Cotton knitted fabric waste as reinforcement in cement screed

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Abstract:
Cement screed consists of cement, sharp sand and water, laid as a thin layer over the concrete subfloor. Although the screed is strong, it can be additionally reinforced with fibres, most often polypropylene fibres. In this study, cotton knitted fabric waste (CKFW) was obtained from a local factory producing underwear to reinforce the cement screed. A total of eight mixtures were made: reference mixture, screed reinforced with polypropylene fibres and six mixtures reinforced with CKFW. CKFW was added in 1,25 %, 2,50 % and 5,00 % of the total volume. Before adding to the mixtures, the first CKFW group was saturated with tap water, whereas, the second CKFW group was saturated with dispersion that improves adhesion. The density and air content of the fresh mixtures were tested, and the compressive strength and flexural strength were determined when the specimens were 28 days old. The specific fracture energy is determined based on the curve from the plot of load vs. displacement. The CKFW increases the ductility of cement screeds, although it has no significant effect on the compressive and flexural strength of the specimens. The CKFW that was saturated with tap water achieved better results.

Keywords:
cement screed; cotton knitted fabric waste; compressive and flexural strength; specific fracture energy

1 Introduction

Cement-based screeds are widely used in the construction industry and are among the most traditional flooring materials. According to the BS 8204-1:2003 and BS EN 13318 standards, screed can be defined as levelling screed, wearing screed, bonded, unbounded, floating screed, or self-smoothing screed [1]. Cement-based screeds are typically produced from fine aggregates, Portland cement, water, minerals, and chemical admixtures. Moreover, the screed can be reinforced by adding polypropylene fibres, increasing the tensile strength and minimising shrinkage cracking. Hwalla et al. [2] replaced Portland cement with geopolymeric binders, resulting in higher early strengths than cement mixtures. Canbaz et al. [3] tested self-levelling screens using a new-generation superplasticiser. The authors used several sand types and different additive amounts and concluded that screed mixtures with 1,0 % superplasticiser and 0-1 mm river sand as aggregates yielded good results. Georgin et al. [4] also tested a self-levelling screed with calcium sulfoaluminate cement and found that curling is 3,5 times lower than an ordinary Portland cement screed. Miranda et al. [5] tested screed mortar with recycled sand and recommended composition for screed mortar. According to [4], mortar is made of 250 kg/m^3 to 350 kg/m^3 of cement, and the share of material finer than 75 μm must be lower than 28%. Yoosuk et al. [6] studied geopolymer mortars by adding 0,0 %; 0,5 %; 1,0 %; 1,5 %; 2,0 %; 2,5 %, and 3,0 % of polypropylene fibres by weight. The maximum flexural strength was obtained for the specimen with 2,5 % polypropylene fibre.

The textile industry is among the largest industries in the world in terms of both production output and employment opportunities. However, textile manufacturing and processing produce numerous waste streams, such as liquid, gaseous, and solid wastes, some of which are potentially hazardous. The production process of garments, particularly the cut and sew waste phases, has a significant effect on the occurrence of pre-consumer waste [7]. Apparel cutting process results in cut-and-sew waste, which varies from 10 % to 15 % [8], and in some cases, up to 20-25 % of the total quantity of materials used for production [9].

One strategy that can be implemented to alleviate waste accumulation is waste minimisation through the reuse of production waste before energy recovery, treatment, or disposal [10]. This approach uses an open-loop recycling method known as industrial metabolism [11]. There is an increasing interest in exploring building materials made from textile byproducts, as evidenced by a growing number of studies [12-15].

Specific literature discusses using textile waste cutoffs similar to cotton knitted fabric waste (CKFW) in concrete [16-18]. This type of textile is a byproduct, and because of its fragmented form, knit pattern, and material composition, it cannot be considered for use in the manufacture of true textile-reinforced concrete, where synthetic noncrimp textiles are predominantly used [19]. Textile cuttings can be regarded as neither an aggregate nor a reinforcement, although they increase the volume and tensile strength of the mixtures [16].

Qin et al. noted that concrete with nylon waste fabric cuttings performed better in compressive strength than concrete with waste nylon fibres or concrete without any reinforcement [20, 21]. Leading to the idea that it might be redundant to shred the fabric to the level of fibre to achieve improvements in concrete. The same conclusion was drawn by Jayasinghe et al. [22] while experimenting with cement block mortars. Fabric waste (1,0 × 2,5 cm) exhibited a somewhat poorer compressive but significantly better flexural performance than the same but additionally grounded waste. It must be noted that in this case, textile waste was used in a significantly high amount of 25 % of aggregate sand replacement and that, ultimately, waste specimens fared worse than the reference sample without any waste. In line with energy conservation and the aforementioned research [20-22], textile waste was not reduced to the fibre level.

