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Influence of the Oriented Configuration of the BarChip Fibre Polypropylene to the Ductility Factor of the Reinforced Concrete Beam

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Abstract

Bending and shear strength of fiber reinforced polimer concrete beams was studied in this research project. The reinforced concrete beam behaves in brittle structure in the certain reinforcement configuration. BarChip fibre polypropylene as the material for enhancement of the ductility factor is applied to the concrete beam. Three types of BarChip fibre configuration were examined: randomly spreading, placing at the mid-span area, and concentration on the tension zone. The experimental program included five beam specimens. Two of the beams were control specimens in which one was reinforced with no fibre, while the other one did not have any Barchips polypropylene. Each one of the other three specimens was reinforced with one of the above mentioned fibers by 0,4% volumetric ratio. Investigating the following issues for medium-high concrete strength was the goal of this study. In order to determine whether adding 0.4% volumetric ratio of polypropylenes as additional bar reinforcement in beams would provide adequate strength and stiffness properties comparable to reinforcing steel used as minimum bar reinforcement, it was necessary to first assess the effectiveness of each type of oriented fiber configuration on the bending strength, then to look into each beam's bending strength, shear strength, toughness, crack patterns, and near ultimate load crack width. The findings demonstrated that the bending capacity of the beam specimens was raised by all three types of polypropylene configuration more than by the beam reinforced with the fewest amount of bar reinforcement. Additionally, some of the employed fibers may cause failures other than pure shear. It is reccomended to spread the polypropylene within the tension zone of the reinforced concrete beam on the bottom mid span.

Keywords: Fibrous Concrete, Polypropylene, Ductility, Reinforced, Beam

1. Introduction

Polypropylene fibers can be classified as coarse and fine fibers. Fine polypropylene fiber is relatively small, and it can repair cracks after mixing with concrete, repair the original defects of concrete structure to a certain extent and inhibit cracks. The diameter of coarse polypropylene fibers varies from 0.1 to 1.0 mm, and their surface is formed by profiled rolling. In recent years, many research results on the mechanism of action of concrete blocks with polypropylene fibers have been obtained. **Khalid et al. (2018)** used recycled plastic waste as fibers in concrete blocks and found that higher amounts of fibers result in higher tensile strength of concrete structures.

Khan et al. (2011) established constitutive models for elastic failures of concrete members, including concrete fractures, carbon fiber reinforced polymer fractures and concrete carbon fiber reinforced polymer interface failures. **Lee (2017)** evaluated the infusion of concrete strength and fiber content at the proportional limits of concrete, residual bending strength and energy absorption capacity, it was shown that fiber-reinforced concrete blocks with a strength of 45 MPa shows a high increase in residual bending strength immediately after cracking concrete, especially for the 0.5% fiber volume fraction.

Ferreira et al. (2016) found that reinforced concrete with mixed fibers showed excellent toughness due to the interaction between fibers. **Sahoo et al. (2015)** found that the ductility of beam specimen displacement increased by 120% with the addition of polypropylene fibers with a volume fraction of 1%. In all beam specimens, a better post-peak residual strength response is generated due to multi-site cracks caused by connections between fibers. **Asgari et al. (2019)** found that glass fiber reinforced concrete layers can significantly increase the bearing capacity and final defection of blocks by strengthening concrete blocks with section expansion methods.

Abdelrazik et al. (2020) discussed fiber type and volume infusions on the properties of fiber-reinforced concrete. Liu et al. , 2016; Zhang et al., 2018) studied the effects of fiber types and hybrid modes on tensile behavior, flexural toughness and fracture mechanical properties of very high-performance concrete, it was shown that the critical value of coarse aggregate substitution rate is 25%, and the effects of different types of fibers on compressive strength are similar. Saje et al. (2011) found that the shrinkage of fiber-reinforced concrete was greatly reduced by increasing the fiber content to 0.5% of the composite volume. Hameed et al. (2020) found that the negative effects of recycled aggregates can be minimized by the addition of polypropylene fibers. Das et al. (2018) revealed that fibers play an important role in determining the tensile and flexural strength of split concrete, whose maximum increases are 12.01% and 17.15% for split and flexural strength values.

