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Behaviour of Normal Strength concrete and High Strength concrete subjected to In-plane Shear

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ABSTRACT: Transfer of the shear force is critical in a composite section, corbel, deep beams, brackets, shear wall and pre-cast components since the mode of failure is brittle and catastrophic. Evaluation of shear capacity in these components to perfection is still an unsettled topic. An attempt has been made to study the complex shear behavior of concrete along specific plane using push-off test.

The principal objectives of this study was to investigate the shear capacity of Normal Strength Concrete (NSC) and High Strength Concrete(HSC) at different inclination of shear plane using push-off test specimen. The grades of concrete used are M30 for NSC and M70 for HSC. Dimension of push-off specimen chosen was 150x150x260mm with two notches of 10mm thick with varying length 75mm, 65mm, 55mm and 45mm to induce shear plane inclination of 0°, 11°, 22°, 31° respectively. Notches were 100mm apart perpendicular to the axis of loading on specimen and equidistance from the mid height of shear plane. Plain push-off specimen and End-Block strengthened push-off specimens were used to study influence of induced compressive stress normal to the shear plane on shear strength. It was observed from the experimental results as the inclination increased, the in-plane shear stress increased

KEYWORDS: HSC, In-plane shear, Ultimate shear strength, Transverse compressive stress

I. INTRODUCTION

Concrete members like corbels, precasted members, ledger beams, shear walls etc predominantly fail in direct shear. This type of failure takes place without warning. The shear behaviour of HSC is substantially different from that of NSC [1]. Nowadays with use of HSC in construction field has increased due to improved mechanical properties exhibited when compared with NSC, but on the other side ductility is reduced significantly.

The push-off test is a conceptual test, but widely recognized, used to understand shear in concrete. The push-off test has the advantage of being relatively small, inexpensive and easy to perform.

The push-off test is based on the concept of applying an axial force (P) to produce a pure shear on a predetermined plane of the specimen (shear plane) [2]. Shear plane is the plane where slip occurs at a location where either the load or the geometry is discontinuous in a direction perpendicular to the axis of the member. A shear load is a force that tends to produce a sliding failure on a material along a plane that is parallel to the direction of the force.

The stress that develops at maximum load or rupture in which the plane of fracture is centrally located along the longitudinal axis of the specimen between two diametrically opposed notches machined halfway through its width is termed as In-Plane Shear Strength.

High Strength Concrete (HSC): Concrete having compressive strength greater than 40 MPa is termed as HSC, as per American concrete institute (ACI). High strength is achieved by lowering water-cement ratio. Since water-cement ratio is low, to maintain workability, superplasticizers are usually added while preparing HSC mixes. With the recent advancement in concrete technology and the availability of various types of mineral and chemical admixtures, and

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 5, Issue 7, July 2016

special superplasticizers, concrete with a compressive strength of 100 MPa can be easily produced with an acceptable level of variability using ordinary aggregates. The use of HSC for construction, especially in case of multi-storied buildings, has become very common in industrialized and developing countries. HSC not only implies the increased strength, but also increased durability. Use of HSC reduces the cross section of structural components. These concrete have an increased modulus of elasticity, resulting in increased stability and reduced deflections. It has been observed from the literature, shear transfer mechanism is different in HSC due to change in the fracture surface HSC fails as the fracture surface passes through aggregate and matrix.

II. LITERATURE REVIEW

The literature review provides a comprehensive background of the pertinent information related to the present studies. Few researchers have performed experimental studies with variables such as types of concrete, reinforcement ratio, fibers volume fraction using different methods in order to learn how the shear strength in concrete changes in accordance with the variables considered. Previous research efforts on the shear behavior of concrete in the inclined shear planes are limited. Literatures pertinent to this experimental program is reviewed orderly.

