CAPSULES AS A PREVENTION OF FIBRE CLUSTERS IN CONCRETE

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Homogenous concrete mixture without aggregate pockets and fibre clusters is a presumption for appropriate properties of concrete element or structure. There are technological measures how to achieve homogenously looking mixture from aggregate point of view, but fibres are still predisposed for clusters forming. The paper evaluates originally designed and protected within European patent treatment of fibre, based on capsules containing individual rolled fibre which can be admixed into a concrete mixture and set up homogenously in its whole volume within the mixing process.

INTRODUCTION

The paper introduces originally designed method of prevention of fibre clusters based on an application of capsules enveloping an individual rolled fibre into a concrete mixture. The method is verified by an experiment described and discussed in the paper.

THEORETICAL

As well known, cement concrete features low values of tensile strength. For this reason, concrete elements, which are subject to tensile, bending or shearing loads, are usually made as reinforced or prestressed. During the recent decades, technologies based on fibres (glass, polymeric, steel etc.) admixed to a concrete mixture have been elaborated and implemented. The technologies beside its many advantages considered in relatively easy fibre incorporation into a mixture, have several knotty and risky factors.

As described Rosen in 1965 [1], there are two different fibre buckling modes, i.e. extensional and transverse. Even if following studies improved Rosen's first model within defining more accuracy mechanics using a different approach to solve the problem, all of them agree in the dependence of fibre buckling on three main parameters, i.e. matrix shear strength, fibre initial misalignments and volumetric participation of the fibres in the composite, as stated by Martinez and Oller in 2009 [2].

The second parameter, i.e. fibre initial misalignments, propagates within fibre orientation in concrete mass or fibre clusters (clumps, pockets) forming which play against intended randomly distributed fibres. They exhibit a nonlinear behaviour, called damage, which could be described in terms of microcrack initiation, growth and coalescence leading to the creation of macrocracks. A micromechanics-based continuum damage mechanics model is proposed by Boulfiza in 2003 [3] for the prediction of the effect of initial microcrack configuration on the macroscopic Young's modulus and thermodynamic force associated with the chosen damage variable.

The effects of the fibre gradient distribution on the strength of cement-based materials were studied by Yang, Hai, Dong and Wu in 2003 [4]. Their findings result in expected affirmation that the flexural strengths of concrete reinforced with fibres differs in relationship with the fibre gradient distribution. As known and shown e.g. in [4] effectiveness of the reinforcement strongly depends on reinforcement orientation and distribution. If the parallel orientation of the reinforcement with the tensile tension cannot be achievable due to technological reasons, random and homogenous principle of fibre reinforcement placement should be kept.

Numerical investigation on the size effect in fibre-reinforced concrete specimens has been elaborated by Bruggi and Venini [5]. The research is based on an alternative approach for cohesive crack propagation. Pakravan et al. [6] described influence of geometry of acrylic fibers on the mechanical performance of fiber-cement composites.

Distribution of steel fibres was studied by Ponikiewski and Golaszewski [7]. They present an analysis of cross-sections of beams made of Steel Fibre Reinforced High Performance Self-Compacting Concrete. The studies showed the characteristic dispersion of steel fibres in the moulded concrete elements, and confirmed the usefulness of the developed methods. No clusters were observed. Horta et al. [8] shows that fibre-reinforced concrete (FRC) composites had not been fully explored with regard to the mechanical behaviour of the random distribution of the fibres inside the matrix, which tend to fibre clusters. They studied the influence of the random distribution of fibres in the matrix by means of computer modelling.

Existing solutions

There are several patented solutions or solutions applying for patent which are trying to make fibres implementation easier and to prevent fibre-clusters creation. The document US 3616589 [9] suggests to add thin wires into the concrete mixture. Wires are adapted to form of diverse shapes, such as rings, pentagons, circular leaves, partitioned rings, rings with spliced ends or the like. These objects have in so far varied sizes and shapes that they are not subject to mutual attracting forces and may be randomly oriented within the mixture. Nevertheless, such elements require expensive preparation methods that are not applicable to any other material but steel. The document US 4565840 [10] suggests adding carbon fibres having dual length, the longer ones having the values of Young's module higher than the base concrete material has and, conversely, the shorter ones having the values of Young's module lower than the base concrete material has The preparation of such dual fibres is arduous and, moreover, it is not obvious whether the embodiment provides a sufficient solution of the aforesaid problem resulting from the formation of fibrous clusters.