Selvaraj and Priyanka [17] studied the effects of textile cuttings collected from tailoring shops on conventional concrete made of Portland cement. Although the compressive strength was reduced, it improved the splitting and flexural tensile strength, which can be attributed to the reinforcing effect of the cloth in the concrete. Flexural strength increased up to the highest amount of cloth addition, which was 5 % by the weight of cement. Splitting strength was highest for the 1 % cloth sample and decreased with cloth quantity increase up to the point where the

5 % cloth specimen was worse than the reference mix. In addition, the impact energy absorption increased significantly with an increase in cloth quantity. Samples with 5 % cloth cuttings by the weight of cement achieved more than twice the impact strength of the reference mixture [17].

Manishankar and Sathiyaraj [18] conducted experiments on concrete with textile waste cuttings incorporated at various textile-to-cement weight ratios. They found that including textile waste generally improved the strength of concrete. Specifically, concrete samples containing up to 3 % textile waste exhibited greater flexural and split tensile strengths than the control samples, whereas the 4 % textile waste addition reduced the strength.

In addition to textile cuttings and waste applications in concrete, one of the investigation directions is using textile waste in cement mortar, in which a smaller aggregate fraction is used. Specifically, there is a growing interest in the textile fibre reinforcement of cement mortars for plastering [23, 24], especially for plasters with increased thermal performance [25, 26]. In terms of mechanical properties, the most common case is that waste textile fibres reduce the compressive strength of cementitious mortar while improving its flexural strength [25, 26]. However, the performance of fibres significantly depends on their composition, type, length, and recycling treatment, particularly in the case of recycled fibres, for which consistency can be a problem. Thus, there are studies in which both the compressive and flexural strengths are reduced [23]. However, post crack properties, such as ductility, residual strength, and toughness, are improved [23, 27].

Kalkan and Gündüz [28] achieved an increase in compressive and splitting strengths of lightweight pumice and perlite mortar with an amount of 1 % of fibres by the total weight of the mix. However, with higher amounts of textile fibres, the strength decreased. Furthermore, they noted that cotton fibres bonded better with mortar than synthetic fibres because of their rough surfaces [28]. Gunathilaka et al. [29] observed a significant decrease in the compressive strength of mortar specimens composed of river sand aggregates. In addition, they noted that samples made with cotton fibres performed significantly better than those made with polyester fibres. Juradin et al. [30] reinforced pervious concrete with waste cloth strips and improved the ductility and mechanical properties of the tested concrete by adding fine fractions.

Furthermore, when producing clothing from cotton, the fibre quality is evaluated and blended to achieve uniformity and reduce variations in the fibre properties. This process addresses the problem of variability in the mechanical properties of natural fibres to some extent. Moreover, processed and homogenised textile waste (cuttings, carded fibre, yarn, and other types of waste) from industrial cloth-making processes are conserved in treating virgin fibres.

According to the literature [31-33], the research focus of textile waste in cuttings is on its application in cement-based composites. In contrast, mortar textile waste is most commonly used in the form of fibres or short yarns. Therefore, the goal of this research is to explore the reinforcement effect of textile waste on cement-based screeds and examine the influence of the textile pre-soaking solution on the behaviour of the reinforced composite.

2 Methodology

2.1 Materials and specimen preparation - testing in fresh state

A commercial ready-mix screed was used in this study. According to the Technical sheet [34], the classification of screed is, according to EN 13813, CT- C20 - F4, which means that its flexural strength after 28 d is higher than 4 N/mm2 and its compressive strength is higher than 20 N/mm2. The screed is composed of cement, sand, and additives. The maximum grain size is 4 mm, and the particle size distribution of the dry mixture is shown in Figure 1. The polypropylene fibres used in this study have a length of 12 mm, and a polypropylene fibre with a volumetric fraction of 0,4 % was used to prepare the PP mixture. The textile reinforcement comprises cotton waste obtained from a local underwear factory. Textile waste is made entirely from natural cotton fibre yarn and comprises two fabric types: single jersey and fine ribs. The main characteristics of the ready-mix cement screed, PP fibres, and fabrics are listed in Table 1.

