



Article

The Effect of HDPE Plastic Fibres on Concrete Performance

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Abstract: HDPE (high-density polyethylene) plastic waste is stronger, harder, and more resistant to high temperatures than other plastics. Using it as an additive in a concrete mixture is one solution to reduce this type of waste. We examined how HDPE-type plastics can be used as an additive material in the manufacture of concrete to improve its hardness, tensile strength and compressive strength. Using 156 samples, we aimed to identify the effect of HDPE plastic fibres on concrete of three qualities; B0, f'c10 MPa (low quality), and f'c25 MPa (medium and high quality). We added four compositions (2.5%, 5%, 10% and 20% by weight of cement) of HDPE plastic fibre to each quality of cement, with HDPE plastic fibre sizes of 1 x 1 cm, 0.5 x 2 cm or 0.25 x 4 cm. We found that the addition of 5% HDPE plastic fibre with a 0.5 x 2 cm cross-sectional shape to the f'c10 MPa concrete gives the best result, with increased tensile and compressive strength of the concrete.

Keywords: Concrete quality; concrete additive; cross-section; concrete mixture; concrete composition; plastic waste; HDPE; plastic fibre

1. Introduction

Plastic has long been considered a human-made material that has many benefits. It has lightweight properties and is easily shaped to the desires of its designers. This has led to its widespread use. In 2016–2017, plastic consumption increased from 335 million tons to 348 million tons. This demand is expected to reach 485 million tons by 2030 [1]. The downside of plastic use is the waste generated, which can cause environmental pollution because it is a non-biodegradable material that takes between 500 and 1000 years to decompose [2]. The pollution risks associated with plastic include the following: pollution of groundwater, death of animals due to toxins released by plastics, food chain poisoning, and reducing soil fertility [3]. Furthermore, if it is burnt in an open space, it produces carbon monoxide (a greenhouse gas), and if it is disposed of in the river, it can cause siltation and impede river flow, causing flooding [4,5].

Research on beaches showed that the amount of plastic waste that reached the coast of 192 countries in 2010 was between 4.8 and 12.7 million metric tons [6]. This waste harms the life of organisms that live in the sea [7]. This may require restrictions on plastic use and shaping behaviour at the consumer level [8], as well as encouraging recycling as a solution to avoid the environmental impact caused by plastic waste. By 2050, it is projected that about 12 billion metric tons of plastic litter will end up in landfills and the natural environment [9]. Poor processing and managing of plastic waste in developing countries is caused by limited plastic waste treatment facilities, across the stages of collection, separation, and disposing into landfills.

In developed countries, it is known that, since 2006, recycling rates have increased, and by 2018, processing of waste plastic for energy used 42.6% of the collected post-consumer waste stream [1]. The recycling of plastic waste starts with sorting it into several types of polymers, followed by cleaning, scraping, smelting, and finally, converting it into pellets, which are later recycled into plastic

bags, plastic containers, carpets, jacket insulation materials, and other materials. Traditional recycling suffers from cross-contamination with various types of plastic materials and requires high-energy consumption [10]. Low-carbon reusable materials are being considered as alternatives, instead of disposing of single-use plastics, e.g., PET (polyethylene terephthalate) and HDPE (high-density polyethylene) [11]. Identifying the particular local strategy for waste (including plastics) and tailoring partnerships with the various main stakeholders, i.e., business, industries, and civil society, is necessary [12, 13]. Therefore, building a nexus between the waste and construction sectors offers a possible option for increasing the circularity of plastic, especially microplastics, as they are one of the main forms of plastic pollution due to their widespread use [14].

The fact that plastic materials are generally lightweight, resistant to weather, and have high thermal insulation properties [10,15] means that they can be considered suitable as an added material, for instance, in concrete [16]. The addition of plastic to a concrete mix (to give 25% plastic) can be used in construction for structural and non-structural applications [17]. A recent publication showed that addition of plastic fibre to a concrete mix is more suitable for non-structural works [18], e.g., wall panels [10], shotcrete (or Gunitite) [19], or concrete footpaths [16, 20], since they do not need to have a high strength. In Indonesia, precast concrete walls are a common example of a non-structural application. Together with fillers (e.g., sand, quarry fine), the concrete mix could help prevent heat transfer within its elements. Further, there is a strong connection between thermal conductivity and concrete weight. The use of plastic fibres as lightweight aggregates can reduce concrete thermal conductivity [21]. Poonyakan et al. [10] showed that HDPE, LDPE (low-density polyethylene), polypropylene (PP), and PET have lower thermal conductivity compared to plain concrete, which increases air voids in the concrete. Therefore, they can reduce the heat, and thus, lower the energy consumption, in buildings.

Depending on the mixtures, the concrete can harden with a strength stronger than that of wood and asphalt. However, previous studies have found different amounts of tensile strength and compressive strength in different concretes [22-25]. A higher percentage of plastic fibre decreases the workability of the concrete due to its complex structure, except for 30% PET [10]. In addition, previous studies have found a relationship between PET and the properties of concrete [26,27], and depending on the size, type, and shape of the plastic aggregate, the plastic admixture can influence the properties of the concrete, i.e., its tensile strength and compressive strength [16,28,29].

This study focuses on HDPE fibres because of their characteristics. They are translucent, more rigid and relatively stable compared to PET, which makes them more difficult to crack. They also have a higher temperature resistance compared to PET (melting at 130–135 °C), and are more waterproof [30]. They can be found in different types of products, e.g., cable insulation, containers, milk bottles, and children toys. In Indonesia, plastics have become the second biggest waste products generated after organic waste, reaching 16.65% in 2018 [31]. Therefore, we aimed to investigate the potential use of HDPE fibres in concrete mixes, as a means of reducing the solid waste disposal of HDPE plastic into soil and water. We also aimed to assess the effect of HDPE recycled plastic fibres on concrete that is used for non-structural works, as an alternative to lightweight concrete mixes. Our study is based on the concrete quality, and the size of the HDPE cross-section and its percentage to the total cement used.

