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Manufacturing of reinforcing bars from COVID-19 syringes plastic waste and comparing them with different reinforcing bars

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Abstract: COVID-19 syringes plastic waste is difficult to recycle, so this study focuses on the use of this waste in manufacturing reinforcing bars as an alternative to steel reinforcing bars or carbon fiber reinforced polymer bars. After sterilizing COVID-19 syringes, these syringes are immersed in liquid nitrogen and then hammered to turn into random fibers. After spinning these fibers to the appropriate diameter, they are coated with a layer of epoxy to become reinforcing bars. To test the efficiency of these bars, six samples of concrete beams were cast. The first beam sample was reinforced with manufactured plastic bars made from COVID-19 syringes. The second and third beam samples were reinforced with deformed and plain steel reinforcing bars, respectively. The fourth beam sample was reinforced with carbon fiber reinforced polymer bars. Meanwhile, the fifth and sixth beam samples were reinforced with glass fiber reinforced polymer bars and basalt fiber reinforced polymer bars, respectively. The experimental results showed a 29.5%, 18.2%, and 6.8% increase in the ultimate load of the beam sample reinforced with the manufactured plastic bars compared to the beam sample reinforced with plain steel reinforcing bars, the beam sample reinforced with basalt fiber reinforced polymer bars, and the beam sample reinforced with glass fiber reinforced polymer bars, respectively.
Keywords: *BFRP bars, CFRP bars, COVID-19 syringe, GFRP bars, Manufactured plastic bars, Plastic waste, Reinforced concrete beams.*

1. Introduction

Plastic wastes in general and plastic waste from COVID-19 syringes in particular, are dangerous to the Earth's ecosystem [1, 2]. COVID-19 vaccine syringe waste is considered the most dangerous type of waste from a medical point of view because it is difficult to dispose of Vanapalli, et al. [3] and Salman and Nhabih [4]. This waste is usually disposed of by throwing it away and collecting it in the form of cubes. Or by burning it, which causes the emission of toxic gases that lead to global warming and environmental pollution [5, 6]. The last method for disposing of COVID-19 vaccine syringe waste is by burying it in the soil. This method requires large areas and negatively affects the properties of the soil, especially its agricultural properties, because this waste is slow to decompose. During the COVID-19 pandemic, the production of syringes for this disease increased [7]. The world began producing millions of tons of these syringes. All of these single-use syringes are disposed of in waste cubes. This increased the danger of managing the plastic waste file, which was already complex before this pandemic. On the other hand, the matter is not limited to vaccine syringes, but includes all personal protective equipment from gloves, protective shields, eyeglasses, and sterilizer boxes. All of these equipments and supplies are single-use. All of these factors and conditions exacerbate the problem of disposing of this huge amount of plastic waste resulting from this pandemic [8]. Therefore, it has