ConstantinescoHoria et al [1] reported on the shear strength of High-Performance Concrete with clamping reinforcement and compared the results with specimen without clamping reinforcement using push off test. Shear cracking load was independent of clamping reinforcement. In case of specimens without clamping reinforcement, cracking load and ultimate load was almost same.

B J Al-Sulayavani et al [4] studied the shear transfer in uncracked fibrous concrete using push off and modified push off specimen. The variables investigated were volume fraction of fibres, the amount of stirrups crossing shear plane, and the ratio of direct shear stress to shear stress. When the shear plane was inclined, compressive stress normal to shear plane was induced which increased the difference between cracking and ultimate strength. Because this lateral compressive force will decrease diagonal tensile stresses developed by shear.

Omar A. ABD Elalim et al [6] have studied the effect of axial compression stress on the shear behavior of high strength steel fibre reinforced concrete T-beams by experimental approach. The variables adopted were volume ratio of the steel fibre, the stirrups ratio and flange width of T-beam section. They over-reinforced the beams in flexure to assure shear failure. The presence of axial compression stress resulted in improving both cracking and ultimate strength. Improvement in cracking strength was significantly higher than the improvement in the ultimate strength.

Harish Kumar N R et al [7] made an experimental investigation on in-plane shear strength by varying the polypropylene fiber % (0.15, 0.3 and 0.45), height of shear plane and grade of concrete. The shear capacity was maximum when 0.3% of fibers by weight of cement was used. Also it was observed that as the height of shear plane increases, ultimate shear stress decreased.

Allan H. Mattock et al [8] have attempted experimental works on the shear transfer strength of reinforced concrete. Modified push-off specimens were used to study the influence of direct stress acting parallel and transverse to the shear plane respectively. In modified push-off specimen with angle $\theta = 30^\circ$ or less, failure occurred with continuous crack propagating through the diagonal tension cracks along shear plane. Also the slips at failure were in excess of 0.76mm and the separations were large enough to indicate yielding of the reinforcement when θ was 30° or less. For the specimens with θ equal to 45° , separations did not develop rapidly until immediately prior to failure.

III. MATERIALS AND MIX PROPORTION

The following materials were used for preparing the concrete mix.

Cement: Ordinary Portland cement of 53 grade with specific gravity 3.15. **Coarse Aggregate:** Crushed angular aggregates (granite stones) with a maximum nominal size of 20mm having specific gravity 2.65 was used for NSC. In case of HSC specimens, 12.5mm downsize aggregates with specific gravity 2.62 was employed.

Fine Aggregate: Locally available manufactured sand (M-Sand), free from silt and organic matter. **Superplasticizer:** Conplast 430 BS free of chloride & low alkali. **Steel:** 5mm dia bars with $f_y=550\text{N/mm}^2$.

Mix design for NSC M30 was carried out according to IS 10262:2009. There is no single channelized and branded procedure available for producing HSC, however according to Canadian Portland cement association, the trial mix

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

approach is best for selecting proportions for HSC. In present study mix design proposed by R Prabhakara et al is adopted. The final mix after many trials is as shown in Table 1.

Table 1- Mix proportion for NSC and HSC

Materials	NSC	HSC
Ordinary Portland cement	348.33 kg/m ³	500kg/m ³
Manufactured sand	681.66 kg/m ³	1000 kg/m ³
Coarse aggregates	1146.8 kg/m ³ (20mm downsize)	666.01 kg/m ³ (12.5mm downsize)
Water	191.58 kg/m ³	150 kg/m ³
Super Plasticizer (CONPLAST)	-	12.5 ltr/m ³

