THE SIGNIFICANCE OF RELIABLE FIBRE DOSAGE EQUIPMENT AS PART OF THE QA SYSTEM IN THE PRODUCTION OF FIBRE REINFORCED CONCRETE LININGS

Bernard Berge
Maccaferri Central Europe, Slovakia, phpb@bitmailer.net

Summary
This paper addresses the importance of reliable and precise dosing systems for concrete fibres. Fibre reinforced concrete (FRC) is a composite material where the fibres are added either into the fresh concrete or during the batching process. The addition of the fibres is a decisive process, because of its influence on the main properties of fibre reinforced concrete, which are only provided when the fibres are evenly dispersed without any clustering. A regular dispersion of the fibres is fundamental for the performance of the composite material. Further, a high precision of the dosage equipment is paramount to ensure the correct dosage of fibres, where the design is based on. A fully integrated and automatically operating dosage system for fibres not only provides the required dosage precision and fibre dispersion, but also excludes human errors that can derive from manual addition of the fibres. An overview on existing dosage equipments will be presented where the different systems are discussed. It can be concluded that different applications of fibre reinforced concrete demand different and specifically designed batching equipment to accomplish the particular requirements of the application.

Keywords: Steel fibres, micro-synthetic fibres, fibre reinforced concrete, tunnelling, segmental lining, dosage system, fibre dispenser, fibre doser, fibre distribution

1. Introduction
Concrete is a well established and reliable construction material for underground applications, but features a disadvantageous lack of tensile capacity. Its application in temporary and permanent linings of tunnels and galleries in shotcrete, segmental linings and cast-in-situ concrete requires a ductile and robust performance. Moreover, the safety requirements on tunnels demand an improved resistance of the concrete lining during fires. The addition of specialised steel fibres overcomes the natural brittleness of concrete, providing a sound structural performance, which in many cases allows replacing conventional reinforcement, leading to substantial cost savings in the project. Apart from the structural performance, which is given by steel wire fibres [1, 2, 3, 4], specialised micro-polypropylene fibres are added to improve the resistance of concrete against explosive spalling in tunnel fires [5, 6, 7]. Furthermore, these micro-PP fibres reduce plastic shrinkage of concrete by retaining water within the matrix.
The addition of the appropriate fibre or fibre blends respectively to concrete can become quite challenging, because underground applications typically require relatively high fibre dosages. This means integrating a vast specific surface area, which needs to be well dispersed into the concrete and properly embedded into the binder paste within a limited time frame. The methodology how to add the fibres to concrete has enormous influence on the fibres' dispersion and hence, on the quality of the composite material. There are different methodologies existing, because any of the a.m. applications show their distinct particularities with regards to the required batching technology; starting from the application technique principle, over the required mix design and also the referring performance requirements of fresh and hardened concrete. Thus, the batching and dispersing technology is a key part of the quality assessment of fibre reinforced concrete production. Specially designed fibre dosage equipments account for the particular requirements of these kinds of applications. The main parameters to be provided herein are:
- even feed and regular dispersion of the fibres to avoid bulking of the fibres in the mix;
- high precision of the dosing, especially on batches with small quantities, which allow very little tolerances;
- high speed of introduction of the fibres to account for short batching time frames, which are often encountered in the production of precast lining segments.

Care needs to be taken during batching of the fibres to provide exacting dosages and to avoid clustering of the fibres. Hence, quality assurance needs to be implemented in the production process of FRC. For this, proper batching systems and methods need to be enforced in project sites by choosing the right kind of systems based on experience and expertise of leading service providers. To assure proper dispersion and dosage of steel fibres in concrete, specialised dosage equipments are required.

