AN INVESTIGATION INTO THE USE OF FIBRES IN CONCRETE INDUSTRIAL GROUND-FLOOR SLABS

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ABSTRACT: The concrete industrial ground-floor slab is a key structural element in most industrial enterprises. The art of designing most industrial floors is to provide sufficient reinforcement to control the amount and size of cracks to a level consistent with the intended use of the floor. However, one of the most common causes of cracking in ground-floor slabs is that the tensile stresses imposed on the concrete by external restraint to thermal or shrinkage contraction exceed the tensile strength of the concrete. Therefore, the function of the steel-fabric reinforcement or the fibre-reinforcement is to limit the crack width by preventing micro-cracks from becoming macro-cracks and thus protect concrete from aggressive environmental attack.

The use of fibres in flooring concrete has increased with the development of fast-track construction. In fact nearly 65% of the fibres produced worldwide is currently used in industrial floors, road pavements and other slabs-on-grade. Fibre-reinforced concrete floors offer significant economic and technical advantages over conventional steel-fabric reinforced concrete floors, such as increasing toughness and ductility, tighter crack control and improved load-carrying capacity.

Currently, the use of fibres in concrete, while growing, is not as widespread as its mechanical advantages would suggest it should be. A possible reason for this is the natural hesitancy of engineers and practitioners to use a material for which adequate; experience, experimental data and code provisions have not been well developed. Moreover, the availability of various commercial types and brands of fibres could have added to the difficulty of selecting the proper materials for particular field applications.

This paper reports upon the literature review of using various types of fibres as a replacement to steel-fabric reinforcement in industrial ground floors. A programme of experimental tests on beams and slabs is on the way to provide tests results that can be used as an input data into the finite element analysis programme.

Key words: concrete, fabric-reinforcement, fibres, finite element analysis, ground-floor slab

1. INTRODUCTION

The concrete industrial ground-floor slab is a key structural element in most industrial enterprises. It has two functions: first to sustain the operational loads from loaded racking system, goods stored directly on the floor, fork-lift truck wheel loads and mezzanine floors, and transfers them to the supporting soil without any structural failures or unaccepted settlements; second to provide a suitable wearing surface upon which the operations in the facility may be carried out efficiently and safely. This dual role of industrial ground-floor slab has concentrated attention on its critical contribution to the success of modern commercial facilities (Neal, 2002).

The art of designing most industrial floors is to provide sufficient reinforcement to control the amount and size of cracks to a level consistent with the intended use of the floor (Deacon, 1991). For this purpose, over very many years standardised welded steel fabric has become the traditional choice for the reinforcement of ground floor slabs, but during recent years, with the development of fast-track construction such as laser-screed machines, the use of fibres in flooring concrete has increased. The main purpose of adding any of fibre types to concrete is not to prevent cracking but to control it. The two main types of fibre that have been used around the world for many years in concrete structures, including floor slabs, are polypropylene and steel (Kelly, 1990).

Various fibre-reinforcing materials are available nowadays, but structural applications of fibre-reinforced concrete are mainly made of steel fibre (Meda et al, 2004). More recently, new breeds of structural synthetic equivalents are proving their usefulness. Lighter weight, lower abrasion and better structural performance are making synthetic reinforcement an economic alternative. They are not in common use in floors but are an interesting development in fibre reinforcement technology (Concrete Society, 2003). Due to uncertainty, reflected in current design practice, over the ability of structural synthetic fibre to replace fabric or fibre reinforcement the need for an extensive research programme is identified.

An initial stage of a PhD study on the design and analysis of fibre-reinforced concrete floors using finite element method has been conducted. As a part of the literature review, this paper reports upon the historical development of fibres, describes the various types of fibre that have been used in concrete industrial ground floor slabs and evaluates their influence on concrete properties. Also, a programme of experimental tests on beams and slabs to provide tests results that can be used as an input data into the finite element analysis programme will be presented.

2. HISTORICAL USE OF FIBRES

The use of fibres in brittle matrix materials has a long history going back at least 3500 years when sun-baked bricks reinforced with straw were used to build the 57 m high hill of Aqar Quf near Baghdad (Newman et al, 2003). In addition, horsehair was used to reinforce masonry mortar and plaster (ACI Committee 544.1R, 1996). After that, asbestos fibres have been used to reinforce cement products, such as roofing sheets, for about 100 years. However, primarily due to health hazards associated with asbestos fibres, alternate fibre types were introduced throughout the 1960s and 1970s.