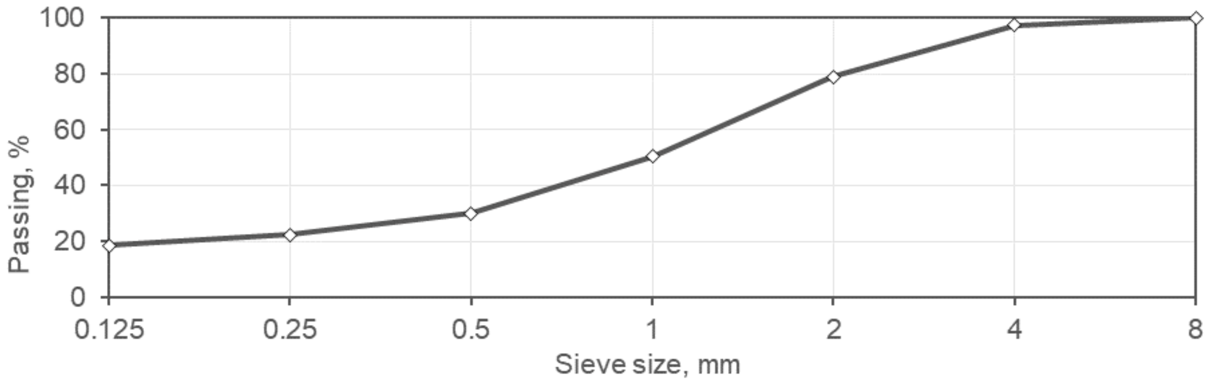
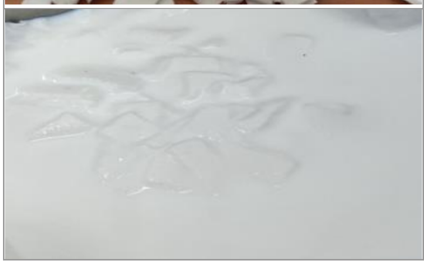
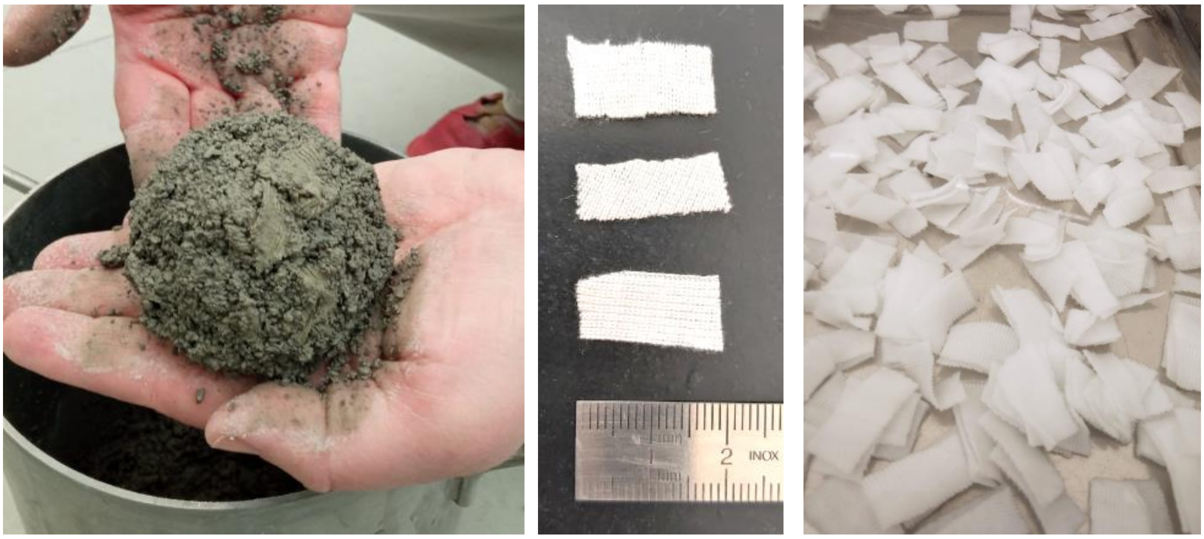


Figure 1. Particle-size distribution of dry ready-mix screed

Table 1. Material properties

<table>
<tr><th>Material</th><th colspan="3">Material properties</th></tr>
<tr><td></td><td colspan="3">Ready-mix screed:
Flexural strength after 28 days: > 4 N/mm²
Compressive strength after 28 days: > 20 N/mm²
Dry specific density: approx. 2100 - 2200 kg/m³</td></tr>
<tr><td></td><td colspan="3">Polypropylene fibers:
Fiber length: 12 mm
Density: 900 kg/m³
Colour: white</td></tr>
<tr><td rowspan="4"></td><td colspan="3">Cotton knitted fabric waste:</td></tr>
<tr><td></td><td>Single Jersey</td><td>Fine Rib</td></tr>
<tr><td>Fineness of yarn (tex; Nm, Ne)</td><td>20 tex × 1; Nm 50/1; Ne 30/1</td><td>20 tex × 1; Nm 50/1</td></tr>
<tr><td>Mass per unit area, dry (kg/m²):
Loop density per 10 cm (wale/course direction)</td><td>0,154
150/214</td><td>0,180
120/180</td></tr>
<tr><td></td><td colspan="3">Aqueous dispersion of polymer binders and additives:
Aggregate state: liquid
Color: white
Relative density (at 20°C): 0,990 – 0,993
pH: 6,0 - 7,0</td></tr>
</table>

According to the instructions for screeds, the recommended amount of water is approximately 1-2 L per 25 kg bag. The final amount of water was determined such that the “snowball” could be made from a wet screed mix, and the consistency was adequate if the formed ball held together, Figure 2a.



a) b) c)

Figure 2. a) Screed snowball test; b) Pieces of cotton knitted fabric waste (CKFW); c) CKFW saturation in tap water

Eight mixtures were prepared: an unreinforced reference mixture (RM), one with polypropylene fibres, and six mixtures reinforced with CKFW. In addition, the CKFW was manually cut into approximately two 0,5-1,0 cm pieces (Figure 2b) and placed first in a saturated state and subsequently a surface-dry state before adding to the mixture. The first CKFW group was saturated with tap water (Figure 2c), whereas the second CKFW group was saturated with an aqueous dispersion of polymer binders and additives that improve adhesion (Table 1). The CKFW specimens saturated with this dispersion were labelled as SN. The CKFW amounts for the mixtures were 1,25; 2,50; and 5,00 % of the total volume. The label of the mixture indicates the proportion of the textiles.

