Influence of glass and polymer fibres on physical and mechanical properties of cement composites

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Abstract. This paper focused on the effects of using glass and polypropylene fibres in cement mortars. Were used glass fibres Cem-FIL Anti-Crack HP 12mm long and polymer fibres BeneSteel 55 (shortened to 12mm) in 1wt.%, 3wt% and 5wt% of cement. The water and filler dose were constant. Tests were performed on 40x40x160mm beams. From the results we have found that by the addition of fibres, the shrinkage of hardened cement composites is eliminated, with the use of polymeric fibres for better results. The filaments also positively influenced tensile strength at bending. By adding the fibres, the consistency of the fresh mortar deteriorates, and the bulk density of fresh and hardened mortars decreases, resulting in less compressive strength.

1. Introductions

In the design and manufacture of fibre-reinforced concrete, it is necessary not only to select the appropriate type of fibre and its corresponding quantity (to achieve the desired properties of the concrete), but also to adequately handle the production technology. Fibres with high flexural stiffness and characteristic needle-shaped geometric shape are fundamentally different from other components of fresh concrete and are difficult to mix in fibre concrete production.

Various fibres can be added to the concrete: steel, glass, basalt, polypropylene, carbon, organic and so on. Selected mechanical properties of fibres and cement matrix are shown in table 1. This wide range of fibres can be divided into two groups, depending what goal is being followed by adding fibres [1, 2].

If only the aim is to avoid the emergence and development of the number of shrinkages micro cracks at the initial stage of hydration, fibres of high fineness and relatively low Young modulus are used. However, it must be higher than the Young modulus of the solidified cement matrix. The cement matrix in this case is very uniformly reinforced with a large amount of fibres. The addition of such fibres does not substantially affect the physical and mechanical properties of the hardened concrete. The most widely used fibres of this type are some polypropylene and glass fibres.

In the latter case, the addition of fibre reinforcement to the concrete significantly affects some of its otherwise unfavourable properties in the hardened state. In general, increases the cross-tensile strength of the concrete, its toughness and impact resistance, ductility, resistance to temperature changes. Concrete has an increased energy absorption capacity and is more resistant to fatigue. The
accompanying phenomenon of the presence of structural fibres in the concrete is the reduction of the volume changes caused by the shrinkage of the concrete. It is mainly a secondary reinforcement, not a main bearing reinforcement [3, 4].

Table 1. Mechanical properties of fibres and cement matrix [1, 2].

| Fibre        | Diameter (μm) | Density (kg/m³) | Young modulus (GPa) | Tensile strength (MPa) | Elongation at break (%) |
|--------------|---------------|-----------------|--------------------|------------------------|-------------------------|
| Steel        | 5 - 500       | 7 850           | 210                | 500 – 2 000            | 0.5 - 3.5               |
| Glass        | 9 - 15        | 2 600           | 70 - 80            | 2 000 – 4 000          | 2 - 3.5                 |
| Carbon       | 7 - 10        | 1 900           | 230 - 240          | 2 600 – 4 000          | 1.4 - 1.8               |
| Polypropylene| 20 - 200      | 900             | 5 - 77             | 500 - 750              | 8                       |
| Flax         | 5 - 38        | 1 500           | 27.6               | 345 - 1035             | 2.7 - 3.2               |
| Jute         | 10 - 25       | 1 300           | 26.5               | 393 - 773              | 1.5 - 1.8               |
| Cotton       | 12 - 13       | 1 500           | 5.5 - 12.6         | 287 - 597              | 7 - 8                   |
| Aramid (Kevlar)| 10          | 1 450           | 65 - 133           | 3 600                  | 2.1 - 4                 |
| Cement matrix| -             | 2 500           | 10 - 45            | 3 - 10                 | 0.02                    |

Shrinkage is one of the negative properties of cement composites that arise due to volume changes due to physical and chemical processes occurring in the cement paste. These processes may result in cracks or other deformations. Surface cracks are most often caused by plastic shrinking by intense evaporation of water from the surface of fresh concrete. These occur most frequently on large areas of concrete (slabs, walls, sidewalks). Disruption of the surface entirety reduces the durability of the concrete structure. Negative effect is increased with increasing wind speed, reducing the relative humidity and with rising the temperature of environment, etc. [5 – 7].

Composition of cement composites significantly affects not only the drying shrinkage, as well as autogenous shrinkage. Shrinkage of cement composites increase with higher water to cement ratio, higher water and fine particles content, fineness of filler granularity and a greater proportion of binder sealant. Composition of concrete (composite) also has an impact on the type of shrinkage that occurs in concrete. Drying shrinkage is a substantial part of the regular concrete with higher water to cement ratio (above ca. 0.4). In the case of concrete with a low water to cement ratio increases the importance of autogenous shrinkage, which can form a dominant part of the total shrinkage [8]. In practical tests is a problem to differentiate these two types of shrinkage. Measured values generally represent the total shrinkage of concrete at a certain time interval.

