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# BEHAVIOUR OF POLYPROPYLENE FIBER REINFORCED CONCRETE UNDER DYNAMIC IMPACT LOAD

A. SAADUN, AZRUL A. MUTALIB*, R. HAMID, MOHAMED H. MUSSA

Department of Civil and Structural Engineering,
Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia,
43600 UKM Bangi, Selangor Darul Ehsan Malaysia
* Corresponding Author: azrulaam@ukm.edu.my

## Abstract

A study was conducted to examine the effect of mixing additives with concrete to increase the strength and durability of the concrete. The study looked at the how the use of additives affect several properties of the concrete. In this study a polypropylene (PP) fibre was mixed with concrete to study the mixture's dynamic response under impact load. References related to dynamic impact test for polypropylene fibre reinforced concrete (PPFRC) is very scarce and there is no specific research and information relating to this research. Therefore, this study looked at the dynamic impact of PPFRC through the use of Split Hopkinson Pressure Bar (SHPB). The samples used in this study comprised of concrete mixed with 1.0 kg/m³ PP fibre and 2.0 kg/m³ PP fibre, as well as plain concrete as a control sample. The PP fibre contains twisted bundle non-fibrillating monofilament and fibrillating network fibres. Samples were prepared using a cylindrical mould and three samples of each mixture were prepared with a 28-day curing period and a concrete grade of 35 MPa. These samples were then tested for dynamic impact using the SHPB at 2 MPa pressure under the strain rate of 10 s-1. The results for dynamic compressive strength showed that the values for samples SC1 and SC2, 13.22 % and 76.9 % respectively, increased compared to value of the control sample, and the dynamic compressive strength for sample SC1 and SC2 are74.5 MPa and 116.4 MPa respectively compared to 65.8 MPa for the control sample. The dynamic increase factor (DIF) showed that sample SC2 yielded the highest value (4.15) whereas the values for samples SC1 and SC3 are 2.14 and 1.97 respectively.

Keywords: Polypropylene (PP) fiber, Split Hopkinson Pressure Bar (SHPB), Impact load, Dynamic compressive strength.

| **Abbreviations** | |
|---|---|
| DIF | Dynamic increase factor |
| MPF | Macro Polymeric Fiber |
| PP | Polypropylene |
| PPFRC | Polypropylene fibre reinforced concrete |
| SFRHPC | Steel Fibre Reinforced High Performance Concrete |
| SHPB | Split Hopkinson Pressure Bar |

## 1. Introduction

Concrete is known to be a brittle material when subjected to tensile stress and impact load, with the tensile strength of concrete approximately one tenth of its compressive strength. As a result, concrete members are not able to withstand such loads and stress that are usually imposed on concrete structural members. Concrete members are usually reinforced with continuous reinforcing bars to withstand tensile stresses and to countervail for the lack of ductility and strength. Although the addition of steel reinforcement to concrete significantly increases its strength, the use of fibres to produce a concrete with homogenous tensile properties and better micro cracking behaviour has its advantages.

Different types of fibres have been used to reinforce concrete, and the choice of fibre range from synthetic organic materials, synthetic inorganic, natural organic, and natural inorganic. The most commonly used fibres to reinforce FRC are short discrete steel, glass, polyester, and polypropylene fibres. The type of fibres used as reinforcement is determined by the properties of the fibres, such as diameter, specific gravity, young's modulus, tensile strength, and the extent to which these fibres affect the properties of the cement matrix.

This study focused on the use of Forta Ferro fibre from different types of macro polymer fibres (Macro Polymeric Fiber, MPF) made from 100% virgin copolymer/polypropylene (PP), which were mixed with concrete as an additive. Simply stated, the polymer fibres used in this study is polypropylene fibre. PP fibre contains twisted bundle non-fibrillating monofilament and fibrillating network fibres. Laboratory studies were conducted to compare the properties of concrete mixed with PP fibre and plain concrete.

The effect of polypropylene fibre on the compressive strength of concrete has been discussed in some studies and they showed that polypropylene fibre either decrease or increase the compressive strength of concrete, but the overall effect is negligible in most cases. Many researchers reported that polypropylene fibre in small volume fraction (between 0.05% to 0.5%) has no or very small effect on the compressive strength of fibre reinforced concrete [1-4]; other researches have shown a significant increase in the compressive strength of fibre reinforced concrete. Ziad et al. [5] concluded that polypropylene fibres have a relatively small favourable effect on compressive strength of concrete when 12 mm (1/2 in.) long fibres were used. Song et al. [6] noted an enhancement of approximately 6% when using polypropylene fibres with a fibre content of 0.6 kg/m³ (0.037 lb/ft³). Mtasher et al. [7] noted a 22% increase in the compressive strength of concrete due to the presence of fibres in the concrete mix; the results of their study showed that the addition of polypropylene fibre in the amount of 0.4% and 1.5% increased the compressive strength up to 11% and 56% respectively.

