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Review Article

A Review for the Performance of Polymers in Pumice Aggregate Concrete

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Lightweight aggregates have been utilized in concrete production for many years, and the incorporation of polymer materials into such composites has recently received growing attention due to the potential improvements in mechanical and durability performance. Polymer concrete or PC is concrete that has been coated, reinforced, or made without cement. It uses polymer materials to make the concrete stronger and last longer. The properties of polymer concrete made with pumice aggregate (PAPC) are described for this reason. This review looks at the mechanical and physical properties of PAPC. The results demonstrate that PAPC exhibits superior compressive and flexural strength compared to conventional concrete, along with reduced density and lower water absorption capacity. These enhancements make PAPC a promising material for lightweight and durable construction applications. This study is the first to look at PAPC and gather information that can be used to guide future research.

Keywords: mechanical properties; physical properties; polymer concrete; pumice aggregate

1. Introduction

It is called lightweight aggregate (LWA) if its particle density is less than 2000 kg/m^3 or its dry loose bulk density is less than 1200 kg/m^3 [1]. Two types of LWAs are natural (pumice, scoria, and diatomite) and artificial (perlite, expanded clay, slag, and vermiculite) [2]. LWAs are presently produced in various sizes, densities, and strength classes to meet specific engineering requirements. This shift has led to a growing interest in LWAs, particularly pumice, due to their availability and favorable properties such as low density and good thermal insulation. Several studies have demonstrated the potential of LWA in reducing the overall weight of concrete structures, thereby decreasing the seismic load and improving handling [3–5]. In this way, very low-density concrete can be made for insulation, and at the same time, a high-strength concrete with a compressive strength of more than 80 MPa (15 cm cube) can be made for structural use. The main benefit of lightweight aggregate concrete (LWAC) is that it is not very dense. This lowers the dead load and makes the concrete more insulating. Plus, it is simple to work with and requires no heavy-duty tools [1–6]. Recently, there has been more research into the structural performance of LWAC and the growth of its uses in the construction industry [6–11]. This is because quality aggregates are hard to come by and LWAs are easy to get.

Depending on the source, LWAC is made with aggregates with low density and a compressive strength of more than 16 MPa [1, 2]. Since recently, LWAC materials have been used more in construction for a variety of reasons, including lower dead loads, smaller cross sections, and less reinforcement; better thermal insulation and seismic resistance; more extended service life with low maintenance; and easier handling and fabrication [4, 6–8, 11–14].

Over the past 25 years, concrete polymers have gotten much attention. The widespread use of polymer concrete (PC), polymer-impregnated concrete (PIC), and polymer-modified concrete (PMC) in the future was seen as a bright future trend. Initially, the current applications of the materials will be examined, followed by a discussion of their potential future uses. PC gained prominence in the 1970s and has since been widely utilized for repair works, the production of precast components, and as thin overlay systems for floors and bridges. In order to develop a comprehensive understanding of this material, it is essential to review both its historical development and future prospects, particularly as advancements continue beyond the late 20th century [15].

Compared to regular Portland concrete, PC has excellent properties, making it a popular building material (OPC). According to many studies, using polymers in concrete makes it easier to work with, stronger, and lasts longer [16–24]. Individuals from all over the world are interested in various approaches to using polymers. There are three distinct ways that polymers are utilized in concrete. They include PC, polymer cement concrete (PCC), and PIC [25].

Many years of successful use have been made with lightweight aggregate polymer concrete (LWPC) for building structures. The structure's efficiency is more important than just strength when lightweight concrete is used for building structures. The self-weight, foundation size, and building costs are lower when the density is lower while the strength level stays the same. High-performance concrete is easier to make now that concrete technology has quickly changed in the past few years. High-performance, lightweight concrete has been the subject of several studies since 1980 [21, 24, 26].

This study reviews the properties of polymer concretes produced with pumice aggregate (PAPCs). The properties of PAPC have never been put together before in a review study like this one. There is information in the study about the physical and mechanical properties of PAPC. These are PAPCs' mechanical properties, which include their compressive, flexural, and tensile strengths. Their physical properties are their density, slump, and water absorption.

2. LWAs

LWA can make lightweight concrete, lightweight bricks, road construction insulation, and water filters [26]. As they formed, tuff, pumice, pumice stone, lava slag, diatomite, and other materials gave LWA its porous structure. The aggregates were classified into two groups: crushed and uncrushed (natural) aggregates. According to EN 1097-6 [27], aggregates are defined as lightweight when their oven-dry particle density is less than 2000 kg/m^3 or when their oven-dry bulk density (including voids) determined in accordance with EN 1097-3 [28] is less than 1200 kg/m^3 for mineral-based aggregates.

Pumice aggregate (PA) is a porous, silicate-based, spongy-looking rock formed after volcanic activities. It is usually light in color and can be found in various colors, from off-white to gray, red, and brown to black. There are two types: acidic pumice and basic pumice (Figure 1). Commonly used, acidic pumice is light-colored, and basic pumice is dark-colored. Its hardness is 5–6 according to the Mohs scale, and its density is relatively low; it is between 0.5 and 2 g/cm^3. Its chemical composition contains high amounts of silicon, aluminum, iron, calcium, magnesium, sodium, and potassium, as well as trace amounts of titanium and sulfur (Table 1) [29–33].

