| | |
|---|---|
| Title | DAMPING PROPERTIES OF POLYVINYL ALCOHOL FIBRE REINFORCED CONCRETE |
| Author(s) | NOUSHINI, A.; SAMALI, B.; VESSALAS, K. |
| Citation | Proceedings of the Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), September 11-13, 2013, Sapporo, Japan, B-5-2., B-5-2 |
| Issue Date | 2013-09-11 |
| Doc URL | http://hdl.handle.net/2115/54255 |
| Type | proceedings |
| Note | The Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), September 11-13, 2013, Sapporo, Japan. |
| File Information | easec13-B-5-2.pdf |

# DAMPING PROPERTIES OF POLYVINYL ALCOHOL FIBRE REINFORCED CONCRETE

A. NOUSHINI[1*†], B. SAMALI[2] and K. VESSALAS[3]

[1, 2, 3] *Centre for Built Infrastructure Research, School of Civil and Environmental Engineering, University of Technology Sydney, Australia*

## ABSTRACT

This paper presents results of an experimental investigation evaluating dynamic properties and damping ratio of fibre reinforced concrete (FRC) including PVA fibres of two different geometric lengths, 6 and 12 mm, with volume fraction of 0.25% and 0.50%. The impact resonance test is used to determine the resonant frequency of 75 × 100 × 400 mm prisms by applying a small load impulse and measuring the resulting acceleration through the specimen for transverse mode of vibration. For each concrete type, impact resonance test was carried out at 14 and 28 days of ageing. From the test results, the fundamental (natural) frequencies are measured and acceleration-time history graphs are prepared. Acceleration-time history is used in order to calculate the damping ratio, following logarithmic decrement method. The dynamic modulus of elasticity (DMOE) is also being calculated from the fundamental transverse frequency which is comparable to the static chord modulus of elasticity. The compressive strength of concretes at the age 28 day is also evaluated. Test results indicated that the compressive strength of concrete increased by fibre addition. However, it has been observed that PVA fibre addition in low volume fraction used in this study do not significantly affect the concrete modulus of elasticity and damping ratio.

**Keywords:** Polyvinyl alcohol (PVA) fibre, fundamental frequency, damping ratio, dynamic modulus of elasticity.

## 1. INTRODUCTION

In places such as New Zealand or Australia, earthquakes or wind loads, respectively, pose high risks to buildings and more specifically tall buildings. Vibration in structure which is caused by these dynamic loads varies in amplitude and frequency with excitation source, depending on structural type and applied load. There is no doubt that dynamic property of concrete material is of great significance to these structures, particularly in vibration control and noise mitigation.

Damping is defined as a process whereby vibrational energy is dissipated over a period of time (Smith 1988). To avoid resonance of a specific structure at typical modes, whether in material level

---

[*] Corresponding author: Email: amin.noushini@uts.edu.au

[†] Presenter: Email: amin.noushini@uts.edu.au

or member and structural level, damping is helpful in reducing vibration and resonance (Amick & Monteiro 2005; Zheng, Sharon Huo et al. 2008).

Two main sources of damping are categorised as intrinsic damping which is basically provided by the structure and the material damping. The other damping is the supplementary damping created utilizing additional devices attached to the structure such as tuned mass dampers, sloshing dampers, viscous dampers, and friction devices. Concrete buildings are generally known to have damping ratio between 1% and 3% of critical damping. 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. It is also investigated that by increasing the damping ratio of concrete to 10 or 15% the structure gains the capacity to dissipate the vibrating energy without needing any additional dampers (Jinping, Tiejun et al. 2008; Ou 2002).

Damping ratio is the main parameter representing the property of materials in vibration reduction (Zheng et al. 2008). Due to the number of variables that affect damping in a system, the most realistic way of determining damping of a material or structure is through laboratory investigations. Logarithmic decrement (δ) is one of the most popular methods of measuring and calculating the damping properties of concrete. This method simply provides a measure of the rate of decay of oscillation is used to find the damping ratio (ξ) of an underdamped system based on the assumption of viscous damping. The logarithmic decrement is defined as the natural logarithm of the ratio of any two successive positive amplitude peaks as shows in equation (1) (Chopra 1995) and graphically illustrated in Figure 1.

$$\delta = \frac{1}{m}\ln\frac{U_n}{U_{n+m}} = \frac{2\pi\xi}{\sqrt{1-\xi^2}} \tag{1}$$

where $U_n$ is the amplitude of a successive peak, $U_{n+m}$ is the amplitude of a peak after $m$ cycles and $m$ is the number of cycles between the two successive positive peaks.

