Strength and Structural Performance of Reinforced Concrete Beam with Artificial Plastic Fibre (APF)

S N Mokhatar¹, N A N A Mutalib², A M A Budie¹, A F Kamarudin¹ and M S Md Noh¹

¹ Jamilus Research Centre, Faculty of Civil & Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Batu Pahat, Johor
² Graduate Centre, Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Batu Pahat, Johor
Corresponding author: shahruln@uthm.edu.my

Abstract. Behaviour of Reinforced Concrete (RC) in beam structure has captured attention of many researchers. Many past researchers investigated the issue of concrete strength in tensile zone. The present research investigates the effect of waste nylon cable ties fibre that act as an Artificial Plastic Fibres (APF) in normal concrete mix and RC beam element. The concrete strength of 30 MPa have been utilized in this research. The percentage of APF that has been mixed with the concrete paste are 1% and 3%. For strength performance, nine (9) cube specimens and nine (9) cylinder specimens were tested under compressive and splitting tensile test, respectively. In addition, six (6) RC beam specimens were prepared and tested under three points bending test in order to investigate its structural performance. Based on the results, 0%, 1% and 3% of APF in concrete mix produces tensile strength of 1.89 MPa, 3.37 MPa and 2.66 MPa respectively. While, from the compression tests, 50.9 MPa, 47.2 MPa and 24.5 MPa were generated from 0%, 1% and 3% of APF, respectively. From this observations, only 1% of APF was employed in concrete mix to produce RC beam for structural performance investigations. Based on three point bending test, RC beam that consisting 1% of APF produced maximum load about 35.98 kN with 1.8 mm deflection compared with control specimen that can only endured until 27.93 kN of maximum load with 2.37 mm deflection. Further observation reveals that cracking of RC beam consisting 1% of APF reduce and delay the crack formation. Overall, utilization of 1% APF in RC beam successfully improves its strength and structural performance.

1. Introduction

Construction is one of the most dynamic industrial sectors around the world. The construction industry usually uses concrete as the major building materials [1-3]. Despite that, concrete still shows its weaknesses in term of cracking [4] at tensile zone. One of the inventions that can be done to increase the strength and structural performance of concrete beam is by using fibre. Many researchers such as [5-6] and [7] has been conducted study on the performance of concrete beam consisting fibre materials. However, study on efficiency of waste nylon cable ties as plastic fibre in concrete mix is still as yet fully explored. On the other hand, the production of waste in Malaysia is in the average of 30 000 tons with 5 percent were recycled [8]. This waste are also included for non-degradable waste [8]. An existent of this non-degradable waste in large quantities may somehow give bad impact towards environment [9]. Generally, nylon cable ties is one of the wastes that are non-degradable and take the high cost to recycle it back [10]. This material has been produced approximately 4 million tonnes with 13% is the production of chemical fibre production around the world in the year 2000 [10].
In concrete production, combination of steel with concrete helps in increasing the tensile strength capacity of the concrete. Therefore, the function of concrete could contribute for compression region, meanwhile, steel bar resolve problem in tension region [11-14]. Although RC can help in reducing the problem in tensile zone of concrete element, it is still undeniably that steel reinforcement cannot perform effectively in concrete. Steel reinforcement bar will only reduce the crack but not eliminate it [15]. Control or restrain the formation of cracking is significant in order to increase the lifespan of reinforced concrete in term of the durability of concrete structure [16]. In the previous research, many additional ingredient of concrete mix has been investigated such as from local waste product, waste organic materials, waste non-degradable products, etc. There is one literature conducted research on strength properties of nylon fibre and polypropylene fibre in reinforced concrete [17]. This research determines the best type of fibre that can be used to stop/reduce the development of micro-crack before it becomes macro-crack [17]. Based on study by Song et al [17], they found that the nylon fibre has the good strength properties compared to polypropylene fibres in improving the behaviour of concrete. Further, from the study by Nokman and Aziz [18], they applied heavy duty nylon cable ties fibre to solve the problems that related to concrete. They also found that the compressive and tensile strength of concrete can be increased by adding 1% of heavy duty nylon cable ties [18].

