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Evaluation of oil palm shells and mask fiber on the flexural strength of pre- and post-corrosion concrete

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Abstract. One of the innovations in concrete technology that is also in line with reducing industrial and community waste is making mask fiber concrete mixed with oil palm shells as an aggregate substitute. In this research, 10% oil palm shells were used with mask fiber added at 0.2% of the specimen volume to increase the flexural strength value of corroded concrete. Tests include corrosion acceleration tests and concrete mechanical properties such as flexural strength, density, and ductility. There are two specimens, namely pre- and post-corrosion concrete. With the acceleration process, pre-corrosion specimens are carried out on the reinforcement before the concrete molding process, while post-corrosion specimens are accelerated by corrosion after the concrete is 28 days old. Tests on pre- and post-corrosion specimens show differences in the properties and characteristics of the concrete mechanical properties test results. The flexural strength value of post-corrosion concrete tends to increase with increasing corrosion. Meanwhile, the flexural strength value of pre-corrosion concrete experienced a decreasing trend along with increasing levels of corrosion.

1 Introduction

Concrete is one of the important elements in a building. Good quality concrete has several advantages, including high compressive strength, being resistant to environmental conditions, and being resistant to weather (hot, cold, sunlight, and rain). However, concrete has several weaknesses, including weakness in tensile strength, expansion, and contracting when temperature changes occur, difficulty completely waterproofing, and brittleness. Building construction materials, one of which is concrete, generally consist of a mixture of cement, fine aggregate, coarse aggregate (crushed stone), and water [1, 2]. Aggregate in crushed stone is one of the natural materials often used, so it must be limited to preserve nature. One solution is to use oil palm shells [3] as a substitute for some or all of the aggregate [4, 5].

The potential for producing palm oil waste in Indonesia is very large, considering that Indonesia has the largest palm oil producers in the world. As an illustration, one of the palm oil wastes in empty bunches or shells produced per ton of palm oil can reach around 23%. However, this waste has not been widely utilized, and its management is still limited to burnt ash. One of the palm oil wastes is oil palm shells (OPS), which are the hard part of the palm fruit that protects the contents or kernel of the palm fruit. The surrounding environment would experience a worse impact if waste produced from palm oil continues to increase. Therefore, parties involved in the palm oil industry must be able to process this waste into something more valuable and profitable to produce high economic value. One use made to reduce environmental pollution due to palm oil waste is OPS as a substitute for coarse aggregate in concrete [6]. One way to reduce environmental pollution from palm oil waste is to use OPS as a substitute for coarse aggregate in concrete. However, concrete with OPS has a lower flexural strength or compressive strength value than normal concrete [7, 8]. Therefore, fiber is necessary to strengthen the concrete. Many fiber types have been used to strengthen concrete, including fiber from masks.

Apart from that, the current post-COVID-19 pandemic conditions are still ongoing and not yet completely over. People's habit patterns have also changed from never using masks when leaving the house to becoming more accustomed to using masks, which are a barrier to air pollution entering the body. This impacts various fields, including the environment, with a lot of mask waste, which can cause environmental pollution because nature cannot decompose masks. Therefore, this research will also use mask waste as fiber or additional material in the concrete mixture.

Concrete with a mixture of OPS and mask fiber must consider the reinforcement condition. Because one thing that influences the strength of concrete is the condition of the reinforcing steel, corrosion of reinforcement in concrete can reduce the quality or strength of the reinforcement, so control of the reinforcement is needed [9]. Corrosion is defined as damage or reduction in the quality of reinforcement caused by a reaction between the environment and the reinforcement [10]. Corrosion in reinforcing steel can occur when the passive layer on the reinforcing steel is lost. Corrosion is a problem that causes significant losses in the world of construction.

Losses caused by corrosion of reinforcement in concrete can reach trillions of rupiah. One of these losses is due to the costs of repairing structures that have experienced corrosion. Corrosion is a risk for concrete in aggressive environments, such as swamp water, groundwater, seawater, and industrial sulfate areas [11].