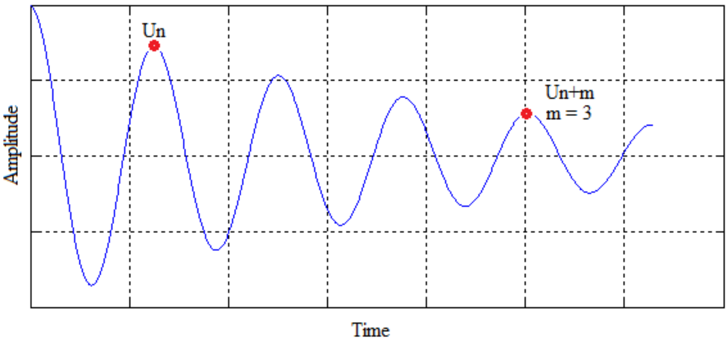

**Figure 1: Schematic amplitude-time curve for the determination of logarithmic decrement.**

Since damping ratio is generally small in the case of concrete (<20%) (Menefy 2007), equation (1) can be further simplified to give a direct relationship between the δ and the ξ as follows;

$$\delta \approx 2\pi\xi \quad (2)$$

Thus, damping ratio (ξ) can be calculated as;

$$\xi = \frac{1}{2\pi m} \ln \frac{U_n}{U_{n+m}} \quad (3)$$

The first serious study on the damping behaviour of concrete is performed in 1940 by Thomson (Thomson 1940). In this investigation, it has been reported that the mechanical properties of concrete e.g. compressive strength and modulus of elasticity can be predicted through dynamic methods and damping measurements. Following the mentioned study, many researches have been carried out so far to explore the effect of various parameters (such as concrete composition, curing condition, moisture content, temperature, compressive strength and modulus of elasticity) on damping properties of concrete and concrete elements.

As a concrete specimen is excited dynamically, each element of the matrix absorbs a portion of the load. The synthetic fibre itself, due to its viscoelastic energy dissipation character as a polymeric material, is able to absorb the energy inside itself (Sun, Chaturvedi et al. 1985). However, although fibres in synthetic FRC are viscoelastic and have damping ratios higher than concrete, the FRC composite is not a good viscoelastic material since it is usually provided by a low volume fraction of fibres. In such cases, adequate damping may not necessarily be produce due to the hysteresis energy loss in matrix because of the strain cycling in the vicinities of fibre ends, nor from synthetic fibres (Yan, Jenkins et al. 2000a). It can take place due to fibre/matrix debonding which may occur under certain strain and stress conditions surrounding the fibres. This may cause energy loss under alternating loading. Concrete is considered as a brittle material which contains micro cracks that may open and close during dynamic loading under flexure. Theses cracks may cause the matrix to rub on the fibre surface and results in energy loss during vibration (Yan et al. 2000a; Yan, Jenkins et al. 2000b) and accordingly higher damping ratio can be achieved for FRCs (Fu & Chung 1996; Nelson & Hancock 1979).

Fibres generally and synthetic fibres specifically are reported to enhance the dynamic properties of concrete by increasing the damping ratio of plain concrete (Yan et al. 2000a). Furthermore, it has been reported that damping ratio can be used as an indication of changing concrete mechanical characteristics e.g. flexural strength and ductility (Arivalagan & Kandasamy 2009).

In this study, the performance of using uncoated PVA fibre on damping properties of concrete has been investigated. PVA fibres of two geometric lengths, 6 and 12 mm, with volume fraction of 0.25% and 0.50% were utilised to prepare FRC mixes. Furthermore, a non-FRC mix (control) was also made to be used as the reference point of this study. The compressive strength and modulus of elasticity (MOE) of concrete samples were also measured to evaluate the mechanical properties of FRC and control concrete.

