# Experimental Evaluation of Dynamic Properties of Fibre Reinforced Polymer Modified Concrete

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**ABSTRACT**

Findings of this research will determine how Fibre Reinforced Polymer Modified Concrete (FRPMC) can provide improved mechanical performance under dynamic loading conditions. One important parameter in a concrete structure is the damping characteristics of the concrete material. In places with earthquakes or wind loads, high risks are posed to buildings and more specifically tall buildings. Two main sources of damping are categorised as intrinsic damping which is basically provided by the structure and its material, and the supplementary damping that is the additional devices attached to the structure such as tuned mass dampers, sloshing dampers, viscous dampers, and friction devices. Damping ratios of plain concrete, with or without reinforcement, is known to have relatively non-desirable properties. Accordingly, to improve the structural damping of buildings, additional dampers are introduced. The human resource, material and maintenance costs of these dampers are relatively high. Concrete buildings are generally known to have damping of 1-3% of critical. If it is possible to increase this percentage up to 5% or more, dampers can be eliminated or reduced in some of the structures and save a lot of energy and money. In this research, Styrene Butadiene (SB) Latex as polymer and Polypropylene (PP) fibre as intrinsic reinforcement have been added to concrete to evaluate the dynamic properties of FRPMC. Mechanical properties of the concrete are tested and an impact resonance test is performed on prismatic concrete samples. Results of the tests show that adding 10% SB latex increases the damping ratio of the concrete material. Adding lower percentage of PP fibre does not affect the material damping ratio significantly whereas in higher percentage up to 1%, damping enhancement can greatly be achieved.

**Keywords:** Polypropylene fibre, SB latex, damping ratio, fibre reinforced concrete, polymer modified concrete.

## 1. INTRODUCTION

Concrete damping properties have been of great attention and effects of each of concrete components have been investigated to work out damping properties of concrete. The benefit of

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damping test is that, it is generally a non-destructive test and the structure, element or specimen is not damaged after the test. Researchers have investigated the methods and behaviour of concrete and also the relationships between the mechanical properties and damping ratio. Research on the relationship of fresh properties and damping properties specify that damping ratio is proportional to moisture content and the water /cement ratio affects damping properties (Kesler and Y.Higuchi 1954) and damping ratio is more dependent on the interfacial relations of the microstructure within the concrete matrix (Jones 1957). The influence of mechanical properties on the damping ratio is researched to have no significant effect on damping properties; age and moisture content have much higher effect on concrete damping properties than the type of concrete particles (Coles and Spooner 1965). Researchers have revealed that the damping ratio of a crack free concrete is around 0.0032-0.0064 while this value for a cracked concrete is around 0.0127-0.0207 and that these values decrease by ageing (Yan, Jenkins, et al. 2000). Being dynamically loaded, a concrete element consisting of fibres does not behave like a normal concrete as the presence of the fibres help with energy dissipation inside the matrix. This is due to energy dissipation at fibre ends specifically. As the specimen is excited dynamically, each element of the matrix absorbs a portion of the load; wherever there is stress concentration inside the matrix, this energy absorption is higher and energy loss is observed (Yan, Jenkins and Pendleton 2000). Furthermore, the fibre itself, due to its viscoelastic energy dissipation character as a polymeric material (Sun, Chaturvedi, et al. 1985), is able to absorb the energy inside itself. Cracks inside the concrete matrix can also help with the energy dissipation (Yan, Jenkins and Pendleton 2000) but not as much as the fibre itself. The relationship between the damping ratio and other characteristics of the concrete matrix have been discussed in some previous research, for example, as the damping ratio changes, there are changes in flexural stiffness as well (Yan, Jenkins and Pendleton 2000) and the damping ratio can give an indication of how concrete characteristics change with respect to the changes in the ductility factor and compressive strength (Kandasamy 3 Nov 2009).

## 2. EXPERIMENTAL PROGRAM

### 2.1. Materials

Fibrillated and Monofilament polypropylene fibres (19mm and 18mm long, respectively) have been introduced to the mix with 0.25%, 0.5% and1% volume of the whole mix. Mechanical properties of fibres are demonstrated in Table 1. These mixes also include the addition of 30% fly ash (FA) for partial replacement of Portland cement (PC) and utilisation of manufactured coarse and fine sands to replace natural coarse and fine sand, respectively, to aim for producing a ‘greener’ concrete. Water ratio to cementitious material of the mix is fixed at 0.35 and a target slump of 80±20 is set. Water used for concrete mix is drinking tap water.

