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Closed loop wire reinforcement to concrete beams

Alan Richardson *, Antony Broadfoot

Northumbria University, Newcastle upon Tyne, NE 1 8SA, UK

HIGHLIGHTS

- Due to orientation, straight fibres are not effective in bridging cracked concrete.
- We examined closed loop versus straight fibre technology for energy absorption.
- Results showed superior performance for closed loop fibres at equal fibre dosage.

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ABSTRACT

The purpose of this paper is to seek a way to improve the transfer of post crack forces in concrete using fibre technology. When straight fibres are added to a concrete mix, the direction of the fibres can be influenced by the mould, balling together and random orientation. This may result in a smaller percentage of fibres being effective when compared to that which it was originally designed for, when coping with post crack forces in concrete. The closed loop fibre technology is designed to place the fibres in an orientation and position where they will be of most benefit, thus reducing the likelihood of having fibres in concrete where they will not be of structural benefit and as a result of this, they will maximise the engineering qualities of the fibre addition.

Beams were manufactured with a fixed addition of fibres by weight, and then they were tested for toughness (energy absorption) using a three point test, recording load and deflection. As an additional measure of the beams ability to absorb energy, a drop hammer test was used to analyse the energy absorbed and the total impact energy dissipated.

The findings showed a significant improvement in performance when closed loop fibres were used, when compared to an equal dose of straight steel fibres.

This work is significant in that the closed loop fibres are not commercially available at this present time and this research assists in a new product development. Closed loop fibres use lower amounts of steel than straight fibres for an equivalent performance to be achieved. They therefore have sustainability credentials with regard to carbon footprint and use of raw materials in construction and building.

1. Introduction

Concrete is a widely used material within the built environment, having many varied applications that utilise its inherent qualities. When concrete is subject to rapid or impact loading it can suffer failure as it is inherently weak in tension. The inclusion of fibres may go some way to mitigate this weakness. This paper investigates a new closed loop fibre design with regard to energy absorption.

Concrete with high degrees of toughness is valuable in many areas of construction and infrastructure provision. Motorway barriers, blast and projectile resistance barriers, industrial floors, airport runways and earthquake resistant design all benefit from high levels of toughness/energy absorption.

The post crack performance of reinforced concrete can be improved with the use of steel rebar, steel fabric or fibres. The fibres are used to provide reinforcement within the full concrete section and not just at discrete points. Concrete with fibres displays greater degrees of toughness than concrete without. This paper reports upon the comparative investigation as to how 2D closed loop steel fibres when compared to straight hooked end commercial steel fibres, affect the flexural strength and toughness (energy absorption) of concrete.

The aim of 2D closed loop steel fibres is to interlock with the aggregate in the mix in order to increase the pull out performance of the fibre and this effect is displayed in Fig. 1. The aggregate a shown in Fig. 1 is not representative of the rounded marine aggregate used in the batching as this aggregate has a large degree of

* Corresponding author. Tel.: +44 191 243 7350.
E-mail address: alan.richardson@northumbria.ac.uk (A. Richardson).

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Fig. 1. 2D closed loop fibres interlocking with aggregate.

flakiness as defined in BS 812-105.1 and has been used to display the interlocking characteristics between closed loop fibre and aggregate. There is very little information in the public domain about how 2D closed loop steel fibres behave.

The problem with using straight fibres is that the fibres may congregate within the concrete at positions where they provide no useful load transfer. Fibres stick to the sides of rotary drum mixers and are not used within the final product, therefore there is an effective reduction in the dosage addition. Finally, the orientation of the fibre to the rupture plane is random and many fibres are not used effectively within the concrete mix. Closed loop fibre technology casts in a random layer of fibres in the tension area of a beam/slab and a vibration table was used to ensure the orientation of the fibres did not change significantly due to compaction.

It is generally accepted the strength of the concrete has little effect on the failure load for the fibres, as it is the bond between the concrete and the fibre that breaks first [1]. The final post crack load will be influenced by fibre direction, total number of fibres, fibre type and concrete type. Parviz and Cha-Don Lee [2] concluded that, only 65% of the "straight" fibres should be considered for structural analysis, and from previous research [3] it should be considered that this figure may be slightly too high and caution should be exercised when establishing performance parameters.