IV. EXPERIMENTAL PROCEDURE

Specimen Geometry and Mould

In the present investigations, variations in the size of test specimen (push-off specimen) was based on the previous literature studies [5] [27]. Dimension of push-off specimen used was 150×150×260mm with varying shear plane area. Two notches of 75mm depth and 10mm thickness were cut 100mm apart, perpendicular to the axis of the specimen, for the full width of specimen as shown in Fig 1(a). Notch depth of 75mm, 65mm, 55mm and 45mm would induce inclined shear plane with inclinations of 0°, 11°, 22°, 31° respectively with the vertical. Shear plane area for push-off specimen with 0°, 11°, 22°, 31° shear plane inclinations were 150×100mm, 150×101.87mm, 150×107.85mm, 150×116.66mm respectively. End-Block of push-off specimens were strengthened using 5mm diameter longitudinal bars ($f_y=550$ N/mm²) which were inclined at 0°, 11°, 22°, 31° to induce failure at the respective inclined shear planes., the cross sectional area view of which are shown in Fig 1(b) and Fig 1(c). Mould geometry and dimensions used in present study is shown in Fig 2(a), 2(b) and 2(c), where two specimens can be casted at a time.

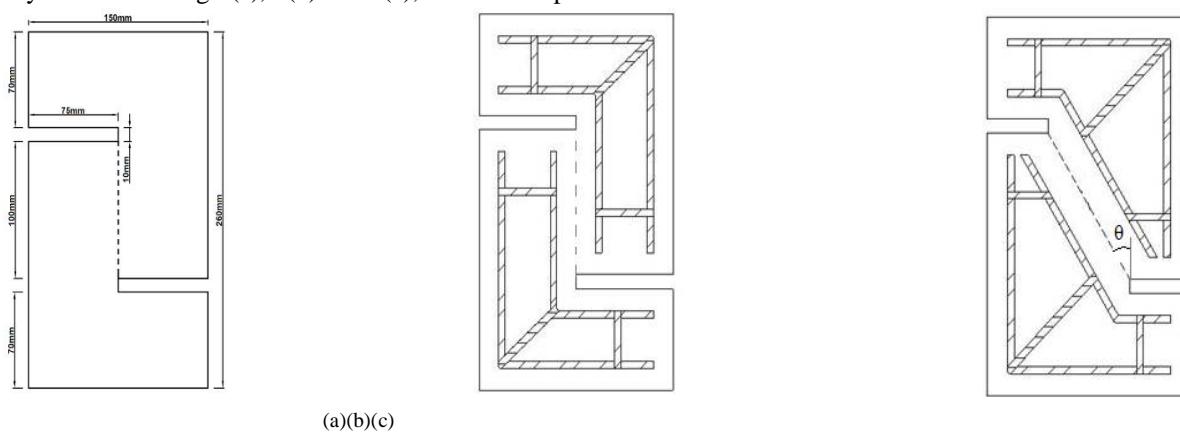


Fig. 1. (a) Push-off specimen geometry (b) End block strengthened push-off specimen (c) End block strengthened push-off specimen (θ variation 11°, 22°, 31°)

