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Mechanical Properties of Concrete with Recycled High-Density Polyethylene Macro Flat Fiber and Rice Hull Ash as Partial Replacement to Cement

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Abstract: As concrete is still one of the most used in construction, development on improving its strength and possible reduced environment impact is necessary. This study determines the mechanical properties of concrete with the addition of recycled High-Density Polyethylene (HDPE) Macro Flat Fiber (MFF) and Rice Hull Ash (RHA) as partial replacement to cement. The objective of this study is to identify the optimum mix ratio for compressive and flexural strength of concrete. Various percentage of HDPE MFF (0.5%, 0.75%, and 1.0%) and 10% partial replacement of RHA to cement is incorporated in the mixture. The RHA is obtained through uncontrolled burning while HDPE MFF is collected through shredding and manual cutting. The results showed that the addition of HDPE MFF had a positive effect on the compressive and flexural strength of concrete. The optimum value is achieved on concrete with 0.5% HDPE MFF and no RHA, as it had showed an average of 31.87 MPa with a 18.04% increase in compressive strength, and an average of 4.532 MPa with a 17.78% increase for flexural strength. Moreover, the combination with RHA had not showed promising results. It had been concluded that the addition of recycled HDPE MFF with no RHA increases the compressive and flexural strength of concrete.

Keywords: Recycled high-density polyethylene, rice hull ash, macro flat fiber, concrete

1. Introduction

Cement is a basic component of concrete. It is a very important material in the construction industry but also a considerable factor that affects the environment. Emissions to air is the main environmental challenge faced by the production of cement. The emissions from cement plants which cause great damage and should be controlled with are dust, carbon dioxide, sulfur dioxide and nitrogen oxides. Rice Hull Ash (RHA) have been used in other research as partial replacement to cement as well as adding it to concrete. Furthermore, concrete is still one of the most used in construction study. Continuous study is still conducting on utilizing alternative construction materials aside from partial replacement of cement by incorporating fiber to increase its strength.

As one of the top producers of rice, the country is abundant of Rice Hull (RH). The estimated production of RH in the Philippines is more than 2 million tons per annum [1]. Since it is considered as waste, most RH are just dumped or burned which eventually turns into ash. According to [2], RHA enhances the durability and strength of concrete because of the high pozzolanic activity. Also, [3] concluded that 10% partial replacement of RHA to cement increases the compressive strength of concrete. Many studies have already proven that RHA replacement increases the mechanical properties of concrete.

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Likewise, numerous studies show that addition of fibers such as HDPE increases the flexural toughness of concrete. Based on the study of [4], the use HDPE fiber Reinforced Concrete (FRC) can maintain a constant post-cracking tensile capacity of concrete at the level of 30%-40% of the peak flexural capacity with only 0.75%-1.25% of the HDPE fiber volume. HDPE is huge in the worldwide market. It is hard and resistant to impact and can take high temperatures (120°C) without being affected, making it non-biodegradable and can take centuries to decompose which makes it crucial that HDPE waste should be recycled. Manufacturing HDPE also has an environmental effect because it uses a large amount of fossil fuel and a total of 1.75kg of oil to manufacture just 1 kg of HDPE [5]. However, producing plastic fiber emit a lot less carbon footprint compared to when producing steel [6].

Many studies have used HDPE fibers as reinforcement to concrete, specifically synthetic fibers, which are commercially produced, usually at a round cross-sectional area. Synthetic fibers increase the strength of concrete, but it has some disadvantage. According to [7], synthetic fibers have a smooth surface and a water-repellant property that affects its binding with cement and aggregates.

With this environment related and binder strength issues, this study used recycled HDPE MFF. According to [8], among all fiber geometry in their study, the MFF shows one of the excellent results. It states that the use of MFF has a higher modulus of elasticity than round cross-sectional fiber.

The advantages in both RHA and HDPE fibers were seen in terms of increasing the strength of the concrete. The objective of this study is to determine the compressive strength and flexural strength of concrete with varying percentages of recycled HDPE MFF and RHA as partial replacement to cement.

2. Methodology

The supply of rice hull was obtained from rice mills. It was subjected to uncontrolled combustion for a week until white-gray color ash was obtained based from [3]. RH were put down at a metal bucket with a small hole at the side and an igniter was placed at the bottom to start the burning. The burning black RH were transferred to a covered metal container for a week. The RH were checked and mixed every day until white-gray color was obtained. The white-grey RHA were then cooled for another week until it was no longer burnt. The white-grey RHA were then cooled for another week until it was no longer burnt as shown in Fig. 1.