Xu et al. (2017), Deng et al., (2018); and **Huang et al., (2019)** studied the bond strength of defective reinforcement embedded in the matrix of polypropylene steel hybrid fiber reinforced concrete and the interface bond properties of steel fiber in polypropylene steel hybrid fiber-reinforced cement-based composites, it was found that compared to specimens made with plain concrete, the introduction of hybrid fiber can exert a clear positive influence on bond strength.

Spinella et al. (2012) predicted a complete load-versus-displacement curve by adapting a nonlinear finite element code for plain and reinforced concrete. **Zhang et al. (2014)** studied the shear behavior of polypropylene fiber-reinforced ECC beams with various shear reinforcement ratios. **Navas et al. (2020)** studied the shear behavior of macro synthetic fiber reinforced concrete blocks and compared them with steel fiber reinforced concrete blocks. **Arslan et al. (2017)** found that the shear strength and ductility of the beam were improved by adding polypropylene fibers, but the addition of polypropylene fibers even at 3% by volume could not change the failure mode for beams with effective shear depth and width ratios of 2.5 and 3.5.

The concrete technology of utilizing fiber from polypropylene material as a concrete mixture is to increase the performance of concrete which has actually been widely used abroad and proven its effectiveness. The use of polypropylene course synthetic fiber can also be an alternative material to replace reinforcing steel in concrete that is able to provide better concrete performance. To determine the effectiveness of adding polypropylene plastic synthetic fibers in terms of the amount of strength contributed and the level of ease of work, it is necessary to conduct a study and assessment in the laboratory through testing the configuration of polyporylene fiber courses on the strength and ductility factor of reinforced concrete beam specimens.

2. Methodology

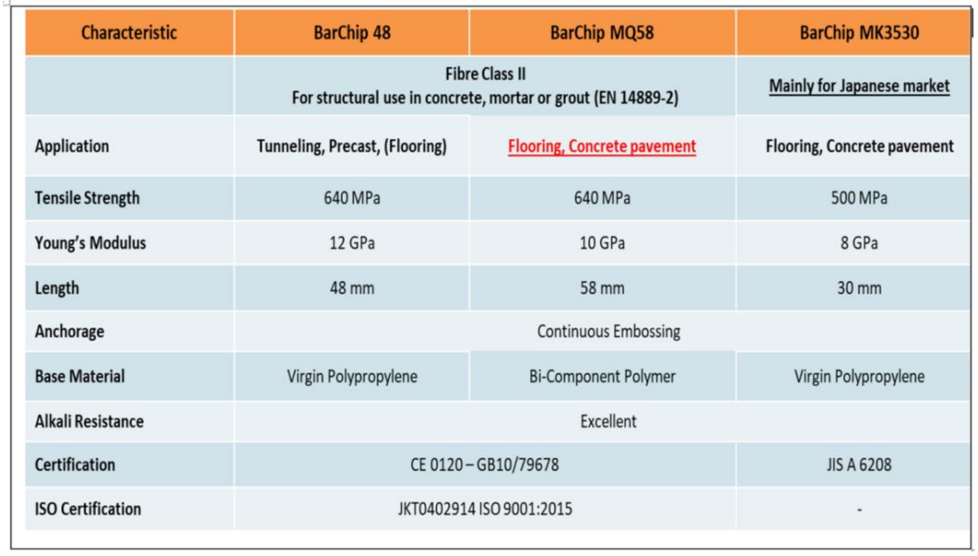
Polymer processing technology into Polypropylene continues to show very rapid development. One of them is formed into plastic fibers that are useful for strengthening concrete (fibre concrete) with various types and sizes, this fiber concrete began to be widely applied to improve the brittle properties of concrete to become more ductile. Furthermore, this synthetic fiber is commonly referred to as fiber reinforced plastic (FRP / Fiber Reinforced Plastic), as shown in Figure 1 below.