This objective of this study is to determine the mechanical properties of polypropylene fibre reinforced concrete (PPFRC) when subjected to dynamic load at high strain rates, particularly from the loads of heavy vehicles. In this study PP fibre was used in concrete mixture used in the construction of slabs on the grounds outside buildings exposed to dynamic loads from various types of vehicles. The addition of PP fibres could prevent micro cracks in concrete. Control of micro cracks could prevent the development of macro cracks when a dynamic load is imposed directly on the surface of the concrete. This idea has been applied to improve the strength of the building structure (beams, slabs and columns) through the addition of PP fibres. This research studied the mechanical properties of dynamic compressive strength and dynamic load strength.

## 2. Material and Methods

### 2.1. Mixture composition and preparation

The materials required to produce fibre reinforced concrete is ordinary Portland cement, water, gravel, sand, and PP fibre. Ordinary Portland cement was prepared based on the British Standard (BS 12:1978) and has a moderate rate of hardening [8]. Water is an important factor in the reaction of the cement particles which serve to bind the aggregates; the strength of e concrete is also dependent upon the ratio of cement to water and the use of sanitary water. The water used in this study is tap water from the laboratory. Sand (fine aggregate) and gravel (coarse aggregate) are commonly used aggregates in concrete mix. Sand is usually not more than 5 mm in size while coarse aggregate is between 5 mm to 50 mm. The ratio of aggregates in conventional concrete mixes is between 60% to 80% of the concrete volume. The amount of PP fibre used in this study is accordance with the ratio set by the manufacturer of this PP fibre (MMM Industries Sdn Bhd).The PP fibre contains twisted bundle non-fibrillating monofilament and fibrillating network fibers. The material properties of the PP are shown in Table 1.

**Table 1. Material properties of PP.**

| Properties | Characteristics |
|---|---|
| Shape | Monofilament and twisted fibre system |
| Specific gravity | 0.91 |
| Tensile strength | 570 - 660 MPa |
| Length | 54 mm and 38 mm |

The ratio of the mix design is in accordance with with the method set by the British Department of Environment (DoE Method of Concrete Mix Design) [9]. Table 2 shows the amount of mixture for PP fibre reinforced concrete for a series of samples. Three types of samples were prepared and each sample contain varying amounts of PP fibre, namely concrete without fibre, PP fibre concrete with 1.0 kg/m$^3$ volume, and PP fibre concrete with 1.2 kg/m$^3$ volume. The units of mixture are kg/m$^3$ and concrete grade M35 or 35 maps were used in accordance with the schedule set by Vijay Mohan Dave [10]. The ratio of the concrete mix was cement material: water: coarse aggregate: fine aggregate at 441.18: 225: 1113.98: 599.84 kg/m$^3$. The compressive strength of each specimen was determined based on BS 1881: part 110: 1983 [11].

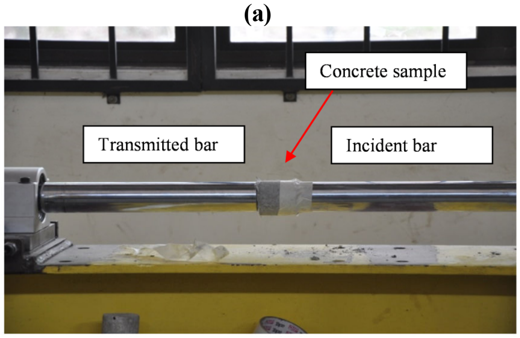
**Table 2. Design of concrete mixture for each series of mix (fcu = 35 MPa at 28 days).**

| No. | Code | Cement ($kg/m^3$) | PP ($kg/m^3$) | Water ($kg/m^3$) | Sand ($kg/m^3$) | Gravel ($kg/m^3$) |
|---|---|---|---|---|---|---|
| 1 | **SC1** | 441.18 | 1 | 225 | 599.84 | 1113.98 |
| 2 | **SC2** | 441.18 | 2 | 225 | 599.84 | 1113.98 |
| 3 | **SC3** | 441.18 | - | 225 | 599.84 | 1113.98 |