2. Fibre batching equipments

2.1 Mobile systems for steel fibres

Fig. 1 Pneumatic mobile batching system for steel fibres

Mobile batching systems are typically required where the fibres will be delivered in smaller units, i.e. in carton boxes or bags of 20-25kg each. In such applications, like industrial flooring with SFRC or smaller shotcrete lining projects, the fibres are often added on site into the truck mixer. Chevron conveyor belts are commonly in use, because they facilitate the addition of the steel fibres into the mixer drum. Care must yet be taken to provide an initial dispersion of the fibres on the belt in order to attain an even distribution in the fresh concrete and to avoid clustering of the fibres (fibre balling). Hence, this procedure is quite time consuming and does not guarantee even fibre dispersion in the mix.
Pneumatic batching machines as shown in Fig. 1 have been developed to achieve trouble-free introduction of the steel fibres. The fibres are added from the carton box onto a vibrating grid that initially breaks up potential clusters. From there the fibres fall onto a vibrating channel where baffle plates and fingers avoid bulking of the fibres during transport. The vibrating channel moves the fibres towards a funnel where they fall into an airstream conveying the fibres through a steel pipe where they are blown into the hopper of the truck mixer. An even dispersion of the fibres in the fresh concrete can be guaranteed without fibre balling. Batching speeds of up to 40kg per minute allow quick addition of the fibres. The precision of such mobile batching units is controlled manually.

2.2 Integrated systems for steel fibres

Dosage equipments, which are integrated in the batching procedure, can feed steel fibres fully automatised into the batching process. These systems typically consist of a basic drum dispenser having integrated load cells in their feet (Fig. 2). The steel fibres are filled from big bags, thus, allowing quantities of up to 1000kg to be ready for use. The drum is agitated by excenter motors and the fibres move by the vibrating energy. The fibre dosage quantity is monitored by control of the four load cells, typically at a frequency of 1Hz. The dispenser will be connected to the main batching control panel and by this, fully integrated in the batching process. The machine will be triggered to start operation by the main batching computer. A control panel will be installed in the main operation panel so that the batching operator can make adjustments from remote. This panel also indicates when the dispenser needs to be refilled.
Through a weighing and vibration system, the dosage equipment can precisely feed the steel fibres onto the conveyor belt, as shown in Fig. 2, or directly into the mixer with a prefixed quantity of fibres and within a defined time frame. Being fully integrated in the batching process, these dosage systems not only facilitate the addition of the fibres, but improve the efficiency of the production process substantially.

Fig. 2 Standard installed drum dosage system adding steel fibres on the conveyor belt

Moreover, they ensure that the dispersion of the fibres is regular, already during batching, so that bulking is avoided and the exacting quantity of fibres required will be evenly dispersed in the concrete.
The precision of these standard installations is satisfactory and can be further improved by integrating intermediate batching units as described further on. The feeding speed is depending on the geometry of the steel fibres. Coarse fibres, i.e. long fibres with larger diameters can yield higher batching speeds than very fine fibres having a larger bulk volume. Hence, the time required to feed the predetermined dosage of steel fibres onto the conveyor belt can vary. Accordingly, it might happen that the batching speed of the standard machine is not sufficient, such as in cases where the batching cycles are very short. Here, intermediate batching kits are required to accomplish the short cycles, which is further detailed in chapter 3. Generally, batching speeds of up to 200kg per minute can be reached, depending on the steel fibres' geometry.

Fig. 3 Weighing vibration unit as reach extension for the standard dosage machine (Hobson Bay sewer tunnel project, Auckland)

Intermediate units are also required in batching plants where it is physically difficult to install the machine close enough to the batching process. An extension is required in the case that the machine's outlet does not reach the conveyor belt (see Fig. 3). These units must be designed in the same way as the principle doser to avoid bulking of the fibres and to ensure even dispersion into the process. They have separate motors for vibration to move the fibres along the channel and baffle plates to ensure that the fibres do not bulk up and fall evenly dispersed into the batching process. The own load cells of the intermediate batching kit provide a redundant control of the dosage quantity. Its operation is controlled by the main unit, which is connected to the batching control panel.