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become necessary to think of environmentally friendly ways that achieve the goals of sustainable development to dispose of and reuse plastic waste. Recycling plastic waste and using it in the field of building materials is very effective and vital. Many studies and research have been conducted on this topic, including in the year 2021 [9] conducted a study on the possibility of using plastic waste to improve the flexural capacity of reinforced concrete beams. The researchers cut the plastic waste into strips of 0.8 mm thickness and 12 mm width. The researchers reached the conclusion that when using 9 strips, the maximum load of the reinforced beam increases by 280%, and when using 3 strips, the maximum load increases by 225%. Also, the deflection increases by 500% when using 9 strips and by 190% when using 3 strips [10] conducted a study focusing on evaluating the compressive strength, flexural strength and tensile strength of concrete after reinforcing it with a plastic mesh made of plastic waste with three layers. The most important conclusions of this study are an improvement of 11.1% in compressive strength, 2.7% in tensile strength and 13% in flexural strength. Ghanem, et al. [11] investigated the flexural behavior of concrete beams reinforced with plastic mesh formed from plastic waste. Twenty-seven beam specimens were cast, 24 beam specimens were reinforced with plastic waste mesh with varying gap ratio and effective width. The experimental results showed an increase in the flexural strength and stiffness of beams when using plastic waste mesh. It was observed that with increasing the effective width ratio from 0 to 0.58 the ultimate load increased, after this limit it decreased. Falih, et al. [12] studied the effect of using polyethylene terephthalate bottle waste as reinforcement bars in concrete beams. Polyethylene terephthalate bottle waste was cut by a tool into strips with a thickness of 0.5 mm, a width of 6 mm, and lengths ranging from (6000-11000 mm). These strips were used to form bars in three different ways, two braids were formed and twisted bundles were formed. The formed bars were placed in the same location of the reinforcement steel as an alternative to the reinforcement steel bars in the tension zone. They were also tensioned before casting with a tool in order to give them a straight texture. In this study, five concrete beams with dimensions of (150 * 200 * 1400) mm were cast. Two of them were control beams with and without steel reinforcement. The other three concrete beams were reinforced with three different shapes of polyethylene terephthalate bottle waste bars. The experimental results showed that the specimens containing bars formed from polyethylene terephthalate bottle waste had a maximum failure load 25% of the failure load of the specimens containing reinforced steel bars. This method can be used to produce reinforcing bars from polyethylene terephthalate bottle waste used for reinforcing secondary structural elements. Kumar, et al. [13] used waste polyethylene terephthalate as reinforcement in concrete beams with three different types of specimens, combined waste polyethylene terephthalate and steel reinforcement, waste polyethylene terephthalate only reinforcement, and without steel reinforcement. In type I, composite reinforcement beams with waste polyethylene terephthalate and steel in the tension zone. The type II is concrete beams reinforced with hollow waste polyethylene terephthalate bars only with inner and outer diameters of 22.8 mm and 24 mm respectively. The type III is concrete beams made without any reinforcement. The results showed that all types improved the flexural strength. Nhabih, et al. [14] manufactured plastic fibers (PFs) equivalent to carbon fiber reinforced polymer (CFRP) from plastic waste. By immersing the plastic waste in liquid nitrogen and then hammering it to turn it into fibers, then spinning and weaving it to become sheets similar to (CFRP) sheets. They studied the economic feasibility of producing these fibers and found that the cost of producing a square meter of these fibers is 25 times less than the cost of producing a square meter of (CFRP). They also found a great similarity between the mechanical and physical properties of the manufactured fibers and (CFRP). To verify the properties of the fibers manufactured from plastic waste, five reinforced concrete beams were cast. The first is a control beam. The second and third beams were reinforced and repaired with (CFRP) respectively. The fourth and fifth beams were reinforced and repaired with plastic fibers manufactured in this study respectively. From the results of the study, the increase in the ultimate load for the beams reinforced with (CFRP) or manufacturing plastic fibers ranged between 45.45 and 51%, respectively. Also, a variation in the type of failure occurred when varying the type of fibers, as the failure was ductile and gradual in the concrete beams reinforced or repaired with manufacturing plastic fibers, unlike what was in the concrete beams reinforced or repaired with (CFRP), where the failure was brittle and sudden. Aaroon and Majid [15] studied the effect of adding reinforcing bars manufactured from plastic waste on the properties of mortar less construction in seismic areas. They found that mortar less construction is more efficient than mortar-bound construction in seismic areas due to greater energy dissipation. In this study, plastic waste was recycled and reshaped using extrusion method, to produce low-cost reinforcing bars. Bamboo bars were taken as a reference. The stiffness and tensile strength of both were evaluated according to ASTM. The manufactured plastic bars could be an alternative solution to steel or bamboo bars in mortar less construction.

The main objective of this study is to find an effective, easy and fast way to dispose of COVID-19 plastic syringe waste. And reuse them in useful things that serve human society in an environmentally friendly way. This study also aims to manufacture reinforcing bars from these plastic wastes and compare them with traditional steel reinforcing bars and carbon or glass or basalt fiber reinforced polymer bars.

