Structural Characteristics of HPDSP Concrete on Beam Column Joints

Sushil Kumar Swar, Sanjay Kumar Sharma, Hari Krishan Sharma, Sushil Kumar

***Abstract*—**The seriously damaged structures during earthquakes show the need and importance of design of reinforced concrete structures with high ductility. Reinforced concrete beam-column joints have an important function in all structures. Under seismic excitation, the beam column joint region is subjected to horizontal and vertical shear forces whose magnitude is many times higher than the adjacent beam and column. Strength and ductility of structures depends mainly on proper detailing of the reinforcement in beam-column joints and the old structures were found ductility deficient. DSP materials are obtained by using high quantities of super plasticizers and high volumes of micro silica. In the case of High Performance Densified Small Particle Concrete (HPDSPC), since concrete is dense even at the micro-structure level, tensile strain would be much higher than that of the conventional SFRC, SIFCON & SIMCON. This in turn will improve cracking behaviour, ductility and energy absorption capacity of composites in addition to durability. The fine fibers used in our mix are 0.3mm diameter and 10 mm which can be easily placed with high percentage. These fibers easily transfer stresses and act as a composite concrete unit to take up extremely high loads with high compressive strength. HPDSPC placed in the beam column joints helps in safety of human life due to prolonged failure.

***Keywords*—**High Performance Densified Small Particle Concrete (HPDSPC), Steel Fıber Reinforced Concrete (SFRC), Slurry Infiltrated Concrete (SIFCON), Slurry Infiltrated Mat Concrete (SIMCON).

I. INTRODUCTION

TRADITIONALLY, High Performance Concrete (HPC) may be regarded as synonymous with high strength concrete (HSC). It is because lowering of water-to-cement ratio, which is needed to attain high strength and this also generally improves other properties in HPC [3]. Hence, it is important to understand how concrete performance is linked to its microstructure and composition. In fact, performance can be related to any properties of concrete. It can mean excellent workability in fresh concrete, or low heat of hydration in case of mass concrete, or very quick setting and hardening of concrete in case of spray concrete which is used to repair roads and airfields [3]. However, from a structural point of view, one understands usually that high strength, high ductility and high durability, which are regarded as the most favorable factors for a construction material, are the key attributes to HPC. Decades ago, HSC was only tested in laboratory without real applications because there were still many uncertainties on the structural behavior of HSC at that time. Up to the present, HPC has been widely used in tall building construction. FIBER reinforced concrete (FRC) can sustain a portion of its resistance following cracking to resist more cycles of loading [2]. Since beam-column joints in building frames have a crucial role in the structural integrity of building, they must be provided with adequate stiffness and strength to sustain load transmitted from beams and columns. Formation of plastic hinge must be prevented as it affects the entire structure. For adequate ductility in beam-column junction, use closely spaced hoops as transverse reinforcement was recommended in the ACI-ASE committee 352 report (ACI 2002). However, due to congestion of reinforcement, casting of beam-column joints will be difficult and will lead to honeycombing in concrete at these joints.

Sushil Kumar Swar (Ph-D Scholar), Sanjay Kumar Sharma (Professor) and Sushil Kumar ME CTM, are with the Civil Engineering Department, National Institute of Technical Teachers Training and Research (NITTTR), Chandigarh, India (e-mail: swarsushil@rediffmail.com, sanjaysharmachd@yahoo.com, sushilkmr591@gmail.com).
Harı Krishan Sharma, Professor, Department of Civil Engineering, NIT, Kurukshetra, India (e-mail: hksharma1010@yahoo.co.in).

A. High Performance Concrete

The term "high performance" implies optimized combination of properties such as strain hardening, strength, cracking, toughness, energy absorption, durability and corrosion resistant [1]. High performance concrete is designed to give performance characteristics satisfying such a compressive list of requirement based on hardened properties. The mix proportioning which relies on the concept of densified system with effective combination of mineral additives, ultrafine material and chemical admixtures in addition to low water cement ratio. The reduction in total concrete volume and improvement in strength and structural durability by the use of high performance concrete is evaded [1].

