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ENHANCING SUSTAINABLE PAVING BLOCK PERFORMANCE THROUGH THE INCORPORATION OF BIRMINGHAM WIRE GAUGE (BWG) WIRE

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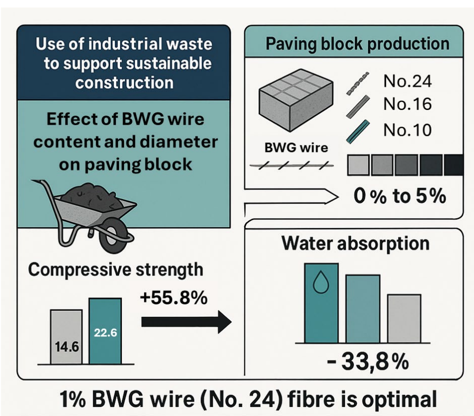
Graphical abstract



Abstract

The use of industrial waste as concrete additives is a strategic approach to support sustainable construction. One of the underutilised wastes is BWG (Birmingham Wire Gauge) wire, which has the potential to improve the performance of paving blocks. This study evaluated the effect of BWG wire fibre content and diameter on the compressive strength and water absorption of paving blocks. Paving blocks were made by a conventional method, using wire fibres with diameters of No.10 (3.1 mm), No. 16 (1.55 mm), and No. 24 (0.5 mm) at varying levels 0% to 5%. The test results showed that 1% fibre content was the optimal configuration, with the highest compressive strength increase of 55.8% for No. 24 wire (from 14.6 MPa to 22.60 MPa). The addition of fibre above 1% caused a decrease in strength due to agglomeration and compaction resistance. Water absorption decreased as fibre content increased, with a maximum decrease of 33.8% at 5% content and small diameter. Smaller fibre diameters gave the best performance, both in increasing strength and decreasing porosity.
Overall, 1% BWG wire fibre configuration with No. 24 diameter is recommended to produce high-performance and environmentally efficient paving blocks.

Keywords: Paving block, BWG wire fibre, compressive strength, water absorption, fibre diameter.

1.0 INTRODUCTION

In recent decades, efforts to develop environmentally friendly construction materials have received increasing global attention, as awareness of the ecological impacts of the construction industry grows. The cement industry in particular accounts for about 5-8% of total carbon dioxide (CO2) emissions from anthropogenic activities [1, 2, 3]. Therefore, innovative approaches are needed to reduce the dependence on conventional cement.

One strategy that continues to be developed is the utilisation of industrial waste as a substitute or additive in concrete mixes. This approach aims not only to reduce the use of conventional raw materials that contribute significantly to carbon emissions, but also to address industrial waste issues in a sustainable manner.

The increase in modern industrial activities has led to an increase in the use of metal wires, which has also resulted in a significant increase in the volume of wire waste [4, 5]. In addition, this wire waste can also exacerbate soil, air and water pollution due to the release of hazardous compounds during the construction process [6].

One type of metal waste that has high utilisation potential is BWG (Birmingham Wire Gauge) wire waste. This material is relatively abundant but has not been optimally utilised. Proper management and recycling of wire waste is essential to minimise the potential for environmental pollution [4]. The utilisation of waste wire fibre as an additive in concrete products not only reduces the volume of waste disposed of in landfills but also lowers the emissions resulting from the waste combustion process [7]. This strategy supports sustainable construction practices through reuse of waste materials and reduction of environmental impacts [6, 8]. BWG wire possesses several characteristics that distinguish it from other types of construction wire. One notable feature is its consistent and standardised diameter, produced with tight dimensional tolerances. This precision enables a more uniform distribution of fibres throughout the concrete matrix, which is beneficial for achieving stable mechanical behaviour. In practical terms, BWG wire is also available in a wide range of diameters. Even in local markets in Surakarta, Indonesia, at least eight standard sizes can be found, from No. 10 (3.4 mm) to No. 24 (0.5 mm). This variety allows for more accurate comparisons of the influence of wire diameter on the performance of paving blocks. The surface characteristics of BWG wire also provide an advantage. It typically has a clean, smooth surface and demonstrates greater resistance to corrosion than commonly used construction wire such as binding wire, which is prone to oxidation. Such resistance helps maintain the integrity and strength of the wire. A cleaner surface additionally promotes more stable bonding between the fibre and the cement paste, allowing stresses to be transferred more effectively. Furthermore, BWG wire is manufactured according to recognised material grades, ensuring predictable mechanical behaviour. This contrasts with miscellaneous construction wire waste, which often exhibits inconsistent quality due to variations in composition and manufacturing processes. In addition, several studies have shown that waste wire has potential as a micro-reinforcing material in concrete, which can improve mechanical properties such as compressive strength, tensile resistance, and flexural strength [9, 10].

