Trial Examination of Synthetic Polymer as Shear Reinforcement

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Abstract*: Steel Plays major role in the field of construction industry. Due to Rapid industrialization and urbanization has increased to twofolds the demand and usage of materials. Increasing demand creates depletion of material. Excessive waste plastic creates Environmental pollution, in order to reduce the waste it can be converted into polymers and can be used in the field of construction industry. Waste material can be used to replace the steel material in concrete as an alternative source. Usage of synthetic material increases day by day due to its advantages. A study was carried out to understand the behavior of synthetic polymers to be used in different fields. The research work is carried out for different polymers. It is found from the results that Strength of synthetic polymers is more when compared with other polymers and can be used as reinforcement in concrete there by reducing the weight of concrete member. The application of using synthetic polymer in concrete is not only limited to the weight reduction but also it reduces the cost of construction. Cost of construction can be reduced in the following ways, First it does not need skilled labors, second reduces the corrosion risks. Synthetic polymer has higher tensile strength compared to conventional steel polymer, hence more investigation to be carried out to expose the potentiality of the material.

***Keywords* : Steel, Waste plastic, Synthetic polymers, Strength.**

I. INTRODUCTION

Due to increase in demand the rate of construction activities are becoming expensive, to reduce the cost of construction alternative sources were utilized [1]. Steel is an ideal material used in structural elements to resist the bending behavior, usage of steel in structural components are easily affected by corrosion [9]. To reduce the rate of corrosion in reinforcement, mechanical properties of epoxy combinations were studied[18]. [19] Studied the effect of hybrid construction employing glass reinforcement hybridized on Kevlar polymer to prevent corrosion effects. Corrosion preventing mechanism employs thermal coating (TBC) consists of aluminium alloy (GFRAA) [20]. [13] Studied the usage of composite nano-particles to reduce the construction cost and to improve the properties of concrete.

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Alternative sources utilized in the construction should not harm the environment and to reduce the global warming issues and should lead to sustainable society, Natural materials can be employed [2]. If the naturally available materials are incorporate in construction, a detailed investigation has to be carried out to check the structural stability and strength of concrete [16]. [10] Investigated the use of natural polymers such as bamboo pegs to replace the conventional reinforcement and enhances the bonding property of concrete. To decrease the global warming issues, usage of waste materials in concrete enhances sustainable society by employing waste glass powder and glass polymer [11]. Composite materials are employed due to its higher advantage over its disadvantages, combination of glass polymer with natural polymer are employed to increase the mechanical properties of concrete [7], [6] and [12]. Utilization of bamboo as partial replacement for conventional reinforcement enhances the mechanical properties of concrete [8]. Structural steel is replaced by glass polymer reinforced plastic (GFRP) as main bar, stirrup and GFRP plate's ass shear reinforcement [3]. Polymer reinforced polymer (FRP) composites as shear reinforcement increases strength, stiffness and reduces the corrosion [4]. [5] Studied the use of recycled thermoplastic polymer and natural polymer, palm as synthetic reinforcement. [15] Studied the steel reinforced polymer (SRP) composite materials are more sensitive to fatigue performance of reinforced concrete.

II. PHYSICAL PROPERTIES

According to IS 269-1976, the fineness of cement has a significant role in the heat of hydration. Cement offers a more prominent surface zone for hydration and thus quicker the improvement of solidarity. It is found from the outcome that, Fineness of Cement = 2%. According to IS Fineness of cement is under 10 %. According to IS 4031 (Part-4) 1988, The standard consistency of a cement paste is characterized as that consistency which will allow a Vicat's plunger having 10 mm distance across and 50 mm length to enter to a profundity of 33-35 mm from the highest point of the form. From the test outcomes, the Standard consistency of bond is 34%. According to IS 4031, IS 269, The setting time is the timeframe between the time water is added to cement and time at which the needle penetrates the test block to a depth equal to 33 – 35 mm from the top. From the test outcomes, the setting time of cement is 30 minutes. According to IS 2386 (Part-4), Specific gravity of aggregates utilized in preparation of cement mix should be considered for proper workability and bond between the mix.

The specific gravity of fine aggregate is 2.714 and for coarse aggregate is 2.93. Moisture content in fine aggregate is 11.05% and for coarse aggregate is 15.6%. According to IS 1199-1959, Slump test is the most regularly utilized technique for estimating consistency of concrete, which can be utilized either in research facility or at site of work, from the outcome the slump is 41.83 mm.

