the maximum force. The results are given in Figure 3.14. As the compressive toughness was calculated from the area up to the maximum force, it had similar behavior with the compressive strength. The compressive toughness of waste plastic fiber concretes decreased as the waste fiber ratio increased.

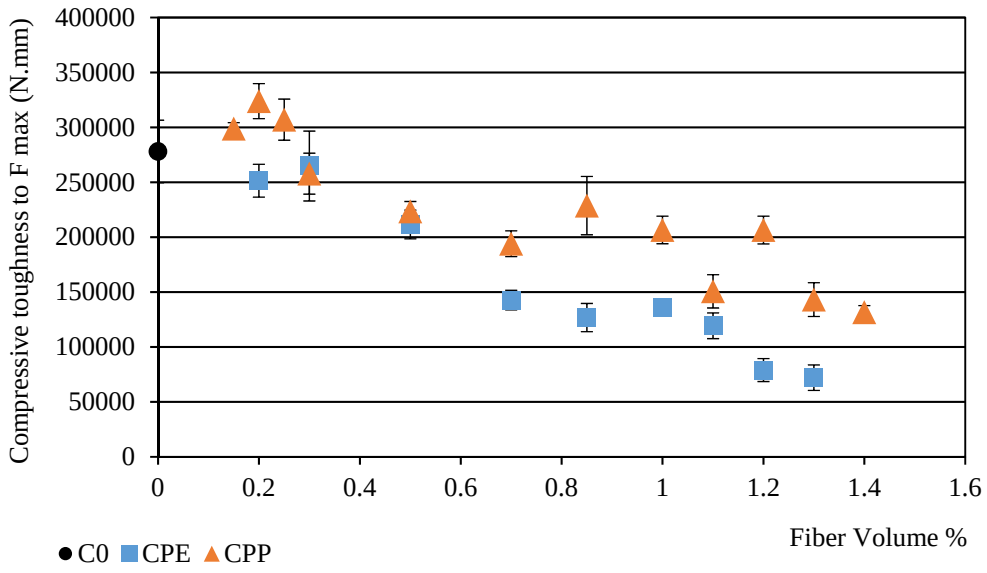


Figure 3.14 Relation of compressive toughness to fiber volume ratio

CHAPTER FIVE
CONCLUSIONS

In order to investigate the effect of waste plastic on the concrete, 40 mixtures were designed. Each mixture was tested with compression test and flexural test. Concrete slump value, compressive strength and toughness, flexural strength and toughness were determined.

The results obtained are as follows:

- Compressive strength reduced by adding waste plastic fiber into concrete. The effect was more pronounced at higher fiber contents.

- The compressive toughness was calculated as the area under force-deflection diagram up to maximum load. Thus the compressive toughness of the mixtures showed similar bend to the compressive strength.

- The flexural strength of waste plastic fiber concretes did not change with reference for first concrete series. On the other hand, decreases in flexural strength values were observed for industrial concrete mixtures. The reason for the decrease in industrial concrete was due to the changes made to obtain the desired slump value of concrete. In concrete, increasing water, decreasing coarse aggregate and increasing fine aggregate caused decrease in strength.
- As the waste plastic fiber ratio increased, flexural toughness increased gradually.

- In first series of concrete mixtures, 1.5% polypropylene and 1.5 polyethylene bearing mixtures showed 6.3 times and 2.77 times greater flexural toughness than reference concrete, respectively. In industrial concrete, the flexural toughness of CPP13 (1.4%) concrete was about 3.5 times greater than that of the reference mixtures. The corresponding value for CPE7 (1.1%) was about 2.

- As the waste plastic fiber ratio increased, the slump value of the concrete decreased. For slump between 20-25cm the maximum value of waste plastic volume percent was 1.4% for polypropylene and 1.3% for polyethylene.

- Even though the compressive strength of waste plastic fiber concrete decreased, the decrease in strength can be compensated by making the mix design again considering this decrease. The use of waste plastics in concrete allows us to obtain ductile. The use of waste plastic fiber reinforced concrete in consideration of the S0 and S45 desired slump values indicated that these waste fibers could be used in construction sector for a successful pumping, placing, compaction and workable. In addition, the use of waste plastics in the building sector contributes to the prevention of environmental pollution.