Table 2. Labels and composition of the mixtures

Mixture	Constituent			
	Ready-mix screed (g)	Water (g)	PP (g)	CKFW (g)
RM	1980	167,2	-	-
PP	1980	169,8	3,84	-
CKFW 1,25	1980	167,2	-	3,08
CKFW 1,25 SN	1980	165,0	-	3,08
CKFW 2,50	1980	167,2	-	6,16
CKFW 2,50 SN	1980	162,8	-	6,16
CKFW 5,00	1980	167,2	-	12,33
CKFW 5,00 SN	1980	162,8	-	12,33

2.2 Preparation of specimens - testing of fresh and hardened specimens

All components were mixed using an electric handheld mortar mixer until complete homogenisation was achieved, as determined visually. The air content of the fresh mixtures was determined according to HRN EN 1015-7:2000 [35], and the density in the fresh state was determined according to HRN EN 1015-6:2000/A1:2008 [36]. After measuring the density and air content, the spatial volume of the mixture was changed, and a new specimen was made for each mixture, which was placed in a standard three-gauge mould of 40 × 40 × 160 mm.

The specimens were de-moulded after 24 h and placed in water at 20 ± 2 °C for 27 days. The compressive and flexural strengths of the mortar specimens after 28 d of curing were tested according to HRN EN 1015-11:2019 [37]. Moreover, the density of the hardened mortar was determined by EN 1015-10:2001 [38].
The flexural tensile strength on 40 × 40 × 160 mm unreinforced reference specimens (RM) and the compressive strength of the prism halves of all specimens were determined according to EN 196-1:2016. A 300 kN load capacity hydraulic device was used for the flexural tensile strength test of the specimens. The load was applied at the mid-span. An LVDT device mm was installed for the displacement measurement, as shown in Figure 3. The device has a maximum measuring offset of 10 mm and a nominal sensitivity of 165 mV/mm. To obtain the declining section of the force-displacement curve, loading was continued after the first crack in the specimens. After the flexural tensile test, the compressive strength was tested using the six prism halves.

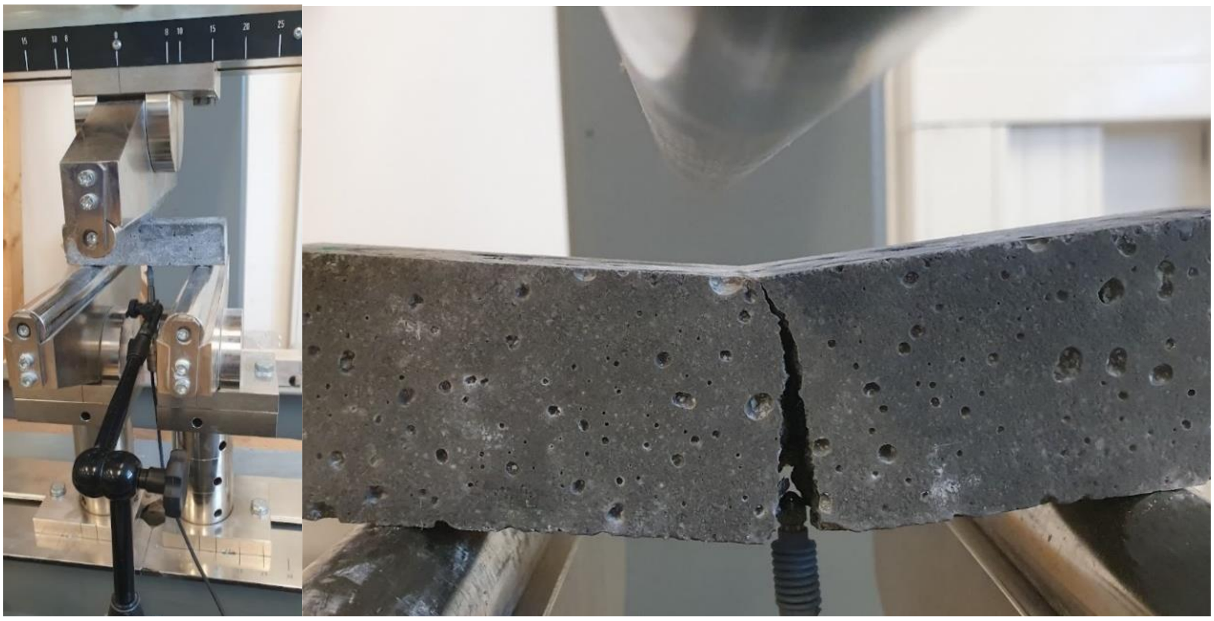


Figure 3. Experimental set-up

3 Results and discussion

The results of the fresh- and hardened-state tests are presented in Table 3. For the hardened state, the average values and standard deviations of the measured results are provided.