The document DE 2337129 (A1) [11] discloses the device for batching all types of fibres, i.e. those made of steel, plastics, glass, etc., to be added into concrete mixtures. The device consists of the basic hopper made up of a pair of joint funnels, the first funnel being used for batching cement components and the second one serving for preparing concrete admixtures. The first funnel leads into the masticating worm, the latter being movably fitted in the tube located underneath the hopper, in which tube the first mixing phase takes place. Subsequently the resulting mixture made up of the individual material constituents is discharged through the overflow into the other tube, namely into the postmixing one. The postmixing tube, which is located in the opposite orientation underneath the first tube, is also equipped with the masticating worm serving as an agitating conveyer. Furthermore, the postmixing tube accommodates the outlet of the second funnel that dispenses the reinforcing fibres to be added into the mixture. The fibre dispensing funnel is equipped with the upstream feeding trough that is driven in oscillation. In this oscillating trough, the fibres are scattered in order to be prevented from forming clusters. The separated fibres are then separately poured into the second funnel from which they get into the mixture to form the final fibrous concrete mixture taken off from the outlet end of the postmixing tube. The device described above is extremely demanding with respect both to the design and to the energy consumption.

The document US 7267873 [12] suggests to add fibres made of a steel wire having 0.05 to 0.3 mm in diameter into the concrete mixture in such a manner that fibrous bundles are formed that are not mutually bound any more due to their lightweight constitution. Alternatively, fibres having markedly different lengths may be used. Herein, the drawbacks consist in the use of steel on the one hand and in the demanding preparation of the fibrous bundles and/or differently sized fibres on the other hand.

In WO 9602715 [13] elements consisting of fibres which are bound into a bunch and held together by a casing material are presented. Such bunches are mixed with concrete or mortar and the casing material dissolves in the concrete and the fibres are allowed to spread out in the mixture. Indeed this is a method how to bring the fibres into the mixture, nevertheless the uniform dispersion can not be secured. In an anonymous article [14] there is the discussion concerning bags of water soluble material as cellulose or polyvinylalcohol containing about 2-50 kg of steel fibres for dissolving in concrete are mentioned. The steel fibre can be glued together in groups of 5-40 fibres. This is again a method how to bring the fibres into the mixture, nevertheless the uniform dispersion can not be secured.

Ground of patented solution

Solution disclosed in [15-17] presents a method of the production of concrete reinforced with added fibres as well as the method of the prefabrication of building elements or monolithic structures with the use of such fibre-reinforced concrete (FRC). The method enables the fibres to be uniformly distributed.

The drawbacks mentioned in previous sections are eliminated by the capsules intended to be added into concrete mixture, wherein each capsule comprises an individual fibre formed as coiled element and a solid wrapper made of a water-soluble glue or water ice and enclosing said coiled element, see Figure 1.

Capsules have a similar size and shape as used aggregate with which is dosed into dry concrete mixture. Capsules, each containing an individual coiled fibre, are randomly placed within mixing in all of mixture volume.

The capsules temporarily fix coiled shape of fibres up to time of water dosage. Within water incidence capsules are dissolved of melted, fibres obtain their initial linear shape but stay randomly placed in all of concrete mixture volume.

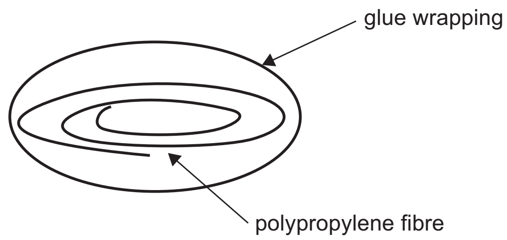

Figure 1. Schematic representation of particular capsule.

The chemical status of the glue used should not negatively affect properties of concrete mixture or/and hardened concrete. Functionality of glue or water ice can undertake admixture which would be dosed due to prescription anyway.

Aim of the research and hypotheses

Fibre capsules described in the previous section "Ground of patented solution" are a product of long-term elaboration with FRC, self-compacting concrete and observation of placement of particular components of concrete mixture. Research described in the next part of the chapter tried to verify at laboratory conditions presumptions of capsules positive affecting of fibre placement. Effectiveness of capsules operation was evaluated by verification of three following hypotheses:

- Rolled (coiled) fibre is able to achieve undeviating initial shape;
- Capsules are able to be placed randomly in a concrete mixture;
- Capsules are able to disintegrate their-self in a concrete mixture.

Pilot project prepared for semi-industrial evaluation will verify the next three hypotheses:

- Fibres are able to be placed randomly in whole volume of hardened beam sample;
- Method is cost effective;
- There is a producer for production of capsules.

The first three hypotheses were verified using the procedure described hereafter. The next three ones need considerable quantity of capsules and will be verified on real gilders in a pilot testing project where producers of concrete and potential producers of capsules will be involved.

EXPERIMENTAL

Material

Fibres

On the base of agreement of potential capsules producer, commercially produced 25 mm length polypropylene fibres were selected for the experiment. One kilogram of the fibres represented 220 thousand pieces of fibres.

