WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2025.154133
ARCHIVES OF CIVIL ENGINEERING
Vol. LXXI ISSUE 2 2025

pp. 491 – 501

Research paper

Utilization of asphalt plant waste powder as a partial cement replacement in concrete

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Abstract: Asphalt Plant Waste Powder (APWP) is a sort of waste that asphalt mixing facilities produce in enormous amounts. These materials have the potential to cause a plethora of new health and environmental concerns; thus, they should be changed into something more useful and environmentally friendly. This substance comprising silicon and aluminium, which can be utilised as a cement substitute or in building. Utilization of APWP is a novel, since very limited research has used this material especially in concrete. This study will evaluate the use of Asphalt Plant Waste Powder (APWP) as a cement substitute in order to produce regular, usable concrete. This study aims to determine the ideal amount of cement replacement by APWP for use as a building material and to manufacture normal concrete with a density of less than 2400 kg/m^3. To partially replace cement, four proposed percentages of 10%, 20%, 30%, and 40% are

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utilised. Compressive and flexural strength were examined at 28 days throughout the project. All specimens were water-cured prior to being examined. The optimal replacement of cement by APWP is therefore 10% with compressive strength of 53.75 MPa, density of 2456 kg/m^3, Ultra Pulse Velocity (UPV) of 3.82 km/s, and flexural strength of 5.84 MPa. Consequently, it is suggested that APWP can be utilised as a cement alternative at a replacement rate of 10%.

Keywords: asphalt plant waste powder (APWP), concrete, flexural strength, compressive strength, ultrasonic pulse velocity (UPV)

1. Introduction

The construction and building business is one of the world's fastest-growing sectors, resulting in environmental issues due to the extensive usage of natural resources such as natural sand and cement. The demand for sand, aggregate and cement has risen dramatically because of globalization and expanding urbanization.

Presently, the depletion of natural resources is a concern for every nation on earth. According to past researchers [1–4], the likely solution to this issue could lead to an increase in the utilisation of industrial waste and by-products in the future. As a result, an investigation into the physical features of asphalt plant waste powder as a partial substitute in concrete was urgently required to supplement the building industry's scarce natural resource materials.

Due to population growth, a substantial amount of construction and demolition waste (CDW) is generated worldwide [5]. The challenges develop when there is a lack of room for trash disposal and disposal techniques. According to Wang et al. [6], urban building has significantly increased the rate of urbanisation, but it has also produced a huge number of industrial products used in the construction sector, such as construction and demolition (C&D) waste. Examples of C&D are asphalt mix and concrete. Over 3 billion tonnes of C&D waste are created annually on a global scale [7]. The unplanned disposal of C&D waste encroaches upon land resources and creates problems such as soil, air, and groundwater contamination and even landslides [7, 8]. Consequently, using APWP as a building material would be one solution to this problem. However, very limited research have utilised plant waste as a replacement material for concrete, either completely or partially. Most of the previous studies have focussed on the recycled or waste materials such as rubber, fiber, slag and recycled aggregate, to be added in the new asphalt pavement [9].

The only application based on previous study that use asphalt plant waste was on road construction [10]. The effect of asphalt plant waste on the asphalt concrete has been investigated [11] and met the required specifications values for road superstructures. The asphalt waste dust or asphalt plant waste had fineness and a relatively high content of calcium oxide (CaO) in the form of limestone ($CaCO_3$) as a major component as analyzed using an X-ray diffraction technique [10]. This study concluded that the asphalt waste dust itself can be used as a subbase course material in road structure according to the standard specifications of pavement materials.

Utilization of APWP is a novel, since no previous research has used this material specifically in concrete as fully of partially replacement. Since this material abundantly increase as a waste from asphalt mixing process, the alternative to convert from waste to something that more valuable product is crucial. Due to the rising demand for concrete production, the objective of comparing the performance of asphalt plant waste powder concrete to that of ordinary concrete is an intriguing topic of study. Furthermore, it is readily available in large quantities, as there are multiple road premix manufacturers in each state.