The low tensile strength and brittle character of concrete have been bypassed by the use of reinforcing rods in the tensile zone of the concrete since the middle of the nineteenth century (ACI Committee 544, 1986). Moreover, patents have been granted since the turn of the century for various methods of incorporating discontinuous steel reinforcing elements such as, nails, wire segments or metal chips into concrete.

During the early 1960s in the United States, the first major investigation was made to evaluate the potential of steel fibres as a replacement for steel reinforcing rods in concrete (Romualdi et al, 1963). Since then, a substantial amount of research development, experimentation, and industrial application of steel fibre reinforced concrete has occurred. In the early 1960s, experiments using plastic fibres in concrete with and

without steel reinforcement were conducted (Goldfein, 1963). Since 1997 Japanese construction companies have been using structural synthetic fibres to replace steel fibre reinforcement and the technology has since spread into Australia, Europe and North America (Elasto Plastic Concrete, epc).
Over the past 40 years, a number of applications have been recommended for the use of fibre reinforced concrete including road and floor slabs, refractory materials and concrete products (ACI Committee 544, 1986).

3. TYPES OF FIBRES

There are numerous fibre types, in various sizes and shapes, available for commercial and experimental use. The basic fibre categories are steel, glass, synthetic, and natural fibre materials. However, in slabs on grade, steel, polypropylene and structural synthetic fibre reinforced concrete are the three main types of fibre, which are used as a replacement for conventional steel fabric reinforcement.

3.1 Steel Fibres

Industrial floors and pavements are major applications for steel fibre concrete. In the United Kingdom, more than 2 million m^3 of steel fibre reinforced slabs have been installed over the past ten years (ACIFC, 1999). The stresses occurring in a concrete slab are complex depending on the type of load. There are, in addition, stresses that are difficult to quantify, arising from a number of causes such as sharp turns from fork lift trucks, shrinkage and thermal effects, and impact loads (Knapton, 2003). These fibres, compared to traditional fabric reinforcement, have a tensile strength typically 2-3 times greater and a significant greater surface area to develop bond with the concrete matrix (ACIFC, 1999)

3.1.1 Types of Steel Fibres

Many efforts have been made in recent years to optimise the shape of steel fibres to achieve improved fibre-matrix bond characteristics, and to enhance fibre dispersibility in the concrete mix. ASTM A 820 provides a classification for four general types of steel fibres based on the product used in their manufacture (ACI Committee 544.1R, 1996):

- Cold-drawn wire
- Cut sheet
- Melt extracted
- Other fibres

A few of the more common types of steel fibres being shown in figure 1.1 (Knapton, 2003). Rounded, straight steel fibres are produced by cutting or chopping wire, typically having diameter between 0.25mm and 1.0mm. Flat, straight steel fibres having typical cross sections ranging from 0.15mm to 0.41mm thickness by 0.25mm to 1.14mm width are produced by shearing sheet or flattening wire. Crimped and deformed steel fibres are produced either with full length crimping or bent or enlarged at the ends only. Some fibres are deformed by bending or flattening to increase bonding and facilitate handling and mixing (Concrete Society, 1994). Some fibres have been collated into bundles to facilitate handling and mixing. During mixing, the bundles separate into individual fibres. Fibres are also produced from cold drawn wire that has been shaved down in order to make steel wool. Moreover, steel fibres are produced by the melt-extraction process (ACI Committee 544.1R, 1996).

The ultimate tensile strength of steel fibre range from 345-1700 MPa, whereas the length range from 19 to 60mm, the aspect ratio (length/diameter) range from 30 to 100 and the young's modulus is 205 MPa.