2. Materials and Methods

We used concrete mixes formed from cement and aggregate (fine and coarse aggregate), which are designed to have three concrete qualities, namely B0, f'c10 MPa, and f'c25 MPa. Three different sizes of HDPE fibres (1 x 1 cm, 0.5 x 2 cm, and 0.25 x 4 cm) were added to the mixtures before examining the effect of plastic-based aggregates on concrete properties using the ASTM (American Society for Testing and Materials) testing standards. The analysis was based on the calculation of bulk density, slump value, and tensile and compressive strength.

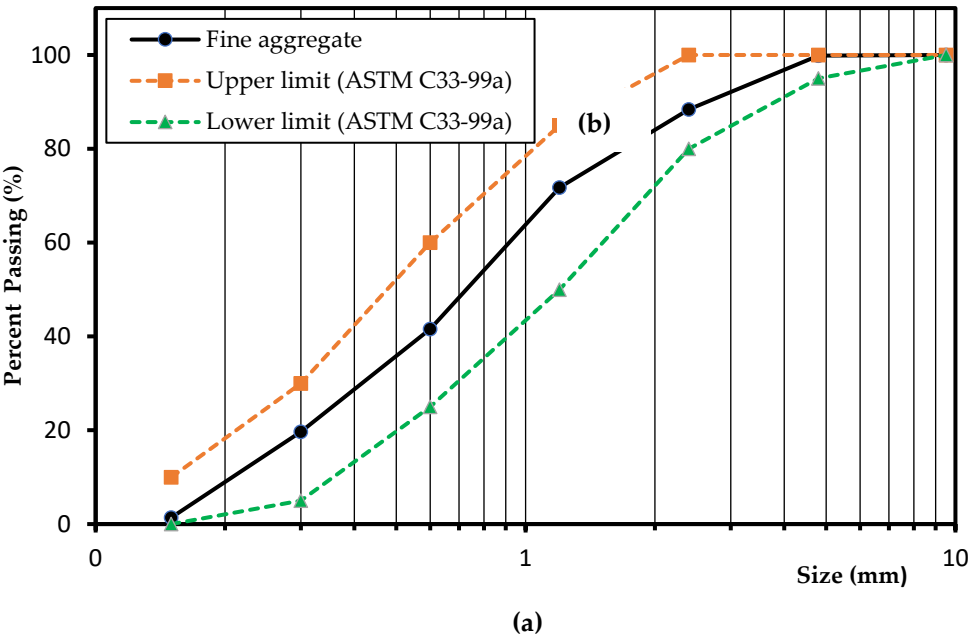
2.1 Materials

2.1.1. Cement Preparation

As the scope of this study was non-structural applications, the cement used for this examination was cement type 1, which is intended for walls, pavement, sidewalks and other precast products. Using the ASTM C-127 standard, the cement material has a specific gravity valued at 3.18 gr/cm³, which meets the acceptable range of 3.1–3.3 gr/cm³. The cement composition comprises four main chemical compounds, including tricalcium silicate (3CaO. SiO₂), which is shortened to C₃S (55% of the weight), dicalcium silicate (2CaO. SiO₂), which is abbreviated to C₂S (17%), tricalcium aluminate (3CaO.AL₂O₃), shortened to C₃A (10%), and tetracalcium alumino-ferrit (4CaO. AL₂O₃.Fe₂O₃), shortened to C₄AF (7%), as well as carbon disulfide (CS₂) (6%).

2.1.2. Aggregate

We used coarse and fine aggregates, which were collected from Palu, Central Sulawesi, Indonesia. The physical characteristics of the aggregates and their quality provided adequate consolidation in concrete mixes, compared to different aggregates obtained from the areas in East Kalimantan. The aggregates were further tested in the Laboratory of the Faculty of Engineering, Mulawarman University, Samarinda, following the standard ASTM procedure of C 33-99 [32], which defines the adequate requirement for grading and aggregate quality in concrete. The results of this test are shown in Figure 1 below.



