Strengthening a thin crust of lightweight pumice aggregate in low strength concrete for tensile and compressive strengths

Karim, F.R.[1,*]

[1] lecturer, College of Engineering, University of Sulaimani, Al-Sulaimanyah, Kurdistan region-Iraq

*Corresponding Author: (Phone: + 964 770 22 48 973; Email: ferhad.karim@univsul.edu.iq)

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Abstract

The primary drawback of lightweight aggregate is its porous surface, which hinders the production of lightweight concrete. Therefore, the process of infusing the porous spaces inside the lightweight aggregate and forming a thin layer around the aggregate results in the production of more robust lightweight concrete. This inquiry aims to highlight the impact of silica fume and Sika level 100T on the tensile and compressive strengths of lightweight concrete. Therefore, we cast and tested a total of 84 lightweight concrete cubes and prisms. In this way, adding 7.23% silica fume to lightweight pumice aggregate concrete raises the compressive strength by up to 22.73% and lowers the flexural strength by up to 5.4%. Also, adding 9.6% Sika level 100T made the lightweight pumice aggregate concrete, which has 7.23% silica fume, 34.57% stronger when it came to compressive strength. By strengthening the bond between the pumice aggregate and the concrete matrix, the addition of 9.6% Sika level 100T significantly boosts the flexural strength by up to 28.12%.

Keywords: Cementitious crust, Lightweight concrete, Pumic stone, Silica fume, and Sika level .

1. Introduction

Lightweight aggregate is used to make lightweight concrete when its weight is less than 1120 kg/m^3(Mehta andMonteiro, 2006). Lightweight aggregates may be made from both natural and manufactured resources, including pumice, volcanic cinders, iron blast furnace slag and sintered fly ash (ACI 213R-14, 2003, Miled et al., 2004, Neville, 2011).The mechanical properties of lightweight aggregate concrete are largely dependent on the amounts of aggregate in the formulation (Kitouni andHouari, 2013).

Each porous aggregate has unique characteristics that have a significant impact on the qualities of lightweight concrete. Pumice concrete was typically regarded inadequate for load-bearing applications among lightweight concretes (Ugur, 2003). Thus, plugging these holes on the top of the aggregate may result in a stronger, lighter concrete capable of supporting weights.Pumice stone is volcanic in nature and has a bulk density of 400 to 800 kilogrammes per cubic metre. It is used to make concrete with a density of 450 to 1200 kg per cubic metre (Sivalingarao andManju, 2016).
Furthermore, pumice aggregates have the physical qualities of concrete aggregates and may be efficiently employed as lightweight aggregates, and the concrete generated with these aggregates meets the standards for low strength lightweight concrete (Mang'uriu et al., 2012).

In this study, we focus on how adding a thin cementitious crust to the surface of pumice aggregate affects the compressive and tensile strengths of lightweight concrete with silica fume. Therefore, this study examines the use of cementitious materials to fill the surface pores on pumice aggregates, as well as the density and mechanical characteristics (cube compressive strength, flexural strength, and so on) of lightweight pumice concrete.

2. LITERTAURE REVIEW

As seen in Figure 1, the surface of lightweight pumice aggregates is covered with many pores. A thin cementitious crust applied to pumice aggregate appears to improve the workability retention of the self-compacting concrete (Papanicolaou andKaffetzakis, 2011).

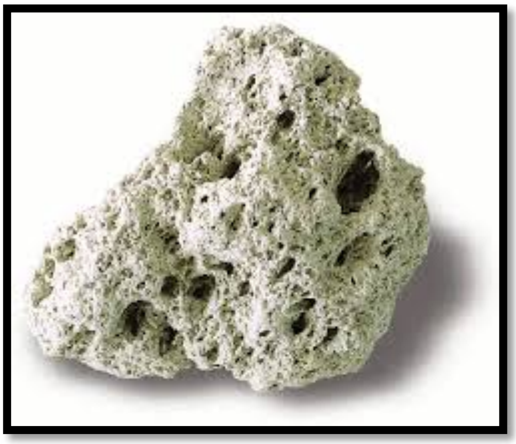

Figure 1: Surface porous on the pumice aggregate

A study was conducted by Katkhuda and Shatarat to investigate the impact that silica fume has on high strength lightweight concrete. In the course of this investigation, the various percentages of silica fume, namely 0.5, 10, 15, 20, and 25 percent, were used for water-binder ratios ranging from 0.26 to 0.42 (Katkhuda et al., 2009). During the course of the investigation, it was discovered that the flexural strength saw the greatest rise, which reached 25%. On the other hand, the compressive strength showed an improvement that ranged from 15% to 25%.