Fig 1. Various forms of Polypropylene Fiber (Barchip) and mixed with concrete
Source: www.barchips.com

The quality of synthetic fibers from poly-propylene polymer material for concrete reinforcement (FRP/Fibre Reinforcement Plastic) is largely determined by the machining process and the accuracy of the process, because it is not enough just from the characteristic properties of tough polypropylene, but the tensile strength and modulus of elasticity are largely determined from the production method. The modulus of elasticity of this plastic fiber will later determine the level of stiffness of the product so that it will provide good toughness when applied to concrete later.

The following table shows several types of specification data for Plastic Reinforcement Fiber / FRP Barchip that have been used in Indonesia for structural reinforcement in the Japek Elevated (MBZ) project and "Shotcrete" for Freeport's underground mine (Table 2 below).

Table 2 Barchip Plastic Fiber Product Specification List



Characteristic	BarChip 48	BarChip MQ58	BarChip MK3530
	Fibre Class II For structural use in concrete, mortar or grout (EN 14889-2)		Mainly for Japanese market
Application	Tunneling, Precast, (Flooring)	Flooring, Concrete pavement	Flooring, Concrete pavement
Tensile Strength	640 MPa	640 MPa	500 MPa
Young's Modulus	12 GPa	10 GPa	8 GPa
Length	48 mm	58 mm	30 mm
Anchorage	Continuous Embossing		
Base Material	Virgin Polypropylene	Bi-Component Polymer	Virgin Polypropylene
Alkali Resistance	Excellent		
Certification	CE 0120 – GB10/79678		JIS A 6208
ISO Certification	JKT0402914 ISO 9001:2015		-

Souces: BarChip (2022)

Several stages of the production and machining process are briefly introduced to process polypropylene plastic pellet raw materials into high quality macro plastic fibers (Barchips). So not only in terms of mechanical properties of fibers that must be controlled quality but also the size per fiber must be completely stable. This is necessary so that later when mixed in the concrete mortar, it will be evenly distributed when mixed in the concrete matrix. The complete process of manufacturing polypropylene synthetic macrofiber production can be seen in Figure 3 below.