Hence, in this study, waste normal nylon cable tie fibre known as Artificial Plastic Fibre (APF) has been proposed as the solution to the above problem by adding this artificial fibre in concrete mix to reduce the tendency of cracking in concrete. Based on the previous research by [18], an additional of this material in concrete can improve the mechanical properties of concrete mix. Basically, this paper highlights the investigation of mechanical properties for concrete consisting of APF. Next, the optimum percentage of APF were added in concrete mix in order to explore the structural behaviour of reinforced concrete (RC) beam consisting this artificial fibre under three points bending test.

2. Samples Preparation and Testing Procedure

Generally, there are three major stages were implemented which includes: a) the preparation of nylon cable ties fibres as artificial plastic fibre known as APF, b) the preparation of concrete mix consisting 1% and 3% of APF, c) the production of RC beam specimens consisting only 1% APF as the optimum percentage of fibre. Compressive strength test were conducted and accordance to BS 1881 Part 116 (1983). All cubes were tested after 28 days of curing. Splitting tensile test is indirect method to obtain the tensile strength of concrete, which the specimen placed in a longitudinal axis and perpendicular to the load. This test conducted after curing at 28 days. The test are accordance to IS: 5816-1970. In this study, the innovation of APF preparation involved process of cutting, cleaning and measure the weight the APF. The length of APF are in the ranges of 30 mm to 50 mm which comply with the normal dimension of existing fibre. To clean up the APF from dust, these artificial fibres are soaked in the water to prevent impurities which may disturbed the bonding interaction with concrete paste. Then, APF are weighed to 1% and 3% as an additional materials in the concrete mix.

2.1. Concrete Mix Design and Specimen Size

Basically, APF acted as additional ingredients in concrete mix which do not affect the normal proportion of main ingredients in concrete mix design. In this research, 1% and 3% of APF were used as additives fibre to concrete mix. The quantities of APF used in this study are tabulated as in Table 1.

Design of normal concrete mix are based on DOE method. The target of concrete strength after 28 days of curing is 30 N/mm². The cube size is 0.1 m × 0.1 m × 0.1 m, while, the cylinder height and diameter are 0.3 m and 0.15 m, respectively. For beam specimen, the size is 0.8 m × 0.12 m × 0.15 m.

Table 1. Quantities of APF in kg
### Percentage of APF

| Sample | 1%  | 3%  |
|--------|-----|-----|
| Cube   | 0.10| 0.22|
| Cylinder | 0.43| 1.30|
| Beam   | 1.13| -   |

#### 2.2. Beam Design

The related specimen details for RC beam are described as in Figure 1. Three points bending test is a testing that measure and monitor the behaviour of specimens after crack initiation and during its propagation. This test revealed the peak load at first crack, ultimate load and maximum deflections of RC beam.

![Figure 1. Size and dimensions of steel reinforcement.](image)

#### 3. Results and Discussions

##### 3.1. Compressive Strength Test

Results for the compressive test of the cubes after 28 days are shown in Fig. 2. It can be observed that the usage of APF in concrete has influences the compressive strength. From this results, it can be seen that the presence of APF slightly reduces the concrete strength. However, the percentage difference for 1% APF in concrete mixes as compared with control specimen approximately about 7.3% which are still not gives the major different. However, 3% addition of APF decreases significantly the concrete strength about 51% in comparison to the reference specimen. More amount of APF in concrete are not efficient and suitable under compression state which reflect to the function of fibre can delay the crack formation during tensile.

![Figure 2. Effect of APF for compressive strength](image)
3.2. Splitting Tensile Strength Test
The tensile test results for cylinder specimens after 28 days are shown in Figure 3. Generally, the use of APF increases the tensile strength of the concrete owing to the bridging effect of the fibre. It can be seen that concrete containing 1% APF produces highest yet optimum tensile strength about 78% from normal concrete. While, the strength of concrete specimen with 3% APF is increased positively, however for only 41% as compared to control specimen (0% APF). This phenomenon can be reflected to the study by Nokman and Aziz [18] that concluded, the increasing percentage of heavy duty nylon fibre in concrete absorbs more water from concrete mix. Since APF is a hydrophilic material, it easily to absorb water and contributed to the lower water-cement ratio. As a result, APF can be limited until 1% in providing good workability of concrete which decreased result for 3% APF was due to the poor bonding interaction between APF, cement and aggregates that created honeycomb surface. Overall, it is confirmed that only 1% APF are suitable to be added in concrete mix.

