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EQUIVALENT VISCOUS DAMPING OF METALLIC FIBER-REINFORCED CONCRETE (MFRC)

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ABSTRACT: In this paper, results of an experimental study to investigate the equivalent viscous damping (EVD) of the concrete reinforced with metallic fibers in mono and hybrid form have been presented. Two types of metallic fibers were investigated: Fibra Flex and Dramix fibers. FibraFlex fibers develop strong bond with concrete due to their rough surface. On the contrary, Dramix fibers develop weak bond with concrete due to their smooth surface. Maximum dosage of fibers was kept equal to 40 kg/m^3. The findings of this study showed that EVD of concrete is improved with the addition of metallic fibers. Comparison of the effectiveness of two metallic fibers investigated in this study on EVD revealed that increase in the EVD was greater with Fibra Flex fibers up to 4 mm deflection in beam and after that Dramix fibers were found to be more effective to enhance EVD of concrete.

Keywords: Concrete; metallic fibers; equivalent viscous damping; reverse cyclic loading

INTRODUCTION

The dynamic response of structure under free or forced vibration depends, among others factors, on its damping properties. The dynamics effects are particularly aggravated when the load has a harmonic vibration with a frequency close to the structure resonance condition. Experiments in structural dynamics have shown that the presence of damping accessories can effectively bound the dynamic response. The control of the dynamic response in a structure can be achieved with discrete damping elements. In civil engineering, damping properties of reinforced concrete are very important in earthquake engineering once damping provides structure energy dissipation during moderate or strong earthquakes (Carneiro *et al*. 2006).

Viscous damping is another means of describing the element's capacity in dissipating earthquake energy. For a structure, damping mechanisms can be represented by a viscous damping ratio (Abdelsamine and Tom, 2010). The process by which free vibration steadily diminishes in amplitude is called damping. In damping, the energy of the vibrating system is dissipated by various mechanisms, and often more than one mechanism may be present at the same time. In a vibrating reinforced concrete building, these different mechanisms include cracking, reinforcement yielding, and friction between concrete and steel bar during slippage (Chopra, 2006). In reinforced fibrous concrete, friction between fiber and matrix, yielding of fiber, breaking or pulling out of fibers from matrix are also additional mechanisms. The damping in actual structures is usually represented in a highly idealized manner. The damping coefficient is selected so that the vibrational energy it dissipates is equivalent to the energy dissipated in all the damping mechanisms, combined, present in the actual structure. This idealisation is therefore called equivalent viscous damping. The equivalent viscous damping is accepted as a satisfactory approximation if it is used in the conditions of quasi-static testing because the natural frequency of the specimen is not equal to the exciting frequency (Chopra, 2006).

According to the displacement based design method it is feasible to select a desirable damage performance criteria for a given structural member or structure under a given hazard level (Priestley, 2000). This is an attractive feature of the displacement based design method, as engineers can select the desired structural performance criteria before the design of any structural member (Binggeng and Pedro, 2006). Selection of performance goals can be related directly to displacement ductility levels, which in turn can be associated with the equivalent viscous damping (Hose *et al.* 2000) and it is one of the crucial parameters in applying the displacement based design method. In seismic design, the EVD for individual reinforced concrete members is estimated from their hysteretic response under fully reversed cyclic loading (Daniel and Loukili, 2002; Binggeng and Pedro, 2006; Clough and Penzien, 1993).

The research reported herein is concerned with the behaviour of reinforced fibrous concrete beams subjected to reverse cyclic bending. The basic purpose of this paper is to examine experimentally the influence of metallic fibers on the EVD of reinforced concrete beam.

MATERIAL AND METHODS

Concrete Composition: Four different concrete mixes, one control and three mixes containing metallic fibers were studied. For all the concrete mixes, CEM I 52.5 R type cement has been used. Local natural sand with maximum particle size of 4 mm was used. Round gravels with size range of 4 -10mm were used as coarse aggregate. A Super-plasticizer has been used as an admixture to improve the workability of the mix in the presence of metallic fibers. Table 1 show the mix proportion of control concrete.

Table 1: Control concrete mix proportion

Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Water (kg/m^3)	Super-Plasticizer (kg/m^3)
322	872	967	193	1.61

Type of fibres used: Two types of macro-metallic fibres, 30 mm in length were used: 1) Fibra Flex fibres (named in this study as FF fibers) are amorphous metallic fibers produced by Saint-Gobain Seva, France. They are composed of (Fe, Cr) 80% and (P, C, Si) 20% by mass (Saint-Gobain Seva, 2012). Due to their rough surface and large specific surface area, these fibres are characterised by high bond with concrete matrix (Hameed *et al.* 2010). 2) Dramix fibers produced by Bekaert, Belgium (named in this study as DF fibers) are made using carbon steel wires, and are characterised by a weak bond with the matrix compared to FF fibres due to smooth surface and less specific surface area. They have circular cross-section and hooked-ends.