Capsules

Two methods of capsules preparation were tested. The first one based on water-soluble glues (three types) = glue capsules [15] and the second one, water deeply frozen after its application on rolled fibre was served as a capsule wrapper = ice capsules [16]. Although facility for capsules production has been designed and currently is composed [17], capsules for the experiment were manufactured manually in the laboratory condition.

In case of glue capsules preparation each polypropylene fibre was rolled using tweezers and instilled by water-soluble glue. Three types of glue capsules were prepared using different types of water-soluble glue. Let us call them GA, GB, GC as Glue Capsules use glues A, B, C respectively.

In case of ice capsules preparation each polypropylene fibre was rolled using tweezers as in case of glue capsules but a water droplet is added to it so as to form an envelope droplet that is immediately afterwards rapidly frozen by means of the action of liquid nitrogen having the temperature of -196°C. This action makes the coiled form of the fibre temporarily fixed, thus creating the capsule. Capsules were maintained in a usual freezing box on the level of -18°C. Let us call IC as Ice Capsule.

Described capsules were used for verifying ability of fibre undeviating shape achievement. For verifying of capsules random placement and their disintegration in concrete mixture empty glue capsules (capsules without fibre) were used. Nevertheless empty capsules had the same size and bulk mass as capsules with fibre but their production was incomparably easier. Arisen both real and empty capsules had more or less the same size as used aggregate, fraction 4-8.

Concrete mixture

The composition of the FRC was as follows (the batching values refer to one cubic meter of mixture). Cement CEM I 42.5 R: 380 kg, quarried aggregate classified as fraction 0-4: 595 kg, crushed aggregate classified as fraction 4-8: 241 kg, fraction 8-16: 430 kg, fraction 16-22: 516 kg, the admixture Adiment FM 62 (0.6 % of the weight of cement): 2.30 kg, the admixture Adiment LP S-A 94 (0.3 % of the weight of cement): 1.15 kg, coiled fibres - originally having 18 mm in length: 1.3 kg, batch water (w/c = 0,38): 145 kg.

Methods

As explained three hypotheses were verified in the research:

- Rolled (coiled) fibre is able to achieve undeviating former shape;
- Capsules are able to be placed randomly in a concrete mixture;
- Capsules are able to disintegrate their-self in a concrete mixture.

Verifying of fibre undeviating shape achievement

Fibre ability of achievement the former undeviating shape was tested using twenty capsule samples for each type of three glue capsules and one type of ice capsules. The experiment was arranged as follows:

- Four transparent glass jars were filled up by water with temperature 15°C;
- Twenty capsules of each glue and ice type were batched into the one of the prepared jar with water;
- Processes of capsules disintegration and unbending of fibre were visually observed within permanent mixing using glass stirrer;

Verifying of capsules random placement in concrete mixture

The experiment should verify if capsules are able to take up a random placement in the concrete mixture due to different bulk masses of capsules and aggregate. As explained in the Material section of the paper, the experiment was arranged with empty capsules. Experiment was done using laboratory mixer equipped by 70 litters mixing vessel, assembled according to utility model [18]. Above described concrete mixture (without water) in the amount of 0,035 m^3 was batched into the mixing vessel. Empty capsules were dosed instead of fibres prescribed in the composition. Amount of capsules was counted at 10 010 capsules, see Table 1.

After 3 minutes of mixing with frequency of 30 cycles per minute the dry mixture has been observed and evaluated. The observation of capsules placement homogeneity was done visually. After opening the top of the concrete mixer 20 randomly selected samplings of dry concrete mixture were taken using a quarter-litter can. Number of capsules was counted in each of the twenty samples manually.

Verifying of disintegration capsules in concrete mixture

Batch water was added in to the dry mixture remained in the mixer. After 4 minutes of mixing, again with frequency 30 cycles per minute, mixing was stopped. After opening the top of the concrete mixer 20 randomly selected samplings of concrete mixture were taken using a quarter-litter can. Each sample was spread on a blotting paper and observed.

RESULTS

Verifying of fibre undeviating shape achievement

According to described procedure in the Method section four transparent glass jars were filled up by water with temperature 15°C and twenty capsules of each glue and ice type were batched into. Processes of capsules disintegration and unbending of fibre were visually observed within permanent mixing using glass stirrer. Record of the experiment displays Table 2 and Figure 2.

As shown in Table 2 and Figure 2, ice capsules IC were able to be melted and fibres achieved their former linear shape in two minutes after their application to the water bath. Glue capsules GA were able to be dissolved in 4 minutes of their application to the water bath. Both IC and GA capsules have been found suitable for next experiments. GB capsules dissolved in 6 minutes and GC capsules, which were not able to be dissolved in 6 minutes, were rejected from further experiments.

Table 2. Verifying of fibre undeviating shape achievement.