Figure 1: Types of pumice aggregates.

Numerous places around the world make pumice. Italians make the most pumice, but countries like Spain, Greece, and Turkey are close behind. This volcanic stone can be found worldwide, wherever gas and water are present in a magma that is cooling quickly. Therefore, pumice will probably be made by some of the volcanoes that start near the shore. Pumice powder is formed when water seeps below the crust of the oceanic plates in certain places, allowing this stone to be found underwater (PP). This stone has many other uses in both modern industry and the past [34].

PA brings many advantages due to its superior properties, like its low density, high heat and noise insulation, air conditioning characteristic, easy plaster retaining, perfect acoustic feature, and elasticity in case of seismic load and behaviors. The most crucial reason pumice is used as a lightweight building material (PA, pumice blocks) in the construction industry is its porous structure since these pores are unconnected [33].

Over 50 different areas use PA as an industrial raw material for various reasons. This material is used extensively in the construction, textile, farming, and chemical industries. Every day, more and more industries use it because of its specific physical, chemical, mineral, and structural features. This substance has been used in many different areas lately, like cosmetics, ceramics, varnish, paint, and landscaping. It is widely used in many places because it is natural, easy to get, and safe for both people and the environment. Unfortunately, PA is not recyclable for reuse in concrete production due to its porous structure and degradation during the mixing and service processes [29].

According to the USGS Mineral Commodity Summaries Report (2022), global pumice production reached 15.4 million tons, with Turkey leading at 5.4 million tons based on finalized 2020 data. Other major producers include Greece (1.02 million tons), Uganda (960 thousand tons), Algeria and Jordan (900 thousand tons each), Ecuador (800 thousand tons), and Chile (680 thousand tons) [34]. The widespread availability and significant production of pumice worldwide highlight its potential as an abundant and sustainable resource for use as a LWA in construction materials, including PMCs. This global distribution underscores the material's relevance for various engineering applications and its accessibility for future industrial use.

TABLE 1: Chemical composition of pumice (%) [29].

Composition	Acidic pumice	Basic pumice
SiO_2	70	45
Al_2O_3	14	21
Fe_2O_3	2.5	7
CaO	0.9	11
MgO	0.6	7
$Na_2O + K_2$	9	8
TiO_2	< 1	<1
SO_3	< 1	<1
Loss of ignition	3	1

3. Properties of PAPC

In this section, studies that look at how PA can be used in PC are gathered. Table 2 shows the different ways that PA can be used in PC, along with the amounts used and their results on the mixture.

Table 2 presents a chronological overview of studies investigating the use of PA in PC. Although research on PCs has increased recently, studies specifically focusing on PA remain limited. Epoxy resin is identified as the most commonly used polymer, followed by polyester and polyurethane. Pumice is incorporated in varying proportions as natural stone, coarse aggregate, or fine aggregate and, in some cases, as polymer-coated aggregate. The reviewed studies demonstrate that the density and mechanical strength of PC are influenced by the amount of PA used.

3.1. Physical Properties of PAPC

3.1.1. Slump Test of PAPC. Workability is a critical property of fresh concrete as it affects the ease of mixing, placing, compaction, and finishing, ultimately influencing the quality and performance of the hardened material. In the case of PAPC, maintaining appropriate workability is essential due to the lightweight and highly porous nature of PA, which can impact the mixture's consistency and handling characteristics. The slump test is commonly used to assess the workability of concrete mixtures. Table 3 presents the slump classes in accordance with TS EN 206-1 [55]. Additionally, ACI 213R-87 [56] states that the maximum permissible slump value for LWA concrete should not exceed 100 mm. Figure 2 illustrates the slump test results obtained in this study, demonstrating the workability levels achieved in the prepared PAPC mixtures.

Mukesh et al. [35] state that the slump value of PC decreases when the percentage of LWAs increases. Wijatmiko et al. [47] note that LWAC coated pumice has a lower slump value; the workability has remained at the same stage as regular weight concrete (NWC). Kurugöl et al. [54] observed that there is lower workability of PAPC ($w/b = 0.55$) including fine pumice, and they see that there is a decrease in slumps of the PL series—representing mixtures with pumice used as LWA—the polymer volume fraction in the aggregate $(\text{Vag}) = 0.36$ series until the polymer content percentage in the mixture $(\text{Vp}) = 20\%$. The results showed that the slump values of the references obtained are evaluated according to TS EN 206-1; it is seen in Kurugöl et al. [54] in the S1 class and its consistency is dry; in Mukesh et al. [35] it is S2, and its surface is plastic. In Wijatmiko et al. [47], it is an S3 class, and its character is fluent. The studies reviewed in this section consistently indicate that the incorporation of PA reduces the workability of PAPC. Moreover, a further decrease in workability is observed with increasing pumice content in the mixture.