Fig. 1 - RHA used in the study

Recycled HDPE plastics were collected from the households of the researchers and junk shops. HDPE plastics were manually cut to have a flat surface and only HDPE plastics with less than 1 mm in thickness were used, see Fig. 2. It was then shredded using a machine with a dimension approximately 4 mm in width and the researchers cut the length to 50 mm. The dimensions used were based on the study of [9].

This study evaluated the compressive strength and flexural strength of the concrete with the addition of 0.5%, 0.75%, and 1.0% recycled HDPE MFF with no RHA; and 0.5%, 0.75%, and 1.0% of recycled HDPE MFF with a constant 10% of RHA as partial replacement to cement. Table 1 provides the summary of research mix design. The samples were made from fine aggregates, coarse aggregates, Portland Pozzolana Cement (PPC) with 10% partial replacement of RHA and varying percentages of recycled HDPE MFF. A special class mix-ratio 1:2:3 was used along with a 0.5 water-cement ratio is used in the study.

The mixing sequence was based on the study of [10] which is in an order of fine aggregates, HDPE MFF, coarse aggregates, cement, and water as shown in Fig. 4. This is to properly mix all the RHA and recycled HDPE MFF to the concrete mixture/ The RHA were mixed with some of the cement beforehand for a better mixture of the binders. The procedure of making and curing of the concrete samples is based on ASTM C31 [11] specification. The samples were cured for 28 days.

(a)

(b)

Fig. 2 - (a) Recycled HDPE Plastic; (b) recycled HDPE MFF after placed in shredder machine

Table 1 - Research Mix Design

Designation	Percentage Replacement of RHA to Cement	Percentage Addition of Recycled HDPE MFF
C1	0	0
C2	0	0.5
C3	0	0.75
C4	0	1
C5	10	0.5
C6	10	0.75
C7	10	1

Fig. 3 - Mixing process of samples from left to right

There are three samples each for both compressive strength test and the flexural strength. The compressive strength test was done with accordance to ASTM C39 (Compressive Strength of Cylindrical Concrete Specimen) [12]. The samples were cylinders with 6 inches diameter and 12 inches in height. The flexural strength test was done with accordance to ASTM C78 (Flexural Strength of Concrete-Using Simple Beam with Third-Point Loading) [13] as shown in Fig. 4. The half of the load is applied at each third of the span length where maximum stress is present over the center one-third portion of the beam. The beam samples had a 6 inches' x 6 inches' x 20 inches' dimension. Tests are performed using Universal Testing Machine.

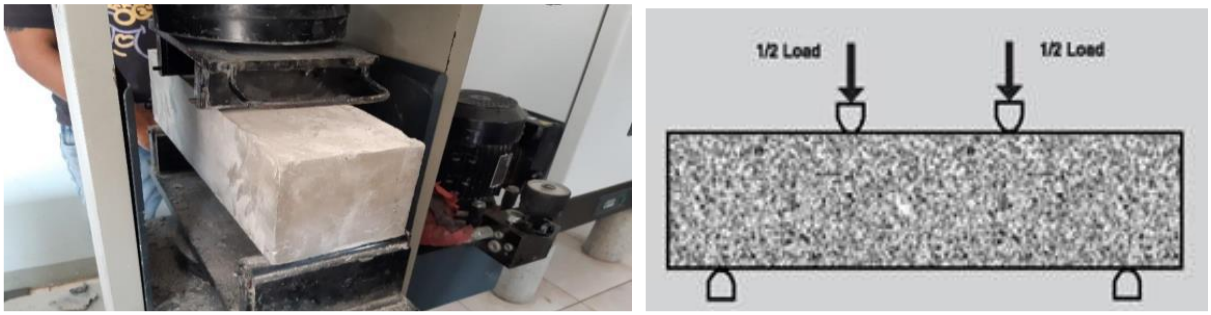

Fig. 4 - ASTM C78 (flexural strength of concrete-using simple beam with third-point loading)

3. Results and Discussions

As presented in Fig. 5, there are several types of fractures that can occur after encountering compressive load on a specimen. Based on the test results conducted as shown in Fig. 6, most of the samples obtained a type-3 fracture, which is the columnar vertical cracking through both ends, no well-formed cones. Eight other samples experienced type-2 fracture; 2 samples from both C1 and C4 while 1 sample on each C3 to C7 specimens which is a well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end. Also, 4 samples exhibited type-5 fracture, 2 samples from C5 and 1 sample from both C2 & C3, which are side fractures at top or bottom. All of these are with accordance to ASTM C39.