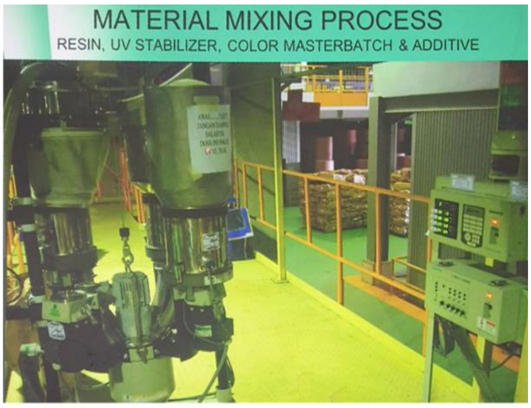


Fig. 3a Material Mixing Process

Fig. 3b Extruding Process

Fig. 3c Fibre Drawing Process

Fig. 3d Fibre Stretching Process

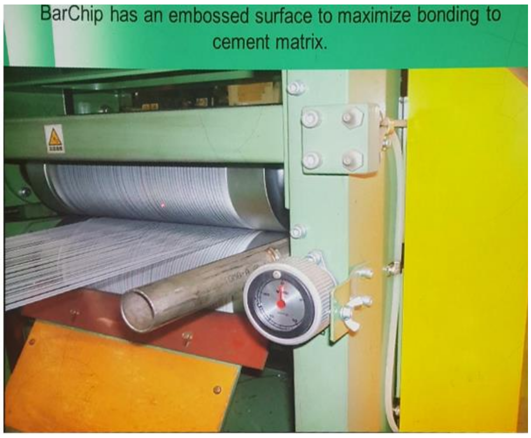


Fig. 3e Fibre Embossing Process

Fig. 3f Annealing Process

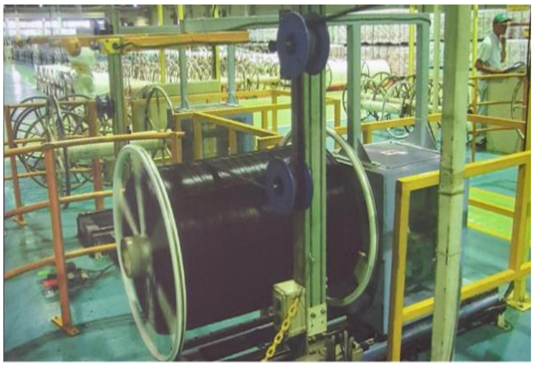


Fig. 3g Winding Process

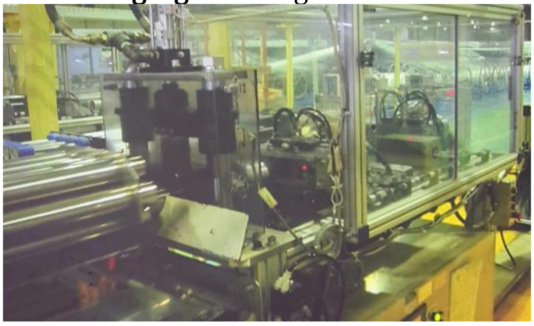


Fig. 3h Cutting Process

After several manufacturing processes of the polypropylene, the final product of BarChip plastic fibres, shown in Figure 4.

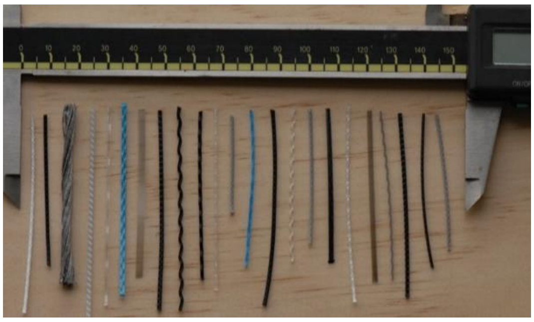


Fig. 4 Barchip polypropylene types

Plain concrete has very low tensile strength, limited ductility and little resistance to cracking despite strong compressive resistance. Internal micro-cracks are inherently (creeping) very easy to occur in this type of concrete because of its poor tensile strength caused by the propagation of the cracks, which eventually break due to the brittle nature of the concrete. The addition of small macroplastic fibres (Barchip) and close to the spread in concrete and evenly will resist cracks. This type of concrete is known as Fiber Reinforced Concrete. Fibers are usually used in concrete to control the rate of cracking (cracking control) due to plastic shrinkage and dry shrinkage. These fibres will also reduce the permeability of concrete and thus reduce water leakage. Some types of fibres have had a greater impact, such as abrasion resistance and rupture resistance in concrete (Sundaram, 2011). Small micro plastic fibre (BarChip 48) applied to the fibre reinforced concrete is shown in Fig. 5 below.

Fig. 5 Polypropilene BarChip48

Material properties of BarChip48 can be depicted in Table 3 below.

Table 3 BarChip48 properties

Characteristics	Material Properties
Basic Resin	Modifed Olefein
Length	48 mm
Tensile strength	640 MPa
Surface texture	Continously emboss
Amount per kg	33.000 pieces
Specific gravity	0.90 – 0.92
Youngs Modulus	10 GPa
Yield point	159 – 179 °C
Flame point	Above 450 °C

Source: www.barchip.com

Concrete Compressive Strength Test

Three cylindrical specimens were tested on the same day as beam testing, which is twenty-eight days after casting. For fibre-reinforced beams, the other three specimens were tested using ACCU-TEK 250 digital series compression testers following ASTM.