Previous research examined the effect of adding palm kernel shells and palm fiber [12], with variations in OPS of 0%, 25%, 50%, and 75%, the flexural strength test will be carried out. The highest flexural strength of control concrete without palm fiber was 8.3 MPa. Meanwhile, research on the decrease in flexural strength capacity in reinforced concrete due to reinforcement corrosion using a 5% NaCl solution shows that the corrosion control beam carries the maximum load. The minimum load-carrying capacity is found in beams with corrosion of 8.9% and a flexural capacity decrease of 17.55% [13]. Additionally, research on reinforced concrete corroded by immersing the specimen in a 3% sodium chloride solution with a corrosion percentage of 5%, 10%, 15%, and 20%. Beams with a corrosion percentage of 5.0%, 10.0%, and 15.0% experienced a decrease in average yield life of 91.3%, 97.7%, and 99.8%, respectively. Research has been carried out regarding recycling used face masks with percentages of 1%, 2%, and 3%, which will be subjected to a pressure test. The highest compressive strength with adding 1% mask fiber was 216 kPa [14].

Based on the descriptions above, research on the influence of different levels of corrosion on the flexural strength of concrete with OPS and mask fiber is necessary because previous related research is still very limited. Previous research only covered the concrete with partial replacement of coarse aggregate with OPS [15-17], the flexural strength of concrete with OPS [12, 18, 19], corroded concrete [14, 20-23], flexural tests on corroded concrete [13], and compression test on concrete with mask fiber [24]. So, in this research, beam specimens measuring 10 cm x 10 cm x 50 cm will be used using a mixture of OPS and mask fiber. Meanwhile, the variations in corrosion levels that will be tested are 1%, 2%, 3%, 4%, and 5%. This research will also evaluate the mechanical properties of concrete mixed with OPS and mask fiber in pre and post-corrosion concrete.

2 Materials and Methods

2.1 Materials

Gravel comes from Clereng, Yogyakarta, and has a maximum size of 20 mm. The sand used in sizes 4.8 mm to 0.0075 mm comes from Kulon Progo, Yogyakarta. The cement used is Portland cement type I with the Holcim Dynamix brand. OPS comes from South Sumatra with a maximum size of 20 mm, while the mask fiber used is 0.5 cm wide and 2 cm long. The specimen used is a beam with dimensions of 500 x 100 x 100 mm^3 and a single reinforcement with a diameter of 12 mm.

Meanwhile, this grain gradation test results refer to SNI ASTM C136:2012 [25]. The fine grain modulus results obtained in this test were 2.38, with the gradation area falling into area 2 because it was between 1.5 – 3.8 and was classified as a relatively coarse gradation. The results of testing aggregates and OPS can be seen in Table 1 below. Meanwhile, OPS [3] and mask fibers can be seen in Figure 1.

(a)

(b)

Fig. 1. Physical form of (a) OPS and (b) mask fiber

Table 1. Results of examination of coarse, fine aggregates and OPS

Test type	Result			Units
	Gravel	OPS	Sand	
Specific gravity	2.65	1.20	2.27	-
Water absorption	1	16.25	2.57	%
Volume weight	1.49	0.64	1.52	gram/cm³
Water content	0.83	3.36	2	%
Mud levels	1	1	2	%
Abrasion	29	5.5	-	%
Fines modulus	-	-	2.38	-

2.2 Mix design

Mix Design is based on SNI 03-2834-2000 [26]. The need for OPS is calculated based on the percentage that will replace gravel in concrete, where the percentage used is 10%. Meanwhile, the masks used for the mixture are 0% and 0.20%. The mix proportions for the mix design can be seen in Table 2 below.