![Figure 3. Effect of APF for tensile strength of concrete](image)

3.3. Three Points Bending Test
Concrete mix containing 1% APF were chosen as optimum percentage. For further investigations, normal RC beam that denoted as NRC and RC beam specimens containing only 1% APF were tested under three points bending test. During this test, first crack load, final crack pattern, ultimate load as well as maximum deflections of both type of RC beam were monitored and recorded accordingly.

3.3.1 First Crack Load
To summarize the results, Table 2 shows the average of loading that produced from first crack formation for three specimens of each type of RC beam. Based on graph in Figure 4, it can be found that the additional of 1% of APF in normal concrete beam has been delayed the formation of crack during certain load being applied. It can be also clearly seen that the APF in concrete reduce the crack growth in tensile region. From the graph, the presence of 1% APF in concrete beam specimen produced 18.2 kN loading value as compared to NRC that generated only 16.7 kN. It can be also concluded that the addition of 1% APF in NRC exhibits the higher loading for first crack by reducing the formation of crack that may harm the concrete structure and reinforcement bar inside the beam element.

| Beam Type          | No. | First crack load (kN) |
|--------------------|-----|-----------------------|
| NRC (control)      | 1   | 13.08                 |
|                    | 2   | 20.38                 |
|                    | 3   | 16.60                 |
|                    | Average | 16.70           |
| RC with 1% APF     | 1   | 17.86                 |
|                    | 2   | 17.11                 |
|                    | 3   | 19.62                 |
|                    | Average | 18.20           |
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3.3.2 RC Beam Behaviour (mode of failure)
The crack pattern and failure modes formed after imposed the ultimate load is shown in Figure 5 (a) and 5 (b). It can be seen that many diagonal and flexural cracks are developed for normal reinforced concrete beam that denoted as NRC (refer Figure 5(a)). While, for RC beam consisting 1% of APF generated lesser crack pattern and no severe flexural cracks are observed (refer Figure 5(b)). It is interesting to notice that the presence of 1% APF in concrete can reduce the formation of crack growth. However, this phenomenon can be further verified in the following sub-section for load-deflection graph.

![Figure 4. Average of first crack and its loading value for beam specimens.](image)

![Figure 5. Mode of failure for RC beam after](image)

3.3.3 RC Beam Behaviour (Load vs. Deflection)
For further observations, the overall load versus deflection curve for both beam specimens has been plotted clearly as shown in Figure 6. From the curve, NRC with 1% APF reaching highest maximum load with low deflection compared with control beam. 1% APF in NRC has increased the maximum load until 35.98 kN with deflection about 1.8 mm. While, for control specimen (NRC), the curve displays the maximum load for about 27.93 kN with 2.37 mm deflection. This curve can be verified the results from sub-section 3.3.1, where the load value trend is comparatively the same. The addition of 1% APF in concrete caused increasing of maximum load but delayed the crack formation. It can be proved from the deflection value for both beam type. Less deflection were recorded for the RC beam consisting 1% of APF.

This result reveals that the characteristic of APF as a fibre on concrete provided positive results towards structural performance of beam element. It is also due to the APF physical characteristic.
Basically, APF has a jagged (rough) physical surface and high toughness produce good bonding interaction with cement paste.

![Figure 6. Load verses deflection graph for beam specimens.](image)

4. Conclusions

Based on the analysis and discussion, several conclusions can be made:

i. Different tensile strength of APF does not give different effect towards producing a good performance of concrete.

ii. The innovation of artificial fibre from waste normal nylon cable tie has the capability to replicate the existing steel fibre in industry.

iii. Compressive strength of concrete are not affected significantly by adding APF in concrete mix.

iv. Tensile strength of concrete increased up to 78% by adding 1% of APF in concrete mix.

v. For structural element, 1% of APF in RC beam reduces the problem of severe cracking and crack formation especially at tensile region.

vi. By reusing waste nylon cable ties known as APF as additional substance in concrete mix, the quantity of this waste material disposed at site can be reduced. This would also reduce landfill consumption and promotes cleaner environment for future generation.

5. References

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