Lightweight concrete created utilizing fine pumice aggregate

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ABSTRACT

In this study, Structural Lightweight Concrete (SLWC) was investigated for its properties using pumice stone as a lightweight aggregate. Three different unit weights of lightweight concrete (G1, G2, and G3) were produced, varying the volume percentages of polypropylene (PP) fiber (0.0%, 0.25%, and 0.50%). The research aimed to understand the impact of unit weight and PP fiber content on both fresh and mechanical properties of SLWC.

Fresh properties, including workability, were assessed, revealing that workability increases with decreasing unit weight of lightweight concrete but decreases with increasing PP fiber volume. Mechanical properties such as compressive strength, flexural strength, and split tensile strength were evaluated.

The results showed that as the PP fiber volume increased from 0.0% to 0.50% and the unit weight of lightweight concrete decreased, compressive strength and split tensile strength decreased. However, flexural strength, thermal conductivity, and performance at elevated temperatures improved.

The study also investigated the correlation between compressive strength and ultrasonic pulse velocity (UPV), providing insights into the non-destructive testing methods for assessing SLWC

Keywords: SLWC, pumice aggregate, PP fiber, unit weight, mechanical property.

1-Introduction

The use of Structural Lightweight Aggregate Concrete (SLWAC) dates back to ancient times, with civilizations such as the Sumerians utilizing lightweight materials in their constructions. While initially natural volcanic aggregates like scoria and pumice were employed, the 19th century saw a shift towards investigating artificial aggregates due to scarcity and the development of reinforced concrete.

SLWAC, characterized by its compressive strength of at least 17 MPa and a unit weight ranging from 1350 to 1900 kg/m^3, has been extensively utilized in civil engineering for its advantages over normal weight concrete. These include higher strength-to-weight ratio, lower density, enhanced fire resistance, improved durability, and superior thermal and sound insulation properties.

Pumice, a natural lightweight coarse aggregate of volcanic origin, is widely used in lightweight concrete production due to its low specific gravity. However, its availability is limited to regions with volcanic activity. Lightweight concrete can be produced through various methods, including utilizing low-density aggregates, aerating the concrete, or omitting fine aggregates.

The purposes of using lightweight concrete vary, with applications ranging from structural use to masonry and heat insulation. To enhance concrete properties, fibers such as polypropylene are often added, improving tensile and flexural strength while reducing plastic shrinkage and thermal cracking. Recent studies have shown the efficacy of polypropylene fibers in enhancing the mechanical properties of lightweight concrete, particularly in resisting higher temperatures.

In this project, we investigate the effects of different volumes of polypropylene fibers (0.25%, 0.5%, and 0.75%) on the compressive, flexural, and splitting tensile strength, workability, as well as compressive and flexural toughness of structural lightweight concrete.

2-Object

This paper aims to explore how fire affects the residual compressive strength of fiber-reinforced structural lightweight concretes. Initially, it will investigate the impact of varying volumes of polypropylene fiber on stress-strain behavior, compressive and flexural toughness of such concretes. Subsequently, the study will employ ultrasonic pulse velocity measurements to analyze the correlation between compressive strength and Vp and Vs values of lightweight concrete post-fire exposure. Additionally, it will examine the influence of polypropylene fiber on residual compressive strength after fire exposure. Thermal conductivity properties of each mix will also be assessed. Furthermore, the paper will delve into the effects of different proportions of polypropylene fiber and pumice on compressive strength, splitting tensile strength, flexural strength, workability, as well as compressive and flexural toughness, and unit weight of structural lightweight concrete

3-LITERATURE REVIEW

This chapter provides a concise overview of existing research conducted on lightweight concrete testing, particularly focusing on properties related to strength, temperature resistance, and durability. Both experimental and analytical studies investigating these aspects of lightweight concrete properties are examined. By reviewing past experimental investigations, we aim to gain a comprehensive understanding of the most significant findings in the field. Subsequently, a thorough literature review is conducted to summarize the current state of knowledge.

Mohod (2015) conducted an empirical study on the application of polypropylene fibers in reinforced concrete. Meanwhile, Milind (2015) investigated the impact of varying percentages of polypropylene fibers on the properties of high-strength concrete mixes (M30 and M40). Their experimental approach involved assessing the effects of different fiber contents (ranging from 0% to 2%) on compressive, tensile, and flexural strength under various curing conditions. The primary objective of the research was to determine the optimal content of polypropylene fibers in the mix. The results indicated a notable enhancement in compressive, tensile, and flexural strength with the addition of fibers. However, both studies suggest the need for further research to gain a deeper insight into the mechanical properties of fiber-reinforced concrete.