Table 2. Mix design concrete per sample

Material	Values	Units
Sand	4.17	kg
Gravel	5.07	kg
Cement	2.62	kg
Water	1.23	liter
OPS	0.32	kg
Superplasticizer	6.6	gram
Fiber mask	26.82	gram

2.3 Corrosion acceleration

The corrosion process uses the accelerated corrosion method, an impressed current technique with the help of a DC power supply. The target corrosion levels are 1%, 2%, 3%, 4%, and 5%. A styrofoam box containing 5% salt solution (NaCl) is used to soak the reinforcement and specimen. The electric current used is 0.2 A to 3.5 A. Pre-corrosion specimens are carried out in the corrosion acceleration process before the concrete casting [17], as shown in Figure 2. Meanwhile, the corrosion acceleration process for post-corrosion test specimens is carried out after the concrete is 28 days old, as shown in Figure 3 below. The corrosion plan can be calculated using Faraday's Law using Equation 1 below. With Δm is Loss of reinforcement weight (grams), M is the atomic or molecular weight of the metal (56 g/mol for steel), I is the electric current (A), t is the duration of corrosion (seconds), z is the number of electrons that react (2 for steel), and F is the Faraday constant (96,500 A/s).

$$\Delta m = \frac{M \times I \times t}{z \times F} \quad (1)$$

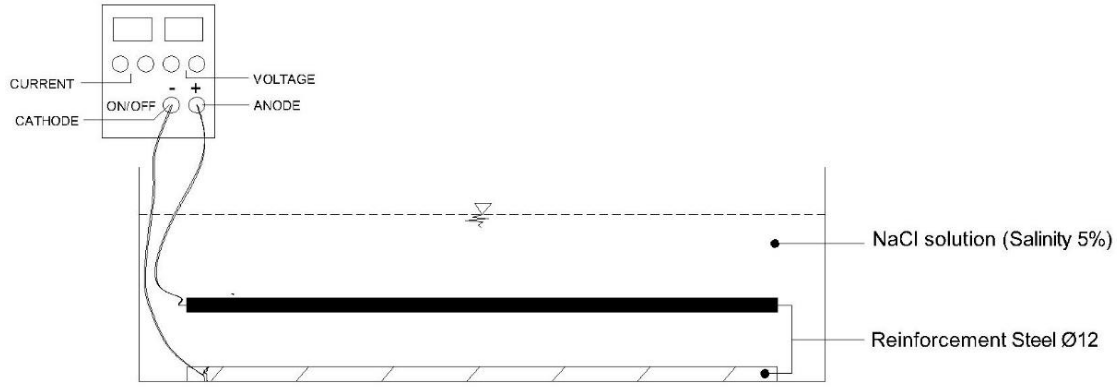

Fig. 2. The process of accelerated corrosion of pre-corrosion specimen

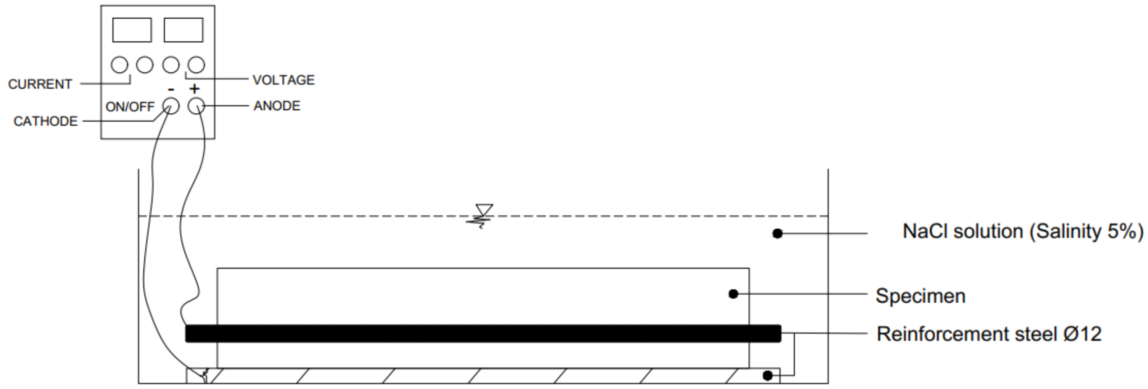

Fig. 3. The process of accelerated corrosion of post-corrosion specimen

2.4 Flexible Strength

The bending test equipment uses a Universal Testing Machine (UTM). Flexural strength testing uses one loading point located in the middle of the beam span with 5 cm between the edge of the beam and the support. The test is carried out until the beam cracks due to the applied load. Using the flexural strength test method with a centralized load [27]. The flexural strength testing process can be seen in Figure 4.