2.3 Batching systems for micro-synthetic fibres

Fig. 4: Fully integrated dosing system for micro-polypropylene fibres (Line 9, Metro Barcelona)

Tunnel linings require increased fire resistance for the case of fire accidents. Micro-synthetic fibres can substantially reduce or entirely avoid the explosive spalling of concrete during fires [5, 6, 7]. Polypropylene fibres are the preferred choice because of their inert property and alkali resistance.

A common way to batch micro-PP fibres is by using tailored bag packaging, i.e. the bags' quantity is adjusted to the mixer volume to suit one batching cycle. The bags are usually made of water-soluble material that dissolves during mixing. The bags can be added directly into the mixer by a staff member. This method still requires manual action and is thus subject to human control and errors. Precision and reliability in batching micro-synthetic fibres is especially vital due to the fact that a control of quantity becomes impossible once the fibres are introduced into the fresh concrete.

A recent development for the automated batching of micro-PP fibres is the POLYDOSO® (Fig. 4). The machine is designed to feed monofilament PP fibres with diameters lesser than 20 microns in a continuous flow. This patented system provides the same features as the equipment for steel fibres. It will be fully integrated into the batching process and automatically operating, electronically controlled by the main batching panel. Moreover, the system enables the use of bulk packaging, which facilitates the procedure of batching significantly. The usage of big bags further reduces the initial costs. The fibres are transported through a screw conveyor where a sophisticated measuring system guarantees precise dosing of the fibres.

3. Specialised dosage equipment for SFRC linings

High dosages of steel fibres and short batching cycles require specialised dosage systems in order to cope with the particular requirements. The concrete grade in segmental linings is usually high to achieve high early strengths for handling operations at young age. Compressive strength classes of 50 to 60MPa and higher are very common. This implies a high degree of brittleness, which at the same time requires a high dosage rate of high performing steel fibres to provide the stipulated ductility and structural performance. Dosages of 40 to 50 kg/m^3 (0.51 to 0.64% vol.) are typical quantities in segmental linings.

Moreover, in large production units of shotcrete or precast segments, the batching cycles are short. Most of the existing standard dispensers have a constant dosage rate which does not always match with the batching cycle requirements. Hence, a shortfall of fibres into the batching process is often a problem encountered with. Today's systems have intermediate units to dose the fibres in order to comply with the requirements of high precision and short batching cycles and hence, not hindering production time. A pneumatic closure system at the outlet of the basic dispenser improves the batching precision (see Fig. 5). The intermediate kit will be filled during the current mixing cycle. This unit has a second weighing system for control and is designed to dispatch the fibres in very short time during the next batching cycle. These intermediate kits complete the adaptability of the dosage system, as they also serve as a reach extension for the main unit. Further, such dosage systems attain an accuracy of less than one percent by weight. This is a value that should be specified in the projects to yield the high precision within the quality assessment.