2. Methodology

2.1. Materials

The plant waste was acquired from Pens Industries Company's plant waste pond in Perlis. The plant waste must be dried in an oven at 100°C for 24 hours. The powdered plant debris was sieved using a stainless steel laboratory test sieve. The powdered plant waste that passes through sieve 200 (0.063 mm) is obtained. The plant waste powder is then re-dried in an oven at 100°C for two hours. The powdered plant waste is then allowed to cool at room temperature. In this study, Ordinary Portland Cement (OPC) Grade 42.5 cement is utilised.

In this investigation, both fine and coarse aggregates are utilised. River sand is used as fine aggregates with an uncrushed size of 70% passing through a 600 mm sieve. Meanwhile, coarse aggregates consisting of uncrushed stones between 10 and 20 millimetres in size have been selected.

Water is needed in concrete mixtures to create paste that glues all the cement and aggregates together. Water causes concrete to harden through a process known as hydration. Water enhances workability by reducing internal friction between cement and aggregates, allowing fresh concrete to be easily mould. The water-to-cement ratio will be 0.55.

2.2. Sample preparation

In this investigation, 45 concrete specimens, including control concrete and APWP-based concrete are casted. In addition, 30 cubes measuring $100 \times 100 \times 100$ mm and 15 cuboidal beams measuring $100 \times 100 \times 500$ mm were used in this investigation. Table 1 displays the quantity of raw materials as concrete mix design for control and partial substitution of cement with APWP in concrete. The percentage of APWP used in this study is based on the preliminary study and referring to the previous studies [10, 11].

Coarse aggregates, sand, cement, and APWP are thoroughly combined with water until a homogeneous state is reached. After the concrete mould has been created, a slump test is conducted to guarantee that the concrete is workable. The mixture is then poured in three layers into the mould, generating concrete cubes with dimension of $100 \times 100 \times 100$ mm and cuboidal beams with dimension of $100 \times 100 \times 500$ mm. Each layer is crushed with a compacting rod at least 25 times. The specimens of concrete were then stored for 24 hours at room temperature in the laboratory. Following demolding, the concrete specimens are immersed in a water tank for 7 and 28 days for curing.

Table 1. Portion of raw material in concrete mix design form

Proportion Materials (g)	**Percentage of raw material in concrete**				
	0%	**10%**	**20%**	**30%**	**40%**
Cement	340	306	272	238	204
Water	160	160	160	160	160
Fine Aggregate	515	515	515	515	515
Aggregate 10 mm	460	460	460	460	460
Aggregate 20 mm	925	925	925	925	925
APWP	0	34	68	102	136
TOTAL	2400	2400	2400	2400	2400

2.3. Testing

In this study, the purpose of the slump research is to evaluate the workability of fresh concrete using British Standard (BS EN 12350-2:2009). Slump height is determined by measuring the distance between the mould's height and the highest point of the sample.

This test method measures the solidity of the concrete by determining the density of hardened concrete. The test is conducted in accordance with BS 1882–114: 1983. In this test, the density of the concrete is investigated by immersing the samples for 7 and 28 days before they are taken out for testing. All 45 specimens prepared for 7 days and 28 days with different percentage replacements of plant waste concrete are tested for density by calculating the density value.

An ultrasonic pulse velocity (UPV) test is an in-situ, non-destructive test to check the quality of concrete and natural rocks. In this test, the strength and quality of concrete or rock are assessed by measuring the velocity of an ultrasonic pulse passing through a concrete structure or natural rock formation. This test is done to assess the quality of concrete using the ultrasonic pulse velocity method as categorized in Table 2. The method consists of measuring the time of travel of an ultrasonic pulse passing through the concrete being tested. Comparatively higher velocity is obtained when concrete quality is good in terms of density, uniformity, and homogeneity. The quality of concrete in terms of uniformity, incidence or absence of internal flaws, cracks, and segregation.