Table 3. Test results

Mixture	Fresh state		Hardened state		
	Density (g/cm³)	**Air content** (%)	**Density** g/cm³	**Compressive strength** (MPa)	**Flexural strength** (MPa)
RM	1,93	8,5	2,44 ± 0,01	35,86 ± 0,93	7,96 ± 0,11
PP	2,00	8,4	2,25 ± 0,13	26,88 ± 1,73	5,84 ± 0,29
CKFW 1,25	1,99	8,2	2,41 ± 0,02	33,00 ± 2,48	6,17 ± 0,34
CKFW 1,25 SN	2,08	10,6	2,35 ± 0,02	24,80 ± 2,50	5,71 ± 0,40
CKFW 2,50	2,00	6,4	2,44 ± 0,01	37,90 ± 2,32	7,10 ± 0,41
CKFW 2,50 SN	2,02	10,1	2,37 ± 0,00	25,08 ± 2,08	5,24 ± 0,74
CKFW 5,00	2,11	6,4	2,40 ± 0,01	27,52 ± 1,26	5,75 ± 0,11
CKFW 5,00 SN	1,95	8,6	2,36 ± 0,02	22,75 ± 3,03	5,59 ± 0,14

According to Table 3, the density in the fresh state was in the range of 1,93-2,08 g/cm^3, whereas the density in the hardened state was in the range of 2,35-2,44 g/cm^3 and air content was in the range of 6,4-10,6 %. The effects of reinforcement on the density in the fresh and hardened states and the air content were evaluated by the ratio of these properties of all mixtures and the reference mixture (RM), as shown in Figure 4.

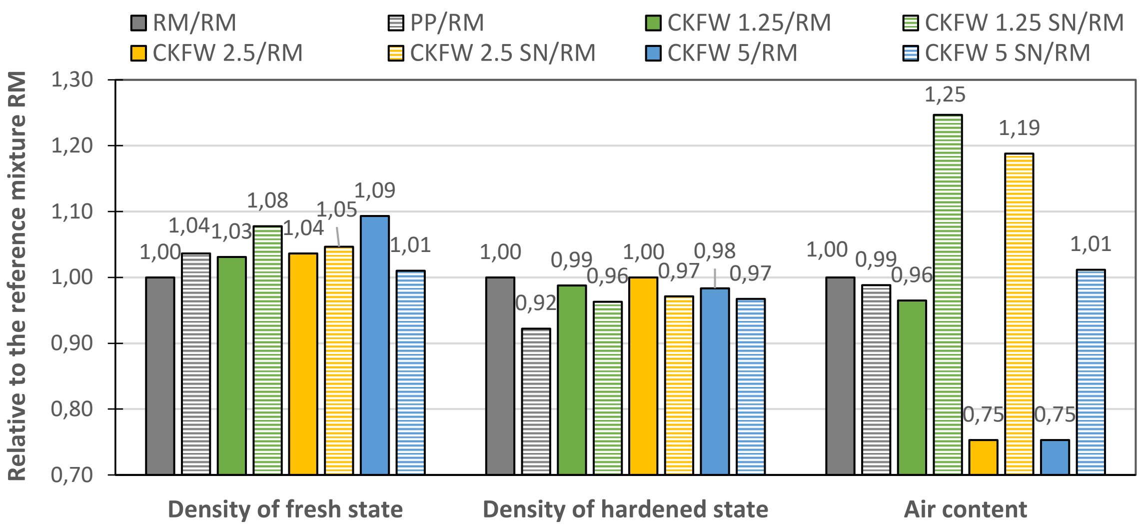


Figure 4. Densities in fresh and hardened states and air content of screeds relative to the reference mixture RM

According to Figure 4, the inclusion of reinforcement in cement screed causes an increase in density from 1-9 % in the fresh state; however, a decreased density in the hardened state was observed from 0-8 %. The reinforcement with PP fibres caused the highest reduction in density in the hardened state; however, it can be noticed that the addition of both CKFW groups did not significantly change the density of the hardened cement screed because the reduction did not exceed 4,0 %. In contrast, the addition of the textile pieces affected the air content. In fresh specimens reinforced with CKFW that were saturated with water, a lower air content was measured by 4-25 % compared to RM, whereas in specimens with CKFW saturated with an aqueous dispersion of polymer binders, an increased air content was measured by 1-25 %. According to technical specifications, the aqueous dispersion of polymer binders and additives penetrates deeply into the porous structures of building materials. It creates bonds between the old and new concrete, plaster, and other building materials. However, this additive behaves differently in a fresh screed mixture; in this case, it causes an increase in the amount of entrained air. The PP specimens exhibited almost the same air content as the screed reference cement.