Paving blocks are one of the commonly used pavement elements in various infrastructure, such as neighbourhood roads, sidewalks, and light industrial areas. Compressive strength of paving block is one of the main parameters in assessing the quality, especially for applications in areas that receive heavy loads repeatedly [11]. In addition to considering the mechanical strength aspect, the need for sustainable raw materials, efficiency in the production process, as well as long-term performance that is not detrimental to the environment. Therefore, the production of paving blocks incorporating industrial by-products serves not only to mitigate environmental impacts but also to enhance their engineering properties, with a particular emphasis on compressive strength.

Several previous studies have shown that paving blocks made from waste of alternative environmentally friendly materials can have mechanical properties that are equivalent or even superior to conventional paving blocks. Some of them show improvements in the parameters of compressive strength, flexural strength, and abrasion resistance [12, 13, 14, 15]. Notably, incorporating metallic fibres, including steel and wire fibres, as supplementary materials in paving blocks has demonstrated promising potential for enhancing the mechanical behaviour of concrete. Numerous investigations have reported that steel fibre inclusion markedly increases the mechanical properties of concrete, primarily by inhibiting crack propagation through an effective crack-bridging mechanism [16, 17]

In addition, steel fibres have also been reported to increase the compressive strength and modulus of elasticity of concrete, although the increase is more pronounced when low levels of fibres are used [18, 19]. Concrete reinforced with steel fibres exhibits increased load-bearing capacity and structural toughness, making it more resistant to dynamic loads and vibration [16, 20]. Therefore, steel fibres are considered suitable for structural applications that require high durability, including in paving block products.

Research by Sitorus et al. [21] used hooked-end steel fibre with a length to diameter ratio (l/d) of 67.7 in varying levels of 0%, 0.1%, 0.2%, 0.3%, 0.5%, 0.75%, 1%, and 1.5%. The findings indicated a proportional increase in the compressive strength of the concrete with the progressive addition of fibre content. Wang et al. [22] examined the effect of using steel fibre in Ultra High-Performance Concrete (UHPC) on flowability and compressive strength. The variation of fibre used was 6%. 9%, 12%, and 15% by weight of cement. The addition of fibre significantly decreased the slump value and degree of expansion of fresh concrete. However, compressive strength increased, although after a certain level, the increasing trend started to decrease.

Ekapraja and Mudiyono [23] studied the use of steel fibres of 0.55 mm diameter and 35 mm length at 0%, 1%, 2%, and 2.5% as additives in paving blocks. The studies indicated that the highest compressive strength was obtained in paving blocks with 1% fibre content. However, the addition of fibre also caused an increase in the water absorption of the paving blocks.

Research by Ikram and Perera [24] used construction wire waste as an additional material with content levels of 0%, 0.5%, 1%, 1.5%, 2%, and 2.5%. Their research concluded that the optimal wire fibre content was 1% considering the compressive strength produced and its application as a paving block additive.

Akbari and Abed [25] compared the effect of adding steel fibre and glass fibre with content levels of 0.3%, 0.6%, and 0.9%. The results showed that steel fibre provided a consistent increase in compressive strength up to 0.9%. Meanwhile, glass fibre also provided an improvement, but not as great as steel fibre and was only effective up to 0.6%. This study did not explore the effect of steel fibre at content percentages greater than 0.9% leaving open the possibility for further development with higher levels.

Anisah et al. [26] used wire fibres obtained from waste tyres at 0%, 2%, 2.5%, 3%, and 3.5% in a paving block mixture. The resulting compressive strength tends to increase up to 3%, then the trend tends to decrease. In addition, the water absorption of paving blocks tends to decrease at certain levels.

Although the use of metallic fibres in concrete and paving block mixes has been widely researched, most studies have focused on the use of commercial steel fibres, welded wire fibres, or fibres from recycled tyre waste. Meanwhile, the potential use of BWG (Birmingham Wire Gauge) wire waste fibres, which are commonly found in construction waste and light industry, has not been systematically explored. In fact, the physical and mechanical characteristics of WG wire fibres, such as stiffness, surface morphology, and their ability to form bonds with cement paste, have the potential to contribute significantly to the improvement of concrete quality. In addition, the effect of fibre diameter variation on paving block performance has not received sufficient attention in the literature. Most previous studies have used fibres of one fixed size, without considering how changes in dimensions can affect the specific surface area, fibre distribution within the concrete matrix and porosity levels. These factors could potentially affect compressive strength and absorption. Considering these gaps, a more in-depth study on the use of BWG wire fibres with varying diameters is needed to evaluate their effect on the mechanical and physical properties of paving blocks. In this context, this study aims to examine the effect of BWG wire fibre content and diameter on the characteristics of paving blocks, particularly on compressive strength and water absorption. This research is expected to contribute to the development of paving block materials that not only have good structural performance but also support the principle of sustainable construction through productive and environmentally friendly utilisation of industrial waste.