## 2.2. Dynamic compressive strength test

Dynamic compression tests were carried out on 50 mm-diameter and 50 mm-high cylinder samples with a 28-day curing period and a concrete grade of 35 MPa. Samples SC1, SC2 and SC3 (three samples each) were prepared and tested for dynamic impact using the Split Hopkinson Pressure Bar (SHPB) at 2 MPa pressure under a strain rate of 10 $s^{-1}$. A Split Hopkinson Pressure Bar (SHPB) was used to test the high strain rate material properties of the samples. The Hopkinson bar was used to impose a dynamic load on the samples akin to load the materials would experience in service. The impact testing system comprised of a gas gun chamber, a striker bar, an incident bar, and a transmission bar which held the concrete specimen in the middle of the bar. The value of the strain obtained from the strain gauge for the dynamic compression test was analysed with MATLAB to obtain the parameters. A dynamic compression test was performed by applying a load to the concrete cylinder sample for high strain rate. The samples comprised of 1.0 $kg/m^3$ PP fibre and 2.0 $kg/m^3$ PP fibre. Figure 1 shows the Split Hopkinson Pressure Bar (SHPB) system.

**(a)**




**(b)**

**Fig 1. (a) Split Hopkinson Pressure Bar system (SHPB), and (b) sample located between the transmitted and the incident bar.**

## 3. Results and Discussion

### 3.1. Static compressive strength test results

Workability is one of the properties of fresh concrete and the workability of a concrete could be measured with a slump test. The test conducted was based on BS 1881: Bahagian 102 [12]. As shown in Table 3, sample SC1 has a 60 mm slump, and the addition of 2 kg/m3 PP reduced the slump to 23 mm. Normal concrete has a slump of 15 mm. The higher slump values could be attributed to the low loss of ignition of the PP.

**Table 3. Results for slump test.**

| Sample | Quantity of PP (kg/m³) | Slump (mm) |
|---|---|---|
| SC1 | 1.0 | 60 |
| SC2 | 2.0 | 23 |
| SC3 | 0 | 15 |

In the study of strength of material, compressive strength is the capacity of a material or structure to withstand load. It is measured by plotting applied force against deformation in a testing machine. The results for a 28-day compressive strength under full water curing for various mixes are shown in Table 4. The compressive strength increased to 4.4 % with the addition of 1 kg/m3 PP but decreased to 15.93 when 2 kg/m3 pp was added. Too much PP might weaken the interfacial zone, hence reducing the strength. Tables 5 and 6 show the values of flexural strength and splitting tensile strength test. In this study, the flexural strength increased 14.62 % and 2.34 % for SC2 and SC3, respectively. Similarly, the addition of 2 kg/m3 PP increased the splitting tensile strength to 18.32 % from SC3. The increment of PP volume enhances the tensile strength of concrete since PP fibre has high tensile strength.

**Table 4. Static compressive strength.**

| Type of samples | Quantity of PP (kg/m³) | Compressive strength average ( MPa) | Percentage increment of strength (%) |
|---|---|---|---|
| SC1 | 1 | 34.87 | 4.4 |
| SC2 | 2 | 28.08 | - 15.93 |
| SC3 | 0 | 33.40 | - |

**Table 5. Static flexural strength.**

| Type of samples | Quantity of PP (kg/m³) | Flexural strength average ( MPa) | Percentage increment of strength (%) |
|---|---|---|---|
| SC1 | 1 | 3.50 | 2.34 |
| SC2 | 2 | 3.92 | 14.62 |
| SC3 | 0 | 3.42 | - |

**Table 6. Static splitting tensile strength.**

| Type of samples | Quantity of PP (kg/m³) | Splitting tensile strength average ( MPa) | Percentage increment of strength (%) |
|---|---|---|---|
| SC1 | 1 | 3.63 | 12.73 |
| SC2 | 2 | 3.81 | 18.32 |
| SC3 | 0 | 3.22 | - |

## 3.2. Results of dynamic compressive strength test

In this study the dynamic compressive strength test was conducted using the Split Hopkinson Pressure Bar (SHPB) at a pressure of 2 MPa for varying volumes of polypropylene fibre reinforced concrete (PPFRC). In a previous study conducted by Tan et al. [12] varying strain rates between30 to 60 s-1 were observed. Table 7 shows that the dynamic compression strength for samples SC1, SC2 and SC3 are 74.5 MPa, 116.4 MPa and 65.8 MPa respectively. The results showed that the values for samples SC1 and SC2 are 13.22 % and 76.9 % respectively with corresponding dynamic compressive strengths of 74.5 MPa and 116.4 MPa compared to 65.8 MPa. The results of critical strain for samples SC1, SC2 and SC3 are 0.00302, 0.001515, and 0.00257 respectively. The percentage difference showed that the critical strain for SC1 increased to 17.51% compared to the control concrete, while the critical strain for SC2 sample decreased to -41.05%.