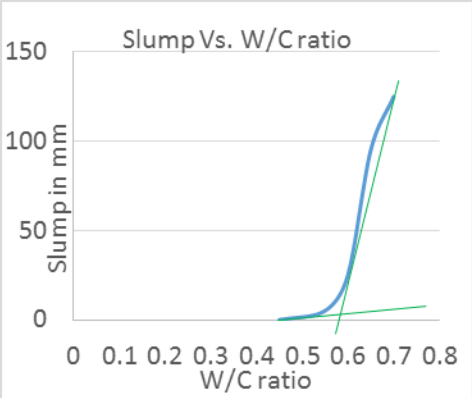

Figure 1. Comparison of slump and w/c ratio

The above figure shows the graph plotted against slump in vertical phase and water-cement ratio in the horizontal phase, the optimum water cement ratio is plotted by drawing two tangent line intersecting each other from the starting and finishing point of the curve and it is found that the optimum water-cement ratio is 0.58.

Table I. Specific gravities of mix ingredients

Material	Cement	Fine Aggregate	Coarse Aggregate	water
specific Gravity	3.25	2.74	2.93	1

Table II. Sieve analysis of fine aggregate

IS Sieve size (mm)	Empty wt. of sieve (kg)	weight of aggregate retained (kg)	% retained	Cumulative % retained	% Passing	Remarks
10	0.422	0	0	0	100	
4.75	0.387	0.039	3.9	3.9	96.1	Aggregates fall in the grading zone II of IS 2386 (part 1)
2.36	0.542	0.031	3.1	7	93	
1.18	0.441	0.206	20.6	27.6	72.4	
0.6	0.496	0.127	12.7	40.3	59.7	
0.3	0.559	0.495	49.5	89.8	10.2	
0.15	0.431	0.092	9.2	100	0	

Table III. Mix proportions of concrete

	Volume of concrete m^3	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Water (liter)	w/c ratio
IS code	1	350	864	1174	140	0.4
ACI code	1	380	920	1224	165	0.4

Figure 2. Longitudinal section of beam models

The above figure shows the longitudinal CAD model of concrete beam consists of steel and plastic stirrup. The green

vertical line represents the conventional steel stirrup, pink vertical line represents the plastic stirrup and the top and bottom blue line indicates the main bars in compression and tension zone.

III. TEST PROGRAMS

A. *Experimental setup and test procedure*

Sixteen beams of reinforced concrete with synthetic polymer is casted and tested at different curing periods as per IS 456:2000 recommendations.

Beams are designed as per Indian standard, consists of two compression reinforcement of diameter 10mm and four tension reinforcement of 10 mm diameter, stirrups are placed as per figure 2. Figure 2, shows the position of synthetic polymer and conventional steel, b1 shows the conventional reinforced concrete beam, b2 shows the reinforced concrete beam with alternative steel and synthetic polymer stirrup at a distance of 150mm center to center, b3 shows reinforced concrete beam with alternative arrangement of steel and steel in shear zone, b4 shows the beam with total replacement of steel by synthetic polymer in shear zone at a spacing of 150mm center to center. The cross-sectional dimensions of concrete beams are 150x200mm, and the cover of test specimen was kept constant of 20mm to protect the steel from corrosion. Beams are tested in loading frame of capacity 2000 kN, under two point loading condition with constant increase in load. Load is increased at a constant rate of 5 kN to study the bending behavior of reinforced concrete beams.

IV. MECHANICAL PROPERTIES

A. *Compressive Strength*

Sixteen cubes of dimension 150x150mm are casted along with specimen beams to check whether the compressive strength matches with the mix design. Compressive strength of concrete is the ability to withstand loads acting on it and also it's the measure of compression value on materials, components and structures. Compressive strength directly relates the Hooke's law. Hookes law states that stress is directly proportional to strain, and it is given by the equation, $\sigma = E\epsilon$, where , σ is the compressive stress, E is the youngs modulus and ϵ is strain. Concrete beams are casted, cured at room temperature and tested at different periods of times as shown below.

