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Effectiveness of FRP confinement on bearing strength of steel fibre reinforced concrete

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ABSTRACT: Carbon Fibre Reinforced Polymers (CFRP) is successfully used to strengthen concrete members in compression, shear and flexure. This paper reports the results of an experimental study into the confinement efficiency of CFRP for bearing strength of steel fibre-reinforced concrete. The total area to bearing area ratio is maintained at 4.6. The results indicate that the confinement efficiency of CFRP, under both compression and bearing, had increased by the presence of steel fibres in the concrete matrix. The relationship between confinement efficiency and steel fibre content has to be established through future results. The ductility improvement for confined concrete over the unconfined concrete is observed from the results. The addition of high modulus steel fibres have further increased the ductility of confined concrete due to the crack arresting capacity of the fibres.

1. INTRODUCTION

Transmission of concentrated forces in concrete footings, bridge bearing on concrete piers and anchorage in post-tensioned concrete beams has always been a significant problem. A number of studies has been reported on bearing strength of concretes (Shelson (1957), Tung et al. (1960), Hawkins (1968), Haagsma (1969), Niyogi (1973), Wheen and Rogers (1979), Lieberum et al. (1989) and Sri Ravindrarajah (1999) and Ince and Arici (2004)). The results had shown that the failure of concrete under bearing load is due to sliding action along principal stress planes. Sri Ravindrarajah (1999) reported combined crushing and splitting failure with lightweight polystyrene aggregate concrete under bearing laod.

The compressive strength of concrete at the bearing area is increased by the confinement effect provided by the enveloping concrete and therefore the bearing strength of concrete is significantly higher than the compressive strength. The ratio of bearing strength to compressive strength is significantly affected by the total area to loaded area ratio for structural concrete grades. Due to low tensile strength of plain concrete, between 3 to 5 MPa, the confinement provided by plain concrete is limited.

In order to improve the bearing strength of concrete, it is necessary to find other means of providing confinement. Use of steel fibre in concrete matrix to improve the tensile strength, crack resistance and ductility of concrete is well established over many decades (Hannant (1978) and Balaguru and Shah (1992)). Naaman (2008) recently reviewed the development of high performnce fibre reinforced composites. Randomly distributed high stiffness and ductile steel fibres provide internal restraint to the surrounding low tensile cementitious matrix and control the crack initiation and propagation of the composite. Incorporating steel fibres in concrete could provide some improvement in internal confinement of concrete.

The other method is using Fibre Reinforced Polymer (FRP) to provide external cofinement. Carbon fibre reinforced polymer (CFRP) composite is known to provide excellent confinement and is used to strength concrete structures to improves their load carrying capacities under compression, shear and flexure (Teng et. al (2002)). Typical tensile strength and stiffness of carbon fibre are 1500MPa and 150GPa, respectively. Kaul et. al. (2006) reported that CFRP confined concrete showed significant increase in strength and improved ductility under compressive loading.

Scheffers, C. & Sri Ravindrarajah, R. (2009) studied the bearing strength of CFRP confined concrete, using square shaped bearing section, under three total area to bearing area ratios of 2, 4 and 6. The results showed that the CFRP confinement increased the bearing strength of concrete by up to 74% over the unconfined concrete. Brittle failure of the confined concrete occurred in an explosive manner with loud acoustic emission as the CFRP confinement experienced excessive tension in the hoop direction. Scheffers et. al. (2010) reported that for a given total area to bearing area ratio, the bearing strength was higher under circular bearing area than that under square shaped bearing area due to uniform stress distrubution around bearing area. However, the results showed that the confinement efficiency was independent of the shape of the bearing area, since both compressive and bearing strengths were found to be affected quantitatively to the same relative amount.

This paper reports the results of an experimental investigation into the effectiveness of CFRP wrapping on the bearing strength of plain and steel-fibre reinforced concrete, of varying volume fraction of fibre content up to 1.5%. CFRP and steel fibres are used to provide external and internal confinement, respectively to the concrete under bearing load.

2. EXPERIMENTAL DETAILS

2.1 Materials

Type GP cement, conforming to AS3972, was used as the binder material in the concrete mixes. River gravel, having the maximum size of 10mm and a combination of fine and coarse sands in equal weight proportion, were used as coarse and fine aggregates, respectively. 40mm crimped type stainless steel fibres were used. Superplasticiser was used in the concrete mixes to achieve sufficient workability to ensure proper distribution of steel fibres in the concrete matrix. Commercial available fabric, having a thickness of 1mm, with high strength carbon fibres in uniaxial direction was used to produce CFRP wrapping. The CFPR wrapping procedure used is detailed in Section 2.4. As per manufacturer's data, the tensile strength and modulus of elasticity of the fabric were 3,800MPa and 240GPa, respectively, with an elongation of 1.5 percent.