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

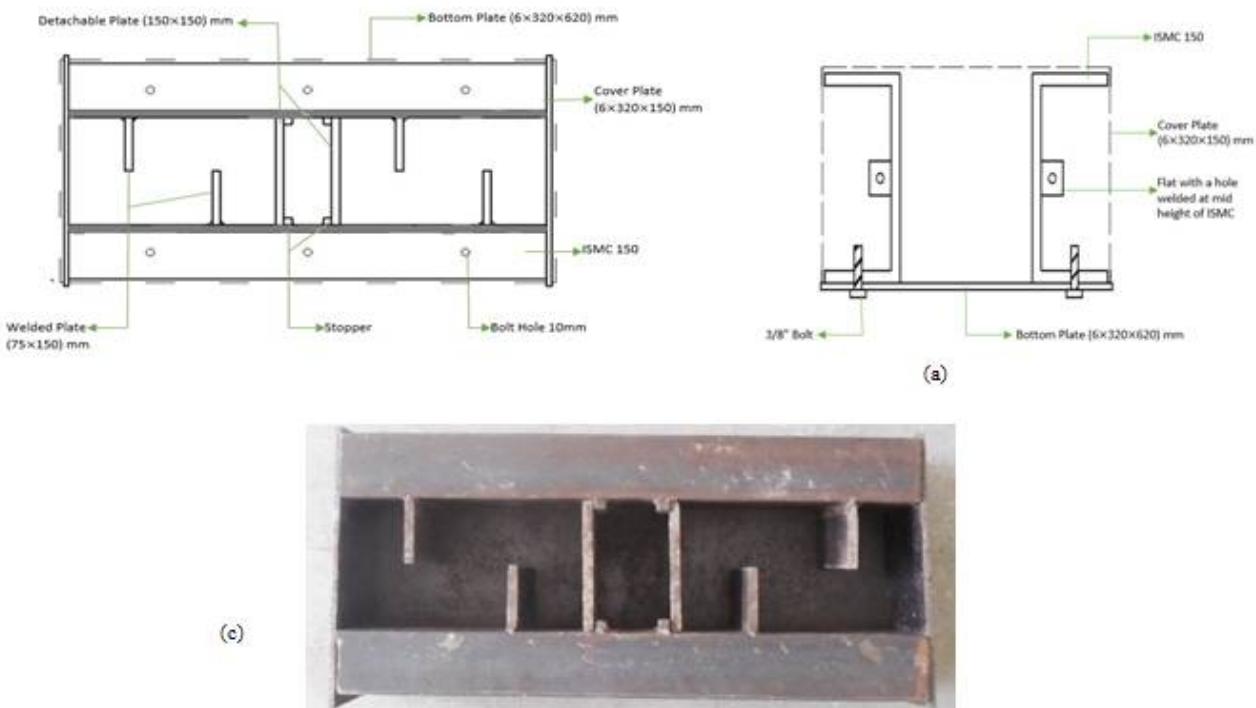


Fig. 2. Mould used in present study (a)Top view of the mould (b) Cross-section of the mould (c)Mould afterfabrication.

Casting the Specimen

Batched quantities of materials as per Table 1 are mixed using pan mixer, when a homogeneous and flowable mix is obtained, the mix was poured into the mould. The specimen obtained is basically two 'L' shaped blocks that are connected through a ligament termed as shear plane. Push off specimens were demoulded at the end of two days after casting. After demoulding specimens were placed for water curing. The specimens were tested in structural laboratory of the Dept of Civil Engineering at M.S.R.I.T Bengaluru under compression testing machine having 1000kN capacity. The test set up is shown in Figure 3. The vertical load is applied through rectangular steel plates of size 15mm width, 15mm thick and 150mm depth. These plates are placed centrally at the top and bottom of the specimen so that the load passes along the vertical shear plane as shown in Figure 4.



Fig. 3.Compression testing machine used for testing



Fig. 4>Loading arrangement done using 10mm steel plate

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

V. RESULTS AND DISCUSSIONS

The average cube compressive strength obtained for NSC and HSC specimen at 28 days was 38.73 MPa and 71.16 MPa respectively. In case of NSC surface-granular fracture (passing over the surface of the aggregates) was observed whereas in case of HSC trans-granular fracture (passing through aggregate) was observed as shown in Figure 5. In case of Plain push-off specimens failure along shear plane was not achieved. For end-block strengthened in most of the push-off specimens failure occurred along the shear plane. Fracture surface of failed plain NSC, end-block strengthened NSC, plain HSC and end-block strengthened HSC push-off specimens are shown in Figure 6, 7, 8 and 9 respectively.



