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Article type	Article
Title	The Effect of Recycled HDPE Plastic Additions on Concrete Performance
Journal	*Recycling* (https://www.mdpi.com/journal/recycling)
Volume	6
Issue	1
Abstract	This study examined HDPE (high-density polyethylene) plastic waste as an added material for concrete mixtures. The selection of HDPE was based on its increased strength, hardness, and resistance to high temperatures compared with other plastics. It focused on how HDPE plastic can be used as an additive in concrete to increase its tensile strength and compressive strength. 156 specimens were used to identify the effect of adding different percentages and sizes of HDPE lamellar particles to lower, medium, and higher strength concrete for non-structural applications. HDPE 0.5 mm thick lamellar particles with sizes of 10 × 10 mm, 5 × 20 mm, and 2.5 × 40 mm were added at 2.5%, 5%, 10%, and 20% by weight of cement. The results showed that the medium concrete class (with compressive strength equal to 10 MPa) had the best response to the addition of HDPE. The 5% HDPE addition represented the optimal mix for all concrete types, while the 5 × 20 mm size was best.
Keywords	concrete additive; concrete mixture; plastic waste; HDPE; plastic lamellar particles

data

Data is of paramount importance to scientific progress, yet most research data drowns in supplementary files or remains private. Enhancing the transparency of the data processes will help to render scientific research results reproducible and thus more accountable. Co-submit your methodical data processing articles or data descriptors for a linked data set in *Data (https://www.mdpi.com/journal/data)* journal to make your data more citable and reliable.

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Review Report

Reviewer 1	Review Report (Round 1) (/user/manuscripts/review/14744396?report=9344073) Review Report (Round 2) (/user/manuscripts/review/14744396?report=9709642)
Reviewer 2	Review Report (Round 1) (/user/manuscripts/review/14744411?report=9343966) Review Report (Round 2) (/user/manuscripts/review/14744411?report=9709644)
Reviewer 3	Review Report (Round 1) (/user/manuscripts/review/14860505?report=9413897) Review Report (Round 2) (/user/manuscripts/review/14860505?report=9709646)

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ROUND 1

Reviewer 1

English language and style
(x) Extensive editing of English language and style required
( ) Moderate English changes required
( ) English language and style are fine/minor spell check required
( ) I don't feel qualified to judge about the English language and style

	Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	( )	( )	(x)	( )
Is the research design appropriate?	( )	(x)	( )	( )
Are the methods adequately described?	( )	( )	(x)	( )
Are the results clearly presented?	( )	(x)	( )	( )
Are the conclusions supported by the results?	( )	(x)	( )	( )

Comments and Suggestions for Authors

The authors have significantly improved the quality of the manuscript and the manuscript can be reconsidered after major revision, including careful English polishing and enrichment of latest research progress in this field.

Submission Date
17 October 2020
Date of this review
13 Nov 2020 03:21:54

Respon to reviewer 1

Dear reviewer,
First of all, allow us to thank you for this constructive feedback. We are grateful to have your comments and make us aware of the mislead terms and the unclear statement that we used in this manuscript. We tried to accommodate the comments in the manuscript. You can find our response below. Thank you again.

Kind regards,

Tamrin Rahman

Response to Reviewer 1 Comments

Point 1: The authors have significantly improved the quality of the manuscript and the manuscript can be reconsidered after major revision, including careful English polishing and enrichment of latest research progress in this field.

We modified the manuscripts and tried to accommodate all the feedbacks in order to meet your expectation and the required standard for publishing. We also send our manuscript to English editing service. Thank you for this remark.

Reviewer 2

English language and style
( ) Extensive editing of English language and style required
(x) Moderate English changes required
( ) English language and style are fine/minor spell check required
( ) I don't feel qualified to judge about the English language and style

	Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	( )	( )	(x)	( )
Is the research design appropriate?	( )	(x)	( )	( )
Are the methods adequately described?	( )	(x)	( )	( )
Are the results clearly presented?	( )	(x)	( )	( )
Are the conclusions supported by the results?	( )	( )	(x)	( )

Comments and Suggestions for Authors

Please see attached file

peer-review-9343966.v1.pdf
Submission Date
17 October 2020
Date of this review
10 Nov 2020 16:35:25

attached file

I had the opportunity to review this paper twice in the past and hence this is essentially a third review. The manuscript describes the effect of the addition of HDPE in the concrete, contributing to a greener environment. The new version of the manuscript is slightly improved, however in my view it requires much work before it is ready to be published in an international journal. I cannot understand if the authors are unable to do the revisions or if they disagree with them, as I cannot see any responses to previous comments. Unfortunately, the manuscript is still poorly written in terms of its scientific content and language. I strongly advise the authors to seek a professional editing service or a native speaker to help them.

The ms contains several drawbacks which are summarised below:

1. The Introduction has not been improved significantly. It contains many generalities, it does not describe the problem statement and does not provide a good, relevant literature review. This is a comment which has never been addressed. The readers have to know in the introduction what the current situation is, with regards to the use of plastic aggregates in concrete, what the-state-of-the-art is and what the problem they wish to solve is.
2. Unfortunately again an important setback is the fact that data and interpretations are not separated. This makes reading and comprehending the manuscript very difficult. On top of this, the text contains vague statements and expressions and so many repetitions, which make it difficult to read.
3. The authors improved the section of materials and methods. However, still we do not know the type of material, which is used as aggregate. If the type of aggregate is not important then why do the authors have one chapter for its description, and they provide densities and resistance to abrasion? How does this information help the manuscript? Where is it used? Still I cannot understand why the values of the tests (density, tensile and compressive strengths) are not provided. Not even as ranges with std in each concrete category.
4. It is very unclear what the originality and the contribution of this paper is. The authors frankly mention that all their "findings" have already been studied and 2

described by other authors. Hence, they fail to highlight the significance and the novelty of this study.
5. The Discussion section has been revised, however now it is just a repeat of the results! No scientific evidence, no interpretations, no robust discussion!
For the above reasons, I very much regret that once again I cannot recommend acceptance of the manuscript in its present form. I hope the authors to find my comments useful for improving the manuscript.
Below I recommend few detailed comments:
- Once again I will suggest to use consistent language: most of the text is written in American English, however both fiber (American) and fibre (English) are used. Likewise, “behavior” and “behaviour” are both used.

Lines 95-99: These components sum up to less than 100%. What is the rest?
Line 102: What physical characteristics? What did you measure? Nothing is provided. What is the material used? Why is it so difficult to mention if it is limestone, sandstone or any other material?
Lines 141-142: Repetitive statement
Line 147: Table 2 provides properties for the aggregates. What is the “sieve size” in table 2? Also, the SI symbol for gram is g and not gr. For unit weight apparently the unit should be g/cm3 (not kg)
Line 157: Are you sure it is 0.05 mm? In the figures they do not look so laminated. Probably you mean cm?
Figure 2: Both images have poor quality. What is their importance? What do they show? A squared paper?
Line 175: which tests are you talking about? Do you mean slump value? Are you implying that you let the concrete 28 days to cure, as it is the standard practice? Very confusing here.
Line 181: Omit “was” before started.
Table 2: a) The legend is unacceptable! b) it’s hard to believe that the amount of water is always the same, with and without HDPE; c) please omit decimal digits from the number of specimens. 3

Lines 194-195: Confusion. How many samples? 2 or 6?
Line 200: Exactly! Therefore, the water content was not the same, as it is stated in Table 4. Which test are you talking about?
Line 221: Please add "is" before "shown".
Lines 221-222: I suggest replacing: "In these experiments… testing." with "In this test, the fibers were added to the fresh concrete before its testing" (if this is what you mean). I suggest omitting the next sentence: "The result…"
Lines 226-228: Apart from requiring syntax correction, this statement is interpretation and should not mix with results.
Lines 230-231: Which is what? the graphs look nearly identical.
Lines 233-241: This is discussion and does not belong to a results section.
Lines 260-261: What do you mean here? Plastic itself has lower density than concrete and hence it is logical that the density of the mixture decreases.
Lines 268-269: Exactly! So, what are you talking about air in lines 260-261?
Lines 270-274: I recommend replacing "Therefore, …Figure 6." with "The size of the HDPE fibers does not affect the concrete unit weight as they all show the same value for certain percentages (Figure 6)."
Figure 6: Poor quality. Small letters and unreadable. Please use open symbols and perhaps re-scale Y-axis, otherwise we are unable to see something.
Lines 292-293: I suggest omitting the sentence: "They are… specification". Nothing special to say.
Lines 294-295: This is an unclear statement. Please explain better. How do you show this? All qualities show an improvement followed by a general decline.
Lines 297-298: Syntax.
Line 321: Omit strength and add it after high concrete…
Lines 321-322: What does this sentence say? Yes of course they have but you do not show this because you never use the aggregate properties!
Line 325: I suggest replacing "all size HDPE… cm_2" with "all HDPE fibers are equal to 1 cm_2". 4

Lines 326-328: I suggest omitting: “This finding… qualities” with “This finding is in line with the results of the compressive strength, where the 0.5 x 2 cm HDPE fibers in all concrete qualities show better performance (Figure 8).”. Generally, there are many vague expressions and errors. Please take care of your text. I will not suggest more corrections.

Lies 326 and 328-330: I suggest deleting “in the addition of HDPE fibers, and be subjected” (incomprehensible) and “Hence… c10.” (repetitive).

Lines 362-363: Vague sentence.

Lines 364-367: a) Why do you repeat the previous sentence again? b) The photos are of poor quality and resolution and the specimens are not cut. Cutting would imply a flat surface where you would be unable to see the fibers out of the concrete. These are apparently hammered, and this is what you need.

Line 369 (and elsewhere): It is not the 0.5 x 2 cm sample, it is the concrete sample which contains this size of HDPE fibers.

Lines 370-371: This a repetition.

Lines 372-373: And again the same repetition! How many times do you have to mention that?

Line 399: What is the two dimensional? Strange expression.

Line 412: Vague. What does the 30% PET do here?

Line 418: Why do you care? Your results show increase of strength with the addition of HDPE. Are they not true? Why do you not discuss this?

Lines 428-429: Again, you repeat the previous sentence!

Lines 430-431: Vague. What is the phenomenon of self-weight concrete? Is it a phenomenon?

Line 444: Again, why do you discuss PET? You have used HPTE.

Lines 451-454: This is not shown in Figs 7 and 8. If you wish to corelate tensile with compressive strength (I cannot see the reason why in this ms) you have to provide a simple graph with these two parameters at the axes.

Response to Reviewer 2

Point 1
The Introduction has not been improved significantly. It contains many generalities, it does not describe the problem statement and does not provide a good, relevant literature review. This is a comment which has never been addressed. The readers have to know in the introduction what the current situation is, with regards to the use of plastic aggregates in concrete, what the-state-of-the-art is and what the problem they wish to solve is.

Thank you for this remark. We actually modified the introduction in our last submission. It started by addressing the plastic problems in general, i.e., number and low recycling rate (paragraph 1 and 2) that leads to the need for another perspective on plastic as used by waste and construction sector (paragraph 3). This was then narrowed down to the Indonesian problem of plastics and why we selected HDPE (paragraph 4). Paragraph 5 mentions the literature review of the use of plastics for construction and research gap. In this version, we add more literature. We conclude in paragraph 6 about the objective of our study and have reshaped paragraph 6 to make it more clear.

Point 2
Unfortunately again an important setback is the fact that data and interpretations are not separated. This makes reading and comprehending the manuscript very difficult. On top of this, the text contains vague statements and expressions and so many repetitions, which make it difficult to read.

We have modified section three into “The results”, and section four as “The Discussion and Analysis” to add more clarity in the content. Section three now only provides visualizations of the raw data in the Figures and describes the results.

Point 3
The authors improved the section of materials and methods. However, still we do not know the type of material, which is used as aggregate. If the type of aggregate is not important then why do the authors have one chapter for its description, and they provide densities and resistance to abrasion? How does this information help the manuscript? Where is it used? Still I cannot understand why the values of the tests (density, tensile and compressive strengths) are not provided. Not even as ranges with std in each concrete category.

The term “aggregate” refers to any particulate materials, including sand, gravel, crushed stone and blast-furnace slag to produce concrete or hydraulic cement mortar (SNI 2847:2013). Coarse aggregates refer to any particulates that are greater than 4.75 mm, while fine aggregates are usually sand or crushed stone less than 9.55 mm. As it contains a broad category of coarse materials used as an inert filler in concrete, we based our category to follow ASTM C33. Therefore, in this manuscript, we maintain the use of the term fine and coarse aggregate. We added this information in line 106-108.

The aggregates themselves meet the standard for aggregate conditions, for example, abrasion to test the ability of the aggregate when bonded with other materials. We used ASTM C131/C131M-20 as the basis of the minimum abrasion requirements for the aggregate. The value of allowable range for the size of coarse and fine aggregates is presented in Table 1.

In section 2.1.2, as a preparation phase, we carried out a sieve analysis to identify the acceptable range for fine and coarse aggregates to be used in concrete mixes. The value of unit weight, tensile and compressive strength are presented in section 3, based on the analysis of concrete specimens at 28 days after casting. The composition of experimental conditions is presented in Table 4. Of the 156 specimens and based on our experimental design, we took two samples for each type of design. Therefore, we used “mean value” instead of std in determining the value.

Point 4
It is very unclear what the originality and the contribution of this paper is. The authors frankly mention that all their “findings” have already been studied and 2 described by other authors. Hence, they fail to highlight the significance and the novelty of this study.

We believe that novelty is something any new findings that can contribute to the wide range of discussion in HDPE plastic uses. We based our study on previous literature that had discussed how plastics have been already used in concrete and could increase the tensile and compressive strength at certain percentage. What we do here recognize the idea that certain amounts of plastic could increase concrete properties. However, we have investigated difference aspects compared with previous research. The difference is in terms of size of HDPE lamellar used; the percentage of addition (not as substitute) that we based on weight of cements, instead of aggregate volume; and, the class of concrete (lower, medium and higher concrete) aimed for non-structural applications.

Point 5
The Discussion section has been revised, however now it is just a repeat of the results! No scientific evidence, no interpretations, no robust discussion!

We offer apologies, but we tried to connect the previous studies with our interpretation of the findings. However, to make it more rigid, we add explanation in discussion section. Thank you for this remark.

Point 6
Once again I will suggest to use consistent language: most of the text is written in American English, however both fiber (American) and fibre (English) are used. Likewise, “behavior” and “behaviour” are both used.

We edited this and followed the American English. Thank you for your details.

Point 7
Lines 95-99: These components sum up to less than 100%. What is the rest?

We provide the explanation in line 104. The additional 5 wt.% to cement chemical compounds. It is unusual if materials in cement compounds can be clearly defined, as minor components do vary.

Point 8
Line 102: What physical characteristics? What did you measure? Nothing is provided. What is the material used?

As presented in Table 2, the physical characteristics here refer to specific gravity of the aggregates (ASTM C-127), the grading of the aggregates (ASTM C33-99a), unit weight (ASTM C29/C29M-07) and also the abrasion (ASTM C131/C131M-20).

Point 9
Why is it so difficult to mention if it is limestone, sandstone or any other material?
As we mentioned in point 3, we follow the standard in categorizing the aggregate. Considering the wide range of particulates, we refer to aggregate as coarse and fine aggregate based on a grading test of sieve size (ASTM C-33-99a). However, the quality of the aggregate depends on the location of aggregate sources. Therefore, we add the information of location, In our case, this is Palu, Sulawesi; widely known in Indonesia as a location for producing good aggregate quality for concrete mixes. Line 106-108.

Point 10
Lines 141-142: Repetitive statement.
Thank you, we removed the sentences.

Point 11
Line 147: Table 2 provides properties for the aggregates. What is the “sieve size” in table 2?
Sieve size refers to the specification for grading and quality of acceptable fine and coarse aggregate based on ASTM C33. Line 113.

Point 12
Also, the SI symbol for gram is g and not gr. For unit weight apparently the unit should be g/cm3 (not kg).
Thank you for this remark. We appreciate this and realize our error in using the unit.

Point 13
Line 157: Are you sure it is 0.05 mm? In the figures they do not look so laminated. Probably you mean cm?
As we mentioned in line 159-160 and Figure 2 (a) the lamellar thickness is 0.05 mm. We removed the part from HDPE bottle with the thickness lower or higher than 0.05 mm.

Point 14
Figure 2: Both images have poor quality. What is their importance? What do they show? A squared paper?
In Figure 2(a) we would like to show how we create our cutting procedure for plastic bottle by making a marking following the determined sizes. We then select the region of plastic bottles that having thickness of 0.05 mm, and overlay the part on top of the marking size. The cutting process of lamellar size of 10 x 10 mm is shown in Figure 2 (b).

Point 15
Line 175: which tests are you talking about? Do you mean slump value? Are you implying that you let the concrete 28 days to cure, as it is the standard practice? Very confusing here.
A common practice to assess the progressive strength of concrete and this is performed after 7, 14 or 28 days after casting. However, the test results before 28 days are used to observe the strength gain and not for the acceptance criteria. In ASTM C39, the strength tests shall be

performed on the 28-day after casting. The tests performed included compressive and tensile.
Line 176

Point 16
Line 181: Omit “was” before started.
Line 205. We did, thank you.

Point 17
Table 2: a) The legend is unacceptable! b) it’s hard to believe that the amount of water is always the same, with and without HDPE; c) please omit decimal digits from the number of specimens.

a) Do you mean Table 4 in here? We changed the legend into “experimental testing of specimens used”.
b) In the job mix design, we set the ideal slump value to meet the economics and workability in the field. The baseline is to identify how far the effect of HDPE additions to concrete slump following the w/c ratio applied. Therefore, the amount of water used in the certain concrete class is the same for any addition of HDPE lamellar percentages. This w/c ratio will differ following the concrete category.
c) We removed the decimal already. Thank you.

Point 18
Lines 194-195: Confusion. How many samples? 2 or 6?
Line 202-203. For each experimental design, we used 2 samples for each HDPE size. For example, for B0-HDPE 20%, the specimens needed are 12 samples, whereas 6 are applied for splitting tensile test and another 6 for cylinder compressive test. For each HDPE size and type of testing, we prepared 2 samples for sizes of 5 x 20 mm, 2 samples for sizes of 2.5 x 40 mm and 2 specimens for sizes of 10 x 10 mm.