The aggregate grading, aggregate/cement ratio, and water/cement ratio all affect the compressive strength of concrete. To be correctly placed, newly mixed concrete must be workable, and cured concrete must be durable and achieve a specified compressive strength. This test method examines the ability of concrete to withstand loads by applying a compressive axial load to cube concrete specimens until failure occurs. The test was conducted in accordance with British Standard (BS EN 12390-3:2009) with standard dimensions of $100 \times 100 \times 100$ mm cube with three samples for each design. The compressive strength of concrete is determined in this test by uniformly applying an axial load in the range of 0.6–0.2 MPa/s. The characteristic compressive strength target is 30 N/mm^2 at 28 days.

Flexural strength test is the measure of the tensile strength of the concrete. It is determined by loading $100 \times 100 \times 500$ mm of unreinforced concrete beams to see if they can withstand bending failure. The test was conducted in accordance with EN 12390-5:2019. Three specimen with different replacement of APWP concrete are prepared and tested for flexural strength test.

3. Result and discussion

3.1. Slump test

Figure 1 depicts the results of a slump test for the development of workability of Asphalt Plant Waste Powder (APWP), which reveals that all concrete samples with varying percentages of APWP substitution demonstrate a decrease in workability. In accordance with the descending gradient pattern, the greatest slump test result of a concrete sample with APWP was 0% APWP (control) with a reading of 23 mm, and the minimum slump test result was 11 mm at 40% APWP replacement.

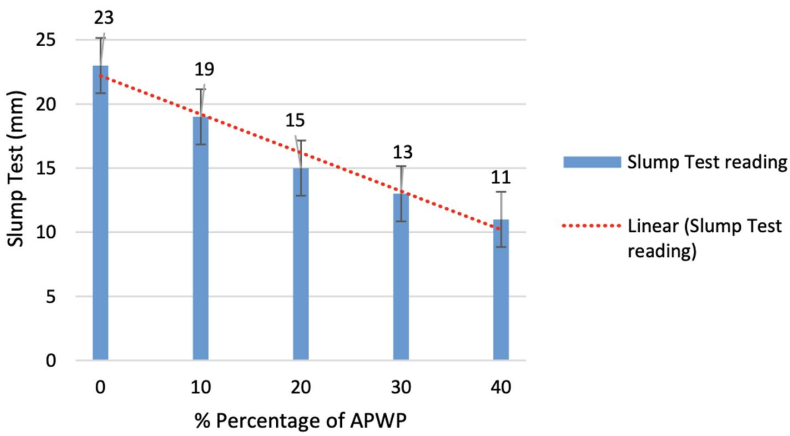

Fig. 1. Slump test result at various percentages of APWP

Due to a reduction in the proportion of OPC cement in the concrete mix design, the workability decreases as the proportion of APWP cement increases. Cement serves primarily as a hydraulic binder, which strengthens the link between fractured particles [8, 9]. APWP can function as a filler, which may necessitate the use of a catalyst to strengthen bonding by filling up the voids in the concrete.

3.2. Density test

Figure 2 shows density of each different percentage of APWP cube sample for 28 days. The development of density of all sample concrete with different percentage of replacement APWP, indicate fluctuate gradient pattern with linear trend.

According to the pattern, the maximum density before curing for concrete samples with APWP of 0% (control) and 10% is 2380 kg/m^3, while the minimum density is 2310 kg/m^3 for samples with APWP of 20%. The maximum density after curing for concrete samples with APWP of 0% (control) and 10% is 2430 kg/m^3, while the minimum density is 2360 kg/m^3 for concrete samples with APWP of 20%.

In addition, the density gradient was quite small, with changes in density before and after curing ranging from 20 kg/m^3 to 50 kg/m^3, or approximately 1% to 2% (from 0% to 40% APWP) for the entire sample. This result is attained because the optimal density is reached when the cement proportion in the concrete mix design is decreased. All samples of concrete's density are in the range of 2300 kg/m^3 until 2480 kg/m^3.