(a)



(b)

Fig.5 (a) Surface granular fracture as observed in NSC (b) Trans granular fracture as observed in HSC

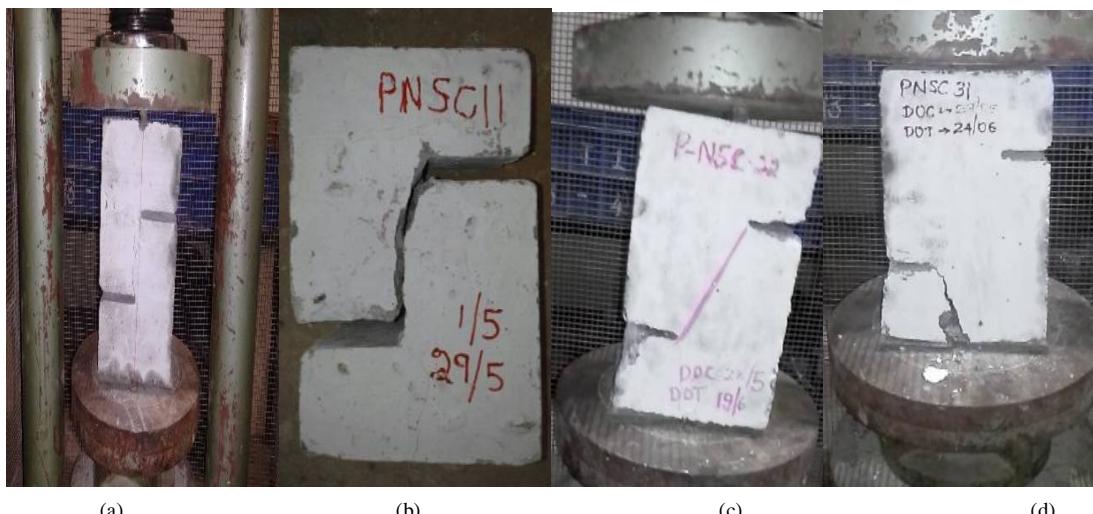


Fig. 6. Failure pattern in plain NSC push-off specimens with shear plane inclination (a) 0° (b) 11° (c) 22° and (d) 31°

Cracks were initiated from one of the notch face, approximately at notch tip and propagated towards the other notch tip; all specimens failed producing cracks in the sides and propagated towards the notch tip. However in case of NSC/11, failure was along shear plane.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016



Fig. 7. Failure pattern in end-block strengthened NSC push-off specimens with shear plane inclination (a) 0° (b) 11° (c) 22° and (d) 31°

For end-block strengthened NSC push-off specimens, with the gradual application of load, several cracks appeared near the top and bottom notch. These cracks joined by propagated along the shear plane and failure occurred forming a single crack band in NSC/0 and NSC/11, but in case of NSC/22 even though crack appeared along shear plane, end block failed. However NSC/31 specimen failed vertically.