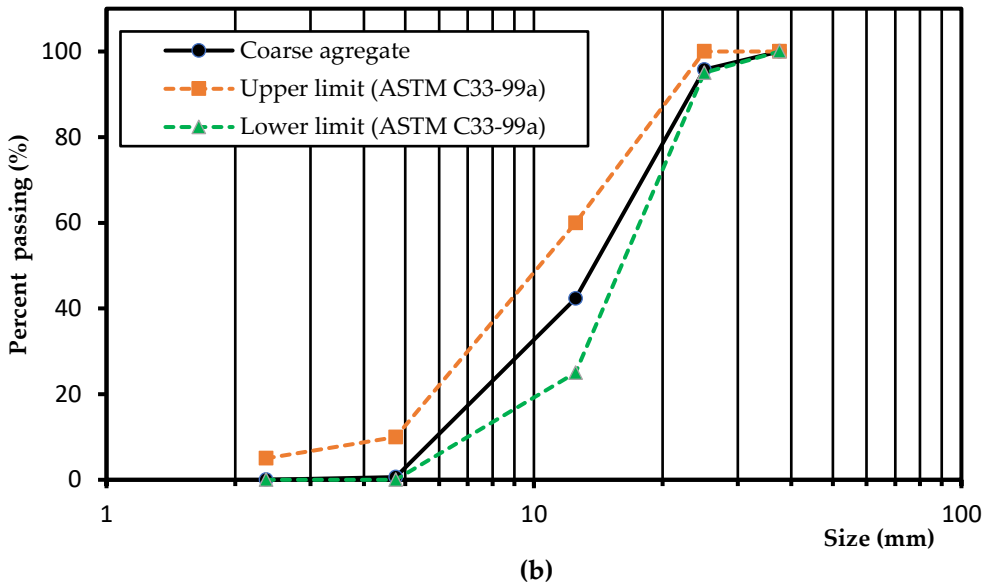


Figure 1. Aggregate size; (a) fine aggregate, (b) coarse aggregate

2.1.3. Preparation of HDPE Fibres

The HDPE plastic materials were collected from the disposal at Samarinda landfills, as part of the plan to reduce non-sustainable waste that can contaminate the waterways and aquifers. We then rinsed them to ensure they were ready for the cutting process. As shown in Figure 2, to ensure visual similarity among the HDPE plastic fibres, we selected plastic materials with a thickness of 0.05 mm and cut them to a size of 1 x 1 cm, 0.5 x 2 cm, and 0.25 x 4 cm. The reason for this was to give them the same surface area of 1 cm². As the interaction between the fibres and cement affects the reinforced concrete mixes, the same surface area was assumed to give a similar bonding effect in the process. HDPE fibre propositions were set at 2.5%, 5%, 10%, and 20% of the total cement used.



Figure 2. The preparation of HDPE plastic fibres; (a) preparation for the cutting process and tools, and (b) HDPE fibres at a size of 0.5 x 2 cm

2.2 Concrete Preparation and Testing

2.2.1. Job Mix Design

The concrete mix designs and material composition of the three concrete qualities are shown in Table 1. The calculation was based on a standard density of construction materials, and a total of 156 specimens were considered and tested with two samples for each variation. The process to identify the right proportion of concrete mixture complied with the code requirements for reinforced concrete and commentary of the American Concrete Institute (ACI 318-89) [33]. Therefore, based on the ACI, the concrete tests were performed 28 days before they were used to ensure the concrete properties satisfied the designs for quality control.

Table 1. Concrete Job Mix Design

Description	B0 Concrete	f'c 10 MPa	f'c25 MPa
Compressive Strength	7 MPa	10 MPa	25 MPa
Targeted of average compressive strength of the concrete	B0	f'cr 10 MPa	f'cr 25 MPa
Cement Water Factor	0.95	0.63	0.52
Combined aggregate content	1,040	1,250	1,780
Slump Value	120 ± 5 mm	120 ± 5 mm	120 ± 5 mm
Amount of Water	180 kg/m ³	190 kg/m ³	215 kg/m ³
Amount of Cement	190 kg/m ³	295 kg/m ³	413 kg/m ³
Fine aggregate content (36%)	969 kg/m ³	828 kg/m ³	687 kg/m ³
Coarse aggregate content (64%)	1,010 kg/m ³	1,014 kg/m ³	1,220 kg/m ³

2.2.2. The mixing process

As seen in Table 2, this study included three concrete qualities, four percentages of HDPE fibres, and other aggregate particles that were used for the mixture. The process was started by mixing the different types of cement and aggregates under dry conditions for a few minutes and then adding water into the mixture until it was evenly mixed and homogeneous. The HDPE fibres were then added to each concrete type as per their size categories (1 x 1 cm; 0.5 x 2 cm; 0.25 x 4 cm) until the concrete mixture became homogeneous. To facilitate observation, the test items were grouped as shown in Table 2. The terms used in the mixed composition can be explained as follows:

- a) B0 concrete is a normal concrete without the addition of HDPE fibres, B0-HDPE 2.5% is B0 concrete with the addition of 2.5% HDPE, B0-HDPE 5% is B0 concrete with the addition of 5% HDPE, B0-HDPE 10% is B0 concrete with the addition of 10% HDPE, and B0-HDPE 20% is B0 concrete with the addition of 20% HDPE.
- b) f'c10 concrete is f'c10 MPa normal concrete without the addition of HDPE fibres, f'c10-HDPE 2.5% is f'c10 concrete with the addition of 2.5% HDPE, f'c10-HDPE 5% is f'c10 concrete with the addition of 5% HDPE, f'c10-HDPE 10% is f'c10 concrete with the addition of 10% HDPE, and f'c10-HDPE 20% is f'c10 concrete with the addition of 20% HDPE.
- c) f'c25 concrete is f'c25 MPa normal concrete without the addition of HDPE fibre, f'c25-HDPE 2.5% is f'c25 concrete with the addition of 2.5% HDPE, f'c25-HDPE 5% is f'c25 concrete with the addition of 5% HDPE, f'c25-HDPE 10% is f'c25 concrete with the addition of 10% HDPE, and f'c25-HDPE 20% is f'c25 concrete with the addition of 20% HDPE.

Table 2. Testing specimens

Mixed composition	Water Cement (W/C) Ratio	Cement (kg/m³)	Sand Aggregate (kg/m³)	Coarse Aggregate (kg/m³)	Water (kg/m³)	Fibre Plastic HDPE (kg)	Number of samples		
							Compressive Strength	Tensile Strength	Total sample
B0 Concrete	0.95	190	969	1010	180	-	2	2	4
B0-HDPE 2.5%	0.95	190	969	1010	180	4.75	6	6	12
B0-HDPE 5%	0.95	190	969	1010	180	9.50	6	6	12
B0-HDPE 10%	0.95	190	969	1010	180	19	6	6	12
B0-HDPE 20%	0.95	190	969	1010	180	38	6	6	12
f'c10 MPa	0.63	295	828	1014	190	-	2	2	4
f'c10-HDPE 2.5%	0.63	295	828	1014	190	7.38	6	6	12
f'c10-HDPE 5%	0.63	295	828	1014	190	14.75	6	6	12
f'c10-HDPE 10%	0.63	295	828	1014	190	29.50	6	6	12
f'c10-HDPE 20%	0.63	295	828	1014	190	59	6	6	12
f'c25 MPa	0.52	413	687	1220	215	-	2	2	4
f'c25-HDPE 2.5%	0.52	413	687	1220	215	10.33	6	6	12
f'c25-HDPE 5%	0.52	413	687	1220	215	20.65	6	6	12
f'c25-HDPE 10%	0.52	413	687	1220	215	41.3	6	6	12
f'c25-HDPE 20%	0.52	413	687	1220	215	82.6	6	6	12
Number of samples									156

We set a higher w/c ratio to produce a workable concrete. Usually, the minimum w/c ratio is set at 0.35–0.4, as a lower ratio may cause concrete to be too dry and unworkable [34]. This study complies with the ASTM standards for test methods to evaluate the effect of HDPE on concrete properties. These standards include ASTM C143 [35] for testing concrete slumps, ASTM C617 for surface specimen capping [36], ASTM C496 for testing concrete tensile strength [37] and ASTM C39 for testing the compressive strength of concrete [38].