3.2. Density of PAPC. The density of PAPC is a critical parameter that directly influences its mechanical properties, thermal insulation capacity, and overall structural performance. Lightweight concretes are classified according to their density ranges, as defined by various international standards. For instance, TS EN 206-1 specifies density classes for lightweight concrete, as summarized in Table 4. Depending on regional practices and material characteristics, the densities of lightweight concrete vary: 1200–2200 kg/m^3 in Norway, 1800 kg/m^3 or higher in the United States and Australia, 800–2000 kg/m^3 in Russia, and 900–2000 kg/m^3 according to European standards [57].

The density results (maximum–minimum) obtained from the available studies on PAPCs are given in Figure 3.

It was found that the PAPC densities were between 1346 and 1940 kg/m^3 based on the available studies. According to ACI 213, all of the concretes evaluated in the reviewed studies are classified as structural lightweight concrete. For the PAPCs, the densities were seen to be between D 1.4 and D 1.8, which is what TS EN 206-1 says. When epoxy concretes were used at different rates, their densities ranged from 1346 to 1940 kg/m^3. When polyester was used, they went from 1582 to 1678 kg/m^3, and when styrene-butadiene polymer was used, they ranged from 1730 to 1940 kg/m^3. As the polymer possesses a higher density than the PA, its increased content in the mixture results in a higher overall density of the concrete.

3.3. Water Absorption of PAPC. With its porous structure and high water absorption (30%–40%), PA has some good qualities, but it makes it hard to work with fresh concrete in the design of lightweight concrete mixes. The factors that affect the water absorption rate most, according to Ulusu [58], Neville [57], and Aicitin [59], are the amount and structure of the aggregate voids, the water/cement ratio, and the amount of binder. It is recommended that lightweight concretes with high durability should not absorb more than 10% water. Due to their hydrophobic nature and ease of molding, polymers are expected to reduce the water absorption capacity of the concrete. Figure 4 shows the water absorption results (highest and lowest) from research on PAPC.

Susilawati et al. [36] reported that PC incorporating singkut leaf fibers exhibited lower water absorption compared to PC without these fibers. However, they also observed that as the complexity and content of the leaf fiber composition increased, the water absorption values tended to rise. This was attributed to the excessive fiber content interfering with

TABLE 2: Studies on pumice aggregate use and effects in polymer concrete.

Polymer type	Application form	Pumice type	Polymer content (%)	Effect of PAPC	References
Epoxy	Concrete	Fine	100%	Reduced density Increased compressive strength	Mukesh et al., [35]
Epoxy	Concrete	Stone	20%	Increased density	Susilawati et al., [36]
Polyester	Concrete	Coarse and fine	20%	Increased compressive strength	Sevim, [37]
Polyester	Concrete	Coarse and fine	15%, 30%, 45%	Increased density	Kaplan and Özel, [38]
Polyurethane Polyester	Concrete	Coarse and fine	20%, 25%, 30%	Reduced density Increased compressive strength	Maghfirah et al., [39]
Epoxy	Concrete	Coarse and fine	20%, 25%, 30%	Reduced density	Fauzi et al., [40]
Polyurethane	Concrete	Coarse	15%, 20%, 25%	Increased density Increased compressive strength and flexural strength	Maghfirah et al., [41]
Epoxy	Concrete	Coarse and fine	25%, 30%	Increased flexural strength	Hakim et al., [42]
Epoxy	Concrete	Coarse and fine	20%, 25%, 30%	Reduced density Increased compressive strength and flexural strength	Maghfirah et al., [43]
Epoxy	Concrete	Coarse and fine	20%, 25%, 30%	Reduced density Increased strengths	Fauzi et al., [44]
Epoxy	Concrete	Coarse and fine	20%, 25%, 30%	Reduced water absorption	Maghfirah et al., [45]
Epoxy	Concrete	Coarse and fine	10%, 15%, 20%	Reduced density Increased strengths	Neşer et al., [46]
Polymer liquid	Coated	Coarse	100%	Increased flexural strength	Wijatmiko et al., [47]
Polyurethane Polyester	Coated	Coarse and fine	100%	Positive effect creep and shrinkage Increased compressive strength	Bideci et al., [48]
Epoxy	Concrete	Stone	10%, 15%, 20%	Reduced density Increased strengths	Fauzi et al., [49]
Polyurethane Polyester	Coated	Coarse and fine	100%	Reduced water absorption	Sallı Bideci et al., [32]
Epoxy	Concrete	Coarse and fine	10%, 15%, 20%	Increased compressive strength Reduced water absorption	Uygunoğlu et al., [50]
Polyurethane Polyester	Coated	Coarse and fine	100%	Increased compressive strength	Bideci et al., [51]
Polyurethane Polyester	Coated	Coarse and fine	100%	Increased compressive strength	Bideci et al., [52]
Polyester	Concrete	Coarse and fine	10%, 15%, 20%	Increased strengths	Kılıç et al., [53]
Epoxy	Concrete	Coarse	10%, 20%, 30%, 40%	Reduced the slump Low polymer content positively affected Young's modulus of elasticity (MoE)	Kurugöl et al., [54]

