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Analysis of Water Absorption in the Utilization of Plastic Waste as a Mixed Material for Making Environmentally Friendly Paving Blocks

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A B S T R A C T

Paving blocks with a mixture of plastic waste have lower water absorption (2–6%) than conventional paving (8–12%), due to the hydrophobic nature of plastics and more porous structure conventional paving. This study aims to analyze the absorption of paving blocks and the use of PET (Polyethylene Terephthalate) plastic waste as a mixture of making environmentally friendly paving blocks. This research uses literature and experimental study methods through the manufacture of plastic shredders, sample testing in the laboratory, mix design planning, casting, testing, and data analysis. The test was carried out by adding 5% of PET plastic waste with a size of 0.1-2 cm with a soaking time of 48 hours able to produce a water infiltration value on the paving block between 4.3-6.4% with an average water infiltration value of 5.2%, with compressive strength between 20 and 32 MPa in concrete quality B, which can be used for roads with medium loads.

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INTRODUCTION

Plastic is one of the non-organic waste that is difficult to decompose and can cause various problems for the environment. When plastic waste is disposed of carelessly and not processed, the plastic waste will pollute the environment because plastic waste is non-biodegradable which is difficult to decompose in nature so that it will last a very long time in the environment and accumulate. Based on data for the year (2019-2024), the total percentage of waste composition in Indonesia is made up of food waste (39.65%), plastic (19.21%), wood/twigs (12.09%), paper/cardboard (10.83%), metal (3.24%), fabric (2.91%), rubber/leather (2.53%), glass (2.46%), and others (7.08%). From the data, it can be seen that plastic waste is a type of waste whose percentage is quite high in Indonesia, reaching 19.15% with the second highest position, for this reason the process of processing and recycling plastic waste must be carried out immediately. Figure 1. Shows the percentage of waste composition by type of waste.

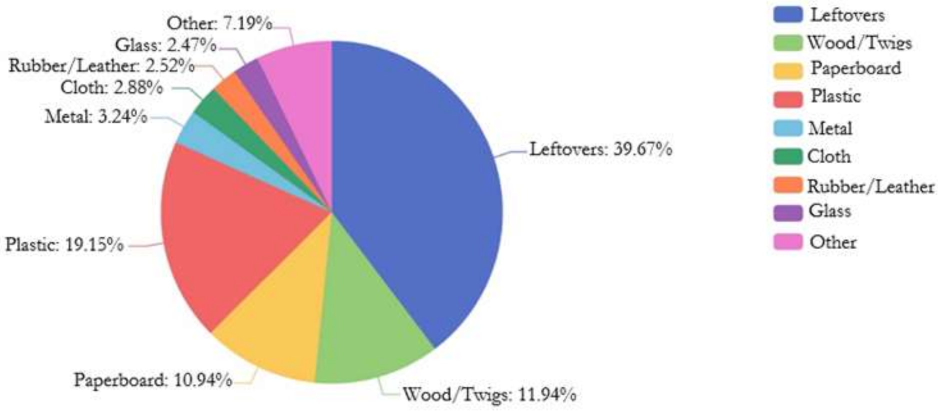

Figure 1. Percentage of Waste Composition By Type of Waste

Source. National Waste Management Information System (SIPSN)-Waste Management Data

The increased use of single-use plastics makes the accumulation of waste difficult to handle, especially in densely populated urban areas such as Jakarta. If not treated properly, plastic waste will cause various environmental, health, and economic problems. From an environmental perspective, plastics that accumulate on land can reduce soil and groundwater quality due to the release of harmful chemical compounds such as bisphenol A (BPA) and phthalates (Sajjad et al., 2022; Teuten et al., 2009) (Laz Persis, 2023). In the waters, plastics are fragmented into microplastics that are eaten by marine life and have the potential to enter the human food chain (De-la-Torre, 2020; Khan et al., 2024). Research shows that plastic in the ocean also triggers ecosystem damage through entanglement, ingestion, and the spread of invasive species (Lebreton et al., 2017; Rochman et al., 2013). In addition, the impact of human health is increasingly real. Micro and nano-plastics can cause oxidative stress, inflammation, hormonal disorders, and the risk of metabolic disorders (Prata et al., 2020). Recent studies have even linked prenatal microplastic exposure to an increased risk of babies being born with low birth weight, which is estimated to be more than 200,000 cases per year globally (Bao et al., 2023). Globally, the production to burning of plastics is estimated to account for 3–14% of greenhouse gas emissions by 2050