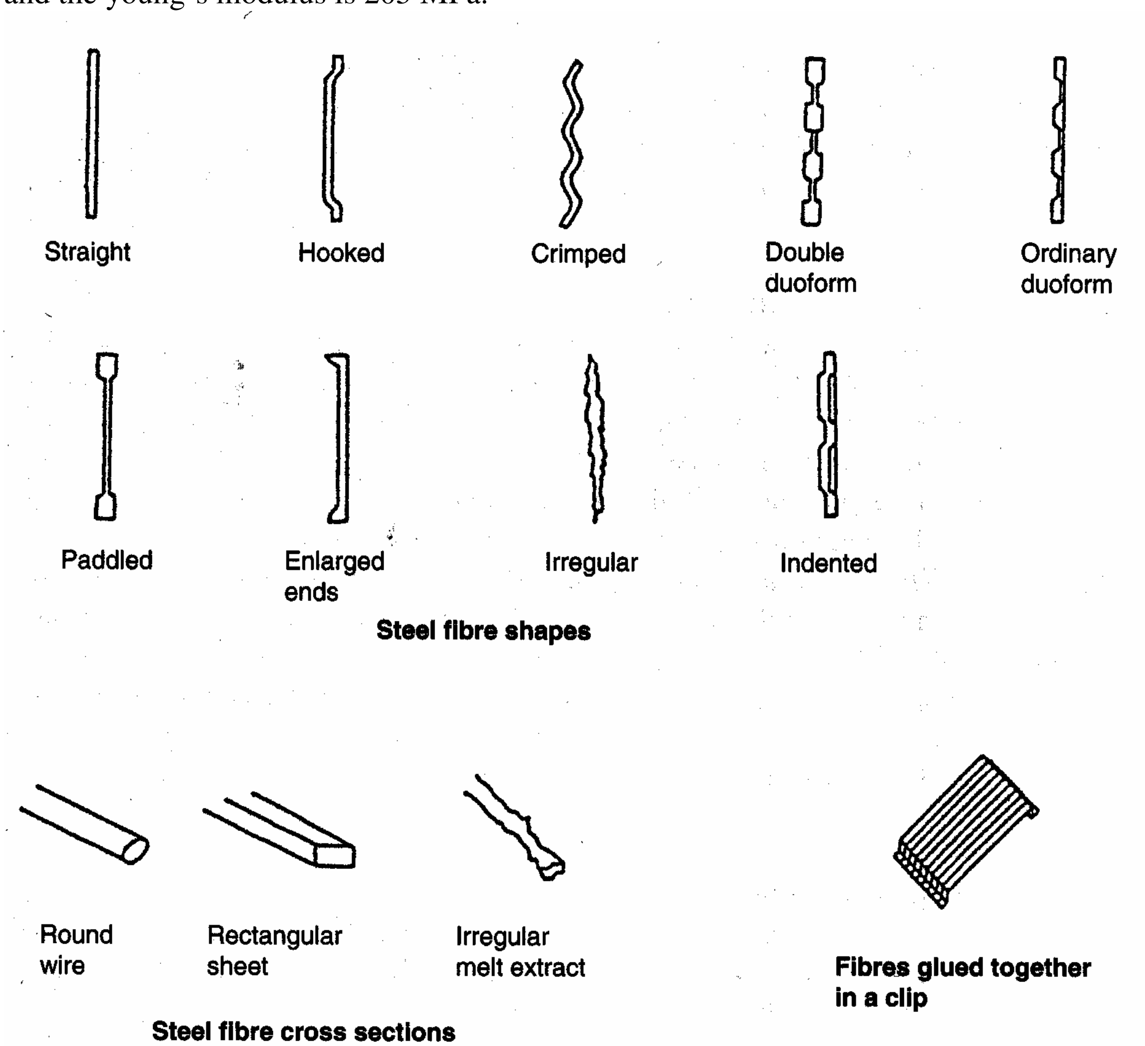

Figure 1.1 Different steel fibre types (Knapton, 2003).

3.2 Synthetic Fibres

Synthetic fibres are man-made fibres resulting from research and development in the petrochemical and textile industries. Synthetic fibre reinforced concrete utilises fibres derived from organic polymers which are available in a variety of formulations (ACI Committee 544.1R, 1996).

Synthetic fibre types that have been tried in Portland cement concrete based matrices are: acrylic, aramid, carbon, nylon, polyester, polyethylene and polypropylene. For many of these fibres there is little reported research or field experience, while others are found in commercial applications and have been the subject of extensive reporting (ACI Committee 544.1R, 1996). Synthetic, organic fibres have low modulus of elasticity and high elongation properties while steel, glass, asbestos and carbon fibres had high modulus of elasticity (Manolis et al, 1997).

