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Linearity between deflection and CMOD in hybrid fibre reinforced concrete

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Abstract **- Few researches were made in recent decades to explain the relationship between mid-span deflection and crack mouth opening displacement (CMOD). In this study, a concrete mix proportion arrived based on the packing density of concrete incorporated with hybrid combination of different types of fibre with different aspect ratio and dosages. High modulus steel fibre of length 60mm and 35mm and low modulus polypropylene fibre of length 47mm and 23.5mm is used in this study. A yoke set up is used to evaluate load-deflection curve and a specially fabricated C-clamp for evaluation CMOD. The paper mainly focuses on the relationship between the mid-span deflection and CMOD. Manual evaluation of the load-deflection curve and load-CMOD curve is carried out of different hybrid concrete specimen. The experimental results show a linear relationship between mid-span deflection and CMOD.**

Keywords**-mid-deflection;CMOD; hybrid; steel fibre; polypropylene fibre; toughness.**

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I. Introduction

Researches were made in many dimensions to evaluate the toughness of a fibre reinforced concrete member **[1-2]**. The evaluation of toughness properties for materials can be made using different methods suggested by standards and guidelines given to use the load-deflection curve **[3-4]**. Consideration of the crack mouth opening displacement (CMOD) is essential as in this evaluation a notch specimen which indicates the failure zone and the performance of fibres in crack bridging action can be observed **[5].** Even though many studies were made to evaluate deflection and CMOD, only limited studies describes about the linearity between these movements **[6].** In this study, a concrete mix proportion in the ratio of 50% coarse aggregate and 50% mortar is considered. Different hybrid combinations of steel fibre (SF) and polypropylene fibre (PP) with different dosages and aspect ratio to the volume fraction (V_f) of volume of mortar (V_m). A yoke set up is used to measure mid span deflection and a specially fabricated C – clamp is used to measure CMOD.The paper work focuses on demonstrating the linearity between mid span deflection and CMOD and corresponding toughness behavior.

II. Mix proportions and fibre used

The concrete mix proportions were conceptually arrived considering 1:1 ratio of coarse aggregate and mortar. The mix proportion and fibres used for the study are given in Table 1 & shown in Fig 1.

Table 1 Concrete composition for different specimens

Mix ID	Binder (B)		Fine Aggregate (FA)	Coarse Aggregate (CA)	Water	HRWR	Polypropylene Fibre		Steel Fibre	
	Cement	Slag					% $V_{fraction}$ Of V_{mortar}			
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	l/m^3	% V_B	47mm	23.5mm	60mm	35mm
M	162	162	876	1200	97.2	1	-	-	-	-
MF1	162	162	876	1200	97.2	1	0.6	-	1.6	-
MF2	162	162	876	1200	97.2	1	-	-	2	2
MF3	162	162	876	1200	97.2	1	-	0.4	-	2.4