2.2 Mix proportions

The plain concrete mix was designed to have slump of 100mm and 28-day compressive cylinder strength of 40MPa. The aggregate to cement ratio was 5.0, by weight and the free water to cement ratio was 0.56, by weight.

2.3 Mixing of concrete and preparation of test specimens

The concrete ingredients were mixed in a pan-type mixer and a total of four mixes having the volume fraction of steel fibres of 0%, 0.5%, 1.0% and 1.5% were produced. The steel fibres were gradually added by hand into the concrete mix, while concrete mixing was in progress. The mixing was carried out until proper dispersion of the steel fibres was achieved.

For each concrete mix, a total of fourteen specimens, consisting of four large standard cylinders (150mm diameter by 300mm high) for bearing strength testing, eight small standard cylinders (100mm diameter by 200mm high) for compressive strength testing and two prisms (100mm by 100mm by 300mm) for ultrasonic pulse velocity determination were cast. Vibrating table was employed to achieve full compaction during casting of the test specimens. The specimens were demoulded after 24 hours and stored in water at 20^{o}C for 28 days.

2.4 Application of CFRP to test cylinders

Four large cylinders and two small cylinders were removed from the water tank after 28 days. The large cylinders were cut at the middle with a diamond saw to obtain eight specimens having the dimension of 150mm diameter by 150mm high. The specimens were then stored in air for 7 days in the laboratory unsaturated environment. Four of large cylinders and four of the small cylinders were wrapped with two layers of CFRP. The choice of two layers is for cost-effective reason.

For the 150mm diameter cylinders, the length of the fibre fabric wrapping for each layer was 705mm, allowing an overlap length equal to half the circumference of the cylinder to ensure proper confinement without premature failure of the fabric wrapping. For the 100mm diameter cylinder the overlap length of the carbon fibre fabric was 157mm. The total thickness of the CFRP wrapping was 2 to 3 mm.

A proprietary primer was prepared using two components. It was then applied to the dried concrete surfaces of the test cylinders using a painting brush. The primer provided proper bonding between CFRP and the concrete surface. A proprietary saturant epoxy resin adhesive was prepared using two components. Both primer and saturant were produced using mechanical mixing process.

The first layer of epoxy resin saturant was applied on to the tacky primer layer. Then, a single layer of fibre sheet was wrapped around the concrete cylinder in the lateral direction. A rip roller was used to press the fibre sheet onto the primer and saturant in the direction of the fibres. Care was taken to avoid any entrapped air within the fibre sheet wrapping. Then, the second layer of fibre sheet was wrapped around the first layer and saturant was applied carefully. The rib roller was used to press down the second layer of fibre sheet onto the first layer. Finally, saturant was applied over the second fibre layer to ensure that the fibres were fully impregnated with the epoxy resin. The CFRP wrapping was left in the laboratory conditions to cure in air for 7 days.

2.5 Testing of fresh concrete and hardened concrete specimens

Freshly mixed concrete mixes, with and without steel fibres, were tested for workability and unit weight, according to the procedures outline in AS1012. The unconfined cylinders (100mm diameter by 200mm high) were tested in direct compression at the ages of 28 and 49 days. The CFRP wrapped cylinders were tested only at the age of 49 days. For each age and wrapping condition, two identical cylinders were tested and the average compressive strength is reported. Ultrasonic pulse velocity measurements were made on 100mm by 100mm by 300mm prisms at the ages of 7, 14 and 28 days.

2.6 Testing of concrete for bearing strength

Bearing strength for both unconfined and confined concrete was determined using 150mm diameter by 150mm high concrete cylinders. These test specimens were obtained by cutting the 300mm high cylinders into two equal parts, using a diamond saw cutter. Prior to loading, the loading surfaces of the cylinders were capped with dental plaster. A cylindrical 70mm diameter and 19mm thick steel plate was used to apply bearing load concentrically on 150mm diameter concrete surface. The total area to bearing area ratio was 4.60. The bearing load was applied gradually until the failure occurred. LVDT was used to monitor the cross-head movement of the testing machine while loading.

3. RESULTS AND DISCUSSION

3.1 Properties of fresh concrete

The workability of fresh concrete decreased with the increase in the steel fibre content. For the concrete with the 1.5% volume fraction of steel fibres, the slump was about 100mm. The steel fibres are properly dispersed and distributed randomly without balling in this workable mix. The unit weight of fresh concrete mixes was varied between 2390 to 2470 kg/m^3. The marginal increase in the unit weight for steel fibre reinforced concrete was due to the low amount of steel fibre volume used.

