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Performance of aerated lightweighted concrete using aluminum lathe and pumice under elevated temperature

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Abstract. The primary objective of this study is to investigate the production and performance characteristics of structural concrete incorporating varying proportions (0%, 25%, and 50% by volume) of pumice stone, as well as aluminum lathe as an additive at 0%, 1%, 2%, and 3%, under fire conditions. The experiment will be conducted over a period of up to 1 hour, at temperatures ranging from 24°C, 200°C, 400°C and 600°C. For the purpose of this, a total of twelve test samples were manufactured, and then tests of compressive strength (CS), splitting tensile strength (STS), and flexural strength (FS) were performed on these samples.Next, a comparison was made between the obtained values and the influence of temperature. To achieve this objective, the manufactured samples were placed at temperatures of 200°C, 400°C, and 600°C for a duration of 1 hour, and were subjected to the influence of temperature.These values at 24 °C were then contrasted with the CS results obtained from test samples that were subjected to the temperature effect for an hour at 200 °C, 400 °C, and 600 °C. A comprehensive analysis of the test outcomes reveals that the incorporation of aluminum lathe wastes into a mixture results in a significant reduction in the compressive strength of the concrete. As a result of this adjustment, the CS values dropped by 32.93%, 45.70%, and 52.07%, respectively. Furthermore, It was shown that testing the ratios of pumice stone alone resulted in a decrease in CS outcomes. Additionally, it was found that the presence of higher temperatures is clearly the primary factor contributing to the decrease in the strength of concrete. Due to elevated temperatures, the CS values decreased by 19.88%, 28.27%, and 38.61% respectively.After this investigation, an equation that explains the connection between CS and STS was provided through the utilization of the data of the experiments that were carried out.

Keywords: aluminum lathe; compressive strength; flexural strength; pumice; splitting tensile strength

1. Introduction

One of the most used building materials in the world is concrete, which is made up of cement, aggregate, water, and several additives. Globally, approximately 33 billion tons of concrete are produced annually (Ikponmwosa and Ehikhuenmen 2017). Manufacturing of concrete is required because of the growing population and the fast industrial growth that leads to the demand for the structure (Canbaz *et al*. 2021). Moreover, the developments in concrete technologies (He at al. 2024a, Yao *et al*. 2023, Liu *et al*. 2024b, Long *et al*. 2023, Huang *et al*. 2020) are also reason for the increase in the use of concrete. These studies increase recently (Wu *et al*. 2024, Wei *et al*. 2023, Zhang *et al*. 2024, Liu *et al*. 2024a, Huang *et al*. 2021). The primary component of concrete, which makes up 60–80% of its volume by volume, is aggregate (Shaikh *et al*. 2019, Karasin *et al*. 2022). In general, natural materials like limestone and basalt have been used. On the other hand, researchers have been looking for alternative aggregate resources rather than natural ones since there has been a major reduce in the daily availability of natural resources of this kind. To protect the natural deposits in this instance, the engineering industry's top priority is the sustainable use and manufacture of aggregate (Ismail *et al*. 2013, Kurtoglu *et al*. 2018). A lot of research has been done recently on the examination of substitute sources for concrete aggregates. Various industrial wastes have been used as substitutes for cement in concrete in both recent and previous studies (Sun *et al*. 2022). These include timber ash (Elinwa and Mahmood 2002), fly ash (Chowdhury *et al*. 2015), glass polishing powder (de Azevedo *et al*. 2021), rice husk ash (Torkaman *et al*. 2014), limestone powder (Hesami *et al*. 2016) and ceramic powder wastes (Samadi *et al*. 2015). On the other hand, some waste products, such as waste foundry sand (Bhardwaj and Kumar 2017), recovered glass (Taha and Nounu 2009), plastic (Khan *et al*. 2021), and rubber (Steyn *et al*. 2021), are used as a natural alternative for fine aggregate. In addition to the waste types discussed above, the literature also emphasizes the use of lightweight aggregate pumice stone as a substitute for pure coarse

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aggregate in concrete. In the last two decades, there has been a notable rise in the comprehension and utilization of high-strength, lightweight concrete that relies on artificial lightweight particles (Shideler 1957, Hoff 1996, Nafees, Amin *et al*. 2021). A volcanic material called pumice resembles a sponge that is created when lava suddenly freezes and traps millions of tiny air bubbles (Ali, Alam *et al*. 2021). Pumice aggregates may be found all around the margins of volcanic areas, especially in the Mediterranean region, much of Indonesia and Turkey, and the US Rocky Mountains (Ali, Masood *et al*. 2021). Nonetheless, limited studies have shown that structural concrete can be produced with enough financial benefits and strength values of up to 25 MPa (Hossain 2004, Xiaopeng 2005, Ali *et al*. 2022). Several studies have been conducted that are considered state-of-the-art or review studies. The use of pumice in concrete was examined by researchers (Rashad 2019, Rashad 2021, Alqarni 2022, Tanyıldızı and Gökalp 2023), who conducted a comprehensive analysis of previous studies including various applications. The practicality of substituting pumice aggregate for conventional coarse aggregate in M30 concrete at percentages of 50%, 80%, and 100% was examined by Karthika *et al*. (2021). The differences among pumice aggregate concrete and standard concrete have been compared. The Pumice Lightweight Aggregate Concrete with 50%, 80%, and 100% replacement demonstrates that only 50% replacement has an optimal value in terms of compressive strength, split tensile strength, and flexural strength. The values for 80%, 100%, and split tensile and compressive strength reduce after 50%. Masresha (2019) performed another investigation. An experimental study was conducted on the use of volcanic pumice as a partial replacement for coarse aggregate in structural lightweight concrete. With replacement weight percentages of 10, 20, 30, and 40% for C-25 grade concrete, coarse aggregate made of volcanic pumice was used. It suggested further research on pumice structural lightweight aggregate concrete over 40% coarse aggregate replacement percentage. Ali *et al*. (2023) observed Pumic stone' physical and mechanical properties. For this reason, different percentages of pumice stone are added to concrete in lieu of the natural coarse particles. The material factors in this study included the total quantity and composition of fine aggregate, coarse aggregate, and pumice aggregates used as a replacement for coarse aggregate. The replacement percentages range from 0% to 100% (0%, 10%, 20%, 30%, 50%, 75%, 100%). Additionally, the study considered the types and amounts of cementitious materials used, as well as the air contents. The research found that concrete containing up to 30% replacement of lightweight aggregate pumice stone may be utilized for structural applications since its strength qualities exceed the regulatory requirements for lightweight aggregate concrete, which is 15 MPa. The characteristics of lightweight geopolymer specimens aerated by aluminum powder were examined by Sanjayan *et al*. (2015). It was well recognized that aluminum powder is suitable for the foaming of conventional concrete. The study revealed a clear correlation between the density and compressive strength values of specimens containing varying percentages of Al powder. It is evident that specimens with lower densities exhibit lower compressive strength. The impact of substituting fine aggregate for waste aluminum sawdust on the durability and strength of concrete was examined by Demir *et al*. (2024). To replace 0%, 0.5%, and 1% of the volume of fine aggregate in the concrete mixes, aluminum sawdust that was collected from the Elazig industrial site was used accordingly. As a consequence of the examinations, it was found that the ideal W/C ratio for using aluminum sawdust in concrete was 40% and the suitable quantity was 0.5% (Demirel *et al*. 2024). Yusuf (2023) examined the influence of different concentrations (0.0, 1.0, 1.5, 2 wt%) of aluminum shaving waste on the mortar made from a mixture of ordinary Portland cement (OPC or C88-100%) and silica fume (0-10%). The research found that the strength decreases were 32.3%, 9.1%, and 2.3%, respectively, when compared to the reference concrete. Panditharadhya *et al*. (2018) examined the use of secondary aluminum dross as a binding agent in the production of concrete. With different percentages of aluminum dross substitution, it is noticed that the cement paste's early setting time rises and its ultimate setting time reduces. It was substituted at 5,10,15, and 20% of the cement's weight, the ideal dose was discovered to be 15%. The viability and workings of scrap aluminum as a substitute to lessen the alkali-silica reaction in concrete are examined by Hay and Ostertag (2019). The study revealed that the porosity caused by gas development leads to a reduction in the strength of concrete. Shabbar *et al*. (2018) produced aerated concrete by using aluminum powder at a proportion of 0.25 to 1% by cement weight. The findings indicate that the aerated concrete achieved its greatest density when 0.25% aluminium powder was used. In Heniega *et al*.'s study (2019), the production and performance of structural lightweight concrete are examined. Pumice stone was substituted for coarse aggregate in different proportions (25%, 50%, 75%, and 100% by volume), and 0.5% of cement weight was added with aluminum powder during fire conditions (which can last up to two hours and vary in temperature from 200 to 800 °C). Through thermogravimetric analysis (TGA), flexural strength, bond strength, and compressive strength investigations, the performance was established. Consequently, the bond, flexural, and compressive strengths are all positively impacted by increasing the replacement ratio of pumice stone with a fixed quantity of aluminum powder when exposed to fire. In another investigation, Heniegal *et al*. (2019) observed the structural behavior of reinforced concrete beams made of pumice stone with aluminum powder after exposure to fire and rehabilitation by three different techniques (concrete jacket, steel plates and carbon fiber). The beams were exposed to a temperature of 800°C for a duration of 2 hours. In terms of flexure and deflection, the pumice stone and aluminum powder improve load capacity. Exposure to fire causes a reduction in the load capacity of flexural beams. Conversely, the beams' deflection is heightened when exposed to fire. Zeyad *et al*. (2023) concentrated on creating ultra-high-performance lightweight concrete by the use of an air-entraining agent in combination with pumice.