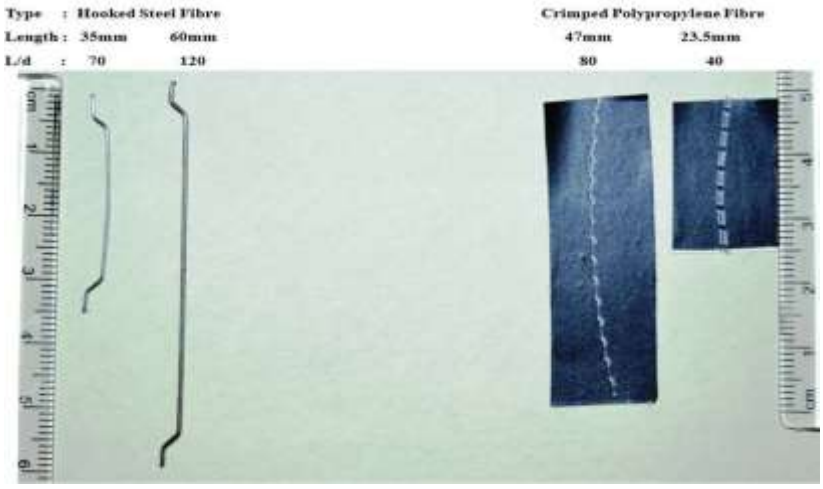

Figure 1. Types of fibre with different aspect ratio

III. Experimental methodology

The concrete prism specimens of 500 x 100 x 100 mm size were casted with different hybrid fibre combinations and cured for 28 days under normal condition. The cured specimens were tested under three point loading under flexural testing machine. The experimental arrangements for both deflection and CMOD measurements are given in Fig 2. The following methods were used to determine the similarity between load-deflection curve and load-CMOD curve.

Load - Deflection Load - CMOD

Figure 2. Experimental set up for deflection and displacement assessment

A. Yoke set up for load-deflection measurement

Yoke set up is used to determine the load-deflection plot for the prism specimen. The fabrication is made in such a way that the yoke is placed along the longitudinal section of the prism specimen such that the ends are restrained which avoids enormous deflection at the ends. Since the ends are restrained, the mid-span will be subjected to pure bending and hence an accurate load-deflection plot can be arrived. The evaluation of deflection is done along the Y direction (direction to which load is applied).

B. C-clamp set up for load-CMOD measurement

The evaluation of CMOD is made using C-clamp set up. The specimens were casted with a notch at the center of the span which will facilitate the determination of the failure zone. The notch arrangement will initiate the crack propagation because it will be the weaker zone along its cross section. The C-clamp is fabricated to measure the displacement along the x direction (lateral direct to load application) and clamped is placed closer to the notch. Since the notch area helps in the initiating the failure as that cross section will be the weaker, the development of the crack will cause a lateral movement in the C-clamp set up from which the corresponding displacement is evaluated.

C. Flexural testing

The toughness evaluation is made from the plot arrived from load-deflection values from yoke set up and load-CMOD from C-Clamp arrangement. Using the Graph 4.3 version, the toughness values for both deflection and CMOD curves were evaluated. The following toughness properties were assessed for control concrete (M) and hybrid fibre reinforced concrete (MF1, MF2 & MF3).

i) Absolute toughness was calculated from the area under entire load-deflection and load-CMOD curve from the start of loading till the complete failure of specimen.

ii) Post peak toughness was measured from the area between the ultimate load and failure load

under load-deflection and load-CMOD curve.

IV. Result & discussion

Based on the experiments carried out in laboratory, the following results were arrived.

A. Evaluation of toughness properties

From the experiment results the value of absolute toughness and post crack toughness were assessed systematically. Fig 3 & Fig 4 shows the values of absolute and post crack toughness measured from the load-deflection and load-CMOD plot using Graph 4.3 version. The load-deflection curve is arrived based on the value attained from the prism specimen with yoke set up and from C clamp set up.

Even though the variation in the toughness values is observed between deflection and displacement measurement, Fig 3 and Fig 4 represent the toughness values graphically shows a similarity in its trend