A study conducted by Tan et al. [12] on steel fibre reinforced high performance concrete (SFRHPC) with fly ash showed that the values for dynamic compression strength for concrete samples C50F00, C50F05, C50F10 and C50F15 are 84.71 MPa, 116.4 MPa, 150.7 MPa and 177.6 MPa respectively, as shown in Table 8. The percentage increase for samples C50F05, C50F10 and C50F15 are 37%, 78% and 110% respectively compared to the control sample K50G00. The critical strain for samples C50F05, C50F10 and C50F15 are 1%, 4% and 20% respectively.

**Table 7. Results of dynamic impact test.**

| Code | PP (kg/m³) | Dynamic Compressive Strength ( MPa) | Difference (%) | Critical Strain (mm/mm) | Difference (%) |
|---|---|---|---|---|---|
| **SC1** | 1 | 74.5 | 13.22 | 0.00302 | 17.51 |
| **SC2** | 2 | 116.4 | 76.9 | 0.001515 | -41.05 |
| **SC3** | 0 | 65.8 | - | 0.00257 | - |

The results obtained in this study and a previous study conducted by Tan et al. [12] showed that dynamic compressive strength increased with the addition of fiber into the mixtures. It showed that the value for critical strain increased in sample SC1 compared with control concrete, but the value for SC2 decreased. The increase in the critical strain of sample SC1compared with the control sample is consistent with the increase in the ultimate dynamic compressive strength. This observation shows that the increase in critical strain in sample SC1 was due to the insufficient volume or composition of PP fibre (1.0 kg/m³) to absorb impact.

**Table 8. Results for the test conducted by Tan et al. [12] for Steel Fibre Reinforced High Performance Concrete (SFRHPC) with fly ash at strain rate (30 to 50) s-1.**

| Code | Strain Rate ($s^{-1}$) | Dynamic Compressive Strength ( MPa) | Difference (%) | Critical Strain (mm/mm) | Difference (%) |
|---|---|---|---|---|---|
| **C50F00** | 30.21 | 84.71 | - | 0.002896 | - |
| **C50F05** | 32.9 | 116.4 | 37 | 0.002932 | 1 |
| **C50F10** | 40 | 150.7 | 78 | 0.003005 | 4 |
| **C50F15** | 47.21 | 177.6 | 110 | 0.00347 | 20 |

SC2 showed a clear decrease in critical strain with a high ultimate dynamic compressive strength. This is due to the total volume of PP fibre, 2.0 kg/m³, which allows the fibre to absorb impact effectively. This, in turn, resulted in the PP fibre having a high tensile strength, namely 570-660 MPa. The tensile strength of PP fibre has a positive influence on the concrete samples during the transformation process of impact load. Figures 2 to 4 show the stress-strain graph for each sample tested with the Split Hopkinson Pressure Bar (SHPB).

## 3.3. Dynamic Increase Factor (DIF)

DIF is an important parameter in numerical modelling when a structural system is subjected to impact and blast load [13-15]. The results of dynamic increase factor for the concrete samples are shown in the Table 9. Sample SC2 has the highest value compared to all other samples. This shows that the increase in the volume of PP fibre is directly proportional with the value of dynamic increase factor. The results showed that the dynamic compressive strength was higher compared to static compressive strength. This proved that mixing PP fibres with concrete increase the dynamics ultimate compressive strength of the concrete. Table 10 shows the results from a previous study conducted by Tan et al. [16], in which the increase in dynamic compressive strength and static compressive strength are the same as in the results obtained in this study.