Two researchers, Sivalingarao and Manju (Sivalingarao andManju, 2016), investigated the impact that silica fume had on the mechanical qualities of lightweight aggregate concrete, often known as pumice. For the purpose of this investigation, the typical aggregate has been substituted with a pumice aggregate that is composed of one hundred percent pumice by volume. In addition, cement has been mixed with silica fume in several proportions, including five, eight, ten, fifteen, and twenty percent by weight. It was discovered that the compressive strength, flexural strength, and split tensile strength all increased when silica fume was used in lieu of 10% of the cement in the mixture.

Mohammadi et al. investigated the impact that silica fume had on the characteristics of lightweight concrete that was self-compacted (Mohammadi et al., 2015). While doing this investigation, the ratio of water to binder was maintained at 0.5. It was discovered that the compressive strength and density of Lica and Perlite self-compacted lightweight concrete improved when the proportion of silica fume was raised from 5% to 15%. This was the case for both types of concrete. Additionally, the density of concrete will rise if there is an increase in the proportion of silica fume content.

3. EXPERIMENTAL WORKS

In order to investigate the impact of applying a thin cementitious crust to the surface of pumice aggregate, which is a component of lightweight concrete that contains silica fume, eighty-four cubes and prisms were cast.

A control mix proportion that was established based on mix proportioning of structural lightweight aggregate concrete, and it was intended for 15.57MPa (Chandra andBerntsson, 2002). The mix was specifically designed for this purpose.

A number of different proportions, including 5.797%, 7.237%, and 8.696%, are used to determine the percentage of silica fume, which is the initial parameter in this inquiry. While the second parameter is based on the optimisation of the amount of silica fume in the mixture, the coating of the pumice aggregate surface by Sika level 100T with different proportions of 4.08%, 9.615%, and 14.54 percent is the focus of the evaluation.

3.1 MATERIALS, MIX PROPORTIONS AND SPECIMEN PREPARATION

For the purpose of manufacturing lightweight pumice aggregate concrete, the following sections will discuss the materials that are used and the proportions of the mix between the various constituents. In addition, the processes for compressive and tensile testing are broken down and described.

3.1.1 MATERIALS AND MIX PROPORTION

The specified compressive strength of the lightweight pumice aggregate concrete was 15.57 MPa. The production of this lightweight concrete included the use of regular Portland cement (Type I), Pumice aggregate with a maximum size of 19 mm, Pumice fine aggregate, silica fume, tap water, and Sika level 100T (ASTM C150/C150M-22, 2022, ASTM C330/C330M-23, 2023). The composition ratio of these components is shown in Table 1. The physical characteristics of lightweight pumice aggregates, Silica fume, and Sika level 100T, which were used in the production of 84 cubes and prisms for this study, are shown in Tables 2 and 3, respectively (ASTM C1240-20, 2020, ASTM C1602/C1602M-22, 2022).

Table 1 Mix proportion of lightweight (Pumice) aggregate concrete

Materials	Quality, kg/m^3
Cement (Type I)	430
Fine lightweight aggregate	203.3
Coarse lightweight aggregate	334.4
Water	212.5
Slump, mm	50

3.1.3 FIBRICATION OF SPECIMENS

A tilt mixer with a capacity of 0.05 m^3 was used for the casting of lightweight pumice aggregate concrete. The blending process included first mixing lightweight coarse aggregate and lightweight fine aggregate for a duration of 30 seconds. Next, half of the concrete mixing water was introduced to the blending components for a duration of 30 seconds. If Sika level 100T is added at the conclusion of this step, it should be done within a 30-second timeframe. Subsequently, the conventional Portland cement was introduced to the amalgamated substances, and the act of blending persisted for an additional duration of 30 seconds. Subsequently, the residual concrete mixing water was introduced to the blending ingredients for a duration of 30 seconds. Subsequently, silica fume was introduced to the combined substances for an additional duration of 30 seconds, as seen in Figure 2.