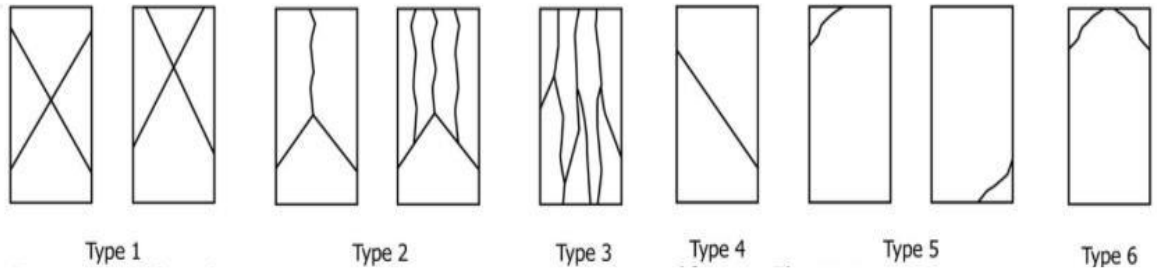

Fig. 5 - Types of schematics of typical fracture patterns

(a) (b) (c)

Fig. 6 - (a) type 3 fracture; (b) type 2 fracture; (c) type 5 fracture

Based on the average compressive strength data seen in Table 2, the controlled mix obtained a value of 27 MPa. Comparing other samples with 0% and 10% RHA and varying amounts of recycled HDPE MFF, only three combinations showed a positive increase which means it attained a higher value than the controlled mix. The C2 specimens which have an additional 0.5% recycled HDPE MFF obtained the highest compressive strength with an average value of 31.87 MPa which exhibits an increase of 18.04%. C3 specimens obtained the second-highest value of compressive strength with an average value of 30.5 MPa and an increase of 12.96%. Thirdly, C4 specimens obtained an average compressive strength of 28.4 MPa with an increase of 5.19% compared to the control mix.

Table 2 - Average compressive strength

Designation	Percentage Replacement of RHA to Cement	Percentage Addition of Recycled HDPE MFF	Average Compressive Strength in MPa
C1	0	0	27
C2	0	0.5	31.87
C3	0	0.75	30.5
C4	0	1	28.4
C5	10	0.5	23.6
C6	10	0.75	22.1
C7	10	1	19.7

A concrete mixture has a standard value of 21 MPa (3045 psi) which can be used for structural elements such as slabs and foundations. Higher strength of concrete such as 28 MPa can be used for any structural elements on most of buildings. It can be seen from Fig. 7 that only C7 specimens are below the standard value. The normal mix as well as the other sample combinations obtained a higher compressive strength that is within the standard value of concrete. Furthermore, it shows a trend where the addition of more recycled HDPE MFF alone results in a decrease in compressive strength. It also observed that adding 10% partial replacement of RHA to cement is not effective in improving the compressive strength of the concrete with a combination of recycled HDPE MFF.

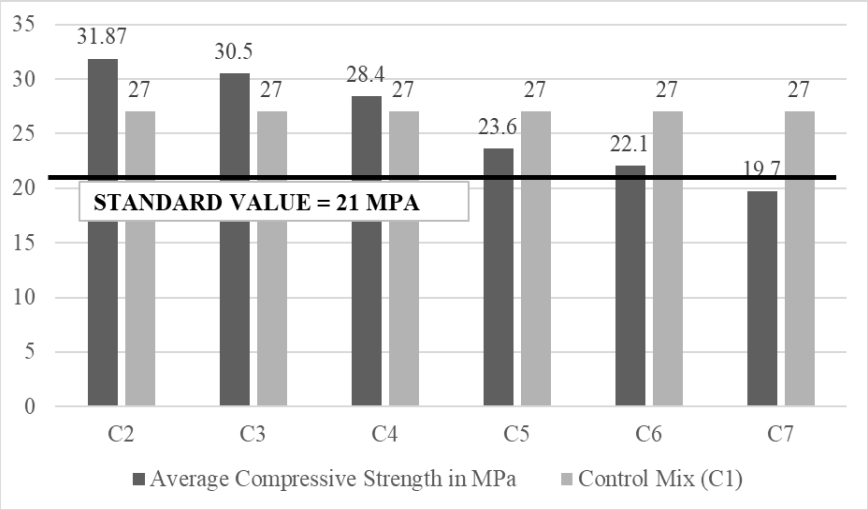

Fig. 7 - Compressive Strength of RHA & recycled HDPE MFF combination compared to Control Mix (C1) and Standard Value of 21MPa

After the maximum load is applied, it was observed that concrete with recycled HDPE MFF did not break into two parts as compared with the control mix as shown in Fig. 8. It is because the main function of fiber in concrete used for reinforcement causes delay and allow the concrete to deform plastically [14].