2. Laboratory Work

2.1. Manufacturing of Reinforcing Bars from COVID-19 Syringe Plastic Waste

First, the COVID-19 syringes are washed with soap and water. Then, they are sterilized with disinfectants. After that, they are immersed in liquid nitrogen. After being extracted from liquid nitrogen, these syringes are placed in a rotating vessel containing iron balls. These syringes are hit by the iron balls while the rotating vessel is rotating, turning them into random fibers. These fibers are spun to the required diameter, so they become like a rope. Then, the ends of the rope are fixed with a wooden board and nails and coated with epoxy [16, 17]. The final result turns into a bar similar to a carbon fiber reinforced polymer bar or a steel bar as shown in Figure 1. According to the authors' limited view and based on the literature review of previous research, we reached the conclusion that there is no method similar to this method in manufacturing reinforcement bars. Therefore, this method is considered the first method in the world in manufacturing reinforcement bars.

1) COVID-19 syringes after washing.

2) COVID-19 syringes after being immersed in liquid nitrogen.

3) Extraction of random fibers after hitting Covid-19 syringes

4) Spinning plastic fibers with the required diameter

5) Epoxy coating of spun fibers

6) Reinforcing bars from COVID-19 syringes

Figure 1.
Manufacturing of reinforcing bars from COVID-19 syringes plastic waste.

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2.2. Tensile Testing of Different Reinforcing Bars

To know the mechanical properties of the reinforcing bars manufactured from plastic waste of COVID-19 syringes (MP bar) and compare them with the mechanical properties of other reinforcing bars such as (CFRP bar, deformed steel bar DS, plain steel bar PS, GFRP bar, BFRP bar), a tensile test was conducted. The average results of three samples were taken for each type of reinforcing bars. Figure 2 shows the samples of reinforcing bars and the tensile testing device. The test results are mentioned in Table 1.

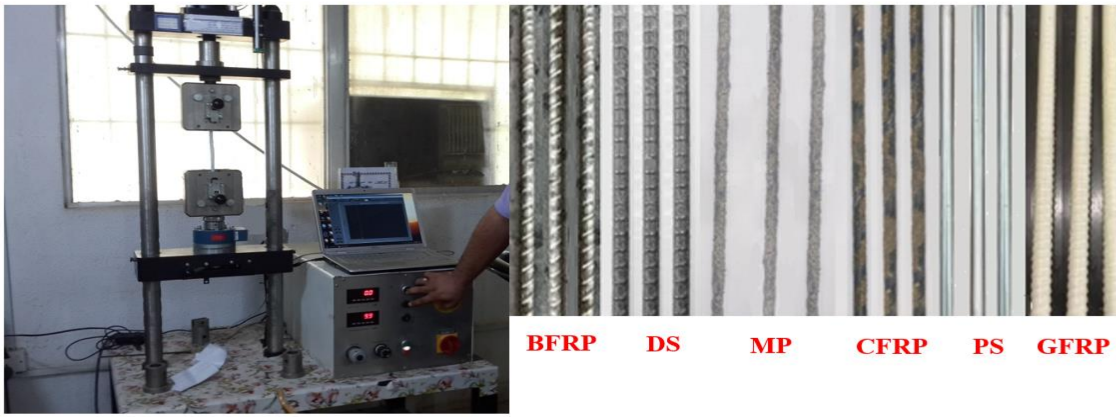

Figure 2.
The samples of reinforcing bars and the tensile testing device.

Table 1.
Tensile test results for different reinforcing bars.

Bar type	Diameter D (mm)	Yield strength F_y (MPa)	Ultimate strength F_u (MPa)	Modulus of elasticity GPa	Elongation %
MP	8	320	430	96	8.9
DS	8	440	580	201	11.4
CFRP	8	-	1654	155	1.8
GFRP	8	-	987	64	1.2
BFRP	8	-	890	57	1.7
PS	8	436	574	201	11.8

2.3. Materials Used

In the method of manufacturing reinforcement bars from plastic waste of COVID-19 syringes, Sikadur 330 C epoxy was used [18, 19]. This epoxy consists of two main parts, Resin A and Hardener B, mixed together in a ratio of 1:4. In order to investigate the structural performance of the reinforcement bars manufactured from plastic waste of COVID-19 syringes, concrete beams were cast. The concrete used for casting the beams consisted of washed sand, graded gravel (5-20 mm) [20, 21] ordinary portland cement [22] and potable water. The mixing ratio of the concrete components (cement: sand: gravel) was (1:1.32:2.62) and the W/C was equal to 0.45. Three cubes of 150x150x150 mm were cast to measure the compressive strength of concrete. The compressive strength of concrete was 24.67 MPa [23].