In recent years, there has been a growing interest in employing fibers to enhance the reinforcement of composites. Kolli and Ramujee (2013) conducted a study focusing on the strength properties of concrete reinforced with polypropylene fibers. Their research investigated the compressive strength and splitting tensile strength of concrete samples containing varying fiber content (ranging from 0% to 2%). The study revealed that the highest compressive strength (45.25 MPa) was achieved with a 1.5% polypropylene fiber content.

Guler (2018) examined the impact of fibers on the strength and resilience of structural lightweight concrete. The study involved the incorporation of two different sizes (12 and 14 mm) of polyamide fibers. The findings indicated that the inclusion of 0.75 hybrid polyamide fibers (combining micro and macro sizes) led to a decrease in workability. However, it resulted in enhancements in compressive strength, toughness, splitting tensile strength, and flexural strength of structural lightweight concrete (Guler, 2018).

Shihada (2017) investigated the influence of polypropylene fibers on the fire resistance of concrete. Various concrete mixtures were prepared with different volumes of polypropylene fibers: 0%, 0.5%, and 1%. These mixtures were subjected to heating at temperatures of 200°C, 400°C, and 600°C for durations up to 6 hours, followed by testing for compressive strength. The study concluded that the presence of polypropylene fibers resulted in higher relative compressive strength compared to concretes without such fibers after exposure to fire. Furthermore, the optimal residual compressive strength after fire exposure was observed in samples containing 0.5% of polypropylene fibers.

In their study, Harun Tanyildizi and colleagues (2007) statistically and experimentally investigated the impact of silica fume on the compressive and splitting tensile strength of lightweight concrete after exposure to high temperatures. They varied the percentage of silica fume in the mixture, ranging from 0% to 30%, replacing Portland cement. Specimens were then heated in an electric furnace to temperatures of 200°C, 400°C, and 800°C, and subsequently tested for splitting tensile and compressive strength. The results indicated that the highest compressive and splitting tensile strength was achieved when 20% silica fume was utilized across all temperature levels.

Furthermore, the study observed a decrease in both compressive and splitting tensile strength of lightweight concrete as the temperature increased, starting from 200°C.

4-METHODOLOGY

1-The Cement

The study utilized ASTM Normal Portland Cement (NPC) CEM I 52.5R for all concrete formulations. This cement, manufactured by TS EN 197-1-CEM Adana in Turkey, boasts a 28-day compressive strength of 52.5 N/mm2 (MPa) and a specific gravity of 3.156 g/cm3. Ensuring the cement's freshness and uniformity is imperative, with strict adherence to quality standards. Any presence of foreign particles or lumps renders the cement unsuitable for use. Proper storage in dry conditions is essential to maintain its integrity. Refer to Table 3.1 for a comprehensive overview of the chemical and physical characteristics of the cement.

2-Silica Fume

ilica fume, a crucial mineral admixture, consists of ultrafine particles of amorphous silicon dioxide (SiO_2), substantially smaller (100 to 150 times) than cement grains. Renowned for its remarkable physical and chemical characteristics, silica fume serves as a highly reactive pozzolan, making it invaluable in concrete admixtures. Concrete formulations incorporating silica fume exhibit exceptional durability and high strength. This material is derived from the production of silicon metal and alloys in electric furnaces. In this study, silica fume powder was employed to enhance both the fresh and hardened mechanical properties of structural lightweight concrete. For a comprehensive overview of the physical and chemical attributes of silica fume, please refer to Table 3.2.

3-Pumice Aggregate.

Pumice, an extrusive igneous volcanic rock formed from rapidly cooled air-pocketed lava, exhibits a low density and high porosity. In this research, fine-grained pumice with particle sizes ranging from 0 to 3 mm serves as a lightweight aggregate. The raw pumice material, sourced from a quarry in Erciş (Van), undergoes a drying process in an oven for 48 hours. Subsequently, it is crushed to achieve the desired particle size range of 0 to 3 mm using a laboratory-type dodge jaw crusher. Refer to Figure 3.1 for visual representation of the pumice particles sized from 0 to 3 mm.