the proper adhesion between the fibers and the epoxy resin matrix, thereby creating voids that facilitate water ingress. In contrast, Maghfirah et al. [39] demonstrated that PC generally exhibits lower water absorption compared to conventional cement-based concrete, due to the hydrophobic nature of the polymer matrix. Maghfirah et al. [41] found that the water absorption value increases as the amount of epoxy resin increases. A study by Maghfirah et al. [43] found that a composite mixture consisting of sand, pumice, coffee shells, and polyurethane in the proportions of 60:14:6:20 g yielded the most favorable water absorption performance, indicating reduced water uptake compared to other tested formulations. Fauzi et al. [44] found that adding epoxy resin (47.5:47.5:5) to the mixture led to at least 7.2% of the total weight being absorbed, and the PC produced in their study exhibited low water absorption and a smooth, dense, and nonporous surface. In their study, Maghfirah et al. [45] discovered that PC absorbed 6.81% of the water it was given. According to Fauzi et al. [49], the amount of polyurethane resin spread out in the sample significantly affects how much water the PC can hold.

The available studies in this section concluded that the maximum water absorption rate is 21.2% and the minimum 1.7%. In addition, apart from this high water absorption rate, it was observed that the water absorption rate was between 3.0% and 3.8%. It has been determined that the water absorption rate of PAPCs is lower than the rate (10%) stated in the literature.

TABLE 3: Slump classifications of concrete as per TS EN 206-1 [54].

Class	Slump (mm)	Consistency
S1	10–40	Dry
S2	50–90	Plastic
S3	100–150	Fluent
S4	160–210	Very fluent
S5	≥ 220	Spreading

3.4. Compressive Strength of PAPC. According to the ACI Committee 213 "Guide for Structural Lightweight Aggregate Concrete" (ACI 213, 2001) [60], LWAC is primarily classified based on its unit weight, which typically ranges from 300 to 1850 kg/m^3. In addition, its compressive strength can vary significantly, from as low as 0.3 MPa to as high as 90 MPa, depending on the specific application and mix design. There are three different lightweight concrete type divisions in terms of strength range, which are nonstructural concretes (< 10 MPa), medium strength concrete (10–15 MPa), and structural concretes (> 17 MPa). The density of these concretes is in the range of 700–1400, 1400–1600, and 1850 kg/m^3, respectively (Table 2). The relation of PC compressive strength with the material composition is shown in Figure 5.

Mukesh et al. [35] found that PC with PA showed higher compressive strength than other LWAs, and the compressive strength value continued to increase as the percentage of LWA in the concrete mix increased. Susilawati et al. [36] found the compressive strength value of PCs containing 20-g pumice stone and 20-g epoxy resin to be 33.7 MPa.

Maghfirah et al. [39], in another study where they used a mixture of polyester resin and polyurethane resin with an additive, found that this double mixture (compared to single combinations) increased the compressive strength. Maghfirah et al. [41] found the compressive strengths of 15, 20, and 30 g polyurethane-added PCs, respectively, of 11.7, 13.7, and 16.2 MPa. The study found that the compressive strength increased with the addition of polyurethane. Lukman Hakim and Diego Van [42] explained in their studies that the acquisition of epoxy resin strengthens the bonds of sand, pumice, and pulp fiber wastes, and this is because epoxy resin acts as a bonding agent with the aggregate. Maghfirah et al. [43] observed that the compressive strength value increased when the amount of epoxy resin was added due to its bond to sand, pumice, and corn husk fibers. Also, in this study, they found that the adhesive functionality of epoxy resin could increase the compressive strength of PC, and the best compressive strength was obtained with a value of 8.41 MPa in 30% epoxy resin. Fauzi et al. [44] concluded that the incorporation of epoxy resin as a binder enhances the compressive strength of the composite. The presence of epoxy resin improves the adhesion between the sand, pumice, and pulp fiber waste, as the resin effectively functions as a binding agent, strengthening the overall matrix structure. Neşer et al. [46] stated that the mixtures are within the appropriate limits for compressive strength. Polymer additives positively affect the strength of the materials as they increase the bonding strength of the particles and reduce the water requirement of the mixtures. The mix with the lowest density has the most insufficient compressive strength. Wijatmiko et al. [48] found that the relative replacement of the gravel aggregate with the PA caused a decrease in the 28-day compressive strength. Furthermore, the addition of the coated polymer on the pumice caused a slight reduction in the compressive strength. They stated that this decrease can be attributed to the lack of clinker (C_3S), which causes a slowing of hydration and a reduction in the heat generation rate, mainly when polymer coating is applied. Maghfirah et al. found that PC compressive strength was 7.67 MPa. Bideci et al. [49], when the compressive strength values of concrete samples (on the 3rd, 7th, and 28th days) were compared with those of the control samples, observed that the compressive strength values of the KBP samples increased up to 4%–11%. In contrast, the compressive strength values of the SNMC and PLP samples decreased. Fauzi et al. [49] indicated that the compressive strength of PC is reduced with increasing polyurethane as a natural binder matrix. Uygunoğlu et al. [50] observed that the increase in compressive strength of PLC compared to NLC in PCs with 30% epoxy additive was mainly due to the strength gain of the epoxy with its hardener.