3. Results and Analysis

Previous studies indicated that fibre materials, including plastics, at an appropriate mix composition can improve concrete properties [10, 30]. Owing to its low biodegradability, the use of plastic in concrete mixes could improve the long-term performance of the concrete structure and contribute to the green construction industry [39]. A small amount of added plastic does not affect the mixture workability. However, a higher percentage could decrease the compressive strength of concrete due to the high water absorption of the aggregates [30]. Fibres that have often been used in previous studies include steel fibres, plastic fibres, carbon fibres, and fibres from natural materials, such as flax or other plants. Recently, two types of plastic fibres have also been used in concrete mixes and have shown satisfactory results with addition of 30% plastic waste [40]. Besides compressive strength and tensile strength, another important factor that needs to be considered for addition of fibres to a standard mix design is workability. This is so the concrete can be easily carried to work locations, and is easy to work with, easily compacted, and easy to finish. The level of concrete workability can be measured by testing the value of slump, which is identical to the concrete mixture plasticity. To examine the appropriate mixes of HDPE fibres as an addition to concrete for non-structural applications, this study conducted several trials to observe the effects of HDPE sizes on normal concrete, low quality concrete and high quality concrete.

3.1 Concrete Slump test

As the slump value depends on many factors, e.g., temperature and concrete ingredients, we set the slump value for normal concrete to 115–125 mm. As the workability of concrete mixes may reduce with increased plastic addition, we investigated the effect of varying the percentage of HDPE fibres (2.5%, 5%, 10% and 20%) on concrete workability. The changing slump value may be attributed to water absorption due to the flakiness of plastic fibres. The plastic percentage influences the insufficient mixes in the fresh state because of their impervious character, which at a later stage could reduce the concrete mass and cause cracks.

Figures 3 shows the effects of HDPE fibre additions on the concrete slump value. The results show that a larger HDPE fibre addition causes a lower slump value compared to normal concrete. This finding supports previous studies showing that slump value will decrease sharply following an increase in plastic waste in the concrete mixture due to the angular and non-uniform aggregate particles, resulting in lower fluidity in the mixture [30, 41]. However, the addition of plastic could improve toughness and energy absorption, which can be useful for non-structural works, i.e., precast concrete and walls [41]. Previous studies have proposed ways to prevent segregation, which can happen during casting due to the low workability of fresh concrete [42,43]. These suggestions include increasing the amount of water used in the job mix concrete mixture and adding the additives to maintain concrete density.