Fig. 1 Pumice stone and Aluminum lathe

Aluminum powder and lightcrete were applied at 0.1, 0.2, 0.3, 0.4, and 0.5% by cement weight to form air bubbles. With or without aluminum powder or lightcrete, crushed pumice has been utilized as a 25%–50% sand substitute. The study also examined the impact of elevated temperatures ranging from 20 to 800 °C on compressive strength. It may be possible to minimize destruction of mechanical qualities by combining pumice and air agents.

As shown above, a limited number of studies utilizing aluminum powder and pumice stone have been documented, as revealed by a review of the relevant literature (Parhizkar *et al*. 2012, Widodo *et al*. 2014, Torić, *et al*. 2016, Rahman *et al*. 2022). As a result, it is clear that the rate of utilization and the impacts of pumice stone and aluminum powder in the manufacturing of concrete are still a matter that requires more investigation. In contrast to previous studies, the present research primarily examines the investigations that have explored the usefulness of pumice stone and aluminum powder as a coarse aggregate in concrete.

1.1 Importance of research

Previous literature study has shown that in the limited number of tests done on lightweight concrete, there was a tendency to employ excessive amounts of pumice stone and aluminum powder instead of coarse aggregate in the concrete. Nevertheless, no studies on lightweight concrete that substituted pumice stone and aluminum lathe for coarse aggregate in the material were found in the literature. This study is important because it discusses a crucial part of the topic—that is, the effects of different chemicals combined with lightweight concrete under different temperature. Durability characteristics such as abrasion resistance and compressive strength, in addition to mechanical characteristics like as impact resistance, were evaluated by the researchers. Because of the special advantages and challenges of lightweight concrete, further study is required. This research aims to enhance understanding of lightweight concrete by analyzing its workability and strength, specifically its compression and splitting tensile strengths under different temperature. The study focuses on the use of pumice stone and aluminum lathe as substitutes in the production of lightweight concrete under different temperature. To achieve this objective, the coarse aggregate was replaced with pumice stone and aluminum lathe in three different proportions under different temperature. To achieve this, it was determined to make a total of 12 mixes, with varying replacement ratios of pumice stone and aluminum lathe. Furthermore, elevated temperature were applied such as 24C°, 200C°, 400C° and 600C°. The results of the study provide encouragement to the more general use of lightweight concrete since it reduces waste disposal considerably. The following subsections provide further information.

Table 1 Pumice stone

Component	Pumic %
SiO_2,a	60.14
Al_2O_3,b	11.90
Fe_2O_3,c	1.504
CaO	67.60
SO_3	0.075
Na_2O	3.44
K_2O	3.19
TiO_2	0.144
NiO_3	0.007
ZrO2	0.013
Sladge (>45 μm)	0

2. Experimental program

To create lightweight concrete, aluminum lathe was used. Three distinct aluminum waste samples with 1%, 2%, and 3% aluminum content were used for this objective. Additionally, a reference sample without any aluminum trash was generated. For this purpose, three separate pumice stone samples were used, each containing different amounts of pumice stone: 0%, 25%, and 50%. In addition, different replacement ratios of pumice stone and aluminum lathe were used at elevated temperatures of 24 C, 200 C, 400 C, and 600 C. Two additions to the reference mixture were pumice stone samples and aluminum trash. Figure 1 shows the aluminum waste and pumice stone samples that were used in this investigation. Aluminum lathe waste had a length that varied from 0.5 to 1.5 cm. Two kinds of aggregate sizes, namely fine and coarse, were used for the concrete mixture. Sizes 0–4 mm were used for fine aggregate, whereas sizes 5–12 mm were used for coarse aggregate. The concrete mixture included Portland cement with CEM 32.5. A ratio of 0.5 water to cement was used in this experiment. Table 1 presented component of pumic stone. Furthermore, Fig. 2 presented mixture and expansion of concrete.

3. Experimental results and discussions

The primary objective of this research study is to conduct a complete investigation into the manufacture of different kinds of concrete using varying proportions of pumice stone and aluminum lathe as replacements. The



Fig. 2 Mixture and expansion of concrete

study will be conducted at high temperatures of 24°C, 200°C, 400°C, and 600°C. In this research, the following inquiry has been noted. The specimens were produced in accordance with the ASTM C192/C192M (Concrete)standard, and subsequently, the cold strength (CS) was assessed using the ASTM C39/C39M (Concrete) standard.

3.1 The Impact of Compressive Strength (CS)

Fig. 3 displays the CS values of the test samples generated using various aggregate kinds, such as pumice stone and aluminum lathe. As can be seen in Table 1 and Fig. 3, the reference that did not include pumice stone and aluminum lathe had the highest CS values. It was

discovered that the CS values of the reference concrete series that did not include pumice stone and aluminum lathe at 28 days were, respectively, 26.05 MPa. The ratio of aluminum lathe was raised to 1%, 2%, and 3%, respectively, in Set #1, while the ratio of pumice in the mixture remained the same until the end of the experiment. Following the addition of this alterations, the values of CS were determined to be 26.05 MPa, 17.47 MPa, 14.14 MPa, and 12.49 MPa, respectively. The CS values decreased by 32.93%, 45.70%, and 52.07%, respectively, as a consequence of this modification. The ratio of pumice stone to the mixture was raised to 25 in Set#2, while the quantity of aluminum lathe was increased from 0% to 3%, just as it was in Set#1. After all of these changes were added, the values of CS were found to be, in order, 21.18 MPa, 16.36 MPa, 12.79 MPa, and 11.86 MPa. As a direct result of this alteration, the CS values experienced a reduction of 29.62%, 22.77%, and 44.00%, respectively. In Set#3, the proportion of pumice stone to the mixture was increased to 50%, while the amount of aluminum lathe improved from 0% to 3%, similar to Set#1 and Set#2. It was discovered that the values of CS were, in the order of 17.10 MPa, 14.40 MPa, 11.18 MPa, and 9.46 MPa, while all of these modifications were included. The CS values noticed a decrease of 15.79%, 34.61%, and 44.65%, respectively, as a direct consequence of this modification. An examination of the test results indicates that the inclusion of aluminum lathe wastes in a mixture leads to a substantial decrease in the CS value of the concrete. Additionally, increasing the proportion of pumice stone in the mixture also results in a reduction in the amount of CS that is produced.

When the ratios of pumice stone alone were tested, it was discovered that it produced a drop in CS results. This was the case even if aluminum lathe was not included in the combination. The findings that were discovered in the literature are comparable to this one (Abdulazeez *et al*. 2020, Idi *et al*. 2020, Tanyıldızı and Gökalp 2023). The study conducted by Karthika *et al*. (2021) examined the efficacy of concrete using pumice aggregate (PA) that was substituted in varying proportions of coarse aggregate, namely 50%, 80%, and 100%. The 50% replacement level was found to be the ideal value in the investigation, and the researchers noted that increasing substitution rate resulted in a loss in mechanical strength. The study conducted by Öz *et al*. (2017) examined the efficacy of self-compacting concrete including pumice as a replacement for natural aggregate, specifically in relation to CS. The researchers reached the conclusion that an augmentation in the PA content resulted in a reduction in the CS (Parhizkar *et al*. 2012, Widodo *et al*. 2014, Kurt *et al*. 2016, Bhavana and Rambabu 2017, Öz *et al*. 2017, Manoj *et al*. 2021, Prayuda 2021, Shafiq *et al*. 2021). This may be explained by the following reasoning. The use of pumice as an aggregate in concrete results in a reduction in mechanical strength, mostly attributed to its low density, large porosity, and poor structural properties (Tanyıldızı and Gökalp 2023).