Therefore, for each beam specimen there are at least three cylindrical specimens tested. The results of the compressive test and the calculation of the compressive strength characteristics are shown in Tables 4 below. Figure 6 follows a plotting of specimen compressive strength results based on adjustment to standard deviation, with the target of the compressive strength f_c' 25 MPa.

Table 4 Compressive strength

Speciment	f_c' (MPa)	f_{ck}' (MPa)
CPC-1	25,45	
CPC-2	26,02	
CPC-3	26,30	
f_{cm} (MPa)	0,353	
Mean: 25,93 MPa		25,45
CPC-B1	26,59	
CPC-B2	26,87	
CPC-B3	27,15	
f_{cm} (MPa)	0,231	
Mean: 26,87 MPa		26,56

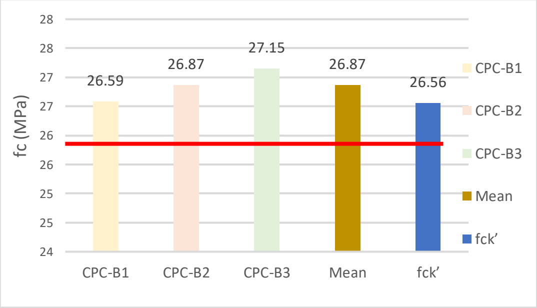


Fig. 6 Cylinder f_c'BarChip48

For parameters of reinforced concrete beam specimens used with several dimensional variables, see Figure 7 below. The beam specimens has 500 mm length, square size 150/150 mm with two applied point loads. The RC beams are designed into single reinforcement beam (SRB) and doubly reinforced beam (DRB).

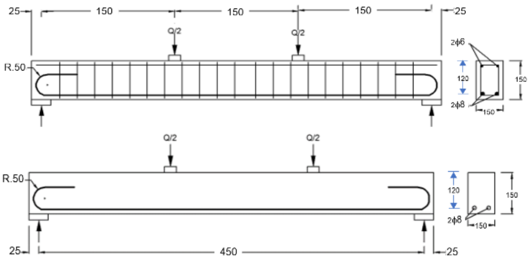


Fig. 6 RC beam specimens

The RC beams are subjected to additional polypropylene BC48 with the oriented configuration as shown in the Fig. 7 below.

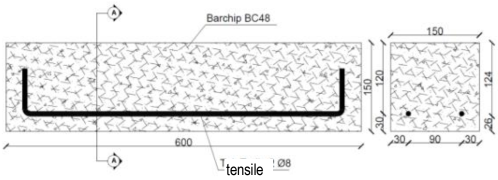


Fig. 7a BarChip in randomly oriented

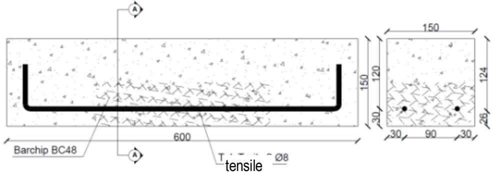


Fig. 7b BarChip in tension area of SRB

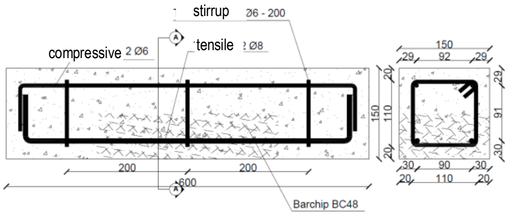


Fig. 7c BarChip in tension area of DRB

In ASTM C1018, toughness (or energy absorption defined as an area under the loaddeflection curve) is calculated out to 4 specified deflections (δ, 3δ, 5.5δ and 10.5δ, Fig. 8). The toughness calculated out to the deflection δ is considered the elastic or prepeak toughness (first-crack toughness), while the other three (at 3δ, 5.5δ and 10.5δ) are considered the post-peak toughness. Area OAB = Toughness corresponded to deflection of δ, (T_{δ}) Area OACD = Toughness corresponded to the deflection of 3δ, ($T_{3\delta}$) Area OAEF = Toughness corresponded to the deflection of 5.5δ, ($T_{5.5\delta}$) Area OAGH = Toughness corresponded to the deflection of 10.5δ ($T_{10.5\delta}$) where δ = The deflection at the linear elastic limit.