When the compressive strengths reported in the reviewed studies are evaluated according to the classification criteria of ACI 213, five studies [35, 36, 39, 47, 51] fall within the structural lightweight concrete category. Three studies [48–50] are classified as medium-strength concrete, while five studies [41–43, 45, 46] fall into the nonstructural lightweight concrete category. According to TS EN 206-1, these classifications may vary based on national standards and application requirements; however, a detailed evaluation according to this standard was not provided in the reviewed studies.

3.5. Flexural Strength of PAPC. Flexural strength is a measure used to determine the stress and strain distribution within a concrete element under bending loads. This property is particularly important in lightweight concrete because such materials are often used in structural and nonstructural applications where bending and tensile stresses are significant, such as floor panels, cladding, and bridge decks. Ensuring adequate flexural strength in lightweight concrete helps prevent cracking and failure under service loads, thereby improving the durability and overall performance of the structure. The flexural strength of average density aggregate PCs is between 8 and 35 MPa. The flexural strength results obtained from the available studies on PAPCs are shown in Figure 6.

Mukesh et al. [35] obtained that PC with PA showed higher flexural strength than other LWAs, and the value continued to increase as the percentage of LWA increased. In addition, they found in the study that when the rate of LWA was 2.5%, it showed a bending strength of 12.73 MPa. Fauzi et al. [40] obtained the maximum flexural strength of 11.0 MPa from concretes with 30% of the total weight of

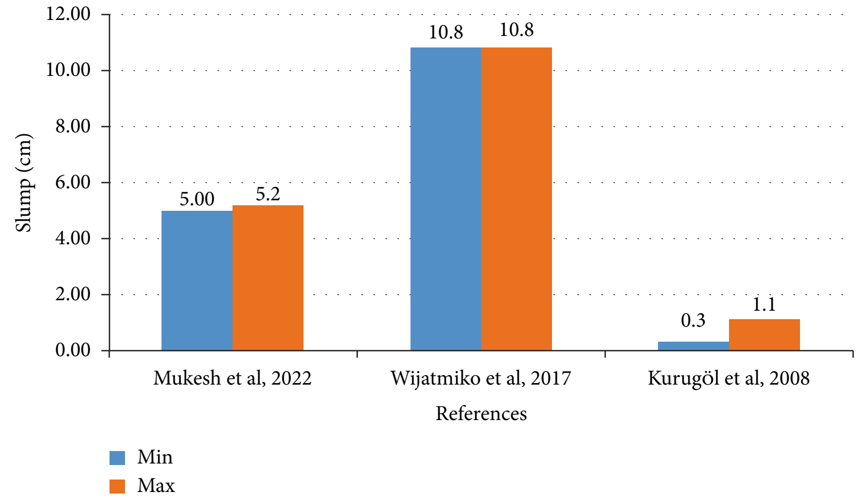

Figure 2: Slump values of PAPCs.

TABLE 4: Classification of LWAC.

ACI 213	Properties of LWAC Density (kg/m^3)	Low density 300–800		Moderate strength 800–1350		Structural 1350–≈1920	
TS EN 206-1	Density class Density (kg/m^3)	D 1.0 ≥ 800 and ≤ 1000	D 1.2 ≥ 1000 and ≤ 1200	D 1.4 ≥ 1200 and ≤ 1400	D 1.6 ≥ 1400 and ≤ 1600	D 1.8 ≥ 1600 and ≤ 1800	D 2.0 ≥ 2000 and ≤ 2000

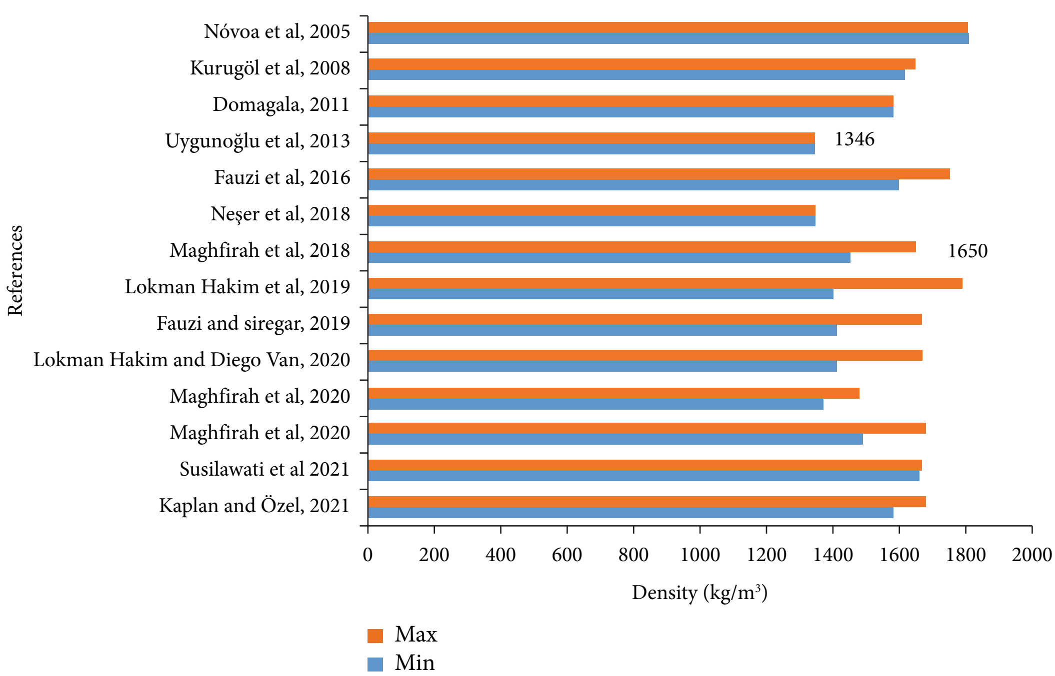

Figure 3: Densities of PAPCs.