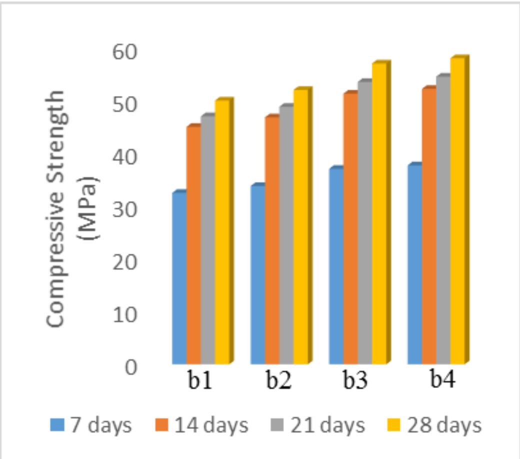

Figure 3. Compressive strength of concrete mix proportions and curing ages

B. *Modulus of Rupture*

Sixteen prism of dimension 100x100mm cross-section and a length of 700mm also casted along with beam specimen to check the flexural strength of concrete. Modulus of rupture indirectly evaluates the tensile property of concrete, specimens were casted based on indian standard conditions and tested at different period of times in a three-point test configuration. Modulus of rupture can also be calculated using the formula shown below:

$$f_{cr} = \frac{FL}{wd^2} \quad (1)$$

Where, f_{cr} = Modulus of Rupture, F = Maximum load applied, L = length of Specimen, w = width, d = depth

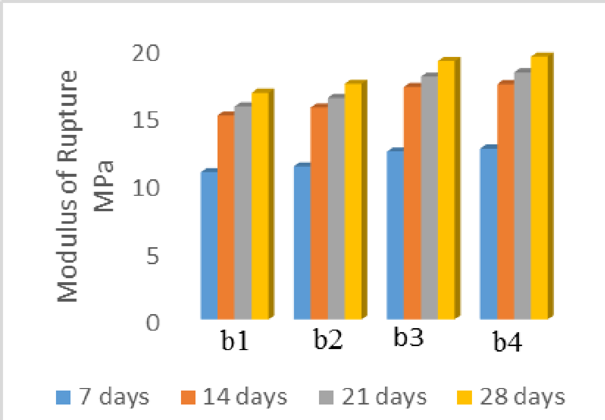

Figure 4. Modulus of rupture of concrete mix proportions and curing ages

C. *Shear Strength*

Shear strength of the specimen are found based on Indian standard and American standard codes. Based on IS456-2000, the loading condition of the beam are adopted. Figure 4. shows the shear strength value of different beams for different curing ages, b4 shows higher shear strength of 1.21 MPa on 28 days of curing, when compared to all other specimens

$$\delta = 1 + \frac{5P}{A_g f_{ck}} \quad (2)$$

Where, δ = Shear Strength, P = Axial compressive force, A_g = Gross area of the concrete section, f_{ck} = Characteristic compressive strength of concrete.

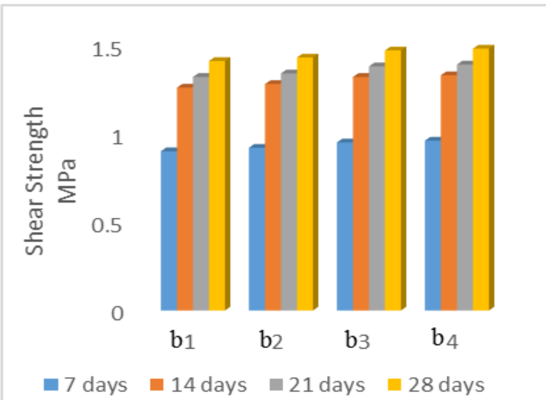

Figure 5. Shear strength of concrete mix proportions and curing ages

Bending Equation

$$\frac{E}{R} = \frac{M}{I} = \frac{f}{y} \quad (3)$$

Cracking moment

$$M_{cr} = f_{cr} \times \frac{I}{y} \quad (4)$$

Total moment

$$M = \frac{w_{cr} \times L^2}{8} \quad (5)$$

Cracking load

$$w_{cr} = \frac{8M}{L^2} \quad (6)$$

D. *Stress-Strain for Synthetic polymer and conventional HYSD bar*

Stress-Strain graph for HYSD bar and synthetic polymer are shown in fig 6 & 7. Ultimate stress of synthetic polymer is 5.85 kN/mm^2, Where the Ultimate stress of HYSD bar is 0.7 kN/mm^2. The stress-strain diagram demonstrates clearly that the load carrying capacity of synthetic polymer is more than HYSD bar. Young's modulus of synthetic material is higher than customary HYSD bars, so it tends to be utilized in the replacement of conventional steel. Utilization of synthetic polymer diminishes the plastic waste which makes environmental contamination, decreases the dead weight of structures, oppose the inward anxieties and to lessen the expense of development through cost varieties of steel and synthetic polymer.