**Table 9. Dynamic Increase Factors.**

| Code | Dynamic Compressive Strength ( MPa) | Static Compressive Strength ( MPa) | DIF |
|---|---|---|---|
| **SC1** | 74.5 | 34.87 | 2.14 |
| **SC2** | 116.4 | 28.08 | 4.15 |
| **SC3** | 65.8 | 33.4 | 1.97 |

**Table 10. Dynamic Increase Factors for Tan et al. [13]**

| Code | Dynamic Compressive Strength ( MPa) | Static Compressive Strength ( MPa) | DIF |
|---|---|---|---|
| **C50F10** | 172.9 | 70 | 2.47 |
| **C50F15** | 191.0 | 74.38 | 2.57 |

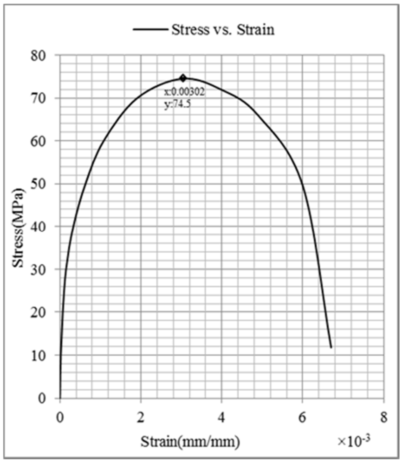



**Fig. 2. Stress-strain for SC1 under dynamic load.**

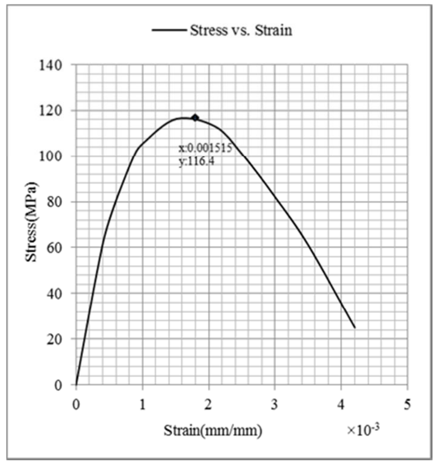



**Fig. 3. Stress-strain for SC2 under dynamic load.**

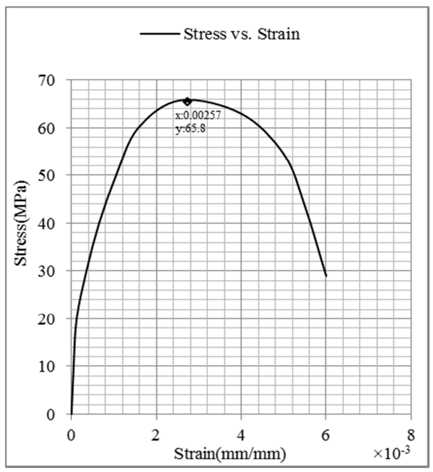



**Fig. 4. Stress-strain for SC3 under dynamic load.**

## 4. Conclusions

Based on the test results, it could be said that the objectives for this study have been achieved. The parameters of concern in this study are dynamic compressive strength, high strain rate, and dynamic increase factor for PP fibre reinforced concrete samples. The fibre used in this study was Forta Ferro brand polypropylene fibre sponsored by the MMM Industries Sdn Bhd. PP fiber has shown promising potential as an additive in steel reinforcement for concrete slabs. Laboratory tests were carried to determine the effects of PP fibre on concrete. In general, the increase in the values of the parameters due to the mixing of PP fibers with concrete could be applied to other structures such as slabs, beams, columns, and walls bearing load. The observations in this study showed that PP fibre could increase the ultimate dynamic compressive strength of the concrete effectively. The ultimate increase in dynamic compressive strength, namely 76.9%, was observed in sample SC2, which contain 2 kg / m³ PP fibre. Increasing the volume of PP fibre caused an increase in the ultimate dynamic compressive strength of polypropylene fibre reinforced concrete. On the other hand, the lowest critical strain was observed for sample SC2 (2.0 kg/m³), namely is 0.001515 (mm/mm), and this value showed that an increase in the amount of PP fibre have a positive impact on polypropylene fibre reinforced concrete. The values of the dynamic increase factor (DIF) for polypropylene fibre reinforced concrete samples with 1.0 kg / m³ and 2.0 kg / m³ fibers are 2.14 and 4.15 respectively. This shows that the ultimate dynamic compressive strength in polypropylene fiber reinforced concrete increased significantly two- to fourfold compared with static compressive strength. Thus, it can be concluded that PP fibre increases the ultimate dynamic compressive strength of polypropylene fiber reinforced concrete.

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