Table 2 Physical properties of lightweight (Pumice) fine and coarse aggregates

	Lightweight fine aggregate	Lightweight coarse aggregate
Sieve analysis		
Sieve size, mm	% Pass	% Pass
25	-	100
19	-	94.78
12.5	-	30.42
9.52	100	13.45
4.76	92.66	4.77
2.36	70.09	-
1.18	53.30	-
0.60	38.48	-
0.30	16.93	-
0.15	5.10	-
Water absorption		
% of absorption	3.48	16.65
Moisture Content		
% of moisture	2.4	1.5

The pumice aggregate concrete, which was lightweight, was poured into the plywood mould in a single layer. Each layer was then vibrated for a duration of 20 seconds with vibrating table from the outside of the mould. The moulds were used to assess the quality of the mixture, consisting of six cubes for compression testing and six prisms for flexural testing.

Table 3 Physical properties of Silica fume and Sika level 100T (ASTM C1240-20, 2020)

Properties	Silica fume	Sika level 100T
Color	Gray powder	Standard grey powder
Specific gravity	2.26	-
Silicon dioxide, SiO_2, %	85	-
Chemical base	-	Polymer modified Portland cement
Compressive strength at 28 days, MPa	-	30

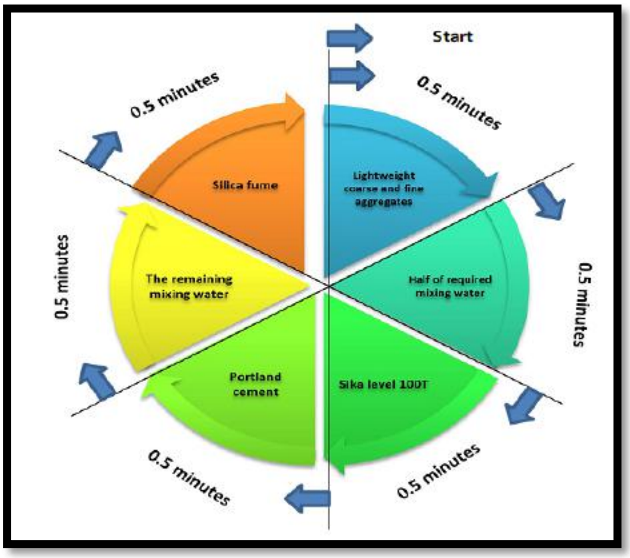

Figure 2: Mixing process of lightweight pumice concrete

3.2 TESTING OF CUBES FOR COMPRESSIVE STRENGTH

The experiment used plywood cube moulds with a side length of 100 mm. For each mix casting, six cubes were made. The concrete cubes were placed in the curing basin for a duration of 7 and 28 days. Subsequently, the concrete cubes underwent testing using a compressive machine with a capacity of 3000 kN. The loading rate used was 0.4 MPa/sec (BS EN 12390-3, 2002). Figure 3 displays the instances of cube failures during the compression test.

Figure 3: Compressive test of cube

3.3 TESTING OF PRISMS FOR FLEXURAL STRENGTH

For the purpose of determining the modulus of rupture of lightweight pumice aggregate concrete, the third-point flexural test was used (ASTM C78/C78-18, 2018). A mould size of 100 × 100 × 500 mm was used in accordance with the ASTM C78 standard. A single layer of the moulds was cast, and then they were vibrated for twenty seconds. Besides, the second layer of the concrete prisms was cast and vibrated as the first layer.The concrete prisms were taken out of the mould after they had been cast for a period of twenty-four hours. After wet curing prisms for seven and twenty-eight days in the curing basin, the prisms were removed from the chamber and allowed to remain at room temperature and humidity until the time of testing. As can be seen in Figure 4, the prisms were put through their paces by the compressive machine, which had a capacity of 100 kN and a loading rate of 0.05 MPa/min.

3.4 TESTING OF CUBES FOR DENSITY OF LIGHTWEIGHT CONCRETE

Plywood cube moulds with side lengths of 100 millimetres were used. Each mixture was produced with a total of six cubes. For a period of seven and twenty-eight days, the concrete cubes were kept in the curing basin. Following that, the concrete cubes were evaluated according to the dimensions of the cubes (BS 1881, 2002).

Figure 4: Sample of prism after flexural failure

4. RESULTS AND DISCUSSIONS

In the continuing debates on the effects of silica fume alone and of coating pumice aggregate with a thin layer of Sika level 100T in concrete that contains silica fume, this article makes a tiny contribution. Lightweight pumice aggregate concrete's characteristics were also evaluated using ASTM and BSI standards.