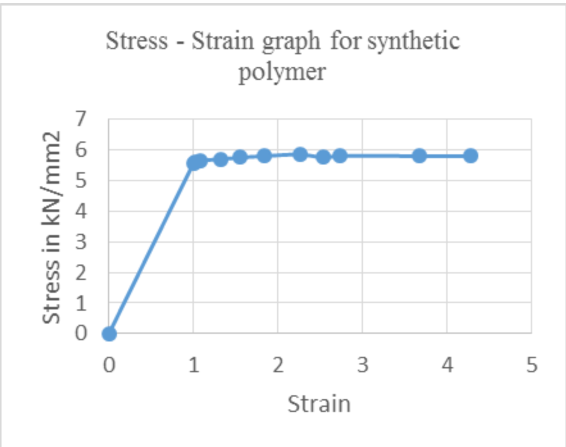

Figure 6. Stress - Strain graph for synthetic polymer

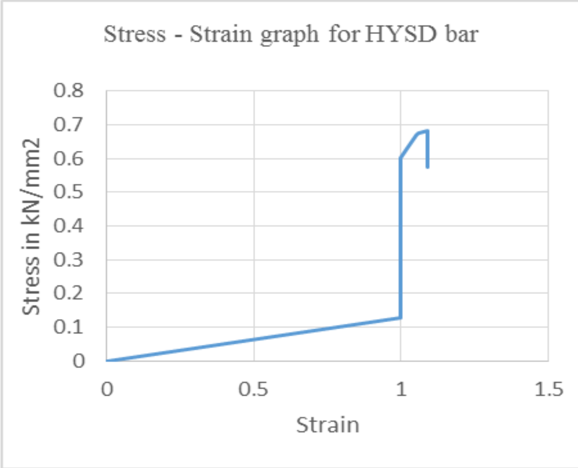

Figure 7. Stress - Strain graph for HYSD bar

E. *Predicted Modulus of rupture and shear strength from experimental compressive strength*

Designing structural elements required certain equations to determine the modulus of rupture and flexural strength from compressive strength. American concrete institute ACI 363R-92 and ACI 318-99 recommends equation (7) and (8) shows the relation between modulus of rupture and compressive strength, equation (9) and (10) shows the relation between shear strength and compressive strength of concrete. Equation (11) and (12) shows the predicted relation between modulus of rupture and shear strength from compressive strength

$$f_{cr} = 0.82fc^{0.53} \quad (7)$$
$$f_{cr} = 0.61fc^{0.50} \quad (8)$$
$$V_t = 0.62fc^{0.49} \quad (9)$$

$$V_t = 1.06fc^{0.49} \quad (10)$$

$$f_{cr} = 0.33fc^{0.99} \quad (11)$$

$$V_t = 0.404fc^{0.31} \quad (12)$$

Where, f_{cr} is the modulus of rupture, f_c is the compressive strength, v_t is the shear strength

