Comparative Study of the use of Man-Made and Natural Fibre Reinforced Concrete for Ground Floor Slab Applications

B. Nepal
Xi'an Jiaotong- Liverpool University, Suzhou, China.
Email: bhooma.nepal@xjtlu.edu.cn

C. S. Chin[1] and S.W. Jones[2]
[1]Xi'an Jiaotong- Liverpool University, Suzhou, China
[2]University of Liverpool, Liverpool, UK
Email: chee.chin@xjtlu.edu.cn, stephen.jones@liverpool.ac.uk

***Abstract*—Fibres have been used recently in ground floor slabs to limit the cracks and increase its resistance to loads but due to limited experience in their use, design code coverage and availability it is still not widespread. In this paper, an investigation of the mechanical properties of rice, polypropylene and steel fibre-reinforced concrete is presented and discussed. Tests were undertaken on mixes containing 0.25% by volume of each fibre type and their effect on ground floor slab behaviour was studied. A displacement controlled point load was applied to the slabs at the centre. At the same time, cubes and beams were cast to determine the compressive strength and flexural properties of the concrete. Data generated from the tests were examined and the test results indicated that inclusion of fibres had increased the compressive strength by about 16% for polypropylene and flexural strength by about 18% for steel fibres compared with plain concrete. Rice straw fibres showed a decrease in the flexural and compressive strength but showed higher load carrying capacity for slabs. Experimental observations regarding the development of cracks and the failure pattern are presented.**

***Index Terms*—fibre reinforced concrete, steel, polypropylene, agricultural straw**

I. INTRODUCTION

Concrete is the most widely used construction material on the earth. It is known for its high compressive strength and low tensile strength. Normal concrete is used with steel reinforcing bars to overcome that disadvantage. But not only is steel expensive, but it has a high energy consumption and it comes from a non-renewable resource; unprotected steel is also liable to corrosion which might lead to infrastructure deterioration.

Concrete industrial slabs cast on grade have to sustain the heavy loads from operational movements of vehicles, stored materials, resist surface abrasion and also transfer the loads to the foundations without significant settlement or failure. Most of the ground floor slabs are designed with the inclusion of heavy reinforcement bars or welded mesh to control cracking and resist failure in flexure and sometimes shear. However, an innovative solution in recent years had been to use fibres in concrete. Fibres are known to control cracking and increase the capacity of the slabs without degrading any of its intrinsic properties.

Steel and polypropylene fibres are the most common fibres that have been used and now commercially manufactured almost everywhere around the globe. More recently due to increasing attention towards green and sustainable concrete, natural fibres are receiving more attention in the construction industry. Patents from the last century refer to the use of natural plant fibre as a component of building materials made from cements and plasters. Natural fibre (mainly wood fibre) as a reinforcement for fibre cement has mainly taken place in the last 10–20 years [1]. However, the use of such fibres is mostly limited to research. Natural fibres present an immense possibility towards sustainable building materials.

Roesler *et al*. [2] applied constant static loads on plain concrete and fibre reinforced concrete slabs on ground to understand the effect of fibre quantity and type of fibres. The tensile cracking loads of plain and fibrous slabs were found to be similar but there was a significant increase in the flexural strength of fibre-reinforced concrete slabs, relative to plain concrete slabs. The addition of fibres increased the collapse load of slabs, with the key factors affecting the magnitude of the collapse load being fibre type and quantity. Strain and deflection profile measurements showed that fibres assisted in crack propagation resistance, crack bridging, and load redistribution. The shape of the load deflection curves indicated that the synthetic and the steel fibre reinforced concrete slabs behaved similarly at different stages of cracking.

Sorelli *et al.* [3] tested several full scale slabs under a point load at the centre. All the slabs were steel fibre reinforced with varying volume fractions ranging from 0.38 to 0.57% and various shapes of fibres both of long

Manuscript received January 1, 2017; revised May 1, 2017.

doi: 10.18178/ijscer.6.3.182-185

and short dimensions. Slabs were of sides 3000 mm and thickness of 150 mm. 64 steel supports were provided at the bottom of test specimens to reproduce the effect of subgrade.