The most popular synthetic fibres used in concrete ground floor-slabs are: Polypropylene (micro-synthetic) and structural (macro-synthetic).

3.2.1 Polypropylene Fibres (micro-synthetic fibres)

Polypropylene fibres are gaining in significance due to the low price of the raw polymer material and their high alkaline resistance (Keer, 1984; Maidl, 1995). They are available in two forms i.e. monofilament or fibrillated manufactured in a continuous process by extrusion of a polypropylene homopolymer resin (Keer, 1984; Knapton, 2003). Micro synthetic fibres, based on 100% Polypropylene are used extensively in ground-supported slabs for the purpose of reducing, plastic shrinkage cracking and plastic settlement cracking. These fibres are typically 12mm long by 18μm diameter (Perry, 2003).

3.2.2 Structural Synthetic Fibres (macro-synthetic fibres)

Macro synthetic fibres have been developed during the last seven years. They have the potential to provide concrete with significant ductility. As a result, in concrete floors and slabs, these fibres are able to control cracking caused by thermal movements and long-term drying shrinkage (Concrete Society, 2003). Although these macro-synthetic fibres usually contain some polypropylene, they differ from polypropylene micro-fibres in that they are significantly larger- typically 40-50mm long and 1.0 to 1.5mm wide-, made from selected polymers and used at significantly higher dosage than polypropylene micro-fibres (Perry, 2003). These properties allow synthetic structural fibres to provide a significant level of post-crack control in the same way as that achieved by steel fabric and steel fibres (Clements, 2002)

The following sections discuss the addition, mixing, placing, finishing and curing of steel, polypropylene and structural synthetic fibres. Also, they present the effect of adding theses fibre types on the properties of fresh and hardened concrete

4. STEEL FIBRE REINFORCED CONCRETE

4.1 Composition and Quality

Compared to plain concrete, fibre reinforced concrete mixes generally have higher cement and fine contents and smaller aggregates. The slump decreases as the fibre content increases. (Newman et al, 2003; ACI Committee 544.1R, 1996). So, in order to obtain steel fibre-reinforced concrete that is easy to pump and to work, with minimum shrinkage, a steel wire manufacturer specifies the following (Bekaert, 1990)

- Quantity of cement should be between 320 and 350 kg/m^3
- 750-850 kg/m^3 good quality zero to 4mm well graded sharp sand should be used
- Use a continuous aggregate grading with a maximum size of 28mm for rounded gravel and 32 for crushed stone. Limit the fraction larger than 14mm to 15-20%
- Characteristic compressive strength of at least 25 N/mm^2 should be used
- Water/cement ratio should be about 0.50, and should not exceed 0.55
- The used of super-plasticizer is permitted to obtain the necessary workability
- Admixtures of chloride or chloride containing concrete additives are not permitted

4.2 Addition and Mixing (Steel Fibre)

The recommended dosage rate of steel fibres is usually between 20 and 40kg/m^3. The greater the dosage rate the greater is the flexural strength of the concrete (Knapton, 2003). Generally the fibres are added last to the fresh concrete, care being taken to ensure that no clumps are added and the fibres are rapidly moved from the entry point to the mixer. Alternatively they may be added onto the aggregate on the conveyor belt (Newman et al, 2003). As long as the aspect ratio of the fibre is less than 50, the fibres may be dispensed directly without any risk of balling. With higher aspect ratios some manufacturers employ special packing techniques to reduce the risk (ACI Committee 544.1R, 1996). However, visual inspection during pouring is necessary to check fibre distribution is satisfactory (Knapton, 2003).

4.3 Placing Finishing and Curing

Good quality and economic construction with steel-fibre reinforced concrete requires approved mixing, placing, finishing and quality control procedures be followed (ACI Committee 544.1R, 1996). It is good concrete practice to place concrete as near to its final position as possible. This is ever more true for SFRC because of its reduced flow characteristics (Unwalla, 1982; Swamy, 1974)
Conventional tools, equipment and procedure may satisfactorily be used for placing, finishing and curing steel-fibre reinforced concrete (Knapton, 1999; Killen et al, 1997; Swamy, 1974; ACI Committee 544, 1993). After compaction and levelling, anti-wear products and cement are often spread on top of the concrete surface (Knapton, 2003). SFRC should be cured and protected by the same methods and techniques as plain concrete. Inadequate curing methods can produce plastic and shrinkage cracking encountered in conventional concrete (Knapton, 1999; ACI Committee 544, 1993; Swamy, 1974).