The characteristics of these two types of metallic fibres are given in Table 2, where L, W, T, D and E are length, width, thickness, diameter and modulus of elasticity respectively.

Table 2: Fibres investigated in this study

Fiber	Fiber Type	Dimension (mm)				Geometry	E, GPa	Tensile strength (MPa)
		L	W	T	D			
FF	amorphous metal	30	1.6	0.03	-	Straight	140	2000
DF	carbon steel	30	-	-	0.5	Hooked-end	210	1200

Test Specimen and Testing Procedure: Cross section of the test specimen (Beam) was 150 x 200 mm with length of 1260 mm. Two steel bars of 6 mm diameter (steel ratio = 0.19%) with characteristic yield strength of 500 MPa were used as conventional reinforcement. Flexural failure of the beam was ensured by providing necessary shear reinforcement. Details of all the tested beams regarding concrete type, steel ratio, fiber type and dosage are given in Table 3.

Table 3: Details of tested beams

Beam Type	Concrete	Steel ratio ρ, Ø	Dosage of Fibers, (kg/m^3)		Total quantity of fibers, kg/m^3
			FF	DF	
RCB-cont	Control		--	--	--
RCB-FF20	Mono fiber	0.19 % (6 mm)	20	--	20
RCB-DF20			--	20	20
RCB-FF40			40	--	40
RCB-DF40			--	40	40
RCB-40HyF	Hybrid fiber		20	20	40

Cyclic tests were performed using SCHENCK Standard PS 3007 B Hydroplus Machine with maximum capacity of 100 kN in static loading and 80 kN in dynamic loading. Schematic diagram of the experimental setup is shown in Fig.1.

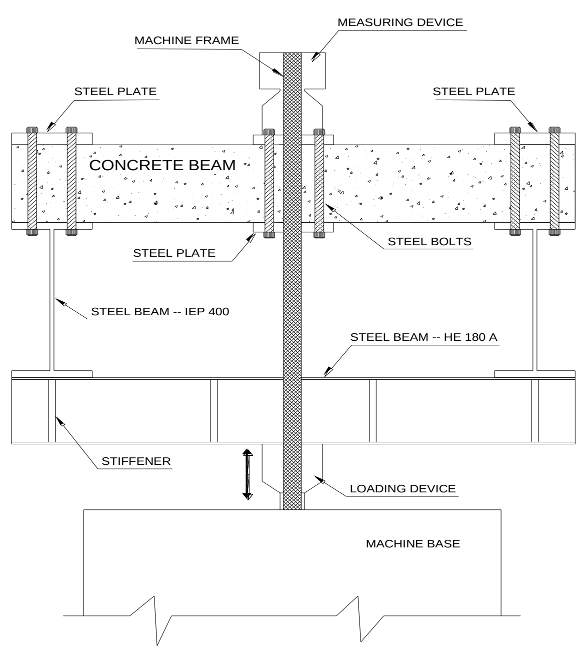

Fig. 1: Experimental setup for reverse cyclic bending test on beam

Displacement controlled reverse cyclic bending tests were performed. Numbers of loading cycles on the specimens for each amplitude value of the imposed displacement were three. The amplitude of imposed displacement was gradually increased from 1 mm to 10 mm. The loading rate of imposed deflection was kept as 0.2 mm/second.

Nomenclature of Tested Beams: Regarding the nomenclature of tested beam, for **RCB-cont, RCB** stands for reinforced concrete beam and "**cont**" stands for control (without fibers), for **RCB-FF20**, **FF** stands for FibraFlex fibers and **20** is quantity of fibers in kg/m^3, similarly **RCB-DF20**, where **DF** stands for Dramix fibers. The beam containing fibers in hybrid form is designated by **RCB-40HyF**, where **40** is total quantity of two fibers in kg/m^3 (20 kg/m^3 of each fiber) and **HyF** stands for hybrid fiber reinforced concrete.