Point 19
Line 200: Exactly! Therefore, the water content was not the same, as it is stated in Table 4. Which test are you talking about? What we would like to discuss:
Line 212. We rewording the sentence. As the standard of w/c ratio is 0.35-0.4, therefore, we set the minimum at 0.52. The amount of water will differ depending on the concrete class (Table 3), which explains that the higher concrete will consume more water in line with the amount of lamellar additions. What we mean with in this test refers to the strength test for specimens after 28 days after casting. .

Point 20
Line 221: Please add “is” before “shown”.
Line 226. We added “is”. Thank you.

Point 21
Lines 221-222: I suggest replacing: “In these experiments… testing.” with “In this test, the fibers were added to the fresh concrete before its testing” (if this is what you mean).
I suggest omitting the next sentence: “The result…”
Line 226-227. We changed the sentences with “in this test…” and removed “the result…”

Point 22

Lines 226-228: Apart from requiring syntax correction, this statement is interpretation and should not mix with results
We removed the sentences and placed it in discussion par; line 435.

Point 23
Lines 230-231: Which is what? the graphs look nearly identical.
Line 240-244. We add the related Figure. The addition of HDPE at certain class will affect the value of slump for different HDPE percentage and sizes and we identified that the reduction ranged from 5 to 20 mm.

Point 24
Lines 233-241: This is discussion and does not belong to a results section.
Thank you for this remark. We shifted this part into discussion section; line 435-439.

Point 25
Lines 260-261: What do you mean here? Plastic itself has lower density than concrete and hence it is logical that the density of the mixture decreases.
. Indeed, the density of concrete depends on the mixes of concrete composition. The immiscibility of plastics could affect the compactness with the aggregates where, at a certain amount of the mixture, it will be replaced with the addition of HDPE lamellar. Therefore, the dry concrete density contained higher plastic lamellar is lower. To make it clear, we have shifted this sentence into discussion. Line 453-459.

Point 26
Lines 268-269: Exactly! So, what are you talking about air in lines 260-261?
We provided more explanation in discussion. Thank you. Line 452-460.

Point 27
Lines 270-274: I recommend replacing “Therefore, …Figure 6.” with “The size of the HDPE fibers does not affect the concrete unit weight as they all show the same value for certain percentages (Figure 6).”
Line 270-272. We changed the wording. Thank you.

Point 28
Figure 6: Poor quality. Small letters and unreadable. Please use open symbols and perhaps re-scale Y-axis, otherwise we are unable to see something.
For Figure 6, as the weight is similar, the unit weight do overlay one another. The difference would be apparent in numbers in a Table. However we added an example for an explanation. Line 272-272.

Point 29
Lines 292-293: I suggest omitting the sentence: “They are… specification”. Nothing special to say.
Line 317-318. We have removed it.

Point 30
Lines 294-295: This is an unclear statement. Please explain better. How do you show this? All qualities show an improvement followed by a general decline.

Line 344-354. The results of the tests indicated the novelty of this research. From Figure 7, we can see that, compared to other percentage addition, specimens with 5% HDPE addition indicated higher value to any size of HDPE lamellar shown by the value above the baseline. From this percentage, the lamellar size of 5 x 20 mm performed better with the value higher than the other two sizes. From the compressive strength test in Figure 8, f'c10, indicated the best response, compared to two other concrete classes, whereas its value to any HDPE percentage and sizes are above the baseline.

Point 31
Lines 297-298: Syntax.
Line 349-350 we added the syntax for the size of HDPE lamellar.

Point 32
Line 321: Omit strength and add it after high concrete…
We omit the sentences as we already explained the term in material and methods section. Thank you for this.

Point 33
Lines 321-322: What does this sentence say? Yes of course they have but you do not show this because you never use the aggregate properties!
We omit the sentences. However, the weight of aggregate (aggregate properties) and other composition as mentioned in Table 3 indicates the targeted quality of concrete. We used them as prerequisite of concrete.

Point 34
Line 325: I suggest replacing "all size HDPE… cm2" with "all HDPE fibers are equal to 1 cm2".
Line 346-347. We changed the wording. Thank you.

Point 35
Lines 326-328: I suggest omitting: "This finding… qualities" with "This finding is in line with the results of the compressive strength, where the 0.5 x 2 cm HDPE fibers in all concrete qualities show better performance (Figure 8).". Generally, there are many vague expressions and errors. Please take care of your text. I will not suggest more corrections.
Line 350-354. We reshaped the sentences. Thank you.

Point 36
Lies 326 and 328-330: I suggest deleting "in the addition of HDPE fibers, and be subjected" (incomprehensible) and "Hence… c10." (repetitive
Line 354. We deleted the sentences. Thank you.

Point 37
Lines 362-363: Vague sentence.
Line 382-383" we changed into "In addition, for the compaction, Figure 9 (a) and 9 (b) show a two-dimensional (2D) image of HDPE lamellar position in concrete mixture".

Point 38
Lines 364-367: a) Why do you repeat the previous sentence again? b) The photos are of poor quality and resolution and the specimens are not cut. Cutting would imply a flat

surface where you would be unable to see the fibers out of the concrete. These are apparently hammered, and this is what you need.
Line 384-385. We apologize for the wording. Indeed, what we did is based on the broken piece of concrete, after the compressive test, we took the part to be analyzed visually. The aim is to identify whether it is bending or straight.

Point 39
Line 369 (and elsewhere): It is not the 0.5 x 2 cm sample, it is the concrete sample which contains this size of HDPE fibers.
Line 384 and other places. It is true, we opt the term to make it easier for explanation. But the idea is that 5 x 20 mm is the specimen, with the addition of lamellar size of 5 x 20 mm.

Point 40
Lines 370-371: This a repetition.
We deleted the sentences. Thank you.

Point 41
Lines 372-373: And again the same repetition! How many times do you have to mention that?
Line 458-459. We deleted it. In the beginning what we tried here was to give an emphasis; a sort of conclusion.

Point 42
Line 399: What is the two dimensional? Strange expression.
Line 481. We change into 2D images

Point 43
Line 412: Vague. What does the 30% PET do here?
We deleted the sentences

Point 44
Line 418: Why do you care? Your results show increase of strength with the addition of HDPE. Are they not true? Why do you not discuss this?
Thank you. We restructured the discussion part. The addition of plastic can increase the concrete strength up to certain percentage. Based on our finding, the use of HDPE lamellar additions fits into concrete quality of f'c10, which refers to medium quality. Concrete with this quality is best used with the 5% of HDPE addition. The higher percentage or lower percentage will not give the best results (in terms of concrete strength).

Point 45
Lines 428-429: Again, you repeat the previous sentence!
We apologize, as before, we considered it as an emphasis. We have deleted it.

Point 46
Lines 430-431: Vague. What is the phenomenon of self-weight concrete? Is it a phenomenon?
Line 463. We changed the wording into development

Point 47
Line 444: Again, why do you discuss PET? You have used HPTE.

We deleted to avoid the confusion. Thank you. Previously we would like to connect that more discussions are on PET. However, from that literature, we understand that the addition can be generalized to any plastics. They can increase concrete properties, but only to certain percentage.

Point 48

Lines 451-454: This is not shown in Figs 7 and 8. If you wish to corelate tensile with compressive strength (I cannot see the reason why in this ms) you have to provide a simple graph with these two parameters at the axes.

Line 489. We changed the word “relation” into “connection”. What we meant by the connection here that the value of tensile strength is always smaller than the compressive. However, there is no definite correlation that explains the relationship between tensile and compressive. So, the graph of tensile and compressive are shown separately.

Reviewer 3

English language and style
( ) Extensive editing of English language and style required
(x) Moderate English changes required
( ) English language and style are fine/minor spell check required
( ) I don't feel qualified to judge about the English language and style

	Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	(x)	( )	( )	( )
Is the research design appropriate?	(x)	( )	( )	( )
Are the methods adequately described?	( )	( )	(x)	( )
Are the results clearly presented?	( )	( )	(x)	( )
Are the conclusions supported by the results?	( )	(x)	( )	( )

Comments and Suggestions for Authors

The paper deals with the development of a concrete mix which incorporates as additions recycled HPDE plastic particles. These particles are added in different percentages by volume. Tests on fresh and hardened concrete are performed to determine the optimal percentage and plastic size to be inserted in the mix.

The research is interesting and surely very topical, since the great amount of plastic produced every year all over the world. This aspect is well explained in the introduction.

Anyway, some observation must be done. The title of the paper, which refers to “plastic fibers”, and more in general, the terms “fibres” which is used all over the paper to denote the HDPE plastic particles, is misleading. From the picture shown in Figure 2, the plastic particles added have not the usual shape of fibres. In the text (and this is also confusing) sometimes you refer to these particles as aggregates. As I can understand from the paper they are neither aggregate nor classic fibres. They are plastic additions in the shape of lamellar macro fibres or rather lamellar particles. I think you should use this terms all over the paper. The title of the paper could be modified as: “Effect of recycled HDPE plastic addition on concrete performance”.

So, when you describe the geometry of these lamellar plastic particles, you should also mention their thickness, to justify the term (as an example: in the abstract, line 18: lamellar plastic square or rectangular particles with thickness 0.05 mm and size 10 x 10 mm, 5 x 20 mm, 2.5 x 40 mm). Dimensions in mm are preferable.

Fiber content. In the paper, there is sometimes a misunderstanding with the terms “composition” and “percentages”, which are quite different in the meaning of the research. As I understand in your research, you varied the percentage of fibre content, but not the composition (no chemical analysis is shown). So, please replace this term along the text when it isn't used correctly. And also: you speak about 4 plastic additions but you never specify how these percentages have been valuated. Usually the percentage is calculated by volume – kg/m^3 (volumetric content % with respect to concrete volume), but this is not specified in the text. In Table 4 the quantity of fibres (kg) used for 0.021 m^3 are specified, but the information about HPDE density seems missing, so it is not possible to check how this percentage was computed. Please clarify the meaning of the percentage.

Concrete class. You speak about three concrete mix, denoted as B0, f'c10, f'c25. As I can understand, this is the notation you used in your experimental campaign, so you can use it only after the meaning of this notation has been defined in the text. So in the abstract, as an example, you should be more general, since when you begin to read, it is not clear what "concrete B0" is. In general, you can refer to the three mixes with "concrete of lower, medium and higher strength". These terms (low and high) should be in any case relative to your experimentation, since a concrete with fc=25 MPa cannot absolutely be considered a high strength concrete.

Experimentation on fresh concrete. How do you explain that concretes with different Water content showed the same slump? It's quite strange that mix B0 and mix f'c25 had the same slump. Did you use any superplasticizers? Did you do any test concerning water absorption in the different concrete mix? This could be interesting.

Experimentation on hardened concrete. It is not clear when you did the tests. After 28 days curing? You should also specify the curing condition (temperature, humidity). Did you perform splitting tensile tests on cylindrical specimens? In this case, you should speak about splitting tensile strength. The same for compression: it is cylindrical compressive strength.

In the conclusions it should be underlined that to generalise the results and to see an application of this recycled material, more and different tests should be performed, also concerning the chemical analyses of the plastic material or other tests concerning the valuation of physical properties.

In any case, you cannot generalise your results and compare them to the behaviour of a fiber reinforced concrete, since the materials you tested cannot be assimilated to fibre reinforced concrete. You should re-elaborate section 4.3.

Some more specific observations (see also the attached file):

- Line 16 and line 74-75, 81. Not clear. What is B0? What do you mean for f'c10 MPa or f'c25 MPa? Usually it is better to define concrete strength by using the class. Do you mean concrete of class C25/30? Or please substitute with "concrete with cylindrical strength f'c = 10 MPa. If you refer to a specific symbol adopted in some particular code, refer the notation to the code. One thing is the notation you used to define your mix and your specimens (which you explain in section 2.2.2), one other is the standard notation that everyone can easy understand. In the abstract is better to be more clear and directly refer to the strength value and not to the notation. Or you have to explain.

- Line 17. The sentence “HDPE additive treatments with compositions of 2.5%, 5%, 10%, and 20% were combined with plastic fibers sizes…”. is absolutely not clear. What do you mean for “compositions of 2.5%, 5%, 10%, and 20%”. What is this percentage referred to? Perhaps you intended: HDPE plastic was added in percentages of 2.5%, 5%, 10%, and 20% by concrete volume? Please reformulate this sentence.

- Line 83. Why now do you speak about plastic aggregate? This is confusing. Did you also add plastic aggregate? Which was the maximum diameter? Did they have all the same diameter or it was different? In the following I don’t think you also added plastic aggregate, so this sentence is misunderstanding.

- Line 176: what do you mean “…concrete tests were performed 28 days before use…”???? Usually concrete tests are performed 28 days after casting. I don’t know the meaning of your sentence. Please verify.

- Line 177 – Table 3. If B0, f’c10 and f’c25 are the name you adopted for your concrete batch, don’t add MPa after the name of the batch. The first two rows are not clear. I think here you should only indicate the targeted average compressive strength you want to obtain for each batch. Is this a 28 days - concrete cylindrical compressive strength? What is now f’cr? In the table substitute the “Cement water factor” with the term water/cement ratio. 0.95 is in any case a very high ratio. How do you explain that concretes with different water content have the same slump? Quite strange, you should mention and justify this in the text. In Table 3, you indicate “fine aggregate content (36%)” and “coarse aggregate content” (64%). This seems to be correct for concrete batch f’c25, but this proportion cannot be verified for batch B0 and f’c10. Are the values in Table 3 correct? Are the values referred to $1m^3$? Because if you have less water you should have more aggregates. Please verify. What do you mean for “combined aggregate content”?

- Line 180 – where do you define the four HDPE fibers compositions? I understand that 3 “fiber” geometries were adopted (1x1, 0.5x1, 0.25x4) with the same thickness of 0.05, but I thought that the composition was the same (HPDE plastic). Perhaps you meant four HDPE fiber percentages? For “various aggregate particle sizes used” do you mean the natural fine and coarse aggregate reported in Fig.1?

- Line 234 – please substitute the term “composition” with the term “percentage”.

- Line 267 – Sometimes you refer to your batch with the notation f’10 or f’c10 or fc10 or f’cr10 (and the same with 25). Please decide only one notation and use always the same.

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Article

The Effect of HDPE Plastic Fibers on Concrete Performance

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Abstract: This study examined HDPE (high-density polyethylene) plastic waste as an added material for concrete mixtures. The selection of HDPE was based on its increased strength, hardness, and resistance to high temperatures than other plastics. This study focused on how HDPE plastic can be used as an additive in concrete to increase its tensile strength and compressive strength. The total number of specimens in this study was 156. The aim was to identify the effect of different compositions of HDPE fibers' addition on concrete, including B0, f'c10 MPa concrete, and f'c25 MPa concrete. HDPE additive treatments with compositions of 2.5%, 5%, 10%, and 20% were combined with plastic fibers sizes of 1 × 1 cm, 0.5 × 2 cm, and 0.25 × 4 cm for use with the three concrete types. The f'c10 MPa concrete had the best response to the addition of HDPE fibers. The fibers with 5% HDPE represented the optimal composition for all concrete types, while the size of 0.5 × 2 cm was best.

Keywords: concrete quality; concrete additive; concrete mixture; plastic waste; HDPE; plastic fibers

1. Introduction

Plastic has long been considered a manmade material with many benefits. It has lightweight properties and is easily shaped to the designer's desires; its versatile properties lead to its widespread use. From 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, thereby causing environmental pollution, because it is a nonbiodegradable 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 reduction in soil fertility [3]. Furthermore, if plastic is burnt in open space, it produces carbon monoxide (a greenhouse gas), and, if it is disposed of in a river, it can cause siltation and impede river flow, thereby causing flooding [4,5].

Research on beaches showed that the amount of plastic waste reaching the coastline of 192 countries in 2010 was between 4.8 and 12.7 million metric tons [6]. This waste harms the organisms living in the sea [7]. This may require restrictions on plastic use and shaping behavior at the consumer level [8], with recycling encouraged 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]. The insufficient processing and management of plastic waste in developing countries is caused by the limited number of plastic waste treatment facilities, thereby affecting the stages of collection, separation, and disposal in landfills.

In developed countries, it is known that, since 2006, recycling rates have increased, whereas, by 2018, the processing of plastic waste 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

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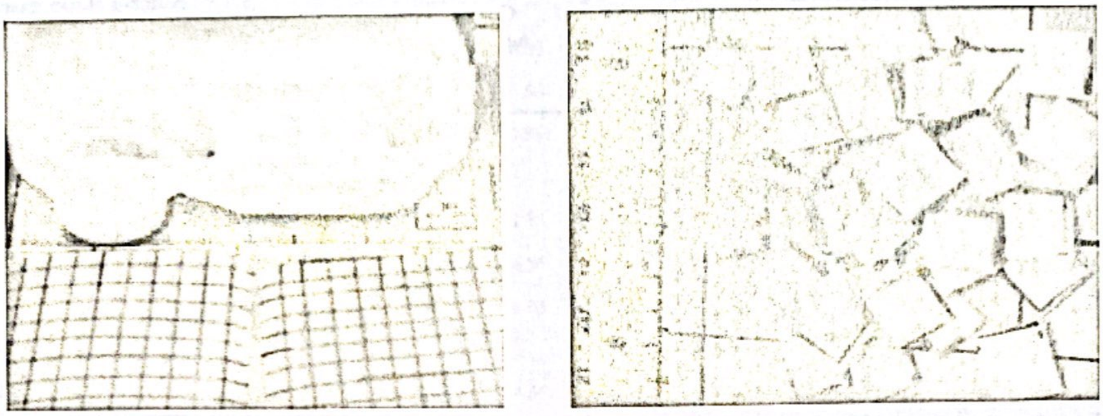
were not used. The cutting process resulted in three sizes, namely, 1 × 1 cm, 0.5 × 2 cm, and 0.25 × 4 cm, resulting in an identical surface area of 1 cm^2. Following the concept where the interaction between the fibers and cement affects the reinforced concrete mixture, the same surface area was assumed to result in a similar bonding effect during the process. Figure 2(b) shows an example of HDPE fibers with a size of 1 × 1 cm after the cutting process.