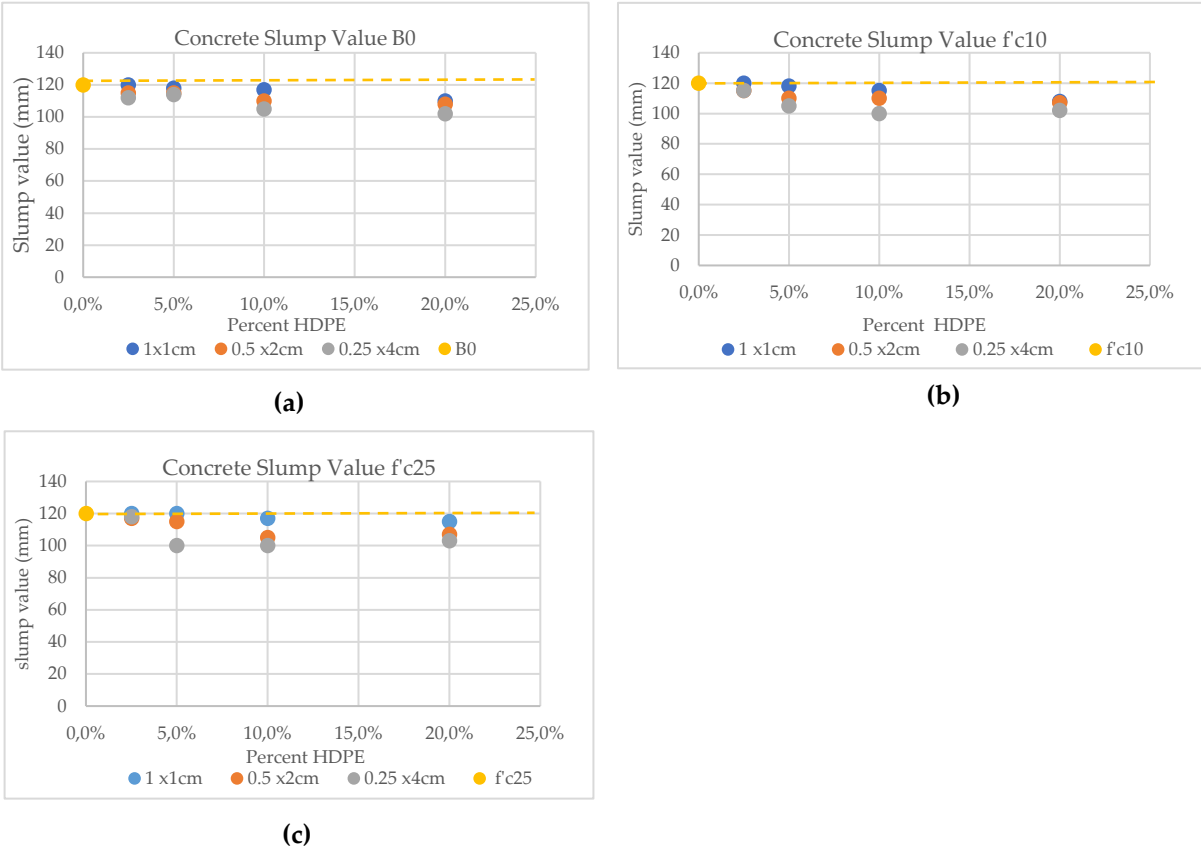


Figure 3. The relation between slump value, the percentage of HDPE and the size of HDPE, (a) B0, (b) f'c10, and (c) f'c25

As shown in Figure 3, the addition of HDPE fibres to concrete will make the concrete mixture thicker, and the concrete slump value lower, due to the hydrophobicity of the plastics. We found that

this started to occur with the addition of 5% HDPE. The greater the addition of HDPE, the greater the reduction in fresh and dry densities in the concrete mixture. This study found that the max value of the reduction ranged from 10 to 60 mm, compared to normal concrete. The preparation process of specimens and mixtures is shown in Figure 4.

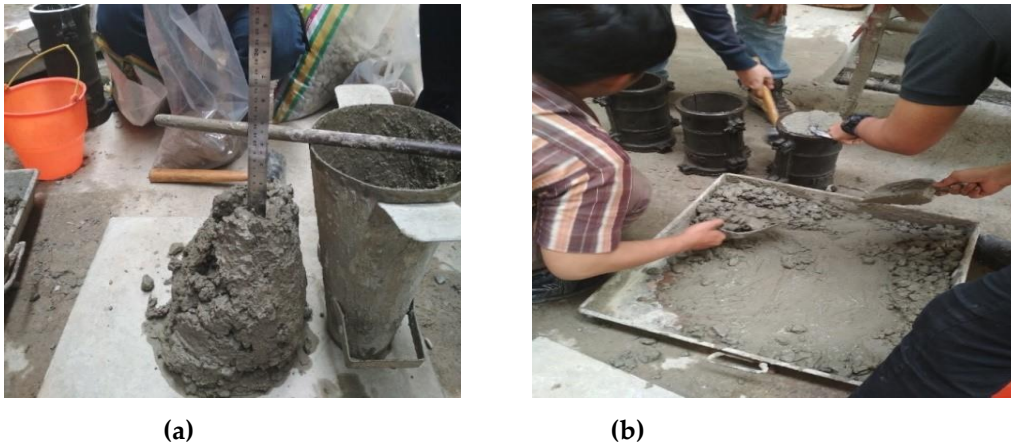


Figure 4. The preparation of B0 concrete for the slump test; (a) slump test, (b) sample printing

3.2 Concrete Bulk Density

We also tested the density of the concrete mass after the addition of HDPE fibres. We found that concrete added to HDPE fibres decreased in weight compared to normal concrete, as shown in figure 5.

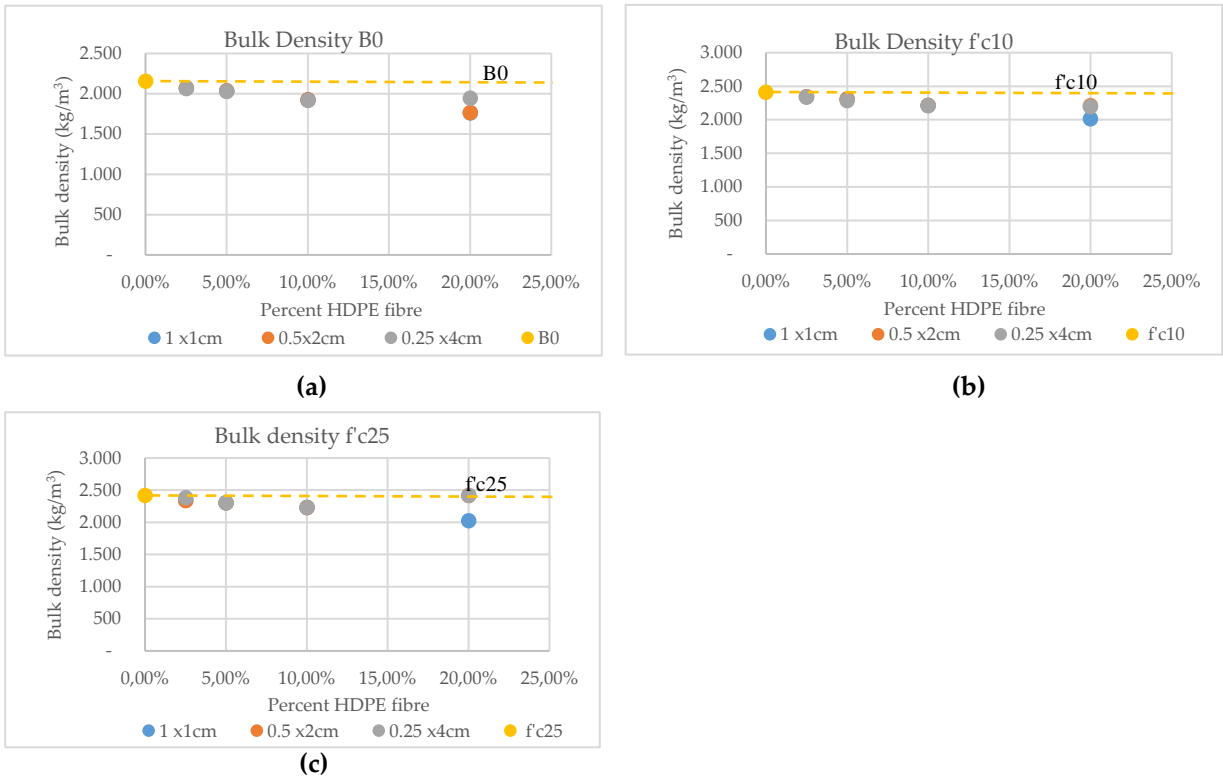


Figure 5. The relation between the bulk density, the percentage of HDPE and the size of HDPE; (a) B0, (b) f'c10, and (c) f'c25.