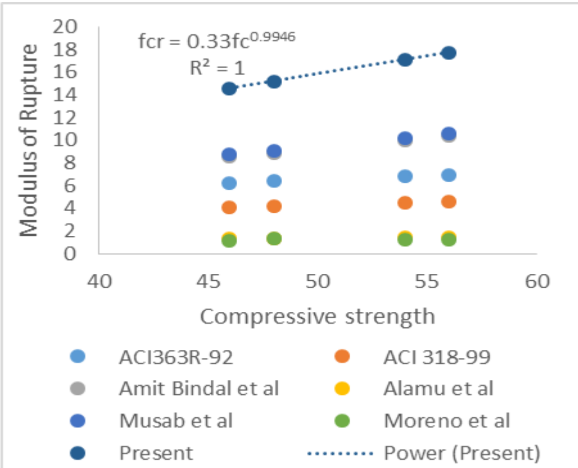

Figure 8.Comparison of modulus of rupture values

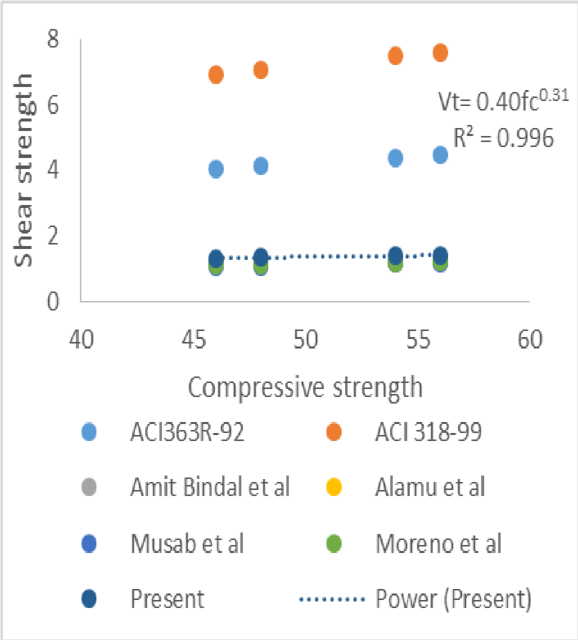

Figure 9.Comparison of predicted shear strength values

F. *Elastic Modulus*

Elastic modulus is indirectly dependent on compressive strength and size of specimen. If the specimen size increases the compressive strength decreases and the elastic modulus of concrete will increase. On the other hand if the specimen size decrease the compresive strength increase and the elastic modulus decrease. Elastic modulus of concrete M20 grade after 28 days of curing gives 22360 MPa as per Indian standard 456-2000. Modulus of elasticity for different specimens are calcuated based on trial and error method and non-linear numerical model, and values lies between 29324 to 29756 MPa.

I) Based on American building code (ACI 318-14) the Elastic modulus of concrete can be calculated by using equation (13)

$$E_c = 0.043\ \rho^{1.5} fc^{0.5}$$

II) Based on Indian standard (IS 456-2000), the Elastic modulus of conventional concrete can be calculated using equation (14)

$$E_c = 5000\ fc^{0.5} \quad (14)$$

III) Based on trial experiments of Amit Bindal et al. the Elastic modulus of Polymer reinforced composite concrete can be calculated using equation (15)

$$E_c = 29825\ fc^{0.0742} \quad (15)$$

IV) Alamu et al. shows the equation to find the Elastic modulus of concrete in equation (16)

$$E_c=27815fc^{0.0742} \quad (16)$$

V) Musab et al. and Moreno et al. described the equation to determine the Modulus of Elasticity in equation (17) & (18)

$$E_c=25852fc^{0.0742} \quad (17)$$

$$E_c=23937fc^{0.0742} \quad (18)$$

The above results shows the predicted model to determine the Modulus of Elasticity of concrete, Equation (19) displays the numerical model developed based on compressive strength of concrete.

$$E_c=22073fc^{0.0742} \quad (19)$$

The proposed equations to determine the elastic modulus of concrete is shown in table 6, comparison between American, Indian and past experiments are shown.

Table IV. Predicted Modulus of Rupture for several relationships

Specimen	Experimental data		Predicted data						
			ACI363R-92	ACI 318-99	Amit et al	Alamu et al	Musab et al	Moreno et al	Present
	Compressive strength (Mpa)	Modulus of Rupture (Mpa)	$f_{cr}=0.82fc^{0.53}$	$f_{cr}=0.61fc^{0.5}$ 0	$f_{cr}=0.193fc^{0.99}$	$f_{cr}=0.26fc^{0.43}$	$f_{cr}=0.197fc^{0.99}$	$f_{cr}=0.25fc^{0.3}$ 9	$f_{cr}=0.33fc^{0.99}$
b1	46	13.8	6.23	4.13	8.54	1.34	8.72	1.11	14.6
b2	48	14.4	6.38	4.22	8.91	1.37	9.08	1.31	15.22
b3	54	16.2	6.79	4.48	10.01	1.44	10.22	1.18	17.12
b4	56	16.8	6.92	4.56	10.38	1.46	10.59	1.2	17.75