4-Filler and Aggregate Stone

Porphyritic natural stone sourced from a Van quarry will serve as both filler and normal-weight aggregate in structural lightweight concrete. The raw material will undergo size reduction using a laboratory dodge jaw crusher to achieve a particle size of 0-2 mm. Following crushing, the materials will be sieved and categorized based on size (0.5-1 mm and 1-2 mm for fine aggregate, <500 microns for filler) before incorporation into the lightweight concrete mixture.

5-Polypropylene Fiber

Polypropylene, the initial stereo regular polymer to gain industrial significance, holds a pivotal role in the construction sector, particularly with its fibers extensively employed in fiber-reinforced concrete. For this study, commercially accessible fibrillated Polypropylene fibers will be utilized.

6-Water

The water utilized in the mixing is to be fresh and free from any organic and harmful solutions which will lead to deterioration in the properties of the mortar. Saltwater is not to be utilized. Potable water is fit for utilize mixing water as well as for curing of beams.

7-Superplasticizer

For achieving better workability for fiber-reinforced structural lightweight concrete, the use of a superplasticizer is required. Therefore, a commercially available superplasticizer with the brand name of Gallium ACE-30 will be used in this study.

8-Air-Entraining Agents

Air-entrained concrete contains numerous tiny air bubbles per cubic meter, enhancing its workability and durability while reducing overall weight. This type of concrete is made using air-entraining admixtures, such as the commercially available MasterAir-200, to improve workability and reduce weight in the structural lightweight concretes being investigated in this study.

6-Tests for Mechanical Properties

1- Compressive Strength Test

In concrete testing, the compressive strength is determined by extracting standard cylindrical samples measuring 150 mm in diameter and 300 mm in height after 28 days of casting. During this curing period, the concrete's strength progressively increases, with the rate of gain slowing down after 28 days, indicating near-final strength attainment. As such, the compressive strength at 28 days, representing approximately 99% of the concrete's ultimate strength, serves as the primary basis for design and evaluation. In this study, compressive strength assessment involved testing three 150x300-mm cylinders at 7, 14, and 28 days post-casting, adhering to ASTM C39 standards. A UTEST hydraulic compression machine with a maximum capacity of 3000 KN was utilized for testing, as depicted in Figure 3.4.

Figure 3. 4Compressive Strength Equipment

2- Splitting Tensile Strength Test

The tensile test, which is one of the most common test methods in the world., it is used to determine the maximum load (tensile strength) and that a material behavior of a sample when applying an axial tensile load. In this test, utilization cubic specimens 150mm*150mm determined tensile strength at 28 days. For according to ASTM C39 used a UTEST hydraulic compression machine with an optimum capacity of 3000 KN, as shown in Figure 3.4

3- Flexural Strength Test

In assessing the tensile strength of concrete, flexural strength is commonly measured using un-reinforced beam or slab specimens. Two methods, namely the mid-point loading method outlined in ASTM C293 or the third point loading method specified in ASTM C78, are typically employed. In this study, flexural strength determination utilized concrete beam specimens sized 100x100x400 mm and followed the third point loading method as per ASTM C78 standards. The testing apparatus employed was the UTEST Bending Apparatus, as depicted in Figure 3.5.

Figure3.5 Flexural Strength Equipment

4-Slump Test

Generally, concrete slump value is utilized to find the workability, which indicates water-cement ratio, but there are different factors containing properties of materials, mixing methods, dosage, admixtures, etc. also affect the concrete slump value. One of the most important factors affecting the quality of concrete applications is concrete consistency. Concrete should be poured at the appropriate consistency according to the ambient conditions.in this paper, the procedures ASTM C143 used to prepare the slump cone (Figure 3.8). a sample is taken from fresh concrete and put the slump cone in three equal layers. The rod used to tamp 25 times in each layers. then the cone is filled, the surface of the mold smoothed by the role. Then the mold removed vertically. afterwards, the slump is taken from the vertical distance between the top of the sample and the top of the mold. Also, it can be seen the value of slump test in table 3.8.

