Plastic and Slag as a Potential Aggregate Replacement in Concrete with Glass Fibers and Silica Fume Admixtures

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ABSTRACT

The objective of this research study was to investigate sustainable aggregate replacements in concrete. Waste plastic and steel slag were added as a coarse-aggregate replacement by 0%, 15%, 30%, and 45%. This has the potential to reduce material cost while having a beneficial impact on the environment. Silica fume and glass fibers were also added to offset the changes in mechanical properties of concrete. The study involves 130 concrete specimens with various combinations of these materials, which were prepared, cured, and tested. The mechanical properties, including compressive strength, tensile strength, and modulus of elasticity of concrete were investigated and compared to those of ordinary concrete. The results indicated that plastic replacement with an aggregate resulted in decreased concrete strength, while remaining useful up to 15% replacement. The slag aggregate improved the mechanical properties of concrete and can potentially replace up to 45% of natural coarse aggregate. A combination of plastic and slag aggregate along with silica fume and glass fibers can be used to allow replacement of coarse aggregate in concrete by 15% with only a slight decrease in concrete strength.

DEDICATION

I dedicate my thesis work to my family. Special gratitude to my loving Father, who encouraged me and stood beside me in every difficult time I ever faced.

ACKNOWLEDGMENT

I would like to express my gratitude to my thesis advisor Dr. Richard Deschenes whose help, patience, motivation, immense knowledge, supervision, and advice was invaluable. He directed me in the right direction whenever I needed it. His guidance was very valuable in completing this research and writing my thesis.

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Author

Sameer Alam

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CHAPTER 1. INTRODUCTION

1.1. Introduction and Background

Concrete is one of the most versatile construction materials. Like water, concrete can be formed to almost any shape. Some advantages of concrete include: excellent fire and water resistance, high compressive strength, low maintenance, and a long service life. The disadvantages of include poor tensile strength and the requirement of formwork. Concrete tensile strength typically ranges from approximately 8% to 15% of compressive strength[1]. As concrete is one of the most common materials used in the construction industry, there is a continued search for concrete with greater durability and strength. To produce concrete with the desired characteristics for construction, much research and modification has been done in the past. In this matter, silica fume, glass fibers, and other admixtures have been introduced to increase strength and durability. In addition to Portland cement, pozzolans are used as a concrete constituent to improve durability, reduce cost, and introduce recycled or waste materials.

Concrete is the most widely used construction material in the world and over 10 billion tons of concrete are produced every year[2]. The global concrete market is about $395 billion USD [3]. Concrete is used in buildings, bridges, dams and road construction. Cement is an important component of concrete. In the United States around 85.9 million metric tons of cement were produced in 2016 and 4.2 billion metric tons worldwide[4]. Other materials used in concrete include sand and coarse aggregate. According to the United States Geological Survey (USGS), the 2016 domestic (US) production of sand and gravel was 1.01 billion tons[5]. The ratio of aggregate to cement in concrete is typically 3 to 6 times, while aggregate typically acts as an inert filler material.

Researchers have investigated the use of plastic, slag, fiber reinforcement, and silica fume in concrete individually, but limited research has been conducted to investigate the combined effect of the aforementioned materials. Previous research indicates a decrease in tensile and compressive strength when plastic and slag replace aggregate in concrete. Silica fume and fiber reinforcement are added to concrete in order to offset the resulting decrease in compression strength due to the use of waste materials as aggregates. The satisfactory results of this work could alter the concrete industry. Incorporating several non-degradable materials in construction would be cost efficient, lightweight, and beneficial to the environmental. Incorporating these materials into concrete on a commercial scale could revolutionize the industry.

1.2. Problem Statement

The results of previous research indicate that the complete replacement of natural aggregate with waste materials is impractical. Decreases in both tensile and compressive strength have been previously observed when plastic and slag are used at high replacement rates. However, there is a lack of research into the combined usage of plastic and slag with silica fume and glass fibers in concrete. In addition, plastic and slag have negative impacts on the environment. However, these materials are readily available in some regions, inexpensive, and lightweight. In this research, silica fume and glass fibers were added to concrete with natural aggregate partially replaced by slag and plastic aggregates. This was done to increase the concrete tensile and compressive strength. This combination may have improved mechanical properties when compared to mixtures containing only plastic or slag aggregates.

1.3. ASTM Standard Tests to be Performed

The mechanical test methods performed for each concrete mixture included:

1. Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens (ASTM C496)[6].
2. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (ASTM C39)[7].
3. Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression (ASTM C469)[8].

The fresh properties of concrete were tested according to following standards:

1. Standard Test Method for Slump of Hydraulic-Cement Concrete (ASTM C143)[9].
2. Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory (ASTM C192)[10].

1.4. Objectives of Thesis

To assess the strength and toughness of concrete mixtures containing partial coarse-aggregate replacement with plastic or slag aggregates in addition to partial replacement of cement with silica fume and glass fibers. The mechanical properties of the modified concrete were compared to those of ordinary concrete, while keeping local conditions in consideration.

1.5. Thesis Limitation

This thesis focuses on the use of waste materials as an aggregate. Additional investigation into the mechanical properties and durability of concrete containing plastic and slag aggregate is required before it is used in critical structures like bridges, dams, building columns, and beams, etc. However, there are many others possible civil engineering applications of this concrete, such as sidewalk, structure rehabilitation, channel linings and airport aprons.

1.6. Scope of the Study

The target of this thesis is to contribute to the knowledge of the mechanical properties (strength) of concrete where natural crushed aggregates and cement are replaced with plastic, slag, silica fume, and/or glass fibers. The proposed concrete mixtures were compared to normal concrete, helping to increase the use of the alternative materials as concrete aggregates.

1.7. Thesis Organization

The organization of the thesis has been worked out as follows;

1. Chapter 1: Introduction
2. Chapter 2: Literature review and basic definitions
3. Chapter 3: Methodology used in the investigations
4. Chapter 4: Results and discussions
5. Chapter 5: Summary of the investigation and findings

CHAPTER 2. LITERATURE REVIEW

2.1. Basic Definitions

Some of the basic terminologies are as follows;

Split Tensile Strength: The ultimate resistance to forces which tend to elongate the material until rupture, measured as the maximum tension the material can withstand without rupture.

Compressive Strength: The ultimate structural or material capacity of bearing loads which tend to reduce the size of the material or structure (compress) is the compressive strength.

Modulus of Elasticity: Within the elastic limit, the ratio of applied static stress to the resulting strain, is known as the static modulus of elasticity.

Flexural Strength: The ability of material to resist increase in curvature (bending) under an applied load is called Flexural strength, also known as modulus of rupture, bending strength, or fracture strength.

2.2. Plastic Aggregates

Plastic is a non-degradable material in many environments and can last for thousands of years having a negative impact on the environment [11]. Nearly 1 million plastic bags per minute are used worldwide which equates to 500 billion bags per year [11]. Manpower and resources are required to recycle plastic waste, with a comparatively little amount of plastic being successfully recycled. Plastic loses its strength when it is recycled, so most of the plastic ultimately accumulates in a landfill. It is a problem to reuse waste materials, such as plastic, steel slag, and rubber. Therefore, incorporating plastic waste in concrete is a top priority for the construction industry. Plastic can be used as fine or coarse aggregate in concrete.

Aggregate crushing can lead to failure in concrete structures. Due to the low specific gravity of plastic, concrete containing plastic as coarse aggregate is lighter than normal concrete. This reduces the dead loads applied to structures. Different experiments have shown that the complete replacement of coarse aggregate is infeasible, however, a certain percentage of coarse aggregate can potentially be replaced by waste materials[12].

2.2.1. Selected Results

Past research has been conducted using different types of plastic and adopting different techniques. **MB Hossain, P Bhowmik, KM Shaad**[13] (2016) investigated waste Polyethylene Terephthalate (PET) plastic in concrete. The shredded plastic replaced the course aggregate by volume at 5%, 10%, and 20%. Four mixtures were evaluated, which includes a control mixture with 0% plastic for comparison and three mixtures with increasing plastic content. The specimens were tested for compressive, tensile, and modulus of elasticity (MOE) at 7, 14, and 28 days. A decrease in density of concrete, compression strength, tensile strength and modulus of elasticity was indicated with the increase in plastic quantity in concrete. The unit weight of concrete, however, could be reduced by PET aggregate, which led to reduced structural concrete dead loads.

Ashwini Manjunath[12] investigated the use of E-plastic waste. E-plastic waste is obtained from polyethylene plastic used in electronics. E-plastic replaced conventional mixture course aggregate by 0%, 10%, 20%, and 30%. The results indicate that the increase in quantity of plastic reduces compressive strength of concrete but increases the tensile strength of concrete up to a certain limit. The results are summarized below in **Figure 2.1** and **Figure 2.2** and **Tables 2.1** and **Tables 2.2**.

Table 2.1 – Compressive strength test result. (Data by Ashwini[12]).

Mix Specification	Conventional Mix S1	S2	S3	S4
Production of E-Plastic Waste	**0%**	**10%**	**20%**	**30%**
7 Days	36	33.18	19.9	16.39
14 Days	44.81	41.25	17.95	19.03
28 Days	47.18	44.07	24.69	22.15

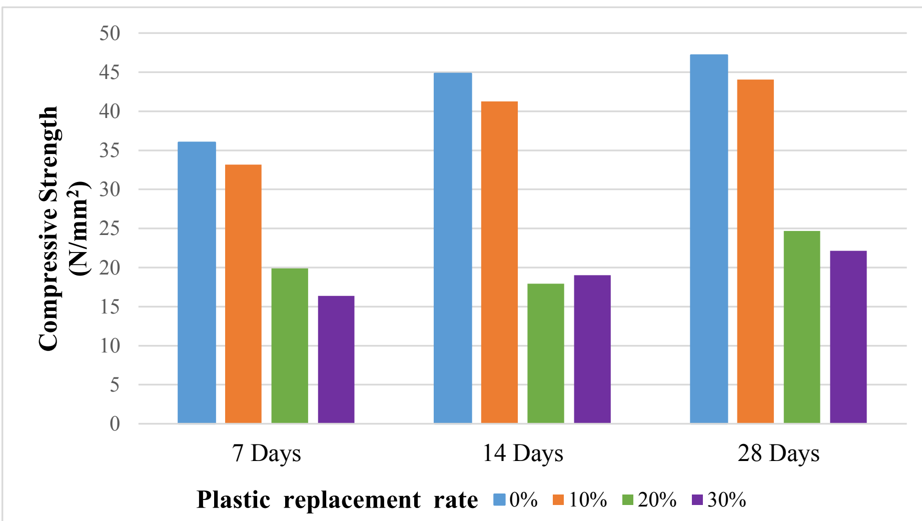

Figure 2.1 – Variation of compressive strength. (Data by Ashwini[12]).

Based on the experimental results provided, it appears that with the increase of plastic in concrete, there is a decrease in compressive strength at replacement rates over 10%.

Table 2.2 – Tensile strength test results. (Data by Ashwini[12]).

Mix Specification	Conventional Mix S1	S2	S3	S4
Replacement rate E-Plastic Waste	0%	10%	20%	30%
7 Days	4.3	4.3	3.15	2.4
14 Days	4.66	4.4	5	3.1
28 Days	4.9	4.8	5.4	3.8

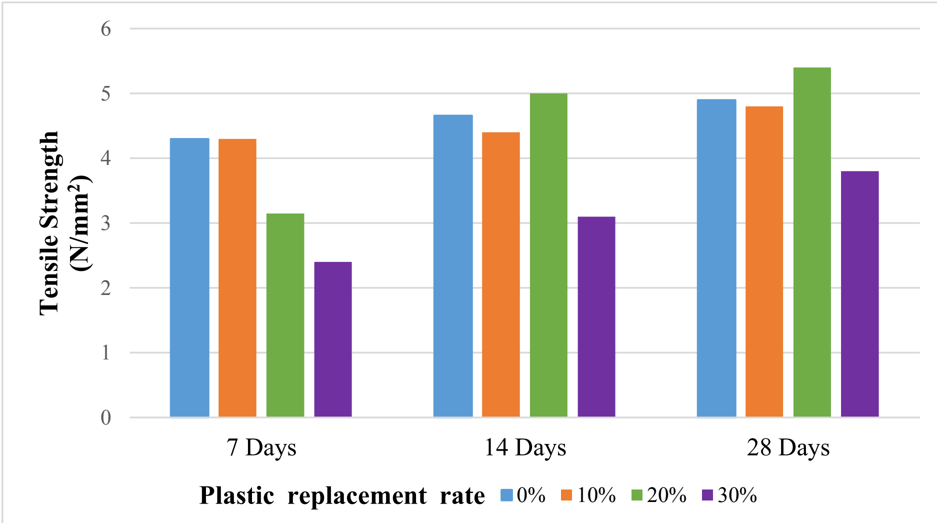

Figure 2.2 – Variation of tensile strength (Data by Ashwini[12]).

Based on these results, for up to 20% replacement of aggregate with plastic, an increase is shown in tensile strength of concrete. However, further replacement of aggregate with plastic causes a decrease in tensile strength.

Raghatate Atul M.[11] utilized polyethylene bags and found that increasing plastic quantity reduces concrete compressive strength while increasing tensile strength up to a certain limit. The results summarized in **Table 2.3** and **Figure 2.3** indicate that increasing the percentage replacement by volume of aggregate with recycled polyethylene plastic in concrete reduces the concrete compressive strength.

Table 2.3 – Compressive strength test (Data from Atul[11]).