2.0 METHODOLOGY

A paving block is a construction unit composed of a blend of Portland cement or an equivalent hydraulic binder, water, and aggregates, optionally supplemented with other additives, provided that such additions do not compromise the quality of the final product. In Indonesia, traditional paving blocks are generally made from a mixture of cement, sand, and water without the addition of reinforcing materials, and are produced manually by small industries or households.

Based on the production method, paving blocks can be made through two main approaches, namely the conventional method and the mechanical method. The conventional method is done simply by compacting the material mixture using a manual compactor, namely *Gabokan* [23], and it is still widely applied on a small industrial scale. In contrast, the mechanical method utilises a press machine to produce a more uniform and high-precision compaction, which is commonly used in large-scale production and manufacturing.

In this study, the paving block manufacturing process was conducted in one of the small business units located in Surakarta City, Indonesia, using the conventional method. This method was chosen to represent the real production conditions commonly applied in the field, as well as to test the effectiveness of BWG wires in the context of small-scale production.

Based on its typical properties, SNI 03-0691-1996 classifies the quality of paving blocks into four categories, namely for use on vehicle roads, parking areas, pedestrian paths, and parks or other purposes [37]. Each category has different technical requirements, where the higher the use class, the higher the requirements for compressive strength, wear resistance, and the lower the allowable water absorption. The complete classification and technical specifications of paving blocks can be seen in Table 1.

Table 1 Paving Blocks Classification (SNI 03-0691-1996)

Grade	Compressive strength (MPa)		Wear resistance (mm/min)		Maximum water absorption average (%)
	Average	Minimum	Average	Minimum	
A	40	35	0.090	0.103	3
B	20	17	0.130	0.149	6
C	15	12.5	0.160	0.184	8
D	10	8.5	0.219	0.251	10

The fibre material used in this study came from BWG wire with a quality specification of carbon steel grade Q195, which has a tensile strength between 350 and 500 MPa. Figure 1 shows the cut BWG wire pieces used in the mixture. The length of the wire was uniform at ±1 cm to ensure consistency in the distribution of fibres in the concrete matrix and to facilitate observation of their effects. The wire diameter variation consisted of three sizes, namely BWG No. 10 (3.1 mm), No. 16 (1.55 mm), and No. 24 (0.5 mm). The fibre length was fixed at approximately 1 cm because the paving block has a relatively small structural depth of only about 6 cm. Using longer fibres would reduce workability and risk improper alignment during compaction. With the fibre length held constant, the variation in wire diameter resulted in different aspect ratios, namely 3.22, 6.45, and 20 for BWG No. 10, No. 16, and No. 24 respectively. Consequently, the investigation of diameter effects is inherently linked to aspect ratio effects, as both parameters change concurrently. The study therefore recognises that the mechanical response observed for each diameter reflects the combined influence of diameter and the associated aspect ratio. At the same mix level, the amount of large diameter wire that can be incorporated into the paving block will be less than that of small diameter wire, thus affecting the fibre distribution mix.

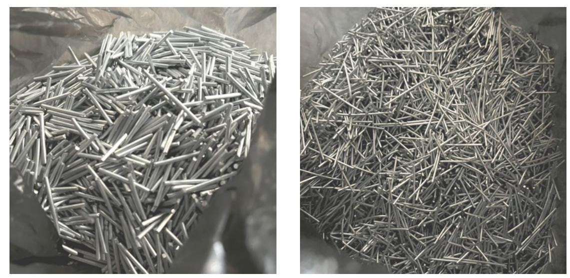


Figure 1 BWG Wire

The cement used in this study was type 1 Portland cement under the brand name "Semenku", which is a commercial cement commonly used by small industries in Surakarta region of Indonesia. The selection of the cement was intended to reflect realistic production conditions and practices at the local industry level. Meanwhile, the fine aggregate used was local sand, which was also obtained from the source of fine aggregate used by the paving block industry in the local area.

2.1 Test Specimen

The paving block specimen used in this study had dimensions of 210 x 105 x 60 mm. Six levels of BWG wire fibre were varied, namely 0%, 1%, 2%, 3%, 4%, and 5% of the total weight of sand and cement, for each wire diameter size: No. 10 (3.1 mm), No. 16 (1.55 mm), and No. 24 (0.5 mm). The basic composition of the mix used a cement-to-sand ratio of 1:3, while the water-to-cement ratio (w/c) was kept constant at 0.25. Details of the paving block mix composition are shown in Table 2.