An increase in the proportions of aluminum lathe separately was shown to result in a decrease in the CS findings while the ratios were evaluated. Pumice stone was not a part of the the combination, although this was nonetheless the case. When aluminum is added to the mixture, it has been noticed that the volume of the mixture increases. The results identified in the existing literature exhibit similarities to the present study (Pereira, de Aguiar *et al*. 2000). The investigation done by Pereira *et al*. (2000) observed a significant volumetric expansion in the raw aluminum slag mortar. A consistent decrease in compressive strength was observed when the proportion of aluminum lathe exceeded 10% (Pereira, de Aguiar *et al*. 2000). This has to do with the concentration of silicon dioxide (SO2) and calcium oxide (CaO), which are the primary ingredients that fortify the concrete (Elseknidy *et al*. 2020). The observed phenomenon may be attributed to the creation of air voids resulting from aggressive reactions and an excessive presence of alumina when a greater proportion of Al dross is substituted as can be observed in Fig. 4 (Pereira *et al*. 2000).

3.2 An analysis of the impact of Splitting Tensile Strength (STS)

The STS is a crucial statistic for determining the tensile strength of concrete (Hamada *et al*. 2020). This research aims to conduct a comprehensive evaluation of various production-based sub-assemblies of concrete, taking into consideration the influence of pumice stone and aluminum lathe concentrations on the split tensile strength of the concrete. There are several test photographs shown in Fig. 5. The STS values were found to be greatest in the reference that didn't contain pumice stone and aluminum lathe, as demonstrated by the data presented in Table 1 and Fig. 6. The STS values at 28 days were found to be 2.19 MPa for the reference concrete series without pumice stone and aluminum lathe, correspondingly. As was previously noted, the amount of pumice in the mixture was constant until the completion of the experiment, while the amount of aluminum lathe in Set #1 was increased to 1%, 2%, and 3%, respectively. After these changes were carried out, the STS values were found to be 2.19 MPa, 1.95 MPa, 1.47 MPa, and 1.39 MPa, in that order. As a result of this modifications the STS values dropped by 11.24%, 32.82%, and 36.83%, respectively. In Set#2, the proportion of pumice stone to the mixture was increased to 25, while the amount of aluminum latheimproved from 0% to 3%, similar to Set#1. Following the addition of all of these modifications, the STS values were discovered to be 2.14 MPa, 1.86 MPa, 1.39 MPa, and 1.29 MPa, in that sequence. These changes brought in a decrease in the STS values of 13.04%, 35.11%, and 39.67%, respectively, as a direct consequence of the change. As was the case with Set#1 and Set#2, the quantity of aluminum lathewas raised from 0% to 3% in Set#3, while the percentage of pumice stone to the mixture was increased to 50% in Set#3. When all of these adjustments were present, it was found that the STS values were, in the order of 2.07 MPa, 1.75 MPa, 1.34 MPa, and 1.23 MPa. The adjustment resulted in a drop of 15.35%, 35.15%, and 40.45% in the STS values, respectively. A comprehensive analysis of the test STS reveals that the incorporation of aluminum lathewastes into a mixture results in a significant reduction in the STS value of the concrete. Moreover,

Table 2 Experimental results

Test Number#	Set#	Volume Ratio		Compressive Strength, MPa	Splitting Tensile Strength, MPa	Flexural Strength, MPa
		Aluminyum %	Pumice%	Average (μ)	Average (μ)	Average (μ)
1	Set#1	0	0	26.05	2.19	4.61
2		1		17.47	1.95	4.50
3		2		14.14	1.47	3.84
4		3		12.49	1.39	3.21
5	Set#2	0	25	21.18	2.14	4.34
6		1		16.36	1.86	4.27
7		2		12.79	1.39	3.59
8		3		11.86	1.29	2.66
9	Set#3	0	50	17.10	2.07	3.52
10		1		14.40	1.75	3.48
11		2		11.18	1.34	2.98
12		3		9.46	1.23	2.20

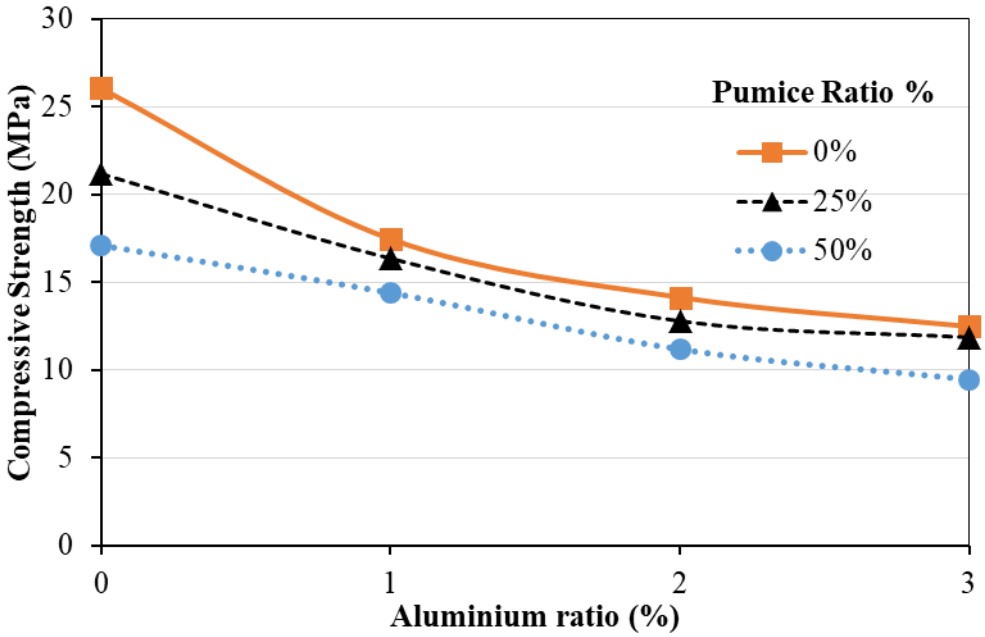


Fig. 3 Results of CS

increasing the ratio of pumice stone in the mixture leads to a decrease in the quantity of STS generated. As previously stated, these data once again demonstrate the resemblance between the inclination towards CS and the inclination towards STS. The results identified in the existing literature exhibit similarities to the present study. Investigating the impact of an improvement in the pumice stone proportion on the STS of concrete was the main focus of Naveenkumaar *et al.*'s study (2020). In this context, the experimental analysis included three replacement rates: 5%, 10%, and 15%. The results indicated that a rise in the content of Pumice stone led to a decrease in the strength of the concrete structure when subjected to splitting tensile forces. Manoj *et al.* (2021) used 100 mm dia × 200 mm cylindrical specimens to study the impact of substituting pumice stone for coarse aggregate on the STS of concrete. The researchers arrived at the conclusion that the STS exhibited a reduction across all replacement values in comparison to the control concrete. In their study, Minapu *et al.* (2014) observed a consistent decrease in the STS of concrete as the replacement ratios of a coarse aggregate with pumice stone increased. In an experimental comparison, Sangeetha *et al.* (2020) generated concrete that included 10%, 20%, 30%, 40%, 50%, 60%, 80%, and 100% pumice in lieu of coarse particles, compared to concrete obtained without such substitutions. The test findings