Fig. 4. Flexure test scheme

3 Results and Discussion

3.1 Corrosion Acceleration Results

The results of accelerated corrosion of pre-corrosion and post-corrosion concrete specimens are shown in Table 3 and Table 4 below.

Table 3. Results of accelerated corrosion in pre-corrosion concrete

Sample	Corrosion level (%)	Estimated Mass Loss (grams)	Actual Mass Loss (grams)	Derivation (grams)
A1	1	5	5	0
A2	1	5	10	5
B1	2	10.2	5	5.2
B2	2	10.2	15	4.8
C1	3	15.3	5	10.3
C2	3	15.3	15	0.3
D1	4	20.4	15	5.4
D2	4	20.4	15	5.4
E1	5	25.5	20	5.5
E2	5	25.5	20	5.5

Based on the results of pre-and post-corrosion specimens, it is shown that the difference in corrosion mass loss is in the range of 0 - 10.3 grams. The most significant difference occurred in specimen C1, this may have occurred due to the uneven distribution of current in the DC power supply device.

Table 4. Results of accelerated corrosion in post-corrosion concrete

Sample	Corrosion level (%)	Estimated Mass Loss (grams)	Actual Mass Loss (grams)	Derivation (grams)
B1A	1	5.15	5,15	0
B1B	1	5.15	5	0.15
B2A	2	10.3	10	0.3
B2B	2	10.3	10,3	0
B3A	3	15.45	15	0.45
B3B	3	15.45	15.2	0.25
B4A	4	20.6	20.5	0.1
B4B	4	20.6	20.6	0
B5A	5	25.75	25.5	0.25
B5B	5	25.75	25	0.75

Meanwhile, as shown in Figure 5, pitting corrosion occurs in the reinforcement because of the corrosion process. Pitting occurs only at the ends of the reinforcement that are not covered with concrete. The occurrence of pitting at the ends of the reinforcement is thought to be caused by the installation of cables in the concrete to be connected to the DC power supply only at the ends of the reinforcement, thus causing the current supplied to the steel reinforcement to be less evenly distributed into the concrete. Apart from the cable installation being less than optimal, pitting at the ends of the reinforcement is also thought to be caused by the leaking of the waterproof layer at the ends of the concrete reinforcement. Leaking the waterproof layer at the ends of the reinforcement causes the 5% NaCl solution to immediately diffuse into the steel reinforcement, causing pitting corrosion at the ends of the concrete reinforcement steel. The corrosion process of reinforcing steel in NaCl solution shows that chloride ions selectively precipitate, absorb, and accumulate in the damaged area, resulting in pitting corrosion on the surface of reinforcing steel [28].

Fig. 5. Post-corrosion reinforcement

3.2 Density

Density testing is carried out to determine the density value of fresh concrete. The BN specimen is normal concrete that does not contain OPS, mask fiber, and is not corroded. BN has the highest density, namely 2510 kg/m^3. Meanwhile, other specimens containing OPS and mask fibers had a lower density. This is thought to have occurred because replacing some of the coarse aggregates with OPS by 10% reduced the density of the concrete. Because OPS has a lower specific gravity than gravel, it can make the concrete lighter. It can be seen in Figure 6 that the density value of the pre-corrosion specimen tends to experience a decreasing trend as the level of corrosion increases.

Meanwhile, the density value of post-corrosion specimens tends to experience an increasing trend along with increasing levels of corrosion. The decrease in density in the pre-corrosion specimens is thought to be due to weight loss in the concrete reinforcement due to the corrosion process. Meanwhile, the increase in density in post-corrosion concrete is caused by the accumulation of reinforcement corrosion cells in the concrete, increasing the mass of the concrete.