Equivalent Viscous Damping: The most common method of defining equivalent viscous damping is to equate the energy dissipated in a vibration cycle of the actual structure and an equivalent viscous system. For an actual structure the load-displacement curve obtained from experiment under cyclic loading is determined; such a curve of arbitrary shape is shown in Fig. 2. For any cycle *i*, the equivalent viscous damping ζ_{eq} can be calculated using the following relation (Abdelsamine and Tom, 2010):

$$\xi_{eq} = \frac{1}{4\pi}\left(\frac{E_D}{E_S}\right) \quad (1)$$

Where: the area within the inelastic force-displacement response curve denoted by E_D, is a measure of the hysteretic damping or energy dissipation capacity of the member and E_S depicts the recoverable elastic energy stored in an equivalent linear elastic system. Both E_D and E_S are defined in Fig.2.

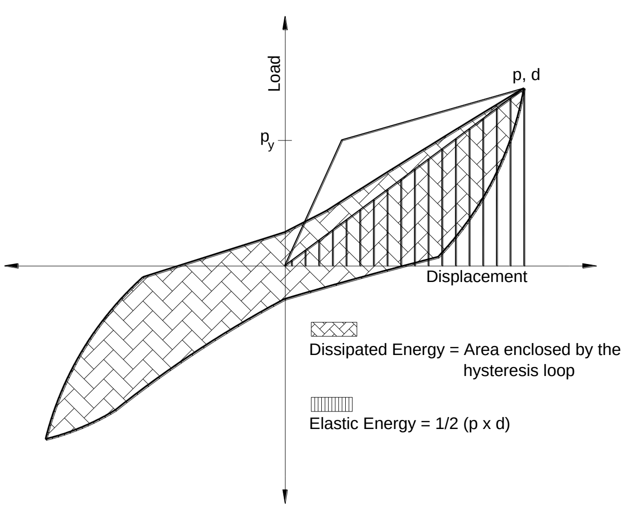

Fig. 2: Evaluation of equivalent viscous damping

The calculation of the equivalent viscous damping for a loading cycle was divided into two parts as shown in Fig.3. The EVD was calculated for each part separately and then average of two was obtained. The average value for each cycle was considered to represent the equivalent viscous damping of the beam. The ζ_{eq} was calculated up to maximum displacement of 10 mm for each tested beam and a comparative study was carried out to investigate the effect of each type of fiber used in this study on EVD.

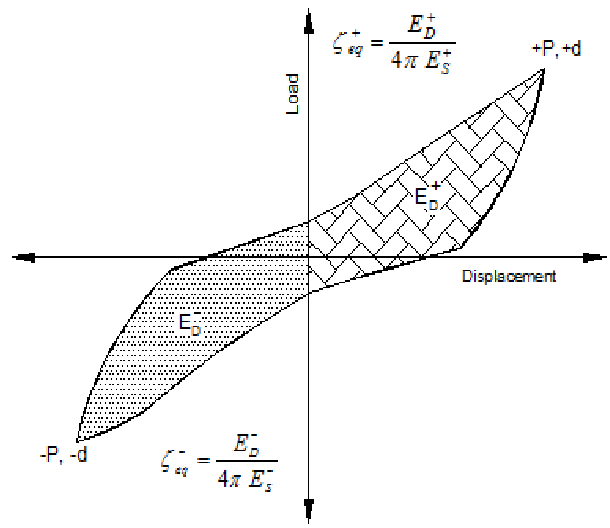

Fig. 3: Equivalent Viscous Damping (EVD) in a typical loading cycle

RESULTS AND DISCUSSION

Comparison of ζ_{eq} of RC beams containing Fibra Flex fibers (RCB-FF20 & RCB-FF40) and control RC beam (RCB-cont) is shown in Fig. 4, where increase in EVD can be observed by the addition of Fibra Flex fibers. Regarding the effect of fiber dosage of Fibra Flex fiber, it is difficult to conclude that ζ_{eq} increases with increase of fiber dosage because values of EVD of RCB-FF20 and RCB-FF40 varied significantly with respect to each other at different displacement amplitude. The EVD of RCB-FF20 and RCB-FF40 was dropped to value lower than RCB-cont after displacement amplitude of 4 and 5 mm, respectively. This was due to the breaking of fibers at wider crack openings at 4 and /or 5 mm deflection of beam.

In Fig.5, comparison between control beam and beams containing Dramix fibers in terms of EVD is presented. It is observed from this comparison that similar to Fibra Flex fibers, Dramix fibers also contribute to improve ζ_{eq}. With the increase of Dramix fibers content, generally EVD was also increased.