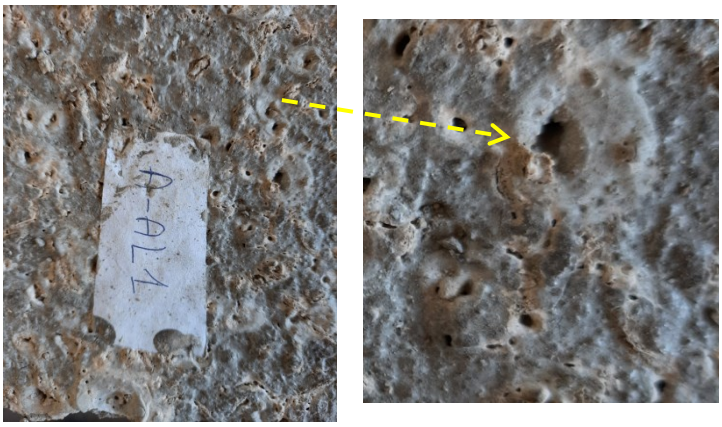


Fig. 4 Deterioration of concrete



Fig. 5 Test pictures of STS

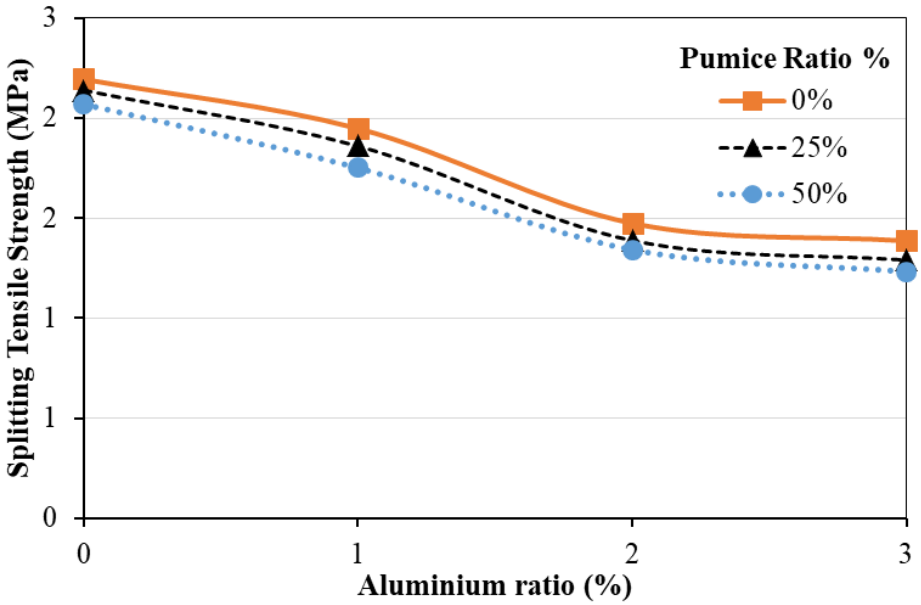


Fig. 6 Results of STS

demonstrated a consistent decline in STS performance as the pumice stone concentration increased. When the ratios were analyzed, it was seen that increasing the amounts of aluminum latheindividually led to a drop in the STS results.

The current study's findings are comparable to those found in the body of previous research. Research on replacing 1%, 2%, and 5% of the sand in a concrete mix with recyclable aluminum components was done by Rahim *et al*. (2014).

The observed reduction in compressive strength resulting from the incorporation of aluminum waste, such as sand, may be ascribed to a diminished link between the cement paste inside the concrete and the aluminum waste. A reduced quantity of aluminum waste in concrete facilitates a strong adhesion between the constituent ingredients of the concrete. The reason for this is because aluminum trash has a sleek and lustrous surface, which poses challenges in its ability to adhere to other particles inside the concrete (Rahim *et al*. 2014).

3.3 An Analysis of the impact of Flexural Strength (FS)

The parameter of FS has significant importance in the assessment of the strength performance of concrete(Hamada *et al*. 2020). Fig. 7 displays a collection of test images. Table 1 and Figure 8 exhibit data indicating that the reference without pumice stone and aluminum lathehad the highest FS values. The reference concrete series, which did not include pumice stone and aluminum lathe, had FS values of 4.61MPa at 28 days. As mentioned earlier, the quantity of pumice in the mixture remained consistent throughout the experiment, but the quantity of aluminum lathein Set #1 was progressively augmented to 1%, 2%, and 3%, correspondingly. The following FS values were obtained after these improvements: 4.61 MPa, 4.50 MPa, 3.84 MPa, and 3.21 MPa, in that sequence. The FS values decreased by 2.38%, 16.84%, and 30.49%, respectively, due to these alterations. Similar to Set #1, Set #2 observed an increase in the quantity of aluminum lathefrom 0% to 3% while increasing the amount of pumice stone to the combination to 25%. The combination of all these improvements resulted in the following sequence of FS values: 4.34 MPa, 4.27 MPa, 3.59 MPa, and 2.66 MPa. As a direct result of the mentioned improvements, there was a reduction in the FS values of 1.46%, 17.14%, and 38.66%, correspondingly. Similar was the situation with Set#1 and Set#2, the amount of aluminum lathe was increased from 0% to 3% in Set#3, and the proportion of pumice stone to the combination was expanded to 50% in Set#3. Both of these changes were made in Set#3. In the event where all of these modifications were present, it was discovered that the FS values were, in the order of 3.52 MPa, 3.48 MPa, 2.98 MPa, and 2.20 MPa respectively. The change caused in a decrease in the FS values of 1.14 percent, 15.33 percent, and 37.65 percent, correspondingly. A thorough examination of the test FS indicates that the addition of aluminum lathe wastes to a mixture leads to a considerable decrease in the FS value of the concrete. This is the conclusion reached by the study. There is also a correlation between increasing the proportion of pumice stone in the mixture and a reduction in the amount of FS that is produced.

It was noted that maintaining a constant aluminum lathe ratio of 0% in the mixture, while increasing the pumice stone ratio by 0%, 25%, and 50%, resulted in a drop in the FS values of the combination to 4.61 MPa, 4.34 MPa, and 3.52 MPa, respectively. However, when the ratio of pumice stone was increased by 0%, 25%, and 50%, the FS values of the combination decreased to 4.50 MPa, 4.27 MPa, and 3.48 MPa, respectively. This was the outcome of keeping a constant aluminum lathe ratio of 1% in the mixture. The combination's FS values decreased to 4.61 MPa, 4.34 MPa, and 3.52 MPa for the 2% and 3.21 MPa, 2.66 MPa, and 2.20 MPa for the 3% aluminum lathe ratio, respectively, when the pumice stone ratio was increased by 0%, 25%, and 50%. Based on these findings, it was noted that adding more pumice stone to the mixture resulted in a reduction in the amount of FS produced. The current investigation's findings are consistent with those found in a collection of literature(Kılıç and Teymen 2009, Minapu *et al*. 2014, George and Rajeshwari 2015, Tamai 2015, Bhavana and Rambabu 2017). The study conducted by Manoj *et al*.(2021) examined the impact of substituting coarse aggregate with pumice stone on the FS of concrete. According to Kılıç and Teymen 2009, the FS of the concrete that included just pumice stone was almost 42% less than that of the reference concrete.

4. Fire procedure and testing

After a day of completion of curing, concrete samples were exposed to direct fire. That is, the specimens were allowed to dry for 24 hours at room temperature prior to being exposed to the fire. The examples were then directly exposed to flames in a gas oven for one and two hours at temperatures of 200 °C, 400 °C, and 600 °C. A temperature increase of 5 °C per minute was used to achieve the target temperature, and then the temperature was maintained at that level for a period of one hour.

4.1 Influence of aluminum lathe and pumice stone on the CS after fire exposure

The main aim of this section is to comprehensively examine the production of various types of concrete by using varied ratios of pumice stone and aluminum lathe as substitutes, while subjecting the mixture to variable increased temperatures. To achieve the intended objective, the specimens were thereafter subjected to direct exposure to fire inside a gas oven for a duration of one hour, with temperatures set at 200 °C, 400 °C, and 600 °C. After that, the CS values obtained at 24 °C were compared with these samples to evaluate the impact of temperature. In accordance with the information that was shown in Table 2 and Fig. 9, the CS values that were produced by combining pumice stone and aluminum lathe in varying amounts and at varying temperatures were demonstrated here. The reference that did not contain pumice stone and aluminum lathe within the temperature range of 24 °C had the greatest CS values, as can be shown in Table 2 and Fig. 9. It was found that at 24 °C, the CS values of the reference concrete series, which didn't have pumice stone and aluminum lathe, were 26.05 MPa, respectively. By increasing the temperature to 200°C, 400 °C, and 600 °C, respectively, these values drops to 20.87 MPa, 18.68 MPa, and 15.99 MPa, correspondingly. As a result of this adaptation, the CS values reduced by 19.88%, 28.27%, and 38.61%,