All compressive and flexural strength values were higher than the limiting strengths of 20 N/mm^2 and 4 N/mm^2, respectively, and were in the range of 22,75-35,80 N/mm^2 for compressive strength and 5,24-7,96 N/mm^2 for flexural strength. Figure 5 shows the compressive and flexural strengths relative to the reference cement screed. The PP fibres and CKFW incorporation in the cement screed caused a decrease in the compressive strength from 8-37 %, except for the CKFW 2,50 mixture. This mixture exhibited a higher compressive strength at 6 % about RM. The authors also observed the reduction in the mechanical characteristics by adding fibres in [39]. Khedari et al. [40] believed that the decrease in strength was caused by the lower density of the fibre-reinforced specimens since fibre addition induces more voids [41]. Sadrolodabaee et al. [42] observed similar results and added that the voids lighten and weaken the material. The results presented in Figure 5 show that reinforcing the cement screed decreased the specimens' flexural strength by the order of 11-34 % compared to RM. The CKFW 2,50 mixture achieved the lowest reduction. In contrast to these results, Bartulović et al. [31] found that CKFW in concretes without additional silica fume improved flexural strength compared to reference concretes. Compared with the corresponding reference mixture, this increase was 19-25 % for concrete with larger aggregate grains and 26-38 % for fine-grained concrete.

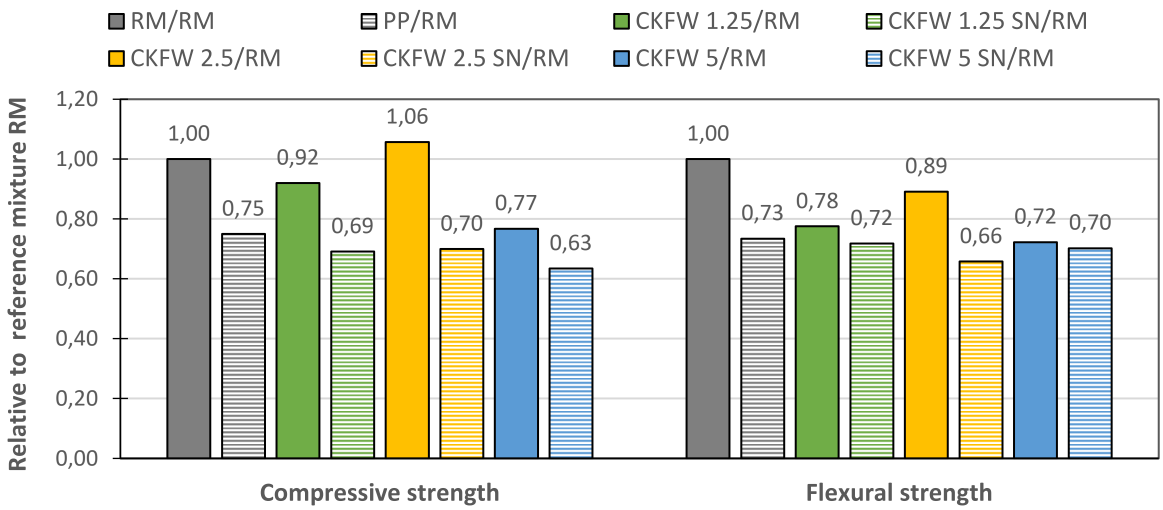


Figure 5. Compressive and flexural strengths relative to the reference mixture RM

Figure 6 shows the influence of the saturation of textile pieces with an aqueous dispersion of polymer binders and additives compared with water-soaked textile reinforcement. The specimens with CKTW soaked in this dispersion have 17-34 % lower compressive strength and 3-26 % lower flexural strength. It was expected that dispersion would increase the adhesion between the cement matrix and the cotton textile but would trap more air in the mixtures (Table 3, Figures 4 and 7) and reduce the mechanical characteristics of the screw. In Figure 7d, a large number of voids are visible in the cross-section of specimen CKFW 1,25 SN, which is in accordance with the results shown in Table 3 and Figure 4.