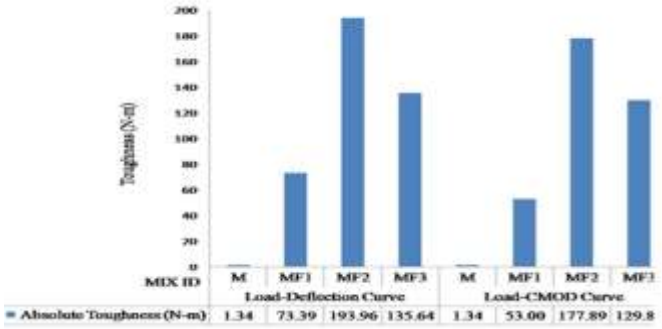

Figure 3. Absolute Toughness

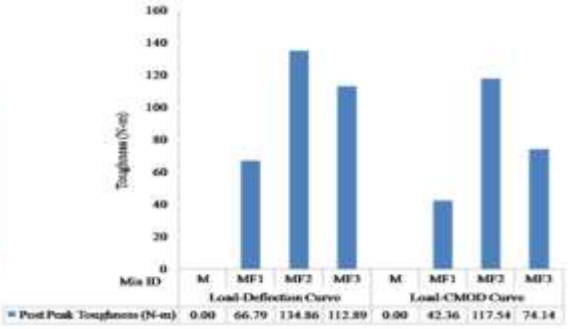

Figure 4. Post Peak Toughness

B. Experimental Relationship between deflection and displacement

The experiment observation of the load-deflection curve and load-CMOD curve shown in Fig 5 explains the relationship between deflection and displacement. From the recorded values of deflection and displacement, the graphs were plotted and it is observed that both load-deflection and load-CMOD curve shows a similar trend.These results also demonstrate that the deflection measured along Y direction will be similar to the displacement measured along the Z direction of the specimen. Fig 8 shows the linearity between the deflection and CMOD values assessed experimentally. Hence this method of evaluation is evidently justifies the linearity between deflection and displacement.

C. Analytical relationship between deflection and CMOD

Evaluation of deflection and displacement clearly shows the relation between the measurements. From the experimental results, the regression values were arrived which is shown in Table 2.

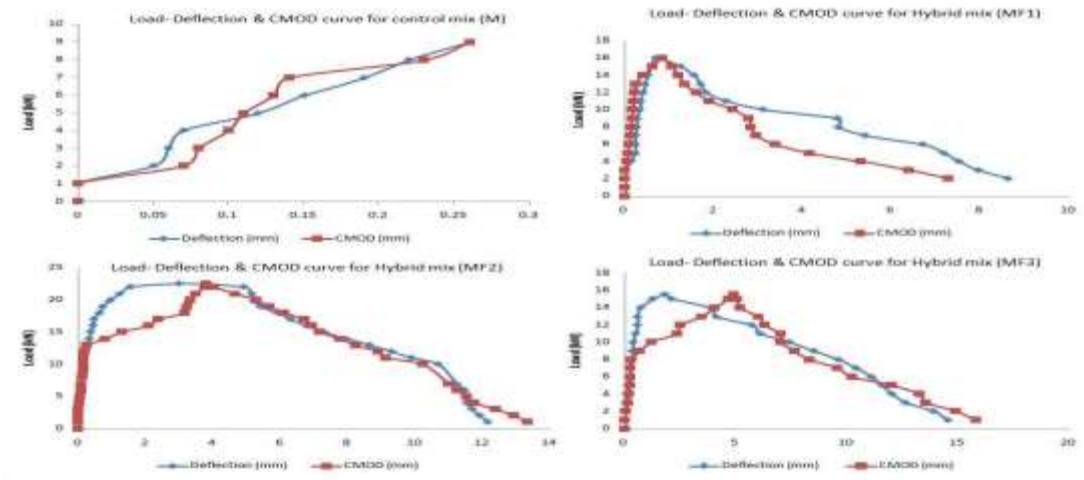

Figure 5. Load-deflection and load-CMOD plots for different mixes

Table 2 Analytical representation of the relationship between deflection and CMOD

Mix ID	Regression value (R^2)	Equation of slope
M	0.9368	y = 1.0369x - 0.0041
MF1	0.9456	y = 1.3735x + 0.1201
MF2	0.9616	y = 1.017x - 0.4797
MF3	0.9351	y = 0.9958x - 0.7951

V. Conclusion

The following conclusions can be drawn from the present study within the limitations of the experimental observations recorded during testing. The test results significant shows the similarity in the toughness trend but also emphasize the influence of the end condition towards energy absorption capacity. The new approach of C clamp set up for CMOD assessment shows a similar trend that is observed using clip gauge set up or LVDT for CMOD measurement. Hence this set up can be suggested from its less cost and easy operation. In general, deflection and displacement shows a linear relationship.

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