All materials were mixed homogeneously according to the planned proportions, then put into the paving block mould. Compaction was done manually using *Gabokan*, in accordance with conventional methods commonly applied in small industries. After the moulding process, the specimens were left for 24 hours in open air conditions, then were cured in a pool of water until they reached 28 days of age before testing. The paving block production process is presented in Figure 2

Figure 2 Paving Block Production

Table 2 Paving Block Mix Composition

Variation	BWG wire Size	BWG wire Content	BWG wire Weight (gr)	Cement (gr)	Sand (gr)	Air (mL)	Quantity
V0	-	0%	-	793.80	2400.00	198.45	6
V1-a		1%	31.8				6
V1-b		2%	63.5				6
V1-c	No 10	3%	95.3	793.80	2400.00	198.45	6
V1-d		4%	127.0				6
V1-e		5%	158.8				6
V2-a		1%	31.8				6
V2-b		2%	63.5				6
V2-c	No 16	3%	95.3	793.80	2400.00	198.45	6
V2-d		4%	127.0				6
V2-e		5%	158.8				6
V3-a		1%	31.8				6
V3-b		2%	63.5				6
V3-c	No 24	3%	95.3	793.80	2400.00	198.45	6
V3-d		4%	127.0				6
V3-e		5%	158.8				6
Total			1428.8	12700.80	38400.00	3175.20	96

2.2 Compression Test

Each specimen variation was subjected to compressive strength testing at the age of 28 days. The test method refers to SNI 03-0691-1996, where the compressive strength test specimen must be cut into cubes. The dimensions of the cube ribs are adjusted to the size of the test specimen, in this case is ±60 mm. Thus, the block-shaped paving test specimens were cut to a size of 60x60x60 mm. The primary reason for this requirement is to ensure uniformity of the stress distribution during loading. Paving blocks have irregular shapes, chamfers, and interlocking profiles that cause non-uniform contact surfaces when placed under a compression platen. These geometric irregularities may introduce local stress concentrations, leading to premature failure and unreliable strength values.

Then the cube test specimen was press tested using a Universal Testing Machine. The force required to press the specimen to destruction was recorded. The compressive strength value is obtained by dividing the recorded force by the surface area of the compressive area. The compressive strength testing procedure and the tested specimens are presented in Figure 3.

2.3 Water absorption test

The water absorption test in this study was carried out on intact paving blocks, as required by SNI 03-0691-1996, which specifies that the specimen must be tested in its full form without cutting. Using an uncut specimen is essential because water absorption represents the overall porosity, permeability, and density of the paving block as a finished product. Figure 4 illustrates the water absorption test. Testing the full block therefore ensures that the measured absorption corresponds to the functional behaviour of the paving block as installed in the field, where moisture interacts with the component as a complete unit rather than as a smaller extracted sample. The specimens were initially immersed in water for a minimum duration of 24 hours and subsequently weighed to determine their saturated mass. They were then oven-dried for 24 hours before being reweighed to record their dry mass. Water absorption was calculated based on the difference between wet weight and dry weight divided by the dry weight. This test aims to evaluate the porosity and internal density of concrete paving blocks. High water absorption values indicate a more porous concrete structure and tend to have low long-term resistance to environmental degradation.

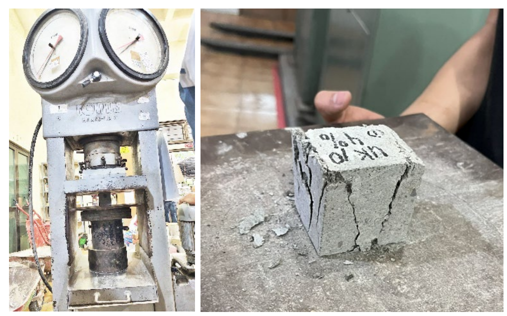


Figure 3 Compressive Test

Figure 4 Water Absorption Test

3.0 RESULTS AND DISCUSSION

3.1 Sand Test Results

The characterisation of sand as fine aggregate was carried out through several tests, including tests for mud content, organic content, specific gravity, water absorption, and gradation analysis. The complete results of these tests are presented in Table 3 and Figure 5.

The mud content test results show that the sand has a mud content of 2.70%. This value is still within the limit allowed by ASTM C33 and SNI 8321-2012, with the maximum allowable being 3%. A low proportion of mud content generally does not adversely affect the quality of concrete or paving blocks. Mud particles or fine dust in aggregates can deteriorate the mechanical properties of concrete, including a decrease in compressive strength, modulus of elasticity, and bond strength between cement paste and aggregate, especially in the early stages of bonding. In addition, the presence of mud also widens the Interfacial Transition Zone (ITZ), which is associated with reduced tensile strength and durability of concrete [27]. Therefore, low mud content in sand will increase the potential for a dense and strong bond between cement and aggregate.