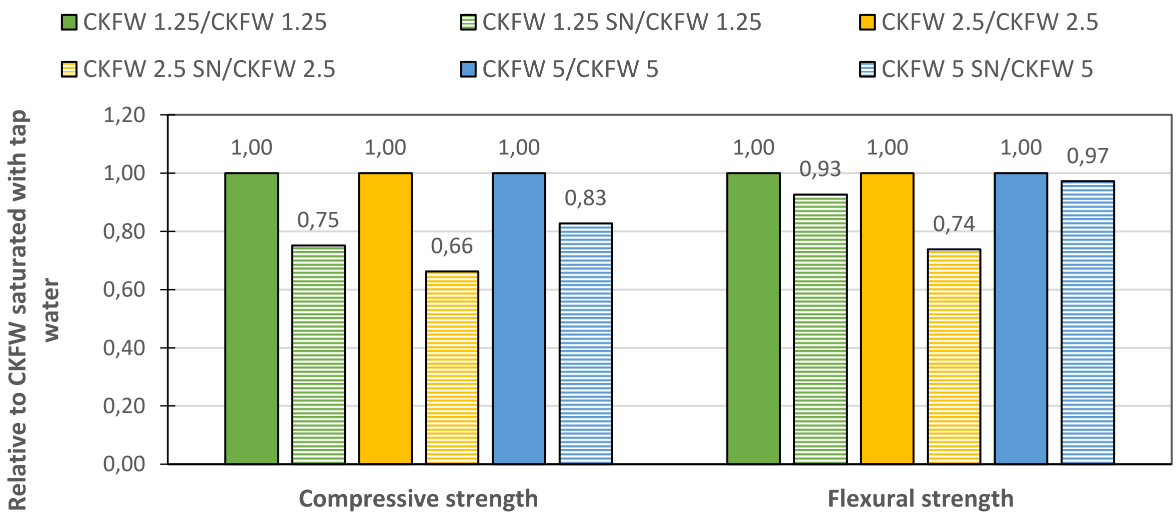


Figure 6. Compressive and flexural strengths of CKFW specimens relative to CKFW saturated with tap water specimens

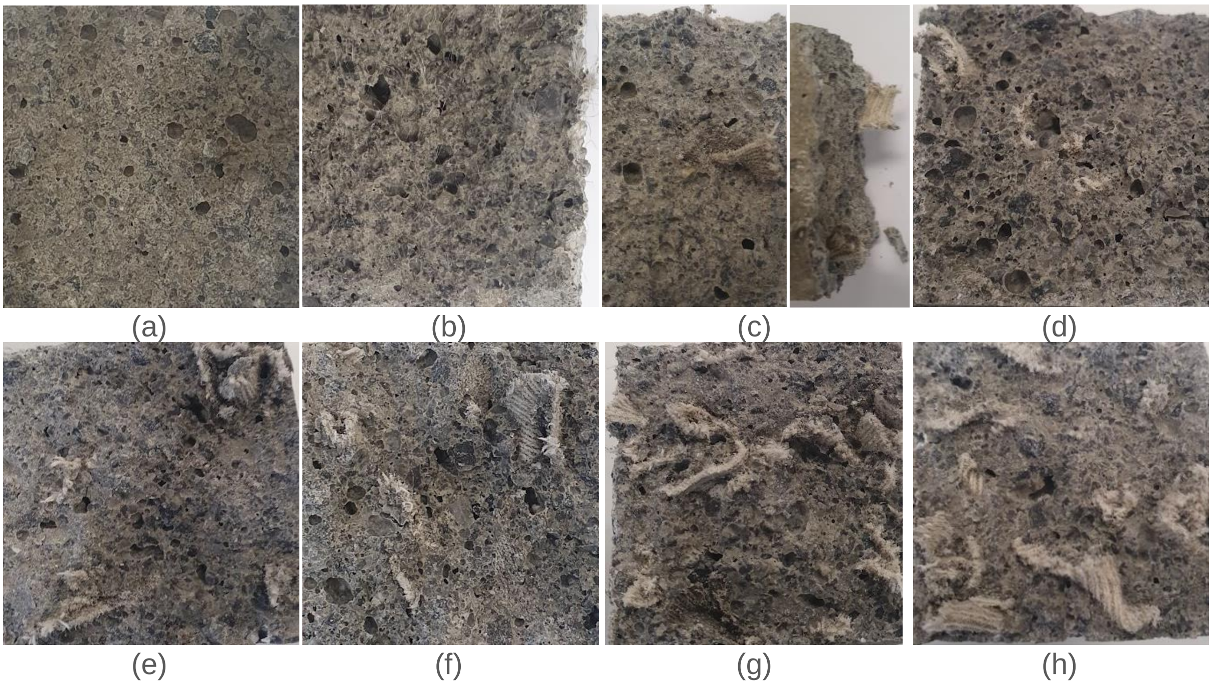


Figure 7. Screed specimens after fracture: a) RM; b) PP; c) CKFW 1,25; d) CKFW 1,25 SN; e) CKFW 2,50; f) CKFW 2,50 SN; g) CKFW 5,00; h) CKFW 5,00 SN

Figure 8 shows the force-displacement graphs of the reinforced specimens compared with those of the unreinforced specimens. According to [43], the post-crack energy absorption ability of a material is defined as its fracture energy. The results showed that reinforcement in the mixtures enhanced the fracture energy of the unreinforced cement screed because the elongation values of all specimens reinforced with PP fibres and CKFW were significantly higher than those of the reference mixture. The specific fracture energies of the specimens were calculated to compare the results obtained for the reinforced and unreinforced specimens. The specific fracture energy of the specimens Gf (N/m) was calculated as the area under the load (N)-displacement diagram (m) up to the point of displacement of 0,002 m (Figure 8) and divided by the fracture area (0,04 × 0,04 m) [44]. The obtained results, which represent the mean values obtained for the three prism specimens, are shown as the relative specific fracture energy in relation to the reference screed in Figure 9 and the relative specific fracture energy of the CKFW samples about the CKFW samples saturated with tap water (Figure 10).