**Table 1: PP fibre properties.**

| Technical Data | 18 mm Monofilament | 19 mm Fibrillated |
|---|---|---|
| Nominal Diameter (μm) | 22 | 55 |
| Elongation at Break (%) | 63 | 17 |
| Melting point ( ˚C) | 160 | 160 |
| Density (grams/ml) | 0.91 | 0.91 |
| Youngs Modulus (GPa) | 3.5 | 3.5 |

As the base mix design for all stages of the project is not changing, the amount of raw material used is constant and the water to cementitious material proportion is also constant and equal to 35%. In the mixes, Portland Cement (PC) has been partially replaced with 30% FA and 10% SB latex was added to all the preliminary mixes. It is worth mentioning that all FRC mixes containing SB Latex have the same amount of 10% of the additional material inside. The amount of SB Latex added is by mass of cementitious material. FRPMC mix designs together with their 28day compressive strength are presented in Table 2.

**Table 2: Mix design and compressive strength.**

| Mix ID | CF | CFL | PM0.25L | PF0.25L | PM0.5L | PF0.5L | PM1L | PF1L |
|---|---|---|---|---|---|---|---|---|
| Fibre -$V_f$ (%) | 0.0 | 0.0 | 0.25 | 0.25 | 0.5 | 0.5 | 1 | 1 |
| SB latex (kg/m3) | 0.0 | 43.0 | 43.0 | 43.0 | 43.0 | 43.0 | 43.0 | 43.0 |
| $f'_C$ (MPa) | 57.5 | 40.0 | 36.5 | 39.0 | 31.5 | 34.0 | 23.0 | 37.5 |

## 2.2. Test setup and instrumentation

Non-destructive dynamic testing involves use of a hammer test with accelerometers attached to the specimens . Tests are performed after 28 days of ageing to compute the material damping ratio and natural frequency .

Various dynamic characteristics can be measured to evaluate material and ultimately structural behaviour of a structure. For instance, damping ratio, natural frequency, dynamic Young’s modulus of elasticity, the dynamic modulus of rigidity, etc. which are characteristics that depend on the mechanical properties and geometry. It has been reported that concrete has damping ratio more than 0.5% (Yan, Jenkins and Pendleton 2000) which can be a reference point. To ensure proper comparisons in this research, control mixes have been tested to compare the damping ratio results of the concrete matrix to FRPMCs. Free beam vibration measured using hammer impacts is a well-known method to determine the vibration characteristics of concrete which has been employed. The typical logarithmic decrement method test and vibration response frequency for the first mode is also used to capture the dynamic characteristics of the concrete specimens.

In this project the dynamic behaviour of concrete has been evaluated using ASTM C215 provisions. From this test one measures the transverse, longitudinal and resonant frequency of concrete specimens to calculate the dynamic properties of concrete material. In this test method the frequency can be measured by the impact response technique, which is the utilised method in this project. An impactor (hammer) is used to excite the concrete supported prism. The response is captured via accelerometers attached to the specimen.

As per standard specifications, a hammer head has been chosen to excite the highest frequency that can be measured. Different types of supports have been examined and an elastomeric dense rubber support has been selected to meet the standard requirements to let the specimen vibrate freely and have resonant frequency out of range of concrete material. The system analyser for this test is the LABVIEW program. All the specimens have been prepared according to related standards to "Making and Curing Concrete Test Specimens in the Laboratory", AS 1012.8.

## 3. RESULTS AND DISCUSSION

Conducting impact hammer test on concrete prisms and after gathering the signal data, the following results are derived. A summary of damping calculations are shown in Figure 1. As mentioned above, the logarithmic decrement method has been used to calculate damping ratio from the Time-Amplitude free vibration decay curves. For systems with low damping ratios such as concrete, bellow formula can be used with a very good accuracy:

$$\xi = \frac{u_n - u_{n+m}}{2m\pi u_{n+m}} \tag{1}$$

To follow a same trend for calculating the damping ratios " $u_n$ " is taken as " 2 $u_{n+m}$ ". For each mix design damping ratios and frequency of different sample specimens has been tested. After statistical analysis of the data, a series of damping ratios are derived. Test results show that by adding 30% fly-ash, damping ratio of concrete mix is decreased by about 9% comparing to the control mix without FA (C) . This can be explained by the fact that pozzolans such as FA generally reduce the permeability of concert (Kosmatka, Kerkhoff, et al. 2003). FA has finer particles which have low friction along their surface that help particles travel better within the matrix and help with permeability. Researchers have investigated the effect of permeability and voids in cementitious pastes on the damping characteristics, a summary of which is that presence of water in the voids and micro cracksare reported to be responsible for improving damping of plain concrete (Chowdhury 1999, Yan, Jenkins and Pendleton 2000). Accordingly, by adding FA to the mixes, a decrease in damping ratio is observed as expected. On the other hand, for the mix with SB latex, which is a polymeric material (CFL) high percentage increase in damping ratio and decrease in the fundamental frequency is apparent. By adding SB Latex to its reference mix (CF), damping ratio is increased by 131%. Consequently, results show that by adding SB Latex by 10% weight of cementitious materials a noticeable increase in damping properties can be achieved. This is initially due to the inherent elastomeric characteristics of the polymeric material which in this case is latex. On the other hand, adding latex to the mix design, introduces air voids which is a responsible factor for improving damping properties and energy dissipation within the matrix. Below charts, graphically show how the trend of damping ratio changes by the percentage of the fibre used.