Alani and Beckett [4] tested a full scale slab a concrete strength C32/40 and dimensions 6000 mm square and thickness of 150 mm to overcome the limitations of the smaller slab of 3000 mm which resulted in excessive edge and corner lifting. Plain concrete (PC) slabs, polypropylene fibre reinforced concrete (PFRC) slabs with a dose of 7 kg/m^3 and steel fibre reinforced concrete (SFRC) slab at a dose of 40 kg/m^3 were tested. To simulate the maximum racking loads, loads were applied to a contact area of 100 mm by 100 mm. The modulus of sub-grade reaction (k) for ground floor varied from 0.044 – 0.055 N/ mm^3.

Overli [5] studied bending behaviour of a square slab of dimension 3500 mm which had a thickness of 120 mm. The loading to the slab was applied by a steel 100 mm cube which represented a surface load. A larger square load area was chosen rather than a typical wheel load area which is smaller and much more rectangular in order to avoid punching shear failure. A 100 mm thick layer of Jackofoam 400 XPS which had an average stiffness of 0.15 N/mm^3 was used to achieve the stiffness of crushed stone used as subgrade for ground floor slabs.

Chen [6] investigated experimentally the strength of SFRC ground slabs using four square slabs measuring 2000 mm with a thickness of 120 mm. It was reported that at low fibre content the increase in the flexural strength of SFRC compared to PC is very small. The fibre content varied from 0.26-0.36%, which was lower than the recommended minimum fibre content of 0.5% (by volume) in Chinese SFRC construction practice. The results indicated that a substantial increase in the flexural toughness which is an indication of the energy absorption capacity and the load carrying capacity can be achieved even with lower fibre content.

II. Experimental Investigation

A. Fibres

Three different types of fibres were used in the experimental investigation: (a) Polypropylene (b) Steel and (c) Rice straw. Steel and polypropylene being the most widely used fibres, it is of necessity to assess its property and behaviour with concrete and truly understand the capability of synthetic fibres in enhancing the strength and durability properties. Also, agricultural fibre viz. rice straw fibre was chosen to understand the feasibility of using such fibres.

TABLE I. General Properties of Fibres

Fibres	Aspect ratio	Density (kg/m^3)	Tensile strength (MPa)	Modulus of elasticity (GPa)
Polypropylene	96	900	400	3.5
Steel	90	7800	1100	210
Rice straw	96	1102	313	9.5

The properties of fibres used in the test are listed in Table I. The aspect ratio is conventionally defined by the fibre length and the fibre diameter ($\mathbf{L}_f/\phi_f$) in millimeter unit. All the fibres were straight and monofilament fibres. Figs. 1(a), (b) and (c) show the synthetic polypropylene fibres, steel fibres and agricultural rice straw fibres prior to mixing in the fresh concrete.

B. Concrete Specimens and Test Setup

Concrete mixes with design cube strength of 37 MPa were prepared. The proportion of mix was 1:0.55:2.14:3.35 (Cement: water: fine aggregate: coarse aggregate). Eight slabs were cast, two PC, two PFRC, two steel fibre SFRC and two rice straw fibre reinforced concrete (RSFRC). The fibre content was 0.25 % (by volume) in all four mixes. The 56 day strength results for different mixes can be seen in Table II. Compressive strength was measured using BS EN 12390-3 (2009) with cubes of size 150 mm.

For beams to determine the flexural strength, notched beam flexural tests in accordance with BS EN 14651:2005 + A1 (2007) were followed. Specimens were 150 mm wide and 150 mm deep that were tested under a central point load on a span of 500 mm. The specimens were notched to a depth of 25 mm in a side face as cast, and then tested with the notch in the tension face.

Slabs with side dimensions of 750 mm and thickness 50 mm were cast. For simulating the soil behaviour, polystyrene foam of thickness 100 mm was used below the slab. The foam was first tested in the compression testing machine to determine its stiffness. The coefficient was derived by dividing the vertical displacement into the uniform load on the foam surface. The stiffness was then used to compare with the modulus of subgrade reaction of a typical soil. The value for modulus of subgrade reaction was obtained as 0.011 N/mm^3. A single load was applied by means of load actuator with displacement speed of 0.50 mm/min as illustrated in Fig. 2. Linear Variable Differential Transformer (LVDT) was installed to measure the deflection of the slab.