2.4. Reinforced Concrete Beam Samples

All the reinforced beam samples were cast in wooden molds. After the inner surface of the wooden molds was oiled, the reinforcement was placed and then the concrete was poured into the mold. The concrete of the beam sample was compacted using a vibrating press. Then the upper face of the concrete of the beam sample was polished using a trowel as shown in Figure 3.

Figure 3.
Casting process of reinforced concrete beam samples and their finishes.

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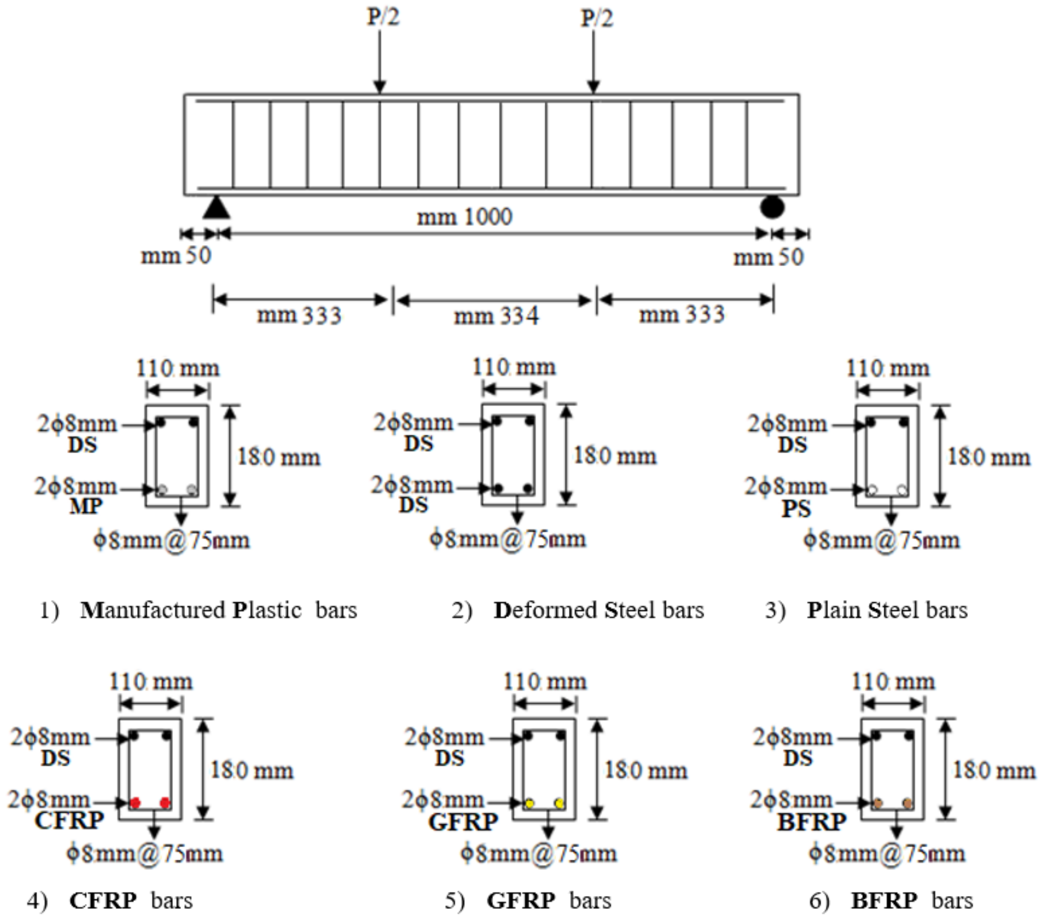

Figure 4.
Reinforcement details and dimensions of beam samples.