epoxy resin in PCs with composition 50:50:0 and minimum flexural strength of 3.2 MPa from concretes with 20% epoxy resin. Maghfirah et al. [39] conducted a study to determine the effect of mixing polyester resin and polyurethane resin, and they indicated that the bending strength value of PC with a mixture of polyester resin and polyurethane resin is

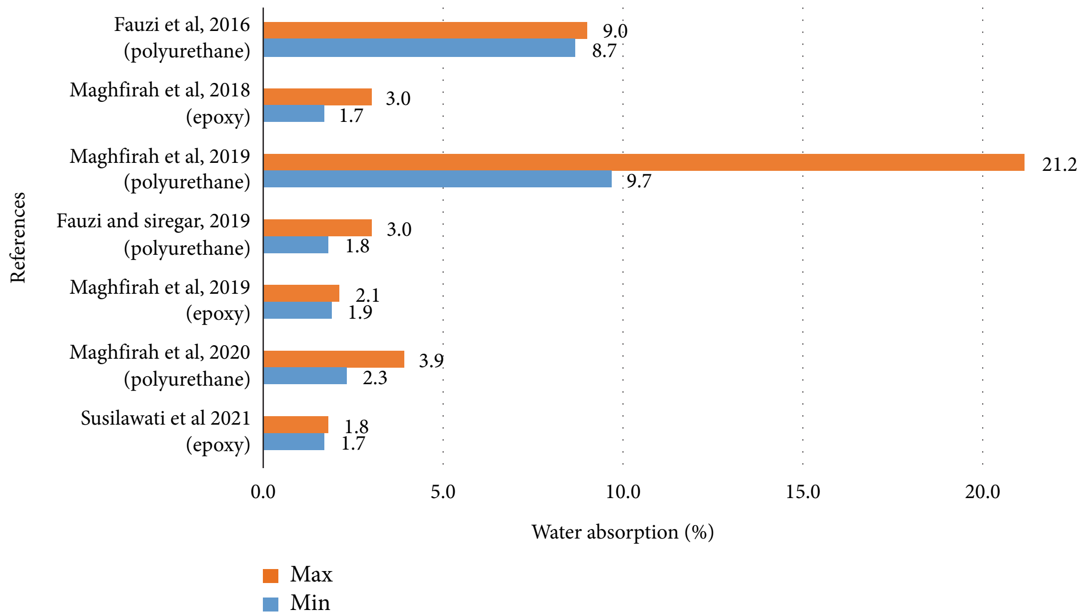

Figure 4: Water absorptions of PAPCs.

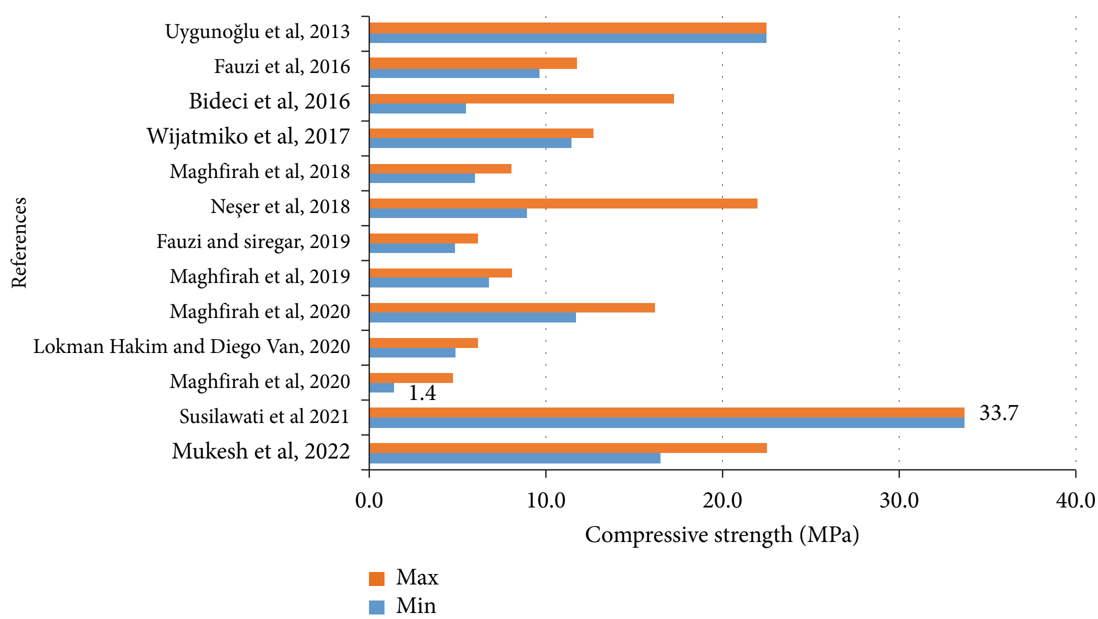

Figure 5: Compressive strengths of PAPCs.