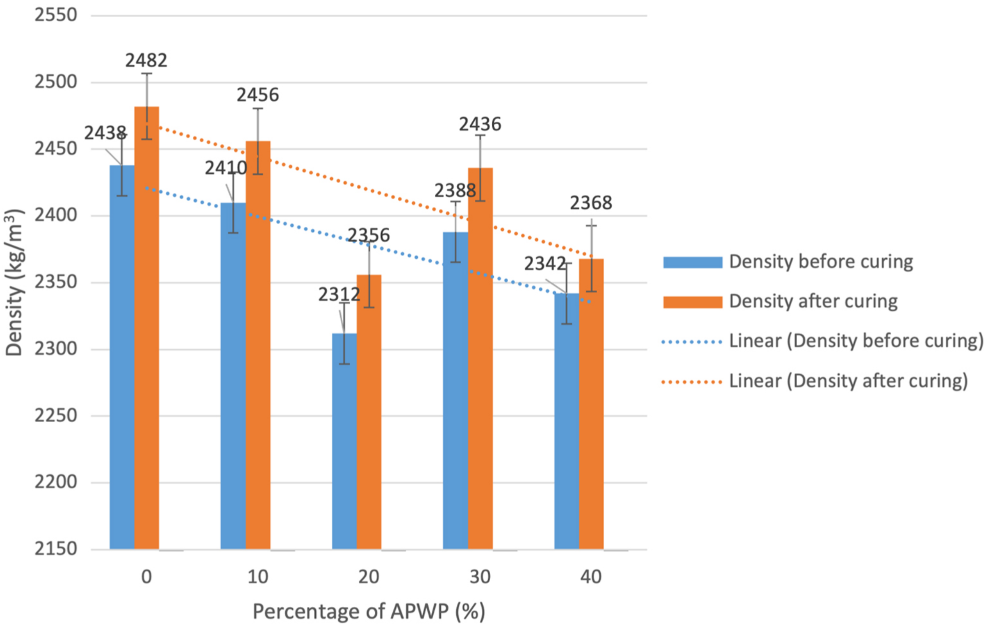

Fig. 2. Density of concrete at various percentages of APWP

3.3. Ultrasonic pulse velocity (UPV) test

Figure 3 depicts the outcome of the UPV test for the development of velocity of concrete with Asphalt Plant Waste Powder (APWP), which reveals that all concrete samples with varying percentages of APWP replacement exhibit a fluctuating velocity gradient. The greatest UPV reading of a concrete sample with 10% APWP was 4.92, and the minimum UPV reading was 3.61 at 40% APWP, as determined by the gradient pattern that fluctuated over a 7-day period.

Further, the fluctuating velocity gradient was minor gap, with changes in velocity for 7 and 28 days ranging from 1% to 29% (from 0% to 40% APWP) for the entire sample. At 20% APWP, the reading grade for a 7-day period begins to fall until 40% APWP is achieved. The ultrasonic pulse velocity (UPV) test is a non-destructive, in-situ examination that enables us to

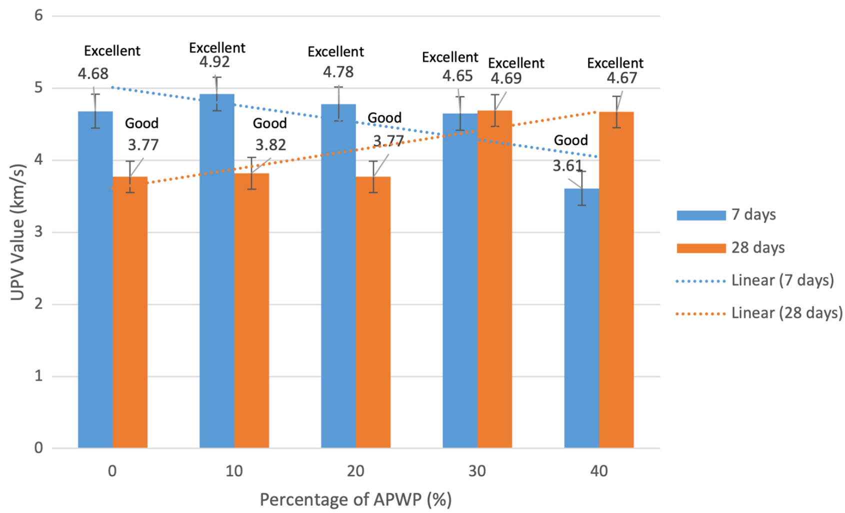

Fig. 3. Ultrasonic Pulse Velocity (UPV) at various percentages of APWP in concrete