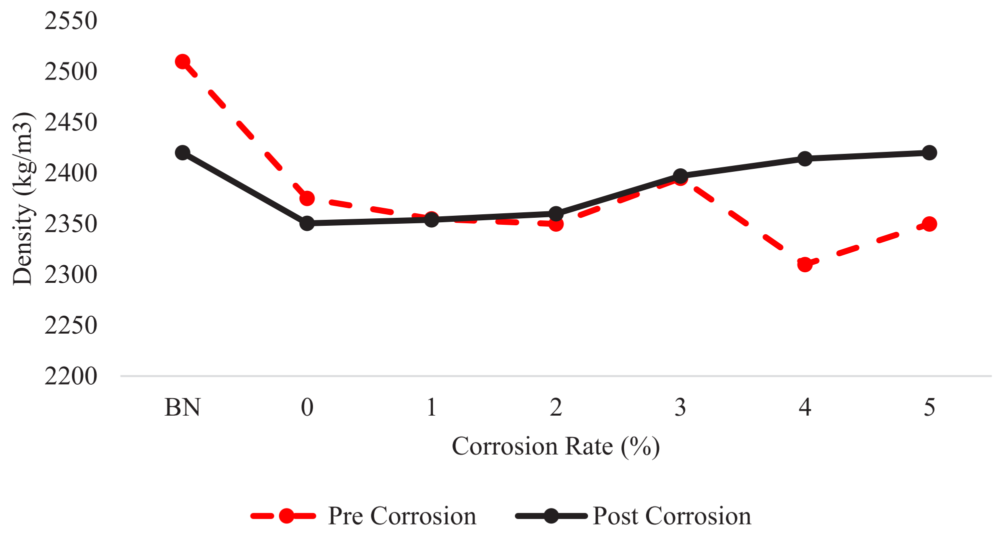

Fig. 6. Test object density graph

3.3 Ductility

Figure 7 the ductility of the specimen tends to decrease with the addition of OPS, which has a lower density than gravel. Concrete with OPS and a high tensile reinforcement ratio has low ductility [29]. In general, ductility decreases as the level of corrosion increases in test specimens containing OPS and mask fibers. The decrease in ductility is thought to occur due to corrosion of the specimen. In their research, Du et al. (2007) showed that corrosion in reinforced concrete beams resulted in a decrease in the ductility of the concrete, which was caused by a reduction in the ductility of the reinforcement and a decrease in bond strength due to corrosion [30].

In addition, a decrease in ductility may occur because the increase in mass loss of reinforcement due to corrosion in the concrete causes the concrete to become more brittle. Research conducted by Zhu et al. (2017) explained that the corrosion process can reduce the ductility of steel reinforcement. The failure in reinforcing steel gradually changes from ductile to brittle failure as the degree of corrosion increases [31].