(a) (b)

Figure 2. The preparation of high-density polyethylene (HDPE) plastic fibers: **(a)** preparation for the cutting process; **(b)** HDPE fibers with a size of 1 × 1 cm.

2.2 *Concrete Preparation and Testing*

2.2.1. Job Mix Design

The concrete mix designs and the material composition of the three concrete types are shown in Table 3. The process of identifying the right proportion of concrete mixture complied with the code requirements for reinforced concrete by the American Concrete Institute (ACI 318-89) [33]. Therefore, according to the ACI, concrete tests were performed 28 days before use to ensure that the resultant properties satisfied quality control designs.

Table 3. Concrete job mix design.

Description	B0	f'c10 MPa	f'c25 MPa
Compressive strength	7 MPa	10 MPa	25 MPa
Targeted 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	1040	1250	1780
Slump value	120 ± 5 mm	120 ± 5 mm	120 ± 5 mm
Amount of water	180 kg/m³	190 kg/m³	215 kg/m³
Amount of cement	190 kg/m³	295 kg/m³	413 kg/m³
Fine aggregate content (36%)	969 kg/m³	828 kg/m³	687 kg/m³
Coarse aggregate content (64%)	1010 kg/m³	1014 kg/m³	1220 kg/m³

2.2.2. Mixing Process

As seen in Table 3, this study included three concrete types, four HDPE fibers compositions, and various aggregate particle sizes used for the mixtures. The process was started by mixing the different cement types and aggregates under dry conditions for a few minutes, before adding water to the mixture until it was homogeneous. The HDPE fibers were then added to each concrete type according to their size categories (1 × 1 cm; 0.5 × 2 cm; 0.25 × 4 cm) until the concrete mixture became

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homogeneous. The terms used in the mixed composition were as follows: B0 refers to normal concrete, meeting the job mix design without the addition of HDPE fibers, while B0-HDPE 2.5% refers to B0 concrete with the addition of 2.5% HDPE. To facilitate observation, the test items were grouped as shown in Table 4. To by volume? HDPE density?

Table 4. Testing specimens.

Experimental Condition	Volume of Concrete ~~Sample~~ (m³)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (kg)	HDPE Fibers (kg)	Number of specimens	
							Compressive strength	Tensile strength
B0 Concrete	0.021	4.03	20.54	21.41	3.82	0.00	2.00	2.00
B0-HDPE 2.5%								
1 × 1 cm	0.021	4.03	20.54	21.41	3.82	0.10	2.00	2.00
0.5 × 2 cm	0.021	4.03	20.54	21.41	3.82	0.10	2.00	2.00
0.25 × 4 cm	0.021	4.03	20.54	21.41	3.82	0.10	2.00	2.00
B0-HDPE 5%								
1 × 1 cm	0.021	4.03	20.54	21.41	3.82	0.20	2.00	2.00
0.5 × 2 cm	0.021	4.03	20.54	21.41	3.82	0.20	2.00	2.00
0.25 × 4 cm	0.021	4.03	20.54	21.41	3.82	0.20	2.00	2.00
B0-HDPE 10%								
1 × 1 cm	0.021	4.03	20.54	21.41	3.82	0.40	2.00	2.00
0.5 × 2 cm	0.021	4.03	20.54	21.41	3.82	0.40	2.00	2.00
0.25 × 4 cm	0.021	4.03	20.54	21.41	3.82	0.40	2.00	2.00
B0-HDPE 20%								
1 × 1 cm	0.021	4.03	20.54	21.41	3.82	0.81	2.00	2.00
0.5 × 2 cm	0.021	4.03	20.54	21.41	3.82	0.81	2.00	2.00
0.25 × 4 cm	0.021	4.03	20.54	21.41	3.82	0.81	2.00	2.00
f'c10 ~~MPa~~	0.021	6.25	17.55	21.49	4.03	0.00	2.00	2.00
f'c10-HDPE 2.5%								
1 × 1 cm	0.021	6.25	17.55	21.49	4.03	0.16	2.00	2.00
0.5 × 2 cm	0.021	6.25	17.55	21.49	4.03	0.16	2.00	2.00
0.25 × 4 cm	0.021	6.25	17.55	21.49	4.03	0.16	2.00	2.00
f'c10-HDPE 5%								
1 × 1 cm	0.021	6.25	17.55	21.49	4.03	0.31	2.00	2.00
0.5 × 2 cm	0.021	6.25	17.55	21.49	4.03	0.31	2.00	2.00
0.25 × 4 cm	0.021	6.25	17.55	21.49	4.03	0.31	2.00	2.00
f'c10-HDPE 10%								
1 × 1 cm	0.021	6.25	17.55	21.49	4.03	0.63	2.00	2.00
0.5 × 2 cm	0.021	6.25	17.55	21.49	4.03	0.63	2.00	2.00
0.25 × 4 cm	0.021	6.25	17.55	21.49	4.03	0.63	2.00	2.00
f'c10-HDPE 20%								
1 × 1 cm	0.021	6.25	17.55	21.49	4.03	1.25	2.00	2.00
0.5 × 2 cm	0.021	6.25	17.55	21.49	4.03	1.25	2.00	2.00
0.25 × 4 cm	0.021	6.25	17.55	21.49	4.03	1.25	2.00	2.00

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f'c25 MPa	0.021	8.75	14.56	25.09	4.56	0.00	2.00	2.00
f'c25-HDPE 2.5%								
1 × 1 cm	0.021	8.75	14.56	25.09	4.56	0.22	2.00	2.00
0.5 × 2 cm	0.021	8.75	14.56	25.09	4.56	0.22	2.00	2.00
0.25 × 4 cm	0.021	8.75	14.56	25.09	4.56	0.22	2.00	2.00
f'c25-HDPE 5%								
1 × 1 cm	0.021	8.75	14.56	25.09	4.56	0.44	2.00	2.00
0.5 × 2 cm	0.021	8.75	14.56	25.09	4.56	0.44	2.00	2.00
0.25 × 4 cm	0.021	8.75	14.56	25.09	4.56	0.44	2.00	2.00
f'c25-HDPE 10%								
1 × 1 cm	0.021	8.75	14.56	25.09	4.56	0.88	2.00	2.00
0.5 × 2 cm	0.021	8.75	14.56	25.09	4.56	0.88	2.00	2.00
0.25 × 4 cm	0.021	8.75	14.56	25.09	4.56	0.88	2.00	2.00
f'c25-HDPE 20%								
1 × 1 cm	0.021	8.75	14.56	25.09	4.56	1.75	2.00	2.00
0.5 × 2 cm	0.021	8.75	14.56	25.09	4.56	1.75	2.00	2.00
0.25 × 4 cm	0.021	8.75	14.56	25.09	4.56	1.75	2.00	2.00

This study used a cylindrical specimen with a diameter of 150 mm and a height of 300 mm (Figure 3). The cylinder molds are made from steel to avoid leakage and hold under severe use. The mold nonabsorbent material's is aimed to avoid the reaction to Portland or other hydraulic cement. For each type of test, two samples were used for each size of HDPE fibers. Accordingly, in each test, the number of samples used for the tensile and compressive strength tests was six. The total number of samples used was 156, including those for normal concrete testing. Since only two specimens were used for each design, the data were processed as averages.

Figure 3. Preparation of concrete cylinder specimen

In this test, we set a higher water/cement ratio to produce a workable concrete (minimum 0.52). Typically, the minimum water/cement ratio is 0.35–0.4, as a lower ratio may result in the concrete being too dry and unworkable [34]. Furthermore, the use of a higher water/cement ratio results in a high slump value; however, the addition of HDPE plastic fibers compensated for this change. To evaluate the effect of adding HDPE fibers to concrete, several tests were conducted, including slump testing using the ASTM C143 standard [35], compressive strength testing using the ASTM C39 standard [36,], and tensile strength testing using the ASTM C496 standard [37].

3. Results and Analysis

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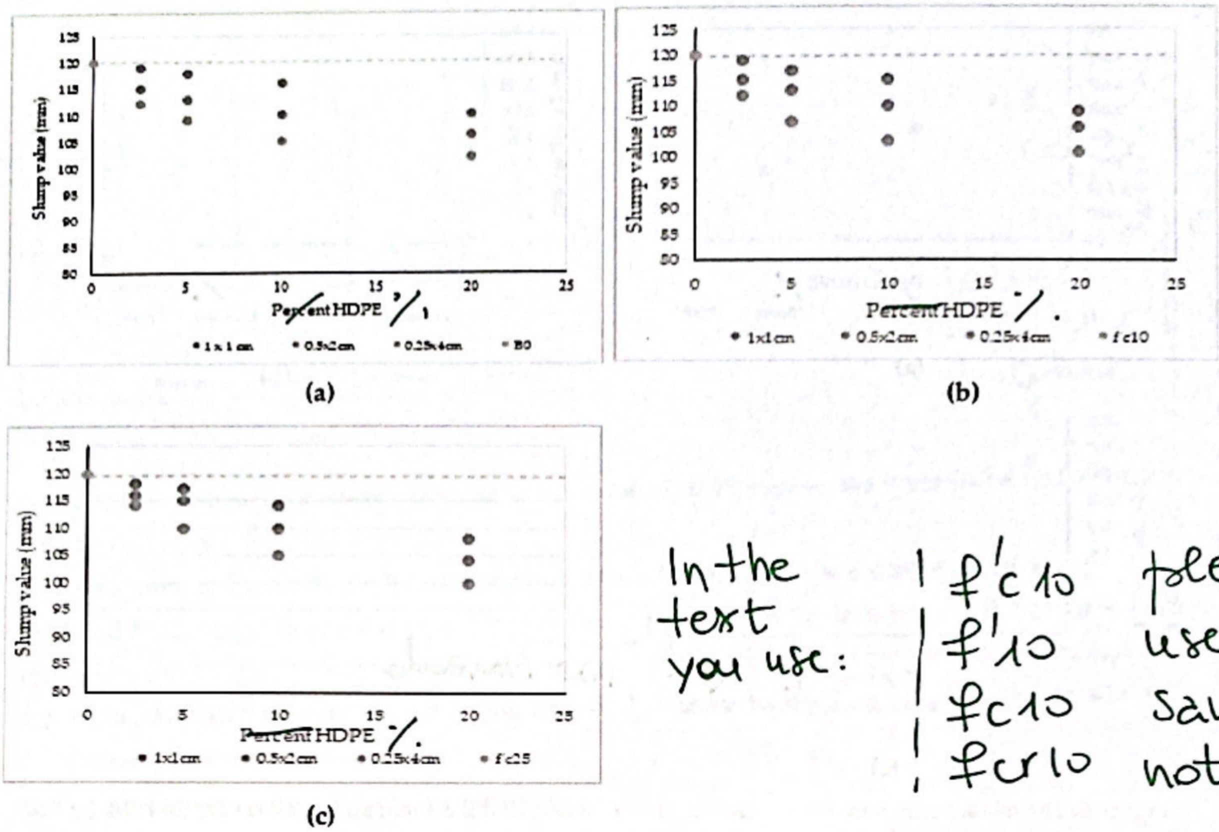

In the text you use: f'c10, f'10, fc10, fcr10 — please use the same notation!

Figure 5. Slump value as a function of HDPE content (%) and sizes: **(a)** B0; **(b)** f'c10; **(c)** f'c25.

3.2. *Unit Weight of Concrete*

Due to plastic nature (e.g., immiscibility), plastic aggregate leads to the increase of air content which affect the concrete density [19]. Following ASTM C29 [31], we use the term of unit weight to refer the concrete property in mass per unit volume, which gives a good indication for sample concrete density. The unit weight for all samples was determined by comparing the specimen's weight with the specimen's substantial volume. The relationship between the unit weight of the concrete, HDPE fiber content and HDPE sizes were shown in Figure 6.

The result shows that a greater addition of HDPE fiber led to lighter concrete due to the low density of plastic fibers, which applies to B0, f'10, and f'25. The unit weight of normal concrete is about 2,400 kg/m^3, and HDPE is about 930 – 970 kg/m^3. Thus, when the HDPE fibers were added into the concrete mixture, the unit weight of the concrete mixture dropped, whereby the reduction is linear with the number of fibers in the mixture. Therefore, for the three different concrete qualities, the addition of 20% reflected a greater decrease in concrete weight, compared to 2.5%, 5%, and 10%. It also presents that the various size of HDPE fiber (1 × 1 cm, 0.5 × 2 cm, and 0.25 × 4 cm) and its their percentage are not directly correlated with the concrete unit weight as its value slightly remained similar as shown in Figure 6.

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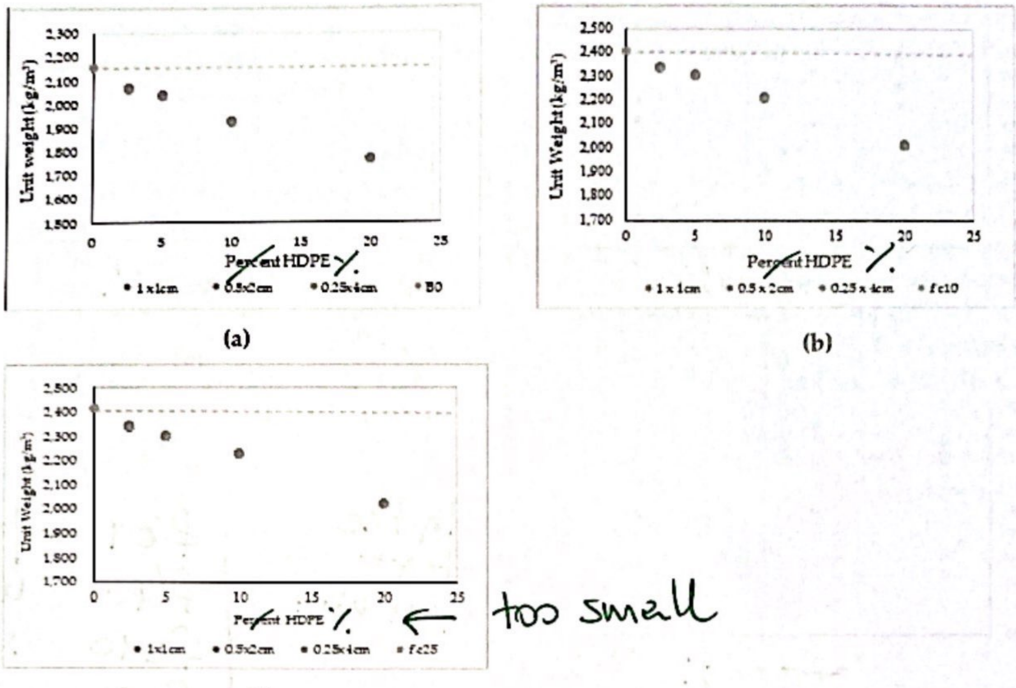
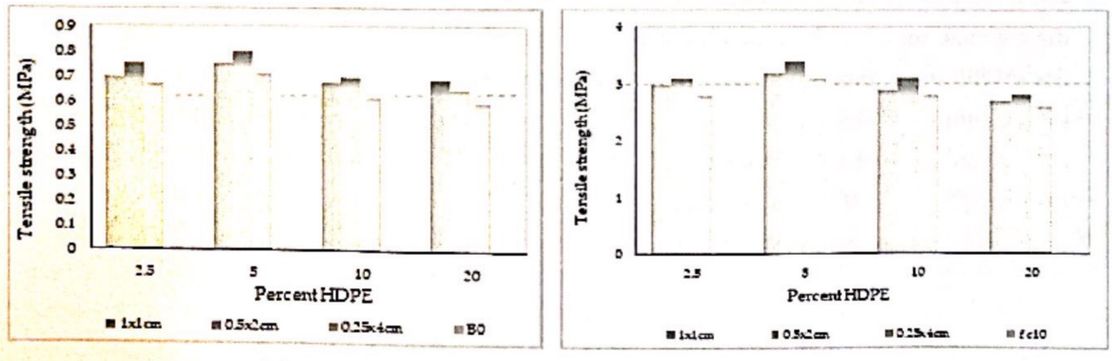


Figure 6. The relationship between concrete unit weight and HDPE content and sizes: **(a)** B0; **(b)** f'c10; **(c)** f'c25.

3.3. Tensile and Compressive Strength

The tensile and compressive strength is the important mechanical properties to identify concrete performance. They are used to determine the concrete specific strength for the required job specification. Figures 7 and 8 display the results of tensile and compressive strength test for the concrete mixtures containing HDPE fibers. The results of this study indicate that the addition of HDPE fibers to f'c10 concrete gives a better response to the increase in concrete quality compared to B0 and f'c25, while the addition of HDPE fibers up to 5% can improve the quality of the concrete above normal concrete quality, and the 0.5 x 4 cm fibers form is the best shape compared to the size of 1 x 1 cm and 0.25 x 4 cm for added concrete. Our experiments indicate that the strength varies depending on the HDPE content and sizes.