Table: Compressive strength test results (N/mm^2)						
Plastic %	**0**	**0.2**	**0.4**	**0.6**	**0.8**	**1**
7 days	16.25	14.28	12.9	11.26	11.25	9.2
14 days	20.3	18.34	17.58	15.23	13.26	12.65
28 days	25.92	23.2	22.1	20.26	19.85	20.2

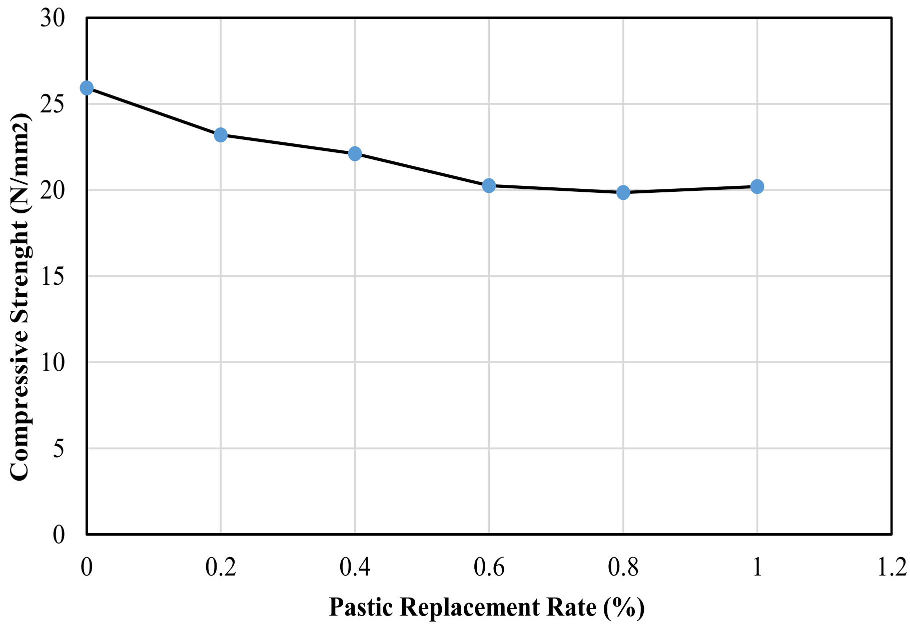

Figure 2.3 – Variation of compression strength (Data from Atul[11]).

The results summarized in **Figure 2.4** and **Table 2.4** indicate that with increasing plastic percentage in concrete the tensile strength of concrete increases until 0.8%, thereafter additional plastic causes decreased tensile strength.

Table 2.4 – Tensile strength of concrete. (Data from Atul[11]).

Tensile strength test results (N/mm^2)						
Plastic %	**0**	**0.2**	**0.4**	**0.6**	**0.8**	**3.85**
7 days	1.54	1.85	2.35	2.83	3.12	9.2
14 days	1.82	1.96	2.63	2.98	1.8	3.12
28 days	4.12	4.38	4.92	5.16	5.57	5.12

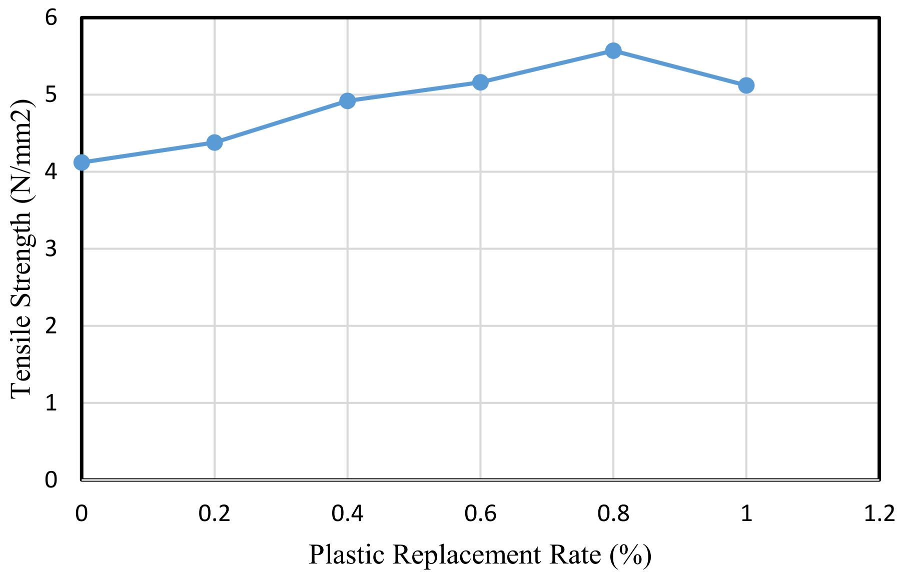

Figure 2.4 – Variation of Tensile Test. (Data from Atul[11]).

Manhal A Jibrael and Farah Peter[14] studied mechanical properties of concrete by adding different percentages of waste plastic (polyethylene). A total of 126 concrete specimen were cast, cured, and tested after 7 and 28 days for compressive and tensile strength. The outcome of experimentation indicated that the compressive strength and indirect tensile strength decreased with increased percentages of waste plastic used in concrete.

Al-Manaseer and Dalal[15] reported that when plastic percentage in concrete increases, there was a decrease in modulus of elasticity due to the lower modulus of elasticity of plastic aggregates. **Choi et al.**[16] also investigated the effect of polyethylene terephthalate (PET) plastic on the modulus of elasticity of concrete. The results indicated that with an increase in PET aggregates, the modulus of elasticity of concrete mixtures also decrease.

2.3. Slag Aggregates

When metal is separated from its raw ore, the by-product is called slag. Slag consist of silicon dioxide, metal oxides, and mixed oxides of elements such as sulfur, phosphorus, aluminum, silicon. When metal melts, slag floats to the surface and protects metal from oxidation by the atmosphere and keep it clean. The slag can be collected, cooled, and then used as course aggregate in concrete and in road construction and pavements.

Slag is another type of waste material that has been used as a replacement of coarse aggregate. Slag is divided into two categories based on the steel being produced: carbon-steel slag and stainless-steel slag. Depending on the manufacturing process, there are also different slag types such as basic oxygen furnace slag (BOFS), electrical arc furnace slag (EAFS) and ladle refining slag (LFS). Steel slag density is typically between 3.3 to 3.6 g/cm^3 [17]. Due to the high content of iron, steel slag is hard and wear resistant. Steel slag consists of SiO_2, CaO, Fe_2O_3, FeO, Al_2O_3, MgO, MnO and P_2O_5 which vary with different furnace, pretreatment methods, and steel grades

2.3.1. Selected Results:

Research on Energy Optimizing Furnace (EOF) slag was conducted by **Y.K. Sabapathy, et al** [18]. Concrete mixtures with different replacement rates of slag were prepared. Concrete aggregate was replaced by slag from 0% to 100%. The results indicate the compressive and tensile strength of concrete increases when coarse aggregate was replaced by 25% of slag. While replacement of coarse aggregate beyond 25% decreased concrete compressive and tensile strength. The experimental results are outlined in **Figure 2.5** and **Figure 2.6** below.

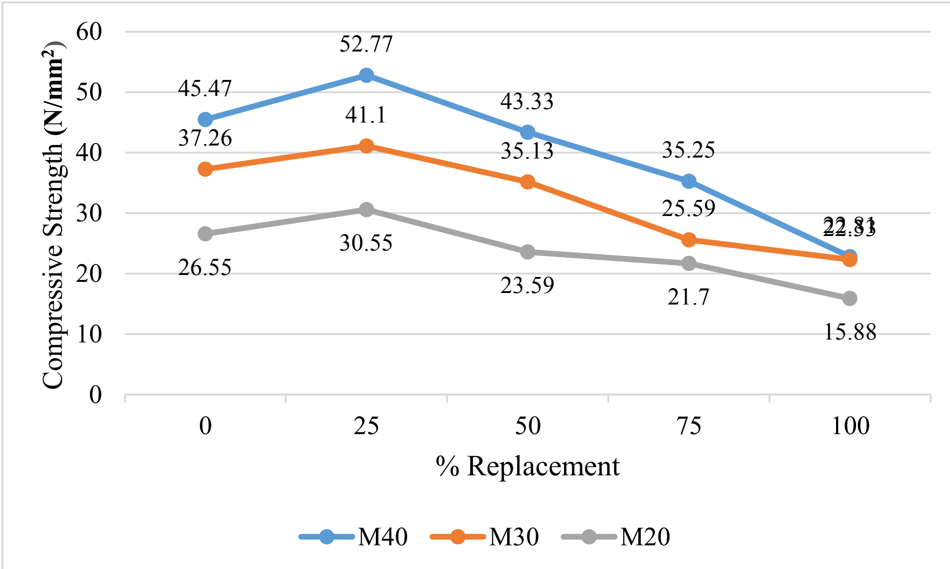

Figure 2.5 – Compressive test results. (Figure reprinted from data by Sabapathy [18]).

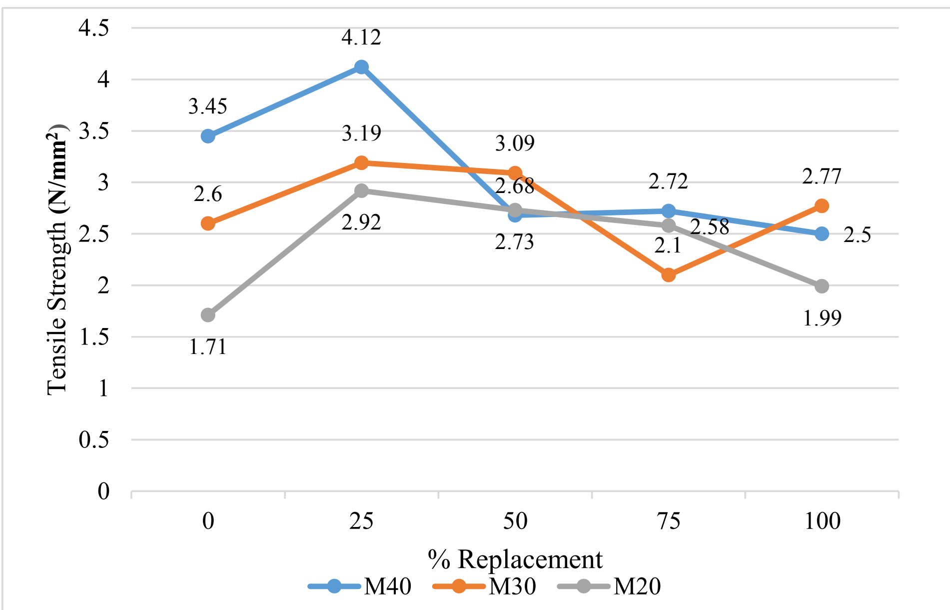

Figure 2.6 – Tensile test result. (Figure reprinted from data by Sabapathy [18]).

V. Subathra Devi and B. K. Gnanavel[19] investigated the effect of slag aggregate added to concrete at different percentages, on the compressive, tensile, and flexural strength of concrete. A total of 71 test samples were prepared with course aggregate replaced by slag materials at replacement rates between 0% and 50%. A constant water/cement ratio of 0.55 was used throughout the investigation. The samples were cured for 28 days and tested. The experimental results are given below. As observed from the results, there is a correlation between increasing slag in concrete and increase compressive strength, up to a replacement rate of 40%. However, slag had no significant effect on tensile strength of concrete for this particular experiment.

Table 2.5 – Compressive strength results. (Data by Devi [19]).

% Replacement	Compressive Strength (MPa)	
	Fine Aggregate replacement	Coarse aggregate replacement
0%	20.67	20.67
10%	19.56	22.8
20%	20.1	24.75
30%	20.78	28.33
40%	21.67	27.02
50%	19.32	25.06

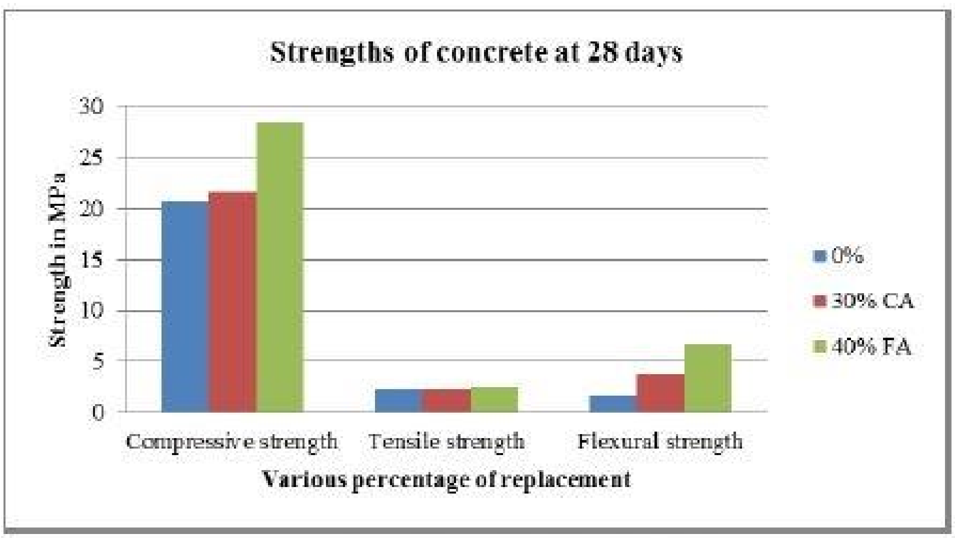

Figure 2.7 – Results from different strength test. (Figure reprinted from data by Devi [19]).

Ivanka Netinger et-al[20] investigated steel slag utilization in concrete mixture. Course aggregate was replaced by different slag proportions and 8 concrete mixtures were prepared. Concrete specimens were cast and then cured for 2, 28, and 56 days. The specimens were tested for compressive strength and modulus of elasticity and then compared with reference concrete mixture test results. The experimental result indicates that slag replacement with course aggregate increased the compressive strength while decreasing the modulus of elasticity of concrete.

2.4. Fiber Reinforced Concrete

Randomly oriented, distributed, unconnected metallic or organic fibers are used in fiber reinforced concrete. Using fibers in concrete is an intuitive concept to improve cracking resistance and fragmentation. For example, in sun backed bricks straws were used as reinforcement while horse hairs were used for reinforcing plaster. With time, different types of fibrous materials were introduced and are continuously introduced for new applications. These fibers are made of glass, metal and organic materials. Fiber reinforced concrete (FRC) typically consists of Portland cement, fine and course aggregates with discontinuous discrete fibers. Fibers can have various sizes, shapes, and aspect ratios.

In the 1960s, **Romualdi, Batson, and Mandel**[21] published the paper which brought fiber reinforced concrete to the world's attention. FRC is strong in flexural strength, splitting strength, and has excellent durability. FRC is used to improve plastic shrinkage, cracking resistance, shock resistance, toughness, and tensile strength of concrete. Various fiber cross sections are available, such as triangular, circular, or flat and are often described by a parameter called aspect ratio which is the ratio of length to diameter. There are various materials used to make fibers (**Figure 2.8)**; however, in this research the use of glass fibers was investigated. Glass fiber is a waste product of the glass industry. This research is about utilization of waste materials in construction. The purpose of utilization of GF in this research is that it is lightweight, corrosion free, and a waste product.