determine whether the quality of the concrete is satisfactory or not. Since the results for 7 days get an outstanding reading (4.92 km/s at 10% APWP) and for 28 days produce an excellent reading (4.69 km/s at 30% APWP), this demonstrates that the concrete sample incorporating APWP is of high quality. Concrete sample incorporating 30% APWP also shows the highest UPV value with 4.69 km/s, showing the addition of APWP at high percentage leads to good quality of concrete produced. Table 2 shows the range of grading UPV test.

Table 2. The grading of Ultrasonic Pulse Velocity (UPV)

Pulse velocity (km/s)	Concrete quality (Grading)
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

3.4. Compressive strength

Figure 4 depicts the strength development of concrete with Asphalt Plant Waste Powder (APWP), demonstrating that all concrete samples with varying percentages of APWP exhibit an increase in strength at 28 days of testing. The concrete sample containing 10% APWP demonstrated a maximum compressive strength of 43.07 MPa after 7 days of testing. The identical pattern was seen on 28 days with maximum pressure of 53.75 MPa.

On the other hand, the highest strength development was only observed at 10% APWP, followed by a progressive decrease to 21% for 7-day samples. After achieving maximum strength at 10% APWP for 28-day samples, the strength gradually declines to a range of 23% to 14%. This result is accomplished by lowering the proportion of cement in the concrete

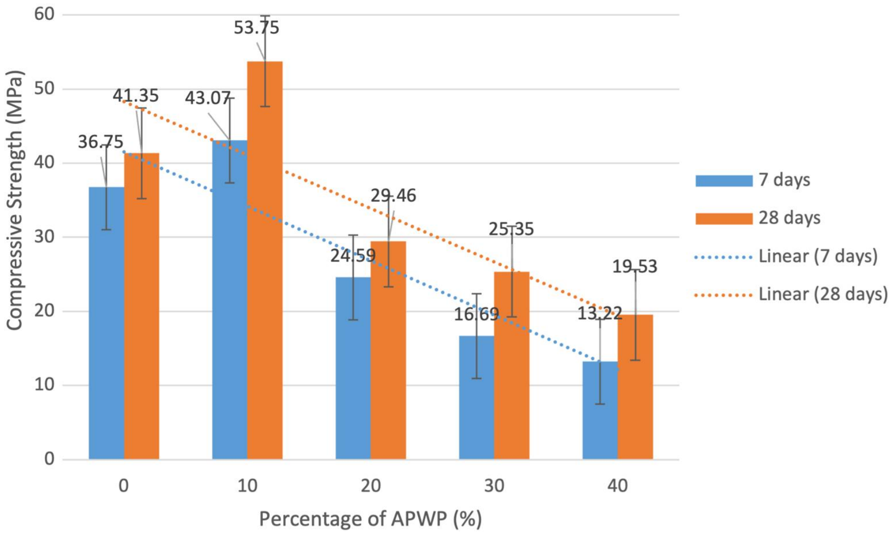

Fig. 4. Compressive strength of concrete samples at various percentages of APWP for 7 and 28 days

mix design. Cement serves primarily as a hydraulic binder, reinforcing the bond between fragmented particles. Since the proportion of APWP has increased, cement's role as a binder has diminished, necessitating the usage of a stronger binder material to bind the particle molecules. APWP can serve as a binder or filler, necessitating the employment of a catalyst to enhance bonding [12]. At 10% APWP substitution of cement, the maximum strength can be attained due to the effect of the filler to fill the spaces in the matrix, hence improving the strength of concrete. This resulted in the reduction of voids in the cement-APWP samples, while at the same time, the hydration reaction were accelerated between adjacent cement particles. The $CaCO_3$ composition in APWP could assist in promoting the strength of concrete samples as also concluded in past research [10, 11, 13]. However, higher replacement of APWP will not necessary function to increase the strength of concrete, thus optimum percentage of APWP will be limited to 10%. Previous study concluded that the percentage of APWP can be maximum at 20% replacement for road construction application [11]. Figure 5 depicts satisfactory cube failures following compression testing.