The composition of HPC usually consists of cement, water, fine sand, super plasticizer, fly ash and silica fumes. Sometimes, quartz flour and fiber are the components as well for HPC having ultra strength and ultra ductility, respectively. The key elements of high performance concrete can be summarized as follows:

- Low water-to-cement ratio,
- Large quantity of silica fume (and/or other fine mineral powders),
- Small aggregates and fine sand,
- High dosage of super plasticizers.

B. Behaviour of High Performance SFRC

The deformation characterization of cementitious matrices in tension is distinguished according to their post-cracking deformation behaviour.

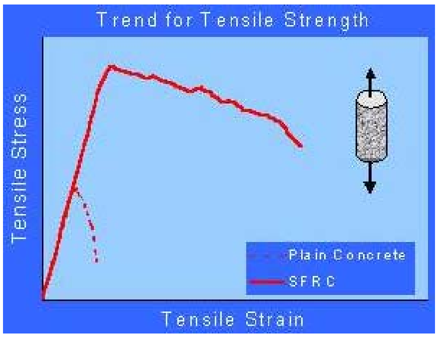


Fig. 1 Tensile stress vs Tensile Strain for Plain Concrete & SFRC

The addition of FIBERS in conventional FRC can increase the toughness of cementitious matrices significantly; however their tensile strength and specially strain capacity beyond first cracking are not enhanced. FRC is therefore considered to be a quasi-brittle material with tension softening deformation behaviour. From Figs. 1 and 2, it shows how SFRC steel fiber reinforced concrete has much higher tensile strength and can resist large bending stresses as compared to plain concrete.

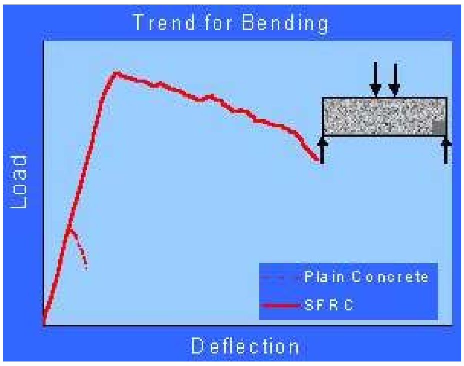
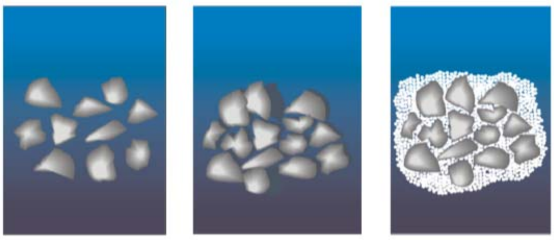


Fig. 2 Load vs Deflection for Plain Concrete & SFRC



(a) (b) (c)

Fig. 3 Formation of DSP Paste (a) Cement Paste, (b) Super-plasticized Cement Paste, (c) DSP Binder Paste

C. Densified with Small Particles (DSP) Systems

The concept of DSP (Densified with Small Particles) materials was introduced by Bache in the 1980's, when the use of sub-micron particles (micro-silica) in cementitious materials was conceived [6]. DSP cement pastes consists of a mixture of Portland cement and micro-silica, densified with a superplasticizer and this is the mechanism of obtaining DSP cement pastes as shown in Fig. 3 [7]. Normally, the micro-silica/binder ratio varies from 0.15 to 0.25; water/binder ratio varies from 0.15 to 0.20. Using this basic formulation and other ingredients (for example, high quality aggregates and fibers), it is possible to obtain several products, in function of the desired final properties and applications [8].

The final properties of these products are very interesting; it is possible to obtain values of strengths and ductility, close to those of structural steel. An increase of mechanical strength is always associated with an increase in brittleness, with consequences that can be catastrophic at the structural level. The use of reinforcing fibers leads not only to the increase of tensile/bending strength and specific fracture energy, but also to reduction of brittleness and, consequently, to production of non-explosive ruptures. Besides, fiber-reinforced materials are more homogeneous and less sensitive to small defects and flaws.