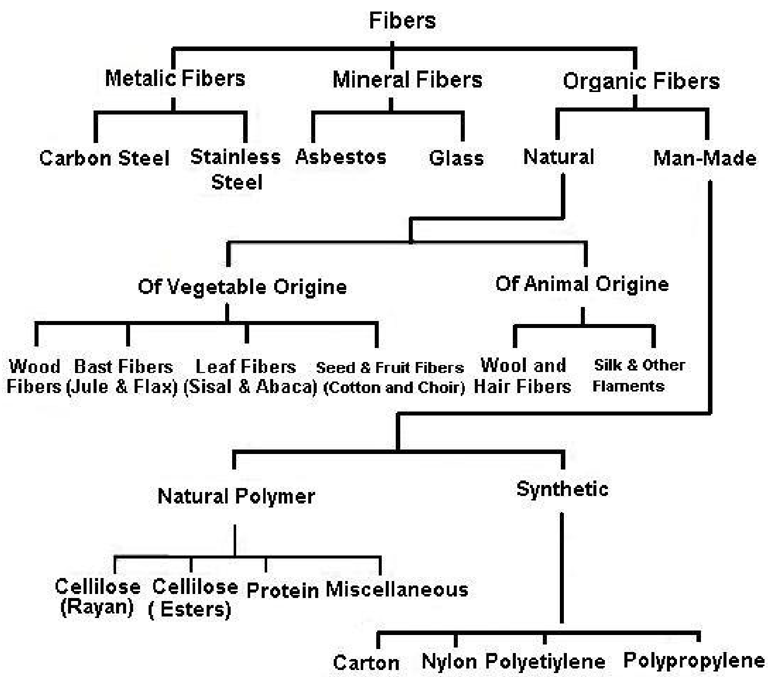

Figure 2.8 – Different types of fibers used in concrete[22]

J.D.Chaitanya kumar et-al[23] investigated glass fibers utilization in concrete at rates of 0.5%, 1%, 2%, and 3% of cement. Cubes, 15cm x 15cm x 15 cm, were prepared and compressive and tensile strength tested after 28 days of curing. An increase in tensile and compression strength was observed for mixtures containing 1% addition of glass fibers, as indicated in **Table 2.6** and **Figure 2.9**.

Table 2.6 – Compressive strength results. (Data by Kumar [23]).

S.No	**M20+GF**	**Compressive Strength(N/mm^2)**	
		7 Days	**28 Days**
1	0.5%	17.7	27.06
2	1%	20.76	28.46
3	2%	19.64	26.98
4	3%	18.4	26.11

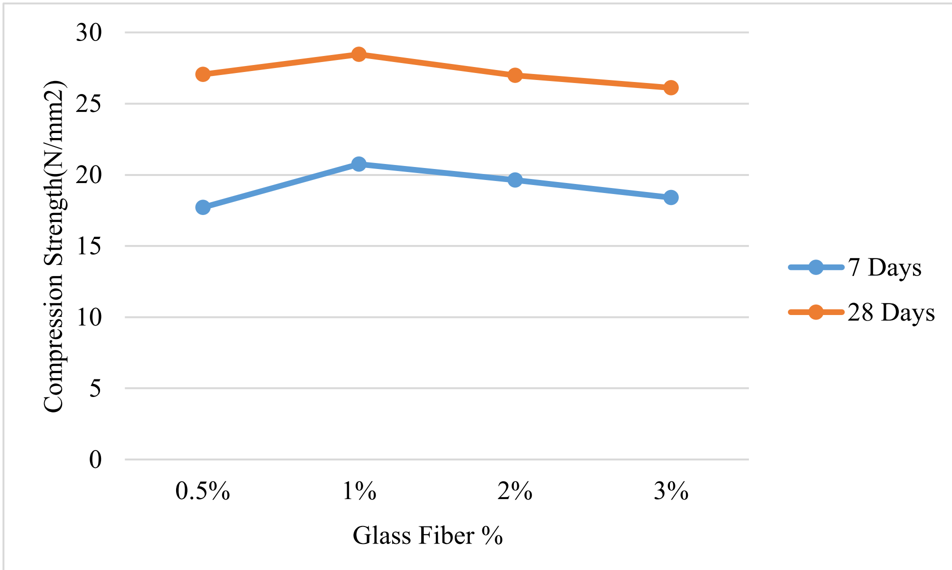

Figure 2.9 – Compressive test result. (Figure reprinted from data by Kumar [23]).

Table 2.7 – Tensile strength test results. (Data by Kumar [23]).

S.No	M20+GF	Compressive Strength(N/mm2)	
		7 Days	28 Days
1	0.5%	1.41	3.4
2	1%	2.83	3.92
3	2%	2.62	3.57
4	3%	2.43	3.42

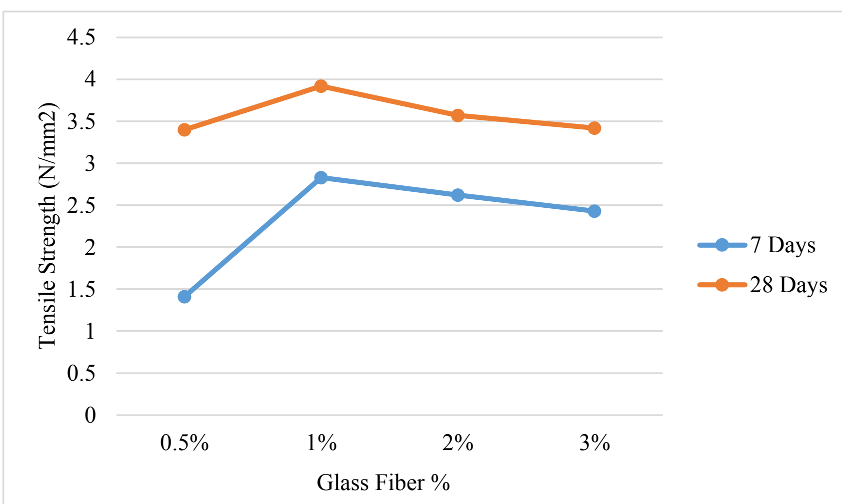

Figure 2.10 – Tensile test result. (Figure reprinted from data by Kumar[23]).

1% of glass fibers utilization in concrete indicated a significant improvement on concrete tensile strength. Based on these results, 1% of glass fiber was used in the research conducted herein.

Komal Chawla and Bharti Tekwani[24] reported a 4.14% increase in modulus of elasticity for 0.33% of glass fibers utilization in concrete.

2.5. Silica Fume

Silica fume is a byproduct of the manufacturing of ferro-silicon and silicon metal in electric arc furnaces [25]. The most important and beneficial use of silica fume is in concrete. It is a highly-reactive pozzolan, increasing both the durability and compressive strength of concrete. In this study, silica fume (or other pozzolans such as fly ash or slag cement) is a necessary admixture used to offset the resulting decrease in compression strength due to the use of waste materials as aggregates. Silica fume remains inert when added to concrete. When water is added to Portland cement the chemical reaction produces two chemical compounds: calcium hydroxide (CH) and calcium silicate hydrate (CSH). CSH is the strength producing crystallization and CH is responsible for lining concrete pores[26]. A pozzolanic reaction between CH and silica fume occurs, producing additional CSH, which improve compressive, flexural, and bond strength by providing a denser matrix[26].

Ozgur Cakır and **Omer Ozkan Sofyan**[27] investigated the effects of incorporating silica fume in concrete mixture to improve the recycled aggregate strength. The silica fume replaced cement at rates of 0%, 5%, and 10%. Test samples were prepared and cured for 7, 28, and 90 days. Increase of compressive strength was indicated when 5 and 10 percent of silica fume was added in different proportions of concrete. Based on the experimental results, the addition of silica fume was also shown to increase tensile strength of concrete.

Rahul Dogra and **Ankit**[28] studied the silica fume substitution with cement in concrete mixture. Silica fume of 0%, 5%, 7.5%, and 10% was utilized in concrete. Concrete specimens were prepared and cured for 7, 14, and 28 days. The compressive and tensile strength increases for 5%, 7.5%, and 10% silica fume addition to cement. The highest strength increase was shown for 10% silica fume substitution.

CHAPTER 3. METHODOLOGY

3.1. Methodology of the Investigation

Many researchers throughout the world have conducted tests for replacing course aggregate with plastic or slag aggregate individually. Silica fume and glass fiber have also been added to concrete over the past three decades. There is, however, limited research data available where all these materials have been introduced into concrete and tested altogether. This thesis aims to add to that body of knowledge through the following steps: (1) Literature Review: Books, Magazines, Websites, Researches, and References, (2) Case study: different types of waste materials were selected to study the effects on concrete performance (e.g. plastic and slag), (3) Experimental Investigation: Concrete mixtures were produced from local ingredients of different proportions to cast and test (28-day curing). The experiment required 130 cylinders (4 inches diameter by 8 inches). The experimental investigation was conducted at the concrete and structure labs of the Youngstown State University Department of Civil/Environmental and Chemical Engineering. (4) Results and Discussion: the research data was interpreted to determine the efficacy of concrete mixtures containing waste materials. Finally, (5) Conclusions and Recommendations: were provided from the synthesis of the literature review, case study, and experimental investigation.

3.2. Materials used in the Experiments

The concrete materials used in the experimental investigation were sourced from within Ohio. The cement used was Ordinary Portland cement with a specific gravity of 3.15. The natural, crushed coarse aggregate was a local crushed limestone of maximum 1.5 in size and was used with a specific gravity of 2.37. The sieve analysis results for the coarse aggregate are provided in Table 3.1. The nominal aggregate size was ¾ inch.

Table 3.1 – Course aggregate sieve analysis.

Sieve Analysis Course Aggregate				
Sieve #	**Weight Retained**	**% Retained**	**Cumulative % retained**	**% Passing**
1 ½ “	0	0	0	100
1”	0.055	1.1	1.1	98.9
¾”	0.97	19.4	20.5	79.5
3/8”	3.825	76.5	97	3
#4	0.143	2.86	99.86	0.14
		Fineness modulus	2.18	

A local natural river sand was selected as fine aggregate. The specific gravity of the sand used in research was 2.67. The sieve analysis results are provided in Table 3.1. The fineness modulus of the sand was found to be 3.9.

Table 3.2 – Fine aggregate sieve analysis.

Sieve Analysis Fine Aggregate				
Sieve #	**Weight Retained**	**% Retained**	**Cumulative % retained**	**% Passing**
4	0.015	0.75	0.75	99.25
8	0.28	14	14.75	85.25
16	0.285	14.25	29	71
30	0.525	26.25	55.25	44.75
50	0.665	33.25	88.5	11.5
100	0.19	9.5	98	2
200	0.025	1.25	99.25	0.75
		Finess modulus	3.9	

Tap water at room temperature was used for all concrete mixtures. The shredded plastic coarse aggregate was obtained from Phoenix Recycling Inc. based in Columbus, Ohio. The type of plastic used in research is Crosslink XLPE with a specific gravity of 0.935. A slag coarse aggregate was locally acquired from Youngstown with a specific gravity of 2.25. Glass fibers were provided by Owens Corning for use in the investigation. The fibers were 1 inch lose recycled fiberglass. The Glass fiber percentage used in all mixtures was 1% of the total volume of the cement. Finally**,** silica fume was used at a cement replacement rate of 7.5% of total weight of cement.

3.3. Mix Proportion

The selected mix proportion ratio was 1:1.5:3 and the water-cement ratio was 0.45. The complete details of the mixture proportioning is given in **Tables 3.3**, **3.4,** and **3.5**.

Table 3.3 – Summary of normal mixture proportions.

Material	**Quantity**	**Proportion**
Cement	680.0 lbs.	1
Sand	1019.9 lbs.	1.5
Coarse aggregate	2040.0 lbs.	3
Water	306.0 lbs.	0.45

For the mixtures containing plastic aggregate, course aggregate was replaced by percent mass with an equivalent volume of plastic aggregate due to the lower density (SG) of plastic. A similar process was use for slag aggregate, however, the density of slag is not as low as plastic and therefore a larger mass was required to replace the same volume of natural crushed limestone.

Table 3.4 – Summary of mixture proportions for plastic aggregates.

Material	P15 (lbs.)	P30 (lbs.)	P45 (lbs.)	P15-SF7.5 (lbs.)	P15-G1 (lbs.)	P15-SF7.5-G1 (lbs.)
Cement	680	680	680	629	673.20	629
Sand	1020	1020	1020	1001	1020	995
Coarse aggregate	1734	1428	1122	1734	1734	1734
Water	306	306	306	306	306	306
Plastic	104.8	209.6	314.4	104.8	104.8	104.8
Silica Fume	-	-	-	51	-	51
Glass Fibers	-	-	-	-	6.8	6.8

Table 3.5 – Summary of mixture proportions for slag aggregates.

Material	S15 (lbs.)	S30 (lbs.)	S45 (lbs.)	S15-SF7.5 (lbs.)	S15-G1 (lbs.)	S15-SF7.5-G1 (lbs.)
Cement	680.00	680.00	680.00	629	673.20	629
Sand	1019.88	1019.88	1019.88	1002	1019.88	958
Coarse aggregate	1734	1427.96	1122	1734	1734	1734
Water	306	306	306	306	306	306
Slag	252.19	582.85	874.28	252.19	252.19	252.19
Silica Fume	-	-	-	51	-	51
Glass Fibers	-	-	-	-	6.8	6.8

Table 3.6 – Summary of mixture proportions for combined aggregates.

Material	C15 (lbs.)	C30 (lbs.)	C45 (lbs.)
Cement	622.20	622.20	622.20
Sand	1000	1000	1000
Coarse aggregate	1734	1428	1122
Water	306	306	306
Plastic	52.40	104.80	157.20
Slag	126.1	252.19	378.29
Silica Fume	51	51	51
Glass Fibers	6.8	6.8	6.8

3.4. Quantity of Specimens

To determine the compressive strength, tensile strength, and modulus of elasticity, 130 specimens were prepared and tested. For simplicity, alpha-numeric names were used for each mixture.

Table 3.7 – Alpha-numeric names of different mixture proportions.