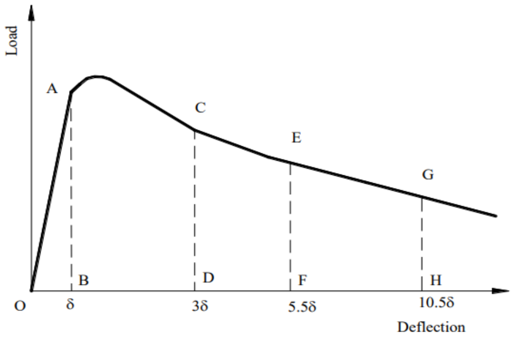


Fig. 8 Fracture toughness and Indices according to ASTM C1018

In addition, the terms of toughness indices (I_5, I_{10} and I_{20}) are also calculated. Each index is the ratio between the post-peak toughness and the pre-peak (elastic) toughness (Fig. 2).

$$I_5 = \text{Area OACD}/\text{Area OAB} \qquad (1)$$

$$I_{10} = \text{Area OAEF}/\text{Area OAB} \qquad (2)$$

$$I_{20} = \text{Area OAGH}/\text{Area OAB} \qquad (3)$$

The residual strength represented the average post-cracking load that the specimen may carry over a specific deflection interval, are usually determined as follows:

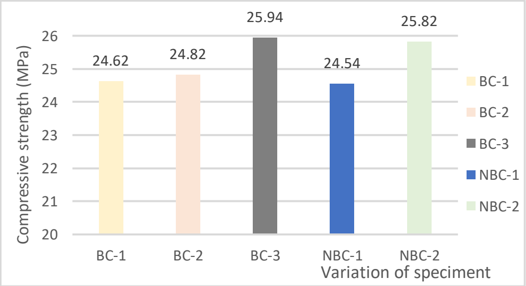
$$R_{5,10} = 20\ (I_{10} - I_5), \qquad (4)$$

$$R_{10,20} = 10\ (I_{20} - I_{10}) \qquad (5)$$

Results and Discussions

For each type of FRP fibre reinforced concrete beam, five specimens of the beam with the size of 150mm x 150mm x 500mm were sampled following ASTM C172, and left in curing for twenty-eight days. The bending strength of steel fiber reinforced concrete is determined based on ASTM C1609 (2007). Control checks of beams with tensile reinforcement and shear reinforcement are tested for the presence of effective fibres within the RC beam. Table 9 below shows the maximum stress of five reinforced concrete beams with 0.4% FRP BarChip added with the portion of 49.68 grams for each beam speciment.

Table 9 Maximum stress of FRB



The results of the comparative analysis between BC2 and NBC1 beams with and without additional BarChip48, analytically and experimentally, can be shown in Table 8 below.

Table 8 Maximum stress of BCT-2 RC beams

Speciment	Load (kN)	P_{max} (kN)	$f_{c,max}$ (MPa)
NBC-1 (E)	15,68	7,84	24,82
NBC-1 (M)	15,96	7,98	24,18
BCT-2 (E)	16,68	8,34	24,94
BCT-2 (M)	16,36	8,18	24,24
Δ P_{max} NBC-1 (E) & BCT-2 (E) = 0,50 kN			5,82%

Based on the results from Table 8 above, it can be seen that the value of the difference between doubly reinforcement concrete beams with the additional BarChip concentrated in the tension area of the lower middle of the span, is only able to increase the maximum load not too significantly by 0.40 kN or only by 5.82%.

The results of the comparative analysis between BCT3 and NBC2 beams with and without additional BarChip48, analytically and experimentally, as shown in Table 9.