Table 3. 1 concret mix propotion

Gr.	Mix	Cement	Silica Fume	Filler	water	W/B	AEA	SP	Fine Aggregate			Fiber
									P(0-1)	P(1-2)	Agg.	
		kg/m^3	kg/m^3	kg/m^3	L/m^3	%	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3
GR 1	#1	575	145	173	320	44.5	1.15	32	202	416	78	0
	#2	575	145	173	320	44.5	1.15	32	202	416	78	2.25
	#3	575	145	173	320	44.5	1.15	32	202	416	78	4.5
GR 2	#4	575	145	173	320	44.5	1.15	32	155	320	78	0
	#5	575	145	173	320	44.5	1.15	32	155	320	78	2.25
	#6	575	145	173	320	44.5	1.15	32	155	320	78	4.5
GR 3	#7	575	145	173	320	44.5	1.15	32	101	208	78	0
	#8	575	145	173	320	44.5	1.15	32	101	208	78	2.25
	#9	575	145	173	320	44.5	1.15	32	101	208	78	4.5

S.F:slica fume S.P:superplasticizer P.P:polypropylene fiber L:liter

7-RESULT

1. Workability

This study examined the slump values and unit weights of various concrete mixes, detailed in Table 4.1. Three sets of lightweight concrete with different unit weights were investigated, each incorporating polypropylene (PP) fiber at concentrations of 0%, 0.25%, and 0.5%. Maximum slump values were recorded for the control mixes in each group (M1, M4, and M7), measuring 230 mm, 270 mm, and 285 mm, respectively. The workability of control mixes improved with higher unit weights of lightweight concrete due to reduced pumice usage, as pumice, being porous, absorbs water, thereby decreasing workability. Within each group, increasing the volume of PP fiber led to decreased workability of lightweight concrete. Specifically, in G1, G2, and G3, the slump values decreased from 230 to 10 mm, 270 to 150 mm, and 285 to 210 mm, respectively, as the PP fiber content increased from 0% to 0.5%. The high water absorption of PP fiber, attributed to its elevated specific surface area, reduces the required water content in the concrete mix, consequently impeding the free flow of fresh concrete (Alsadey & Muhsen, 2016).

Table 4.1 Slump value and Density

Group	mix	Slump (mm)	Density (Kg/m3)
G1	Mix1	230	1585
	Mix2	135	1580
	Mix3	10	1490
G2	Mix4	270	1489
	Mix5	235	1482
	Mix6	150	1544
G3	Mix7	285	1726
	Mix8	250	1690
	Mix9	210	1614

2- **Compressive Strength**

In this study, uniaxial compression tests were conducted on (300*150) mm cylinder samples at 28 days, following TS EN 12390-3 standards, aiming to establish the stress-strain relationship. The volume of PP fiber and the unit weight of concrete were identified as significant factors affecting the stress and strain behavior of concrete.

Figure 4.1 illustrates the stress-strain curves of G1, where the control mix (M1) achieved a maximum compressive strength of 29 MPa without PP fiber. However, as the volume of PP fiber increased from 0.25% to 0.5%, the compressive strength decreased from 26 MPa to 23 MPa, respectively. This decrease is attributed to the reduced workability of concrete with increasing PP fiber volume, leading to inadequate compaction and effective micro-crack retention by the fibers, consequently reducing compressive strength (Alsadey & Muhsen, 2016). Additionally, an increase in PP fiber volume resulted in increased displacement.

In G2, the unit weight of lightweight concrete decreased from 1585 to 1490 kg/m3, approximately 6%, as the volume of PP fiber increased from 0% to 0.25%. This reduction is attributed to the lightweight nature of PP fiber.

Figure 4.2 demonstrates the impact of PP fiber on the compressive strength of G2. A 10% decrease in compressive strength was observed with a 0.5% increase in PP fiber volume. In G3, the addition of 0.5% volume of polypropylene fiber led to a 40% decrease in compressive strength compared to the control mix (M6).