Alpha-numeric name	Mixture proportions
NC	Normal Concrete
P15	Plastic aggregate 15 % replaces course aggregate of concrete mix
P30	Plastic aggregate 30 % replaces course aggregate of concrete mix
P45	Plastic aggregate 45 % replaces course aggregate of concrete mix
S15	Slag aggregate 15 % replaces course aggregate of concrete mix
S30	Slag aggregate 30 % replaces course aggregate of concrete mix
S45	Slag aggregate 45 % replaces course aggregate of concrete mix

P15-SF7.5	Plastic aggregate 15 % replaces course aggregate of concrete mix with 7.5 % Silica fume
P15-G1	Plastic aggregate 15 % replaces course aggregate of concrete mix with 1% glass fibers
P15-SF7.5-G1	Plastic aggregate 15 % replaces course aggregate of concrete mix with 7.5% silica fume and 1% glass fibers
S15-SF7.5	Slag aggregate 15 % replaces course aggregate of concrete mix with 7.5 % Silica fume
S15-G1	Slag aggregate 15 % replaces course aggregate of concrete mix with 1% glass fibers
S15-SF7.5-G1	Slag aggregate 15 % replaces course aggregate of concrete mix with 7.5% silica fume and 1% glass fibers
C15	combined mix with 7.5 % plastic, 7.5 % slag, 7.5 % silica fume and 1 % glass fibers
C30	combined mix with 15 % plastic, 15 % slag, 7.5 % silica fume and 1 % glass fibers
C45	combined mix with 22.5 % plastic, 22.5 % slag, 7.5 % silica fume and 1 % glass fibers

The specimens cast for each mixture are summarized in the **Table 3.8**.

Table 3.8 – Summary of test matrix.

Materials	**Mixes**	**Compression test 28-days**	**Split Tension test 28-days**	**MoE 28-days**	**Total Tests**
NC	1	3	3	4	10
P15, P30,P45	3	3+3+3	3+3+3	6	24
S15, S30, S45	3	3+3+3	3+3+3	6	24
P15-SF7.5, P15-G1,P15-SF7.5-G1	3	3+3+3	3+3+3	6	24
S15-SF7.5, S15-G1, S15-SF7.5-G1	3	3+3+3	3+3+3	6	24
C15, C30, C45	3	3+3+3	3+3+3	6	24
			Total		**130**

3.5. Concrete Mixing and Specimen Preparation

Before mixing the concrete, a sieve analysis test was performed for course and fine aggregate. The concrete mixtures were produced according to the design proportion in the **Table 3.1,** where 1:1.5:3 proportion had been used with 0.45 W/C ratios. The concrete mixtures were prepared in the concrete mixer until well mixed. Some of the pictures taken during mixing and specimen preparation are included. A picture of the mixture design process and slump test are provided in **Figure 3.1** below.

Figure 3. 1 – Picture of mixing process and slump test.

3.6. Slump Test to check Workability

In order to determine the workability of concrete, a slump test was performed for each batch. The slump test was carried out according to ASTM C143. A picture of the slump test is provided in **Figure 3.2**.

Figure 3. 2 - Slump test result.

3.7. Casting and Curing of Specimens

In total, 130 (4 x 8 inch) cylinders were cast according to ASTM C192. The proportion of the material used are summarized in the **Table 3.1**. A picture of the cylinder preparation method used during casting is shown in **Figure 3.3**.

Figure 3. 3 - Casting of Cylinders in the lab

All the samples were cured in the concrete laboratory at Youngstown State University. The cylinders were put in the water tank for 28 days, at a temperature of 21° C (69.8 °F).

Figure 3. 4 - Curing of Specimen

3.8. Testing of Specimen

All of the mechanical tests of cylinders were performed using a 120k Universal Testing Machine (UTM) and 250k Compressive Testing Machine (CTM) within the Strengths of Materials lab at Youngstown State University. The testing procedure is explained below in detail.

3.8.1. Compressive Strength Tests

This compressive strength test was conducted as per ASTM C39, to determine the average compressive strength of each concrete mixture.

Procedure: The following procedure was conducted in testing the compressive strength. First, the specimens were removed from the water bath and allowed to air dry for 24 hours prior to testing. The cylinders were then placed and centered under the CTM loading head. The load was applied to the specimen according at the specified rate of 28±7 psi/second. The CTM provides the maximum load (lbs.) at failure of the cylinders. The machine was recently calibrated and found to be accurate within 1%. The loads results were recorded and the concrete compressive strength calculated by dividing the maximum load at failure by the average cross-sectional area of the cylinder. Finally, the data was collected for analysis. A picture of a cylinder compressive strength test is provided in **Figure 3.5** below.

Figure 3. 5 - Cylinder under Compressive strength test in UTM

3.8.2. Split Tensile Strength Tests:

This test consisted of applying a diametric compressive force along the length of a cylindrical specimen as per ASTM C496 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. The test was performed using the 120k UTM.

Procedure: The Split Tensile strength test procedure was conducted as follows: First, diametric lines were drawn on each end of the specimen so that they are in the same axial plane. Next, the cylinders were placed on thin, flat wooden strips and aligned so the line marked on the ends are centered over strip. A second wooden strip and loading bar was placed lengthwise on the cylinder. The load was applied continuously at a constant rate until failure occured. Finally, the maximum load at failure given by UTM was recorded. Equation 3.1 was used to calculate the splitting tensile strength.

$$F_{st} = 2P/\pi LD \qquad \textbf{Equation 3.1}$$

Where:

P = maximum load in pound

L = length of the specimen in inches and

D = diameter of the specimen in inches

The data for all tested specimens was collected and analyzed. Pictures of a typical split tensile test are provided in **Figure 3.6** below.

Figure 3. 6 - Cylinder under Split Tensile Strength tests in UTM.

3.8.3. Modulus of Elasticity Tests:

This Modulus of Elasticity test was conducted as per ASTM C469 Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression. The test was performed by using a 120k Universal testing machine, compressometer/extensometer collar, axial transducer, and transverse transducer.

Procedure: ASTM C469 requires three steps. First, determine the compressive strength of the specimen by following ASTM C139 to apply on axial compressive load until failure. Record the load at which failure occurs. Second, strain-measuring equipment (compressometer-extensometers) is attached to the specimen. Next, the specimen should be capped and placed on the UTM lower platen. The axis of the specimen should be aligned with the thrust center of the spherically seated bearing block and the load applied on the specimen at a constant rate within the standard specified range. The load is applied until it reaches 40% of the ultimate load. Third, at least two subsequent loadings are recommended by ASTM C469 to ensure repeatability. If repeatable, take the average of the results. Apply the load until it reaches 40% of the ultimate load. Record the load applied, the longitudinal and transverse strain at 50 millionths, and when the applied load is equal to 40% of the ultimate compressive strength. Humidity and temperature should be maintained constant throughout the test.

Figure 3. 7 - MOE tests in UTM.

CHAPTER 4. TEST RESULTS AND ANALYSIS

4.1. Introduction

In this chapter, different mix test results are discussed, the tests were conducted to study mechanical properties of various concrete mixtures as described in Chapter 3. Slump test, compressive strength, splitting tensile strength, and modulus of elasticity test of concrete specimens were discussed to investigate the effects of combined usage of plastic, slag, silica fume, and glass fibers on concrete properties. Concrete with a portion of the natural coarse aggregate replaced with either recycled plastic or slag aggregates, at replacement rates of 0%, 15%, 30%, and 45% by mass, were evaluated. The test results from mechanical tests are discussed herein:

4.2. Compressive Test Results

Tables 4.1, 4.2, and **4.3** summarize the 28-day test results of compressive strength of concrete. The concrete mixtures contained replacement rates of plastic or slag at 15%, 30%, and 45%, respectively, along with silica fume, glass fibers, and a W/C ratio of 0.45. The same mixtures were used for tensile test and modulus of elasticity test.

Plastic replacement: The results indicate that with comparison to reference concrete (NC), there was a statistically significant decrease in compressive strength of concrete as the plastic percentage increases in concrete mix from 15% to 45% (P15, P30, P45). At 15% substitution of plastic with course aggregate, the addition of silica fume and glass fiber individually were observed to decrease compressive strength marginally, while the combined usage of silica fume and glass fibers increases strength marginally as compared to P15.

For 15%, 30%, and 45% aggregate replacement, the strength reduction from reference concrete was 24%, 46% and 59% respectively. The P30 and P45 mix exhibited strength reductions that were likely too large for consideration in structural applications. Therefore, only P15 was further investigated with silica fume and glass fibers as a potentially useful mixture in structural applications. The individual test results are summarized in **Table 4.1**, while the results and statistical significance are compared in **Figures 4.1** below.

Table 4. 1 - Summary of plastic replacement results.

	Load Applied (Lbs.)			Average load	Comp Strength (Psi)
	A1	A2	A3		
NC	89050	90463	92372	90628	7220
P15	68890	71746	66289	68975	5490
P30	47147	51600	46129	48292	3840
P45	36728	36558	40347/34848	37120	2960
P15-SF7.5	68648	67745	69130	68508	5450
P15-G1	67773	62670	71520	67321	5360
P15-SF7.5-G1	68282	72990	70883	70718	5630

*Four specimens were tested for Mixture P45

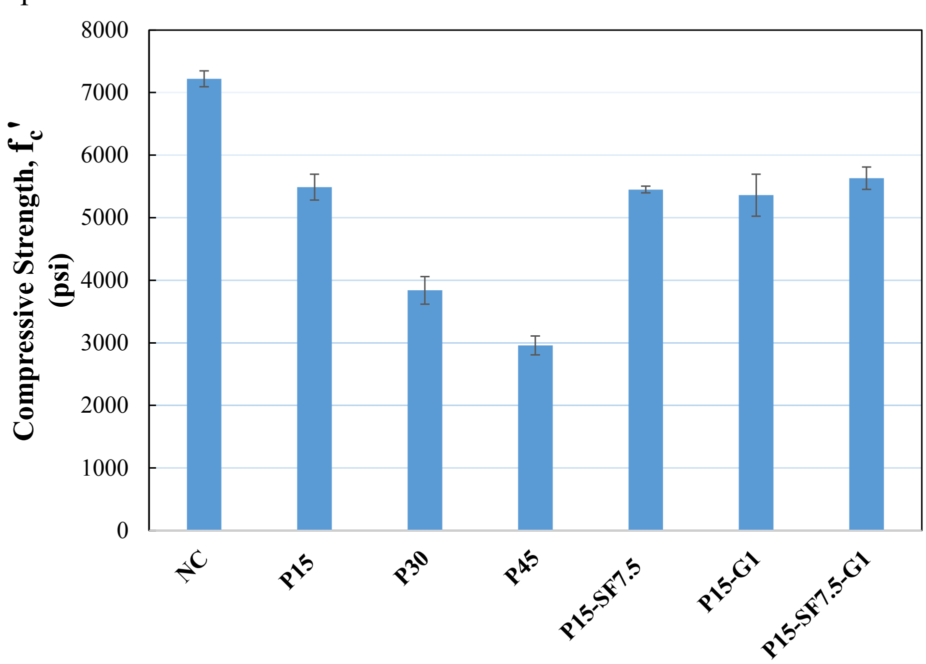

Figure 4. 1 - Compression test results of plastic replacement in course aggregate.

As observed from **Figure 4.1**, the compressive strength decreases relative to the reference material, when silica fume and glass fibers were added individually to P15 mix. The relative decrease in average compressive strength was 24.5% and 25.76% respectively. In comparison, the combined addition of 7.5% silica fume and 1% glass fiber to P15, resulted in a strength reduction from the reference concrete of 22%.

Slag replacement: Concrete course aggregate was replaced by slag aggregates at 15%, 30% and 45% (S15, S30, and S45) by mass and the resulting concrete strength tested. With comparison to reference materials, the results in **Table 4.2** shows statistically significant increase in compressive strength for S15 and minor decrease for S30 and S45. Showing increase in strength, S15 was further investigated for silica fume, glass fibers, and combined silica fume and glass fibers.

In comparison to S15, addition of Silica fume (7.5%) indicated an increase in compressive strength. Similarly, adding glass fiber (1%) to S15 mix, resulted in a marginal increase in compressive strength as shown. The combined addition of silica fume and glass fibers resulted in the highest compression strength. Therefore, any of the mixtures containing slag aggregate would be applicable for use as structural concrete.

Table 4. 2 - Summary of slag replacement results.

	Load Applied (Lbs.)			**Average load**	**Comp Strength (Psi)**
	A1	**A2**	**A3**		
NC	89050	90463	92372	90628	7220
S15	97574	95242	97852	96889	7710
S30	91920	90449	89742/90110	90555	7210
S45	91100	90407	87735/88103	89336	7110
S15-SF7.5	97928	94577	93885	95463	7600
S15-G1	90314	91566	91538	91139	7260
S15-SF7.5-G1	99836	92952	98182	96990	7720

*Four specimens were tested for Mixture S30 and S45

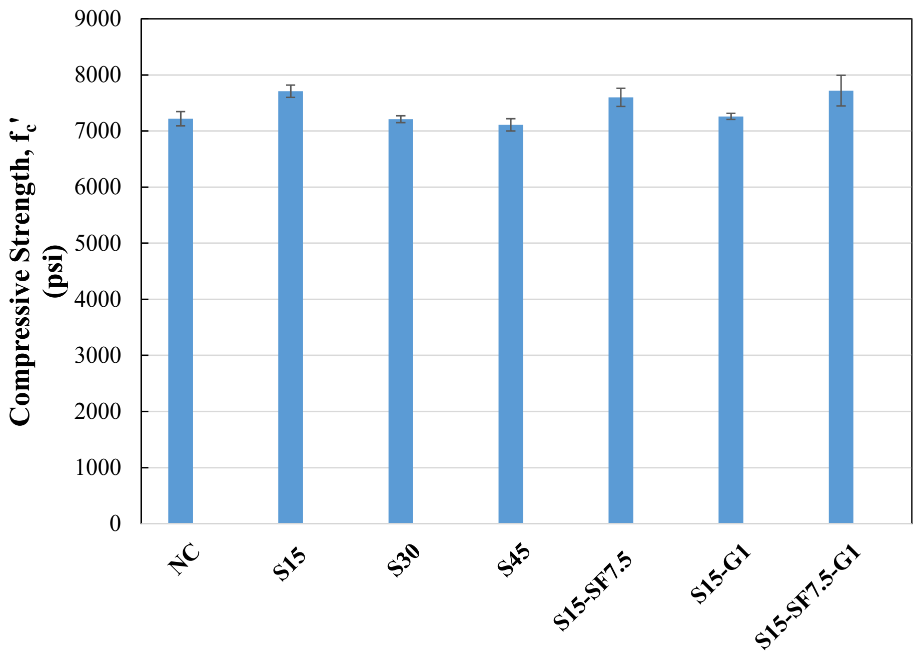

Figure 4. 2 - Compression test results of slag replacement in course aggregate.