(Zheng & Suh, 2019). This shows that the plastic problem is not only an environmental issue, but also a serious challenge to public health and development sustainable. With these various impacts, plastic waste management through circular approaches such as recycling, reuse, and environmentally friendly material innovation is very important for ecosystem sustainability and quality of human life. Plastic waste handling carried out with the 3R (Reduce, Reuse, Recycle) concept is a popular way to manage plastic waste (Hutabarat & Mulyani, 2022; Mohammed et al., 2021; Pandiyarajan et al., 2022). Reduce means reducing the use and purchase of plastic goods, especially disposable ones. Reuse means reusing used items as handicrafts, such as plastic, plastic, and paper bottles. Recycle means recycling plastic waste so that it has a use-value product (Irwan et al., 2022; Maf'ulah et al., 2021; Triawan et al., 2018). Various other studies also explore the use of plastic waste as a mixed material in the manufacture of paving blocks. The approaches learned include (1) partial substitution of fine/coarse aggregate with plastic shredding, (2) The use of molten plastic as a binding material (plastic-sand blocks), which partially replaces cement (3) combination of plastic with additives such as basalt fibers or industrial waste ash to improve mechanical performance. The results show the potential to reduce the use of cement and fine aggregates and reduce the carbon footprint of some compositions, although the effect on compressive strength and durability is influenced by the type of plastic, the mixing ratio, and the production process (Iftikhar, Alih, Vafaei, Ali, et al., 2023; Iftikhar, Alih, Vafaei, Javed, et al., 2023). Shredded plastic can partially replace fine or coarse aggregates, reducing porosity, and water absorption while increasing compressive strength.

LITERATURE REVIEW

According to SNI 03-0691-1996, paving blocks are classified based on compressive strength and water absorption, as shown in Table 1.

Table 1. Classification of Paving Block Based on SNI 03-0691-1996

Paving Block Quality	Minimum Compressive Strength (MPa)	Maximum Water Absorption (%)	Use
A	≥ 40	≤ 3	Highways, areas with very heavy loads (ports, airports)
B	≥ 20	≤ 6	Medium-load roads (neighborhood roads, complex roads)
C	≥ 15	≤ 8	Sidewalks and pedestrian areas
D	≥ 10	≤ 10	Garden area, yard, or light-weight area

Some studies have also stated that plastic-sand-based paving blocks (without or with little cement) are able to achieve adequate strength for low to medium traffic areas when the composition and process are controlled, while other studies have also found a decrease in compressive strength when plastic is only mixed as a substitute for fine aggregates in concrete mixtures, especially at high plastic fractions. so that it is necessary to optimize the proportions and proper surface treatment of plastic aggregates. In addition, LCA (life cycle assessment) studies and preliminary economic analyses show the potential for CO_2 emission and cost reductions if plastic waste can be harnessed locally and production scales are adjusted (Agrawal et al., 2023; Fauzan et al., 2023). A number of research and community service in Indonesia have developed methods for making paving blocks from PET, LDPE, and household plastic mixture waste, as well as evaluating their technical and socio-economic aspects. However, there is a need for more systematic and documented research to: (a) Determine the safe plastic percentage limit so that the quality of paving blocks meets the standards, (b) Evaluate long-term resistance to weather and abrasion, (c) establish process procedures (washing, shredding, melting/binding) that can be applied at small-medium industrial scale, and, (d) conduct a comprehensive life cycle and cost analysis specific to Indonesian conditions (Agyeman et al., 2019; Hardinsi et al., 2022; Mahagadha et al., 2023).