II. Problems in Beam Column Joints

The structures damaged during these earthquakes have once again demonstrated the importance of design of earthquake resistant structures with high ductility [4], [10]. In the analysis of reinforced concrete moment resisting frames the joints are generally assumed as rigid. In Indian practice, the joint is usually neglected for specific design with attention being restricted to provision of sufficient anchorage for beam longitudinal reinforcement [4]. This may be acceptable when the frame is not subjected to earthquake loads. The poor design practice of beam column joints is compounded by the high demand imposed by the adjoining flexural members (beams and columns) in the event of mobilizing their inelastic capacities to dissipate seismic energy [6]. Since past three decades extensive research has been carried out on studying the behaviour of joints under seismic conditions through experimental and analytical studies.

Fig. 4 Mexico City Earthquake: Collapse of an 8 level building in 1985

Various international codes of practices have been undergoing periodic revisions to incorporate the research findings into practice. The seismic design philosophy relies on providing sufficient ductility to the structure by which the structure can dissipate seismic energy [9] (Figs. 4 and 5 show beam column joint failures).

Fig. 5 Beam column Joint failure

III. Experimental Investigations and Result Analysis

A. Concrete Mix Design to Be Adopted

High performance concrete mix was designed to achieve M70 grade concrete using admixture as per ACI Committee 211.4-08. Several trial mixes were carried out to achieve HPC using high range water reducing agent (HRWR) and silica fume. Water-cement ratio was adjusted to have slump of 100 ± 5 mm. The details of the trial mixes are tabulated in Table I.

Concrete mix proportion corresponding to 1:1.36:1.87 (by weight) with water cement ratio 0.24 %, HRWR dosage of 1.4% by weight of cement and silica fume dosage of 12% by weight of cement, provided a concrete mix with compressive strength 76MPa, under normal water curing after 28 days without fiber. Straight steel fibers in varying fiber volume fraction corresponding to 3%, 6%, 9%, 12% and 15% of cementitious material were used to produce steel fiber reinforced high performance concrete of higher grades using same mix proportion.

B. Methodology

In the beginning of project work, raw materials (ingredients) required for casting of concrete cubes were collected and necessary data required for mix design was obtained by various tests in laboratory [1]. Mix design is carried out according to ACI Committee 211.4-08. Recommended guidelines for concrete mix design to get the designed compressive strength and workability. The procedure for design of micro silica in concrete mixes is according to IS: 15388-2003. The trial mix M6 was selected from various trial mixes and same proportion was used because of maximum strength and economy, hence M6 was used for casting of concrete cubes, cylinders and beams with different percentages of steel fibers varying from 3% to 15% of cementitious material.

- Materials are weighted by weigh batching.
- Steel fibers were added from 0%, 3%, 6%, 9% , 12% and 15% to the total cementitious material.
- Concrete cubes of size 150 mm X 150 mm X 150 mm and cylinders of size 100 mm X 200 mm and beams of size 100 mm X 100 mm X 500 mm with varying fiber percentages each were casted for compressive strength, split tensile strength and flexural strength respectively.
- Method of test for determining the compressive strength of samples is according to IS: 516-1959,"Methods of test for strength of concrete".
- Each set consist of 3 cubes, 3 cylinders, 3 beams and the test strength of the samples has been taken as the average strength of three specimens.
- It is observed that the individual variation of specimen strength with in ± 15 percent of average strength. Thus the test results are quite consistent and reasonable.
- Workability of fresh concrete with and without steel fibers is measured by slump test apparatus
- Beam column joints were casted with M6 concrete mix in the junction portion and 20% length of joint remaining portion concrete M20 was placed in the beams and columns [1].

C. Compressive Strength of Concrete

The compressive strength of cubes is carried out according to IS: 516, "Method of test for strength of concrete". The results of compressive, split tensile and flexural strength under normal water curing at ages 7 days, 14 days and 28 days have been reported in Table II and plotted in Figs. 6, 7 and 8 respectively [11]. At 9% percentage fibers there is appreciable increase in strength and beyond this there is insignificant increase of the strength though there is increase in fiber content, decrease in workability with increase in cost.