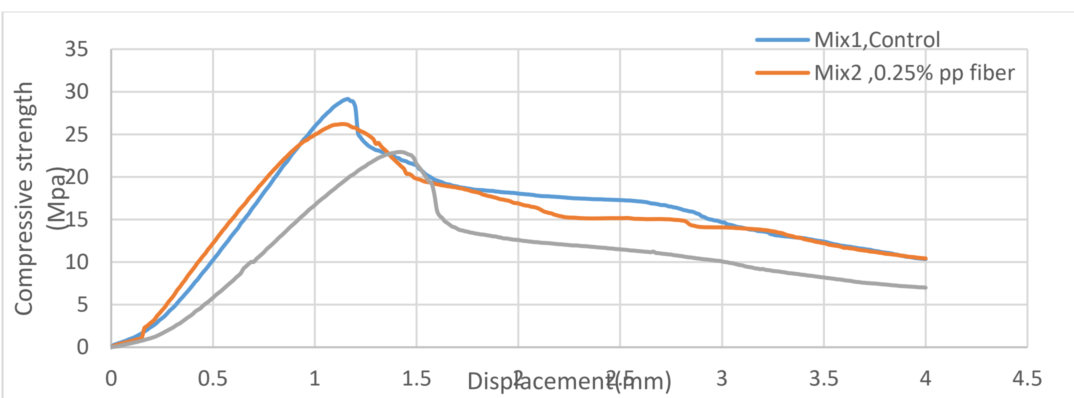

Figure 4.1The Effect of polypropylene fiber on the compressive strength of SLWC specimen’s (M1, M2, M3)

Figure 4.4 depicts the impact of unit weight on the compressive strength of lightweight concrete for M1, M4, and M7, excluding PP fiber. The compressive strength of PP fiber-free concrete increases from 14 to 30 MPa as the unit weight of lightweight concrete rises from 1489 to 1726 kg/m³. A higher quantity of lightweight aggregate necessitates a lower unit weight. Since the strength of lightweight aggregate is comparatively low, a decrease in unit weight results in reduced compressive strength. Specifically, when unit weight decreases by 14%, the corresponding reduction in compressive strength is 53% for PP fiber-free lightweight concrete.

In Figure 4.5, the influence of unit weight on compressive strength is illustrated when the volume of PP fiber is held constant at 0.25%. Here, a 12% reduction in unit weight leads to a 56% decrease in compressive strength with 0.25% PP fiber.

Figure 4.6 presents the relationship between compressive strength and unit weight of SLWC specimens (M3, M6, M9) containing 0.5% polypropylene fiber. With an increase in unit weight from 1490 to 1614 kg/m³, compressive strength decreases from 23 to 18 MPa, respectively.

Based on the study's findings, lightweight concrete in G3 with varying volumes of PP fiber can be utilized for structural elements such as columns, beams, shear walls, and slabs. Conversely, concrete from G2, characterized by lower unit weight, can be suitable for lightweight elements like concrete blocks and certain pre-cast components.

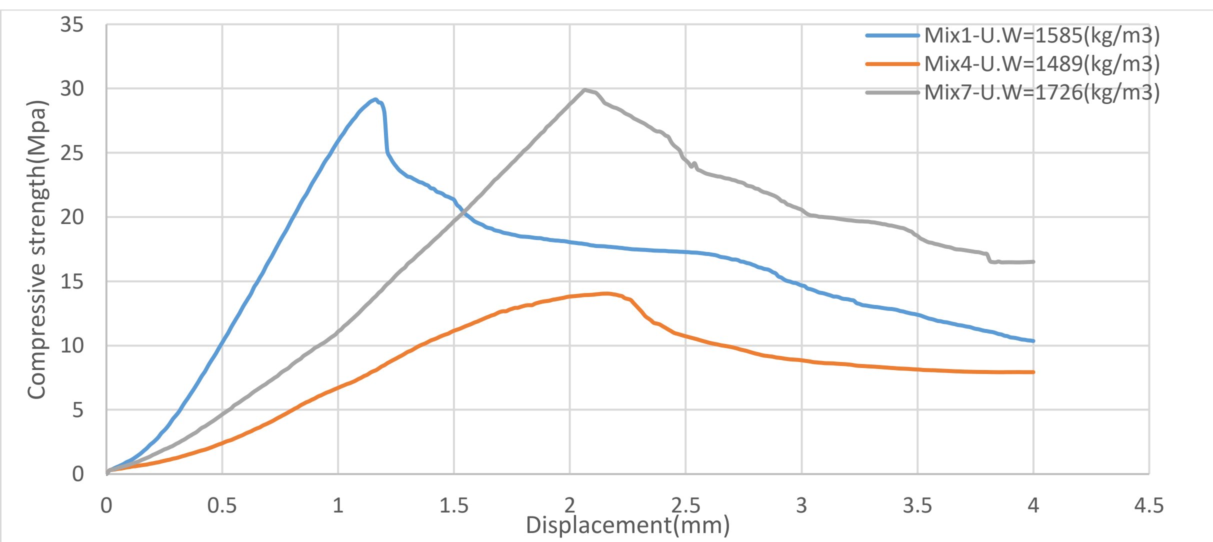

Figure 1 The relationship between compressive strength and unit weight of fiber-reinforced LWC specimens (M1, M4, M7) without polypropylene fiber