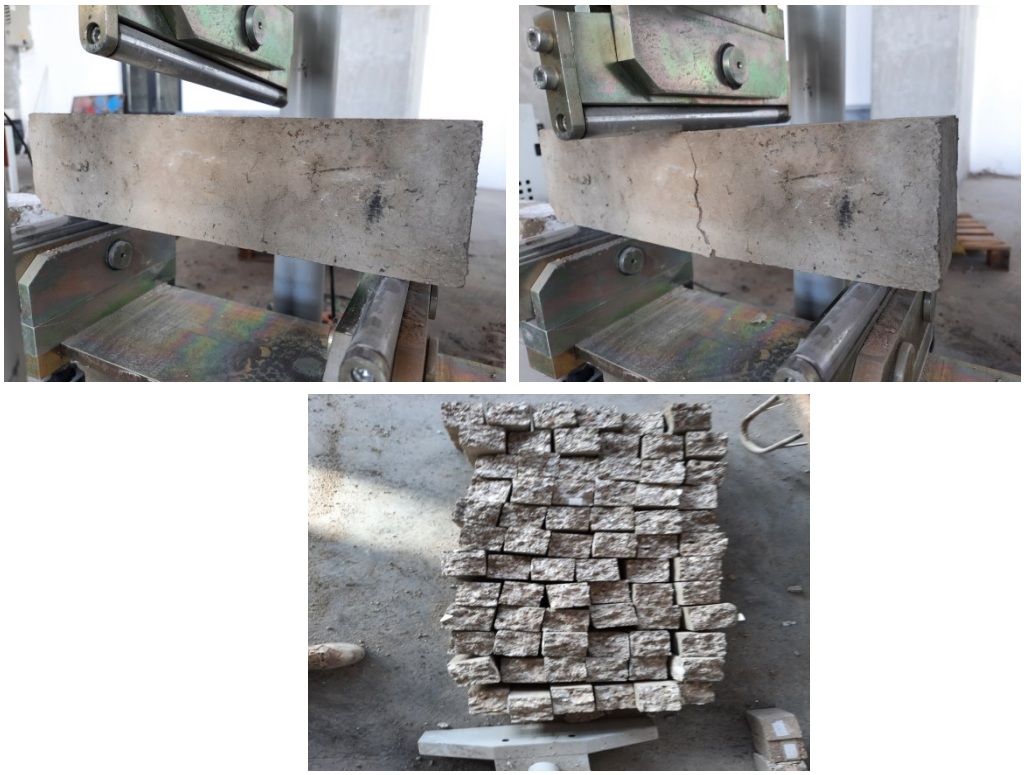


Fig. 7 Test pictures of FS

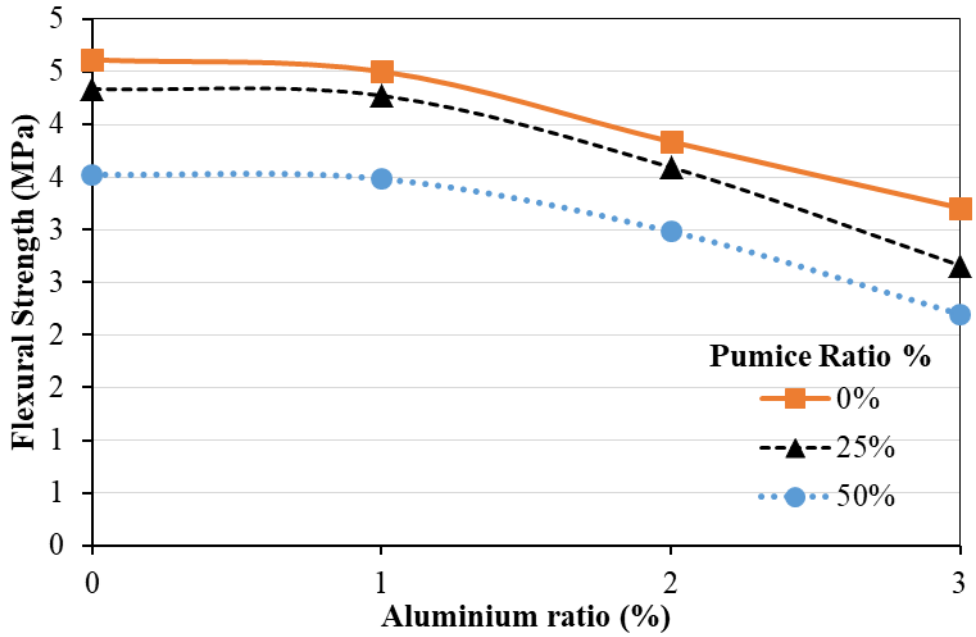


Fig. 8 Results of FS

correspondingly. In Set #1, the ratio of aluminum lathe was raised to 1%, 2%, and 3% successively. At this point, the temperature values were increased to 200°C, 400°C, and 600°C accordingly. However, the ratio of pumice in the mixture stayed the same until the conclusion of the experiment. While the percentage of aluminum lathe was raised to 1%, the temperature values were raised to 200°C, 400°C, and 600°C. The CS values were found to be 17.47 MPa, 15.86 MPa, 13.25 MPa, and 11.19 MPa, after these modifications. At the same time as the proportion of aluminum lathe was increased to 2% and 3%, the temperature values were increased to 200 °C, 400 °C, and 600 °C. When these alterations were made, the CS values were discovered to be 14.14 MPa, 12.42 MPa, 9.73 MPa, 8.27 MPa, and 12.49 MPa, 10.23 MPa, 7.92 MPa, and 6.91 MPa respectively.

At the same time as the proportion of aluminum lathe was increased to 0% and 1%, the temperature values were

Table 3 Experimental Results for different temperature

Test Number#	Set#	Volume Ratio		Compressive Strength, MPa			
		Aluminyum %	Pumice%	24°C	200°C	400°C	600°C
1	Set#1	0	0	26.05	20.87	18.68	15.99
2		1		17.47	15.86	13.25	11.19
3		2		14.14	12.42	9.73	8.27
4		3		12.49	10.23	7.92	6.91
5	Set#2	0	25	21.18	19.87	17.22	15.60
6		1		16.36	14.02	12.11	10.79
7		2		12.79	11.40	9.13	7.66
8		3		11.86	9.19	7.30	6.45
9	Set#3	0	50	17.10	15.94	13.52	12.09
10		1		14.40	12.17	10.11	8.86
11		2		11.18	10.05	8.07	6.68
12		3		9.46	8.22	6.40	5.62

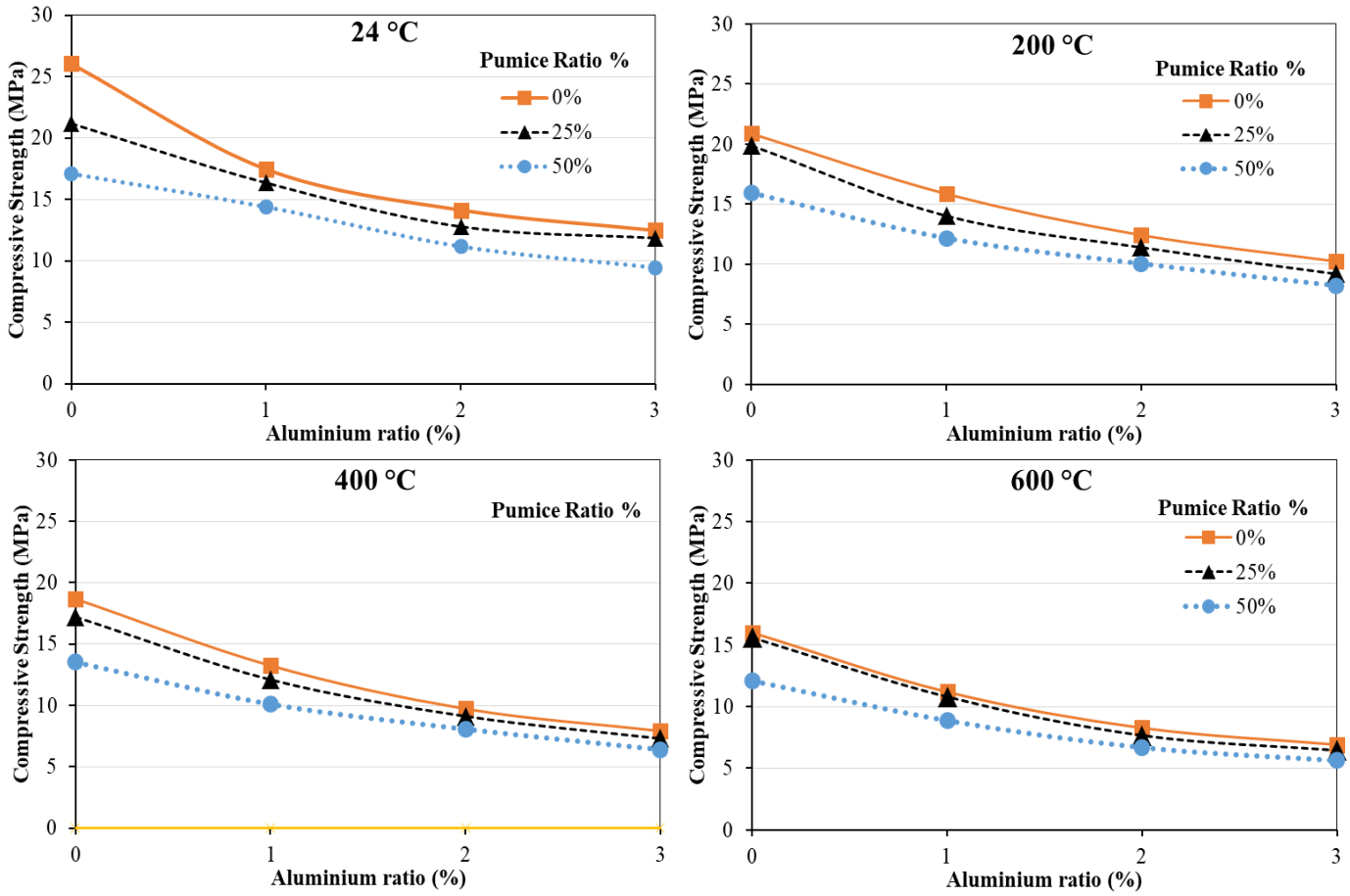


Fig. 9 Results of CS for different temperature

increased to 200 °C, 400 °C, and 600 °C. When these alterations were made, the CS values reduced by 9.25%, 24.16%, and 35.97% , correspondingly. When aluminum lathe fraction climbed to 1% and 2%, temperatures increased to 200, 400, and 600 °C. After these changes, CS values dropped 12.19%, 31.23%, and 41.55%. From 2% to 3% aluminum lathe percentage, temperatures improved to 200, 400, and 600 °C. CS values declined 18.03%, 36.56%, and 44.64% with these adjustments. Set #2 increased aluminum lathe from 0% to 1% and pumice stone to 25%,