## 2. EXPERIMENTAL PROGRAM

### 2.1. Materials

Shrinkage limited Portland cement (PC) and fly ash (FA) were used as the binder for all concrete mixes. Shrinkage limited Portland cement was used in this study to minimise concrete drying shrinkage. The fineness of FA by 45 µm sieve was determined to be 94% passing (tested in accordance with AS 3581. 1-1998).

A maximum nominal size of 20 mm aggregate was used in all mixes. All aggregates used in mix design were sourced from Dunmore, Australia, which includes 50/50 blended fine/coarse manufactured sand and 10 mm and 20 mm crushed latite gravel. The grading of all aggregates complies with the Australian Standard; AS 2758.1 specifications and limits. All aggregate was prepared to saturated surface dry condition prior to batching.

Drinking grade tap water was used for all mixes after conditioning to room temperature (23±2 °C). Furthermore, in order to improve the workability, a polycarboxylic-ether based high range water reducing admixture (HWR) was used. Non-coated polyvinyl alcohol fibre of 2 different geometries, 6 and 12 mm, with specifications mentioned in Table 1, were used in all FRC mixes.

**Table 1: Properties of PVA fibres.**

| Specific gravity [g/cm$^3$] | Diameter [mm] | Thickness [dtex] | Cut length [mm] | Tensile strength [MPa] | Young's modulus [GPa] | Elongation [%] |
|---|---|---|---|---|---|---|
| 1.29 | 0.014 | 1.8-2.3 | 6 and 12 | 1500 | 41.7 | 7 |

### 2.2. Mixing and samples preparations

Mixes were prepared to obtain characteristic compressive strength at 28 days ($f'_c$) of 60 MPa to conform to AS 3600 requirements as structural concrete (ranging from 20 MPa to 100 MPa) even after adding fibres which may cause strength reduction, along with a slump of 80±20 mm. In order to obtain the desired slump, HWR dosage was varied. Details of the mix proportions for control concrete (no fibres) are presented in Table 2. Mix ingredients were all measured and added to the mix by weight. All FRCs also followed the same proportioning and only fibres were added to the mixture by 0.25% and 0.5% of volume fraction of the mix.

**Table 2: Mix proportions of reference concrete.**

| kg/m$^3$ | | | | | | Lit/m$^3$ | Water/C* |
|---|---|---|---|---|---|---|---|
| Cement | Fly ash | Sand | 10 mm aggregate | 20 mm aggregate | Water | HWR | |
| 301 | 129 | 635 | 390 | 700 | 151 | 1.215 | 0.35 |

* Cementitous materials

For non-FRC (control) mix, mixing was performed in accordance with AS 1012.2. However, for FRC mixes, due to the presence of the fibres, the standard mixing regime suggested in Australian Standard for conventional concrete was modified. Accordingly, the mixing time was increased to 3 minutes to achieve a completely homogeneous concrete. Slump was taken to check the workability and, thereafter, freshly mixed concrete was placed into moulds and compacted using an external vibrating table. Curing of test specimens was carried out in accordance with AS 1012.8. Specimens were placed in a water tank after demoulding to be cured in lime-saturated water at a temperature of 20±2 °C until the testing date.

### 2.3. Testing methods

Uniaxial compression and modulus of elasticity (MOE) tests were performed on cylindrical specimens of 100×200 mm and 150×300 mm, respectively, at the age of 28 days in accordance with AS 1012.9 and AS 1012.17 specifications and method.

The impact resonance test is used to determine the resonant frequency of 75 × 100 × 400 mm prisms following the test method recommended in American Standard, ASTM C 215 (08), by applying a small load impulse and measuring the resulting acceleration through the specimen for different modes of vibration. To excite the normal modes of vibration, a small metal hammer (impactor) is used to manually apply a small load impulse to the specimen. The accelerometer attached to the specimen, is used to transform the resulting vibrations into electrical signals. The miniature accelerometer is assumed to have no influence on the resonance frequencies of the beam. Soft rubber supports were also used to permit the specimen to vibrate freely in each mode of vibrations. The schematic of test apparatus are shown in Figure 2. A computer based data acquisition system is used to record hammer force and acceleration response signals during the tests. Data processing, including Fast Fourier Transform (FFT) and Frequency Response Function (FRF) calculations were then executed using a specifically developed MATLAB programme. From recorded dynamic response time histories, using FFT, the auto spectrum of the given signal can be obtained and the FRF can be computed.