3.2 Ultrasonic pulse velocity of concrete

The ultrasonic pulse velocity of steel fibre reinforced concrete was increased with the age of the concrete. No significant influence on the pulse velocity of concrete was recorded with the increase in the steel fibre content. The mean ultrasonic pulse velocity recorded for steel fibre concrete at the ages of 7, 14 and 28 days was 4.33, 4.34 and 4.36 km/s, respectively. The ultrasonic pulse velocity of concrete was improved with age due to continuing cement hydration.

Table 1: Compressive strength of unconfined and confined steel fibre reinforced concrete

Steel fibre volume (%)	Age (days)	Confinement	Compressive strength (MPa)	Confined/ Unconfined Strength ratio
0.0	28	No	47.8	-
0.5	28	No	42.6	-
1.0	28	No	48.3	-
1.5	28	No	45.6	-
0.0	49	No	44.3	-
0.5	49	No	38.1	-
1.0	49	No	48.0	-
1.5	49	No	43.7	-
0.0	49	Yes	66.9	1.51
0.5	49	Yes	77.1	2.02
1.0	49	Yes	79.9	1.66
1.5	49	Yes	79.1	1.81

3.3 Compressive strength of unconfined steel fibre reinforced concrete

Table 1 summarizes the cylinder strength of steel fibre reinforced concrete as a function of curing period and fibre content. The cylinder strength at 28 days varied from 42.6MPa to 48.3MPa, whereas the 49-days cylinder strength varied from 38.1MPa to 48.0MPa. Since the cylinders tested at 49 days were stored in the unsaturated laboratory environment, no significant improvement in strength after 28 days was recorded. From the limited results, no clear effect of steel fibre content on the compressive strength of concrete was noted.

3.4 Compressive strength of confined steel fibre reinforced concrete

The results from Table 1 indicate that the cylinder strength had increased with the lateral confinement provided by CFRP composite. For the plain concrete the confined to unconfined strength ratio, termed as confinement efficiency, was 1.51. For steel fibre reinforced concrete, the confinement efficiency was varied from 1.55 to 2.02. The improvement in confinement efficiency with fibre reinforced concrete could be due to the internal restraint provided by the steel fibres. Further research is needed to establish the relationship between the CFRP confinement efficient and the volume fraction of steel fibre in concrete under compression.

Table 2: Ultrasonic pulse velocity of confined steel fibre reinforced concrete

Steel fibre volume (%)	UPV before testing (km/s)	UPV after failure (km/s)	% Reduction in UPV
0.0	4.39	3.19	27.3
0.5	4.21	2.41	42.8
1.0	4.12	3.06	25.7
1.5	4.04	2.99	26.0

3.5 Ultrasonic pulse velocity of confined steel fibre concrete after failure

Table 2 shows the ultrasonic pulse velocity of fibre reinforced concrete before and after the compression test. The pulse velocity measurements were made in the direction of loading. The results show that the pulse velocity had dropped significantly, indicating the presence of significant internal cracking in confined concrete. The percentage of reduction in the ultrasonic pulse velocity reduction ranged from 25.7% to 42.8% compared to that prior to testing.

Table 3: Confinement efficiency of CFRP for steel fibre reinforced concrete

Steel fibre volume (%)	Bearing strength (MPa)	Confinement efficiency
0.0	141.4	1.74
0.5	156.2	2.01
1.0	179.1	1.77
1.5	166.1	1.98

3.6 *Bearing strength of confined steel fibre reinforced concrete*

Table 3 summarizes the bearing strength of confined concrete and confinement efficiency for steel fibre-reinforced concrete. For the control concrete without fibres, the confinement efficiency factor was 1.74. Whereas, for the fibre reinforced concrete, the confinement efficiency was ranged from 1.77 to 2.01. Similar to the compressive strength, these results indicates the positive contribution of the steel fibres in improving the CFRP confining efficiency, due to the well-established crack arresting capability of steel fibres in concrete.

Table 4: Bearing strength/Compressive strength ratio for steel fibre reinforced concrete

Steel fibre volume (%)	Confinement	Bearing strength (MPa)	Compressive strength (MPa)	Bearing /Compressive Strength ratio
0.0	No	81.0	44.3	1.83
0.5	No	77.9	38.1	2.04
1.0	No	101.1	48.1	2.10
1.5	No	83.7	43.7	1.92
0.0	Yes	141.4	66.9	2.11
0.5	Yes	156.2	77.1	2.03
1.0	Yes	179.1	79.9	2.24
1.5	Yes	166.1	79.1	2.10