In comparison to the reference material, an increase in compressive strength for S15 of 6.79% was measured, while for S30 and S45 a decrease in strength is 0.34% and 1.52% were measured, respectively. For S15-SF7.5 and S15-G1 compressive strength increased 5.25% and 0.55%, respectively. S15-SF7.5-G1 resulted in a compressive strength increase of 6.93%.

Combined mix: In the combined mixture, a percentage by mass of the natural course aggregate was replaced with a combination of plastic and slag, in addition to a portion of the cement by mass being replaced with silica fume and glass fibers. Plastic and slag aggregate replacement rates of 15%, 30%, and 45% were evaluated (C15, C30, and C45). In comparison with reference mixture (NC), the decrease in compressive strength for C15, C30 and C45 was 23.55%, 29.22%, and 37.53% respectively as shown in **Table 4.3** and **Figures 4.3**. The C15 and C30 mixtures remain applicable for use in structural applications, while the C45 would have limited application due to the reduction in compressive strength.

Table 4. 3 - Summary of combined aggregate replacement results.

	Load Applied (Lbs.)			Average load	Comp Strength (Psi)
	A1	A2	A3		
NC	89050	90463	92372	90628	7220
C15	70162	69116	68664	69314	5520
C30	63377	62401	66868	64215	5110
C45	55898	57807	56195	56633	4510

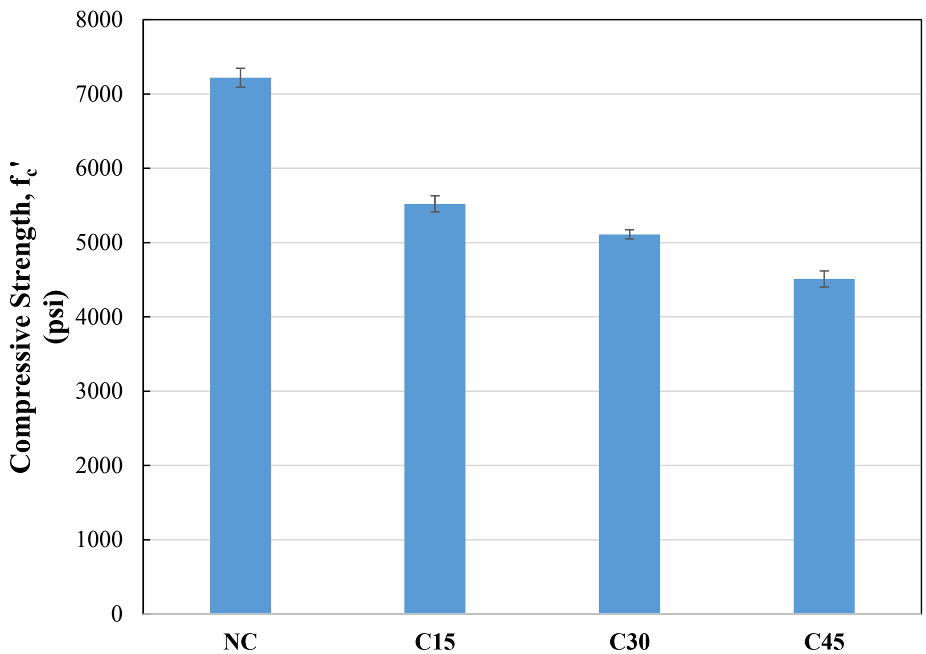

Figure 4. 3 - Compression test results of (plastic, slag) replacement in course aggregate.

4.3. Tensile Test Results

The 28-day concrete tensile strength test results are shown in **Tables 4.4**, **4.5**, and **4.6**.

Plastic replacement: The results indicates that with comparison to reference concrete (NC), the tensile strength decreases for P15, P30, and P45 by 20.56%, 37.58%, and 49.50% respectively. P15 was further investigated with silica fume and glass fibers as it had the smallest decrease in compressive strength of the three replacement rates considered. Again, a decrease in tensile strength was shown when silica fume and glass fibers are added to P15, individually and combined. Individually, the percent strength decrease was 27.65% for the P15-SF7.5 mix and 18.43% for P15-GF1 mix when compared to the NC mixture. The combined mix P15-SF7.5-GF1 had a decrease in strength of 29.07% relative to NC.

Table 4. 4 - Summary of Plastic replacement results.

	Load Applied (lbs.)			Average load	Tensile Strength (psi)
	A1	**A2**	**A3**		
NC	36459	32798	36930	35396	705
P15	27300	30420	26926	28215	560
P30	22655	20770	22880/21700	22001	440
P45	18808	18724	17720/18528	18445	365
P15-SF7.5	25632	25156	25988	25592	510
P15-G1	28892	31429	29893/25813	29006	575
P15-SF7.5-G1	26532	25291	23734	25186	500

*Four specimens were tested for Mixture P30, P45 and P15-G1

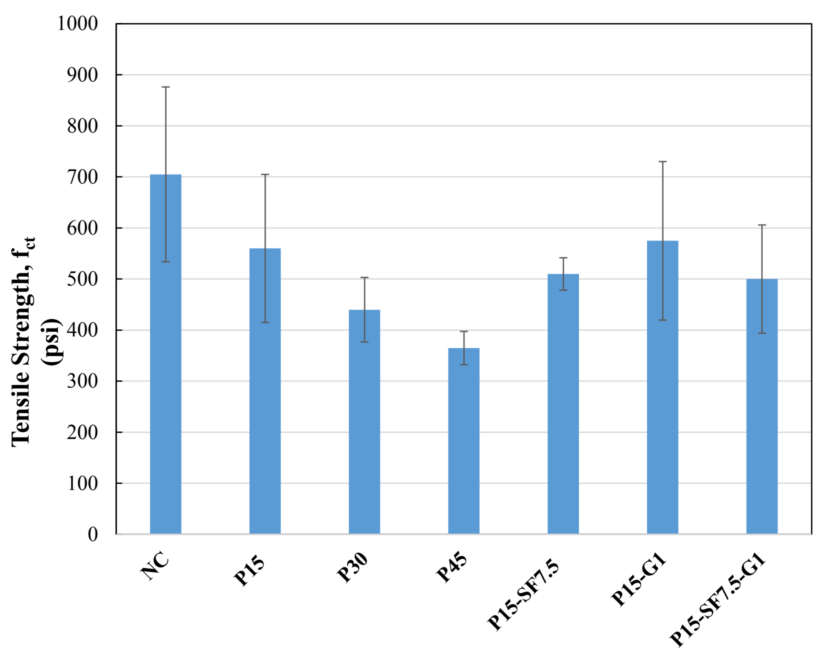

Figure 4. 4 - Tensile test results of Plastic replacement in course aggregate.

Slag replacement: For tensile strength test, slag aggregate replacement rates were again 15%, 30% and 45% (S15, S30, and S45). With comparison to reference materials, the test results in **Table 4.5** indicate a decrease in tensile strength for S15, S30, and S45 of 4.96%, 4.96%, and 12.76%, respectively. S15, being the strongest, was further investigated with silica fume and glass fibers individually and combined.

In comparison to reference materials, the addition of silica fume (7.5%) to S15 (S15-SF7.5) indicates 12.06% decrease in tensile strength. Similarly, adding glass fiber (1%) to S15 mix (S15-G1) resulted in a 9.22% decrease in tensile strength as shown. The combined addition of silica fume and glass fibers (S15-SF7.5-G1) resulted in an 11.35% decrease in tensile strength. The tensile strength decreased by a statistically significant amount in all cases. This limits the applicability of the mixtures in structural and pavement application.

Table 4. 5 - Summary of Slag replacement results.

	Load Applied (lbs.)			**Average load**	**Tensile Strength (psi)**
	A1	**A2**	**A3**		
NC	36459	32798	36930	35396	705
S15	33595	34108	33116	33606	670
S30	34057	33530	33088	33558	670
S45	31068	30316	31310	30898	615
S15-SF7.5	31263	31083	31101	31149	620
S15-G1	32641	31647	29053/35182	32130	640
S15-SF7.5-G1	30980	31388	31952	31440	625

*Four specimens were tested for Mixture S15-G1

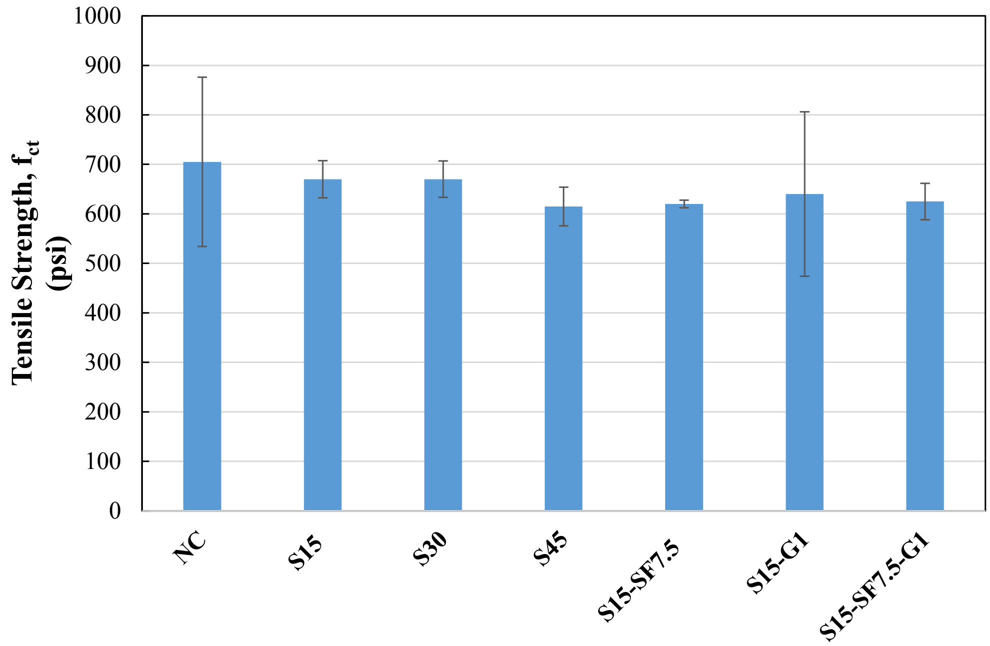

Figure 4. 5 - Tensile test results of slag replacement in course aggregate.

Combined mix: The mixture with plastic and slag aggregate replacement along with silica fume and glass fibers was also tested for split tensile strength. In the combined mix concrete, course aggregate was replaced by plastic and slag with addition of silica fume and glass fibers. After comparing with reference mix (NC), decrease in tensile strength for C15, C30 and C45 was 14.18%, 24.82%, and 27.65% respectively shown in **Table 4.6** and **Figure 4.6**.

Table 4. 6 - Summary of Combined (Plastic, Slag) replacement results.

	Load Applied (lbs.)			Average load	Tensile Strength (psi)
	A1	A2	A3		
NC	36459	32798	36930	35396	705
C15	31609	29856	29980	30482	605
C30	27975	26565	25138	26559	530
C45	24082	27718	25007	25602	510

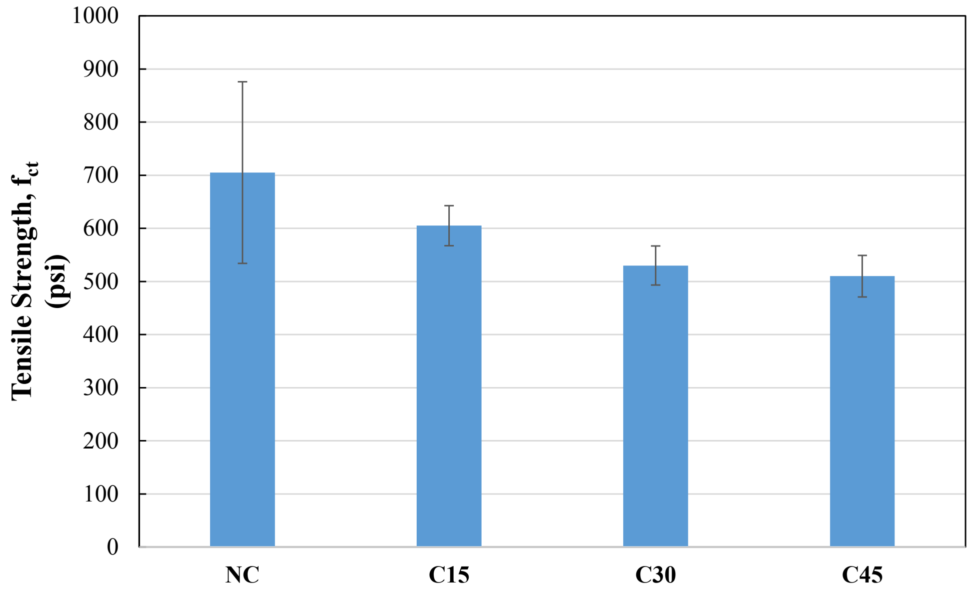

Figure 4. 6 - Tensile test results of combined (plastic, slag) replacement in course aggregate.

4.4. Moe Test Results

The 28-day Modulus of elasticity (MOE) test results are shown in **Tables 4.7, 4.8,** and **4.9**.

Plastic replacement: An increase of plastic quantity in concrete had a statistically significant effect on the modulus of elasticity of concrete. The results in **Table 4.7** indicate that when compared to reference concrete NC, the MOE of concrete decreases with the increase of plastic quantity in concrete. Silica fume and glass fibers were added to P15 and additional modulus of elasticity tests were performed. In comparison to reference materials (NC) the MOE decreased for P15-SF7.5, P15-GF1 and P15-SF7.5-GF1. While comparing to P15, the MOE increased for the P15-SF7.5, P15-GF1 mixture, but decreased for P15-SF7.5-GF1.