Fig. 10 Deterioration of concrete under different temperature

like Set #1. Increasing the temperature from 24 °C to 200 °C, 400 °C, and 600 °C, respectively, results in a decrease in these values to 21.18 MPa, 19.87 MPa, 17.22 MPa, 15.60 MPa and 16.36 MPa, 14.02 MPa, 12.11 MPa, 10.79 MPa respectively. As aluminum lathe was increased to 2% and 3%, temperatures were raised to 200, 400, and 600 °C. These changes revealed CS values of 12.79 MPa, 11.40 MPa, 9.13 MPa, 7.66 MPa, 11.86 MPa, 9.19 MPa, 7.30 MPa, and 6.45 MPa. In Set #3, pumice stone was raised to 50% and aluminum lathe was increased from 0% to 1%. Temperature increases of 200 °C, 400 °C, and 600 °C, respectively, cause these values to decline to 17.10 MPa, 15.94 MPa, 13.52 MPa, 12.09 MPa, and 14.40 MPa, 12.17 MPa, 10.11 MPa, and 8.86 MPa, in that order. The temperatures increased to 200, 400, and 600 °C when the proportion of aluminum lathe was increased from 2% to 3%. As a consequence, these values reduced to 11.18 MPa, 10.05 MPa, 8.07 MPa, 6.68 MPa, and 9.46 MPa, 8.22 MPa, 6.40 MPa, 5.62 MPa, individually. As a result, it is evident that the most significant factor in the reduction of the

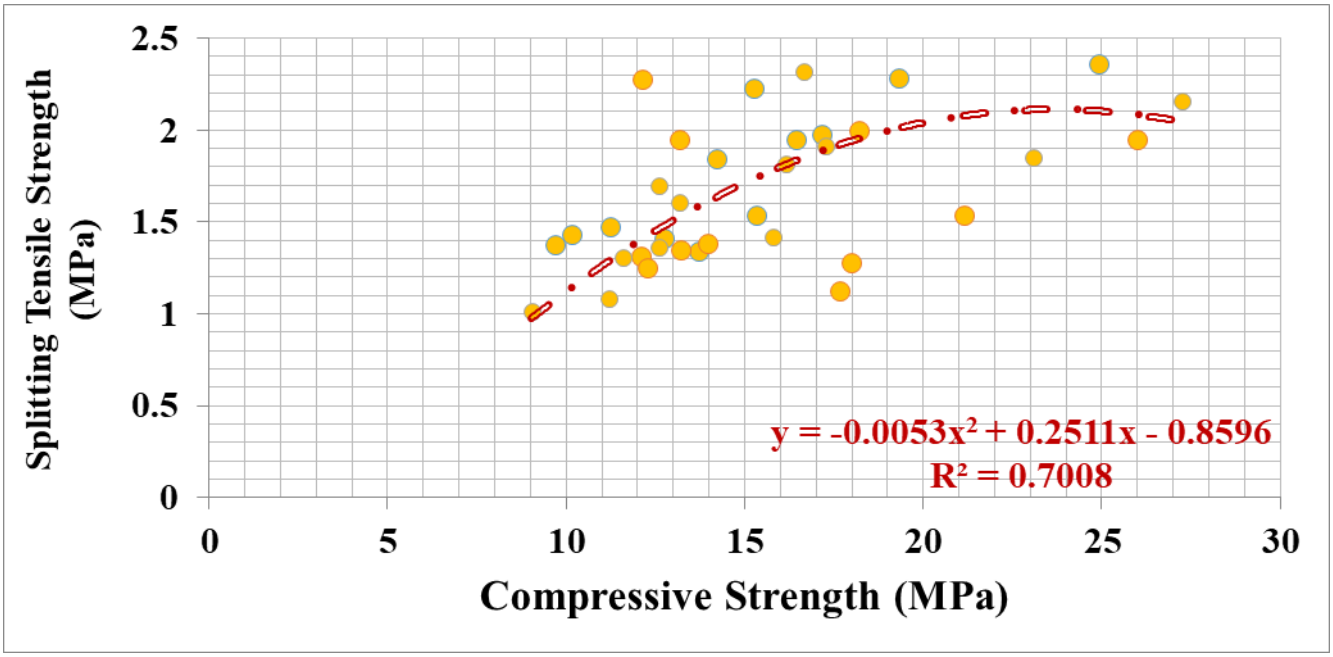


Fig. 11 CS via STS

compressive strength of concrete is the presence of higher temperatures. These findings align with the outcomes reported by researchers (Heniegal *et al.* ; Bingöl and Gül 2004). When the temperature approaches 200 °C, the compressive strength of the material begins to decrease, as was to be anticipated, since the connection between compressive strength and temperature is an inverse one. Micro-cracks appear on the surfaces of concrete as a consequence of this decrease, which is caused by a partial loss of hydration, as well as the chemical changes that occur inside the body of the concrete (Heniegal *et al.*).

4. Proposed equation

Fig. 11 depicts the association between CS and STS when it comes to competitiveness. It is evident from the data shown in Fig. 11 that the regression model between the compressive and STS variables seems to be flat. In addition, as can be shown in Fig. 11, the regression stroke provides evidence of a significant association between CS and STS, with an R2 value that is more than 70 percent overall. Eq. (1) may be used to establish the correlation between CS and STS.

$$f_{STS} = -0.0053(f_{CS})^2 + 0.2511(f_{CS}) - 0.8596 \quad (1)$$

5. Scanning Electron Microscope (SEM) analysis

FESEM (Field Emission Scanning Electron Microscopy) is a type of field emission scanning electron microscopy. With this method, it is possible to examine the microstructure of the concrete sample thanks to high-resolution images of its surface. FESEM analysis uses a high-energy beam of electrons to focus on the surface of the sample and excite the atoms in the sample. These electrons are scattered from the sample surface and detected by a detector. In this way, detailed images of the complex inner surface of the concrete are obtained at the nanometer scale. Thus, details such as complex surface morphology, cracks, pores, distribution of aggregates and reaction products can be observed with FESEM analysis. The microstructural properties of concrete containing pumice aggregate and Al sawdust were examined and analyzed with high-resolution internal images via FESEM. The analysis was performed both on the sample kept at room temperature and on the sample taken by heating at 600°C. In this way, an attempt was made to present the FESEM analysis between both cases in detail. ITZ (Interfacial Transition Zone) in concrete is the interface zone between the aggregate and the cement matrix. A slight ITZ region can be seen in Fig. 12(a). This zone is where the aggregate particles come into contact with the cement matrix. ITZ has a significant impact on the mechanical properties of concrete because the connection between aggregate and matrix occurs here (Özkılıç *et al.* 2023). Chemical and structural properties of aggregate and cement also affect ITZ formation (Ji *et al.* 2023). ITZ is important for the durability of reinforced concrete structures, and the durability of this zone affects the durability and life of the structures (Diridi *et al.* 2013). ITZ may occur more in pasty areas (Fang *et al* 2023). Therefore, ITZ can be reduced by better mixing and homogeneous distribution. Fig. 12(c) shows the homogeneous dispersion of the pumic aggregate and the air spaces formed in between. The addition of Al also has a aerated effect in the formation of these cavities. (Demir *et al*). observed larger cracks and interfacial voids in concrete in SEM images. However, in Fig. 12(d), a crack is seen in the micro level. In Fig. 12(e) there is some formation of ettingite. Water in the concrete reacts with tricalcium aluminate minerals to form ettringite compound. As a result of this reaction,