Table V. Predicted Shear strength for several relationships

Specimen	Experimental data		Predicted data						
	Compressive strength (Mpa)	Shear strength (Mpa)	ACI363R-92	ACI 318-99	Amit et al	Alamu et al	Musab et al	Moreno et al	Present
			$V_t=0.62fc^{0.49}$	$V_t=1.06fc^{0.49}$	$V_t=0.48fc^{0.23}$	$V_t=0.404fc^{0.31}$	$V_t=0.19fc^{0.45}$	$V_t=0.25fc^{0.39}$	$V_t=0.404fc^{0.31}$
b1	46	1.1	4.04	6.91	1.15	1.16	1.06	1.11	1.32
b2	48	1.15	4.13	7.06	1.16	1.18	1.08	1.13	1.34
b3	54	1.2	4.37	7.48	1.2	1.22	1.14	1.18	1.39
b4	56	1.21	4.45	7.61	1.21	1.23	1.16	1.2	1.4

Table VI. Predicted Elastic Modulus for several relationships

Specimen	Compressive strength (Mpa)	Elastic Modulus (Mpa)						
		ACI318-14	IS 456-2000	Amit Bindal et al	Alamu et al	Musab et al	Moreno et al	Present
		$Ec = 0.043 \rho^{1.5}fc^{0.5}$	$Ec = 5000 fc^{0.5}$	$Ec = 29825 fc^{0.0742}$	$Ec=27815fc^{0.0742}$	$Ec=25852fc^{0.0742}$	$Ec=23937fc^{0.0742}$	$Ec=22073fc^{0.0742}$
b1	46	19546.69	33911.64	39623.88	36953.5	34345.57	31801.4	29324.99
b2	48	19967.09	34641.01	39749.21	37070.39	34454.2	31901.99	29417.75
b3	54	21178.3	36742.34	40098.12	37395.78	34756.63	32182.02	29675.97
b4	56	21566.93	37416.57	40206.47	37496.83	34850.55	32268.98	29756.16

V. RESULT AND DISCUSSION

A. *Failure pattern*

Flexure cracks in all the specimens are occurred randomly in the tension zone, increase in load increases number of cracks. The failure pattern of all the test specimens varies, due to change in reinforcement (stirrup) type. The failure type of beams are splitting bond failure, beam specimen with synthetic polymer shows more ductile when compared with reinforced concrete beam with conventional steel stirrup. b1 and b2 shows the failure pattern of flexure and diagonal shear, b3 shows flexure and shear tension failure, b4 shows the failure pattern of flexure, diagonal and shear compression.

Figure 10. shows b1 with flexure and diagonal failure

Figure 11. shows b2 with flexure and diagonal failure

Figure 12. shows b3 with flexure and shear tension failure

Figure 13. shows b4 with flexure and shear compression failure

B. *Load-Deflection behavior*

Maximum load carrying capacity by conventional beam is 52 kN and shear crack observed was at a distance of 25cm from left and 20cm from right support. Maximum load carrying capacity by alternative synthetic polymer beam is 51 kN and shear crack observed was at a distance of 30 cm from left and 23 cm from right support. Maximum load carrying capacity by alternative synthetic polymer in shear zone is 58 kN and shear crack observed was at a distance of 15 cm from left and 10 cm from right support. Maximum load carrying capacity by synthetic polymer in shear zone is 57 kN and shear crack observed was at a distance of 15 cm from left and 5 cm from right support.

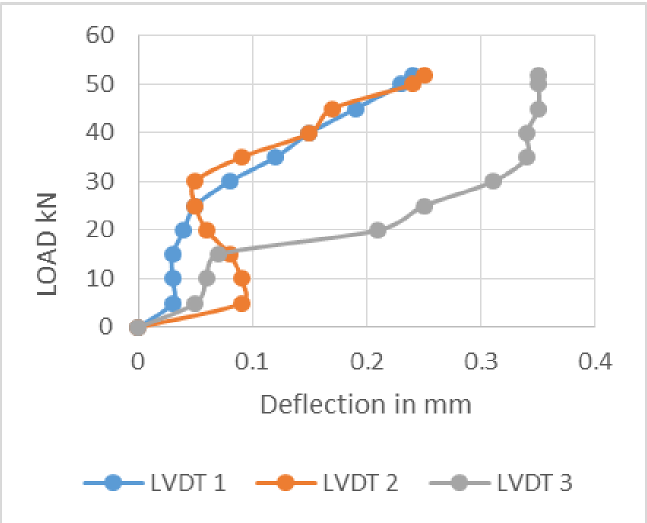

Figure 14. shows load-deflection curve for beam with conventional reinforced concrete beam.