Table 3 Fine Aggregate Test Results

Testing	Result	Note
Mud Content	2.70%	Less than 3% as required by ASTM C33
Organic Content	Passed	Match with Gardner Colour Standard No. 8
Bulk Specific Gravity	2.437	Bulk specific gravity matches the suggested normal value (2.3~2.9) by ACI Education Bulletin E1-07
SSD Specific Gravity	2.486	
Apparent Specific Gravity	2.564	
Water absorption	2.04%	Match with the suggested normal value (0.5~4%) by ACI Education Bulletin E1-07
Fineness Modulus	2.33	Pass the requirement of ASTM C33, which is 2.3~3.1

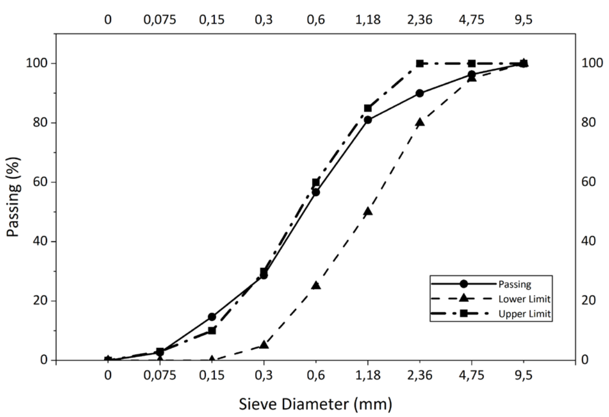


Figure 5 Gradation of Fine Aggregate

In the organic content test, the mixture of fine aggregates with NaOH solution produced a colour that was in the range of Gardner Colour Standard No. 8, lighter than the specified maximum limit (No. 11). This result indicates that the organic content in the fine aggregate is still within the safe threshold as per ASTM C33 and SNI 8321-2012 criteria. High organic content in fine aggregate is known to interfere with the hydration process of cement and weaken the bond with aggregates, leading to a decrease in the compressive strength of concrete [28, 29]. Thus, the fine aggregate used in this study is suitable for application in paving block mixes.

The specific gravity values obtained include bulk specific gravity of 2.437, SSD specific gravity of 2.486, and Apparent specific gravity of 2.564, with water absorption of 2.04%. Based on ACI Education Bulletin E1-07 [38], bulk specific gravity values for fine aggregates are generally in the range 2.4 – 2.9, with water absorption between 0.5 – 4%. These results indicate that the fine aggregates used fulfil the standard criteria and are suitable for paving block production.

Gradation analysis showed that the majority of the aggregate grain size distribution conformed to ASTM C33 and SNI 8321-2012, although there was a slight deviation in the fraction passing No. 100 sieve (0.15 mm), which was 14.67% =, exceeding the required limit (0-10%). This indicates that the fine aggregate has a relatively finer grain size, which increases the specific surface area of the aggregate. This condition can lead to higher water absorption, which results in increased water demand in the mix and potentially reduces the compressive strength of the concrete if the water-cement ratio is not adjusted appropriately. However, based on the water absorption test results and other physical parameters, the fine aggregates still fulfil the requirements of ASTM C33 and SNI 8321-2012. In addition, the modulus of fineness of the fine aggregate was recorded at 2.33, which is within the range required by ASTM C33 and SNI 8321-2012 of 2.3 – 3.1. This value indicates that the aggregate has a gradation that is close to optimum for use in concrete paving block mixes.

3.2 Inter-Content Compressive Test Results

Compressive strength test was conducted systematically in compliance with SNI 03-0691-1996. The compressive strength results for the variations in BWG wire content are presented in Figure 6. In general, the addition of BWG wire shows an increasing trend in the compressive strength value of paving blocks, especially at low levels. However, the trend shows that the increase in compressive strength only lasts up to 1%, after which there is a decrease in strength.