1.1. Fibre use in concrete slabs

For a fibre to be successful as reinforcement in floor slabs it must have the following attributes – be easily spread evenly throughout the mix, should have sufficient bond with the concrete to transfer any tensile stresses across the concrete rupture plane, should be sufficiently stiff and have a suitable modulus of elasticity so as to limit cracking to acceptable limits, provide fracture toughness, should be sufficiently durable to provide service throughout the life of the concrete. The post crack performance of reinforced concrete can be improved with the use of steel rebar, steel fabric or fibres. Destrée [4] reports that it is now possible in some applications to replace traditionally used reinforcement with concrete that is reinforced by fibres alone. Concrete is used widely because of its high compressive strength, however concrete has low tensile strength, cracking easily under tensile forces. Therefore in order to counteract this, reinforcement is necessary to prevent cracks and failure of the material. Traditionally, reinforcing concrete is achieved by using rebar, or steel mesh, in quantities dependent upon the function and application of the concrete member or floor slab.

The potential benefit of using fibres is that they are small enough to be included in the concrete mix and therefore can remove labour associated with placing traditional reinforcement and provide reinforcement throughout the mix in all directions. The other potential benefit is that; if fibres are spread evenly throughout the concrete, then so should the tensile forces, which would lead to a large number of smaller cracks rather than fewer large cracks.

1.2. Blast projectile damage mitigation

When an explosion occurs adjacent to a concrete wall a proportion of the energy will travel through the wall as a 'compressive stress wave'. As the wave meets the back face of the wall it partly rebounds, with some energy travelling back through the wall, and some travelling into the air. The rebound of the 'compressive stress wave' within the concrete can cause a tension rebound. As the concrete fails in tension, back face spalling can occur, ejecting concrete fragments at high speed [5].

Gutierrez de Ceballos et al. [6] state that shrapnel wounds accounted for 36% of all injuries. There is a requirement to reduce concrete spalling and cracking, so that the material does not fragment creating lethal projectiles and for an equal dosage, closed loop fibres may improve the performance of concrete in these situations when compared to straight steel fibres.

2. Materials

The closed loop fibres as used within this test were 50 mm × 50 mm square loops. The loops were created using stainless steel wire of grade 316L, diameter 1.2 mm. Manufacture was using a computer numerical controlled (CNC) machine which bent the wire into the loops of the required dimension. The two ends of the wire section were then resistance lap welded alongside one another. A good aspect of this closed loop fibre design is in its simplicity to be manufactured from a straight wire with four right angle bends and a single friction weld. The straight steel fibres used were of the commercial, hooked end type 50 mm in length, diameter 0.75 mm. A comparison between the two fibre types as used is shown in Fig. 2. The closed loop fibres have a cross sectional area 2.57 times that of the straight steel fibre and a length four times greater. In terms of structural performance the number of straight fibres exceeds the closed loop fibres by 1000% as there are 10 straight fibres for one closed loop fibre.

The BS EN 14845-1:2007, mould and fibre size informed the concrete mix design, using a characteristic design strength C35 with maximum cement content and water cement ratio to help coat the fibres in the plastic matrix. The concrete mix as used is displayed in Table 1.

The quality of the mixing water for production of concrete can influence the setting time, the strength development of concrete and the protection of reinforcement against corrosion. Potable water, described as water which is fit for human consumption is suitable to use according to BS EN 1008:2002, was used in the batch production.

Once batched the beams were marked for identification, de-moulded after 24 h from casting and placed in a curing tank at 20 °C with a pH value of 11 to prevent leaching of the samples for a period of 28 days. The 500 mm beams had a 5 mm deep saw cut across the bottom face of the beam to form an induced crack and cut through the fibres lining the mould. The 400 mm and 500 mm beams were tested using the two opposing cast faces as the top and bottom faces, ensuring good contact with the supports and the drop hammer (tup) or loading head.

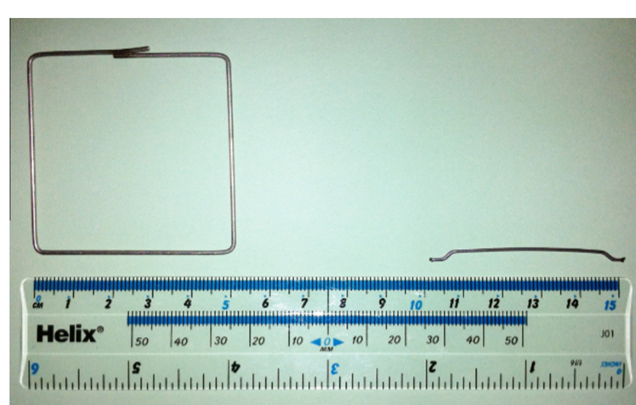

Fig. 2. Closed loop and straight fibre comparison.