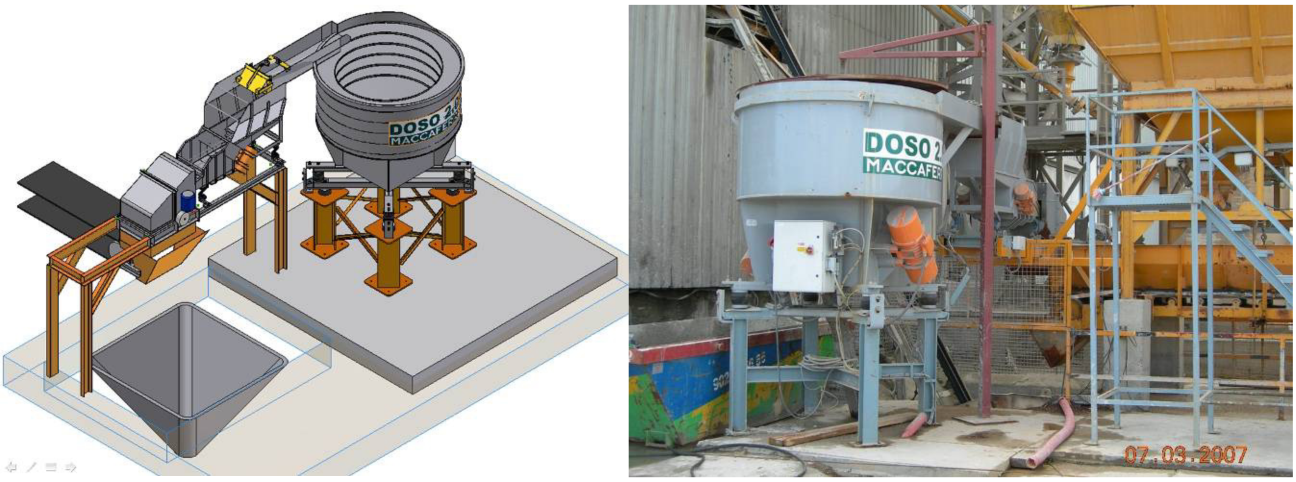

Fig. 5 Steel fibre dosing system with pneumatic outlet closure, intermediate weighing and batching unit (Line 9, Metro Barcelona)

These equipments are designed according to the particular requirements and features of the casting plant and delivered ready to be installed. The plant's layout will be analysed in a preliminary study, which reveals the optimal position of the dosage system and the best point of time to add the fibres. In most cases, the fibres will be added onto the coarse aggregates. This makes sure that a good dispersion of the fibres is already achieved in the dry mix during the batching process. Thus, the batching time for the steel fibres is governed by the time frame of the aggregates.

Site engineers from the equipment supplier shall provide installation support to connect and integrate the system into the production process. The batching process will be further optimised during the following trials. During these trials, primarily time adjustments will be made on the dosage system to optimise the fibre addition into the batching process. Batching of the fibres will be fully automatically after installation and complete integration of the dosing system. Any operation can be controlled then by the control panel of the batching plant. The only remaining manual operation is to refill the drum dispenser. Human errors can therefore be excluded during fibre batching.

During the initial batching trials also final adjustments on the mix design and workability of the fibre reinforced concrete shall be conducted. Leading fibre suppliers shall delegate their experts in order to support this important part prior to the production start. The final mix design and slump of the fresh FRC must be well balanced with the casting procedure, the compaction energy and the vibrating time in the case of precast segments.

Fig. 6 Weather exposed sample segment from trial casting for outfall tunnel segments (Victorian Desalination Plant project, Melbourne)

A fully optimised system will reveal not only a regular steel fibre dispersion within the segment, but furthermore, a preferred horizontal alignment of the fibres as shown in Fig. 6 (right). The weathered segment from trial casting shows surface spot corrosion on the saw-cut face with predominant circular form. Moreover, the segment's intrados does not show any fibre on the surface. The optimised mix design ensures that the steel fibres are fully covered by the binder paste to avoid surface corrosion. This is especially important for segments with high requirements on durability, such as the outfall tunnels of a desalination plant.

4. Conclusions

Since about 20 years now specially designed fibre batching solutions are continuously developed. These fibre dosing systems not only ease the procedure of adding the fibres into the concrete batching process. A high degree of adaptability can be attained by specialised intermediate batching units. They facilitate the integration of the dosage system into the concrete batching process and enable to accomplish short batching cycles

Specialised dosage systems guarantee a precise dosage and a regular dispersion of the fibres and at the same time avoiding clustering of the fibres. Being fully integrated into the batching process, these dosage systems operate completely automatically so that human errors are excluded. Thus, making the sophisticated dosage system being an integral part of the quality assurance. Demanding tunnel projects have specified the usage of these dosing systems to optimise the quality of the fibre reinforced concrete.

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