Based on the results of several studies, PET plastic waste measuring 1 cm with a mixture percentage of 0.45% produces compressive strength of up to 198.89 kg/cm², while the size of 1.5 cm tends to reduce mechanical performance. Thus, a size of 1 cm is considered the most ideal for plastic substitution in paving blocks (Mahagadha et al., 2023). Similar findings were obtained by Dian Nuswantoro (Udinus, 2022) who used plastic shreds measuring about 9 mm, with a mixed proportion of 1% – 12% of the total aggregate. The results showed that relatively small plastic sizes are more easily blended with sand and rock ash, thereby increasing the density of paving blocks. In addition, Said et al. (2023) added multilayer plastic by 0.4% of the total weight of the paving block (approximately 240 cm³ or 0.22 kg/m²). Although the number is small, the results of the study still meet the Indonesian National Standard (SNI 03-0691-1996) with class B quality, which requires a minimum compressive strength of 200 kg/cm² and a maximum water absorption capacity of 8%. Table 2. indicates the type and size of the shredded plastic used as a mixed material in the manufacture of paving blocks.

Table 2. Types and Sizes of Plastic Breakdown

Types of Plastics	Fraction Size	Proportions in the Mix
PET (Polyethylene Terephthalate)	1 cm dan 1,5 cm	0.45% - 0.55%
Shredded Plastic	$\pm$ 9 mm	1% - maximum 12%
Multilayer Plastic	Volume: 240 cm³/ m²	0.4 % of total weight

This study aims to analyze the use of PET (Polyethylene Terephthalate) plastic waste as a mixed material for making environmentally friendly paving blocks with a focus on (1) Composition and size of plastic shredding: sand (or aggregate replacement), (2) water absorption testing according to standards (water absorption) in accordance with SNI, and (3) Assessment of the benefits of a schematic economic environment. By combining the results of laboratory testing and literature studies, it is hoped that this study can provide technical recommendations and production practices that can increase the added value of plastic waste that meets the quality requirements of concrete B, C, and D for use applications in pedestrians, parking areas, and sidewalks. The results are anticipated to provide new empirical data and practical production guidelines, enabling optimized utilization of plastic waste, promoting eco-friendly construction materials, and expanding the application of plastic-based paving blocks across Indonesian urban environments.

METHODOLOGY

The method of conducting research plays an important role in ensuring that the process carried out is appropriate and produces the expected output. This research uses literature and experimental study methods through a series of stages, starting from field surveys, making plastic shredders, testing samples in the laboratory, *planning mix design*, casting, testing, data analysis, to report preparation. The flow chart of the research process can be seen in Figure 2.

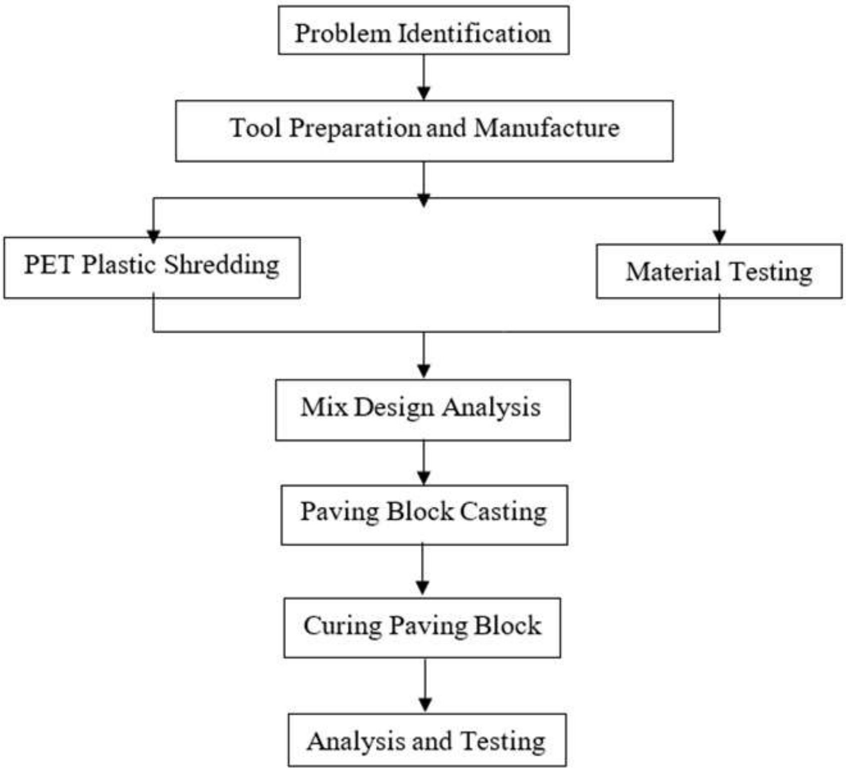

Figure 2. Research Flow Chart for the Utilization of PET (Polyethylene Terephthalate) Plastic Waste in the Making of Paving Blocks