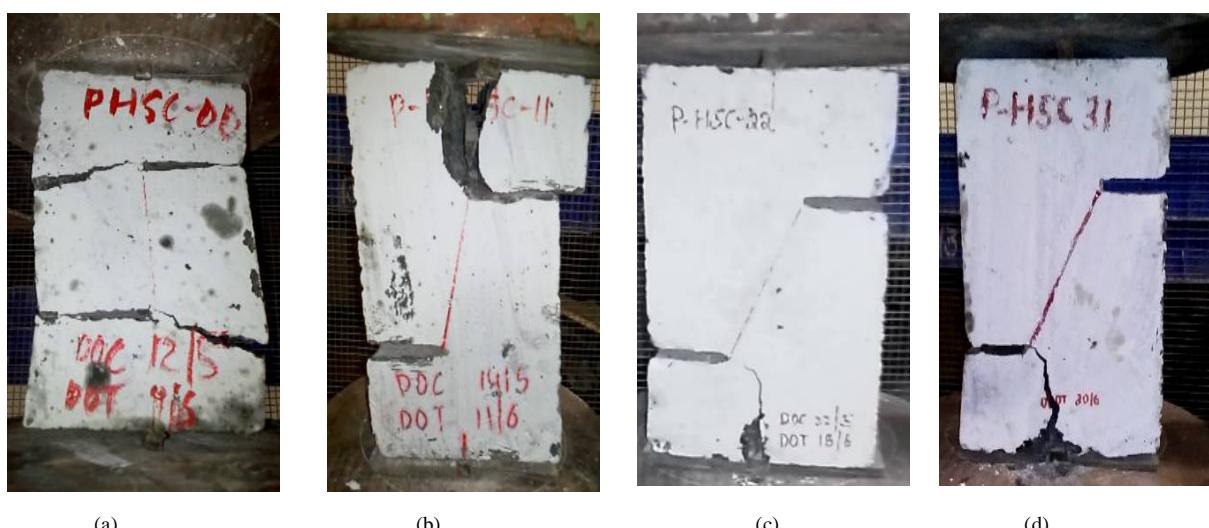


Fig. 8. Failure pattern in plain HSC push-off specimens with shear plane inclination (a) 0° (b) 11° (c) 22° and (d) 31°

Plain push off specimens failed in more brittle manner and broke into pieces losing their integrity. Spalling of concrete was observed at bottom of the shear plane before it reached the failure load.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016



Fig. 9. Failure pattern in end-block strengthened HSC push-off specimens with shear plane inclination (a) 0° (b) 11° (c) 22° and (d) 31°

HSC specimens busted into two pieces along shear plane. The failure started with the formation of discrete diagonal cracks. Then these cracks joined together, forming a dominant crack along the shear plane. In case of HSC/22 end block failed. However HSC/31 specimen failed vertically.

Shear stress and transverse compressive stress results obtained in Table 2 for Plain push off specimens and End-Block strengthened push off specimens (NSC and HSC) respectively are graphically represented in Figure 10 and Figure 11.

Specimen (NSC)	V_u (kN)	τ_u (MPa)	σ_n (MPa)	Specimen (HSC)	V_u (kN)	τ_u (MPa)	σ_n (MPa)
P-NSC/0°	40.51	2.7	0	P-HSC/0°	69.75	4.65	0
P-NSC/11°	50.27	3.23	0.63	P-HSC/11°	112.3	7.21	1.4
P-NSC/22°	110.3	6.32	2.55	P-HSC/22°	182.6	10.45	4.23
P-NSC/31°	142.2	6.97	4.18	P-HSC/31°	210.9	10.33	6.21
R-NSC/0°	75.14	5.01	0	R-HSC/0°	128.31	8.55	0
R-NSC/11°	103.79	6.66	1.3	R-HSC/11°	184.72	11.86	2.31
R-NSC/22°	142.25	8.15	3.29	R-HSC/22°	232.98	13.35	5.39
R-NSC/31°	165.89	8.13	4.88	R-HSC/31°	271.05	13.28	7.98

Table. 2. Test results of the Push-Off Specimens

Here P-NSC and R-NSC implies Plain and End-Block Strengthened Normal strength concrete respectively. 0°, 11°, 22° and 31° are the inclination of shear plane.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

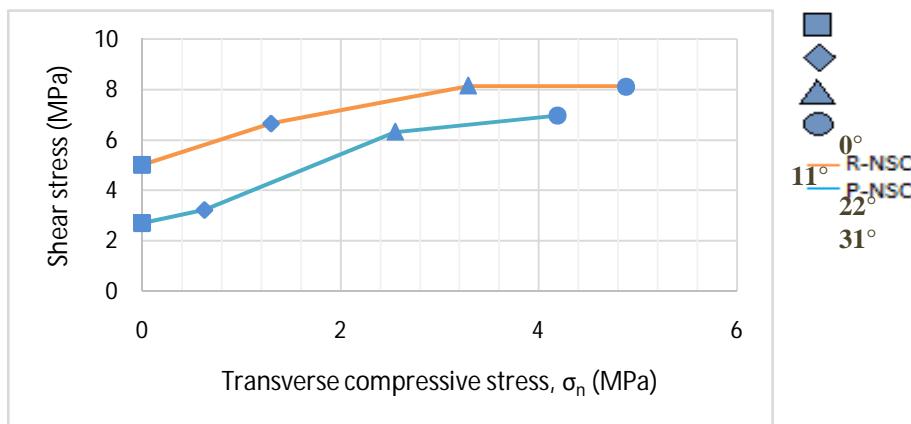


Fig. 10. Variation of the shear stress with the transverse compressive stress for plain and end-block strengthened NSC