For P15, P30, P45, P15-SF7.5, P15-G1, P15-SF7.5-G1, the percent decrease in MOE of concrete in comparison to reference materials are 23.8%, 39.05%, 53.3%, 14.28%, 20.95%, and 25.71%, respectively.

Table 4. 7 - Summary of plastic replacement results.

							Average
	C1			C2			(ksi)
NC	5078	5467	5334	5209	5447	4844	5250
P15	4113	4349	4335	3738	3833	3707	4000
P30	2738	2848	2887	3591	3625	3660	3200
P45	2413	2486	2532	2427	2436	2422	2450
P15-SF7.5	4053	3967	4063	4936	4992	4930	4500
P15-G1	3899	4113	4154	4115	4345	4378	4150
P15-SF7.5-G1	3773	3829	3802	3916	4079	4051	3900

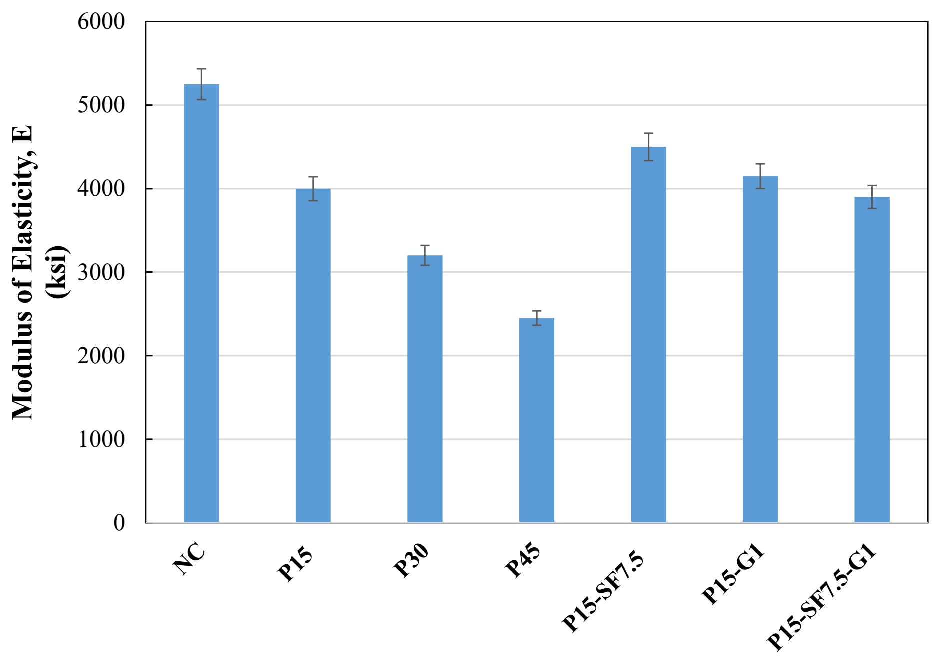

Figure 4. 7 - MOE test results of plastic replacement in course aggregate.

Slag replacement: The modulus of elasticity of concrete for reference mix, S15 and S45 remains the same while an increase was shown for S30 which is 9.5%. After adding silica fume to S15 (S15-SF7.5), there was a 1.90% decrease in MOE. The addition of 1% glass fibers (S15-G1) resulted in an increased MOE of 2.85% as compared to the reference mix. The combined effect of silica fume and glass fibers (S15-SF7.5-G1) on MOE of concrete was a 5.7% decrease in MOE as compared to the reference mix (NC).

Table 4. 8 - Summary of slag replacement results.

							Average
	C1			C2			ksi
NC	5078	5467	5334	5209	5447	4844	5250
S15	5375	5340	4948	5156	5247	5396	5250
S30	5585	5730	5918	5645	5869	5861	5750
S45	5234	5356	5395	5122	5200	5220	5250
S15-SF7.5	4923	5102	4980	5199	5422	5355	5150
S15-G1	5353	5455	5391	5479	5395	5384	5400
S15-SF7.5-G1	4928	4938	4885	5017	5029	5031	4950

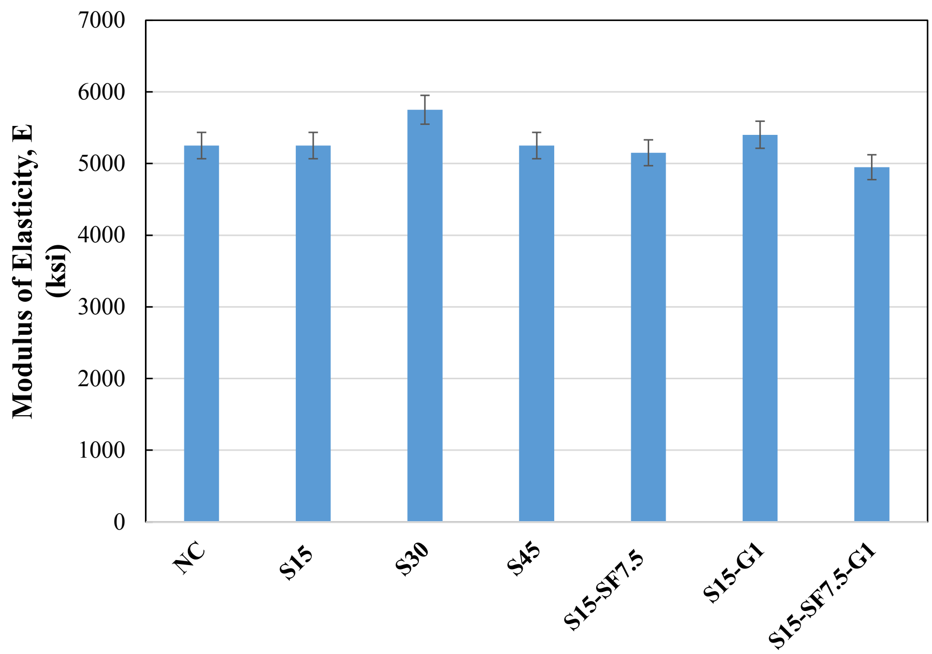

Figure 4. 8 - MOE test results of slag replacement in course aggregate.

Combined mix: The mixtures containing both plastic and slag aggregate indicated the modulus of elasticity decreased as the replacement rate of aggregate increased, regardless of the presence of silica fume or glass fibers. Concrete course aggregate was replaced by a combined plastic and slag aggregate rate of 15% (7.5% plastic and 7.5% slag), 30%, and

45% ratios (C15, C30 and C45). In comparison with reference mix (NC), there was a 17.14% decrease in MOE for C15, 22.85% for C30, and 27.62% for C45 shown in **Table 4.3** and **Figure 4.9**. However, the MOE remained sufficient for use in structural concrete applications for the C15 and C30 mixture, while the C45 mixture may not be sufficient in some applications.

Table 4. 9 - Summary of combined aggregate replacement results.

	C1			C2			Average ksi
NC	5078	5467	5334	5209	5447	4844	5250
C15	4450	4634	4614	4091	4037	4160	4350
C30	4209	4159	4226	3821	3901	3922	4050
C45	3816	3813	3757	3693	3782	3800	3800

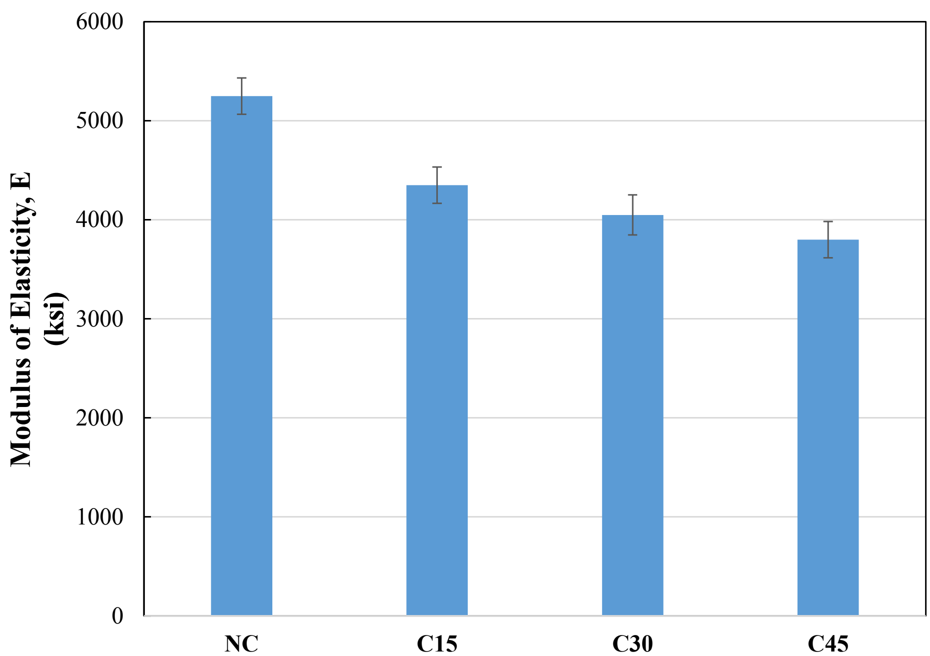

Figure 4. 9 - MOE test results of combined (plastic, slag) replacement in course aggregate.

4.5. Workability Results

Slump test was performed to determine the workability of fresh concrete by following ASTM C143 standard procedure. **Table 4.10** shows the results of normal concrete, plastic aggregate, slag aggregate and combine aggregate mixtures. Compared to normal aggregate mixture, the slump decreases for plastic aggregate and slag aggregate mixtures. However, for combine mixture C15 slump remained similar to normal concrete, however, decreased for C30 and C45.

Table 4. 10 - Summary of slump test results

Mix #	% Replacement Aggregate	W/C Ratio	Slump (in)
NC	0	0.45	2
P15	15		1
P30	30		0.5
P45	45		0.5
P15-SF7.5	15		0.5
P15-G1	15		0.5
P15-SF7.5-G1	15		1
S15	15		1
S30	30		1.5
S45	45		1.5
S15-SF7.5	15		1
S15-G1	15		1.5
S15-SF7.5-G1	15		1.5
C15	15		2
C30	30		1.5
C45	45		1.5

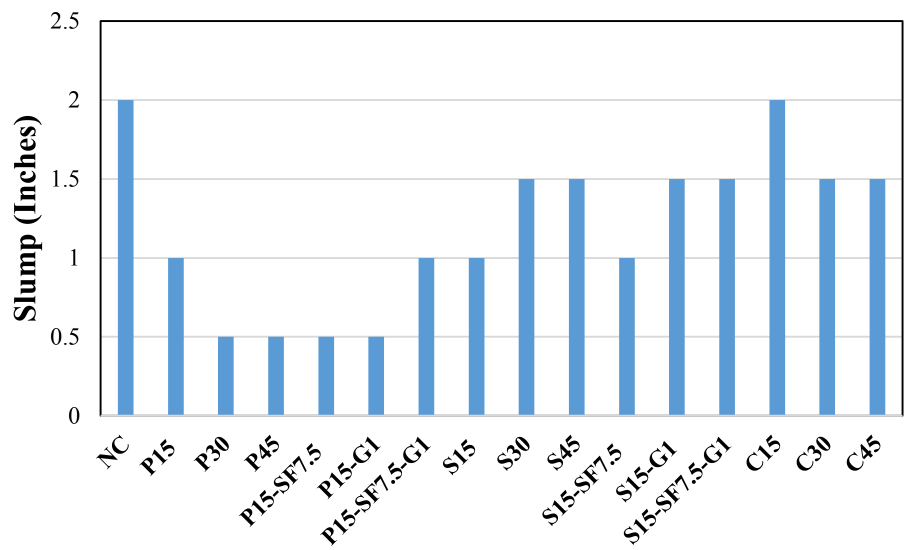

Figure 4. 10 – Summary of slump test results.

4.6. Discussion

The results discussed above indicate that with comparison to NC, compressive strength decreases when plastic quantity increases from P15 to P45, which was also observed by Manhal A Jibrael and Farah Peter [14]. On other hand, compressive strength increases for S15 and decreases when slag quantity increases in concrete after S15 which was also shown by Y.K. Sabapathy, et al in 2015 [18].

Comparing **Figures 4.11** and **4.12** with NC mixture results, P15 had a 24% compressive strength reduction and for S15 the compressive strength increase was 6.79%. After adding SF and GF to both plastic and slag mixtures, the compressive strength had decreased 24.5%, 25.76%, and 22% as compared to the NC mixtures for P15-SF7.5, P15-GF1, and P15-SF7.5-GF1 respectively. However, for S15-SF7.5, S15-GF1 and S15-SF7.5-GF1 compressive strength increase was 5.25%, 0.55%, and 6.93% respectively.

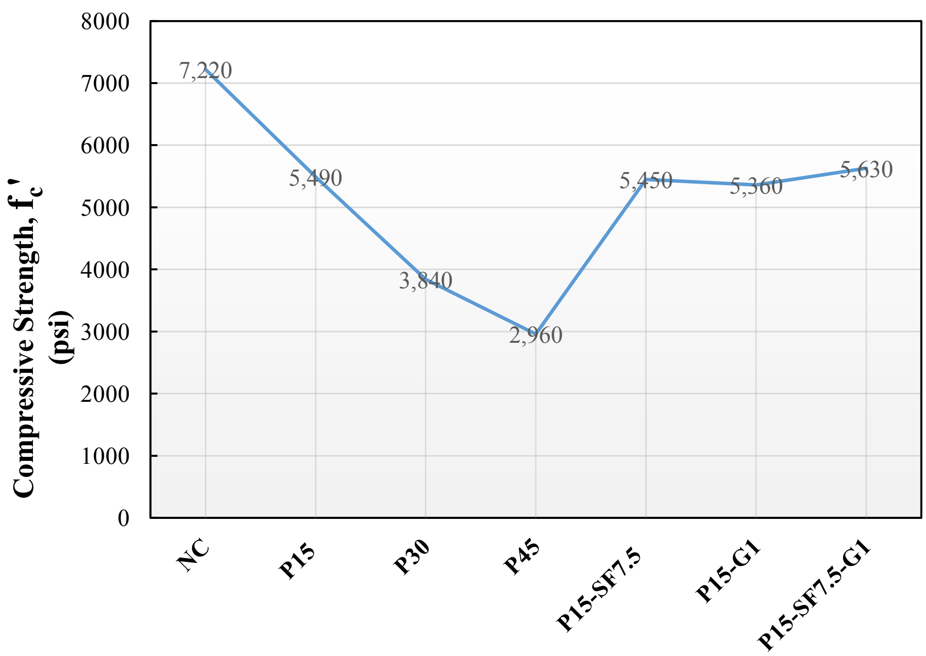

Figure 4. 11 - Compressive test results of plastic replacement in course aggregate.