Problem Identification

Plastic waste used as the main material in making paving blocks consists of various types of plastic waste collected by the community as a form of participation in this activity. Organic and inorganic waste originating from household waste is separated, after separation is then recycled, in this case plastic waste as a mixture into paving blocks. In this way, plastic waste that is usually a source of environmental pollution can be processed into useful and environmentally friendly products (Kader et al., 2021). This process not only helps reduce the accumulation of plastic waste, but also reduces the use of new materials that have the potential to damage the environment.

Plastic Shredder Manufacturing

Plastic shredding machines are designed to produce shreds that are 5 mm to 1.5cm in size. The cutting system was designed and modified using three hook-shaped blades assembled on a shaft with a total of 20 blades. Power transmission is designed through the calculation of shafts, pegs, bearings, as well as belt and pulley systems, where the largest pulley is connected to a 1 HP (±700 Watt) AC motor as the main drive. The engine frame is made using elbow steel (5x5) cm, while the body cover uses polyethylene (PE) sheets that are mounted with rivets. After the fabrication and assembly process, tests are carried out to ensure the performance of the machine and the suitability of the chopped size, with a maximum target of 5 mm.

Plastic shredding

The size and proportion of plastic waste used as a mixture for making paving blocks has a significant effect on the quality of the products produced. Some studies say that the size of the plastic (± 9 mm – 1.5 cm) able to increase the homogeneity of the mixture and increase the compressive strength of the paving block.

Figure 3. Plastic Waste PET (Polyethylene Terephthalate) that has Been Chopped

Mixed Composition of Paving Block Making (mix design)

After the plastic shredding process is completed, the next process is to conduct *a mix design* analysis. The design of the mixed composition is carried out based on SNI standards to obtain the proportions of each mixed material used, (A, 2018; Hakim et al., 2021; SNI 03-2834-2000, 2000; SNI 7656:2012, 2012; Sukardi et al., 2022). Table 3 shows the composition of the mixture of materials for making *paving blocks* with the proportion of 5% PET plastic chopped of fine aggregate.

Table 3. Composition of Mixed Materials for Making Paving Blocks with PET (Polyethylene Terephthalate) plastic mixture 5%

No	Material Description	Composition of Concrete Mixture (kg/ m^3)	Volume Paving Block Balok (0,2 x 0,10 x 0,06) m^3	Composition of Concrete Paving Block Mix(kg)	Number of samples	Composition of Concrete Paving Block Mix (kg)
1	Cement	417	0,0012	0,5	20	10
2	Sand	1621		1.9		38.9
3	Water	250		0,3		6
4	Plastic Fraction (5%) of Sand Material	-		0,097		1.9

Printing/making *of paving blocks* was carried out for 20 samples with the addition of 5% plastic mixture. Before printing, all sand, cement, shredded plastic, and water materials have been prepared in advance according to the results of the *mix design analysis*, (Foulhudan et al., 2022). Figure 4. shows the results of *paving block printing* done in the laboratory. After the paving block printing process , *the paving block will be dried* with a room temperature of 26-28 °C. The paving blocks that have been molded are then cooled until they harden evenly. The conditioning process of this plastic paving block is about 1 day (24 hours) (Badan Standardisasi Nasional, 1996).

Figure 4. Printing and Curing *Paving Block* Using PET Plastic Mixture

RESEARCH RESULT

The purpose of this absorption test is to measure resistance to weather and the environment, check the quality of the mixture, determine the density and strength of the paving block, and support the sustainability of the development of the material mixture (rice husk ash) used. *Paving blocks* with good water absorption tend to have a lower percentage, (Badan Standardisasi Nasional, 1996; Wajdi et al., 2023)**.** This span is important because paving blocks are often used for areas that are open and exposed to direct rainwater. Low absorbency helps the paving block stay strong and resistant to weathering and damage due to temperature changes. The analysis of the calculation of the permeability of paving blocks is used with the formula:

Water Absorption (%) = $\frac{(W2-W1)}{W1}\, x\ 100\%$ .... (1)

Where:

W_1 = Heavy paving block in dry conditions

W_2 = Heavy paving block in wet conditions

Paving Block Immersion Data on Water Absorption

The results of the calculation of water absorption capacity on paving are shown as shown in Table 4.