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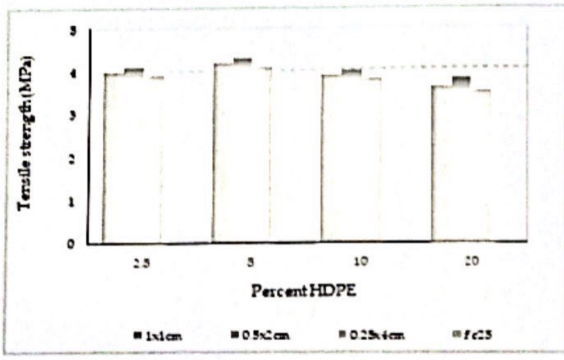
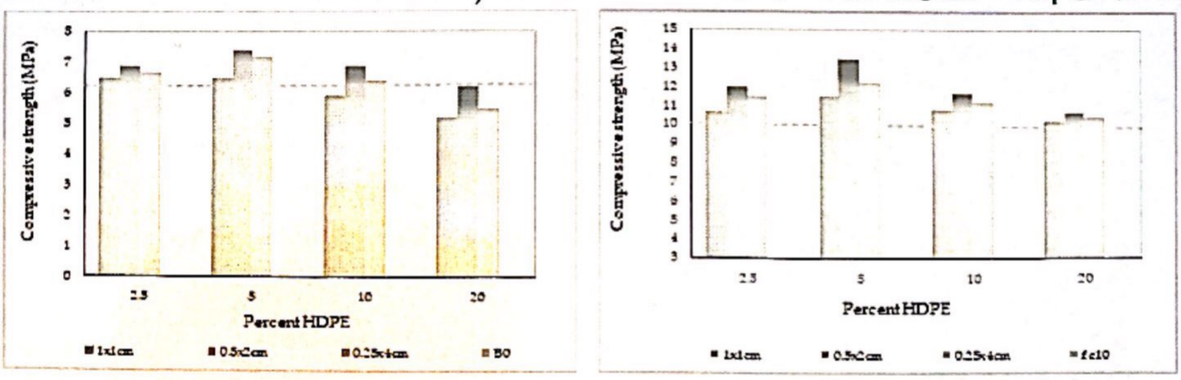


(c)

Figure 7. Tensile strength of concrete mixtures as a function of HDPE content and fibers shape: (a) B0; (b) f'c10 MPa; (c) f'c25 MPa.

As shown in Figure 7, the B0 concrete indicates a lower tensile and compressive, compared to f'c10 and f'c25, this is in line with the job mix design showed in Table 3, where B0, f'c10 and f'c25 represents low strength, medium and high concrete, respectively. The properties of coarse and fine aggregate, and w/c ratio as shown in job mix design seem to have an effect to the tensile and compressive strength.

Further, we observed that the percentage and HDPE sizes behave differently to concrete properties. Though the surface areas of all size HDPE fibers are similar at 1 cm², they have different response to the addition of HDPE fibers, ~~and be subjected to tensile strength.~~ This finding aligned with Figure 8, shows that 0.5 x 2 cm performs better in compressive strength compared to 1x1 cm and 0.25 x 4 cm in three different concrete qualities. Hence, it is apparent that the fibre length (0.25 x 4 cm) brings more chance to a weak element and result to lower tensile, compared to 1 x 1 cm and 0.5 x 2 cm. ~~It also clearly shows that f'c25 compression strength is the highest among B0 and f'c10.~~



(a) (b)

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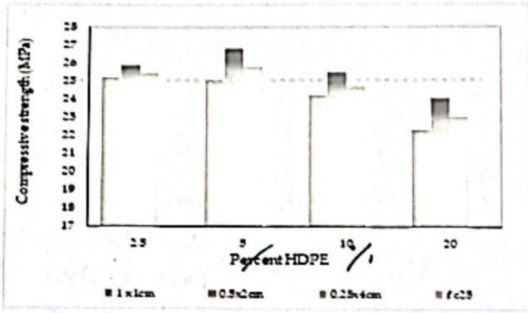
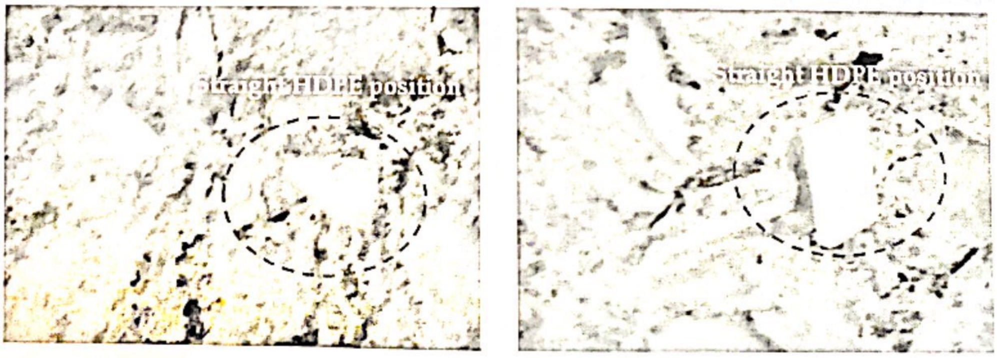


(c)

Figure 8. Compressive strength of concrete mixtures as a function of HDPE content and fibers shape: **(a)** B0; **(b)** f'c10 MPa; **(c)** f'c25 MPa

Added to this, referring to the compaction of concrete, Figure 9 (a) and 9 (b) show a two-dimensional shape of HDPE fibers in concrete mixture. The HDPE fibers with sizes of 1 × 1 cm and 0.5 × 2 cm remained unaffected by coarse aggregate pressure during casting. When the samples were cut using a specimen cutting machine, and observed visually, the plastic fibers of 1x1 cm and 0.5 x 2 cm seemed to pack and bond together with the concrete mixture in straight position. However, we found that the 0.25 × 4 cm HDPE fibers were curved during casting (Figure 9 (c)). Though this phenomenon depends on the different angle of HDPE fibers and the level of coarse aggregate pressure received during casting, the results show that 0.5 × 2 cm specimen performed better compared to 0.25 x 4 cm. This information is clearly visible from Figure 7 and 8, whereby the tensile and compressive strength of 0.5 x 2 cm are higher compared to the other two for B0, f'c10 and f'c25 concrete. More specifically, among the three concrete qualities, 0.5 x 2 cm HDPE fibers has performed better in f'c10 concrete rather than B0 and f'c25, by which its strength values are above the baseline.



(a) (b)

replace as aggregates can reduce the concrete's thermal conductivity [49]. Poonyakan et al. [10] showed that HDPE, LDPE (low-density polyethylene), PP (polypropylene), and PET have lower thermal conductivity compared to bare concrete. This allows reducing heat and, lowering energy consumption in buildings.

4.3 Relationship between HDPE and Tensile and Compressive Strength

Previous studies also found a relationship between PET and concrete properties [20,47]; following the size, type, and shape of the plastic aggregate, the admixture can influence the concrete's tensile strength and compressive strength [19,21]. Depending on the type and fibers composition, previous studies identified different levels of tensile and compressive strength in different concrete mixtures [50,51]. Those include steel fibers, plastic fibers, carbon fibers, and fibers from natural materials, such as flax or other plants. The use of steel fibers has affect the value of splitting tensile and compressive strength [52].

The tensile strength is an essential determinant of how concrete performs under induced stress. As shown in Figure 7 and 8, in essence, there is a relation between tensile and compressive strength, though their relation is not directly proportional. The higher of concrete compressive strength, the higher of the tensile strength, but at a decreasing rate [53]. According to Hasan et al. [39], inserting fibers into a concrete mixture can increase the concrete composite's tensile strength by about 10–15% compared to standard concrete. Several other researchers found similar results that fibers can prevent brittle failure and enhance the ductility of the concrete [38,52,48]. Though, plastic materials have been considered as materials to resist the cracking and improve the concrete strength, due to safety factors and its poor fire-resistant behaviour [47], concrete containing plastics cannot be used as a primary construction material, i.e., for column, beam, and plate constructions.

You cannot compare your material to a fibre reinforced concrete

This study shows that the addition of 5% HDPE fiber increases the tensile and compressive strength of concrete, better than 2.5%, 10% and 20%. More specifically, the addition of 10% and 20% HDPE content to B0 and f'c25 concrete has proven to reduce the concrete strength. Furthermore, the addition of 10% and 20% HDPE content to B0 and f'c25 concrete reduced the tensile and compressive strength. This finding supports other studies showing that increasing the volume fraction can affect fiber bonding and decrease the strength of concrete composites [15,25,49]. This phenomenon did not apply to f'c10 MPa concrete, where an increase in quality was determined even with a content of 20% for fibers with a size of 0.5 × 2 cm (13% increase in tensile strength; 35% increase in compressive strength). Therefore, the amount of added HDPE plastic fibers should be chosen on the basis of the weight of the cement used, as outlined in Table 2. Since all HDPE samples added had the same cross-sectional area of 1 cm^2, therefore, the size largely determined the obtained results, whereby the position of fibers in the concrete can reduce the optimality of the aggregate bond, as seen in Figure 9. The performance of fibers with respect to strength testing was in the order 0.5 × 2 cm > 0.25 × 4 cm > 1 × 1 cm. Thus, the use of HDPE fiber with a size of 0.5 × 2 cm as an additive in the concrete mixture was acceptable.

5. Conclusions

Our study contributes to identify the effect of HDPE fibres addition in terms of size and percentage to concrete qualities. Not only in order to improve its use and exploitation but also to design the concrete mix design process. From the experiments, some important findings are explained as follows:

1) This study evaluated the use of 2.5%, 5%, 10%, and 20% HDPE with fibers sizes of 1 × 1 cm, 0.5 × 2 cm, and 0.25 × 4 cm incorporated into three concrete types (B0, f'c10, and f'c25). It was found that f'c10 MPa concrete performed best in response to the addition of HDPE fibers, whereas 5% was the optimal HDPE content and 0.5 × 2 cm was the optimal size.
2) All variants of HDPE plastic fibers described in this study can be used with f'c10 MPa concrete; however, only 0.5 × 2 cm HDPE fibers should be used with B0 and f'c25 MPa concrete.

Scansionato con CamScanner

Response to Reviewer 3

Point 1: The paper deals with the development of a concrete mix which incorporates as additions recycled HPDE plastic particles. These particles are added in different percentages by volume. Tests on fresh and hardened concrete are performed to determine the optimal percentage and plastic size to be inserted in the mix.The research is interesting and surely very topical, since the great amount of plastic produced every year all over the world. This aspect is well explained in the introduction. Anyway, some observation must be done. The title of the paper, which refers to "plastic fibers", and more in general, the terms "fibres" which is used all over the paper to denote the HDPE plastic particles, is misleading. From the picture shown in Figure 2, the plastic particles added have not the usual shape of fibres. In the text (and this is also confusing) sometimes you refer to these particles as aggregates. As I can understand from the paper they are neither aggregate nor classic fibres. They are plastic additions in the shape of lamellar macro fibres or rather lamellar particles. I think you should use this terms all over the paper. The title of the paper could be modified as: "Effect of recycled HDPE plastic addition on concrete performance".

Thank you for this. We modified the title into "The Effect of Recycled HDPE Plastic Additions on Concrete Performance". We also changed the term of "fiber" in the text into lamellar particles.

So, when you describe the geometry of these lamellar plastic particles, you should also mention their thickness, to justify the term (as an example: in the abstract, line 18: lamellar plastic square or rectangular particles with thickness 0.05 mm and size 10 x 10 mm, 5 x 20 mm, 2.5 x 40 mm). Dimensions in mm are preferable.

We added the thickness dimension in line 87, and justified that all three sizes of HDPE lamellar have the same thickness of 0.05 mm in line 158 – 160.

Point 2: Fiber content. In the paper, there is sometimes a misunderstanding with the terms "composition" and "percentages", which are quite different in the meaning of the research. As I understand in your research, you varied the percentage of fibre content, but not the composition (no chemical analysis is shown). So, please replace this term along the text when it isn't used correctly. And also: you speak about 4 plastic additions but you never specify how these percentages have been valuated. Usually the percentage is calculated by volume – kg/m^3 (volumetric content % with respect to concrete volume), but this is not specified in the text. In Table 4 the quantity of fibres (kg) used for 0.021 m^3 are specified, but the information about HPDE density seems missing, so it is not possible to check how this percentage was computed. Please clarify the meaning of the percentage.

We changed the term "composition" to "percentage" and adjusted the term in the texts accordingly, as what we meant by "composition" is "the percentage addition". Thank you for making this more understandable. The percentage addition of HDPE is based on cement weight as mentioned in line 18 and line 194

Point 3: Concrete class. You speak about three concrete mix, denoted as B0, f'c10, f'c25. As I can understand, this is the notation you used in your experimental campaign, so you can use it only after the meaning of this notation has been defined in the text. So in the abstract, as an example, you should be more general, since when you begin to read, it is not clear what "concrete B0" is. In general, you can refer to the three mixes with "concrete of lower, medium and higher strength". These terms (low and high) should be in any case relative to your experimentation, since a concrete with fc=25 MPa cannot absolutely be considered a high strength concrete.

We modified the abstract by identifying the concrete class as lower, medium and higher, followed by the notation, in line 16 and line 84-86 (materials and methods section).

Point 4: Experimentation on fresh concrete. How do you explain that concretes with different Water content showed the same slump? It's quite strange that mix B0 and mix f'c25 had the same slump. Did you use any superplasticizers? Did you do any test concerning water absorption in the different concrete mix? This could be interesting.

For this manuscript, the analysis based on the results of slump value, unit weight, tensile and compressive test. Unfortunately, we didn't test the water absorption for the different class of concrete mixes here. In job mix design we set the ideal slump value that meet the aspect of economics and workability. The higher the amount of cement used, the more water was used. We didn't use any superplasticizers. Line 177-180.

Point 5: Experimentation on hardened concrete. It is not clear when you did the tests. After 28 days curing? You should also specify the curing condition (temperature, humidity). Did you perform splitting tensile tests on cylindrical specimens? In this case, you should speak about splitting tensile strength. The same for compression: it is cylindrical compressive strength.

The concrete specimens were demolded after 24 hours and keep in water curing tank until the age of testing, at room temperature of 27^{o}C before having them tested on its compressive and tensile strength as mentioned in Table 1. Line 176-178. Yes, what we mean here is splitting tensile and cylindrical compressive test. We added in this manuscript this terms in line 201 (materials and methods) and also in line 318. Thank you very much for this.

Point 6: In the conclusions it should be underlined that to generalise the results and to see an application of this recycled material, more and different tests should be performed, also concerning the chemical analyses of the plastic material or other tests concerning the valuation of physical properties.

Very helpful indeed. We accommodated this by reshaping the conclusion part and added the feedback at point 3 in conclusion part (line 521-524)

Point 7: In any case, you cannot generalise your results and compare them to the behavior of a fiber reinforced concrete, since the materials you tested cannot be assimilated to fiber reinforced concrete. You should re-elaborate section 4.3.

We removed the supporting literature of Dawood et al (2015) https://doi.org/10.1002/suco.201400087 that discussed on reinforced concrete. Thank you.

Some more specific observations (see also the attached file):

We accommodated the feedbacks in the manuscript.

Point 8: Line 16 and line 74-75, 81. Not clear. What is B0? What do you mean for f'c10 MPa or f'c25 MPa? Usually it is better to define concrete strength by using the class. Do you mean concrete of class C25/30? Or please substitute with "concrete with cylindrical strength f'c = 10 MPa. If you refer to a specific symbol adopted in some particular code, refer the notation to the code. One thing is the notation you used to define your mix and your specimens (which you explain in section 2.2.2), one other is the standard notation that everyone can easy understand. In the abstract is better to be more clear and directly refer to the strength value and not to the notation. Or you have to explain.

Thank you for this remarks. We defined the term of B0, f'c 10 MPa and f'c 25 MPa in abstract (line 15) and in materials and methods (line 84-87) .

Point 9: Line 17. The sentence "HDPE additive treatments with compositions of 2.5%, 5%, 10%, and 20% were combined with plastic fibers sizes…". is absolutely not clear. What do you mean for "compositions of 2.5%, 5%, 10%, and 20%". What is this percentage referred to? Perhaps you intended: HDPE plastic was added in percentages of 2.5%, 5%, 10%, and 20% by concrete volume? Please reformulate this sentence.

Indeed, what we mean is the addition of HDPE lamellar at the percentage of 2.5%, 5%, 10%, and 20% from cement weight (line 19 and line 194).

Point 10: - Line 83. Why now do you speak about plastic aggregate? This is confusing. Did you also add plastic aggregate? Which was the maximum diameter? Did they have all the same diameter or it was different? In the following I don't think you also added plastic aggregate, so this sentence is misunderstanding.

We modified the sentences into " ………… were added to the mixtures to examine their effect on concrete properties" (Line 88)

Point 11: - Line 176: what do you mean "…concrete tests were performed 28 days before use…"???? Usually concrete tests are performed 28 days after casting. I don't know the meaning of your sentence. Please verify.

What we meant is 28 days after casting. We modified the sentences in line 176. Apologies for our English issue.

Point 12: - Line 177 – Table 3. If B0, f'c10 and f'c25 are the name you adopted for your concrete batch, don't add MPa after the name of the batch. The first two rows are not clear. I think here you should only indicate the targeted average compressive strength you want to obtain for each batch. Is this a 28 days - concrete cylindrical compressive strength? What is now f'cr? In the table substitute the "Cement water factor" with the term water/cement ratio. 0.95 is in any case a very high ratio. How do you explain that concretes with different water content have the same slump? Quite strange, you should mention and justify this in the text. In Table 3, you indicate "fine aggregate content (36%)" and "coarse aggregate content" (64%). This seems to be correct for concrete batch f'c25, but this proportion cannot be verified for batch B0 and f'c10. Are the values in Table 3 correct? Are the values referred to $1m^3$? Because if you have less water you should have more aggregates. Please verify. What do you mean for "combined aggregate content"?

Thank you again. We removed the unnecessary information in the Table 3 to avoid misunderstanding. We used that number as a "range" for acceptable combination for the mix design. It doesn't necessarily affect the number that mention in concrete job mix as seen in Table 3.

Point 13: - Line 180 – where do you define the four HDPE fibers compositions? I understand that 3 "fiber" geometries were adopted (1x1, 0.5x1, 0.25x4) with the same thickness of 0.05, but I thought that the composition was the same (HPDE plastic). Perhaps you meant four HDPE fiber percentages? For "various aggregate particle sizes used" do you mean the natural fine and coarse aggregate reported in Fig.1?

Line 185-186. We modified the sentence of "….various aggregate particle sizes used" into "…. and various aggregate particles used for the mixtures as described in Figure 1". We change the term of compositions into "percentages", as that is actually we meant here. We apologies for this misunderstanding.

Point 14: - Line 234 – please substitute the term "composition" with the term "percentage".

We changed in the manuscript accordingly.