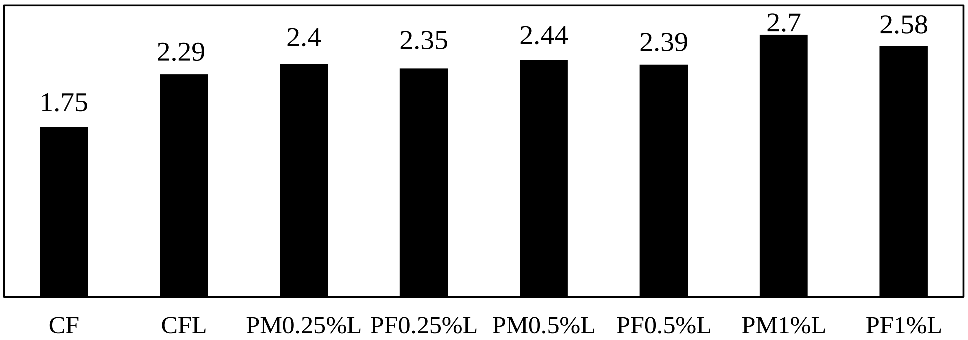


**Figure 1: Damping ratio (%).**

Table 3, shows percentage increases in every mix comparing to PMC (CFL) and referenced with FA (CF).

**Table 3: Percent Increase Damping ratio comparative results.**

| MIX ID | PM0.25%L | PF0.25%L | PM0.5%L | PF0.5%L | PM1%L | PF1%L |
|---|---|---|---|---|---|---|
| CFL | 4% | 3% | 6% | 4% | 18% | 13% |
| CF | 36% | 34% | 39% | 36% | 54% | 47% |

From the results, it is observed that a considerable improvement is noticeable when PP fibre and SB latex are added to the mix. This improvement in damping properties, as mentioned before, is due to elastomeric characteristic of the polymer admixture and fibre. On the other hand, the energy dissipated between the fibre and matrix due to friction because of opening and closing of micro cracks is reported to be a cause of such improvement (Yan, Jenkins and Pendleton 2000). In cases where fibre is used in a polymeric cementitious matrix, the good adhesion between fibre and matrix helps with energy dissipation (Chandra, Singh, et al. 1999). Transverse fundamental frequency of the mixes are also presented in Figure **2**, which also supports that by adding elastomeric material such as SB latex and PP fibres to the mix, dynamic properties of concrete are enhanced.

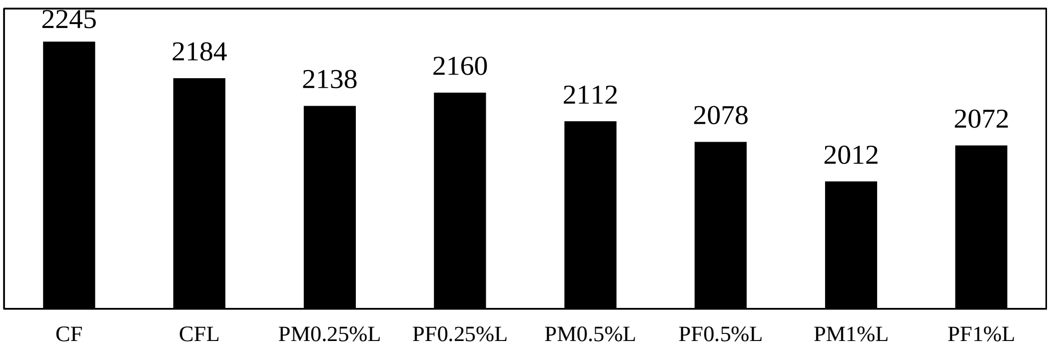


**Figure 2: Transverse fundamental frequency(Hz).**

## 4. CONCLUSION

Results show that adding PP fibre helps with improving damping ratio of concrete material. By adding lower percentages of PP fibre (0.25% and 0.5%) there is a slight increase observed whereas in higher percentages (1%) up to 121% increase in damping ratio can be reached. It can be concluded that adding lower percentage of PP fibre do not affect the material damping ratio significantly whereas in higher percentage of 1% damping enhancement is noticeable. Adding a combination of SB latex and PP fibre to concrete mix is likely to improve the damping ratio by as much as 154% .

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