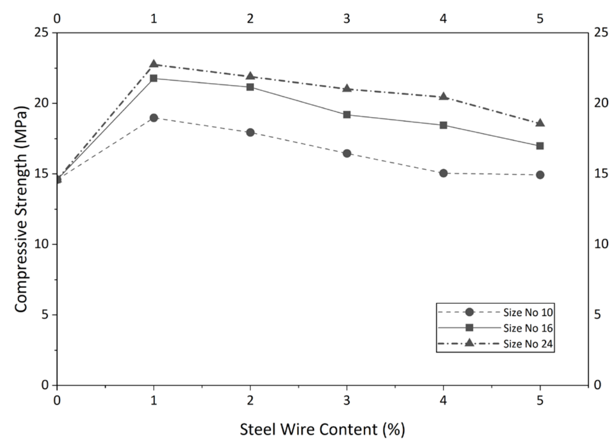


Figure 6 Compressive Strength Test Results

The phenomenon of increased compressive strength at low levels is attributed to the function of wire fibres in inhibiting crack growth. Steel fibres are known to be effective in crack bridging, thereby reducing the rate of crack propagation and arresting crack propagation into larger structural damage. This effectiveness comes from the high interfacial bond strength between the steel fibres and the concrete matrix, which provides resistance to crack initiation and growth [30, 31, 32].

The optimum fibre content was found to be 1% for all three types of wire diameters (No. 10, No. 16, and No. 24). At this level, the distribution of fibres in the paving block mix is quite even and does not disturb the homogeneity of the mix. This allows for a more solid particle bond to be formed, which is very important in supporting the structural strength of the paving block. In addition, the mechanical interlocking effect between the wire fibres and cement paste also strengthens the internal cohesion, thus contributing significantly to the increase in compressive strength.

The highest improvement was achieved by paving blocks with BWG wire No. 24 (0.5 mm diameter) at 1%, where the compressive strength increased by 55.8% compared to the control, from 14.6 MPa to 22.75 MPa. Wire fibres with small diameters, such as No. 24, have more particles per unit volume, making them more evenly distributed and effective in reinforcing the concrete matrix. However, increasing the fibre content above 1% actually caused a decrease in compressive strength. This is thought to be due to clumping or aggregation of fibres in the concrete mix, which disrupts the homogeneity and reduces the bonding efficiency between the cement paste and aggregate. In addition, the high fibre content also reduces the ability to manually compact the concrete, resulting in larger voids and reducing the structural density of the paving blocks.

These findings are in line with the results of previous studies [22, 26, 33, 34], which also showed that increasing fibre content is only effective up to a certain level, above which it causes a decrease in mechanical performance. In particular, the optimum fibre content of 1% obtained in this study is consistent with the results reported by Ekapraja and Mudiyono [23].

3.3 Inter-diameter Compressive Test Results

In addition to the variation in content, this study also evaluated the effect of different BWG wire fibre diameters on the compressive strength of paving blocks. Based on the data shown in Figure 6, it is known that the highest compressive strength value is achieved by paving blocks with the addition of small-diameter wire fibre (BWG No. 24, 0.5 mm) at 1%, followed by wire size No. 16 (1.55 mm), and finally No. 10 (3.1 mm). The increase in compressive strength at 1% for each size was 55.8%, 49.1%, and 30% compared to the control sample without fibres respectively.

The pattern of improvement was consistent up to 2%, 3%, 4%, and 5% fibre content, where No. 24 wire always showed the best compressive performance, followed by No. 16 and No. 10 wire. These findings indicate that wire fibre diameter has an important role in determining the distribution, interaction, and effectiveness of concrete internal reinforcement. In general, the smaller the wire fibre diameter, the greater the number of fibres per unit volume at the same level. This allows for a more homogeneous distribution of fibres in the paving block matrix, thereby improving bond continuity and structural integrity of the mix.

In addition, increasing the number of fibres also results in an increase in the total surface area of the fibres interacting with the cement paste. A larger surface area will result in more contact points for bond formation, thereby strengthening the adhesion between the fibres and the cement matrix. Previous studies have shown that increasing the surface area of fibres can significantly improve the quality of interfacial bonding, either through adhesion, mechanical interlocking, or internal friction mechanisms [35].

In contrast, the use of larger diameter fibres, such as BWG No. 16 and No. 10, results in a smaller number of fibres at the same grade. As a result, the fibre distribution is less even, and the larger spacing between fibres makes the reinforcement function against cracking less effective. In addition, the surface area of fibre interaction with the cement pastes also decreased, which resulted in weak internal bonding and decreased contribution to compressive strength.

Based on the test results, paving blocks with wire addition of 1% and 2% showed significant improvement in performance, allowing a change in the quality classification of paving blocks from grade C to grade B. Grade B paving blocks have the capacity for use in parking equipment areas. Details of the paving block quality classification for all diameters and fibre content variations are presented in Table 4.