Point 15: - Line 267 – Sometimes you refer to your batch with the notation f'10 or f'c10 or fc10 or f'cr10 (and the same with 25). Please decide only one notation and use always the same.

We modified the different notations into B0, f'c 10 and f'c 25.

ROUND 2

Reviewer 1

English language and style
( ) Extensive editing of English language and style required
( ) Moderate English changes required
(x) English language and style are fine/minor spell check required
( ) I don't feel qualified to judge about the English language and style

	Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	( )	(x)	( )	( )
Is the research design appropriate?	( )	(x)	( )	( )
Are the methods adequately described?	( )	(x)	( )	( )
Are the results clearly presented?	( )	(x)	( )	( )
Are the conclusions supported by the results?	( )	(x)	( )	( )

Comments and Suggestions for Authors

can be accepted

Submission Date
17 October 2020
Date of this review
28 Nov 2020 10:17:02

Respons to Reviewer 1

Dear reviewer,

First and foremost, allow us to express our gratitude for your constructive feedback regarding our work. Your comments were very helpful and have enabled us to improve the quality of our manuscript. Thank you very much for this opportunity. We hope it meets your expectations and achieves the required standard for publishing.

Kind regards,

Tamrin

Reviewer 2

English language and style

( ) Extensive editing of English language and style required
(x) Moderate English changes required
( ) English language and style are fine/minor spell check required
( ) I don't feel qualified to judge about the English language and style

	Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	( )	( )	(x)	( )
Is the research design appropriate?	(x)	( )	( )	( )
Are the methods adequately described?	( )	(x)	( )	( )
Are the results clearly presented?	( )	( )	(x)	( )
Are the conclusions supported by the results?	( )	(x)	( )	( )

Comments and Suggestions for Authors

I very much regret but I cannot see any significant improvement and any merit to this ms. Still I believe it looks more like a good techical report rather than a scientific paper. Please see some responses attached.

peer-review-9709644.v1.pdf
Submission Date
17 October 2020
Date of this review
02 Dec 2020 13:50:41

attached file

Point 1 The Introduction has not been improved significantly. It contains many generalities, it does not describe the problem statement and does not provide a good, relevant literature review. This is a comment which has never been addressed. The readers have to know in the introduction what the current situation is, with regards to the use of plastic aggregates in concrete, what the-state-of-the-art is and what the problem they wish to solve is. Thank you for this remark.

We actually modified the introduction in our last submission. It started by addressing the plastic problems in general, i.e., number and low recycling rate (paragraph 1 and 2) that leads to the need for another perspective on plastic as used by waste and construction sector (paragraph 3). This was then narrowed down to the Indonesian problem of plastics and why we selected HDPE (paragraph 4). Paragraph 5 mentions the literature review of the use of plastics for construction and research gap. In this version, we add more literature. We conclude in paragraph 6 about the objective of our study and have reshaped paragraph 6 to make it more clear.

Exactly! Paragraphs 1 and 2 contain generalities about plastics that everyone knows. Paragraph 3 is generally out of context mentioning generalities about recycling and some applications, which are not related to constructions like your paper. However, it can be marginally accepted. Paragraph 5 has been benefited from the new additions however still the readers do not know what the fundamental results of using plastics as aggregates are. You only state that this author used this and the other author used that! Nothing else. Paragraph 6 just now better presents the aim of the paper.

Point 3 The authors improved the section of materials and methods. However, still we do not know the type of material, which is used as aggregate. If the type of aggregate is not important then why do the authors have one chapter for its description, and they provide densities and resistance to abrasion? How does this information help the manuscript? Where is it used? Still I cannot understand why the values of the tests (density, tensile and compressive strengths) are not provided. Not even as ranges with std in each concrete category.

The term “aggregate” refers to any particulate materials, including sand, gravel, crushed stone and blast-furnace slag to produce concrete or hydraulic cement mortar (SNI 2847:2013). Coarse aggregates refer to any particulates that are greater than 4.75 mm, while fine aggregates are usually sand or crushed stone less than 9.55 mm. As it contains a broad category of coarse materials used as an inert filler in concrete, we based our category to follow ASTM C33. Therefore, in this manuscript, we maintain the use of the term fine and coarse aggregate. We added this information in line 106-108. The aggregates themselves meet the standard for aggregate conditions, for example, abrasion to test the ability of the aggregate when bonded with other materials. We used ASTM C131/C131M-

20 as the basis of the minimum abrasion requirements for the aggregate. The value of allowable range for the size of coarse and fine aggregates is presented in Table 1. In section 2.1.2, as a preparation phase, we carried out a sieve analysis to identify the acceptable range for fine and coarse aggregates to be used in concrete mixes. The value of unit weight, tensile and compressive strength are presented in section 3, based on the analysis of concrete specimens at 28 days after casting. The composition of experimental conditions is presented in Table 4. Of the 156 specimens and based on our experimental design, we took two samples for each type of design. Therefore, we used "mean value" instead of std in determining the value.

Dear Authors thank you very much. I know very well what aggregates are! However, I am afraid that maybe you miss that traditional aggregates may be several different types of stones (sand, gravels, etc.). Although few people believe that the type of aggregate is not an important factor, this is not true and certain aggregates can or cannot create bonds with the cement and the added recycled aggregates. That is why it is important to know the type of the aggregate. Why do you provide all the rest properties (density etc) and not simply the name of the aggregate?

I am sorry but I cannot see any table providing the actual data from your test. The readers need to know the actual numbers and how much the replicate tests differ from each other. As you have adopted standards for your ms why don't you adopt ASTM, which require testing of 6 specimens from each sample and taking the average? Standard deviation would provide the info for the spread of your data from the average and hence their reliability. However, still two measurements in each sample can be accepted but again we need to know how large their differences are. But you fail to provide a table with the original data.

I my view, you confuse the terms experiment and test. Table 4 (and elsewhere) shows neither experimental data or testing nor test data. These are merely the amounts used for the preparation of the concrete samples. Measurement of density, porosity, strength etc. are tests.

Point 4 It is very unclear what the originality and the contribution of this paper is. The authors frankly mention that all their "findings" have already been studied and 2 described by other authors. Hence, they fail to highlight the significance and the novelty of this study.

We believe that novelty is something any new findings that can contribute to the wide range of discussion in HDPE plastic uses. We based our study on previous literature that had discussed how plastics have been already used in concrete and could increase the tensile and compressive strength at certain percentage. What we do here recognize the idea that certain amounts of plastic could increase concrete properties. However, we have investigated difference aspects compared with previous research. The difference is in terms of size of HDPE lamellar used; the percentage of addition (not as substitute) that we based on weight of cements, instead of aggregate volume; and, the class of concrete (lower, medium and higher concrete) aimed for non-structural applications.

I agree. Therefore, you should have discussed these details we know from other researchers in the Introduction (to introduce us to the problem you are investigating) and in your text (not here to me) to show the novel aspects of your paper.

Point 5 The Discussion section has been revised, however now it is just a repeat of the results! No scientific evidence, no interpretations, no robust discussion!

We offer apologies, but we tried to connect the previous studies with our interpretation of the findings. However, to make it more rigid, we add explanation in discussion section. Thank you for this remark.

I am sorry but what you mention above is not discussion in a scientific paper. I regret to say that the few new additions have hardly improved the situation. These are mostly like literature review. In a discussion section someone expects to read explanations. Here is the place to highlight your novelty, but you don't.

Point 7 Lines 95-99: These components sum up to less than 100%. What is the rest?

We provide the explanation in line 104. The additional 5 wt.% to cement chemical compounds. It is unusual if materials in cement compounds can be clearly defined, as minor components do vary.

I disagree. What do you mean? You have a secret recipe and secrete compounds? The statement "other minor compounds" is even worse.

Point 8 Line 102: What physical characteristics? What did you measure? Nothing is provided. What is the material used?

As presented in Table 2, the physical characteristics here refer to specific gravity of the aggregates (ASTM C-127), the grading of the aggregates (ASTM C33-99a), unit weight (ASTM C29/C29M-07) and also the abrasion (ASTM C131/C131M-20).

Exactly! The characteristics of the aggregates and NOT the characteristics of the concrete and the legend states!

Point 9 Why is it so difficult to mention if it is limestone, sandstone or any other material?

As we mentioned in point 3, we follow the standard in categorizing the aggregate. Considering the wide range of particulates, we refer to aggregate as coarse and fine aggregate based on a grading test of sieve size (ASTM C-33-99a). However, the quality of the aggregate depends on the location of aggregate sources. Therefore, we add the information of location, In our case, this is Palu, Sulawesi; widely known in Indonesia as a location for producing good aggregate quality for concrete mixes. Line 106-108.

I think you do not know the material and you just try to escape from the question. I think my question is very clear and I have explained above why knowledge of the material is important. FYI your aggregate is most probably an andesite and there is a possibility to be prone to alkali-silica reaction effects.

Point 13 Line 157: Are you sure it is 0.05 mm? In the figures they do not look so laminated. Probably you mean cm?

As we mentioned in line 159-160 and Figure 2 (a) the lamellar thickness is 0.05 mm. We removed the part from HDPE bottle with the thickness lower or higher than 0.05 mm.

Please not that 0.05 mm is thiner than one sheet of a regular A4 paper! Are you sure? The images do not show so thin plastic lamellae

Respons to Reviewer 2

Dear respected reviewer,

First and foremost, allow us to express our gratitude for your constructive feedback regarding our work. We appreciate your involvement and thank you for this opportunity. We have learned a lot from this reviewing process. We have particularly valued and appreciated your different perspective. Your attention to detail and direct comments were very helpful and have enabled us to improve the quality of our manuscript. We have responded in green font in this letter showing how we have accommodated your inputs in the manuscript. We hope this time it meets with your expectations and achieves the required standard for publishing. Please find our response below.

Kind regards,
Tamrin Rahman

Point 1 The Introduction has not been improved significantly. It contains many generalities, it does not describe the problem statement and does not provide a good, relevant literature review. This is a comment which has never been addressed. The readers have to know in the introduction what the current situation is, with regards to the use of plastic aggregates in concrete, what the-state-of-theart is and what the problem they wish to solve is. Thank you for this remark.
We actually modified the introduction in our last submission. It started by addressing the plastic problems in general, i.e., number and low recycling rate (paragraph 1 and 2) that leads to the need for another perspective on plastic as used by waste and construction sector (paragraph 3). This was then narrowed down to the Indonesian problem of plastics and why we selected HDPE (paragraph 4). Paragraph 5 mentions the literature review of the use of plastics for construction and research gap. In this version, we add more literature. We conclude in paragraph 6 about the objective of our study and have reshaped paragraph 6 to make it more clear.
Exactly! Paragraphs 1 and 2 contain generalities about plastics that everyone knows. Paragraph 3 is generally out of context mentioning generalities about recycling and some applications, which are not related to constructions like your paper. However, it can be marginally accepted. Paragraph 5 has been benefited from the new additions however still the readers do not know what the fundamental results of using plastics as aggregates are. You only state that this author used this and the other author used that! Nothing else. Paragraph 6 just now better presents the aim of the paper.
Dear reviewer. Thank you for this comment. We have restructured the introduction into five paragraphs. Paragraph 1 describes the problem of plastic in general and for Indonesia. Paragraph 2 covers the need for waste management in other sectors, e.g., construction, using a circular perspective. Paragraph 3 discusses the benefit of plastic addition in concrete focusing on HDPE, instead of PET, and considers previous literature investigating the use of HDPE in concrete. Paragraph 5 concludes how this paper has contributed to the literature discussion.

Point 3 The authors improved the section of materials and methods. However, still we do not know the type of material, which is used as aggregate. If the type of aggregate is not important then why do the authors have one chapter for its description, and they provide densities and resistance to abrasion? How does this information help the manuscript? Where is it used? Still I cannot understand why the values of the tests (density, tensile and compressive strengths) are not provided. Not even as ranges with std in each concrete category.
The term of “aggregate” refers to any particulate materials, including sand, gravel, crushed stone and blast-furnace slag to produce concrete or hydraulic cement mortar (SNI 2847:2013). Coarse aggregates refer to any particulates that are greater than 4.75 mm, while fine aggregates are usually

sand or crushed stone less than 9.55 mm. As it contains a broad category of coarse materials used as an inert filler in concrete, we based our category to follow ASTM C33. Therefore, in this manuscript, we maintain the use of the term fine and coarse aggregate. We added this information in line 106-108. The aggregates themselves meet the standard for aggregate conditions, for example, abrasion to test the ability of the aggregate when bonded with other materials. We used ASTM C131/C131M20 as the basis of the minimum abrasion requirements for the aggregate. The value of allowable range for the size of coarse and fine aggregates is presented in Table 1. In section 2.1.2, as a preparation phase, we carried out a sieve analysis to identify the acceptable range for fine and coarse aggregates to be used in concrete mixes. The value of unit weight, tensile and compressive strength are presented in section 3, based on the analysis of concrete specimens at 28 days after casting. The composition of experimental conditions is presented in Table 4. Of the 156 specimens and based on our experimental design, we took two samples for each type of design. Therefore, we used

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We really appreciate this explanation. We only use sand and crushed stone from Palu, Central Sulawesi, which is widely known for its quality and physical characteristics. Palu's aggregates are considered basalt, which are widely used for lightweight building walls and concrete in Indonesia. Its physical characteristics and quality provided adequate consolidation in concrete mixes, and offers higher resistance to alkali-silica reaction, compared to other aggregates obtained from areas in East Kalimantan. We add this information in Line 128-134.

I am sorry but I cannot see any table providing the actual data from your test. The readers need to know the actual numbers and how much the replicate tests differ from each other. As you have adopted standards for your ms why don t you adopt ASTM, which require testing of 6 specimens from each sample and taking the average? Standard deviation would provide the info for the spread of your data from the average and hence their reliability. However, still two measurements in each sample can be accepted but again we need to know how large their differences are. But you fail to provide a table with the original data. I my view, you confuse the terms experiment and test. Table 4 (and elsewhere) shows neither experimental data or testing nor test data. These are merely the amounts used for the preparation of the concrete samples. Measurement of density, porosity, strength etc. are tests.

Thank you for this remark. What we meant to show in Table 4 was our design experiment for the specimens. We have changed the legend and the wording. We also include raw data in tabular presentation as appendix 1, and mentioned it in Line 345.

Point 4 It is very unclear what the originality and the contribution of this paper is. The authors frankly Hence, they fail to highlight the significance and the novelty of this study.

We believe that novelty is something any new findings that can contribute to the wide range of discussion in HDPE plastic uses. We based our study on previous literature that had discussed how plastics have been already used in concrete and could increase the tensile and compressive strength at certain percentage. What we do here recognize the idea that certain amounts of plastic could increase concrete properties. However, we have investigated difference aspects compared with previous research. The difference is in terms of size of HDPE lamellar used; the percentage of addition (not as substitute) that we based on weight of cements, instead of aggregate volume; and, the class of concrete (lower, medium and higher concrete) aimed for non-structural applications.

I agree. Therefore, you should have discussed these details we know from other researchers in the Introduction (to introduce us to the problem you are investigating) and in your text (not here to me)

to show the novel aspects of your paper.
We are thankful for this. We have restructured the Discussion part accordingly.

Point 5 The Discussion section has been revised, however now it is just a repeat of the results! No scientific evidence, no interpretations, no robust discussion!
We offer apologies, but we tried to connect the previous studies with our interpretation of the findings. However, to make it more rigid, we add explanation in discussion section. Thank you for this remark.
I am sorry but what you mention above is not discussion in a scientific paper. I regret to say that the few new additions have hardly improved the situation. These are mostly like literature review. In a discussion section someone expects to read explanations. Here is the place to highlight your novelty, but you dont.
We truly appreciate your feedback here. Therefore, we try to address this issue by adding some information in this section.

Point 7 Lines 95-99: These components sum up to less than 100%. What is the rest?
We provide the explanation in line 104. The additional 5 wt.% to cement chemical compounds. It is unusual if materials in cement compounds can be clearly defined, as minor components do vary.
I disagree. What do you mean? You have a secret recipe and secrete compounds? The statement other minor compounds is even worse.
We apologise for this. We did not give it our full attention and, as is common practice, we focused on major components. Thank you for this learnt. We provide information for some minor components of the cement composition in line 121-123, though we do not mention the exact percentage of them.

Point 8 Line 102: What physical characteristics? What did you measure? Nothing is provided. What is the material used?
As presented in Table 2, the physical characteristics here refer to specific gravity of the aggregates (ASTM C-127), the grading of the aggregates (ASTM C33-99a), unit weight (ASTM C29/C29M-07) and also the abrasion (ASTM C131/C131M-20).
Exactly! The characteristics of the aggregates and NOT the characteristics of the concrete and the legend states!
We have modified the legend in Table 2 to clarify the physical properties of cement and aggregate used in concrete mixture. Thank you.

Point 9 Why is it so difficult to mention if it is limestone, sandstone or any other material?
As we mentioned in point 3, we follow the standard in categorizing the aggregate. Considering the wide range of particulates, we refer to aggregate as coarse and fine aggregate based on a grading test of sieve size (ASTM C-33-99a). However, the quality of the aggregate depends on the location of aggregate sources. Therefore, we add the information of location, In our case, this is Palu, Sulawesi; widely known in Indonesia as a location for producing good aggregate quality for concrete mixes. Line 106-108.
I think you do not know the material and you just try to escape from the question. I think my question is very clear and I have explained above why knowledge of the material is important. FYI your aggregate is most probably an andesite and there is a possibility to be prone to alkali-silica reaction effects.
We appreciate your thought here. As mentioned in Line 128-134 earlier, we only use sand and crushed stone from Palu, Central Sulawesi. Palu's is known as basalt, which in crushed form it can be used as aggregate. What we measure is its sieve size/grading that has to be within the allowable range following ASTM C-33-99a. Also, Palu's is locally known as type of aggregate that is more resistant to the alkali silica reaction.

Point 13 Line 157: Are you sure it is 0.05 mm? In the figures they do not look so laminated. Probably you mean cm?

As we mentioned in line 159-160 and Figure 2 (a) the lamellar thickness is 0.05 mm. We removed the part from HDPE bottle with the thickness lower or higher than 0.05 mm.