From the Fig. 10 it was observed that shear strength in both plain and end-block strengthened NSC increased with the increase in shear plane inclination. This increase is due to normal compressive stress induced on the shear plane. In case of end-block strengthened NSC, shear strength was approximately same at an inclination of 22° and 31°. Contribution of end-block strengthening to the shear strength, when compared with the results of Plain concrete specimens was observed.

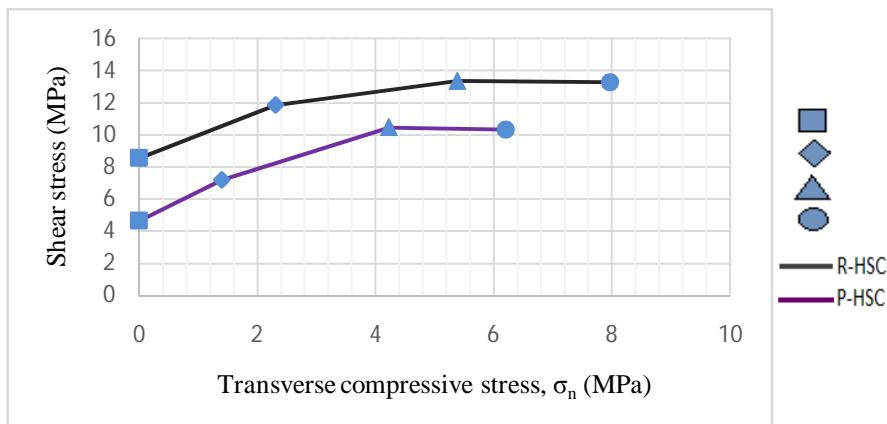


Fig. 11. Variation of the shear stress with the transverse compressive stress for plain and end-block strengthened HSC

From the Fig. 11 it was observed that shear strength in both plain and end-block strengthened HSC increased with the increase in shear plane inclination. This increase is due to normal compressive stress induced on the shear plane. In case of both plain and end-block strengthened HSC, shear strength was approximately same at an inclination of 22° and 31°. Contribution of end-block strengthening to the shear strength, when compared with the results of Plain concrete specimens was observed. When compared with NSC push off specimens, HSC push off specimens were found to absorb more shear stress, both in Plain and End-Block strengthened condition. This is obvious since HSC had a characteristic cube strength of 70MPa, while the NSC was proportioned for a strength of 30 MPa.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

VI. CONCLUSIONS

Concrete push off specimens of NSC-30 and HSC-70 were tested in the laboratory with different inclinations of shear plane on Plain and End-Block strengthened conditions. The following conclusions were drawn based on experiments conducted and observations made during the present study:-