3- **Flexural Strength**

Flexural tensile tests were conducted on beam test samples measuring (400*100*100) mm at 28 days according to EN 12390-5 standards. This research aims to understand the correlation between compressive stress-strain and the impact of PP fiber volume and concrete unit weight on the flexural strength of lightweight concrete.

In Figure 4.7, the influence of PP fiber on the flexural strength of G1 (M1, M2, M3) is depicted. The highest flexural strength of 1.82 MPa was achieved in M3, which had the highest volume of PP fiber. As the volume of PP fiber increased from 0 to 0.5%, the flexural strength rose from 1.39 to 1.82 MPa, respectively. This improvement can be attributed to the enhanced mechanical bond between the cement paste and fiber (Dharan & Aswathy, 2016). Moreover, as the volume of PP fiber increased, the displacement also increased, as PP fiber acts as reinforcement in concrete, thereby enhancing its ductility.

Figure 4.8 illustrates the effect of PP fiber on the flexural strength of G2. As the volume of PP fiber increased from 0 to 0.25%, the flexural strength of lightweight concrete increased by 47%. Compared to the control mix (M6) within the same group, the flexural strength increased by 36% with the addition of 0.5% volume of polypropylene fiber.

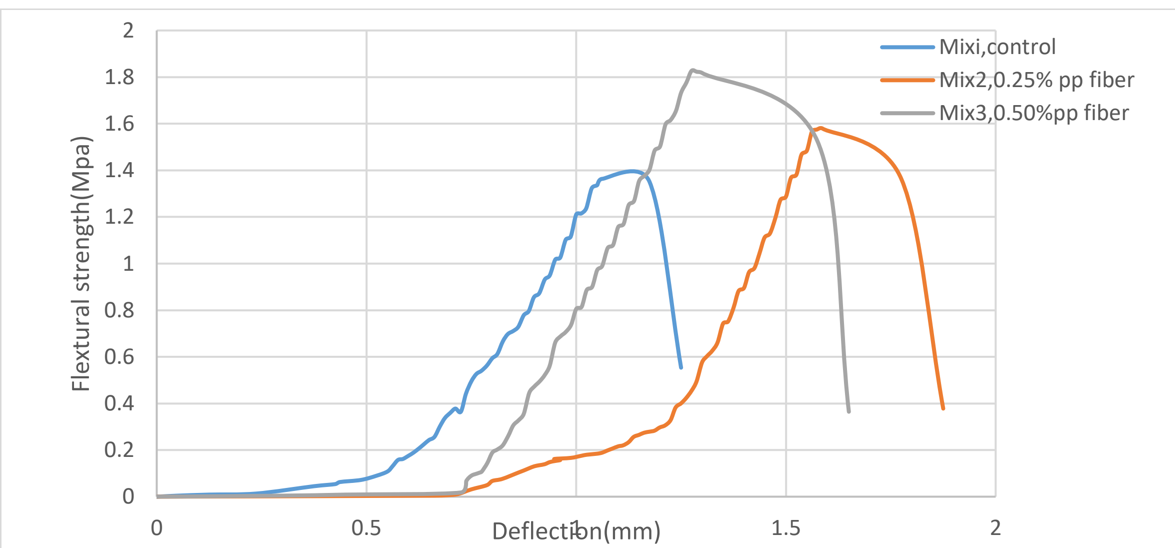

Figure 2 The Effect of polypropylene fiber on the flexural strength of SLWC specimens (M1, M2, M3)

4-Split Tensile Strength

Splitting tensile strength tests were carried out on 150mm*150 mm cube test specimens at 28 days in accordance with EN 12390-6. the split tensile strength decreases with the increasing volume of PP fiber. The split tensile strength systematically decreasing in G1 (M1, M2, and M3) by 8% as shown in Figure 4.13 when the volume of PP fiber increases by 0.5%, because of weak bonding between pp fiber and cement matrix (Libre, Mohammad , Mehrdad , & Parviz , 2010). Figure 4.14 shows that the split tensile strength decreases from 1.68 to 1.2Mpa when the volume of PP fiber increases from 0 to 0.5%. the maximum Split tensile strength 2.11 Mpa obtained in M8 when the volume of PP fiber is 0.25%as shown in Figure 4.15.