Figure 1: (a) Polypropylene (b) Steel and (c) Rice straw fibres

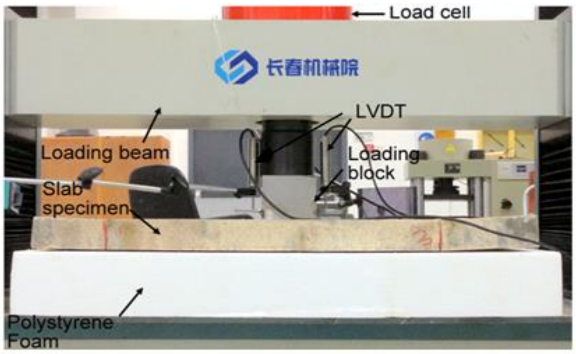

Figure 2: Arrangement for slab test with point load at centre

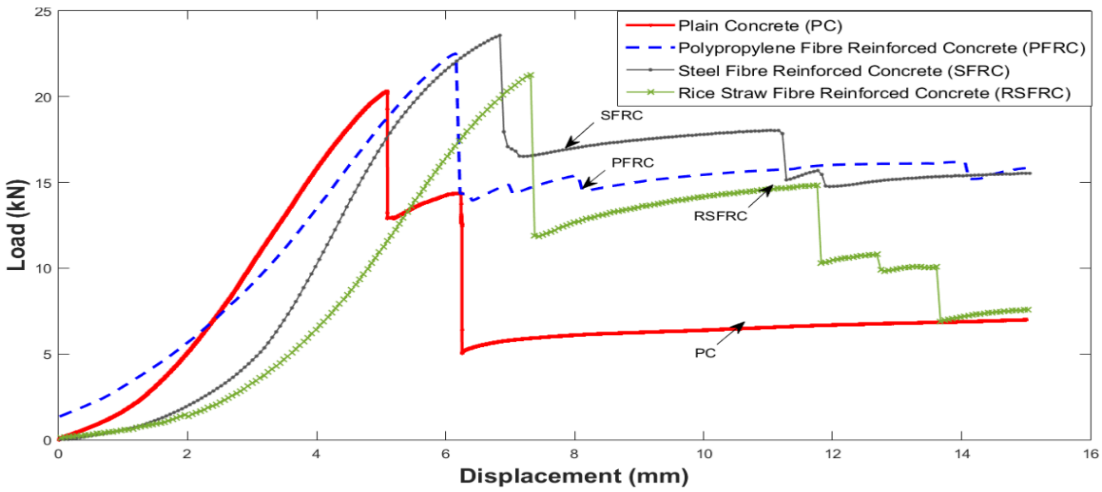

Figure 3. Load-deflection curves of ground floor slabs

III. Results and Discussions

The structural response in terms load versus the deflection of the slab of PC, PFRC, SFRC and RSFRC is compared in Fig. 3. It can be seen that plain concrete reaches the maximum load with a displacement of less than 5 mm whereas all other slabs sustained deflections of more than 6 mm just before the ultimate load was reached. This shows that the load carrying capacity of the fibre reinforced concrete compared to ordinary concrete was considerably higher. Furthermore, after the yielding of the slab, the plain concrete sustained minimal load with large displacement until failure whereas the fibre reinforced concrete had large displacement after the ultimate load due to the residual strength resulting from the crack bridging of the fibres.

Comparison of the results for different fibre reinforced concrete with plain concrete is demonstrated in Table II. It shows that the addition of different types of fibres improved the flexural strength of the concrete slab. SFRC, PFRC and RSFRC had a 16%, 11% and 5% increase in flexural cracking load over the PC slab. Roesler *et al.* [2] reported an increase of 25% and 31% with synthetic macro fibres and hooked end fibres with fibre content of 0.32% and 0.35%, respectively. This test was critical in understanding the bending and shear capacity of the slab. The bending capacity is inherent to the residual flexural tensile strength of the slab. Rice straw fibres showed only a marginal increase in slab load carrying capacity and had less flexural strength compared to the plain concrete.