Shrinkage of concrete can be a problem especially in the case of concrete with high water to cement ratio and finer filler such as self-leveling cement screeds. In these composites, the water to cement ratio is relatively high even with the use of quality super plasticizer agents. The basic technological measure to reduce the shrinkage is to treat the fresh concrete. In some cases, however, the correct treatment of concrete or the reduction of the water to cement ratio by use of the additives, does not necessary guarantee the prevention of cracking [9].

The future of fibre reinforced concrete is in their common application in structures together with the classic reinforced concrete. Not every type of fibre reinforced concrete is suitable for this purpose because different types of fibres affect the physical and mechanical properties of the resulting concrete. Only fibre-reinforced concrete can be considered, in which cracks are produced more evenly than in the case of a classically reinforced fibre-free element. Moreover, even after cracking, they exhibit a certain value of stagnant residual strength (so-called residual or averaged equivalent strength). At present, this is achieved by steel fibre reinforced concrete, fibre reinforced with structural Synthetic Fibre (SSF) or Alkali Resistant Glass Fibres (ARGF) [1].

Due to climate changes, volumetric changes, repeated shrinkage and cracks occur in cement-concrete pavements. Polymer or glass fibre may also be used to eliminate these changes in the
concrete slabs, e.g. polymer-fibres reinforced concrete (PFRC), glass-fibres reinforced concrete (GRC). Polymer fibres have their advantage mainly in terms of corrosion and related economic costs. Commonly used are either polyester or polypropylene fibres. They can eliminate cracks in both transverse and longitudinal directions, important factors are the dimensions of the slab and placing of the joints [10].

2. Materials and methods

Samples were made of cement CEM II/A-S 42.5 R and potable mains water by a standard manner according to EN 196-1 [11]. As additives were used alkali-resistant glass fibres (ARGF) Cem-FIL AntiCrak HP 12mm long and polymer fibres (PF) BeneSteel 55 (shortened to 12mm) at 1wt.%, 3wt.% and 5wt.%. Sand of fraction 0/1mm with constant dosage was used as the filler. Based on the consistency tests of cement mortars with different amounts of water and the indicated fibre doses, a uniform water to cement ratio – 0.65 was chosen (Table 2).

![Figure 1. Glass contacts in the fronts of moulds and Graff-Kaufmann device.](image)

The samples were determined by the following properties: shrinkage and weight change, consistency, bulk density fresh and hardened mortar, compressive and flexural strength. Measurement of shrinkage of the samples was tested at 1, 2, 5, 7, 14, 21, 28, 56 and 91 days in Graff-Kaufmann device (Figure 1). Compressive and flexural strength were tested at 7, 28 and 91 days. Flexural strength (sometimes called the modulus of rupture) is a measure of tensile strength in bending. Tests were performed on 40x40x160mm samples. To the monitoring shrinkage and weight change was used glass contacts situated in the fronts of the moulds (Figure 1). These samples were stored in a laboratory environment, others were stored in water.
3. Results and discussion

3.1. Consistency and bulk density fresh cement mortars

The composition and the measured values of the bulk density of fresh cement mortars and of the consistency by flow table test are given in table 2.

| Mixture | Fibres (%) | w/c ratio | Cement (g) | Sand (g) | Bulk density fresh mortar (kg.m⁻³) | Flow table test (mm) |
|---------|------------|-----------|------------|----------|-----------------------------------|---------------------|
| Matrix  | none       | 0.65      | 450        | 1 350    | 2 007                             | 154.0               |
| ARGF1   | 1          |           |            |          | 1 975                             | 156.5               |
| ARGF3   | 3          | ARGF      | 450        | 1 350    | 1 970                             | 130.5               |
| ARGF5   | 5          | 0.65      | 450        | 1 350    | 1 963                             | 127.0               |
| PF1     | 1          |           |            |          | 1 969                             | 153.5               |
| PF3     | 3          | BeneSteel |            |          | 1 965                             | 152.0               |
| PF5     | 5          |           |            |          | 1 958                             | 135.0               |

The bulk density decreased with an increasing dose of fibres (Table 2). The type of fibres did not have a more significant effect. The effect of the fibre dose was also demonstrated by a consistency test. Decreasing flow diameter was caused by the increasing amount of fibres. The polymer fibres reduced the flow diameter less than the glass fibres.

3.2. Shrinkage

The course of shrinkage on hardened cement composites is shown in figure 2. In this figure can be seen, that the main shrinkage occurred within 28 days then the process was milder. The largest shrinkage was recorded on the non-fibre reference sample during the whole shrinkage monitoring period. In the first days of the measurement, the lowest shrinkage was observed using glass and polymer fibres at a dose of 5wt.%, the polymer fibres being better than glass fibres.