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APPENDICES

APPENDIX - 1: The mixture proportions

The mixture proportions of the first concrete series are given in Table 1.

Table 1 Mix proportions of first concrete series (kg/m^3)

Mixture	Cement	Water	SSD Aggregate					Fiber	Silika Fume	Unit Weight (Teorical)
			Super Plasticizer	0-3 mm	0-5 mm	5-15 mm	15-25 mm			
M0	342,0	224,5	3,8	-	986,4	665,1	-	0	38,0	2260
BPP1	342,0	224,5	3,8	-	983,3	663,0	-	1,8	38,0	2256
BPP2	342,0	224,4	3,8	-	978,6	659,9	-	4,5	38,0	2251
BPP3	342,0	224,3	3,8	-	974,0	656,8	-	7,2	38,0	2246
BPP4	342,0	224,2	3,8	-	970,9	654,7	-	9	38,0	2243
BPP5	342,0	224,1	3,8	-	963,1	649,5	-	13,6	38,0	2234
BPE1	342,0	224,5	3,8	-	983,3	663,0	-	1,8	38,0	2256
BPE2	342,0	224,4	3,8	-	978,6	659,9	-	4,6	38,0	2251
BPE3	342,0	224,3	3,8	-	974,0	656,8	-	7,3	38,0	2246
BPE4	342,0	224,2	3,8	-	970,9	654,7	-	9	38,0	2243
BPE5	342,0	224,1	3,8	-	963,1	649,5	-	13,8	38,0	2234

The mixture proportions of the industrial concrete series are given in Table 2.

Table 2 Mix proportions of industrial concrete series (kg/m^3)

Mixture	Cement	Water	SSD Aggregate					Fiber	Silika Fume	Unit Weight (Teorical)
			Super Plasticizer	0-3 mm	0-5 mm	5-15 mm	15-25 mm			
C0	305,5	169,6	3,1	305,5	573,9	381,5	381,5	0,0	-	2120,5
CPP1	317,7	176,4	3,8	317,7	562,7	374,1	374,1	2,3	-	2126,5
CPP2	334,1	185,1	3,7	334,1	590,0	330,9	330,9	0,9	-	2108,9
CPP3	334,1	185,0	3,3	334,1	607,5	312,1	312,1	1,8	-	2088,3
CPP5	334,1	185,0	3,3	334,1	606,6	311,6	311,6	2,7	-	2086,5
CPP6	334,1	185,0	3,3	334,1	604,9	310,7	310,7	4,5	-	2082,9
CPP7	334,1	185,0	3,7	334,1	603,1	309,8	309,8	6,3	-	2079,6
CPP8	334,1	185,0	5,0	334,1	601,7	309,1	309,1	7,7	-	2078,2
CPP8v2	347,7	192,4	5,1	347,7	608,8	285,7	285,7	7,7	-	2073,1
CPP8v3	368,2	203,6	3,7	368,2	592,0	277,8	277,8	7,7	-	2091,3
CPP9	368,2	203,6	4,1	368,2	590,6	277,2	277,2	9,0	-	2089,0
CPP10	368,2	203,6	4,8	368,2	589,7	276,7	276,7	9,9	-	2087,9
CPP11	381,8	211,0	3,8	381,8	594,6	254,1	254,1	10,8	-	2081,2
CPP12	381,8	211,0	3,8	381,8	593,6	253,7	253,7	11,8	-	2079,5
CPP13	381,8	211,0	3,8	381,8	592,7	253,3	253,3	12,7	-	2077,7
CPP14	381,8	211,0	5,0	381,8	591,7	252,9	252,9	13,6	-	2077,1
CPP14v2	409,1	226,0	4,9	409,1	568,7	243,0	243,0	13,6	-	2103,8
CPE1	334,1	185,0	3,3	334,1	607,5	312,1	312,1	1,8	-	2088,3
CPE2	334,1	185,0	3,3	334,1	606,6	311,6	311,6	2,8	-	2086,5
CPE3	334,1	185,0	3,3	334,1	604,9	310,7	310,7	4,6	-	2082,9
CPE4	334,1	185,0	3,7	334,1	603,1	309,8	309,8	6,4	-	2079,6
CPE5	334,1	185,0	4,3	334,1	601,7	309,1	309,1	7,8	-	2077,5
CPE5v2	368,2	203,6	3,7	368,2	592,0	277,8	277,8	7,8	-	2091,3
CPE6	368,2	203,6	4,1	368,2	590,6	277,2	277,2	9,2	-	2089,0
CPE7	368,2	203,6	4,4	368,2	589,7	276,7	276,7	10,1	-	2087,6
CPE7v2	381,8	211,0	4,2	381,8	595,5	254,5	254,5	10,1	-	2083,4
CPE8	381,8	232,2	3,8	381,8	583,3	254,1	254,1	11,0	-	2091,2
CPE9	381,8	232,2	4,2	381,8	582,4	253,7	253,7	11,9	-	2089,8
CPE10	381,8	232,2	3,8	381,8	581,4	253,3	253,3	12,8	-	2087,6