Fig. 5. Pattern of failures for APWP concrete

3.5. Flexural strength

Figure 6 depicts the strength development of concrete including Asphalt Plant Waste Powder (APWP), wherein all concrete samples containing a varied percentage of APWP exhibit an increase in strength after 28 days of testing. The graph depicts a maximum flexural strength of 5.84 MPa at 10% APWP.

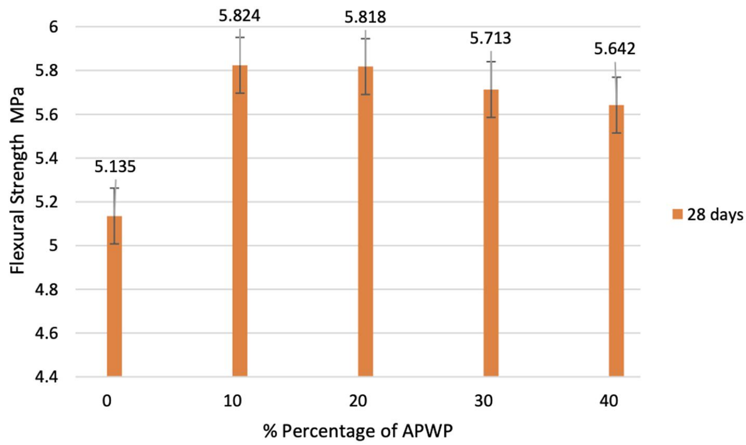

Fig. 6. Flexural strength of concrete samples at various percentages of APWP for 28 days

However, the highest strength development was observed at 10% APWP and subsequently steadily decreased to between 2% and 1% for every sample. Workability, mechanical, and durability properties of cement-based materials can be improved to a certain extent by adding an appropriate amount of supplemental cementitious material within a particular range (5–15%), as stated by He et al. in 2021 [9]. This assertion is supported by the results of this investigation, which demonstrates that the optimal characteristics can be achieved by substituting 10% APWP for cement. By filling inter-particle gaps and providing increased packing density, APWP with a finer particle size will aid to strengthen the strength of concrete [14, 15]. This can facilitate the discharge of some of the mixing water that would otherwise be trapped within the system. The water–binder ratio determines the system's free space in terms of void volume and the amount of fine material needed to fill the voids. Void filling in packed systems can improve particle arrangement, guaranteeing appropriate fluidity [16]. Figure 7 depicts cracks in beams resulting from satisfactory failure based on flexural strength tests.

Fig. 7. Pattern of failures for APWP concrete beam

4. Conclusion and recommendations

The outcomes of this study was determined by a number of tests such as slump test, density test, UPV test, compressive strength, and flexural strength. These tests demonstrated that the best percentage of replacement cement was 10% APWP, where the maximum compressive strength was 53.75 MPa, which higher than the control samples. Consequently, the sample using 10% APWP in place of cement had a maximum density of 2456 kg/m^3, an Ultra Pulse Velocity (UPV) of 3.82 km/s, and flexural strength of 5.84 MPa. As a result, it is suggested that APWP at a replacement of 10% can be utilised as a cement substitute in concrete production. Overall, the findings indicate that the use of APWP as a filler has a positive impact and is a viable choice for the building sector. The $CaCO_3$ composition in APWP could assist in promoting the strength of concrete samples. This research proved that the APWP that represent the asphalt plant waste is a novel additive filler with effective properties found in this study specifically for concrete application purposes.

As a future recommendations, the percentage of APWP as a partially replacement of cement can be explored at specific small percentage (5%, 10%, 15% and 20%), since the results showed important strength increment at those percentage. Other than that, the characterization tests should be emphasized to support the main finding results in this study including chemical composition, bonding analysis, phase characterization and images of microstructures. In addition, addition of superplasticizer can be proposed in the future study to increase the strength of concrete at high percentage replacement of APWP in concrete.

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Received: 2024-02-14, Revised: 2024-06-19