TABLE II. Mechanical Concrete Properties

Properties	Plain concrete	Polypropylene FRC	Steel FRC	Rice straw FRC
Cube strength (MPa)	47.1	54.7	48.7	38.3
Flexural Strength (MPa)	5.6	4.8	5.7	4.7
Ultimate Slab load (kN)	20.3	22.5	23.6	21.3
Energy Absorption Capacity (kNmm)	44.5	64.8	64.1	55.9

The slabs sustained the load and failed with the initiation of four major cracks which started from the slab centre and developed along the median lines as shown in Fig. 4. The failure in plain concrete (Fig. 4A) indicate brittle instantaneous failure as the slab is observed to fail not by crushing like polypropylene (Fig. 4B) and steel fibres (Fig. 4C) but by sudden development of cracks across the whole span. Furthermore, smooth hairline cracks are recorded for plain concrete slab but not for slabs with rice straw (Fig. 4D). Similar observations were made by Sorelli *et al.* [3] where the addition of steel fibres did not substantially affect the final crack patterns.

For the tests in slab, the results are compared in terms of radius of relative stiffness and design load carrying capacity. Radius of relative stiffness (l) is the direct measure of the subgrade deformation for the slab. It is the term derived from the deformation characteristics of subgrade as the subgrade deformation. In Fig. 5, radius of relative stiffness is the radius of slab from the point of load application up to which the hogging moment develops. The design load of the slab is calculated from the codal formula is the ultimate load sustained by the slab before failure. For our slab with thickness 50 mm, the radius of relative stiffness and ultimate load capacity is calculated as 424 mm and 27 kN respectively. The experimental maximum load carrying capacity is 23.6 kN for steel fibre reinforced concrete. The test results are less than the capacity from the design code for steel fibres by 13%, for polypropylene fibres by 17%, for rice straw by 21% and for plain concrete by almost 25%.

The slab is also differentiated on the basis of its energy absorption capacity. Energy dissipation is the capacity of the slab to sustain loads and deform without failing. The energy dissipated for a particular fibre reinforced concrete is taken from the area under the load displacement curve from the initial displacement to the failure displacement. It is found that polypropylene fibres have higher energy dissipation capacity of almost 46% greater than that of plain concrete. Polypropylene and steel fibres have almost similar capacity and rice straw fibres have energy dissipation greater than 25% of plain concrete.

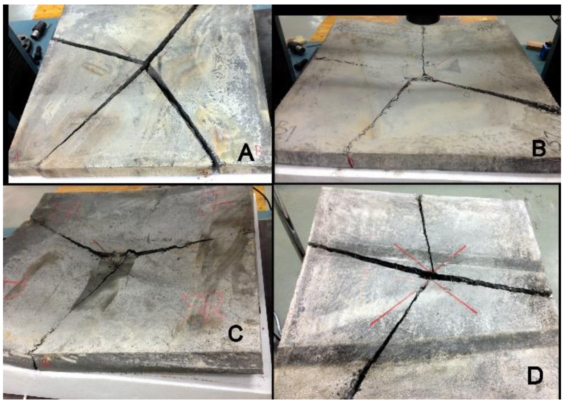

Figure 4. Development of cracks in slab

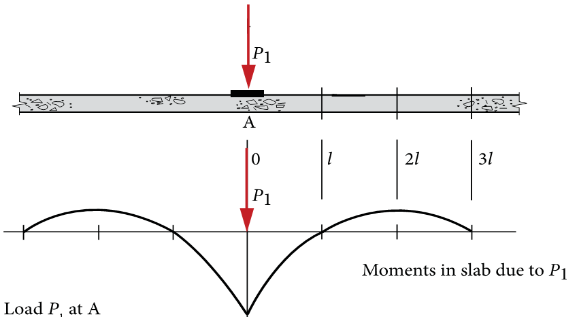

Figure 5. Point load and its bending moment in slab (TR 34)

The load carrying capacity for the test performed by Roesler *et al.* [2] for plain concrete was 135 kN and for 0.35% hooked end fibres was 228 kN which is 46% and 9% less than the code calculated design capacity of 251 kN. In the case of Sorelli *et al.* [3] the steel fibres enhanced the load carrying capacity of the SFRC slabs up to 260 kN which is 32% more than plain concrete. In a few of the other tests performed by Alani and Beckett [4] and Overli [5] the moment capacity of the slab reached 490 kN and 390 kN which is almost double the Eurocode design capacity.