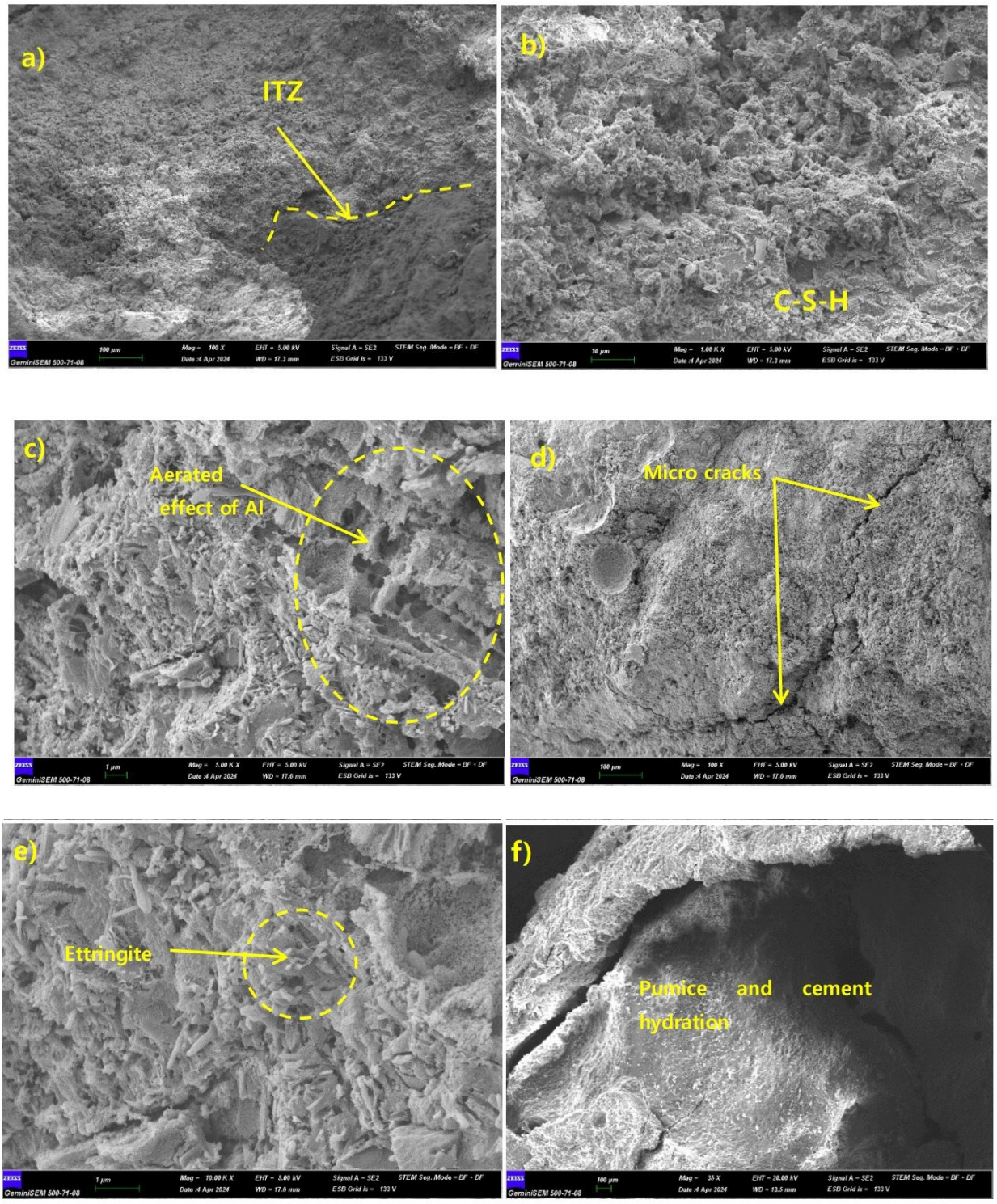


Fig. 12 Microstructure view of samples

ettringite crystals form and become evident in the concrete (Cody *et al*. 2004, Poupelloz *et al*. 2020**)**. Fig. 12(f) shows the voids formed by the effect of pumic and Al, where hydration takes place well.

5.1 EDX (Energy Dispersive X-ray Spectroscopy)

FESEM uses a high-energy electron beam to obtain high-resolution images. Details such as microstructures, cracks, pores and aggregates on the surface of the sample can be observed with FESEM. FESEM-EDX analysis combines field emission scanning electron microscopy (FESEM) and energy dispersive was done. Fig. 13 shows the EDX result taken from a region. C-S-H and ITZ are clearly visible in the SEM image. When we look at the element distribution in Fig. 13, there is 47.71% (Ca) and

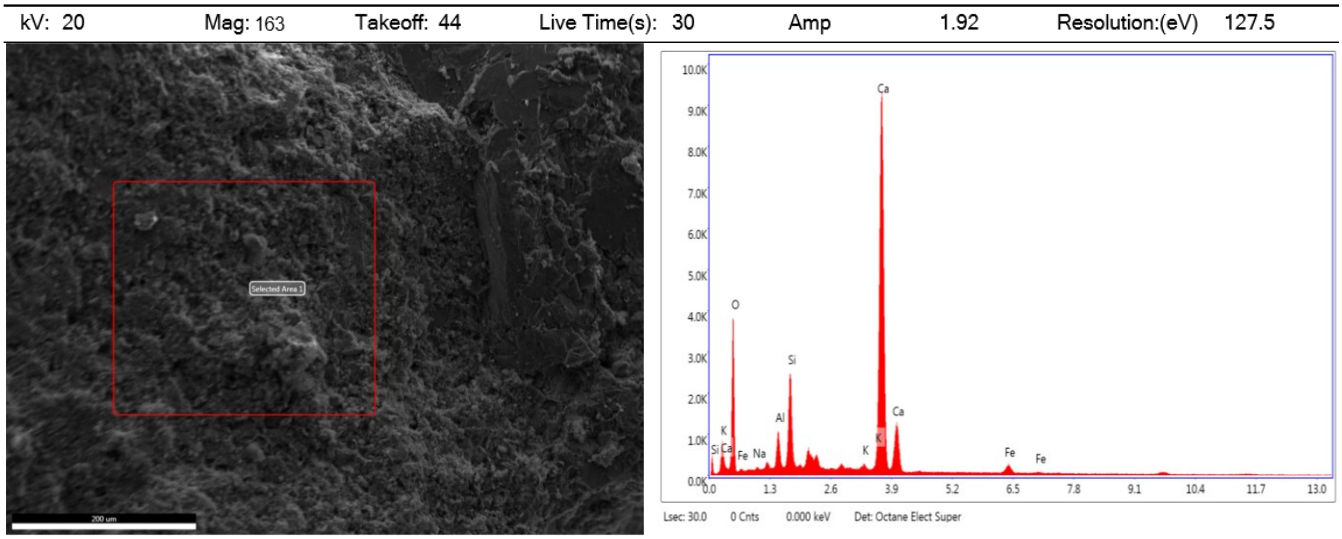


Fig. 13 EDX Analysis

41.48% O by weight. During the hardening process of concrete, these two elements react with a chemical called water and cement mixture. During this reaction, the components contained in the cement transform into crystal structures called hydration products. In this process, components containing calcium oxide (CaO) are known to react with water to form calcium hydroxide (Ca(OH)2). Calcium hydroxide dissolves in concrete and reacts with water to form hydration products. These products are crystal structures that increase the hardening and durability of concrete.

5.2 FESEM Analysis Elevated 600 ºC

Exposure of concrete produced with pumice aggregate to temperatures of 600 degrees may affect the performance of the concrete, depending on the process and materials used. For example, evaporation of water in concrete can cause loss of moisture in the concrete and increase the risk of cracking. High temperature can cause thermal expansion of concrete, and this expansion can cause cracks or deformations in the internal structure of the concrete. Likewise, high temperature can cause thermal degradation of pumice aggregate and components within the cement, which can lead to changes in the mechanical properties of the concrete. As a result, the durability and mechanical properties of concrete may be negatively affected. SEM results confirmed by compression and bending tests confirm these negativities. As seen in the study of Ismail *et al*. (2013), similar SEM images of different sizes and pores were obtained in the sample exposed to 600 degrees. Additionally, segmented wings were formed as a result of the reaction with Al in the cement paste. Again, cracks have occurred, which may be caused by expansion due to high temperatures. Similar results have been observed in previous studies (Bideci *et al*. 2023).