4.1 Effect of silica fume

As shown in Figures 5 and 6, the results of incorporating silica fume into lightweight pumice aggregate are in excellent accord with the findings of previous research. These studies have shown that the incorporation of silica fume into lightweight pumice aggregate up to 7.23 percent increases the compressive and flexural strengths up to 22.73 percent and 5.4 percent, respectively. While the incorporation of silica fume into lightweight pumice aggregate concrete has a marginal impact on the density of the concrete, this is owing to the presence of a significant porosity on the surface of the pumice aggregate, as seen in Figure 7.

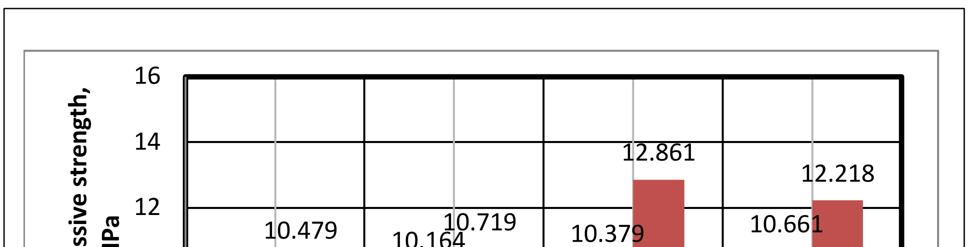

Figure 5: Compressive strength versus the percentage of silica fume

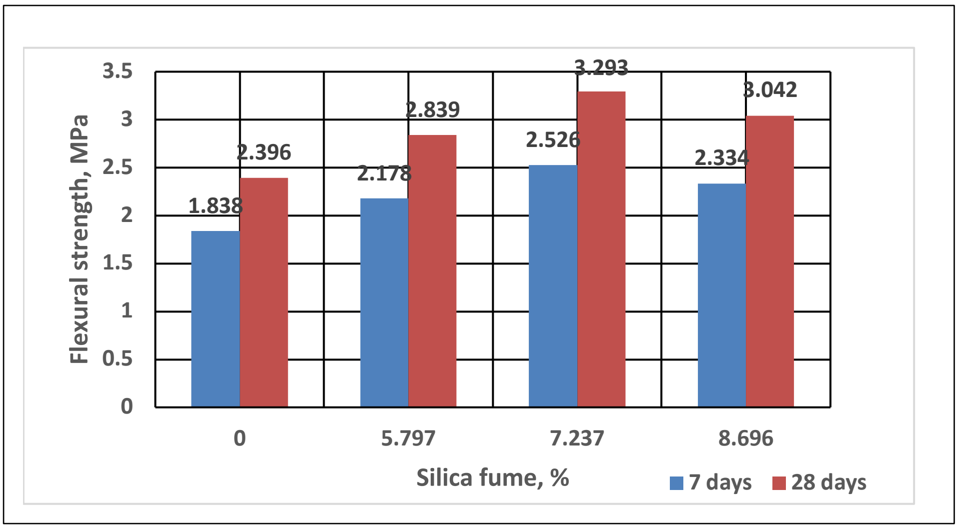

Figure 6: Flexural strength versus the percentage of silica fume

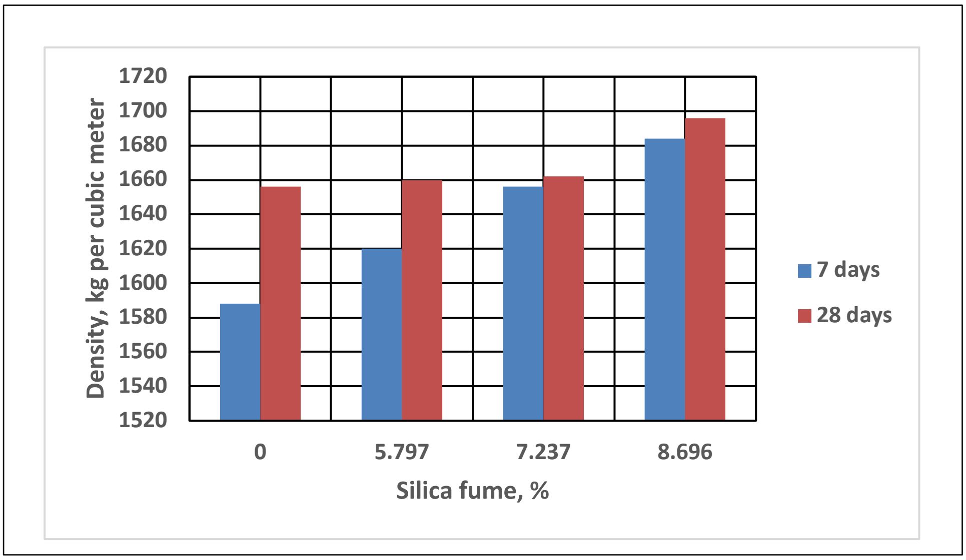

Figure 7: Density of lightweight concrete versus the percentage of silica fume

4.2 Effect of Sika level 100T

The uniqueness of our solution lies in the fact that it is feasible to produce a thin cementitious coat by using Sika level 100T around the pre-wetted pumice aggregate. Thus, it was taken an advantages from the first phase of this investigation and used 7.23% of silica fume for this stage. This not only improves the compressive and flexural strengths of the material by up to 34.57% and 28.12%, respectively, as a result of the addition of Sika level by 9.6% of the mass of cement, as demonstrated in Figures 8 and 9.While this coating does have an effect on the density of lightweight concrete, it is only because of the huge size of the pores that are present on the surface of pumice aggregate, as illustrated in Figure 10.