increased compared to PC with polyester resin adhesive and that it is decreased compared to PC with polyurethane resin adhesive. Maghfirah et al. [41] found the flexural strengths of the concretes obtained by adding 15, 20, and 25 g of polyurethane resin for pumice PCs to be 16.04, 16.56, and 20.04 MPa, respectively. Here, they explained that the high flexural strength is increased as the added polyurethane resin fills the existing gaps and makes the PC more elastic. Fauzi et al. [44] stated that the more epoxy resin is added, the higher the value of bending strength will be, since epoxy resin will fill the voids in the concrete in PCs. Hakim et al. [42] indicated that the maximum flexural strength is 9.5 MPa with the composition 50:50:0 and 30% epoxy resin of total weight, and the minimum flexural strength is 2.62 MPa in composition 50:50:0 with 25% epoxy resin. Furthermore, they stated that the more epoxy resin is added the greater the value of the flexural strength because the epoxy resin will fill the cavity in the PC. Maghfirah et al. [43], in PCs consisting of 50:50:0 composition, obtained the maximum flexural strength (11.5 MPa) 30% from epoxy resin concretes and

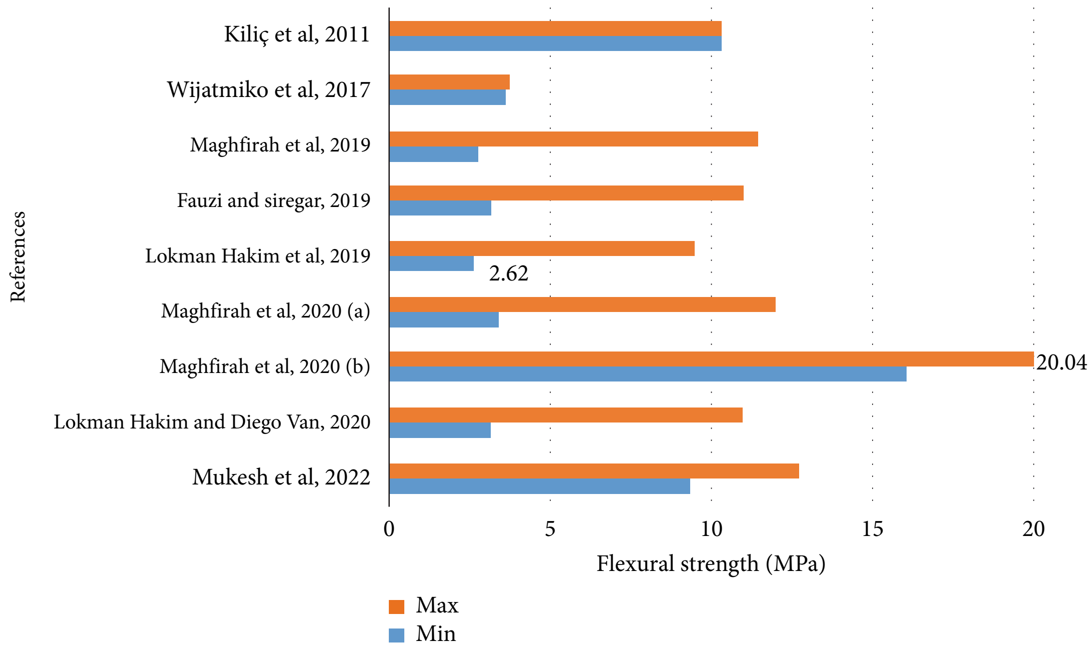

Figure 6: Flexural strengths of PAPCs.

the minimum flexural strength (2.81 MPa) 10% from epoxy resin concretes. Wijatmiko et al. [47] reported that the flexural strength of the polymer-coated pumice concrete was slightly higher than that of the uncoated concrete; however, the coated pumice had lower stiffness due to the reduction of the adhesion effect between cement and aggregates. Kılıç et al. [53] stated that the flexural tensile strength values of the PC samples changed depending on the aggregate types, and the flexural strength of PAPC was 10.4 MPa.

According to the available studies in this section, when examined in general, it was seen that the highest flexural strength (20.04 MPa) was obtained from PCs with polyurethane additives and from PCs with the lowest (2.62 MPa) epoxy additives. From these studies, it can be concluded that since the polymer will fill the void in the concrete, the more polymer added, the higher the flexural strength value; that is, the polymer addition increases the flexural strength of PAPC.

3.6. Tensile Strength of PAPC. Tensile strength is a critical mechanical property of concrete, as it reflects the material's ability to resist cracking and failure under tension forces. Although concrete exhibits high compressive strength, its tensile strength is relatively low, making it susceptible to cracking when subjected to tensile stresses. Therefore, understanding and accurately measuring the tensile strength of concrete are essential for ensuring the structural integrity and durability of concrete elements. Any defects or imperfections introduced during the production process can significantly reduce tensile strength, thereby compromising the overall performance of the concrete. In addition, it is stated that the tensile strength of concretes can be found in two types: indirect and direct, and one of the indirect tests is the splitting method. In the literature, tensile strengths of lightweight concretes (Figure 7), all produced with LWA, range from 2.0 to 2.2 MPa [59].