As seen in Figure 6, which shows the inner layers of each destroyed sample, concrete containing HDPE fibres seems more permeable and not fully solid. This study shows that the greater the amount of fibre added to concrete, the more layers of concrete are porous. Thus, the addition of fibres will be beneficial for reducing the weight of the concrete.

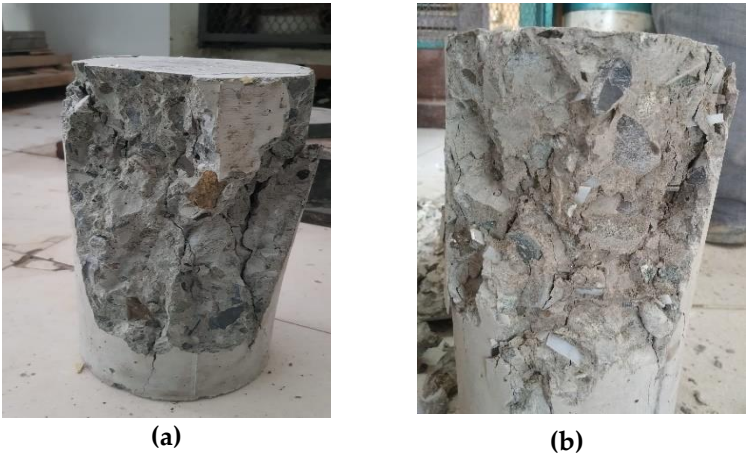
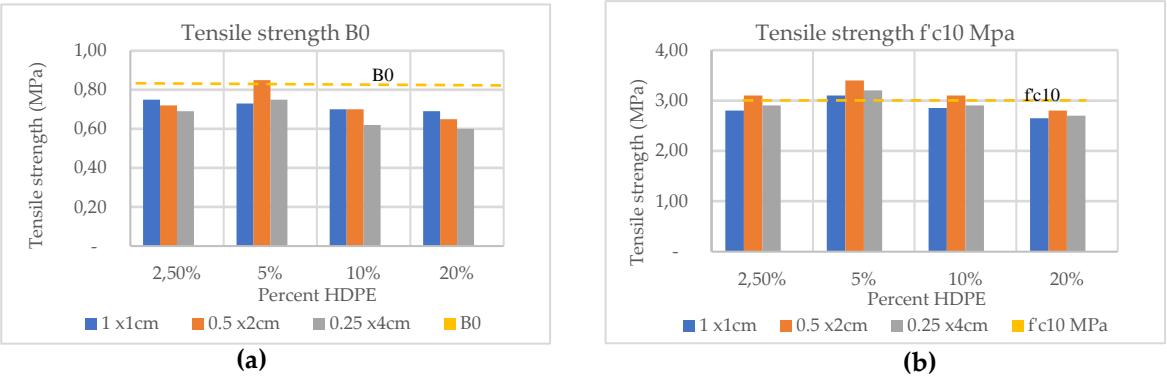


Figure 6. The visualisation of concrete density containing HDPE fibres; (a) without the addition of HDPE, (b) with HDPE addition

Figure 6 shows that, of all the sizes of HDPE plastic fibres that were tested, the size of 0.5 x 2 cm had the greatest influence on the physical properties of all concrete qualities. The addition of 0.5 x 2 cm fibres to concrete gave a higher compressive strength value. Figure 6 (a) shows proper compaction of concrete aggregate which packs the materials together, and increases the concrete density. On the other hand, Figure 6(b) shows that when the concrete collapsed, there was no broken HDPE plastic fibres, and some of the HDPE plastic fibres were folded during casting.

3.3. Tensile and Compressive Strengths

The most important test to do besides the two tests above is concrete strength testing to identify the strength of concrete containing HDPE fibres. The tensile strength is an important determinant of how the concrete performs under the induced stresses. The results of concrete compressive and tensile testing can be seen in Figure 7 and 8.



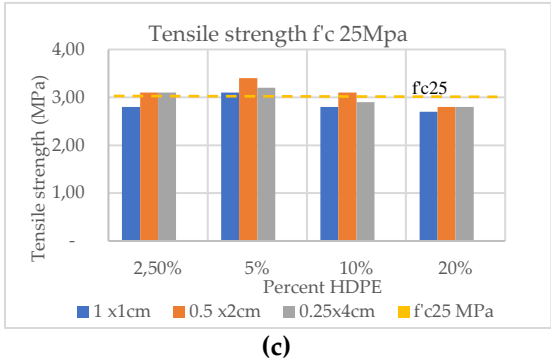


Figure 7. Graphic relationship between split tensile strength, percentage of HDPE fibres and HDPE fibre shape, for (a) B0, (b) f'c10 MPa, and (c) f'c25 MPa