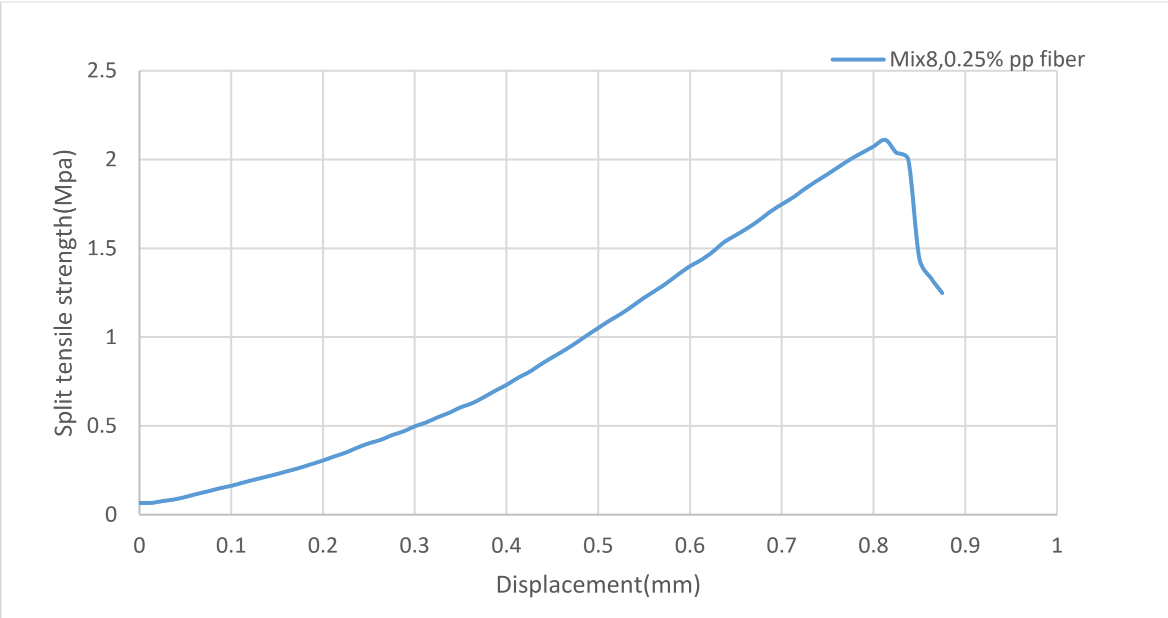

Figure 3 The Effect of polypropylene fiber on the split tensile strength of SLWC specimen's (M8)

8-CONCLUSION

The study focused on examining the impact of unit weight and volume of PP (polypropylene) fiber on the fresh and hardened properties of lightweight concrete (SLWC). Here's a summary of the findings:

1. The volume of PP fiber significantly affects the workability of lightweight concrete, with higher fiber content leading to decreased workability. For instance, in G3, the slump value decreased from 285 to 210 mm as the PP fiber content increased from 0 to 0.5%.

2. The highest compressive strength of 29 MPa was observed in the control mix (M1) without PP fiber. Decreasing the unit weight of lightweight concrete resulted in lower compressive strength, and increasing the volume of PP fiber also reduced concrete strength. Compressive strength increased from 14 to 30 MPa as the unit weight of lightweight concrete increased from 1489 to 1726, respectively.

3. The optimum flexural strength of 1.82 MPa was achieved in M3, which had the highest volume of PP fiber. Increasing the volume of PP fiber from 0 to 0.5% resulted in an increase in flexural strength from 1.39 to 1.82 MPa.

4. Split tensile strength decreased from 1.68 to 1.2 MPa with increasing volume of PP fiber from 0 to 0.5%. The maximum split tensile strength of 2.11 MPa was observed in M8 with a volume of PP fiber at 0.25%.

5. The compressive strength exhibited slight development as the temperature increased up to 150°C. However, further increase in temperature from 150 to 800°C led to a sharp decrease in compressive strength.

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