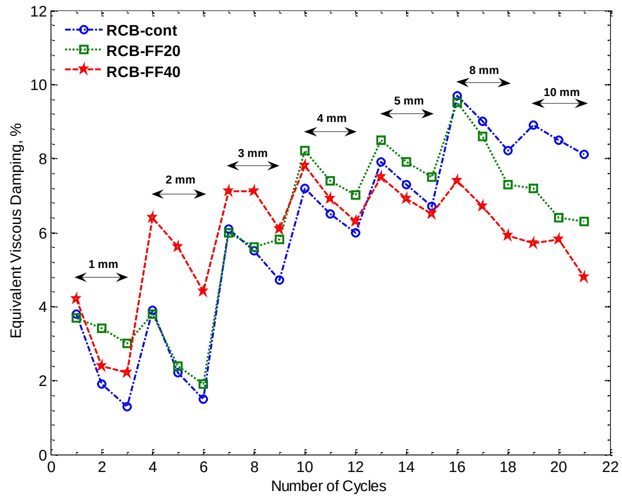

Fig. 4: Equivalent viscous damping (RCB-cont, RCB-FF20 and RCB-FF40)

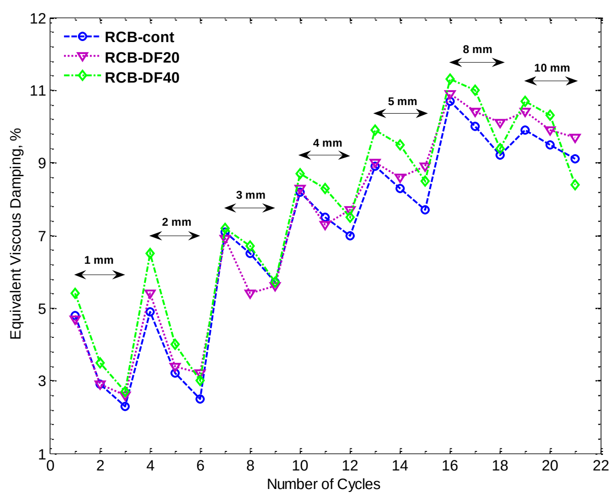

Fig. 5: Equivalent viscous damping (RCB-cont, RCB-DF20 & RCB-DF40)

Comparison of EVD of beams containing Fibra Flex and Dramix fibers at 20 kg/m^3 in mono form is shown in Fig.6 along with values of control beam. Up to displacement of 5 mm, the value of ζ_{eq} was greater with RCB-FF20 with the exception of 2 mm displacement. After 5 mm, it was RCB-DF20 beam which exhibited greater values of EVD.

Similarly in Fig.7, comparison of RC beams containing FibraFlex and Dramix fibers at 40 kg/m^3 in mono form in terms of ζ_{eq} is shown along with values of control beam. It is observed in this figure that up to displacement amplitude of 3 mm, the value of EVD was greater with RCB-FF40. After 3 mm, it was RCB-DF40 beam which exhibited greater values of EVD.

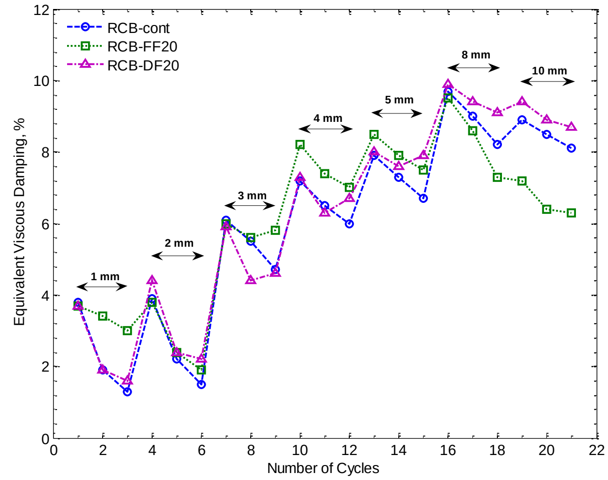

Fig.6: Equivalent viscous damping (RCB-cont, RCB-FF20 and RCB-DF20)

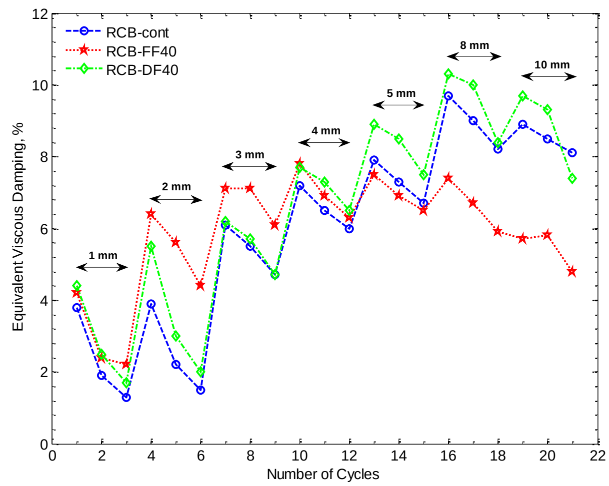

Fig.7: Equivalent viscous damping (RCB-cont, RCB-FF40 and RCB-DF40)