TABLE I
Mix Proportion of Different Trial Mixes Done

Mix Design	Cement (Kg)	Silica Fume (kg)	Fly Ash	Coarse Aggregate (kg)		Fine Aggregate (kg)	Water Cement Ratio	HRWR (%)	Average Strength	
				10mm	20mm				7 Days	28 Days
M1	**450**	**45**	90	398	597	742	0.27	0.7	46.59	62
M2	465	93	-	460	690	800	0.27	1.2	54.24	65
M3	470	47	94	393	589	732	0.27	0.8	58.79	68
M4	475	53	-		1055	700	0.28	1.2	61.11	71
M5	500	50	100	385	577	717	0.27	0.7	59.22	72.23
M6	**525**	**63**	**-**	**440**	**660**	**800**	**0.24**	**1.4**	**60.85**	**75.66**
M7	563	63	-	1100	--	800	0-28	1.4	56.35	73.45
M8	750	179	--	935	--	572	0.22	1.4	55.15	71.14
M9	800	240	--	530	--	700	0.26	1.8	50.14	64.55

TABLE II
STRENGTH OF CONCRETE MIX BY ADDING DIFFERENT PERCENTAGE OF FIBERS

Sr. No	Fiber %age	Average Compressive Strength N/mm^2			Average Split Tensile Strength N/mm^2			Average Flexural Strength N/mm^2		
		7 Days	14 Days	28 days	7 Days	14 Days	28 days	7 Days	14 Days	28 days
1	0%	60.85	69.55	75.66	4.21	4.55	5.26	9.14	9.66	10.29
2	3%	63.67	71.15	83.78	4.42	4.90	5.73	10.73	11.48	12.57
3	6%	70.32	85.66	91.90	4.56	5.02	6.33	11.03	13.79	14.23
4	**9%**	**76.18**	**88.15**	**94.54**	**5.12**	**5.67**	**6.68**	**12.72**	**13.95**	**15.58**
5	12%	81.12	88.67	95.72	5.32	5.2	6.77	12.86	14.09	15.78
6	15%	82.56	91.70	96.23	5.55	6.24	6.82	12.98	14.15	15.86