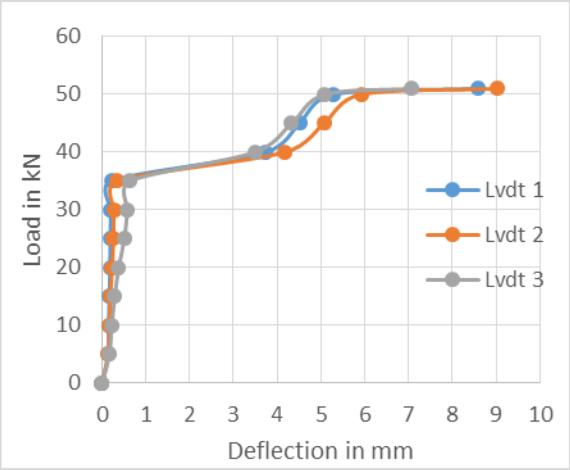

Figure 15. shows load-deflection curve for beam with alternative replacement of steel by synthetic polymer in reinforced concrete beam.

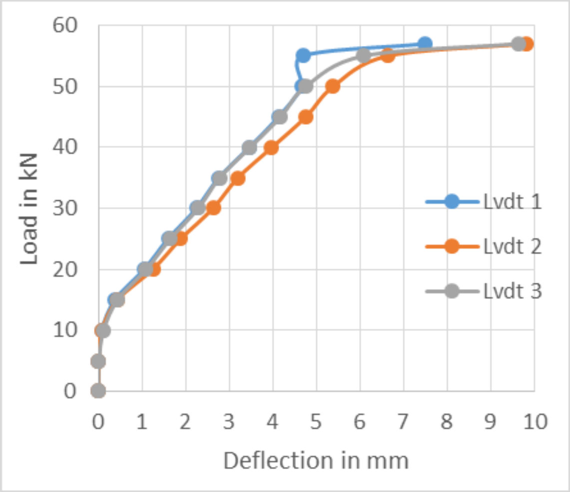

Figure 16. shows load-deflection curve for beam with alternative replacement of steel by synthetic polymer in shear zone.

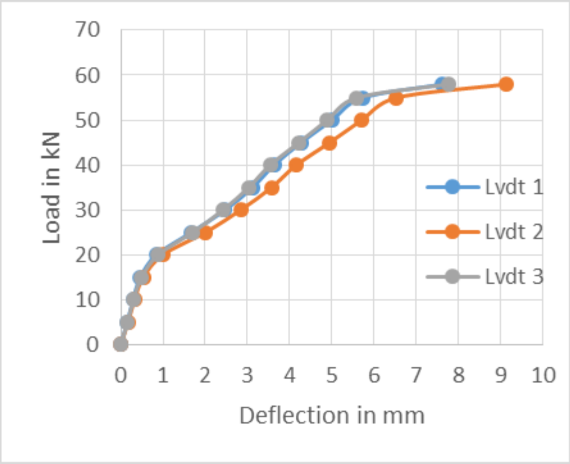

Figure 17. shows load-deflection curve for beam with total replacement of steel by synthetic polymer in shear zone.

VI. CONCLUSION

Compared to all the specimens, b4 shows higher compressive strength of 56 MPa after 28 days of curing and has higher Modulus of Rupture and Shear strength values are 16.8 MPa and 1.21 MPa. A non-linear model was created to study the comparative difference between Modulus of Rupture, compressive strength and shear strength. The model equations for modulus of rupture vs. compressive strength and shear strength vs. compressive strength are $f_{cr} = 0.33fc^{0.99}$ & $v_t = 0.40fc^{0.31}$. Similarly, a numerical model was proposed for Elastic Modulus and compressive strength for the same. The equation for Elastic Modulus vs. compressive strength is $E_c = 22073fc^{0.0742}$. Cracking moment and cracking load on beam is calculated from the bending equations are 8.4 kNm and 16.67 N/mm. All the four beam models shown in figure 2 are casted and tested at different curing ages, and the load vs. Deflection graph is plotted for all beams after 28 days of curing, shows that b4 has higher load intake and saves nearly 44.92% of steel consumption.

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Appendix :

E	Young's modulus
fc	compressive strength
L	length of the specimen
w	width of the specimen
b1	conventional beam
b2	beam with alternate replacement of synthetic polymer
b3	beam with Alternate replacement of synthetic polymer in shear zone
b4	beam with Total replacement of stirrups by synthetic polymer in shear zone.

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