After 24 hours, the beam samples were placed in water tanks for curing. Six reinforced concrete beam samples were cast. All reinforced concrete beam samples were reinforced with ø8 mm @ 75 mm shear reinforcement to resist shear forces and to ensure that they do not fail under shear forces [24]. The cross-sectional dimensions of all beam samples were fixed (110x180mm) and 1100 mm long. All concrete beam samples were reinforced with two ø8mm deformed steel bars at the top [25]. At the bottom, they were reinforced with two bars of different types of reinforcing bars as shown in Figure (4). All reinforced concrete beam samples are coded with a two-part symbol: the first letter B refers to the word (Beam), and the second part refers to the type of reinforcing bars, for example, the symbol B-DS means a beam reinforced with deformed steel bars.

2.5. Testing of Reinforced Concrete Beam Samples

After 28 days (curing period), the reinforced concrete beam samples are painted with yellow paint so that the cracks are visible during the testing process [26, 27]. Then the sample is placed in the testing device and given simple support. The sample is loaded with two loads in the middle and the load is applied gradually (5 kN) until failure as shown in Figure (5). An LVDT is placed in the middle of the sample to measure the deflection. During the load application, the appearance of the first crack in the sample is monitored and the corresponding load is recorded to be the load of the first crack. All cracks that will appear during the test are marked with a marking pen [28].

Figure 5.
Reinforced concrete beam samples testing device.

3. Experimental Test Results and Discussion

The performance of the reinforcing bars manufactured from plastic waste of COVID-19 syringes was evaluated and compared with the performance of different reinforcing bars through load-deflection curve, ultimate load and failure mode, first crack load and crack pattern of test beam samples.

3.1. Load-Deflection Curves

Figure 6 shows the load-deflection curve of the concrete beam sample reinforced with reinforcing bars made from plastic waste of COVID-19 syringes (B-MP) and compares it with the curves of the rest of the beam samples. From Figure 6, it was noted that the behavior of the beam (B-MP) is similar to the behavior of the concrete beam reinforced with deformed steel bars (B-DS), i.e. ductile behavior. Also, the beam (B-MP) was stiffer than the beams (B-GFRP, B-BFRP, B-PS) and less stiff than the beams (B-DS, B-CFRP). This is due to two reasons: the value of the elastic modulus and the bonding strength between the bars and the concrete. Therefore, the bars made from plastic waste of COVID-19 syringes can be considered a successful alternative to the deformed steel bars, as they are superior to them in some important properties such as non-corrosion, light weight, non-magnetic, and non-conductive to electricity. When comparing the behavior of beam (B-MP) with the beam (B-CFRP), we notice that the beam (B-MP) is superior to the beam (B-CFRP) in the property of ductility, i.e. failure is gradual and not sudden, and this is very important in the design of reinforced concrete beams.