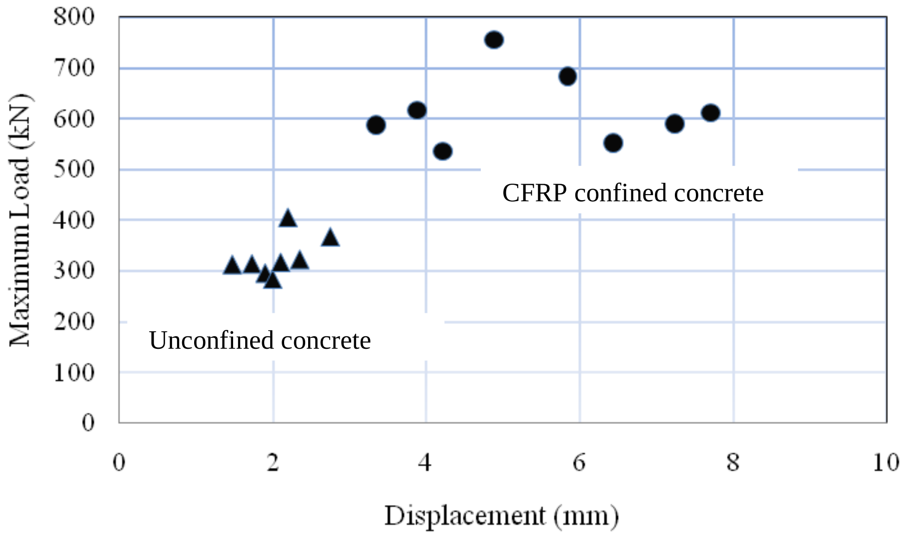

Figure 1: Load- Displacement relationship for confined and unconfined steel fibre reinforced concrete under bearing load

3.7 *Bearing to compressive strength ratio for confined steel fibre reinforced concrete*

Table 4 summarizes the ratio of bearing strength to compressive strength for unconfined and confined fibre reinforced concrete. For unconfined fibre reinforced concrete the bearing strength was 1.83 to 2.10 times the corresponding compressive strength. Whereas, for the CFRP confined concrete the bearing strength was 2.03 to 2.24 times the corresponding compressive strength. This minor improvement in the bearing strength relative to the corresponding compressive strength could be due to the contribution of steel fibres under confined multi-axial stress condition in arresting internal cracking.

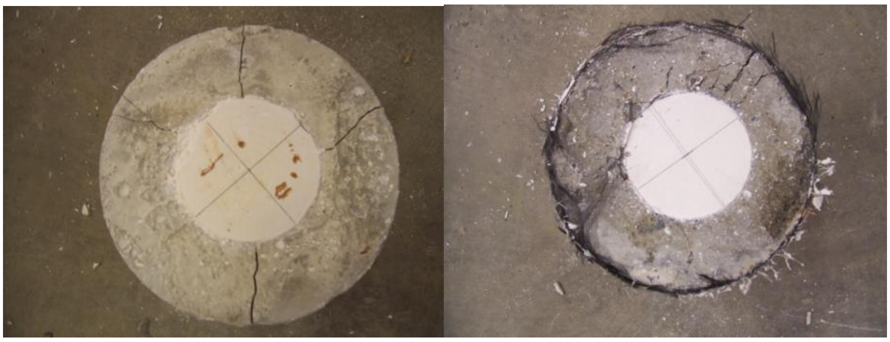

Figure 2: Cracking pattern for unconfined and confined steel fibre reinforced concrete under bearing load (Fibre content= 1.5%)

3.8 Ductility of CFRP confined steel fibre reinforced concrete

Figure 1 typically shows the relationship between maximum load and displacement of cross-head of the testing machine for unconfined and confined steel fibre reinforced concrete under bearing load. Under increasing bearing load, the recorded displacement for confined concrete was significantly higher than that for unconfined concrete. The ductility and fracture toughness for the confined concrete were high, due to increased intensity of internal cracking fracture toughness, as reported by Scheffers and Sri Ravindrarajah (2009). The presence of steel fibre may have further increased the ductility and fracture toughness. Figure 2 typically shows the wide cracks in unconfined steel fibre reinforced concrete compared to that for the confined concrete.

4. CONCLUSION

Performance of fibre reinforced concrete with varying volume content of steel fibres up to 1.5% was studied under uniaxial compressive and bearing loads, for both unconfined and confined conditions. The external confinement to concrete was provided with two layers of CFRP wrapping. The confinement efficiency of CFRP was found to improve due the presence of steel fibres. Under confined condition, ductile failure of concrete was observed under both compressive and bearing loads. By incorporating high modulus steel fibres, both ductility and fracture toughness, had further increased . Research is needed to establish the relationship between the confinement efficiency and fibre volume under compressive and bearing loadings.

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