5.3 EDX Analysis Elevated 600 ºC

In Fig. 15, (FESEM) and energy dispersive X-ray spectroscopy (EDX) techniques were used to examine the microstructure of the surface of pumice lightweight concrete after the sample was heated to 600 ºC and also to determine the chemical composition of this structure. It is known that the porosity and permeability of concrete largely depend on the interface properties and that microcracks in the matrix phase have an impact on these properties (Akçay and Taşdemir 2009). It has also been observed in similar studies that pumice aggregate has micron-sized tubular channels and high porosity around the pore (Hossain *et al* 2011, Hossain 2004, Liu *et al*. 2018). Additionally, it is known that the pore structure of concrete has a great impact on its strength and that physical properties such as porosity and compactness are directly related to the mechanical properties of concrete. However, hydrated phases such as C-S-H, portlandite, ettringite and non-hydrated cement particles may also be detected (Bidaci *et al* 2023). The formation of cracks in the region examined in the figure is striking. Despite the high calcium content, it was observed that the strength decreased due to the increase in cracks and pores after heat treatment.

6. Conclusions

This study examines the fire performance of structural concrete after its manufacture using aluminum lathe and pumice, and then compared its performance. The following findings were reached:

• Adding aluminum lathe reduced the concrete's CS and STS values. The inclusion of aluminum lathe at concentrations of 1%, 2%, and 3% led to a decrease in CS by 32.93%, 45.70%, and 52.07%, and in STS by 11.24%, 32.82%, and 36.83%, respectively.

• Furthermore, Adding pumice stone reduced the concrete's CS and STS values. Following the addition of this alterations, the values of CS were determined to be 26.05 MPa, 17.47 MPa, 14.14 MPa, and 12.49 MPa, respectively. the values of STS were determined to be 2.19 MPa, 2.14 MPa and 2.07 MPa, respectively. The addition of

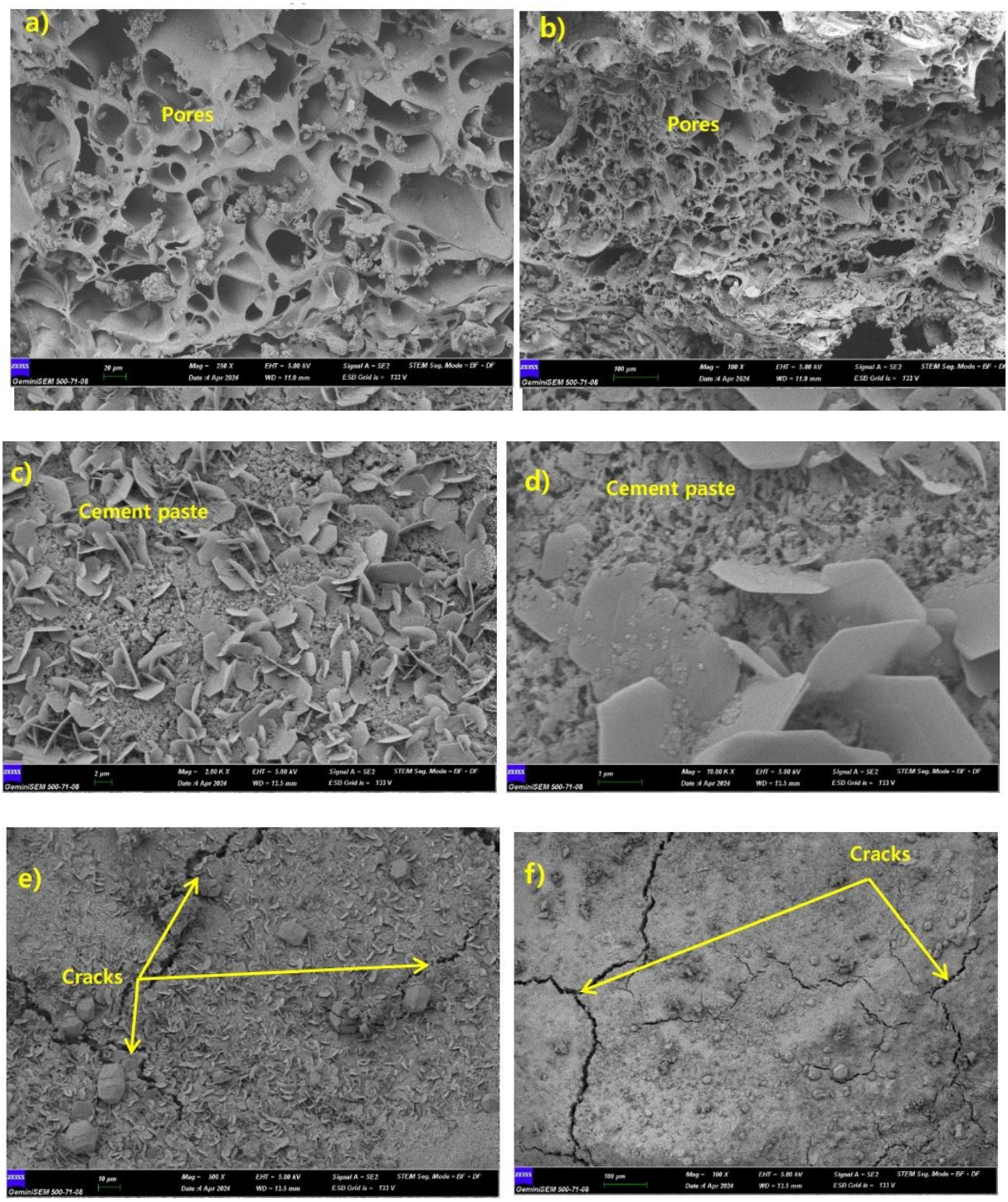


Fig. 14 Microstructure view of samples elevated to 600 °C

pumice stone at certain concentrations resulted in a reduction of 12.68% and 34.35% in CS, and a decrease of 2.50% and 5.69% in STS.

• The CS of concrete containing pumice stone and aluminum lathe, when subjected to fire, is observed to be decreased. Elevating the temperature has a detrimental impact on the concrete composition including aluminum lathe and pumice stone, resulting in a reduction in its strength.

• The reduction in concrete that results from a partial loss of hydration and the chemical changes that take place inside the concrete's body create micro-cracks to develop on the surface of the material.

• Following this analysis, an equation was produced using the data from the tests that were conducted to describe the relationship between CS and STS.

• According to the results of FESEM and EDX analysis, more porosity, aerated zones and cracks were detected, especially in the sample exposed to high temperatures. These results confirm the loss of strength in concrete with

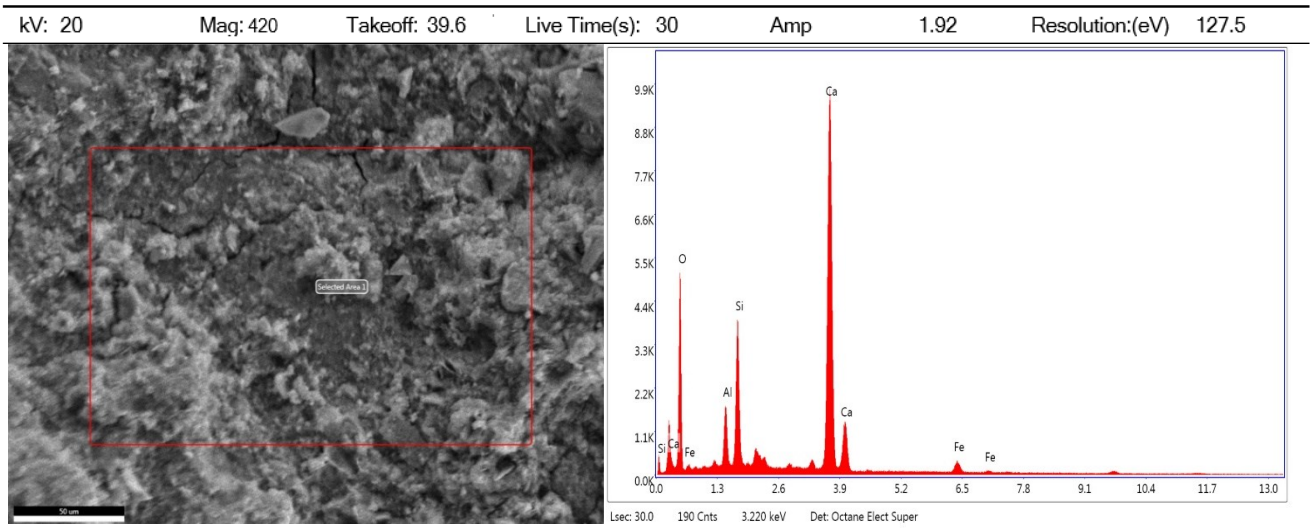


Fig. 15 EDX Analysis elevated to 600 ºC

increasing temperature.

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