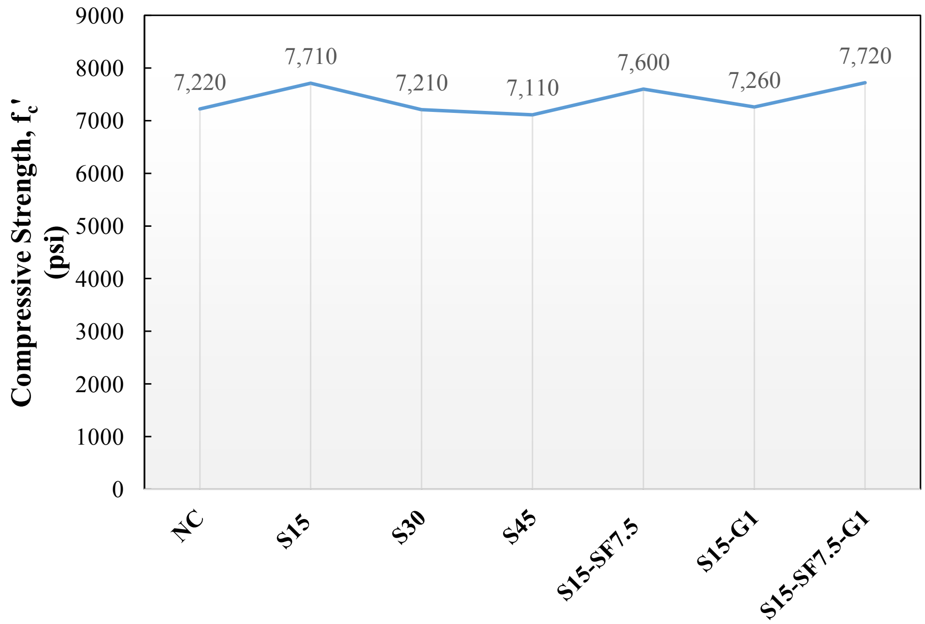

Figure 4. 12 - Compressive test results of Slag replacement in course aggregate.

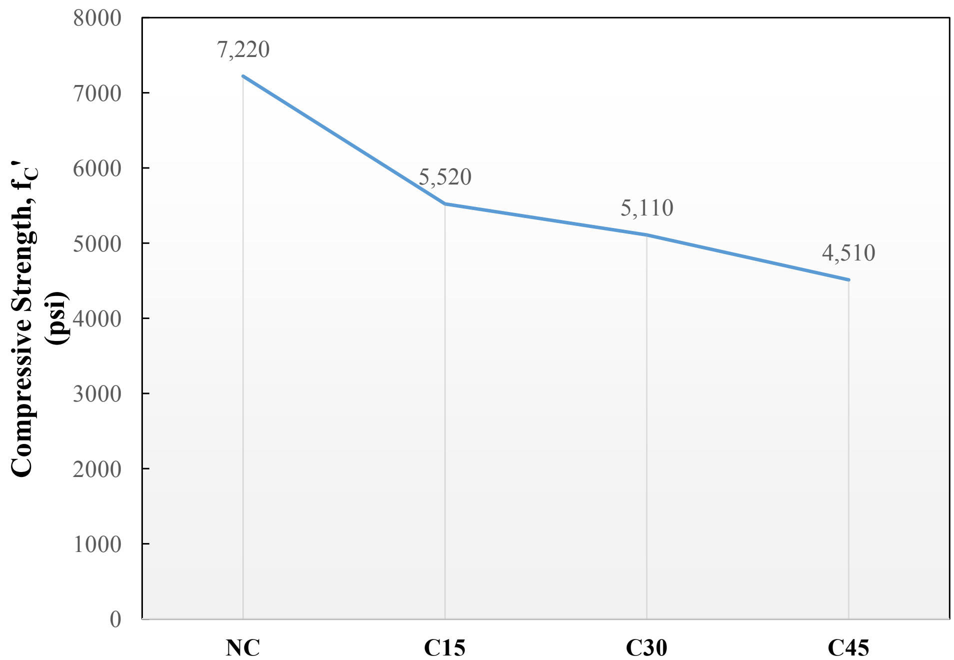

Figure 4. 13 - Compressive test results of combined (plastic, slag) replacement in course aggregate

As shown in **Figures 4.13**, the decrease in compressive strength was 23.55%, 29.22%, and 37.53% for C15, C30, and C45, respectively when compared to NC. Comparing C15 and

C30 to P15-SF7.5-GF1 in **Figure 4.11** indicates a 1.95% and 9.24% decrease of compressive strength from P15-SF7.5-GF1 (5630 psi). Comparing C15 and C30 to S15-SF7.5-GF1 in **Figure 4.12** indicates 28.5% and 33.80% decrease of compressive strength. Although the C30 mixture indicated a decrease in compressive strength when compared to the NC mixture, the compressive strength remains greater than 5000 psi and may be applicable in structural or other applications.

For **Tensile strength**, after comparing with NC the strength decreases significantly when quantity of plastic increases in P15, P30, and P45 which was also indicated by Manhal A Jibrael and Farah Peter [14]. However, tensile strength decreases for S15, S30, and S45 was less when slag quantity increases in concrete accordingly which was also shown by V. Subathra Devi, B. K. Gnanavel [19].

Comparing **Figures 4.14** and **4.15**, the tensile strength reduction in mixtures P15 and S15 was 20.56% and 4.96% respectively. After adding SF and GF to both plastic and slag mixtures, strength decreased for P15-SF7.5, P15-GF1, and P15-SF7.5-GF1 by 27.65%, 18.43%, and 29.07% respectively. Similarly, for S15-SF7.5, S15-GF1, and S15-SF7.5-GF1, the compressive strength increased by 12.06%, 9.22%, and 11.35%, respectively.

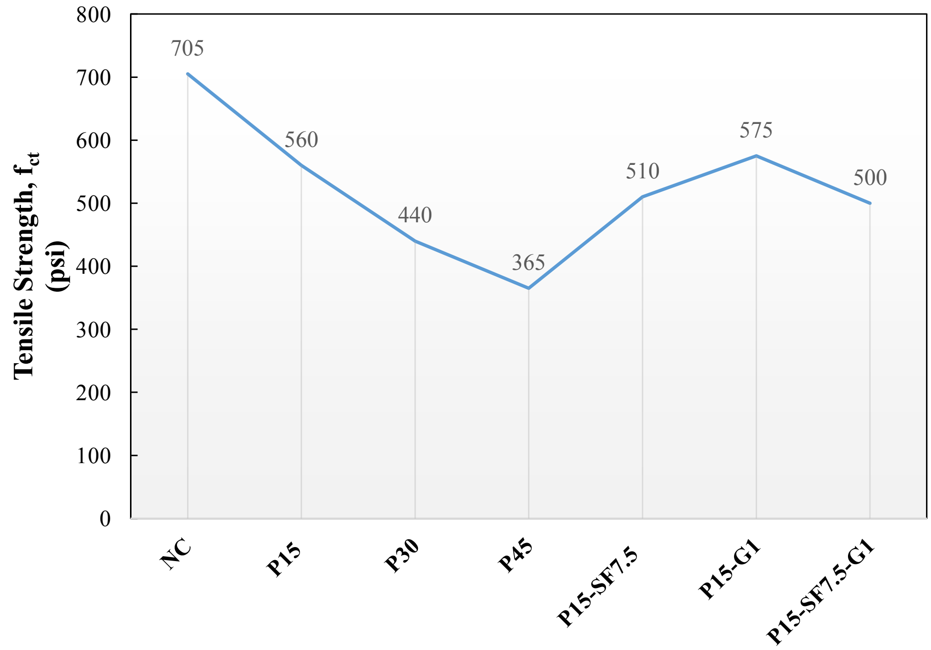

Figure 4. 14 - Tensile test results of plastic replacement in course aggregate.

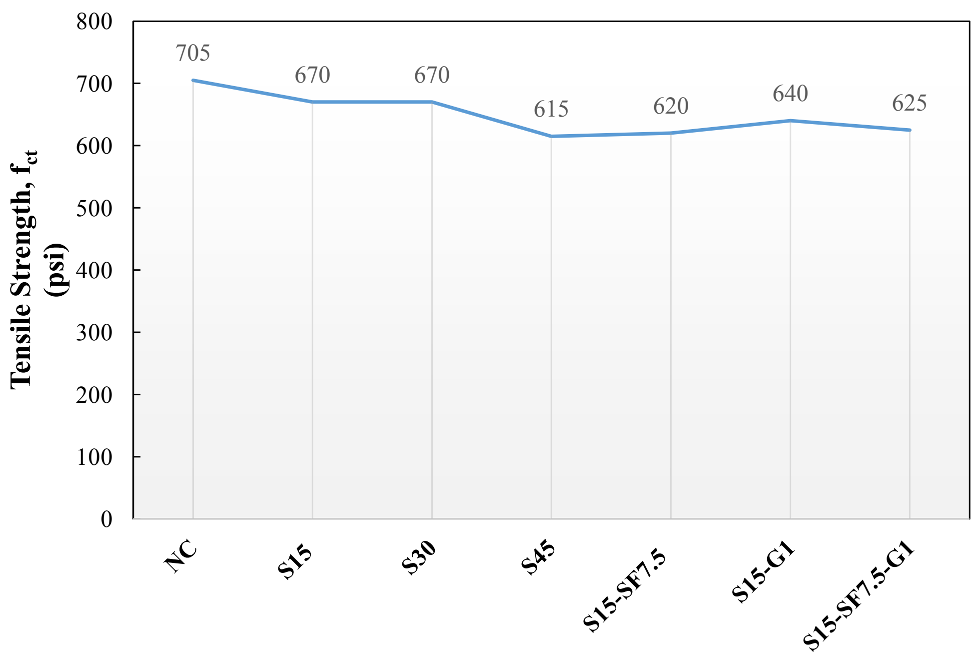

Figure 4. 15 - Tensile test results of slag replacement in course aggregate

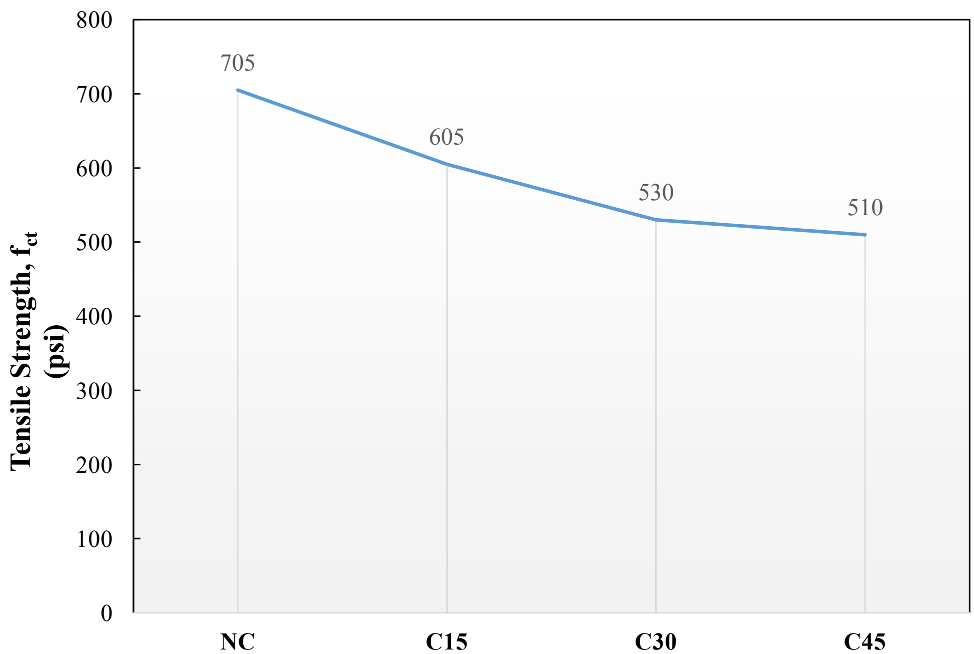

Figure 4. 16 - Tensile test results of combined (plastic, slag) replacement in course aggregate

As observed from **Figures 4.16**, the decrease in tensile strength for C15, C30, and C45 was 14.18%, 24.82%, and 27.65% respectively. Comparing C15 and C30 to P15-SF7.5-GF1 in **Figure 4.14** indicates 21% and 6% increase of tensile strength from P15-SF7.5-GF1 (500 psi). Comparing C15 and C30 to S15-SF7.5-GF1 in **Figure 4.15** indicates 3.2% and 15.5% decrease of tensile strength.

As for the **MOE** results, by comparing with NC the strength it was observed that MOE decreases when the quantity of plastic increases in P15, P30, and P45 which was also indicated by Al-Manaseer and Dalal [15]. Similarly, tensile strength decreases for S15, S30, and S45 when slag quantity increases in concrete accordingly which was also concluded by Ivanka Netinger [20] et-al in 2014.

Comparing **Figures 4.17** and **4.18**, the MOE reduction in P15 was 23.8% and for S15 MOE remained the same as the reference mix. After adding SF and GF to both plastic and slag mixtures, the MOE decrease for P15-SF7.5, P15-GF1, and P15-SF7.5-GF1 was 14.28%, 20.95%, and 25.71%, respectively. Similarly, for S15-SF7.5, and S15-SF7.5-GF1 the MOE decrease was 1.90% and 5.7% respectively. However, increase in MOE was shown for S15-GF1 which was 2.85% in comparison with reference material.