The radius of relative stiffness for the slab tested in this study is 424 mm. As per TR34, the length of 6*l* is required for full moment distribution of slab (including both hogging and sagging moments) for slab loaded at the centre as shown in Fig. 5. This would be 2548 mm to be considered as full scale for moment distribution. Such a larger slab dimension would help in understanding the effect of load and its distribution along the length of the slab. Similarly, the research carried out by Roesler *et al.* [2], Sorelli *et al.* [3] and Overli [5] have a span less than 6*l* for full scale moment distribution.

Thus the comparison of the slab on the basis of dimension only is not sufficient. Overall, the load carrying capacity is dependent on the grade of concrete, stiffness of soil, dimensions, point of application of load and fibre content.

IV. Summary and Conclusion

A comparative study of different fibre reinforced ground floor slabs under concentrated load is reported. It was found that steel, polypropylene and rice straw fibres all performed significantly better than plain concrete and enhanced the capacity of the ground supported slab. The test results were significant in understanding the capacity and behaviour of ground floor slabs when using different types of fibre reinforcement.

With the use of fibres, the energy dissipation capacity significantly improved by up to 46% in case of polypropylene and 25% in case of rice straw fibres. This implies that fibres can absorb the loads sustained in a concrete and deform without failing instantaneously. The strength and ductility of ground floor slabs are enhanced due to addition of fibres as highlighted from the ultimate load carrying capacity and energy absorption. The delayed cracking and residual strength of FRC in ground floor slab is promising.

Steel fibres enhanced the flexural strength compared to plain concrete whereas polypropylene and rice straw fibres decreased the flexural strength. This is due to the high tensile strength of the steel compared to other types of fibre. The experimental results for the slab load carrying capacity are compared with those of the design standard. It was found that the slab span is less than that required for full scale moment distribution. Other researchers also had the similar pattern which could be one of the reasons for lesser load carrying capacity of the slabs tested in this study.

The inclusion of the fibres increased the structural performance of the slab in terms of its compressive and flexural load. However, there are several variables to be considered to arrive at a conclusion regarding the load carrying capacity of the slab and its distribution pattern. Steel and polypropylene fibres are commercially available and used widely in construction of ground floor slabs. Agricultural straw fibres after thorough investigation and treatment could prove that they can be a sustainable alternative to steel and polypropylene fibres.

References

[1] B. Nepal, C. S. Chin, and S. W. Jones, "A review on agricultural fibre reinforced concrete," in *Proc. Sustainable Buildings and Structures: Proceedings of the 1st International Conference on Sustainable Buildings and Structures*, Suzhou, PR China, 29 October-1 November 2015, p. 125.

[2] J. R. Roesler, D. A. Lange, S. A. Altoubat, K. A. Rieder, and G. R. Ulreich, "Fracture of plain and fiber-reinforced concrete slabs under monotonic loading," *Journal of Materials in Civil Engineering*, vol. 16, no. 5, pp. 452-460, 2004.

[3] L. G. Sorelli, A. Meda, and G. A. Plizzari, "Steel fiber concrete slabs on ground: a structural matter," *ACI Structural Journal*, vol. 103, no. 4, pp. 551, 2006.

[4] A. M. Alani and D. Beckett, "Mechanical properties of a large scale synthetic fibre reinforced concrete ground slab," *Construction and Building Materials*, vol. 41, pp. 335-344, 2013.

[5] J. Øverli, "Experimental and numerical investigation of slabs on ground subjected to concentrated loads," *Central European Journal of Engineering*, vol. 4, no. 3, pp. 210-225, 2014.

[6] S. Chen, "Strength of steel fibre reinforced concrete ground slabs," *Proceedings of the Institution of Civil Engineers - Structures and Buildings*, vol. 157, no. 2, pp. 157-163, 2004.