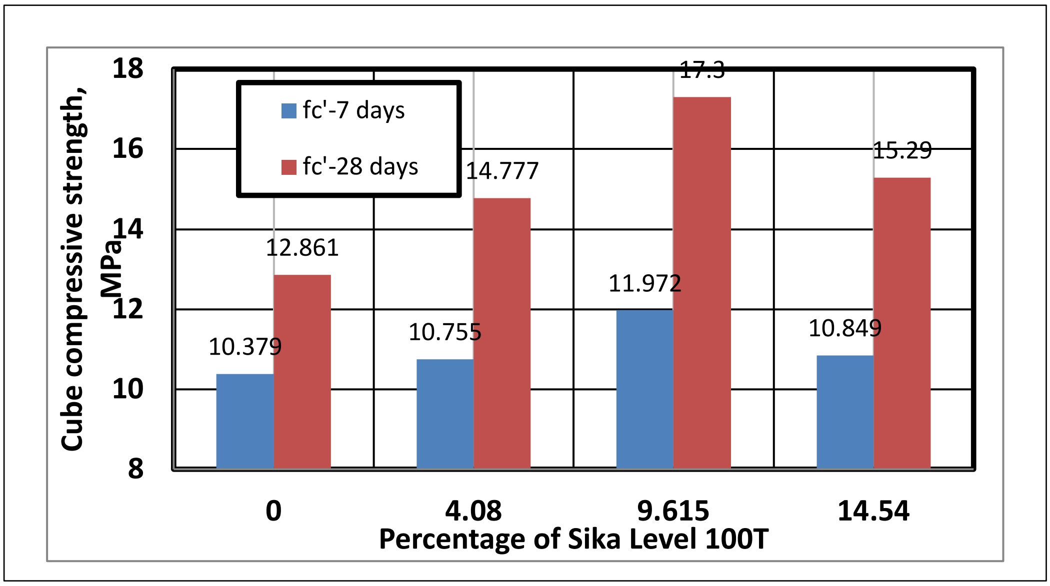

Figure 8: Compressive strength versus the percentage of Sika Level 100T

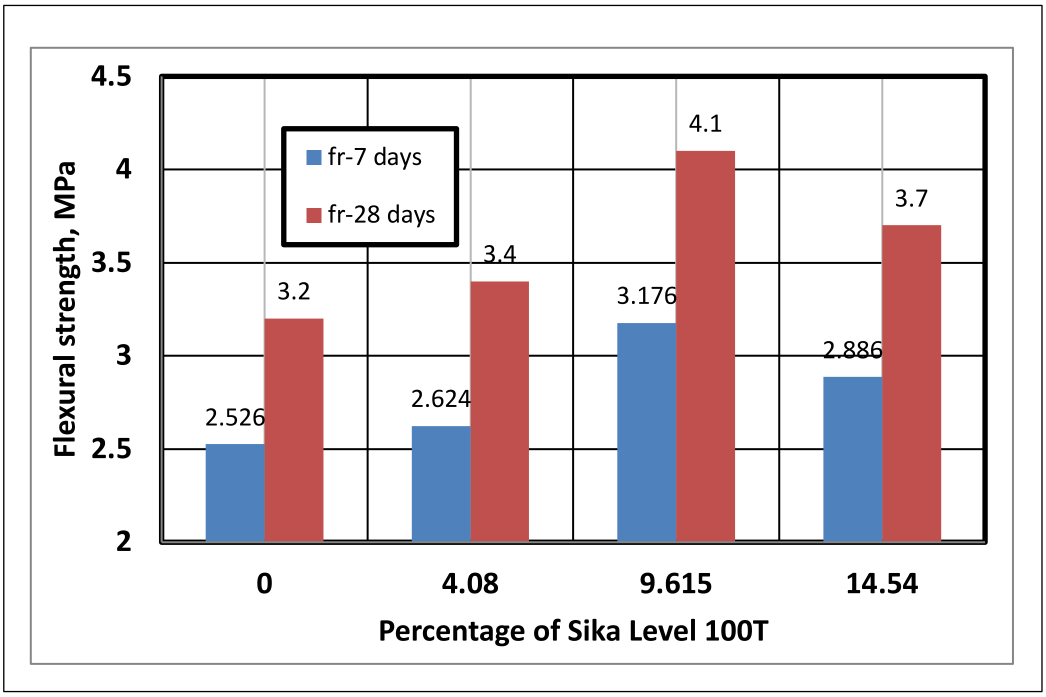

Figure 9: Flexural strength versus the percentage of Sika Level 100T for lightweight concrete included silica fume of 7.237%

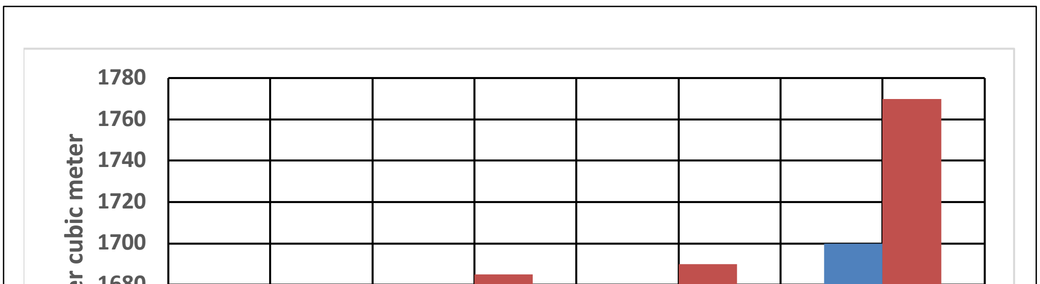

Figure 10: Density of lightweight concrete versus the percentage of Sika Level 100T

Mechanism of using Sika level 100T in lightweight concrete contains silica fume

Despite its ability to form a strong bond with cementitious materials, the pumice aggregate's high suction rate and high percentage of porosity may lead to a low abration ratio in the concrete it produces.

Sika level 100T is a cementitious product that contains a high amount of aluminium dioxide. This product aids in a quick chemical reaction when used in this investigation to cover the surface of concrete, particularly when silica fume is included. Moreover, the incorporation of silica fume strengthens the bonds within the concrete matrix. Therefore, the effectiveness of Silka increases when the concrete contains silica fume and improves the workability of lightweight concrete (Silica Fume Association, 2016).

Furthermore, the porous material on the surface of the pumice aggregate is much larger than the silica fume grain size. As a result, the inclusion of silica fume has a limited effect on the compressive strength of the lightweight pumice aggregate concrete. However, the inclusion of sika level increases the cement setting in the concrete, resulting in a higher compressive strength than concrete that solely contains silica fume.

5. CONCLUSIONS

The investigation's findings shed light on the impact of a thin cementitious crust of lightweight pumice aggregate in low strength concrete on both compressive and tensile strengths. The investigation proceeded in two stages. The first step was to find the best percentage of silica fume, which increased both the compressive and tensile strengths. The second step was to find out what Sika level 100T did, using the best percentage of silica fume from the first step as a guide. The following conclusions may be drawn:

1. Adding silica fume to lightweight pumice aggregate concrete improves compressive strength by

up to 22.73% compared to the control mix. When the percentage of silica fume stays constant at 7.23%, the inclusion of 9.6% of Sika level 100T boosts the compressive strength by up to 34.57%.

2. Inclusion of silica fume in lightweight pumice aggregate concrete up to 7.23% improves the flexural strength marginally by up to 5.4% compared to the control mix. The addition of Sika level 100T results in an enhancement of up to 28.12%, despite the fact that the amount of silica fume remains at the optimal level, as determined in the initial phase of this study.

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