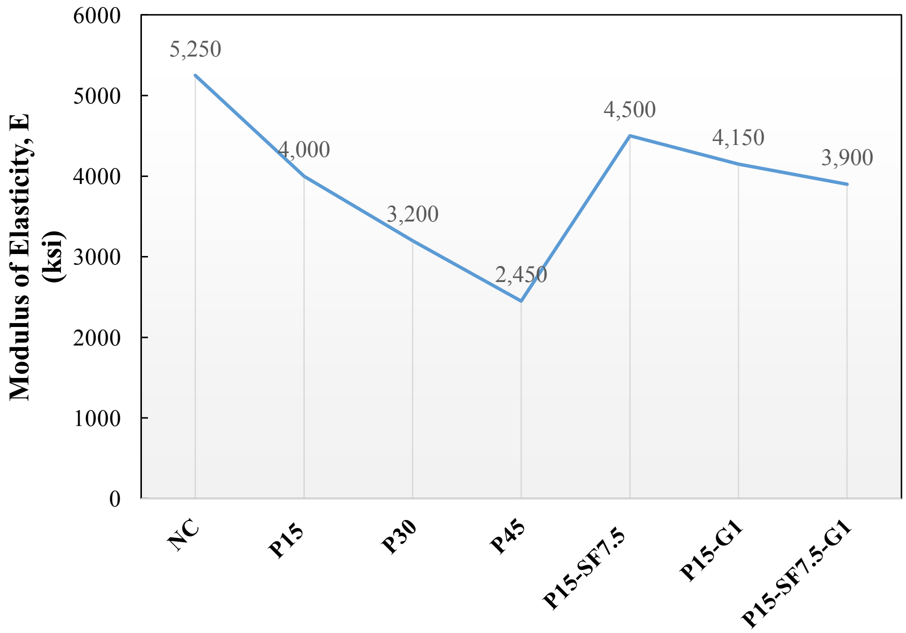

Figure 4. 17 - MOE test results of plastic replacement in course aggregate.

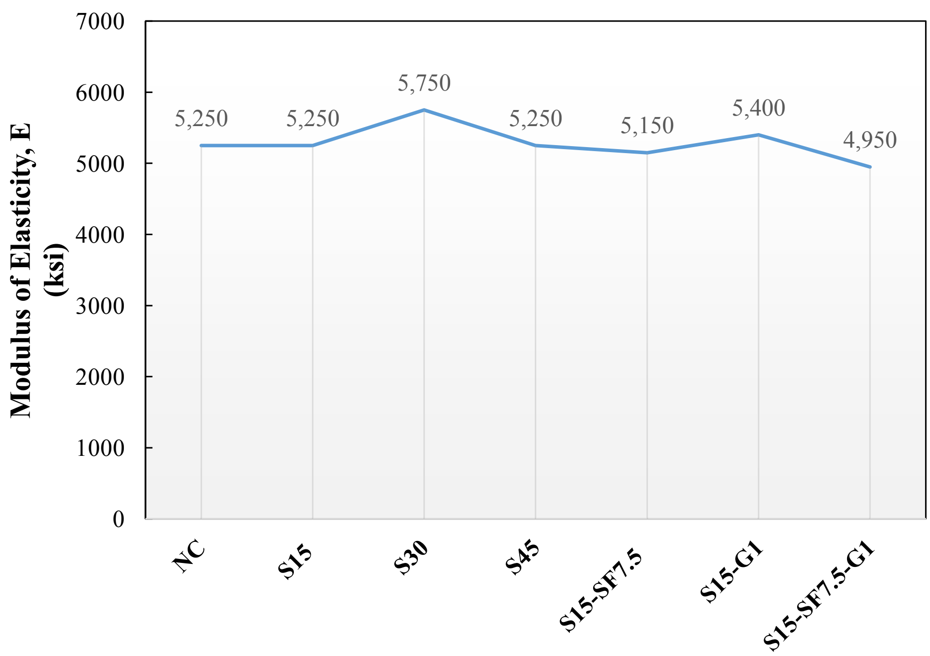

Figure 4. 18 - MOE test results of slag replacement in course aggregate

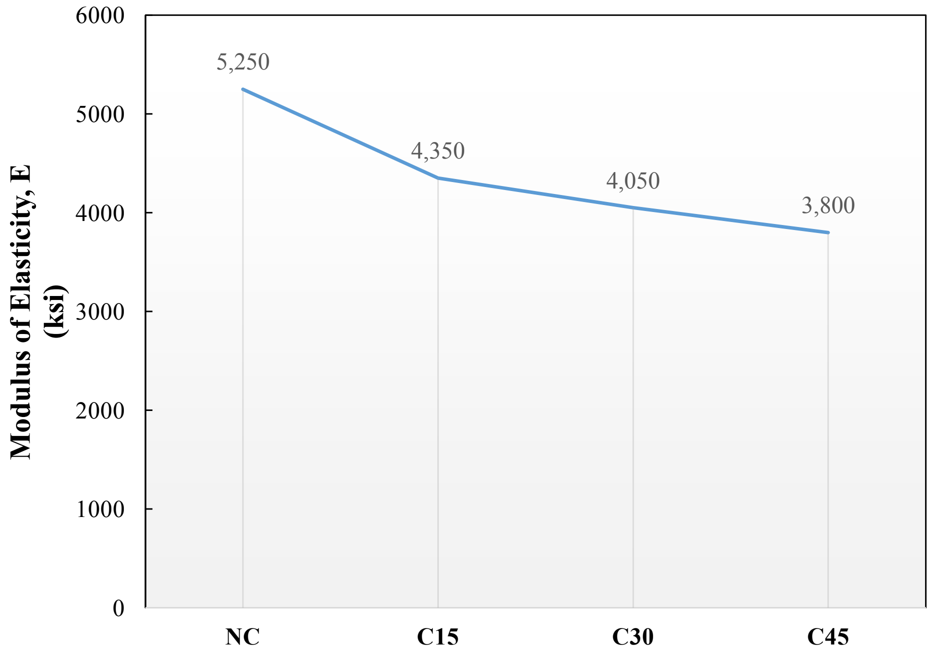

Figure 4. 19 - MOE test results of combined (plastic, slag) replacement in course aggregate

In **Figure 4.19** decrease in MOE for C15, C30 and C45 was 17.14%, 22.85% and 27.62% respectively. Comparing C15 and C30 to P15-SF7.5-GF1 in **Figure 4.17** indicates 11.54% and 3.85% increase of MOE from P15-SF7.5-GF1 (3900 Ksi). Comparing C15 and C30 to S15-SF7.5-GF1 in **Figure 4.18** indicates 12.12% and 18.18% reduction of MOE.

4.6.1. Comparison of Results to ACI Formulas

The tensile strength and MOE of concrete results obtained from experimental testing were compared with the ACI 318-14 tensile strength and MOE formulas. The tensile strength formula is provided by ACI 19.2.4.3 (**Equation 4.1**) and the MOE formula by ACI 19.2.2.1.a. (**Equation 4.2**).

$$6.7\sqrt{f_C'} \quad \textbf{Equation 4.1}$$

$$33w_C^{1.5}\lambda\sqrt{f_C'} \quad \textbf{Equation 4.2}$$

The unit weight (w_c) of concrete was calculated for each mixture from the design mix. In **Table 4.11**, the compressive strength (f_c'), tensile strength (f_{ct}) and MOE (E_c) of concrete were obtained from experimental results. Tensile strength ($f_{ctACI\ 19.2.4.3}$) and MOE ($E_{ACI\ 19.2.2.1.a}$) of concrete was calculated using ACI 318-14 formulas. For plastic aggregate the percent difference between theoretical and actual MOE was ±9 %. For tensile strength the measured value was higher than the theoretical value and the difference was up to 15%.

Table 4.11 – Experimental MOE and tensile strength plastic aggregate.

	W_c	λ	f_c' (psi)	E_c (ksi)	E_{ACI} 19.2.2.1.a	%diff	f_{ct}	f_{ctACI} 19.2.4.3	%diff
NC	149.8	1.00	7220	5250	5144	2.0	705	569	19.2
P15	142.4	1.00	5490	4000	4155	-3.9	560	496	11.4
P30	134.9	1.00	3840	3200	3206	-0.2	440	415	5.6
P45	127.5	1.00	2960	2450	2585	-5.5	365	365	0.1
P15-SF7.5	141.7	1.00	5450	4500	4109	8.7	510	495	3.0
P15-G1	142.4	1.00	5360	4150	4105	1.1	575	491	14.7
P15-SF7.5-G1	141.7	1.00	5630	3900	4178	-7.1	500	503	-0.5

For slag aggregates in **Table 4.12**, MOE of experimental data was 12% more than theoretical except for S15-SF7.5-G1 which was 5% less than theoretical value. For tensile strength the measured value was higher than the theoretical value and the difference was up to 15%.

Table 4.12 - Experimental MOE and tensile strength slag aggregate.

	W_c	λ	f_c' (psi)	E_c (ksi)	E_{ACI} 19.2.2.1.a	%diff	f_{ct}	f_{ctACI} 19.2.4.3	%diff
S15	147.9	1.00	7710	5250	5210	0.8	670	588	12.2
S30	148.8	1.00	7210	5750	5085	11.6	670	569	15.1
S45	148.2	1.00	7110	5250	5022	4.3	615	565	8.1
S15-SF7.5	147.2	1.00	7600	5150	5136	0.3	620	584	5.8
S15-G1	147.8	1.00	7260	5400	5054	6.4	640	571	10.8
S15-SF7.5-G1	147.4	1.00	7720	4950	5191	-4.9	625	589	5.8

For combined aggregate mix in **Table 4.13**, the experimental MOE and tensile strength values were more than theoretical up to 9% and 18% respectively.

Table 4.13 - Experimental and theoretical comparison of combined aggregate MOE and Tensile strength

	W_c	λ	f_c' (psi)	E_c (ksi)	E_{ACI} 19.2.2.1.a	%diff	f_{ct}	f_{ctACI} 19.2.4.3	%diff
C15	144.4	1.00	5520	4350	4255	2.2	605	498	17.7
C30	139.7	1.00	5110	4050	3895	3.8	530	479	9.6
C45	135.0	1.00	4510	3800	3475	8.6	510	450	11.8

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Introduction

The objective of this research was to study the utilization of plastic and slag with combination of silica fume and glass fibers in concrete. Mixtures of different proportions were made, which contained plastic and slag in different proportions, and evaluation of mechanical properties after 28 days. The properties studied included compressive strength, tensile strength and modulus of elasticity.

Awareness about environmental issues and waste management has increased over the past few decades. This has led to utilization of waste materials such as plastic and slag in concrete mixtures. The research has presented the use of plastic and slag as aggregate alternatives in concrete.

5.2. Conclusion

Compressive strength: Natural aggregate can be replaced by recycled/waste plastic by 15% without reducing the mechanical properties to preclude the use in structural applications. Similarly, slag can partially replace natural stone aggregates up to 45%. Significant reduction in mechanical properties were observed when the plastic replacement percentage was increased from 15% to 30% or 45%. For slag replacement, initially compressive strength was increased to 15% replacement, however, a slight decrease of compressive strength was shown for 30% and 45%.

In comparison to NC, increase or decrease in strength of mixtures are as follows:

- Aggregate replaced by plastic up to 15% decreases the compressive strength by approximately 24%, while 15% slag replacement resulted in a compressive strength increases of 6.05 %.

- For P15-SF7.5-GF1, the compressive strength reduction was 22% while the compressive strength of S15-SF7.5-GF1 increased 6.93%.
- For the combined mixture C15, the compressive strength reduction was 23.55%, which was slightly more than P15-SF7.5-GF1 and significantly more than S15-SF7.5-GF1.
- The results indicate that the compressive strength of concrete was unsatisfactory effected by increasing quantity of plastic. However, slag quantity had a positive impact on compressive strength.

Tensile strength: Comparing to NC, an increased percentage in concrete of plastic and slag reduced the tensile strength of concrete. The same result was shown when 7.5% silica fume and 1% glass fibers were added to plastic and slag individually and altogether.

In comparison to NC, a decrease in tensile strength of the mixtures were as follows:

- For 15% aggregate replaced by plastic P15, a significant reduction of tensile strength up to 20.5% was observed. For 15% slag replacement S15, the tensile strength reduction was 4.93%.
- Similarly, strength reduction for P15-SF7.5-GF1 was 29.07%, as compared to 11.35% for S15-SF7.5-GF1.
- For the combine mixture C15 and C30, the strength was reduced by 14.18%, and 24.82%, respectively.
- The results indicate that the quantity of plastic negatively impacts tensile strength of concrete. However, slag quantity effects tensile strength to a lesser degree.

MOE: In comparison to NC, the modulus of elasticity of concrete decreases with an increase in plastic quantity in concrete. However, increasing the slag quantity in concrete had no effects on MOE up to 15% of slag replacement and MOE increased for 30% slag replacement. When 7.5% silica fume and 1% glass fibers were added to plastic and slag individually and altogether, a significant decrease in MOE was shown for plastic. However, for slag mixtures the MOE either remained the same or a slight decrease was noted.

In comparison to NC, increase or decrease in MOE of concrete as follows:

- For P15, the MOE reduction was 23.8%. While for S15, the MOE remained the same. The MOE decreased by 25.71% for P15-SF7.5-GF1 and 5.7% for S15-SF7.5-GF1. The combined mixtures C15 and C30 resulted in a MOE reduction of 17.14%, and 22.85%, respectively.
- The results indicate that the quantity of plastic had an unsatisfactory impact on tensile strength of concrete. However, the slag quantity indicated a satisfactory impact on MOE of concrete.

5.3. Recommendations

- The plastic aggregate can potentially be used at replacement rates up to 15% in concrete mix without significant compressive, tensile strength, and MOE reduction.
- Slag indicated positive effects on mechanical properties of concrete and can be used up to 45% in concrete.
- Combined plastic and slag (with silica fume and glass fibers) can be used up to a combined replacement of 30% without a significant decreases in mechanical properties of concrete.

- Combined mixtures can be used in non-structural construction works such as pavements, road barriers, sidewalks, and buildings not more than one story.

5.4. Future Research

- Slag provided more strength than plastic. In combined mixtures, the slag and plastic replacement were at the same quantity proportion. Future investigation of mixtures with lesser plastic quantity and larger slag quantity is recommended as it may further improve concrete mechanical properties such as 5% plastic 10% slag or 2% plastic and 13% slag for C15, 5% plastic and 25% slag for C30.
- Different plastic sizes and types need to be considered for further research. More research is encouraged to use different percentage of plastic and slag in nonstructural elements.
- Different percentage of admixtures are encouraged to investigate the mechanical properties of concrete containing plastic and slag.

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