![Figure 2](image-url) 

**Figure 2.** Influence of different types and dose of fibres on the shrinkage of cement mortars.
The change of weight loss of hardened cement composites with using a glass fibres did not significantly changed in the first days of measurement compared to a cement matrix sample. Using polymer fibres caused immediately to a higher loss of weight compared to a cement matrix sample on the first days of measurement. Over time, all samples were almost equal. Overall, samples using polymer fibres had a higher weight loss than samples with glass fibres.

3.3. Bulk density, compressive strength and flexural strength

The measured values of the bulk density of hardened cement mortars and of the compressive and flexural strength are given in table 3.

Table 3. The properties of hardened cement mortars.

| Age | Mixture | Bulk density (kg.m⁻³) | Compressive strength (MPa) | Flexural strength (MPa) |
|-----|---------|-----------------------|----------------------------|------------------------|
| 7   | Matrix  | 2 160                 | 31.0                       | 5.4                    |
|     | ARGF1   | 2 145                 | 26.6                       | 5.5                    |
|     | ARGF3   | 2 100                 | 25.4                       | 5.8                    |
|     | ARGF5   | 2 062                 | 22.6                       | 6.9                    |
|     | PF1     | 2 096                 | 22.8                       | 5.1                    |
|     | PF3     | 2 082                 | 22.5                       | 5.3                    |
|     | PF5     | 2 047                 | 22.7                       | 5.3                    |
| 28  | Matrix  | 2 173                 | 43.0                       | 6.2                    |
|     | ARGF1   | 2 140                 | 36.3                       | 6.6                    |
|     | ARGF3   | 2 114                 | 35.2                       | 6.7                    |
|     | ARGF5   | 2 066                 | 34.6                       | 7.4                    |
|     | PF1     | 2 127                 | 34.3                       | 6.2                    |
|     | PF3     | 2 086                 | 32.8                       | 6.2                    |
|     | PF5     | 2 062                 | 31.2                       | 6.1                    |
| 90  | Matrix  | 2 190                 | 43.3                       | 6.6                    |
|     | ARGF1   | 2 142                 | 43.7                       | 6.9                    |
|     | ARGF3   | 2 125                 | 43.2                       | 6.9                    |
|     | ARGF5   | 2 084                 | 42.8                       | 7.5                    |
|     | PF1     | 2 156                 | 45.4                       | 6.8                    |
|     | PF3     | 2 122                 | 43.2                       | 6.9                    |
|     | PF5     | 2 095                 | 42.2                       | 6.9                    |

The bulk density of hardened cement composites gradually increased with the time of sample storage. The growth is due to the continued hydration of the cement and the thickening of the structure resulting from the hydration products. The highest bulk density value was achieved on sample without the addition of fibres. The bulk densities of samples of the both types of admixtures decreased with increasing dose of fibres. This means, that the lowest values of the bulk densities reached samples with the addition of glass and polymer fibres at the dose of 5wt.%. The difference between glass and polymer fibres was not significant.

The fibre dose was showed on the bulk weight of hardened cement mortars. The highest value had the reference sample without a fibre dose throughout the measurement period. The bulk density has increased, which is related to the compaction of the structure by the hydration products. The bulk
density dropped with an increasing dose of fibres, with more pronounced drops in glass fibres. By replacing a portion of the cement with fibres it results in less hydration products and thus a lower bulk density.

This is also the result of compression strength (Figure 3). From the beginning, the cement matrix sample reached higher strength values. After 90 days the results were reached, even the 1% dose reached the higher values in both cases of the fibres used. The most add-on of the fibre dose was shown in the flexural tensile measurement (Figure 4). The higher dose of glass fibres reached a higher increase in strength after 7 days than the other samples. It is more than 28% compared with the cement matrix. This trend was retained even after long-term measurements, but the difference was not so significant (decrease to 14%).

Figure 3. Influence of different types and dose of fibres on the compressive strength of cement mortars.

Figure 4. Influence of different types and dose of fibres on the flexural strength of cement mortars.
4. Conclusion

Based on the achieved results can be concluded that the addition of fibres has a positive influence on the shrinkage of hardened cement composites, especially on the first days of measurement. The increasing dose of fibres resulted in lower shrinkage. Polymer fibres had a more positive effect. Also, during the weight loss measuring, the polymer fibres had a greater impact on the weight loss than glass fibres. The higher dose of fibres led to the increasing weight change of mortars.

Addition of fibres resulted in decreasing values of the bulk densities of fresh and hardened cement mortars. Also, the fibres thicken the consistency and thus reduce the flow diameter. The tensile strength at bending (flexural strength) was the most significant using glass fibre at dose 5wt.%. The results of these mechanical properties were better by a quarter than at the other samples. The fibre dose had on first a negative impact on strength measurements, but after a long-term measurement the differences were lost.

It can be concluded that by adding fibres, shrinkage of hardened cement composites is avoided, especially with the use of polymeric fibres. However, their addition is at the expense of worse consistency and lower compressive strength in the first weeks of hardening of cement composites.

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