Mukesh et al. [35] reported that PC containing different LWAs (perlite, vermiculite, pumice, sawdust, and rice husk) showed higher split-tensile strength than other LWAs, and they observed the value continued to increase as the percentage of LWA increased. Susilawati et al. [36] reported a tensile strength of 4.29 MPa in PC specimens containing 20 g of epoxy resin. This result indicates that the addition of epoxy resin significantly enhanced the tensile strength compared to mixes with lower or no epoxy content, demonstrating the positive effect of epoxy as a binding agent in improving the mechanical performance of PC. Maghfirah et al. [39] used a polyester–polyurethane mixture in PCs as 20, 25, and 25 g and found the tensile strength in splitting to be 1.46, 1.53, and 3.76 MPa, respectively. The study found that the tensile strength of PC containing a mixture of polyester and polyurethane resin adhesives was lower than that of PC made with either polyester resin or polyurethane resin alone. In the experiments using different amounts of polyurethane resin (15, 20, and 25 g) with pumice waste, the tensile strength values ranged between 4.10 and 4.30 MPa. These results suggest that increasing the amount of polyurethane resin led to a reduction in tensile strength, likely due to decreased bonding efficiency in the composite structure. Maghfirah et al. [43], in another study, found that the tensile strength of PC was between 057 and 1.10 MPa. According to the available studies on the tensile strength of PAPCs, the addition of PA generally leads to a reduction in tensile strength. Similarly, the use of certain polymers can also negatively affect tensile performance depending on their type and content. These findings indicate that both pumice and

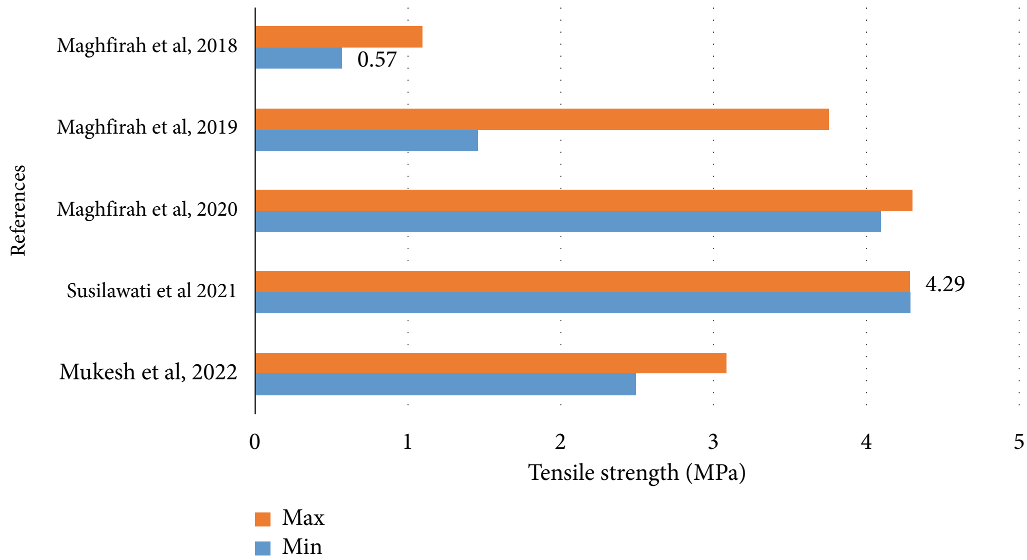

FIGURE 7: Tensile strengths of PAPCs.

polymer content must be carefully optimized to maintain or improve the tensile properties of PAPCs.

4. Conclusion

The current paper provides a comprehensive analysis of the physical and mechanical properties of PAPC. The key findings from existing studies are summarized below. The results obtained from the available studies are given below.

- Including pumice as a part of the aggregate decreased the workability of PAPCs.
- The density of the concretes increased due to the increase in the percentage of polymer addition due to the thickness of the polymer being higher than the aggregate density.
- The water absorption rate of PAPCs is lower than the rate (10%) stated in the literature.
- It was determined that the addition of epoxy, polyurethane, polyester, and polyurethane + polyester to concrete as polymers increased the compressive strength of PAPCs.
- It can be concluded that the addition of polymer to PAPC increases the flexural strength as the voids in the concrete are filled.
- The tensile strength decreases with the addition of pumice and polymers.

In this study, polymer is used in PA concretes; it was determined that the slump value was S1, density was 1346–1650 kg/m^3, water absorption was 1.7%–21.2%, compressive strength was 33.7 MPa, bending strength was 20.04 MPa, and tensile strength was 4.29 MPa. For future research, it is recommended to focus on polyurethane-based PCs incorporating approximately 10% additive content. This proportion has been identified as optimal in previous studies, balancing improved mechanical performance and workability without causing adverse effects such as excessive brittleness or decreased bonding efficiency.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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