For each concrete type, impact resonance test was carried out at 14 and 28 days of ageing. For each age, 3 specimens of the same concrete were tested and since the test is non-destructive, same specimens were used for the next testing age. To provide more accurate results, at least 5 strikes were applied on each sample for each mode of vibration and the average is taken from the successive results.

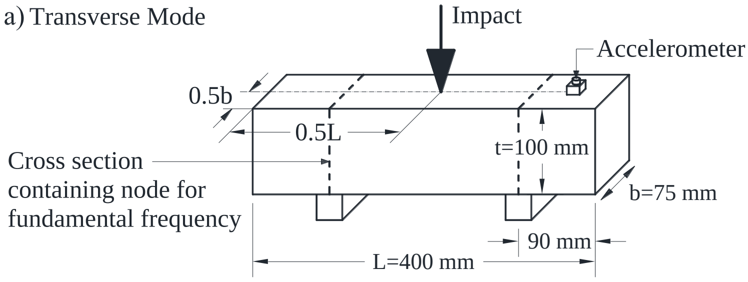

**Figure 2: Typical impact resonance test set-up (locations of impact and accelerometer) for transverse mode of vibration (ASTM C 215 – 08).**

From the test results, the fundamental (natural) frequencies are measured and acceleration-time history graphs are prepared. Acceleration-time history is used in order to calculate the damping ratio, following logarithmic decrement method as described previously.

The dynamic modulus of elasticity (DMOE) can also be calculated from the fundamental transverse frequency, using the below mentioned equation;

$$DMOE_{transverve} = CMn^2 \tag{4}$$

where $M$ is the mass of specimen in kg, $n$ is the fundamental transverse frequency in Hz and $C$ is a factor equal to 1122.6, calculated from table 1 “values of correction factor” of ASTM C 215-08.

## 3. RESULTS AND DISCUSSION

Table 3 presents the mechanical properties of FRCs and control concrete. By looking at the results, it can be noted that most of PVA-FRCs have higher compressive strength at 28 days ($f_{c,28}$) compared to the control except for FRC.6 which includes 0.5% volume fraction of 12 mm fibres. It can also be observed that with a same fibre content shorter fibres act better than longer one in terms of compressive strength and the optimum fibre volume fraction goes to 0.25% for both fibre lengths. In the case of concrete MOE, it can be noted that PVA fibres in low volume fractions used in this study do not significantly affect the modulus of elasticity. However, it is explicable that within the FRCs incorporating the same fibre, 0.25% volume fraction shows higher $E_{c,28}$ and in a same fibre content longer fibres have lower $E_{c,28}$.

**Table 3: Mechanical properties of different mixes at 28 days of ageing.**

| Mix Reference | Fibre length [mm] | $V_f$ [%] | Compressive strength- $f_{c,28}$ [MPa ± SD] | Modulus of Elasticity- $E_{c,28}$ [GPa] |
|---|---|---|---|---|
| Control | - | - | 60.0 ± 3.2 | 39 |
| 6PVA-0.25% | 6 | 0.250 | 67.0 ± 3.2 | 40 |
| 6PVA-0.50% | 6 | 0.500 | 61.5 ± 2.5 | 38 |
| 12PVA-0.25% | 12 | 0.250 | 64.5 ± 3.2 | 39 |
| 12PVA-0.50% | 12 | 0.500 | 58.5 ± 2.8 | 36 |

From the result of the impact resonance frequency test, the material dynamic properties of FRCs and control concrete, including three primary characteristics; resonant (fundamental or natural) frequency, dynamic modulus of elasticity and damping ratio, are calculated for transverse modes of vibration. Figure 3 shows the damping ratio of control and FRCs in transverse mode of vibration at the age of 14 and 28 days. For each concrete mix design a number of 45 samples were recorded as damping ratio. These 45 samples are calculated from the acceleration-time history of 5 hammer strikes over 3 specimens. From each acceleration-time history, 3 damping ratio are calculated from 3 different parts of the graph, to minimise the measurements errors. To follow the same trend for calculating the damping ratios and minimising measurement errors, ‘$U_{n+m}$’ was taken as half the value of ‘$U_n$’(refer to equation (3)).