- ❖ Trial mixing plays an important role before arriving at final mix proportion. Workability of concrete is also an important criteria to be considered in the trial mix.
- ❖ A total of 24 Plain push-off specimens and 24 end-block strengthened push-off specimens were casted with varying shear plane inclination for NSC and HSC. The specimens were water cured for 28 days. Each Specimen was individually tested under Compression testing machine.
- ❖ It was observed that with the shear plane angle increase, the ultimate load carrying capacity and ultimate shear stress increases, both in Plain and End-Block strengthened conditions. This is due to the induced compressive normal stress on the shear plane which decreases the diagonal tensile stresses developed by shear, for a given vertical loading.
- ❖ In case of Plain NSC and HSC only few specimens failed along shear plane which indicates that end block were not withstanding the applied loads.
- ❖ Most of the end-block strengthened NSC and HSC push-off specimens failed along the shear plane.
- ❖ In case of NSC surface-granular fracture (passing over the surface of the aggregates) was observed. In case of HSC trans-granular fracture (passing through aggregate) was observed.
- ❖ HSC push-off specimens was observed to be more brittle when compared with NSC push-off specimens.
- ❖ In case of Plain NSC push-off specimens, shear capacity at an inclination of 0°, 11°, 22° and 31° was 2.7MPa, 3.23MPa, 6.32MPa and 6.97MPa respectively. In case of End-Block strengthened NSC push-off specimens, shear capacity at an inclination of 0°, 11°, 22° and 31° was 5.01MPa, 6.66MPa, 8.15MPa and 8.13MPa respectively.
- ❖ In case of Plain HSC push-off specimens, shear capacity at an inclination of 0°, 11°, 22° and 31° was 4.65MPa, 7.21MPa, 10.46MPa and 10.33MPa respectively. In case of End-Block strengthened HSC push-off specimens, shear capacity at an inclination of 0°, 11°, 22° and 31° was 8.55MPa, 11.86MPa, 13.35MPa and 13.28MPa respectively.

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REFERENCES

- [1] Constantinescu Horia and Magureanu Cornelia, "Study of shear behaviour of high performance concrete using push-off tests", JAES, 2011, pp. 77-82.
- [2] Javier Echegaray-Oviedo, Juan Navarro-Gregori, Estefania Cuenca and Pedro Serna, "Upgrading the push-off test to study the mechanisms of shear transfer in frc elements", VIII International Conference on Fracture Mechanics of Concrete and Concrete Structures, 2013.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 7, July 2016

- [3] Prabhakara R. Muthu K U, Nakul R and Lakshmikanth, "Principles underlying the production of Ultra High Strength Concrete", International conference on advances in concrete composites and structures (ICACS-2005) 6-8 Jan 2005 SCRC Chennai.
- [4] B. J. Al-Sulayyani and J. R. Al-Feel, "Effect of direct compressive stress on the shear transfer strength of fibrous concrete", Al-Rafidain Engineering Mosul University, 2009, vol 17(2).
- [5] R.Prabhakara, NadarNissar Shaik et al "In-plane shear strength of Normal, High strength and Self Compacting concrete using push off specimen", International conference on advances in architecture and civil engineering, paper ID SAM, 2012, vol 1, pp 169-173.
- [6] Omar A. ABD Elalim, Ahmed H. Ghallab, Ibrahim G. Shabaan and Omar A. Elnawawy, "Effect of axial compression stress on the shear behavior of high-strength fiber reinforced concrete T-beams", XII International colloquium on structural and geotechnical engineering Cairo Egypt, 2007.
- [7] N R Harish Kumar, Krishna Gajakosh, Dr. K P Nagaraja and Dr. R Prabhakara, "Variation of in-plane shear strength on aggregate size variation using push-off specimens", Journal of Civil Engineering Technology and Research, Delton books publisher, Delhi, 2014, vol 2, pp. 77-84.
- [8] Alan H. Mattock, Neil M. Hawkins, "Shear transfer in reinforced concrete", Prestressed concrete institute, 1972, vol 17, pp. 55-75.
- [9] Mr. M K Maroliya, "Behaviour of reactive powder concrete in direct shear", IOSR Journal of Engineering (IOSRJEN), 2012, vol 2, issue 9, pp. 76-79.
- [10] K N Rahal and A.L Al-Khaleefi, " Behavior of shear friction push-off specimens made using normal and recycled aggregates", 6th Symposium on Advances in Science and Technology, 2012.
- [11] Nora Ragab, Mamdouh El-Badry, "Effects of Post-tensioning Ducts on Shear Strength of Thin Webs of Bridge Girders", TRB annual meeting, 2011.