Please not that 0.05 mm is thiner than one sheet of a regular A4 paper! Are you sure? The images do not show so thin plastic lamellae

Again , we are really grateful for all your comments helping us improve the quality of this paper. You have drawn attention to details which, in most cases, we missed. After checking our very first submission, we realised that we changed the unit from cm to mm without converting it. This mistake has endured through each submission and we have overlooked this. We have changed the thickness in the manuscript from 0.05 to 0.5 mm accordingly.

Reviewer 3

English language and style

( ) Extensive editing of English language and style required
(x) Moderate English changes required
( ) English language and style are fine/minor spell check required
( ) I don't feel qualified to judge about the English language and style

	Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	(x)	( )	( )	( )
Is the research design appropriate?	(x)	( )	( )	( )
Are the methods adequately described?	(x)	( )	( )	( )
Are the results clearly presented?	(x)	( )	( )	( )
Are the conclusions supported by the results?	(x)	( )	( )	( )

Comments and Suggestions for Authors

The paper was deeply revised and is now presented in an accetable form. However, some minor corrections still have to be done, mainly concerning the abstract writing and the English form throughout the text.

I think that, even if the scientific content is surely not high, the paper was improved and it is now clear and readable. In anycase, it represents a contribution in the field of the development of innovative materials, trying to give a solution for the recycling of plastic waste. For future work, I advise to increase the number of specimens for each batch, above all for the evaluation of mechanical properties, since only 2 specimens are very few to provide a statistical interpretations of results.

In the attached file I suggested some revisions which should be done before accepting it for publication in Recycling.

peer-review-9709646.v1.pdf
Submission Date
17 October 2020
Date of this review
04 Dec 2020 11:56:06

attached file

recycling MDPI

Article

The Effect of Recycled HDPE Plastic Additions on Concrete Performance

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Abstract: This study examined HDPE (high-density polyethylene) plastic waste as an added material for concrete mixtures. The selection of HDPE was based on its increased strength, hardness, and resistance to high temperatures compared with other plastics. It focused on how HDPE plastic can be used as an additive in concrete to increase its tensile strength and compressive strength. 156 specimens were used to identify the effect of adding different percentages and sizes of HDPE lamellar to lower, medium and higher strength concrete - symbolized as B0, Fc10 MPa and Fc25 MPa. HDPE lamellar 0.05mm thick particles at sizes of 10 × 10 mm, 5 × 20 mm and 2.5 × 40 mm were added at 2.5%, 5%, 10% and 20% of the cement weight used. The results showed that the medium concrete class (Fc10 MPa) had the best response to the addition of HDPE. The 5% HDPE lamellar particles addition represented the optimal mix for all concrete types, while the 5 × 20 mm size was best.

Keywords: concrete additive; concrete mixture; plastic waste; HDPE; lamellar particles; plastic lamellar

1. Introduction

Plastic has long been considered a manmade material with many benefits. It has lightweight properties and is easily shaped to the designer's desires. Its versatile properties have led to its widespread use. Since 2016-17 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 and the environmental pollution caused, because many plastics are not biodegradable and can take between 500 and 1,000 years to decompose [2]. The pollution risks from the toxins released can impact groundwater quality, animal/human health, food-chain poisoning and reduction in soil fertility [3]. Furthermore, if burnt in open space, plastics produce carbon monoxide (a greenhouse gas). If disposed of in waterways, plastics can cause siltation and impede water flows, thereby creating a flood risk [4,5].

Research on beaches have shown that coastline plastic waste in 192 countries in 2010 amounted to between 4.8 and 12.7 million metric tons [6]. This waste threatens marine organisms [7] and has led to many demands to restrict plastic use and reshape behavior at the consumer level [8]. Recycling offers a partial solution. By 2050, it is projected that about 12 billion metric tons of plastic litter will end up in landfills and the natural environment [9]. The insufficient processing and management of plastic waste worldwide faces the challenge of insufficient plastic waste treatment facilities at all stages of collection, separation and disposal.

Recycling rates have increased in developed countries since 2006 and by 2018, processing plastic waste for energy used 43% of all of the collected post-consumer waste stream [1]. Recycling plastic waste starts with sorting it into several polymer types, followed by cleaning, scraping, smelting and converting it into pellets to be repurposed into plastic bags, plastic containers, carpets, jacket insulation and other materials. Traditional recycling suffers from cross-contamination and requires high energy consumption [10]. Low-carbon reusable materials are considered suitable alternatives to the disposal of single-use plastics, e.g., PET (polyethylene terephthalate) and HDPE (high-density polyethylene) [11]. The identification of a relevant local strategy for waste (including plastics) and the tailoring of partnerships to suit various stakeholders (i.e., businesses, industries, and civil society) are necessary [12,13]. Therefore, building a nexus between the waste and construction sectors emerges as a possible option for increasing plastic circularity, especially macro-plastics, which are in widespread use [14]. The additional value to be obtained from their use as an additive in concrete mixtures could also create new business opportunities [15].

Indonesia's plastic stream is the second largest waste product after organic waste, reaching 17% in 2018 [16]. This study examines the potential use of HDPE plastics by applying HDPE lamellar as an additive for concrete mixtures to reduce its waste disposal impacting soil and water resources. The advantages of using plastics in concrete are they are lightweight, better resistance to weather and high temperatures than PET (melting at 130–135 °C), waterproof in nature [17] and confer thermal insulation properties [10,15,18].

Concrete has properties that are sensitive to the type of added materials that are beyond those specified in the traditional job mix design. The strength of concrete depends on the type and size of the aggregates used [19,20,21] and different additive materials produce variations in tensile strength and compressive strength [22–25]. The final application from plastic additions to concrete as examined in this study is expected to be for non-structural projects, such as: wall panels, parking lots or paths [26,27,28]. Even plastic fibers can be used below the concrete layer in constructing rigid pavements. Merli et al. [29] identified that HDPE is less discussed in the literature compared to PET. This motivated our interest and focus on HDPE. Pesic et al. [30] investigated the effect recycled HDPE fibers had for reinforced concrete for structural uses by using two different fiber diameters (0.25 mm and 0.4 mm) with 0.40%, 0.75% and 1.25% volume fiber fraction. Neslyn et al. [31] also considered using recycled HDPE for non-structural uses as a partial replacement of coarse aggregate in mixes of 10%, 20% and 30%.

Unlike previous studies, our study assesses the effect of HDPE lamellar on different concrete classes. We assess various HDPE lamellar sizes and percentages as lightweight admixtures into different concrete mixes used for non-structural works, but not as a replacement to cement or other materials. This paper is structured as follows: section 1 is an introduction providing the background and aim of this study. It is followed by a description of materials and methods in section 2. The results of the tests are provided in section 3 and discussed in section 4. Conclusions and recommendations for future research are presented in section 5.

2. Materials and Methods

This study used concrete mixes formed from cement and aggregate (fine and coarse aggregate). These are designed to fall into three concrete classes: lower, medium, and higher concrete strength. Lower concrete strength is named as B0 and is concrete with cylindrical strength of f'c = 10 MPa. Medium and a higher concrete strength refers to cylindrical strength of f'c = 25 MPa. Three different sizes of HDPE lamellar (10 × 10 mm, 5 × 20 mm, and 2.5 × 40 mm) with the same thickness of 0.05 mm were added to the mixtures to examine their effect on concrete properties. The ACI (American Concrete Institute) and ASTM (American Society for Testing and Materials) testing standards were used to calculate specific gravity, slump value, unit weight, and tensile and compressive strength. Table 1 provides a summary of the standard testing used in this research.

Table 1. The standards used for concrete testing.

Standard	Targeted testing
ASTM C-127	Specific gravity of coarse aggregate
ASTM C33-99a	Adequate grading requirement and aggregate quality; sieve analysis

ASTM C29/C29M-07	Unit weight for fine and coarse aggregate
ASTM C131/C131M-20	Resistance to degradation by abrasion on small-size coarse aggregate
ACI 211.1-91	Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
ASTM C143	Slump test
ASTM C39	Compressive strength
ASTM C496	**Tensile strength**

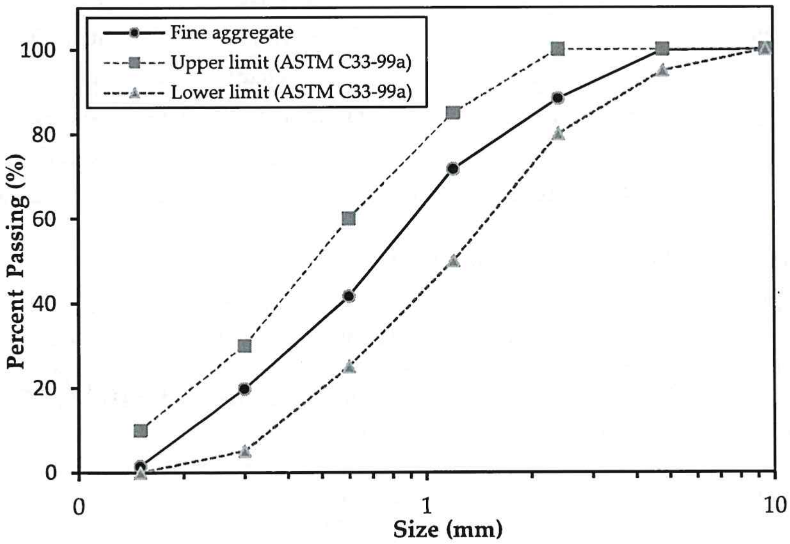
2.1. Materials

2.1.1. Cement

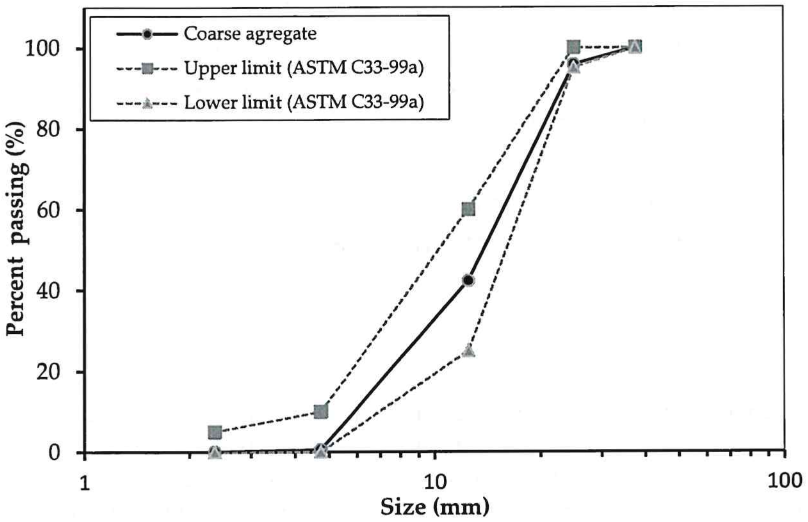
As this study's scope involved non-structural applications, the examination used cement type 1, which is intended for walls, pavement, sidewalks and other precast products. Using the ASTM C-127 standard, this cement material was found to have a specific gravity of 3.18 g/cm³, which falls in the acceptable range of 3.1–3.3 g/cm³. This cement composition comprises five chemical compounds, i.e., tricalcium silicate ($3CaO{\cdot}SiO_2$), shortened to C_3S (55 wt.%), dicalcium silicate ($2CaO{\cdot}SiO_2$), abbreviated to C_2S (17 wt.%), tricalcium aluminate ($3CaO{\cdot}Al_2O_3$), shortened to C_3A (10 wt.%), tetracalcium aluminoferrite ($4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$), shortened to C_4AF (7 wt.%), carbon disulphide (CS_2) (6 wt.%), and other minor compounds (5 wt.%).

2.1.2. The aggregates

The aggregates refer to any particulates using as an inert filler in concrete. These vary from sand, gravel, crushed stone to blast-furnace slag. Following ASTM C33, the aggregates are categorized into fine and coarse aggregate. This study used these aggregates collected from Palu, Central Sulawesi, Indonesia. The physical characteristics and quality of these aggregates provided adequate consolidation in concrete mixes, compared to other aggregates obtained from areas in East Kalimantan. The aggregates were tested in the Laboratory of the Faculty of Engineering, Mulawarman University, Samarinda. This followed the ASTM C33-99a standard [32] for sieve analysis, which defines the adequate grading requirement and aggregate quality in concrete. The results of this test for fine and coarse aggregate are shown in Figure 1.



(a)



(b)

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

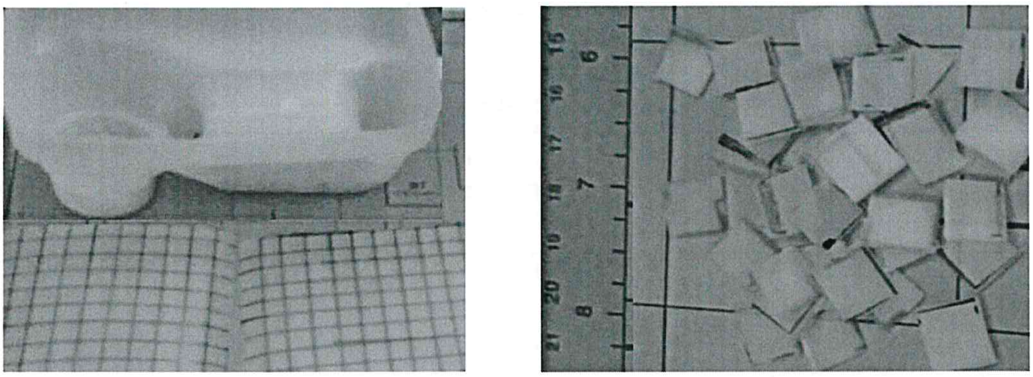
The unit weight testing of fine and coarse aggregates was conducted using the ASTM C29/C29M-07 standard [33]. It obtained results of 2.55 g/cm³ for the coarse aggregate and 2.54 g/cm³ for the fine aggregate, meeting the standard requirement of 2.5–2.7 g/cm³. The test for coarse aggregate abrasion was conducted using the ASTM C131/C131M-20 standard [34] and obtained a result of 23%. This value was lower than the 27% ASTM limit. Table 2 provides the detailed physical properties of the concrete.

Table 2. Physical properties of the concrete.

Materials	**Properties**	**Value**	**Allowable range**
Cement type 1	Specific gravity	3.18 g/cm³	3.1–3.3 g/cm³
Fine Aggregate	Sieve size	Figure 1(a)	Following ASTM C33-99a
	Unit weight	2.54 g/cm³	2.5–2.7 g/cm³
Coarse Aggregate	Sieve size	Figure 1(b)	Following ASTM C33-99a
	Unit weight	2.55 g/cm³	2.5–2.7 g/cm³
	Resistance to abrasion	**23%**	**Maximum of 27%**

2.1.3. Specimen Preparation of HDPE Lamellar Particles

The HDPE plastic materials were collected from wastes disposed of in Samarinda landfills to reflect potential future plans to reduce non-sustainable waste that contaminate waterways and aquifers. They were rinsed in preparation for the cutting process. Figure 2(a) shows the production of lamellar particles and how we ensured a similar thickness for all lamellar. We implemented a cutting procedure using markings determined as a function of the pattern and size. First, a selection of HDPE plastic samples 0.05 mm thick were cut into lamellar particles before adding to the concrete mixture, excluding any thicker or less than 0.05 mm. This process produced three sizes, namely, 10 × 10 mm, 5 × 20 mm, and 2.5 × 40 mm, each with an identical surface area of 1 cm². This ensure commonality of interaction between the plastic addition and cement in any change in properties of concrete mixture and the bonding effect. Figure 2(b) shows an example of HDPE lamellar particles with a size of 10 × 10 mm at a similar thickness of 0.05 mm after the cutting process.



(a) **(b)**

Figure 2. The preparation of high-density polyethylene (HDPE) plastic lamellar: **(a)** marking procedure for the cutting process; **(b)** examples of HDPE lamellar with a size of 10 × 10 mm.

2.2. Concrete Preparation and Testing

2.2.1. Job Mix Design

The concrete mix designs and the material composition of the three concrete types are shown in Table 3. The process of identifying the right proportion of concrete mixture complied with the standard practice for selecting proportions for normal, heavyweight, and mass Concrete (ACI 211.1-91) [35]. Therefore, concrete strength tests were performed 28 days after casting to ensure that the resultant properties satisfied quality control designs. The concrete specimens were demolded after 24 hours and kept in a water curing tank until the age of testing at a room temperature of 27°C. We defined the slump value of the mixture for the three different concrete class at the same range so it met cost efficiency and workability in the field. To meet this value, we set w/c ratio at different levels, according to the water to cement ratio used.

Table 3. Concrete job mix design.

Description	B0	f'c10	f'c25
Targeted average compressive strength of the concrete	7 MPa	10 MPa	25 MPa
Water to cement ratio	0.95	0.63	0.52
Slump value	120 ± 5 mm	120 ± 5 mm	120 ± 5 mm
Amount of water	180 kg/m³	190 kg/m³	215 kg/m³
Amount of cement	190 kg/m³	295 kg/m³	413 kg/m³
Fine aggregate content	969 kg/m³	828 kg/m³	687 kg/m³
Coarse aggregate content	1010 kg/m³	1014 kg/m³	1220 kg/m³

2.2.2. Mixing Process

Table 4 shows the design experiments for the three concrete types, four different percentages of HDPE lamellar additions, lamellar particle sizes, and various aggregate particles used for the mixtures as described in Figure 1. The process started by mixing the different cement types and aggregates under dry conditions for a few minutes before adding water. The lamellar particles were then added to each concrete type according to their size categories (10 × 10 mm; 5 × 20 mm; 2.5 × 40 mm) until the concrete mixture became homogeneous.

The terms used are as follows: B0 refers to normal concrete meeting the standard job mix design without the addition of HDPE lamellar, while B0-HDPE 2.5% refers to B0 concrete with the addition of 2.5% HDPE. The amount of HDPE lamellar particles for the experimental test is calculated on the basis of the weight of the cement used.

Table 4. Experimental testing of specimens used.