Table 4. Analysis of Air Absorption Capacity of Paving Block with PET Plastic Fraction Mixture

No	Paving Name	Dry Weight (W_1) (kg)	Weight After Soaking (W_2) (kg)	Immersion Length (Days)	Difference (Water Absorption) (kg)	Water Absorption (%)
1	Paving Block 1	2.10	2.23	2	0.13	6.0
2	Paving Block 2	2.10	2.22	2	0.12	5.7
3	Paving Block 3	2.25	2.36	2	0.11	4.9
4	Paving Block 4	2.20	2.32	2	0.12	5.5
5	Paving Block 5	2.32	2.43	2	0.13	6.4
6	Paving Block 6	2.10	2.20	2	0.11	4.7
7	Paving Block 7	2.21	2.32	2	0.09	4.5
8	Paving Block 8	2.12	2.24	2	0.11	5.0
9	Paving Block 9	2.20	2.29	2	0.12	5.4
10	Paving Block 10	2.30	2.41	2	0.11	4.6

11	Paving Block 11	2.12	2.24	2	0.12	5.7
12	Paving Block 12	2.10	2.20	2	0.09	4.5
13	Paving Block 13	2.30	2.44	2	0.14	6.1
14	Paving Block 14	2.10	2.19	2	0.09	4.3
15	Paving Block 15	2.23	2.35	2	0.12	5.2
16	Paving Block 16	2.14	2.26	2	0.12	5.6
17	Paving Block 17	2.23	2.34	2	0.11	4.9
18	Paving Block 18	1.90	2.00	2	0.10	5.0
19	Paving Block 19	2.30	2.42	2	0.12	5.2
20	Paving Block 20	2.10	2.22	2	0.12	5.7
Average		2.17	2.28	2	0.11	5.2

From the results of the water absorption analysis carried out on 20 paving block samples using a mixture of plastic waste with an additional percentage of 5%, the value of water absorption in the paving block was 4.3-6.4% with an average water absorption value of 5.2%

Comparison of Dry Weight and Wet Weight of Paving Blocks

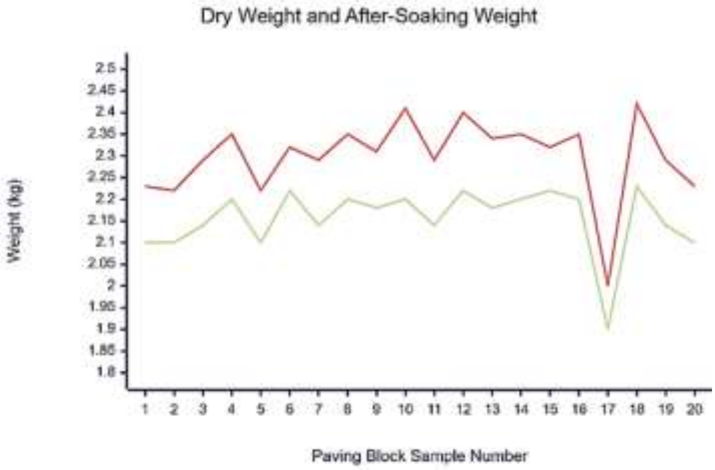

Figure 5. Comparison of Dry and Soaked Weight of Paving Blocks (Data from Table 4)

Figure 5. shows the comparison between dry weight (W_1) and soaked weight (W_2) of paving blocks obtained from the data presented in Table 4. The figure illustrates that all samples experienced a slight weight increase after water immersion, indicating consistent water absorption behavior across the specimens. The test results show that the paving blocks have an average dry weight of 2.17 kg and a weight after soaking for 48 hours of 2.28 kg. There was an increase in mass of 0.11 kg (±5.20%) due to water absorption into the concrete pores. This value remains below the maximum limit of 8% as specified in SNI 03-0691-1996, indicating that the paving blocks possess good water absorption performance. The increase in weight reflects the presence of open porosity within the structure of the paving blocks. Based on an assumed bulk density of 1100–1200 kg/m^3, the effective porosity is estimated to range between 5–6% of the total volume. This indicates that the paving blocks have a relatively dense structure and controlled water absorption capacity, maintaining mechanical stability even after 48 hours of immersion.