Table 4 Compression Strength Test Results

Steel Wire Content	Size No 10 Compressive strength (MPa)	Size No 10 Grade	Size No 16 Compressive strength (MPa)	Size No 16 Grade	Size No 24 Compressive strength (MPa)	Size No 24 Grade
0%	14.60	C	14.60	C	14.60	C
1%	18.98	B	21.77	B	22.75	B
2%	17.95	B	21.16	B	21.90	B
3%	16.46	C	19.20	B	21.02	B
4%	15.06	C	18.45	B	20.45	B
5%	14.93	C	16.99	C	18.57	B

3.4 Water Absorption Test Results between Contents

Water absorption testing of paving blocks was carried out based on the procedures listed in SNI 03-0691-1996. The test results are shown in Figure 7. In general, the increase in wire fibre content from 0% to 5% resulted in a decrease in water absorption values at all fibre diameter variations. The most significant decrease was recorded at 5% fibre content, which was 29.1%, 32.3%, and 33.8% for BWG No. 10, No. 16, and No. 24 fibres respectively, when compared to the samples without fibres. These results strongly show that the addition of wire fibre can increase the internal density of paving blocks and effectively reduce the total porosity of the mix. In addition, the presence of fibres plays a role in strengthening the bond between particles, thereby reducing the formation of macro-cracks that can enlarge the flow path of water in concrete. This reduction in porosity has a direct impact on the water absorption of the paving blocks. Therefore, higher fibre content generally contributes to a denser and more homogeneous concrete.

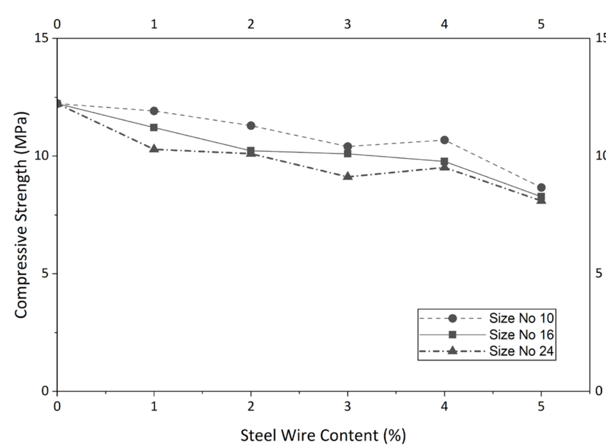


Figure 7 Water Absorption Test Results

Figure 8, Figure 9, and Figure 10 show the relation between the result of compressive strength and water absorption of paving block mixed with BWG wire No. 10, No. 16, and No. 24 respectively. In principle, water absorption values have an inverse relationship with concrete compressive strength. The lower the water absorption, the higher the concrete density, and the greater the compressive strength. However, when compared with the compressive strength test results at 2%, 3%, 4%, and 5% fibre content, although the water absorption continues to decrease, the compressive strength shows a downward trend. This indicates that although the macro porosity was reduced, the excess fibre content disturbed the internal structure mechanically, such as reduced homogeneity and difficulty in compaction.

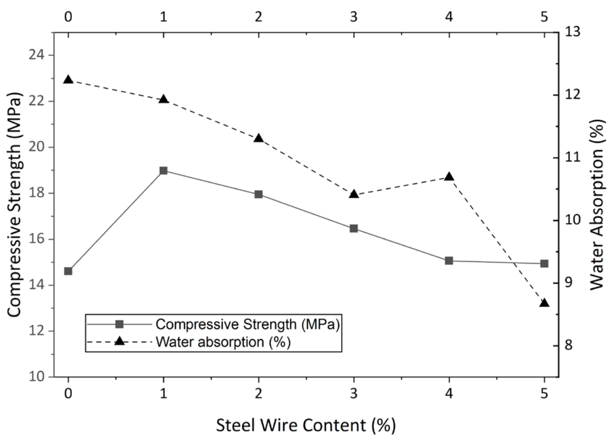


Figure 8 Comparison of Compressive Strength and Water Absorption of Paving Block with BWG Wire No. 10

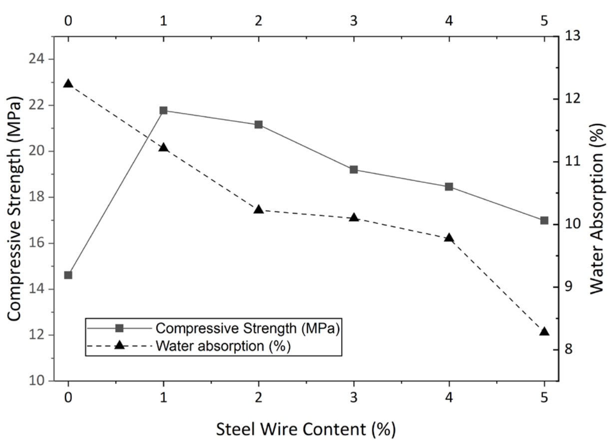


Figure 9 Comparison of Compressive Strength and Water Absorption of Paving Block with BWG Wire No. 16