APPENDIX - 2: Test Result of First Concrete Series

The numerical values of test result of first concrete series in this experimental study are given in the Table 3.

Table 3 Test Result of First Concrete Series

Mixture	Fiber ratio (%)	Flexural Strength Mpa	Flexural Toughness (N.mm)	Compressive Strength 7.5cm Modified Cube (Mpa)	Compressive Toughness 7.5cm Modified Cube (N.mm)
M0	0	5,2	487,6	55,8	272470,0
BPP1	0.2	5,0	1111,6	56,1	-
BPP2	0.5	5,0	2012,5	47,7	284608,6
BPP3	0.8	5,1	2168,4	50,7	292480,0
BPP4	1	5,3	2177,1	47,9	274497,0
BPP5	1.5	5,1	3071,8	43,2	233193,5
BPE1	0.2	5,8	723,6	47,2	279906,5
BPE2	0.5	4,7	749,5	45,1	245964,3
BPE3	0.8	4,6	922,9	45,3	229263,1
BPE4	1	4,4	918,0	44,2	234349,0
BPE5	1.5	4,5	1351,2	37,9	178614,9

APPENDIX - 3: Test Result of of Industrial Concrete

The numerical values of test result of industrial concrete in this experimental study are given in the Table 4.

Table 4 Test Result of Industrial Concrete

Mixture	Fiber ratio (%)	Flexural Strength Mpa	Flexural Toughness (N.mm)	Compressive Strength 7.5cm Modified Cube (Mpa)	Compressive Toughness 7.5cm Modified Cube (N.mm)	Compressive Strength of 10cm Cube (Mpa)
C0	0	8,1	771,2	43,8	277969,4	55,1
CPP1	0.25	8,0	1328,8	49,8	307026,0	58,3
CPP2	0.1	7,6	1342,8	50,8	298803,9	52,9
CPP3	0.2	6,9	1376,5	49,6	323890,6	57,0
CPP5	0.3	5,6	1194,0	44,7	257853,9	53,7
CPP6	0.5	7,1	1526,3	40,2	223448,4	48,4
CPP7	0.7	6,6	2064,7	37,3	194013,0	44,2
CPP8v3	0.85	6,9	2259,0	40,2	228728,1	46,3
CPP9	1	6,5	2132,3	38,4	206590,4	44,1
CPP10	1.1	5,9	2211,0	32,3	150716,0	34,4
CPP11	1.2	6,2	2369,5	35,3	206516,8	41,5
CPP12	1.3	6,7	2272,5	31,3	143155,8	38,1
CPP13	1.4	5,2	2644,8	26,7	131594,6	34,8
CPE1	0.2	7,5	923,0	42,1	251432,8	52,6
CPE2	0.3	7,3	941,7	43,8	264775,4	53,0
CPE3	0.5	6,7	1021,1	38,2	211568,4	46,4
CPE4	0.7	6,6	1199,3	31,3	142654,3	40,5
CPE5v2	0.85	5,0	1156,1	28,0	126820,9	33,8
CPE6	1	5,5	1218,7	30,1	135518,9	34,6
CPE7v2	1.1	5,1	1325,5	26,7	119291,8	32,1
CPE8	1.2	4,6	1172,0	20,8	78995,2	27,0
CPE9	1.3	4,3	1187,7	20,0	72066,4	21,3