Experimental Condition	Volume of Concrete (m^3)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (kg)	HDPE lamellar (kg)	Number of specimens	
							Compressive strength	Tensile strength
B0	0.021	4.03	20.54	21.41	3.82	0	2	2
B0-HDPE 2.5%								
10 × 10 mm	0.021	4.03	20.54	21.41	3.82	0.10	2	2
5 × 20 mm	0.021	4.03	20.54	21.41	3.82	0.10	2	2
2.5 × 40 mm	0.021	4.03	20.54	21.41	3.82	0.10	2	2
B0-HDPE 5%								
10 × 10 mm	0.021	4.03	20.54	21.41	3.82	0.20	2	2
5 × 20 mm	0.021	4.03	20.54	21.41	3.82	0.20	2	2
2.5 × 40 mm	0.021	4.03	20.54	21.41	3.82	0.20	2	2
B0-HDPE 10%								
10 × 10 mm	0.021	4.03	20.54	21.41	3.82	0.40	2	2
5 × 20 mm	0.021	4.03	20.54	21.41	3.82	0.40	2	2
2.5 × 40 mm	0.021	4.03	20.54	21.41	3.82	0.40	2	2
B0-HDPE 20%								
10 × 10 mm	0.021	4.03	20.54	21.41	3.82	0.81	2	2
5 × 20 mm	0.021	4.03	20.54	21.41	3.82	0.81	2	2
2.5 × 40 mm	0.021	4.03	20.54	21.41	3.82	0.81	2	2
f'c10	0.021	6.25	17.55	21.49	4.03	0	2	2
f'c10-HDPE 2.5%								
10 × 10 mm	0.021	6.25	17.55	21.49	4.03	0.16	2	2
5 × 20 mm	0.021	6.25	17.55	21.49	4.03	0.16	2	2
2.5 × 40 mm	0.021	6.25	17.55	21.49	4.03	0.16	2	2
f'c10-HDPE 5%								
10 × 10 mm	0.021	6.25	17.55	21.49	4.03	0.31	2	2
5 × 20 mm	0.021	6.25	17.55	21.49	4.03	0.31	2	2
2.5 × 40 mm	0.021	6.25	17.55	21.49	4.03	0.31	2	2
f'c10-HDPE 10%								
10 × 10 mm	0.021	6.25	17.55	21.49	4.03	0.63	2	2
5 × 20 mm	0.021	6.25	17.55	21.49	4.03	0.63	2	2
2.5 × 40 mm	0.021	6.25	17.55	21.49	4.03	0.63	2	2
f'c10-HDPE 20%								
10 × 10 mm	0.021	6.25	17.55	21.49	4.03	1.25	2	2
5 × 20 mm	0.021	6.25	17.55	21.49	4.03	1.25	2	2
2.5 × 40 mm	0.021	6.25	17.55	21.49	4.03	1.25	2	2

Experimental Condition	Volume of Concrete (m^3)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (kg)	HDPE lamellar (kg)	Number of specimens	
							Compressive strength	Tensile strength
f'c25	0.021	8.75	14.56	25.09	4.56	0.00	2	2
f'c25-HDPE 2.5%								
10 × 10 mm	0.021	8.75	14.56	25.09	4.56	0.22	2	2
5 × 20 mm	0.021	8.75	14.56	25.09	4.56	0.22	2	2
2.5 × 40 mm	0.021	8.75	14.56	25.09	4.56	0.22	2	2
f'c25-HDPE 5%								
10 × 10 mm	0.021	8.75	14.56	25.09	4.56	0.44	2	2
5 × 20 mm	0.021	8.75	14.56	25.09	4.56	0.44	2	2
2.5 × 40 mm	0.021	8.75	14.56	25.09	4.56	0.44	2	2
f'c25-HDPE 10%								
10 × 10 mm	0.021	8.75	14.56	25.09	4.56	0.88	2	2
5 × 20 mm	0.021	8.75	14.56	25.09	4.56	0.88	2	2
2.5 × 40 mm	0.021	8.75	14.56	25.09	4.56	0.88	2	2
f'c25-HDPE 20%								
10 × 10 mm	0.021	8.75	14.56	25.09	4.56	1.75	2	2
5 × 20 mm	0.021	8.75	14.56	25.09	4.56	1.75	2	2
2.5 × 40 mm	0.021	8.75	14.56	25.09	4.56	1.75	2	2

This study used a cylindrical specimen with a diameter of 150 mm and a height of 300 mm (Figure 3). The cylinder molds are made from steel to avoid leakage and hold their integrity under severe use. The mold nonabsorbent material avoids a reaction with Portland or other hydraulic cement. For each test, two samples were used for each size of HDPE lamellar particles. Accordingly, the number of samples used for the splitting tensile and cylindrical compressive strength tests was six. The total number of samples used was 156, including those for normal concrete testing. Since only two specimens were used for each design, the data were processed as averages.

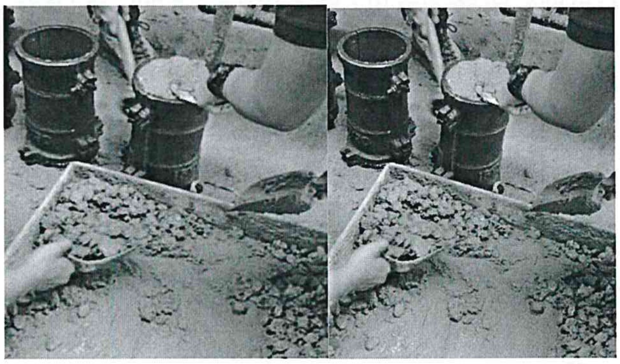


Figure 3. Preparation of concrete cylinder specimen.

We set a higher water/cement ratio to produce a workable concrete (minimum 0.52). Typically, the minimum water/cement ratio is 0.35–0.4, as a lower ratio may result in the concrete becoming too dry and unworkable [36]. Furthermore, the use of a higher water/cement ratio results in a high slump value. However, the addition of HDPE plastic lamellar compensated for this change. To evaluate the effect of adding HDPE lamellar particles, several tests were conducted, including slump testing using the ASTM C143 standard [37], compressive strength testing using the ASTM C39 standard [38], and tensile strength testing using the ASTM C496 standard [39].

3. The results

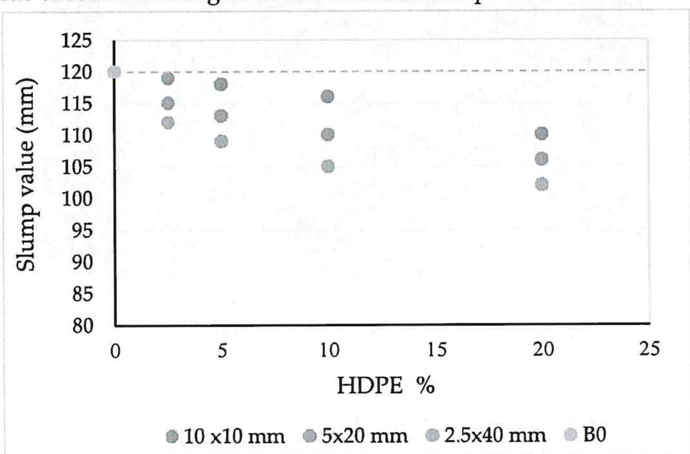
This study conducted tests to examine the appropriate concrete mixtures incorporating HDPE lamellar particles for non-structural applications to determine the effect of HDPE size and additions on low-quality concrete, medium-quality concrete, and high-quality concrete, as follows.

3.1. Concrete Slump Test

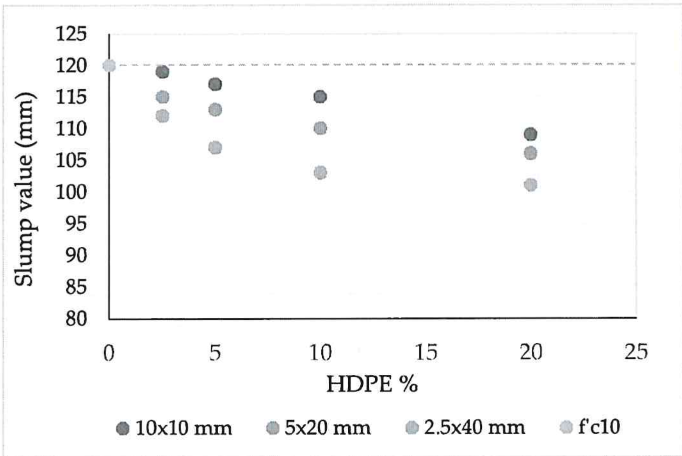
Concrete workability is quantified by concrete slump, which depends on many factors, e.g., mixing methods, concrete materials and admixtures, and the workability changes with time due to those factors. In this slump test, the preparation of specimens using the mold (slump cone) is shown in Figure 4, and the varying of HDPE lamellar particles was added to the fresh concrete before testing.

Figure 4. Preparation of B0 concrete for the slump test.

We set the slump value for normal concrete (baseline) to 115–125 mm. As shown in Figure 5, a greater amount of HDPE to the concrete mix led to a smaller slump value. The slump value of B0 concrete (Figure 5 (a)) with HDPE size at 10 x 10 mm declined by 10% for 20% HDPE lamellar addition (accounted from 120 mm of normal concrete to 110 mm). The lowest percentage reduction at slump value showed up in f'c10 with HDPE size 10 x 10 mm (Figure 5 (b)) , and the maximum value given by f'c25 with HDPE size 2.5 x 40 mm, at 16.7% (Figure 5 (c)). We found, from all the samples used, the maximum value of reduction ranged from 5 to 20 mm compared to the standard value.



(a)



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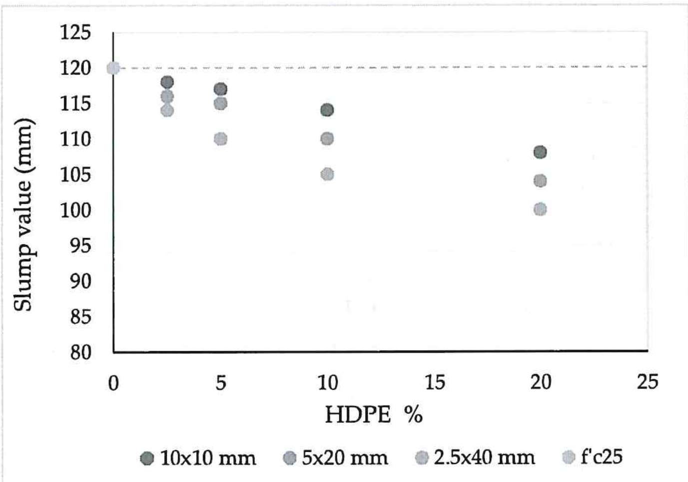
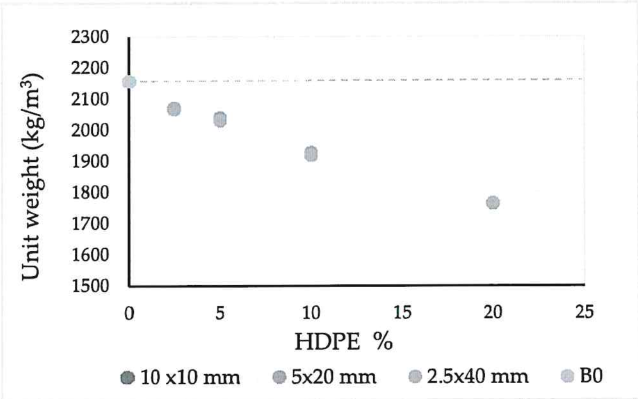


(c)

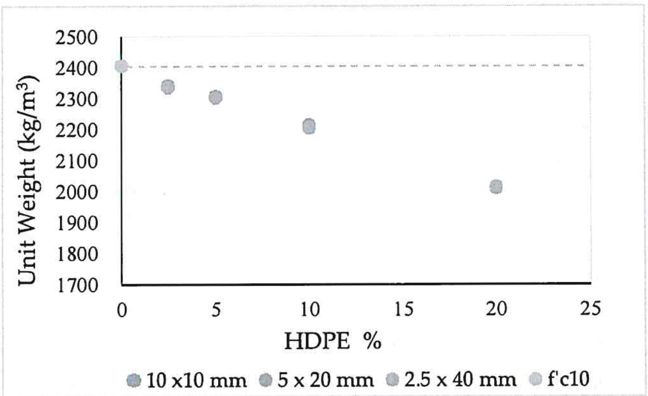
Figure 5. Slump value as a function of HDPE content (%) and sizes: **(a)** B0; **(b)** f'c10; **(c)** f'c25.

3.2. Unit Weight of Concrete

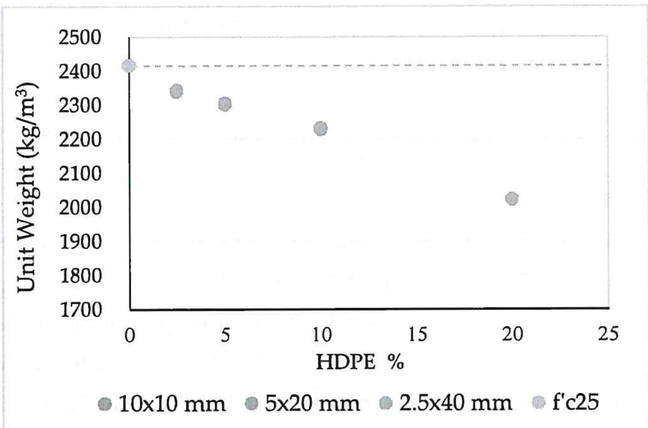
ASTM C29 [33] uses the term of unit weight to refer to the concrete property in mass per unit volume. This gives a good indication for sample concrete density. The unit weight for all samples was determined by comparing the specimen's weight with the specimen's substantial volume. The relationship between the unit weight of the concrete, HDPE lamellar content and its sizes are given in Figure 6. The graphs shows that a greater addition of HDPE lamellar particles led to lighter concrete due to the low density of HDPE plastic, which applies to B0, f'c10, and f'c25. However, the size of the HDPE fibers did not affect the concrete unit weight, as they all show the similar value for certain percentages. For example, in Figure 6 (b), the unit weight of 20% additions is 2,011 kg/m^3, 2,013 kg/m^3 and 2,012 kg/m^3 for HDPE sizes of "10 x 10 mm", "5 x 20 mm" and "2.5 x 40 mm" respectively.



(a)



(b)

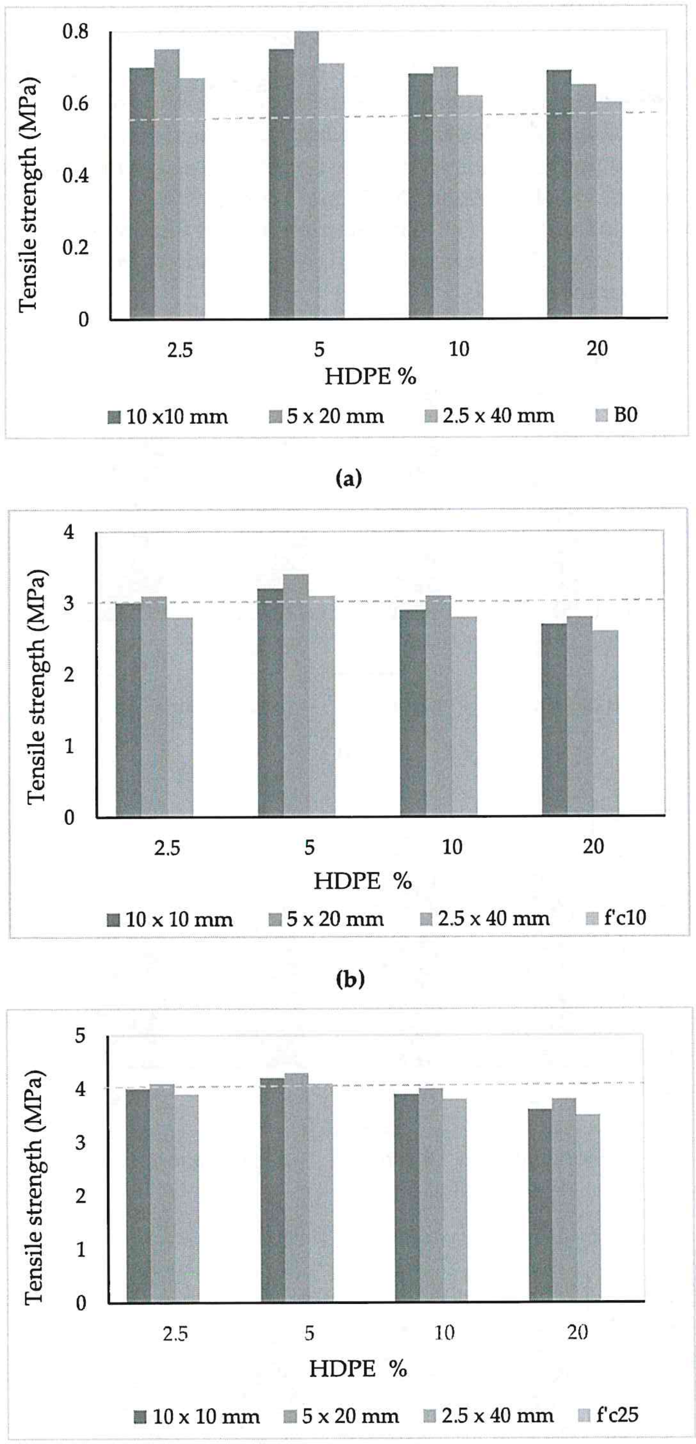


(c)

Figure 6. The relationship between concrete unit weight and HDPE content and sizes: **(a)** B0; **(b)** f'c10; **(c)** f'c25.