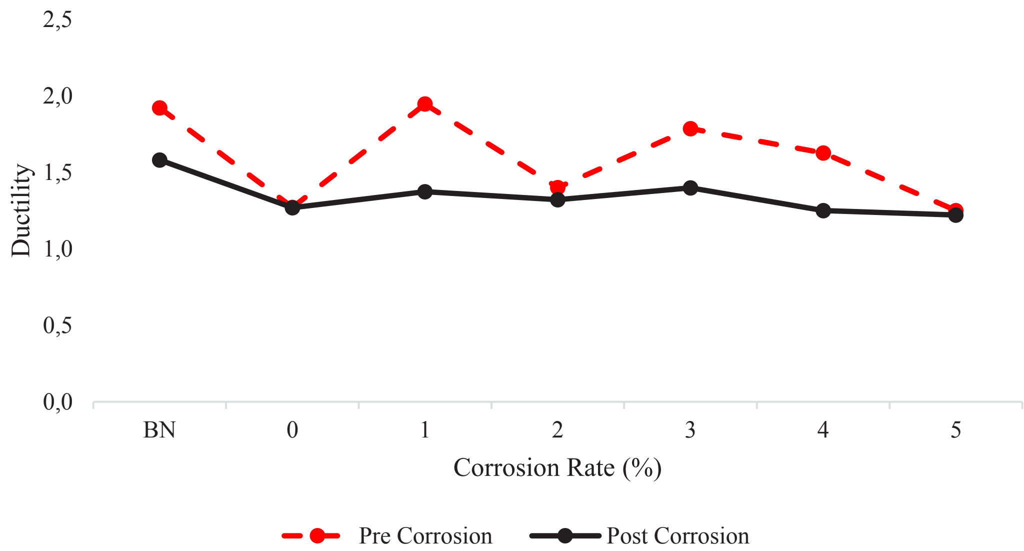

Fig. 7. Test object ductility graph.

3.4 Flexural strength test

Flexural strength testing on concrete was carried out to determine the flexural strength value produced by OPS concrete and mask fiber, which have different levels of corrosion. The test results in Figure 8 show that, in general, increasing the level of corrosion results in an increase in the flexural strength of the specimen. This is inversely proportional to research conducted by Ahmad

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(2018), where the results of flexural strength decreased as the level of corrosion in the concrete increased. Even though the corrosion experienced was high compared to other specimens because it had a high density, the flexural strength of the concrete did not decrease [13]. Research conducted by Othman et al. (2021) and Falliano et al. (2019) shows that the compressive strength and flexural strength of concrete increase with the high dry density of the concrete [32, 33]. This may also happen because the corrosion level of 5% does not have a significant effect on the flexural strength of specimens with OPS and mask fibers [13].

The flexural strength values, which tend to be stable or even increase in the specimens, are thought to occur due to the influence of adding mask fiber to the corroded OPS concrete mixture. The addition of mask fibers ensured that the specimens' flexural strength did not decrease even though the concrete had been corroded. Mask is a material that contains polypropylene fibers, which can increase the strength of concrete. Like research conducted by Abousnina et al. (2021), the flexural strength of concrete increases with the addition of polypropylene fibers in the concrete mixture [34].

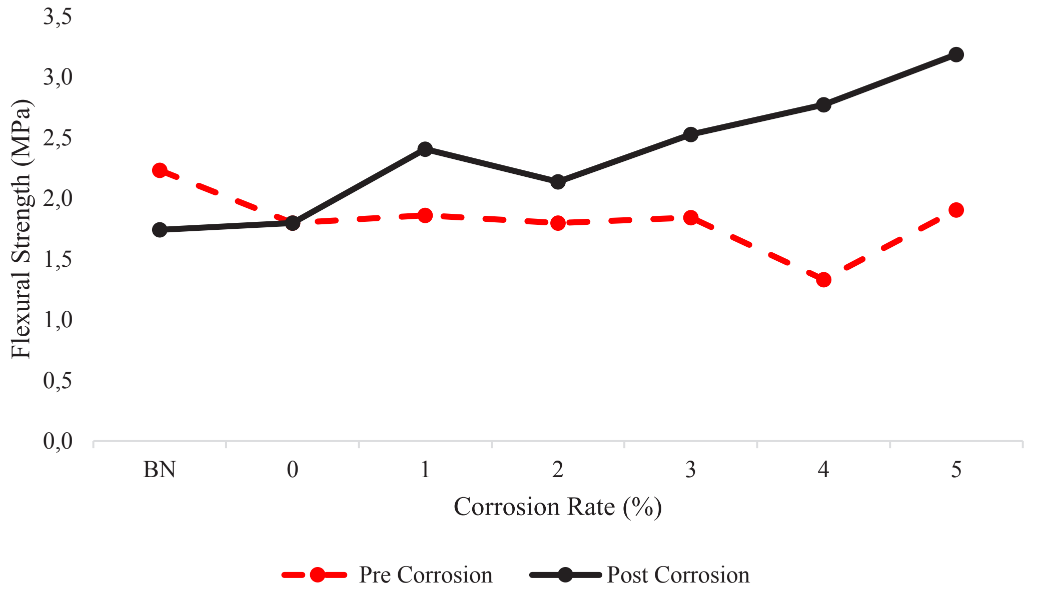

Fig. 8. Test object flexural test graph

3.5 Relationship Between Density and Flexural Strength of Corroded Concrete

It can be seen in Figure 9 that the flexural strength of post-corrosion concrete increases along with increasing density and the level of corrosion in the concrete. This can happen because the rust level of 5% does not have much effect on the flexural strength value. The higher density value of the concrete also increases its flexural strength value [33]. Apart from that, adding mask fiber (polypropylene) to the concrete mixture has been proven to increase the flexural strength of the concrete [35].