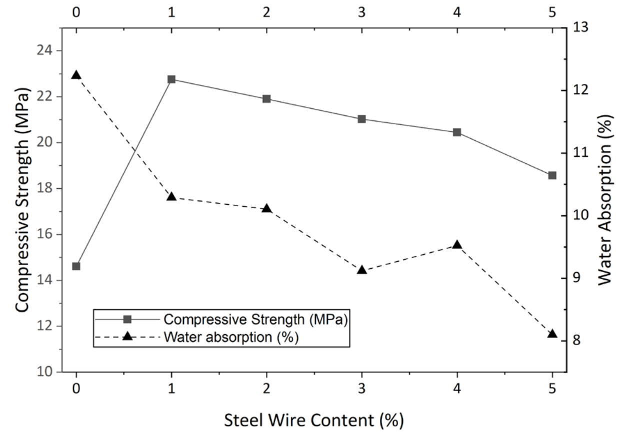


Figure 10 Comparison of Compressive Strength and Water Absorption of Paving Block with BWG Wire No. 24

This phenomenon can be explained by the possibility that the high fibre volume partially replaces the fine aggregate, which is naturally more porous and capable of absorbing water. Since steel fibres are not permeable, the space between particles that could previously absorb water becomes covered by elements that are inert to water, thus lowering the absorption level. On the other hand, this does not necessarily increase the strength, as the bond between particles can be disrupted by compositional imbalances and fibre aggregation. Therefore, although the water absorption value decreases at high levels, the optimum value for increasing the compressive strength remains at 1% fibre content.

3.5 Inter-diameter Absorbency Test Results

The effect of varying the diameter of BWG wire fibres on the water absorption of paving blocks was analysed by comparing three fibre sizes, namely No. 10, No. 16, and No. 24. The test results showed that at the same fibre content, decreasing the wire diameter resulted in a consistent decrease in the water absorption rate. For illustration, at 5% fibre content, the water absorption of each paving block was recorded at 8.67% for wire No. 10, 8.28% for No. 16, and 8.10% for No. 24. This trend indicates that small-diameter fibres have higher effectiveness in reducing the porosity of paving blocks.

The decrease in water uptake value of small-diameter fibres can be explained through two main mechanisms. Firstly, at smaller diameters, the number of fibres in the mix volume increases significantly, which allows for a more even distribution of fibres. This contributes to the filling of micro-spaces in the concrete matrix, thereby reducing the water flow path and increasing the structural density. Secondly, the total surface area of fibres to mix volume also increases, which strengthens the bond between aggregate particles through friction and interlocking mechanisms.

Small fibres also contribute to the formation of a denser internal structure that is resistant to water penetration. This finding is in line with the results of a study by Li et al. [36], who stated that smaller diameter fibres exhibit better bonding performance with the cement matrix, inhibit crack propagation, and ultimately increase the density and strength of composite concrete.

Table 5 Fine Aggregate Test Results

Steel Wire Content	Size No 10		Size No 16		Size No 24	
	Water absorption (%)	Grade	Water absorption (%)	Grade	Water absorption (%)	Grade
0%	12.23	D	12.23	D	12.23	D
1%	11.92	D	11.22	D	10.29	D
2%	11.30	D	10.23	D	10.10	D
3%	10.41	D	10.10	D	9.12	C
4%	10.69	D	9.78	C	9.52	C
5%	8.67	C	8.28	C	8.10	C

Based on the results of the water absorption test, the use of wire fibres at 4% and 5% levels can improve the quality classification of paving blocks from grade D to grade C, as specified in SNI standard. Grade C can be applied to lightweight construction, such as pedestrian walkways. Details of paving block quality classification based on water absorption and fibre diameter variation are shown in Table 5.

4.0 CONCLUSION

This study proved that the addition of fibre significantly affects the compressive strength and absorption of paving blocks. The 1% wire fibre content proved to be the most optimal composition in increasing the compressive strength, with the highest increase of 55.8% at fibre diameter No. 24. Increasing the content above 1% caused a decrease in compressive strength, presumably due to fibre agglomeration that disrupted the homogeneity and compaction process.

Fibre diameter also affects mechanical performance; the smaller the diameter (e.g. No. 24), the higher the compressive strength obtained at the same fibre content. This is due to the increased number and more even distribution of fibres, as well as a larger bonding surface area to the cement paste.

In terms of water absorption, increasing the fibre content from 0% to 5% decreased the water absorption rate consistently. This decrease indicates increased density and decreased porosity of the mix. Smaller fibre diameters also performed better in reducing water absorption, supporting the formation of tighter particle bonds.

Overall, the combination 1% content and a small diameter (No. 24) is recommended as the best configuration to obtain paving blocks with high strength and low water absorption, as per structural paving block quality standards.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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