4.4 Mechanical Properties of Fresh Steel Fibre-Reinforced Concrete

Achieving adequate workability is one of the most important problems generated when using steel fibre reinforced concrete. The inclusion of the fibres into the concrete mix, influences its workability, with increasing in the fibre volume and aspect ratio leading to decreased workability (Hannat, 1978; Swamy, 1974). The ACI Committee report in 1996, reported that in the typical ranges of volume fractions used for steel-fibre reinforced concrete (0.25 to 1.5 volume percent), the addition of steel fibres may reduced the measured slump of the composite as compared to plain concrete in the range of 25 to 102mm. Also, since compaction by mechanical vibration is recommended in most SFRC applications, assessing workability of a SFRC mixture with the V-B test, which simulates the effects of vibration, is recommended rather than the conventional slump measurement. Incorporation of superplasticiser is essential to maintain good workability (120-150 mm). In addition to the above consideration the balling of fibres must be avoided.

4.5 Mechanical Properties of Hardened Steel Fibre-Reinforced Concrete

The most significant consequence of fibre addition to concrete is the delay and control of tensile cracking in the composite material (Ramakrishnan, 1988). Through intercept micro-cracks, many of the mechanical properties of the composite are improved. The level of improvement achieved, compared to plain concrete, depends on the dosage rate and type of fibre (ACIFC, 1999). Some of the properties affected will be discussed in this section.

Steel fibres improve the ductility of concrete under all modes of loading. But their effectiveness in improving strength varies among compression, tension, shear, torsion and flexure.

Compressive strength is slightly affected by the presence of fibres, with observed increases ranging from 0 to 15%, on the other hand, direct tension improved significantly, with increases of the order of 30 to 40%, similarly, shear and torsion generally increased although there are little data dealing strictly with the shear and torsion (ACI Committee 544.1R, 1996, Amir, 2002). Much greater effect on flexural strength than on either compressive or tensile strengths, with increase of more than 100% has been reported (Johnston, 1974; Khaloo et al, 2005). The post-crack flexural performance is a most important part of the commercial uses of steel fibre concrete enabling reductions of thickness to be made in sections subject to flexure or point load. Impact strength and toughness, defined as energy absorbed to failure are greatly increased (Hauwaert et al, 1999), the increased in toughness results from the increased of the area under the load deflection curve in tension and flexure (Newman et al, 2003). Increased resistance to dynamic load and fatigue is often claimed (Concrete Society, 1994), it seems to be related to the distribution of the fibres in concrete (Cachim et al, 2002). Also, it has 15% higher resistance to wear than plain concrete.

Modulus of elasticity and Poisson ratio are generally taken as equal to those of similar non-fibrous concrete when the volume percentage of fibre is less than 2% (ACI Committee 544.1R, 1996).

Generally, steel fibre concrete is more durable than plain concrete, having a positive influence on the shrinkage behaviour of concrete by reducing the number and controlling the width of cracks (Concrete Society, 1994; ACI Committee 544.1R, 1996). If the concrete is well compacted the corrosion of fibres will be limited to the surface of the concrete (ACI Committee 544.1R, 1996), these fibres will corrode rapidly in exposed conditions. Fibres also can reduce the deterioration caused by freeze-thaw cycling (ACI Committee 544.1R, 1996), and they also reduces the permeability of cracks even at low volume (Rapoport et al, 2001).

5. POLYPROPYLENE FIBRE-REINFORCED CONCRETE

5.1 Addition and Mixing (Polypropylene)

The addition of polypropylene fibres is at a recommended dosage of approximately 0.90kg/m^3 (0.1% by volume) (Knapton, 2003), the fibre volume is so low that mixing techniques require little or no modification from normal practice (Newman et al, 2003). The fibres may be added at either a conventional batching/mixing plant or by hand to the ready mix truck on site (Knapton, 2003).