However, the test results of pre-corrosion specimens show that, in general, the relationship between dry density is directly proportional to flexural strength. Density and flexural strength tend to decrease with increasing levels of corrosion on the test object. This happens because the more significant mass loss of reinforcement results in a decrease in the density and flexural strength of the concrete. In addition, the flexural strength of corroded reinforced concrete beams can largely depend on the bond strength of the corroded reinforcement [36].

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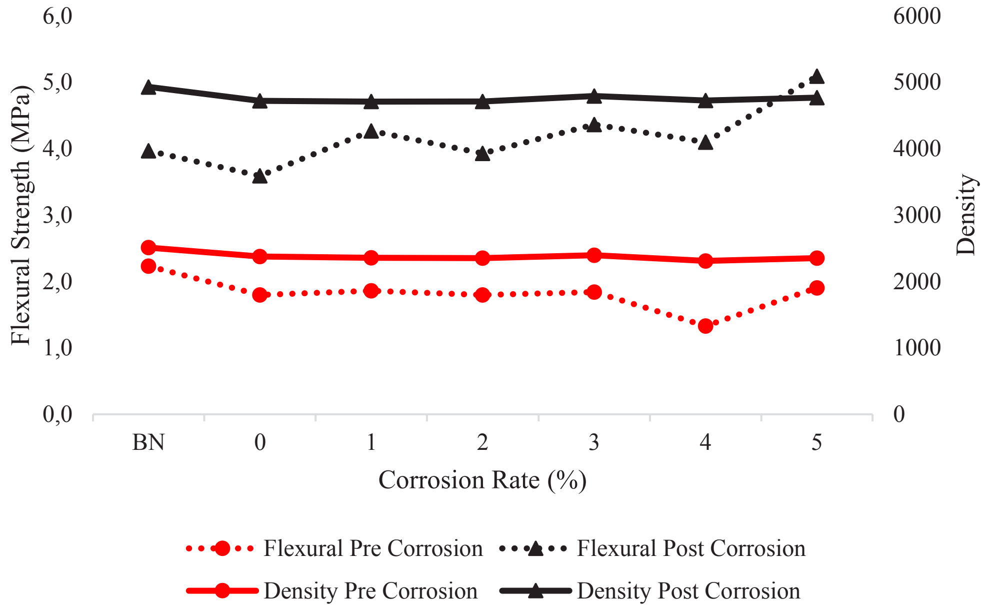

Fig. 9. Graph of the relationship between density and flexural strength

4 Conclusions

Based on test results obtained from research on concrete with OPS and pre- and post-corrosion concrete mask fibers with different levels of variation, it shows that:

- There is a difference between the planned and actual mass loss, which is not too large due to the acceleration of corrosion because there may be an uneven distribution of electric current in the DC power supply current.
- The density of pre-corrosion specimens tends to experience a decreasing trend as the level of corrosion increases. Meanwhile, the density value of post-corrosion specimens tends to experience an increasing trend along with increasing levels of corrosion.
- The ductility of pre-corrosion and post-corrosion specimens experienced a decreasing trend along with increasing levels of corrosion.
- The flexural strength value of the post-corrosion specimen tends to increase with increasing corrosion. Meanwhile, the flexural strength value of the pre-corrosion specimen experienced a decreasing trend along with increasing levels of corrosion.
- The relationship between the flexural strength value is directly proportional to the density value of the specimen. High concrete density increases the flexural strength of concrete even at high levels of corrosion.

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