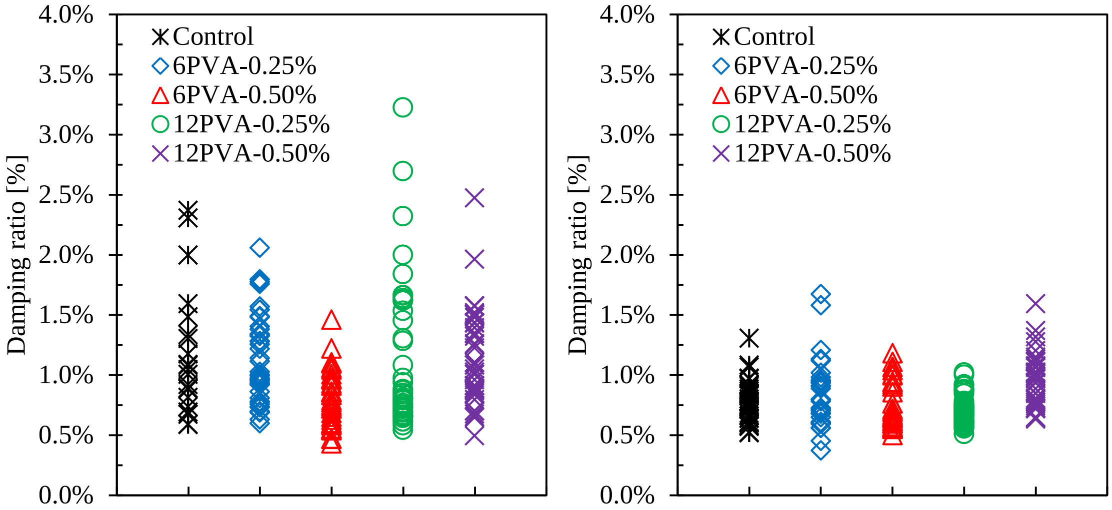

**Figure 3: Damping ratio of FRCs versus control concrete in transverse mode at the age of; 14 days (left) 28 days (right).**

It has been previously (Yan et al. 2000a) reported that concrete has damping ratio more than 0.5% which can be a reference point. Damping ratio of all concretes is observed to decrease by ageing which is in line with previous investigations (Amick & Monteiro 2006; Cole & Spooner 1965; Swamy & Rigby 1971; Yan et al. 2000a). According to the results, it can be mentioned that addition of PVA fibres in low volume fraction has no significant effect on concrete damping ratio. The results of all above calculations for transverse mode of vibration are summarised in Table 4.

**Table 4: Dynamic properties of control and FRCs at transverse mode.**

| Mix Reference | Resonant frequency [Hz ± SD[1]] | | Dynamic-MOE [GPa ± SD] | | Damping ratio (ξ) [% ± SD] | |
|---|---|---|---|---|---|---|
| | 14 day | 28 day | 14 day | 28 day | 14 day | 28 day |
| Control | 2206 ± 11 | 2245 ± 10 | 40.2 ± 0.4 | 41.5 ± 0.4 | 1.2 ± 0.5 | 0.8 ± 0.2 |
| 6PVA-0.25% | 2240 ± 29 | 2260 ± 37 | 41.5 ± 1.1 | 42.0 ± 1.4 | 1.1 ± 0.4 | 0.8 ± 0.3 |
| 6PVA-0.50% | 2210 ± 14 | 2240 ± 7 | 40.5 ± 0.5 | 41.5 ± 0.3 | 0.8 ± 0.2 | 0.7 ± 0.2 |
| 12PVA-0.25% | 2230 ± 22 | 2240 ± 12 | 41.0 ± 0.8 | 41.5 ± 0.4 | 1.1 ± 0.6 | 0.7 ± 0.1 |
| 12PVA-0.50% | 2190 ± 34 | 2220 ± 37 | 39.5 ± 1.3 | 40.5 ± 1.4 | 1.1 ± 0.4 | 1.0 ± 0.2 |