5.2 Placing Finishing and Curing (Polypropylene)

Concrete mixes containing polypropylene fibres can be transported by normal methods and flow easily from the hopper outlet. No special precautions are necessary. Conventional means of tamping or vibration to provide the necessary compaction can be used. Curing procedures similar to those specified for conventional concrete should be strictly undertaken. While placed fibre-dosed mixes may be floated and trowelled using all normal hand and poor tools (Knapton, 2003)

5.3 Mechanical Properties of Fresh Fibre-Reinforced Concrete

Knowledge of the fresh concrete properties is considered to be essential for proper design and application of fibre reinforced concrete mixes (Ramakrishnan, 1988).
Polypropylene fibres act mechanically. They impart a cohesive effect by holding water at or near the surface of the concrete, delaying evaporation and increasing cement hydration (Knapton, 2003). The slump of fibre-dosed concrete is not significantly affected by the addition of polypropylene fibres.

5.3.1 Controlling Plastic Shrinkage Cracks in Concrete

The primary role of polypropylene fibres is to modify the properties of the fresh concrete. They increase the homogeneity of the mix, stabilising the movement of solid particles and blocking bleed water channels. This reduces the bleed capacity of the concrete and slows down the bleed rate, helping to reduce plastic settlement.

Plastic cracking may occur in the plastic concrete as a result of drying shrinkage. Plastic cracks are formed within the first 24 hours after the concrete has been placed when the evaporation rate is high and the surface of the concrete dries out rapidly (Knapton, 2003). It is not only affects the appearance of concrete, but also its physical, mechanical and durability properties (Ma et al, 2004). Polypropylene fibres can limit the width of plastic shrinkage cracks. The fibres also endow the concrete with some post-cracking ductility and increased strain capacity at these very early stages, which will have a beneficial effect on plastic shrinkage cracking (Newman et al, 2003).

5.4 Mechanical Properties of Hardened Fibre-Reinforced Concrete

The introduction of polypropylene fibres into the concrete mix has generally no significant effect on the 28-days compressive strength of concrete cubes (Knapton, 2003). Similarly, it has either little or no effects on the flexural strength of concrete (Ramakrishnan, 1987). Moreover, the toughness/energy absorption of the material specially at higher fibre content is increased (ACI Committee 544.1R, 1996). On the other hand, the surface of abrasion resistance and the resistance to frost attack are significantly enhanced by the addition of polypropylene fibres. They also increase the protection of the steel reinforcement against corrosion and reduce the water permeability of the concrete. But, they do not alter the chemical resistance of concrete (Knapton, 2003). As a result, polypropylene fibres are generally more durable than plain concrete (Concrete Society, 1994).

6. STRUCTURAL SYNTHETIC FIBRES

The lack of design guidelines and available references, for synthetic structural fibres, are the most significant barriers to better understanding to the proper way of its: addition, mixing, placing, compaction, finishing, curing and effect in concrete properties. From limited sources of information, mainly Grace Construction Company, some information in this regard presented below (Grace Construction Company; Perry, 2003; Clements, 2002).

The fibres can be added to the concrete at any point during the patching or mixing processes. Additions rate dependent on the specific application and desired properties and will vary between 1.8 to 7kg/m^3. Their additions require careful attention to both mix design and batching procedures in order to achieve optimum results. Adjustments will generally need to be made to the mix design to ensure the required workability is achieved; in addition, a slight increase in the fine aggregate contents may be needed to coat the fibres fully. This will also assist with rapid placing and efficient finishing of the concrete. However, incorporation of a superplasticiser is essential to achieve medium to high level of workability (120-150mm slump), consequently sufficient pumping will be allowed. The placing of structural synthetic fibres are exactly the same as per normal concrete. While the concrete should be compacted sufficiently to ensure that adequate paste is brought to the surface to allow easy finishing. After compaction, an easy float is usually passed over the concrete to close up the surface. Once the fibre reinforced concrete has been levelled, compacted and floated, it is allowed to cure in accordance with good concreting practice.

Structural synthetic fibre mostly relies on surface friction to achieve anchorage across a crack. It controls plastic shrinkage cracking and cracking due to drying shrinkage of the concrete. Also it improves concrete properties including ductility, fracture toughness, impact and fatigue resistance.

7. FIBRES AS A REINFORCING MATERIAL FOR CONCRETE FLOORS

A major use of fibres is to use them as a replacement for conventional steel mesh in industrial ground-floor slabs (Newman et al, 2003). In fact, nearly 65% of the fibres produced worldwide are currently used in industrial floors, road pavements and other slab-on-grade. In the UK with the advent of fast-track systems in the construction industry, concrete flooring has had to meet quicker construction programmes. With the use of laser screeders, fibres are often specified instead of conventional mesh because of the inconvenience of positioning individual mats of mesh immediately in front of the laser screeding machine as it progresses.