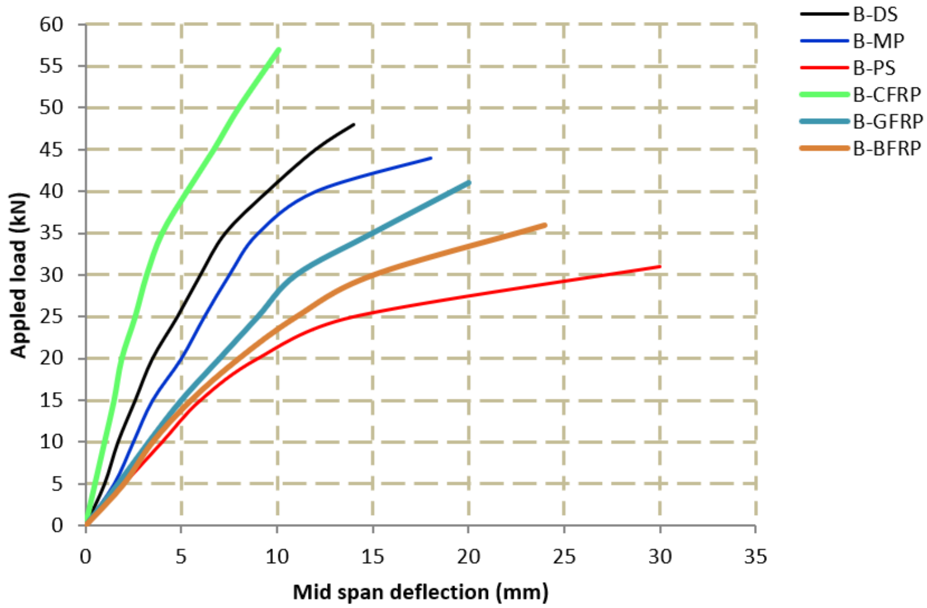

Figure 6.
The load-deflection curves for the tested beams.

The percentage decrease in deflection of beam (B-MP) at ultimate load was (66.7%, 33.3%, 11.1%) compared to the deflection of beams (B-PS, B-BFRP, B-GFRP) respectively. The percentage increase in deflection of beam (B-MP) at ultimate load was (22.2%, 43.9%) compared to the deflection of beams (B-CFRP, B-DS) respectively. This means that the bars manufactured from plastic waste for COVID-19 syringes meet the service requirements emphasized by ACI-code.

3.2. Ultimate Load and Failure Mode

Table 2 shows the ultimate load of the six concrete samples tested in this study. From the table shown below, it is noted that the percentage of increase in the ultimate load for beam (B-MP) was (6.8%, 18.2%, 29.5%) compared to beams (B-GFRP, B-BFRP, B-PS) respectively. As for the percentage of decrease in the ultimate load for beam (B-MP) it was (9%, 29.5%) compared to beams (B-DS, B-CFRP) respectively. Therefore, it can be said that the performance of plastic bars manufactured from plastic waste for COVID-19 syringes is better than the performance of BFRP bars, GFRP bars, plan steel bars and is very close to the performance of deformed steel bars and CFRP bars. The reason why the performance of manufactured plastic bars is close to that of deformed steel bars is their fibrous nature which makes failure gradual and prevents stress concentration while deformed steel bars which have a gap or any defect in their manufacturing process negatively affect the performance of these bars.

Table 2.
Ultimate load and failure mode for beam samples.

Beam samples	Ultimate load (kN)	Increasing in ultimate load %	Failure mode
B-MP	44	-	Flexure and yield in manufactured plastic bars
B-DS	48	-9	Flexure and yield in steel bars
B-CFRP	57	-29.5	Flexure and rupture in CFRP bars
B-GFRP	41	6.8	Flexure and rupture in GFRP bars
B-BFRP	36	18.2	Flexure and rupture in BFRP bars
B-PS	31	29.5	Flexure and deboning in plan steel bars

Also, from the above table it is noted that the failure mode of bars manufactured from plastic waste of COVID-19 syringes is yielding not rupture and it is similar to the failure mode of deformed steel bars. This failure mode is considered a positive point for the manufactured plastic bars.

3.3. Load of First Crack and Cracking Pattern

The efficiency of the bars manufactured from plastic waste of COVID-19 syringes in preventing cracks is almost the same as the efficiency of the deformed steel bars, as the first crack load of the beam (B-MP) was 13 kN, while the first crack load of the beam (B-DS) was 15 kN. The percentage increase in the first crack load of the beam (B-MP) was (7.7%, 23.1%, 30.1%) compared to the beams (B-GFRP, B-BFRP, B-PS) respectively. As for the percentage decrease in the first crack load of the beam (B-MP) was (15.4%, 38.5%) compared to the beams (B-CFRP, B-DS) respectively, as shown in Table (3). Therefore, it can be said that the manufactured plastic bars have efficiency in preventing the appearance of cracks that is comparable to the efficiency of deformed steel bars.

Table 3.
Load of first crack for beam samples.