Table 9 Maximum stress of BC3 RC beams

Speciment	Load (kN)	P_{max} (kN)	$f_{c,\max}$ (MPa)
NBC-2 (E)	16,48	8,24	25,82
NBC-2 (M)	16,36	8,18	25,18
BCT-3 (E)	17,06	8,38	25,94
BCT-3 (M)	17,26	8,58	25,24
Δ P_{max} NBC-2 (E) & BC-3 (E) = 0,40 kN			4,89%

Based on the results from Table 9 above, it can be seen that the value of the difference between doubly reinforcement concrete beams with the additional BarChip concentrated in the tension area of the lower middle of the span, is only able to increase the maximum concentrated load not too significantly by 0.40 kN; 4.89%.

The crack pattern of the speciment NBC-2 plain RC beam with no additional FRP shows slightly low resistance to enhance the deformation capacity after ultimate strength accordingly, as shown in Figure 9 below.

The RC beam shows the behavioural brittle material that the small crack resulted into sudden failure after reaching the maximum strength.

Fig. 9 Crack pattern of NBC-2

The crack pattern of the speciment BCT-3 with the influence of BarChip at the tension zone (TZ) shows significant resistance for enhance the deformation capacity in ductility factor increasing after ultimate strength accordingly, as shown in Figure 10.

Polypropylene fiber addition into concrete beams can effectively improve the initial crack shear force of beams, inhibit crack development, increase the number of cracks and reduce the crack width, which can increase the beam ductility and achieve crack resistance and toughening. It is required to spread FRP within the tension zone only in the area of bottom middle span with one third of RC beam length.

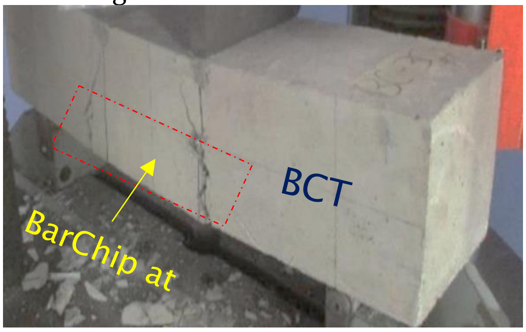


Fig. 10 Crack pattern of BCT-3

Figure 11 shows the typical load-deflection responses of BC48 PFRC, Polypropylene Fibre Reinforced Concrete, and RC beams with tension reinforcement only. When contrasting PFRC with ordinary concrete, it was the response after peak that actually distinguished the PFRC from the normal concrete. The actions were more in line with brittle way, as soon as the tension energy was high enough for the crack to start spreading on its own, fracture happened nearly immediately after the peak load was reached as a result of the enormous quantity of discharge of energy. The fibre in PFRC bridging effect assisted in regulating the pace of discharge of energy. Consequently, FRC kept up its capacity to maintain load after peak.

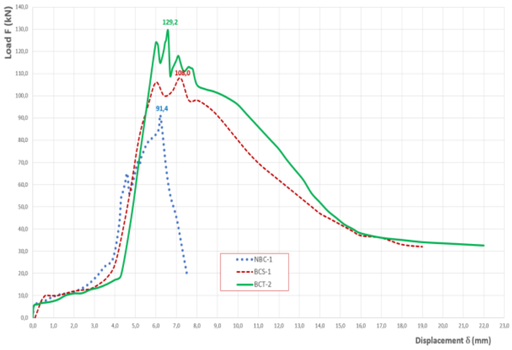


Fig. 11 Typical Load-Deflection Responses of Plain and Steel Fibre RC beam with single reinforcement

Before the peak, the load grows in direct proportion to the rising deflection. However, at the peak (where the concrete broke), there is a brief drop in load before the fibers took over and caused a more progressive drop in load. The downward long post peak response of PFRC indicates that, unlike plain concrete, where the point of concrete crack marked the point of failure, PFRC is able to sustain the load carrying capabilities even after the concrete has broken due to the action of fibers bridging across the crack surface.

The response seen here is a typical "double-peak" response in the case of polypropylene fibre reinforced concrete (PFRC) on the oriented configuration within the tension zone of RC beams on the bottom mid span as one third of the beam length, as illustrated in Fig. 12.