Steel and polypropylene fibres have been used in place of conventional reinforcement for the past 20 years. The polypropylene fibres benefit the concrete during its early life or plastic state and the steel fibres later on in the hardened state. In recent years, new fibres, known as structural synthetic fibres, have been introduced to market. They help to control cracking in both fresh and hardened state of concrete. However, the use of structural synthetic fibres in floors is limited, as they have not yet been widely used.

As this type of fibres is still new, and in order to better understanding of its behaviour in concrete industrial ground floor, further investigation required to ensure that structural synthetic fibres can provide concrete with necessary level of post-crack performance. This could be carried out through simply engineering principles for reinforced concrete design and current testing standards for fibre-reinforced concrete.

8. DESIGN GUIDELINES FOR FIBRE-REINFORCED CONCRETE FLOOR

The existing design methods can hardly be applied to fibre reinforced concrete floor slabs. At the same time, design methods for conventional reinforcement are not suitable because fibres represent a diffused reinforcement and are not localised in defined planes. On the other hand, current design guidelines for ground floor slabs invariably rely on elastic analytical solutions derived in the earlier part of the last century. Plastic design guidelines were introduced to allow for thinner slabs. The main shortcoming of the technique is that it only estimates the collapse load, but does not give any information on the deflections. Elastic methods are usually used to check deflections, but these methods are applicable only up to the first crack and should not be applied thereafter. Also, because fibres start working after cracking of the concrete matrix, where material response is no longer linear, floor slabs can be better analysed by adopting methods based on nonlinear fracture mechanics. It becomes clear, therefore, that a solution that describes the load-deflection history from the start of loading and up to failure is required. This gain suggests the need for modern numerical structural analysis techniques, such as the finite element method, which can better model the true behaviour of the fibre-reinforced slab and can, give a complete loading-deflection history. By using nonlinear finite element analysis, crack development during loading in the slab can be more accurately predicted until a collapse mechanism occurs, with the corresponding load representing the ultimate load of the slab. Due to the outstanding toughness of fibre-reinforced concrete, this load is remarkably higher than the load at which the first crack in the concrete matrix occurs.

9. FLEXURAL PERFORMANCE OF FIBRE-REINFORCED CONCRETE

The preferred method to compare the relative performance of different fibre products is to measure the post-crack capacity of the fibre-reinforced concrete section. This may be tested by measuring energy absorbed by a concrete section as deflected by an applied load; this energy absorption is called toughness. Toughness has been traditionally measured using concrete beam specimens according to the following standards: ASTM C1399, ASTM C1018, JCE-SF4 and RILEM TC-162. This implies that the post-cracking strength of fibre reinforced concrete can be easily calculated using the equivalent flexural strength determined from the bending test specified in standard tests. This equivalent flexural strength is a strength parameter which characterises the post-cracking resistance. Therefore it can be used for design and stress analysis of fibre reinforced concrete structures.

10. CONCLUSIONS AND THE WAY FORWARD

The use of structural synthetic fibres as a replacement for steel reinforcement in flooring has various advantages: light weight, tight cracks, ease of use, safe handling, rapid dispersion and no corrosion. However, measuring the post-crack capacity of the fibre-reinforced concrete section could compare the relative performance of different fibre products. As a result, comparing post-crack performance of synthetic fibres with steel fibres and mesh will reveal the differences in the way the materials work.

In light of the above, a beam test on reinforced concrete sections incorporating: steel fibres, structural synthetic fibres and steel fabric will be carried out according to ASTM C1018 for two purposes: first to compare the post-crack capacity performance of the three sections and, second, to use the flexural strength parameter resulted from beam tests as an input data into the stress analysis of fibre reinforced concrete floors using non-linear finite element analysis programme. After using the finite element analysis to study the fracture behaviour of ground floor-slabs and in order to validate the numerical analysis, three full-scale tests on slabs incorporating steel fibres, structural synthetic fibres and steel fabric will be performed and the experimental results will be compared with the ones obtained from the numerical analysis.

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