Beam samples	Load of first crack (kN)	Increasing in load of first crack %
B-MP	13	-
B-DS	15	-15.4
B-CFRP	18	-38.5
B-GFRP	12	7.7
B-BFRP	10	23.1
B-PS	9	30.1

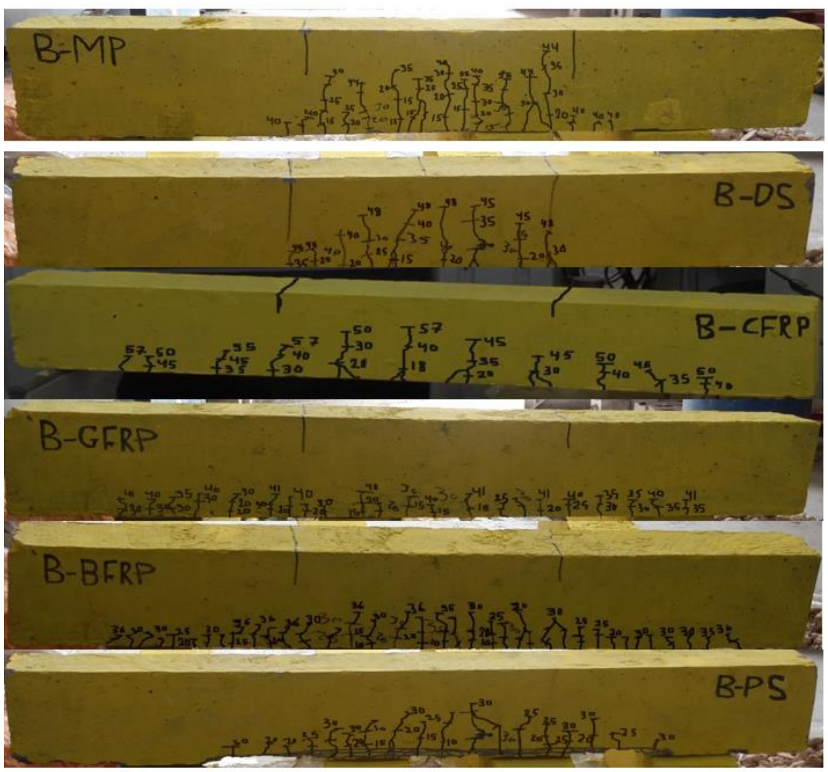

Figure 7.
Cracking pattern for beam samples.

From Figure 7 it is observed that the crack pattern of beam (B-MP) is similar to the crack pattern of beam (B-DS). The flexural cracks are concentrated in the middle third span of beam (B-MP). We can also observe that the crack pattern in beams (B-CFRP, B-GFRP, B-BFRP) is different from the crack pattern of beam (B-MP), where the cracks are spread almost along the entire beam span. The reason is due to the low bonding strength between the FRP bars and the concrete. It is worth noting that beam (B-PS) failed due to the deboning of the plan steel bars from the concrete because these bars do not have any deformed on their outer surface, which leads to a very large decrease in the bonding strength between these bars and the concrete.

4. Conclusions

1) Reinforcing bars can be manufactured from plastic waste from COVID-19 syringes, as they can be considered a successful future alternative to deformed steel bars.

2) The method of manufacturing reinforcing bars from plastic waste from COVID-19 syringes is practical, fast and economical, as the cost of producing a meter of these bars is only 0.5$.

3) The use of epoxy to coat the plastic fibers manufactured from COVID-19 syringe waste has a very important benefit, which is to make these bars rigid, similar to reinforcing steel bars, as it does not require tensile force to tension the manufactured bars when used to reinforce the concrete beam.

4) The percentage increase in the ultimate load of the beam reinforced with bars manufactured from plastic waste of COVID-19 syringes was (6.8%, 18.2%, 29.5%) compared to beams (B-GFRP, B-BFRP, B-PS) respectively.

5) The bars manufactured from plastic waste of COVID-19 syringes are distinguished from steel bars in that they are resistant to corrosion and rust, non-magnetic, non-conductive, lightweight, and resistant to acids and alkalis.

6) The bars manufactured from plastic waste of COVID-19 syringes are distinguished from CFRP bars in that they are ductile and do not behave brittle, which leads to making the failure of concrete beams reinforced with these bars a gradual failure and not a sudden failure, which makes the failure safer.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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