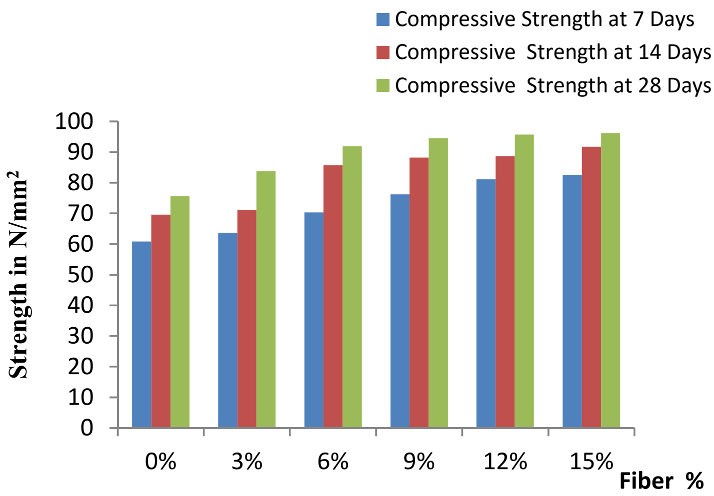


Fig. 6 Compressive Strength verses Fiber Percentage

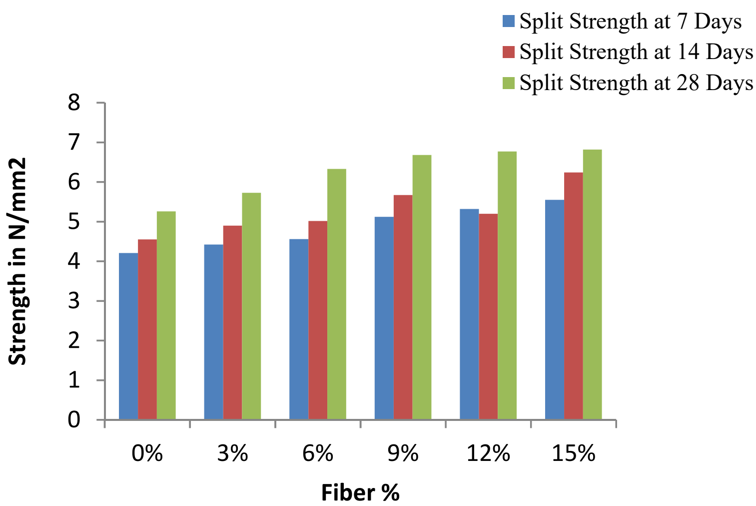


Fig. 7 Split Tensile Strength verses Fiber Percentage

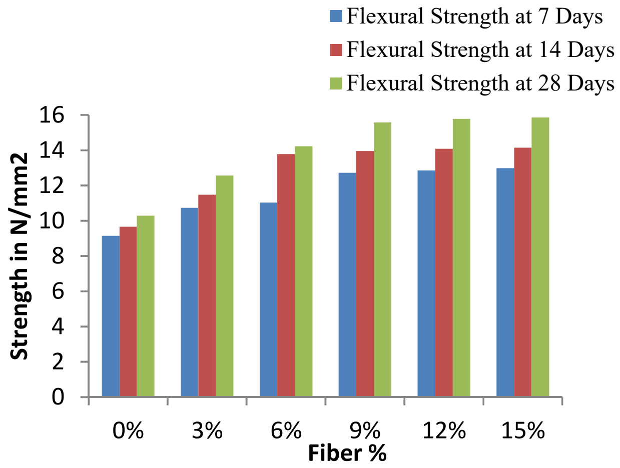


Fig. 8 Flexural Strength verses Fiber Percentage

D. Casting and Testing of Beam Column Joints

Beam-column sub-assemblages used as moment resisting frames as shown in Fig. 9 will be constructed using HPDSPC in the joint region with varying quantities of steel fibers, fiber aspect ratio and fiber orientation in the critical section. Besides loading measurements, frame displacements, diagonal joint strain and rebar strain adjacent to the joint will also be measured to investigate stress-strain behavior, load deformation characteristics, joint shear strength, failure mechanism, ductility associated parameters, stiffness and energy dissipated parameters of the beam column sub-assemblages will also be evaluated. Analytical study can also be conducted by modeling beam column sub assemblage using appropriate software to determine HPDSPC grade corresponding to moment, shear and axial forces to be resisted. The effect of FIBER aspect ratio, FIBER volume contents and FIBER types on failure mechanism of HPDSPC will also be investigated by estimating fracture energy and characteristic length. Finally a design procedure for the optimum design of HPDSPC corresponding to moment, shear forces and axial forces for the reinforced concrete beam-column joint sub-assemblage will be proposed. (Figs. 9 and10 show the casting and testing of beam column assemblage.)

Fig. 9 Casting of beam column joint

Fig. 10 Testing Set- up

IV. Conclusion

On the basis of experimental results, it is observed that compressive strength, split tensile strength and flexural strength are on higher side for 9% fibers as compared to that produced from 0%, 3%, and 6% fibers. Fibers percentages were taken with respect to cementitious material. All the strength properties are observed with fiber of diameter 0.3mm and length 10mm with aspect ratio of 33.33. It is observed that compressive strength increases from 10.73% to 27.19% with addition of steel fibers. It is observed that split tensile strength increases from 8.94% to 18.63% with addition of steel fibers. It is observed that flexural strength increases from 22.16% to 54.13% with addition of steel fibers. With Increase in fiber percentage from 9% to 15% there is no appreciable increase in compressive split tensile as well in flexural strength. From 12% to 15% concrete is not workable and hence 9% is considered [5].

The fact that the implementation of material brittleness measure in the design of RC structures can improve structural reliability by providing uniform safety margins over a wide range of structural sizes and material compositions well recognized in the structural design and research [12]. This has led to the development of high performance concrete for the optimized combination of various structural ratios in concrete for the optimized combination of various structural properties. The deficiencies of SFRC and SIFCON can be overcome by adding FIBERS having low aspect ratio in concrete to avoid balling effect. The fine FIBERS used in our mix are 0.3mm diameter and 10 mm long. Due to its fine thickness and small length they are easily placed with high percentage and in our case up to 15% [11]. The fine FIBERS easily transfer stress and act as a composite concrete unit to take up extremely high loads with compressive strength up to around 100MPa and help in safety of human life due to prolonged failure of the beam column joints with formation of multiple fine cracking. These cost effective parameters will make this material more versatile for use in various structural applications like beam-column joints in industries, airports, parking areas, docks, harbours, and also containers for hazardous material, safety boxes and mould & tools for polymer composites and metals [13].

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