Comparison of Water Absorption and Compressive Strength

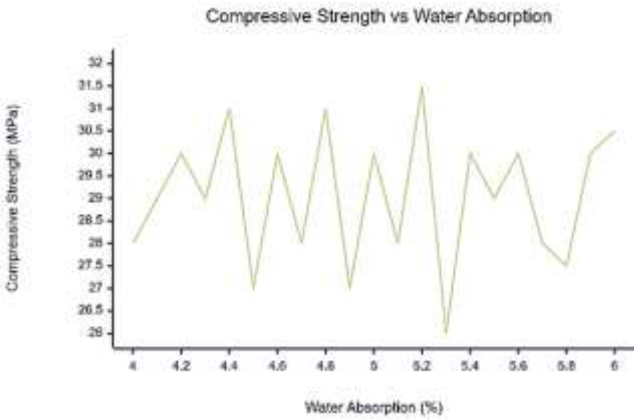

Figure 6. Relationship Between Water Absorption (%) and Compressive Strength (Mpa) of Paving Block Samples

Based on the testing of 20 paving block samples, the water absorption ranged from 4.3% to 6.4%, with an average of 5.2%, while the compressive strength ranged from 26.5 MPa to 32.0 MPa, with an average of 29.3 MPa. All samples meet the Class B standard (20-32MPa) and are deemed suitable for sidewalks, pedestrian paths, and light parking areas.

DISCUSSION

From the results of this test analysis, it shows that paving blocks using the addition of plastic waste with a presentation of 5%, produce ≤ 6% absorption capacity, where the paving block is at quality B, which can be used for roads with medium loads, where paving blocks containing plastic waste show lower water absorption compared to conventional paving, this is due to the hydrophobic nature of plastic that is unable to absorb water. In the immersion test, the increase in water absorption in plastic paving was relatively insignificant, in contrast to normal paving which is more porous. Conventional paving made of pure cement and sand can achieve a water absorption of about 8–12% or more if the pores are not tight, while paving with a mixture of plastic waste is only around 2–6%. Thus, although the variation in immersion length affects the test results, it is not very significant in paving made of plastic waste due to the basic characteristics of plastics that do not absorb water.

The analysis of the relationship between water absorption and compressive strength shows a consistent negative correlation: samples with low water absorption (~4.3–4.5%) tend to have higher compressive strength (~31–32 MPa), whereas samples with high water absorption (~5.9–6.4%) exhibit lower compressive strength (~26.5–27 MPa). Increased water absorption reduces the material density, decreases the contact area between cement and aggregate particles, and increases the risk of microcracks, thereby reducing load-bearing capacity and affecting durability under wet-dry cycles and dynamic loads. The linear trendline for the relationship between compressive strength (MPa) and water absorption (%) is expressed by the equation $y = -2.05 \times WA + 39.0$, which supports this negative correlation. This equation can serve as an initial guideline for designing paving block mixtures to achieve an optimal balance between durability and compressive strength.

CONCLUSIONS AND RECOMMENDATIONS

From the results of the research conducted with the title Analysis of the Utilization of Plastic Waste as a Mixed Material in the Making of Environmentally Friendly Paving Blocks, it was concluded that with the addition of 5% of plastic waste that has been chopped with a size of 0.1-2 cm with a soaking time of 48 hours, it is able to produce a water infiltration value in paving blocks between 4.3-6.4% with an average water infiltration value of 5.2%. From the results of this test analysis, it shows that paving blocks by using the addition of plastic waste with a presentation of 5%, produce ≤ 6% permeability, where from the results of the analysis the paving block is at quality B while the compressive strength ranged from 26.5 MPa to 32.0 MPa, with an average of 29.3 MPa. All samples meet the Class B standard (20-32MPa), which can be used for roads with medium loads. For this reason, based on the results of research conducted by using plastic waste as one of the mixed materials for making paving blocks , it is able to provide good results and reduce plastic waste.

ADVANCED RESEARCH

Suggestions for the further research make different variation presentation of mixture plastic and soaking time to know the other behavior of paving block namely water absorption and compressive strength.

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