3.3. Tensile and Compressive Strength

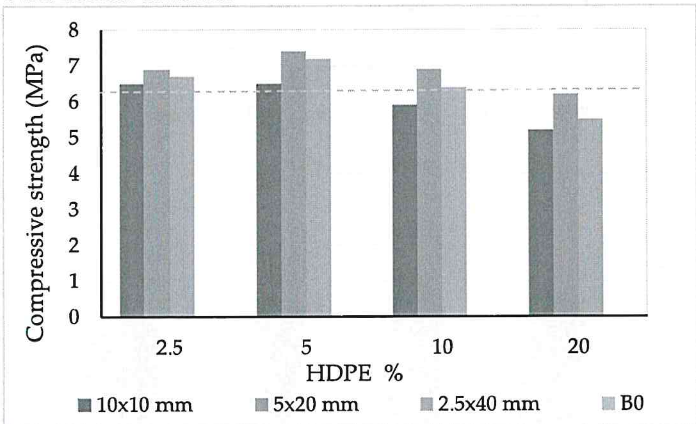
Tensile and compressive strengths are the important mechanical properties which identify concrete performance. Figures 7 and 8 display the results of splitting tensile and cylindrical compressive strength tests for the concrete mixtures containing HDPE ~~lamellar~~ addition. Our experiments indicate that the strength varies depending on the HDPE content and sizes.



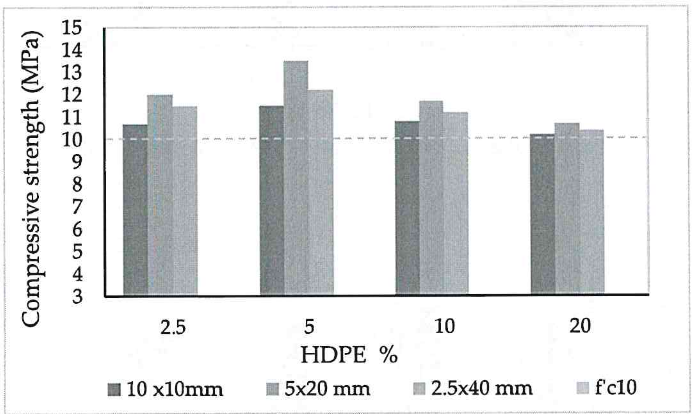
(c)

Figure 7. Tensile strength of concrete mixtures as a function of HDPE content and lamellar shape: **(a)** B0; **(b)** f'c10 MPa; **(c)** f'c25 MPa.

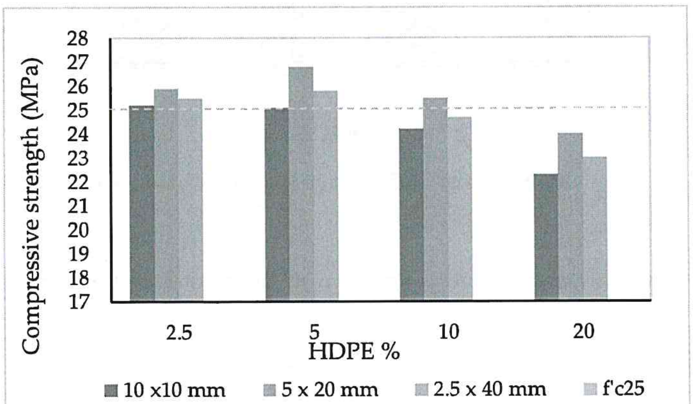
In line with the job mix design showed in Table 3, the concrete aggregate content and w/c ratio have an effect on tensile and compressive strength. Figure 7 shows that the B0 concrete has a lower tensile strength, compared to f'c10 and f'c25 . We observed also that the percentage and HDPE sizes behave differently on concrete strength. Although all sizes of HDPE lamellar have equal surface area (1 cm^2), they produce different response. In this case, we found that for all concrete classes, the addition of HDPE lamellar up to 5% shows higher tensile compared to other percentages (above the baseline), and the "5 x 20 mm" lamellar form is the best shape compared to the size of "10 x 10 mm" and "2.5 x 40 mm". This finding aligns with the compressive strength results as shown in Figure 8 (a), (b) and (c), where the 5% addition and "5 x 20 mm" strength value is above the normal concrete quality. This graph also indicates that f'c10 concrete gives a better response to the increase in concrete quality compared to B0 and f'c25, where in all percentage additions and different lamellar shapes, the value is above the normal concrete.



(a)



(b)



(c)

Figure 8. Compressive strength of concrete mixtures as a function of HDPE content and lamellar shape: **(a)** B0; **(b)** f'c10 MPa; **(c)** f'c25 MPa.

In addition, for the compaction, Figure 9 (a) and 9 (b) show a two-dimensional (2D) image of HDPE lamellar positions in concrete mixture. The lamellar particles with sizes of "10 × 10 mm" and "5 × 20 mm" remained unaffected by coarse aggregate pressure during casting. When tested for compressive strength, the broken piece of concrete was then observed visually. The plastic lamellar size of 10 × 10 mm and 5 × 20 mm seemed to pack and bond together with the concrete mixture in straight position. However, we found that the "2.5 × 40 mm" lamellar became curved during casting (Figure 9 (c)). Though this condition depends on the different angle of lamellar particles and the level of coarse aggregate pressure received during casting, the results show that 5 × 20 mm specimen performed better compared to 2.5 × 40 mm.

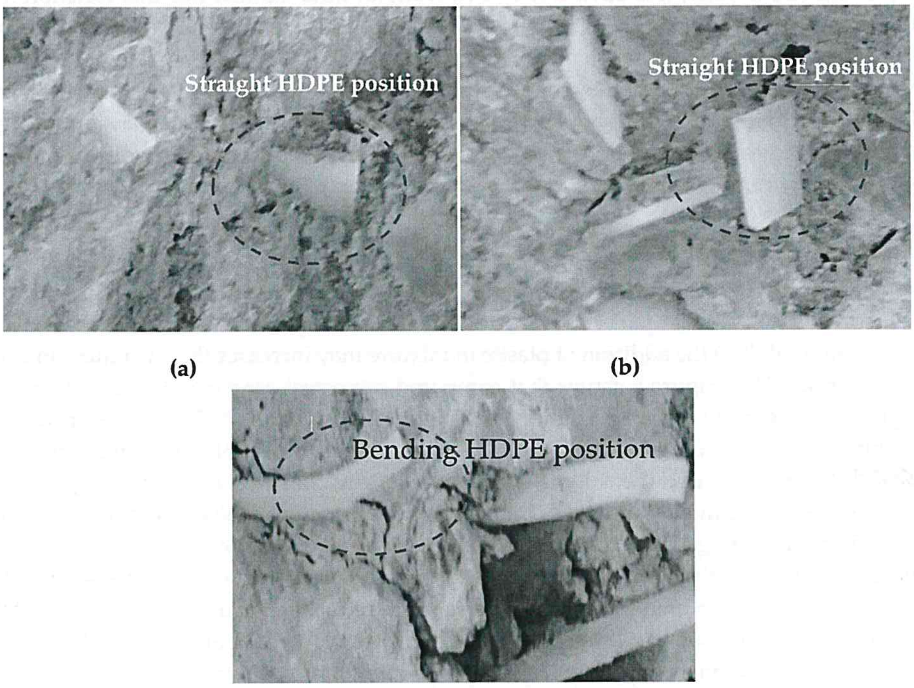


Figure 9. 2D images of HDPE lamellar: **(a)** 10 × 10 mm; **(b)** 5 × 20 mm; **(c)** 2.5 × 40 mm.

4. Discussion and Analysis

4.1. Relationship between HDPE additions and Slump Value

The concrete workability indicates the consistency of concrete mix during the work. It relates to the degree of its compaction provided by the external (contact with the surface) and internal friction (given by the aggregate size, shape, grading). The use of admixtures, e.g., plastics could also affect the compaction. The fact that plastic materials are generally lightweight and resistant to weather, means that they can be considered as suitable additive materials for concrete [19]. Previous studies indicated that added materials, including plastics, can improve the properties of concrete given appropriate percentage mixes [10,17]. Given the very poor biodegradability of plastic, its use in concrete mixes can improve the long-term performance of concrete structures and contribute to environment sustainability and the performance of the construction industry [46,47].

However, the addition of HDPE lamellar to the concrete mixture affected the slump value, which is essential for concrete workability. Recently, two types of added plastic have been used in concrete mixes and have shown satisfactory results when using 30% plastic waste in the total aggregate [48]. We identified that a small amount of added plastic does not affect the mixture's workability, but a higher percentage of added plastic was found to decrease the concrete's workability, due to its hydrophobicity. Figure 5 indicates that for all additions of HDPE lamellar at different sizes, it thickened the concrete mixture, thereby lowering the slump value. This finding supports previous studies that have showed that slump values decreases sharply following an increase in plastic waste percentages in the concrete mixture. This is due to the angular and nonuniform nature of aggregate particles, resulting in lower fluidity in the mixture [17,40].

Previous studies have proposed ways of preventing segregation that can happen during casting, due to fresh concrete's low workability [41]. These suggestions included increasing the amount of water used in the job mix and adding materials at certain application to maintain concrete density [42]. To prevent less fluidity, it is advisable to add water or other admixtures that function to alter concrete properties when making the job mixes. Therefore, in Table 3, we set higher w/c ratio than typical w/c ratio, as we use lamellar shape (bigger size than fiber).

To sum up, when considering the range of slump reduction, the added HDPE lamellar particles fit well for low-degree workability applications. In this case, the addition of plastic can improve toughness and energy absorption at post-cracking [43,44]. We consider that the findings of this study may be useful for non-structural works, where a higher strength is not the main aspect [45,49].

4.2. Relationship between HDPE additions and Unit Weight

The unit weight of normal concrete is about 2,400 kg/m³, and HDPE is about 930 – 970 kg/m³. Thus, when the HDPE lamellar particles were added into the concrete mixture, due to the nature of plastic (e.g., immiscibility) the addition of plastic in mixture may increases the air content in concrete affecting its density [19]. Figure 6 shows that compared to normal concrete, the unit weight of the concrete mixture dropped linearly with the number of lamellar particles in the mixture. The immiscibility of plastics could affect compactness when a certain level of admixture is replaced by HDPE lamellar. However, here, the volume of concrete remains the same, as indicated by the amount pushed out of the sample mold. Further, an increase in HDPE content enables a reduction in concrete weight; an important target in construction. These findings have an impact and add to the development of lightweight concrete for the green construction sector. Thus, the use of HDPE lamellar also could lead to a more sustainable approach to reducing plastic waste.

Previous study discussed the development of lightweight concrete using HDPE additions (25%) opening up new development opportunities for non-structural and structural applications [50]. However, our findings show that the concrete added plastics shall be directed to non-structural concrete applications due to safety factors and its poor fire-resistant behavior [49]. Therefore, mean concrete containing plastics cannot be used as a primary construction material, i.e., for column, beam and plate constructions. In particular, this study identified that the addition of HDPE, in lamellar shape, provide best response to concrete quality up to 5 % for medium concrete quality of f'c10. For instance, in the construction of non-structural walls, base concrete in the rigid pavement on highways, paving blocks for parking lots with low loads, wall panels, shotcrete (or Gunite), and concrete footpaths. Specially for the use for precast concrete walls, concrete mixtures containing HDPE lamellar, could reduce the building's structural load and energy consumption within the building by lowering the inside temperature. Together with fillers (e.g., sand, quarry fine), this type of concrete mix could help prevent heat transfer within a structure, which is relevant to Indonesia's moderate to high temperatures. Furthermore, there is a strong connection between thermal conductivity and concrete's substantial weight whereby uses of plastics to replace aggregates can reduce concrete's thermal conductivity compared to bare concrete [51, 10].

4.3. The effect of HDPE additions to Tensile and Compressive Strength

As stated earlier, previous studies have found a relationship between plastics addition influencing concrete's tensile strength and compressive strength [19,21,52] matching those of steel fibers that affected the value of splitting tensile and compressive strength [53], as well as plastic fibers, carbon fibers, and fibers from natural materials, such as flax or other plants. According to Hasan et al. [39], inserting fibers into a concrete mixture can increase the concrete composite's tensile strength by about 10–15%, compared to standard concrete. Other research found similar results that fibers can prevent brittle failure and enhance the ductility of the concrete [40,50,53].

The tensile strength is an essential determinant of how concrete performs under induced stress. Figure 7 and 8 show the connection between tensile and compressive strength; although their relationship is not directly proportional. The higher the compressive strength, the higher the tensile strength, but at a decreasing rate [54]. This study indicates that the addition of 5% HDPE lamellar increases the tensile and compressive strength of concrete, better than 2.5%, 10%, and 20%. Furthermore, the addition of 10% and 20% HDPE content to B0 and f'c25 concrete reduced the tensile and compressive strength. This finding in line with other studies showing that increasing the volume fraction can affect fiber bonding and decrease the strength of concrete composites [15,25,51].

However, this study identify that this fact did not apply to f'c10 MPa concrete, where an increase in quality occurred, even with a content of 20% for lamellar with a size of 5 × 20 mm (13% increase in splitting tensile strength; 35% increase in compressive strength). Therefore, the amount of added HDPE plastic lamellar should be chosen on the basis of the weight of the cement used, as outlined in Table 2. Since all HDPE samples added had the same cross-sectional area, the size largely determines the results, whereby the position of plastic lamellar in the concrete can reduce the optimality of the aggregate bond, as seen in Figure 9. The performance of fibers with respect to strength testing was in the order of 5 × 20 mm > 2.5 × 40 mm > 10 × 10 mm. Thus, the use of HDPE lamellar with a size of 5 × 20 mm as an additive in the concrete mixture was acceptable.

5. Conclusions and Recommendations for Future Research

Few studies have assessed the effect of added particles length on concrete properties. This study has contributed to the understanding of the optimal percentages and sizes of HDPE lamellar in concrete. Our study contributes to showing the effect HDPE lamellar particle additions have in terms of size and percentage on concrete qualities to improve its use and exploitation and to design the concrete mix design process. Some important findings are:

1) This study evaluated the use of 2.5%, 5%, 10%, and 20% HDPE lamellar particle additions at sizes of 10 × 10 mm, 0.5 × 20 mm, and 2.5 × 40 mm incorporated into three concrete types (B0, f'c10, and f'c25). The f'c10 MPa concrete performed best in response to the addition of lamellar particles, whereas 5% was the optimal HDPE content and 5 × 20 mm was the optimal size.
2) All variants of HDPE lamellar particles described can be used with f'c10 MPa concrete. However, only 5 × 20 mm HDPE lamellar should be used with B0 and f'c25 MPa concrete.
3) Future research should investigate f'c10 MPa to determine the effects of different percentage additions and material composition into concrete mixes. Also, further work is needed to identify whether similar effects apply to different plastic lamellar. More testing could explore the valuation of physical concrete properties, e.g. water porosity.

Author contributions: Tamrin; conceptualization, design and analysis, investigation, initial draft, visualization; Juli Nurdiana; draft preparation, administration process, and the editing process.

Conflicts of Interest: The authors declare no conflicts of interest associated with this publication. There has been no significant financial support for this work that could have influenced its outcome.

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Respon to Reviewer 3

Dear reviewer,

First and foremost, allow us to express our gratitude for your constructive feedback regarding our work. Your comments were very helpful and have enabled us to improve the quality of our manuscript. Thank you very much for this opportunity, and we have learned a lot from this reviewing process. We have responded and accommodated your inputs in this manuscript. Hope it meets your expectations and achieves the required standard for publishing. Please find our response below.

Kind regards,

Tamrin and Juli

Response to reviewer 3:

- Abstract and keywords. We revised the wording accordingly in line 16-20, and line 22 for keywords. Thank you very much.
- Line 75-76, we adjusted into "….fiber volume fraction."
- Line 90, we changed into "…HDPE addition on different concrete classes".
- Line 91, we added "…HDPE lamellar particles…"
- Line 101-103. We modified into " Lower concrete strength in the following….respectively".
- Line 107, we removed "and" before "…..tensile and compressive strength".
- Table 1 and 2, we removed the bold. Thank you for this.
- Figure 1, we reduced the font size.
- Line 170-172, we rephrased into "2.55 g/cm^3 ……23% was obtained."
- Line 181, we changed into "…..for all the sheets".
- Line 185, we added into "This ensures…."
- Figure 2, we modified the legend. Thank you.
- Line 197 ("The concrete mix design…") and line 203 ("….three different concrete classes…"), we changed the plural and singular noun.
- Line 210, we omitted "lamellar", and changed into "….HDPE additions….."
- Line 221-222, we modified into "This study…..under severe use."
- Line 227, we corrected the noun, "…..as average."
- Line 239, we changed into "…HDPE plastic sheets compensated for this change".
- Line 296, we adapted into "….size of the HDPE sheets….".
- Line 344, we added into "….containing HDPE addition…".
- Line 374-375, we omitted the unnecessary wording and changed into "….higher tensile strength……"5 x 20 mm" is the best shape compared….".

- Line 411, we removed the wording and changed into "….HDPE positions in concrete mixture".
- Line 413, we removed the wording and altered into "The size of 10 × 10 mm and 5 × 20…"
- Line 415, we modified into "…. "2.5 × 40 mm" sheet became…"
- Figure 9, we changed the legend.
- Line 458, we omitted the unnecessary word, and adapted into "…..sustainability and performance of the construction industry [43,44]."
- Line 459, we modified the wording into "However, the addition of HDPE to the concrete…"
- Line 477, we altered the wording into "…..for all additions of HDPE at different size…".
- Line 474, we adjusted the wording into "….nature of plastic aggregate…".
- Line 490, we adapted into "…..replaced by HDPE."
- Line 517, we revised into "Thus, the addition of HDPE…"
- Line 501, we modified into "….. for medium concrete strength of f'c10."
- Line 504, we changed into "….concrete mixtures containing HDPE, could…"
- Line 531, we revised into "….that the addition of 5% HDPE increases…"
- Line 537, we altered into "…..of 20% for sheets with a size of…."
- Line 538, we revised into "Therefore, the amount of added HDPE should…."
- Line 541, we added the wording into, "…..whereby the position of plastic lamellar particles….."
- Line 549, we adapted into "….performance of the additions with respect…"
- Line 555-556, we adjusted into " …… and sizes of HDPE in the shape of…. showing the effect that HDPE additions…".
- Line 564, we changed into "….HDPE sheets should be used with B0 and f'c25 MPa concrete."
- Line 567, we modified into "….apply to different plastic shapes."