[1] SD: Standard deviation

## 4. CONCLUSIONS

The effect of PVA fibre addition on damping characteristics of concrete has been investigated in current study. Test results indicated that the compressive strength of concrete increases by fibre addition. However, it has been observed that PVA fibre addition in low volume fraction used in this study do not significantly affect the concrete modulus of elasticity and damping ratio. Further, comparing 28-day dynamic-MOE with static chord MOE shows a similar trend. Dynamic-MOE results are slightly higher than that of static-MOE which complies with literature (Malhotra & Sivasundaram 2004)

# REFERENCES

Amick H. and Monteiro P. J. M. 2005, 'Modification of concrete damping properties for vibration control in technology facilities', Proceedings of SPIE - The International Society for Optical Engineering, vol. 5933, pp. 1-12.

Amick H. and Monteiro P. J. M. 2006, 'Experimental determination of model damping in concrete beams', ACI material Journal, vol. 103, no. 3, pp. 153-60.

Arivalagan and Kandasamy 2009, 'Energy Abrorption Capacity of Composite Beams', Engineering Science and Technology Review, vol. 2, pp. 145-50.

Chopra A. K. 1995, Dynamics of Structures: Theory and Applications to Earthquake Engineering, Prentice Hall, New Jersey.

Cole D. G. and Spooner D. C. 1965, 'The damping capacity of hardened cement paste and mortar in specimens vibrating at very low frequencies', Proceedings of American Society for Testing and Materials, pp. 661-7.

Fu X. and Chung D. D. L. 1996, 'Vibration damping admixtures for cement', Cement and Concrete Research, vol. 26, no. 1, pp. 69-75.

Jinping O., Tiejun L. et al. 2008, 'Dynamic and Seismic property experiments of high damping concrete and its frame models', Jurnal of Wuhan university of technology-Mater.Si.Ed

Malhotra V. M. and Sivasundaram V. 2004, 'Resonant Frequency Method', in, Handbook on Nondestructive Testing of Concrete, p. 384.

Menefy L. 2007, 'Investigation of reactive powder concrete and it's damping characteristics when utilised in beam elements', Griffith University, Gold Coast.

Nelson and Hancock 1979, 'Interfacial slip and damping in fibre reinforced composites', Journal of Materials Science, vol. 13, no. 3, pp. 2429-40.

Ou J. P. 2002, 'Smart Concrete Products and structural Systems', Control and Health monitoring of Structures, pp. 4-5.

Smith J. W. 1988, Vibration of Structures: Application in civil engineering design, Chapman and Hall, London.

Sun C. T., Chaturvedi S. K. et al. 1985, 'Internal damping of short-fiber reinforced polymer matrix composites', Computers &amp; Structures, vol. 20, no. 1â€“3, pp. 391-400.

Swamy N. and Rigby G. 1971, 'Dynamic properties of hardened paste, mortar and concrete', Materials and Structures, vol. 4, no. 1, pp. 13-40.

Thomson W. T. 1940, 'Measuring changes in physical properties of concrete by the dynamic method', vol. 40, proceeding of the American Society of Testing and Materials, pp. 1113-8.

Yan L., Jenkins C. H. et al. 2000a, 'Polyolefin fiber-reinforced concrete composites: Part I. Damping and frequency characteristics', Cement and Concrete Research, vol. 30, no. 3, pp. 391-401.

Yan L., Jenkins C. H. et al. 2000b, 'Polyolefin fiber-reinforced concrete composites: Part II. Damping and interface debonding', Cement and Concrete Research, vol. 30, no. 3, pp. 403-10.

Zheng L., Sharon Huo X. et al. 2008, 'Experimental investigation on dynamic properties of rubberized concrete', Construction and Building Materials, vol. 22, no. 5, pp. 939-47.