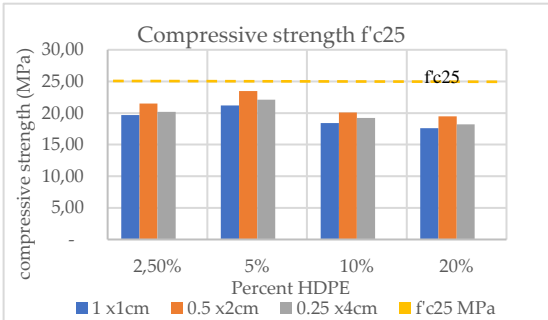
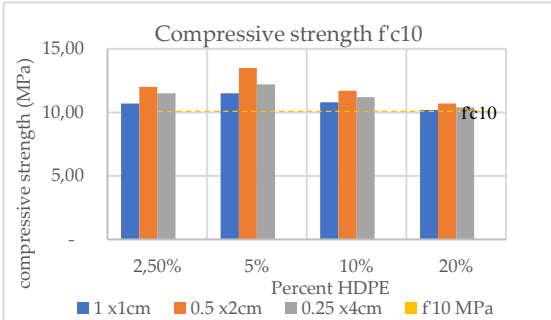
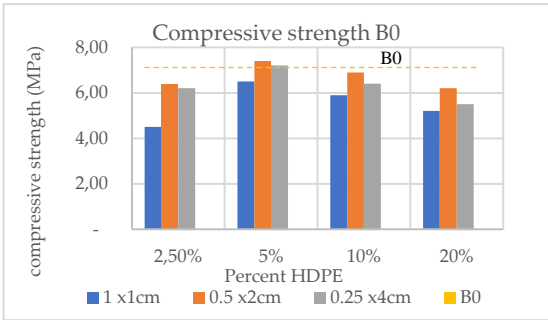


Figure 8. The relationship between compressive strength, percentage of HDPE fibres and HDPE fibre shape, for (a) B0, (b) f'c10 MPa, and (c) f'c25 MPa

In essence, the tensile strength of concrete is very low when compared to its compressive strength. Thus, in construction applications, the part of the concrete that experiences a pull-out strength is embedded by pulling iron. Recently, plastic materials have been considered to replace the function of pulling iron. However, due to safety factors such as fire hazards, concrete containing plastics cannot be used as primary structure construction materials, i.e., columns, beams, and plate constructions. According to Hasan et al. [42], inserting fibres into a concrete mixture can increase the strength of concrete composites by about 10–15% of the tensile strength of normal concrete. Several other researchers have found similar results [44–46].

Our study showed that addition of 5% HDPE plastic fibre, with a size of 0.5 cm x 2 cm, to all concretes increased the tensile strength to 13% above that of normal concrete, which is in line with the previous study [10]. Furthermore, this study also found that the optimal amount of HDPE plastic

fibre to add was 5% with a fibre cross-sectional shape of 0.5 x 2 cm. Fibres with a size of 1 x 1 cm and 0.25 x 4 cm increased the tensile strength by only 10% and 5% (Figure 7). Visualisation of the condition of the HDPE fibres in f'_{c10} MPa concrete when the concrete is split under tension is presented in Figure 9.

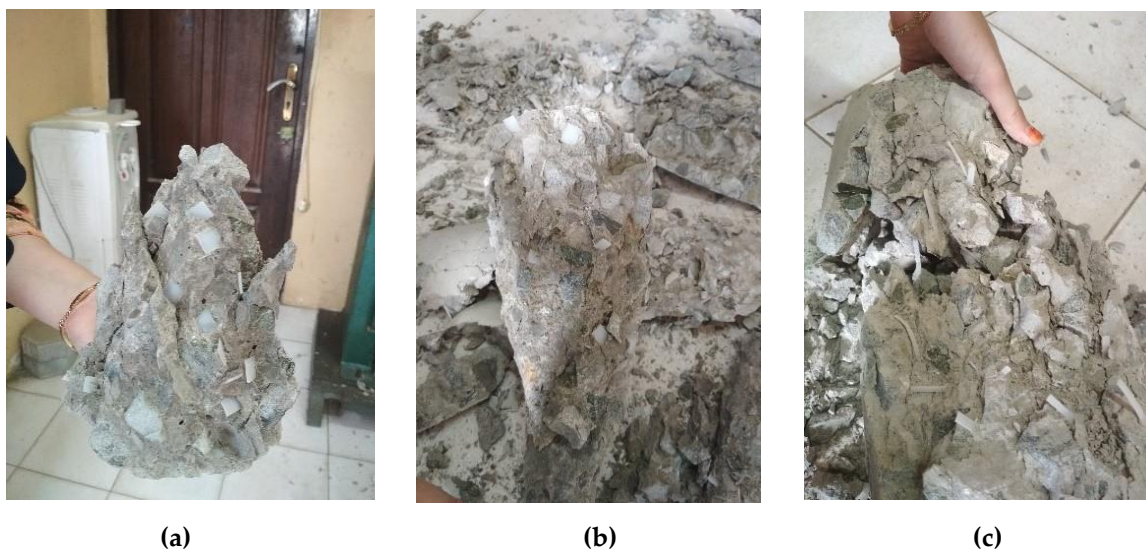


Figure 9. Visualization of the condition of the HDPE fibres; (a) 1 x 1 cm, (b) 0.5 x 2 cm, (c) 0.25 x 4 cm

Figure 9(a) shows that when the concrete obtains a crack, the HDPE plastic fibres remain intact and do not suffer damage; this picture also shows that the HDPE fibres do not experience bending during casting. In contrast, Figure 9(b) shows that when the concrete is broken, some HDPE fibres break up. In this picture, the HDPE fibres were also not found to be flexed during casting. Figure 9(c) shows that when the concrete was broken, HDPE fibres were still intact and the plastic was released from the concrete bond when the concrete received the load during testing. Many plastic positions were flexed during casting, so plastic is not optimal for accepting external forces.

4. Discussion

This study identified several findings, which are discussed below.

4.1 Concrete Properties

Figure 1 shows that the addition of HDPE fibres to concrete affects the properties of the concrete. One of the properties that changes due to the addition of HDPE is the slump value, which is essential for concrete workability. It also affects the quality of the concrete, due to the reduced slump value, as the concrete will become thick and more compact. However, the addition of proportional HDPE fibres to the concrete can increase its quality, as shown for a 5% addition of HDPE in Figure 7b and 8b.