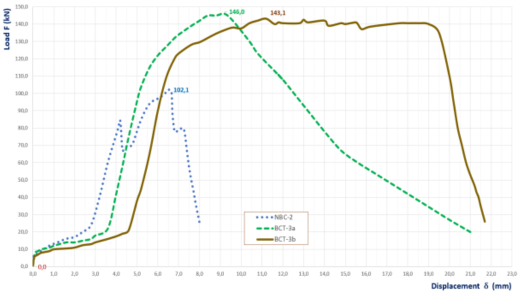


Fig. 12 Typical Load-Deflection Responses of Plain and Steel Fibre RC beam with doubly reinforcement

According to this method, the toughness is measured at four different deflections: one prior to the peak (T_{δ}) and three after the peak ($T_{3\delta}$, $T_{5.5\delta}$ and $T_{10.5\delta}$) (Table 10). Once obtained, they were then used to determine the toughness indices as shown in Table 10 and Fig. 13.

Table 10 ASTM Toughness Indices

RC beam type	Toughness (N-m)				Toughness Indices		
	δ	3δ	5.5δ	10.5δ	I_5	I_{10}	I_{20}
NBC-1	1,5	4,5	8,25	15,75	7,3	14,3	20,0
BCS-1	1,8	5,4	9,90	18,90	5,4	32,3	66,2
BCT-2	2,0	6,0	11,00	21,00	10,6	43,7	70,9
NBC-2	1,5	4,5	8,25	15,75	8,7	17,2	22,7
BCT-3a	1,9	5,7	10,45	19,95	10,6	40,2	68,4
BCT-3b	2,0	6,0	11,00	21,00	9,3	30,5	96,4

The ASTM toughness at various deflections appeared to function effectively in terms of capturing and reflecting the actual hardness characteristics of NBC and BCT.

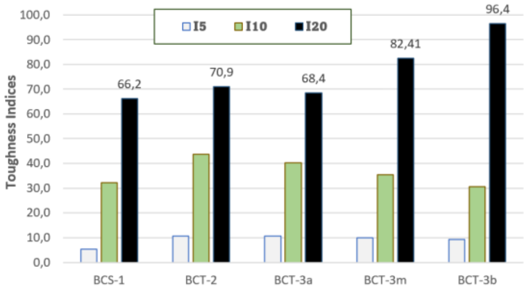


Fig. 13 Toughness Indices according to ASTM C108

Taking into account the hardness indices alone, failing to consider the load-deflection curve, a general depiction of the actions of both BCTs might be accomplished. For instance, the BCT's I_5 small value suggested that the BCT's performance at the little redirected. Nonetheless, the rising value of I_{20} raising the BCT to nearly equal levels with those of according to BCT, the effectiveness of the BCT was seen rather well at bigger distortion.

Conclusions

Based on the result and discussion above, it can be concluded that:

1. With the 0.4% BarChip concentrated in the lower tension area in the middle span, it will be able to replace some portion of the main reinforcement and shear reinforcement although not too significant.
2. Crack changes from the presence of BarChip, able to reduce the spread of cracks concentrated in tensile and shear zone.
3. With the addition of polypropylene fiber for random distribution through-out the concrete block, it can increase the value of thoughness index by 46,2 or doubled
4. With the addition of polypropylene fibre for distribution in the tensile area of concrete beams in the middle of the lower span, it can increase the value of thoughness index by 4,7 or 7,1%
5. The addition of BarChip48 polypropylene fibre within tension zone is able to significantly increase the ductility of reinforced beams through toughness indices, although the flexural strength increases not too significantly
6. The effectiveness of each type of fiber distribution (random orientation, half of the beam from the bottom along the beam, and only half of the beam from the bottom and centre of the beam stretch) on the shear strength of the beam, shows a significant increase in ductility with incresead touhness index if concentrated placing of the fibre in the tensile area along the middle of the lower span.

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