The average flexural strength results are tabulated in Table 3. The control mix obtained a value of 3.85 MPa. Comparing other samples with 0% and 10% RHA with varying amounts of recycled HDPE MFF, there are four specimens that showed a positive increase which means it attained a higher value than the control mix. C2 has an additional 0.5% recycled HDPE MFF obtained the highest flexural strength with an average value of 4.53 MPa with an increase of 17.78%. C6 obtained the second-highest flexural strength with an average value of 4.50 MPa, which compared to the control mix increased by 17.05%. Also, C3 and C4 exhibited positive increases with an average value of 4.21 MPa and 4.48 MPa. However, C7 got the lowest flexural strength with an average value of 3.18 MPa, which compared to the control mix declined by 17.28%.

(a) (b)

Fig. 8 - (a) Normal Concrete after flexural strength test, and; (b) sample with recycled HDPE MFF after flexural strength test

Table 3 - Average flexural strength

Designation	Percentage Replacement of RHA to Cement	Percentage Addition of Recycled HDPE MFF	Average Compressive Strength in MPa
C1	0	0	3.85
C2	0	0.5	4.53
C3	0	0.75	4.21
C4	0	1	4.48
C5	10	0.5	3.66
C6	10	0.75	4.50
C7	10	1	3.18

Moreover, the trend of the flexural strengths shows that with the addition of recycled HDPE MFF alone had an increase in flexural strength as seen in Fig. 9. Also, partial substitution of RHA shows inconsistent data results but two batch of specimens, specifically C5 and C7 illustrates a decrease in flexural strength.

Considering the results of compressive strengths and flexural strengths of the concrete using one-way ANOVA, the computed p-values are less than 0.05 which means there is significant difference among the samples. It signifies that the addition of various percentage of HDPE MFF and with 10% RHA partial replacement to cement have an impact to the increase and decrease of the strengths.

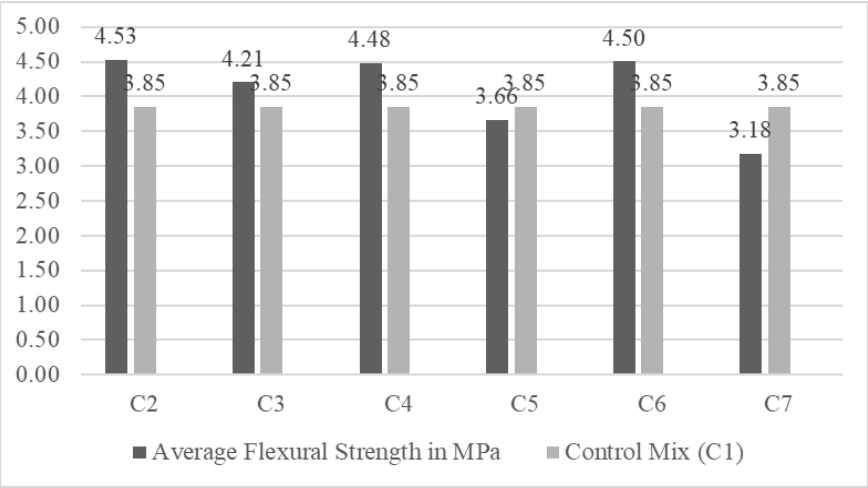

Fig. 9 - Flexural Strength of RHA & recycled HDPE MFF combination comparing to Control Mix (C1)

4. Conclusion

The sample C2 (0% RHA and 0.5% HDPE MFF) had the highest compressive strength with an average value of 31.87 MPa which has an increase of 18.07%. Also, it obtained highest flexural strength with an average value of 4.53 MPa and had an increase of 17.78%. The partial replacement of RHA to concrete did not effectively increase the compressive strength. On the other hand, the recycled HPDE MFF improves both compressive and flexural strength on concrete without RHA. There are inconsistent results on flexural strengths obtained for concrete with RHA.

Nevertheless, the mix designs used in the study except for C7 can be used for foundation and slabs. But C2, C3 and C4 can be used for any structural element in most of the buildings.

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