Based on the figures, it can be said that the greater the addition of HDPE fibres into the concrete, the higher the viscosity of the concrete [22,29], which results in the accumulation of coarse aggregate, causing segregation. Therefore, to prevent segregation due to the addition of HDPE plastic fibres in casting, adding additives to the concrete or adding water after a job mix can be done, which in line with previous research [30,41,42].

4.2 Bulk Density of Concrete

In this study, a concrete density test was carried out to determine the relationship between the weight of the test specimen and the amount of HDPE fibre addition. This study inferred that the more plastic fibres in the concrete mixture, the lower the weight of the concrete compared to normal concrete [42,47,48]. This is because the irregular stack of HDPE fibres in concrete causes the formation of porosity on the surface [25]. We found that the lowest weight was obtained at a size of 0.25 x 4 cm. This shows that the length of the HDPE fibres is one of the variables that affect concrete bulk density, as during the casting process, many fibres may be folded under pressure by coarse aggregates. The lowest bulk density in quality B0 concrete is 1765 kg/m³, in f'c 10 concrete is 2010 kg/m³, and in f'c 25 concrete is 2021 kg/m³.

We identified that increased porosity in the concrete causes a decrease in concrete weight, due to the tension on the surface of the uneven HDPE fibres. Furthermore, the surface tension is also primarily determined by the position of HDPE plastic fibres during casting, which may cause the coarse aggregate bond in the concrete mixture to not be optimal. This research shows that adding more plastic fibres to concrete causes a reduction in concrete weight, which is directly proportional to the reduced density of the concrete.

4.3 Tensile Strength and Compressive Strength

The f'c10 MPa concrete showed better tensile and compressive test results for all sizes of HDPE fibres and HDPE percentages. However, the addition of 5 % HDPE fibres gave a higher value than the others. Furthermore, the addition of 10% and 20% HDPE fibres, lowered the tensile and compressive strength for all HDPE sizes. These findings support other studies that showed that an increase of the volume fraction can affect the fibre bonds and reduce the strength of concrete composites [15,25,49].

The most optimal shape of the HDPE plastic fibres (for f' c10 MPa) is 0.5 x 2 cm, which is relatively proportional compared to others. The fibres were not folded during the casting and did not break during the tensile and compressive test. This implies that this form provides better bonds between plastics and cement, and shows a higher value of concrete quality compared to 1 x 1 cm and 0.25 x 4 cm. The 0.5 x 2 cm size increased the tensile strength by 14%, and the compressive strength by 13%, compared to normal concrete. Therefore, this suggests that the size of the fibre is an important factor in concrete quality. This is in line with Hasan et al. [42], who showed that fibres can increase cement composites in concrete and can increase the tensile strength of normal concrete by about 10–15%.

This study also suggests that addition of up to 20% of HDPE fibres in the form of 0.5 x 2 cm can be used for f'c10 MPa concrete quality aimed for non-structural works. On the other hand, for 1 x 1 cm and 0.25 x 4 cm, only 10% addition is recommended. In this case, although the cross-sectional area of the HDPE fibres inserted into the concrete is the same (1 cm²), the different shapes differentially affect the concrete properties. More information can be summarised as follows:

- a. HDPE fibres with a size of 0.5 x 2 cm give better results on compressive and tensile strength tests than other sizes. This indicates that this size offers an ideal shape, both length and width, that will be able to adjust and will not fold during the casting process. Furthermore, the shape is not too

wide, meaning that the cement can work well with other aggregates and the fibres work optimally at strengthening the concrete composite.

- b. Although HDPE plastic fibres with a size of 1 x 1 cm have the same contact area, they do not work well when receiving force due to their square shape. The length of the cross-section that receives the force is shorter, and the square shape will tend to have difficulty in adjusting itself during casting. Eventually, it causes a higher number of pores in the concrete and lower bonding between the cement and other materials, especially those that are smaller than the HDPE fibre size.
- c. Although the 0.25 x 4 cm HDPE fibres have the same contact area, they do not work properly due to their small width, especially during the casting process. In this process, HDPE plastics can be folded and may create pores in the concrete, which lowers the bonding between cement and other materials smaller than the size of the HDPE fibres.

4.3 Advantages of Concrete with a mixture of HDPE fibres

The phenomenon of increasing porosity in concrete containing HDPE fibres opens the possibility of developing lightweight concrete. It was found in other studies that the addition of plastic in concrete could help reduce the spread of heat [10]. Therefore, we propose using HDPE fibre addition for building walls, in particular for Indonesia. This may reduce the burden on the structure and the use of energy consumption within the building for cooling the inside temperature. However, these findings do not exclude the use of Bo concrete for pavement foundry on highways and paving blocks for parking with low loads.

5. Conclusions

We conclude that the use of HDPE plastic fibres as a concrete additive material is able to increase the strength of concrete in the composition with the addition of 5% HDPE for all fibre sizes. Of the three concrete qualities examined, the f'c10 MPa concrete quality was the best quality to interact with added HDPE plastic fibre material. We found that added HDPE plastic should only be used on low-quality concrete, aiming for non-structural concrete works.

In the cases where the concrete containing HDPE plastic fibres is for the manufacture of wall panels from precast concrete (f'c10 MPa), the addition should only be around 5–10%. For future research, further investigations are needed to determine the effects of more than 20% HDPE and other varying plastic addition into concrete, including to thermal insulation. This study has contributed to the understanding of the optimal composition of HDPE plastic fibres in concrete. These findings will add to the development of lightweight concrete for the green construction sector, especially for non-structural concrete applications. Furthermore, the use of HDPE fibres could also lead to a more sustainable approach to reducing plastic waste.

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