While comparing the results of equivalent viscous damping for the beam containing both fibers in hybrid form at content of each fiber equal to 20 kg/m^3 (RCB-40HyF) and the beam containing only Fibra Flex fibers at 40 kg/m^3 (RCB-FF40) in Fig.8, it was found that ζ_{eq} of RCB-40HyF was less than the RCB-FF40 up to amplitude of 4 mm. After 4 mm, it was reversed and RCB-40HyF exhibited higher values of ζ_{eq}. Since it has been already observed that both fibers contribute to enhance EVD at different displacement amplitude compared to control beam, the use of these fibers in hybrid form would be more promising instead of using only Fibra Flex fiber at dosage of 40 kg/m^3 when improvement in EVD over a wide range of displacement amplitude is desired.

In Fig.9, comparison of beams containing only Dramix fibers (RCB-DF40) and beam containing Fibra

Flex and Dramix fibers in hybrid form (RCB-40HyF) shows that replacing 50% of Dramix fibers by Fibra Flex fibers is not advantageous, since the values of EVD of RCB-40HyF were lower than that of RCB-DF40 at all displacement amplitude up to 10 mm.

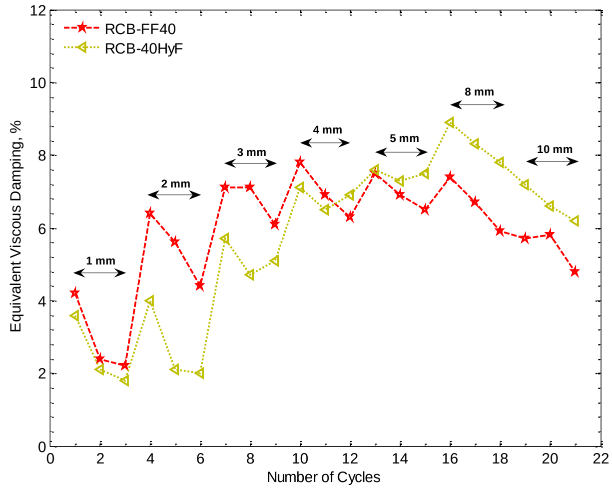

Fig. 8: Equivalent viscous damping (RCB-FF40 and RCB-40HyF)

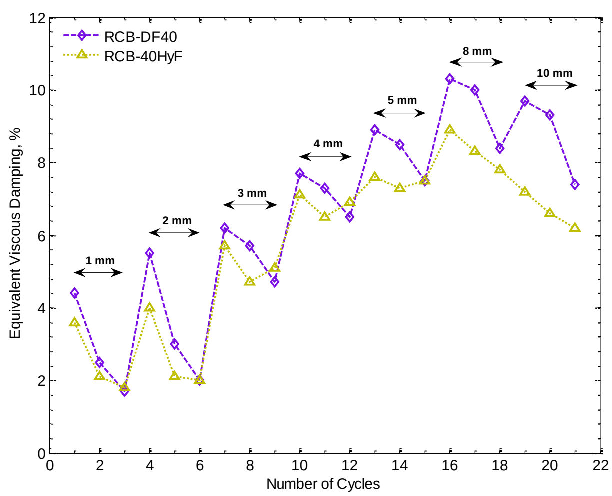

Fig. 9: Equivalent viscous damping (RCB-DF40 and RCB-40HyF)

Conclusions: The influence of metallic fiber addition on the equivalent viscous damping of the RC beams has been examined. From the analysis of the results and discussion, it is possible to draw the following conclusions;

- For all the tested beams, the value of the EVD through the first cycle was significantly higher than the value through the third cycle at the same displacement amplitude. This was mainly due to decrease in E_D in subsequent cycles at the same displacement amplitude.
- Equivalent viscous damping of RC beams is improved with addition of metallic fibers investigated in this study. This improvement is limited up to certain level of displacement amplitude for Fibra Flex fibers which depends on the content of fibers. However, effectiveness of Dramix fibers is noticed at each level of displacement amplitude.
- Equivalent viscous damping is improved over wide range of displacement amplitude by the use of Fibra Flex and Dramix fibers in hybrid form.

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