		Percentage of fibres achieved their former undeviating shape after (%)		
Capsule type	Label	2 min	4 min	6 min
Glue Capsules	GA	65	100	–
	GB	50	85	100
	GC	20	45	50
Ice Capsules	IC	100	–	–

Table 1. Number of capsules needed for the experiment.

Prescribed mass of fibres in the mixture	1.3 kg
Number of fibres per kg	220 000 fibres/kg
Fibres needed for the mixture	1.3 × 220 000 = 286 000 fibres/m^3 of mixture
Amount of mixture in the experiment	0.035 m^3
Fibres (capsules) needed for the experiment	286 000 × 0,035 = 10 010 capsules

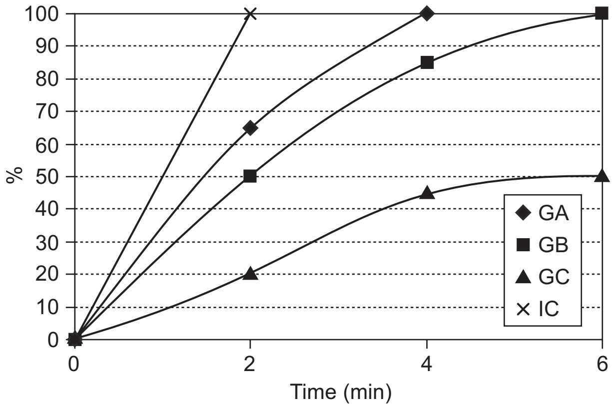

Figure 2. Percentage of fibres achieved their former undeviating shape depending on time and type of capsule.

Verifying of capsules random placement in concrete mixture

According to the methodological section of the paper twenty quarter-litter samples of dry mixture were taken from the mixer. Samples were spread on a table and capsules in each sample were manually counted. Results are shown in Table 3.

The number of capsules expected in the sample can be counted simply: 10 010 capsules were applied into the mixture of 35 litres volume, i.e. quarter-litter sample should have 10 010/35/4 = 71.5 capsules (statistically). However, in-depth math analyses cannot be done because of used method of verification and size of statistical file, observed average amount of capsules (71.9) taken from the Table 3 well fits with the presumption. Sample deviation calculated as 3.2 capsules shows that there is no significant difference among samples from capsules placement point of view.

Table 3. Number of capsules in 20 randomly selected samples.

Sample no.	Number of Capsules
1	68
2	75
3	73
4	67
5	78
6	78
7	72
8	69
9	74
10	68
11	68
12	70
13	73
14	74
15	75
16	71
17	72
18	69
19	70
20	73
Arithmetical mean	71,9
Sampling deviation	3,2

Note: sample deviation was calculated using generally known formula:

$$S = \sqrt{\frac{\sum(x-\bar{x})^2}{(n-1)}}$$

where S is sample deviation, x counted number of capsules in each sample, $\bar{x}$ arithmetical mount of capsules in samples and n number of samples (20).

Verifying of capsules disintegration in concrete mixture

According to the methodological section of the paper twenty quarter-litter samples of mixture were taken from the mixer. Samples were spread on a blotting paper and observed if each capsule disappeared (disintegrated). The observation resulted in finding, that all capsules were disintegrated under water and mixing influence.

DISCUSSION

Experiments verify all three hypotheses as discussed in the following section.

Former shape achievement

In case of one used glue (of three used) and ice capsules rolled (coiled) fibres were able to achieve undeviating former shape in designated time. The next research at this stage can continue with selection of the appropriate cheapest glue with no chemical impact to concrete mixture. An admixture can serve as optimal glue preferably, because it can improve workability or other properties of concrete mixture and in the same time it does not increase the price of mixture.

Random placement

Random placement of the capsules in mixture is also fundamental issue of the newly-designed technology. Experiments confirm promising ability of the capsules to take a random place in mixture, even if their bulk mass is about 2.5 times lower than bulk mass of aggregate. This finding is essential for the next steps in research.

Disintegration of capsules in mixture

In conformity with the first step of verification, where achievement of initial linear shape of fibres was observed in the water bath, capsules placed into real concrete mixture were dissolved as well. However the experiment did not verify if fibres had been able to achieve their initial linear shape, it verified that capsules behaviour in their dissolving point of view is the same in both case, i.e. in water bath and concrete mixture. Ability to achieve initial linear shape is subject of the pilot semi-industrial testing which follows described experiments.

CONCLUSION

Newly designed technology of FRC based on capsules containing coiled individual fibre has been designed on the base of theoretical findings and in confrontation with other known and patented technologies.

However there are a lot of open questions, e.g. cost-effectiveness, functionality on real elements, interest of producers etc., the described laboratory verifications states promising conditions for next pilot semi-industrial testing and after successful them their implementation in practice.

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