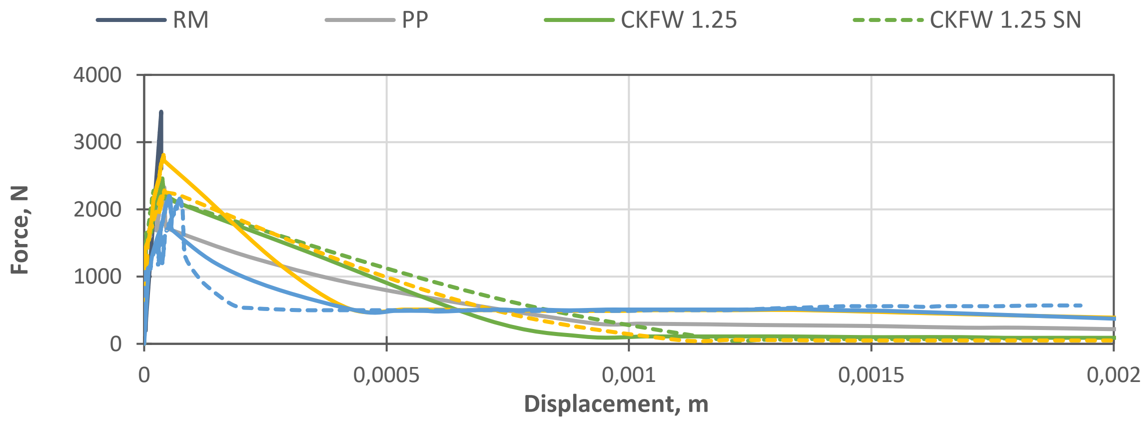


Figure 8. Force–displacement diagram

According to Figure 9, reinforcing cement screed with PP fibres increased the specific fracture energy by 19,79 times. Specimens reinforced with textiles increased the specific fracture energy of plain screed from 17,58 to 22,91 times, depending on textile share and soaking liquid. Optimal results were achieved with the CKFW 2,50 mixture. Xie et al. [45] obtained similar results when examining composites containing bamboo fibres. The authors reported that the fracture toughness of the reinforced specimens improved by 2,7; 14,0; 34,1 and 45,9 times. Juradin et al. [44] compared a reference plain mortar with mortars reinforced with Spanish broom fibres treated with seawater. They found that the specific fracture energy of the reinforced mortars increased by 5,9 to 16,7 times.

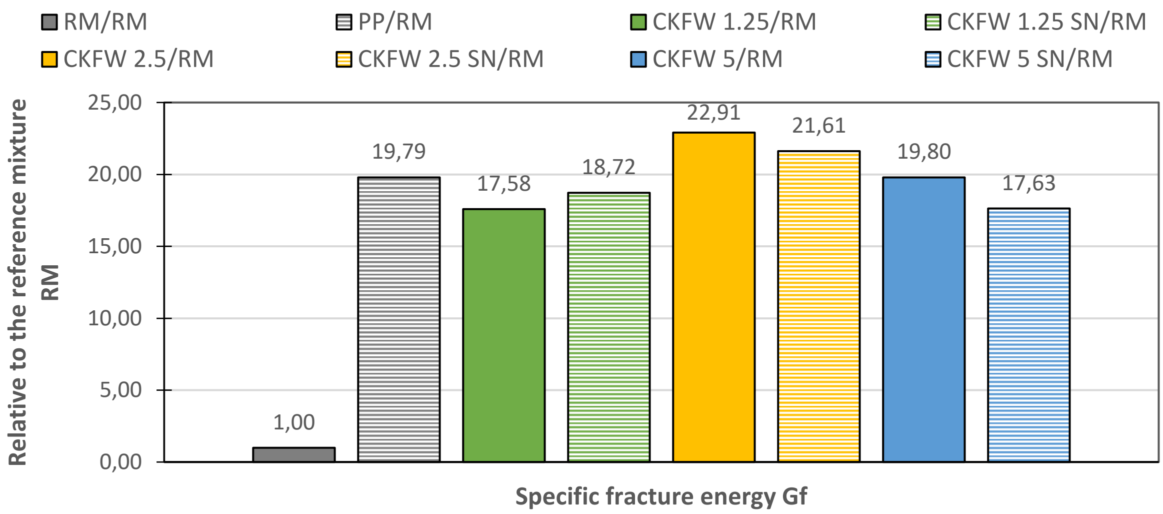


Figure 9. Specific fracture energy G_f relative to reference mixture RM

As shown in Figure 10, the saturation of textile pieces with an aqueous dispersion of polymer binders and additives, compared with water-soaked textile reinforcement, reduced the specific fracture energy, except in the case of the smallest amount of reinforcement. Considering all the obtained test results, it can be concluded that ordinary tap water is a much better medium for soaking textile pieces.

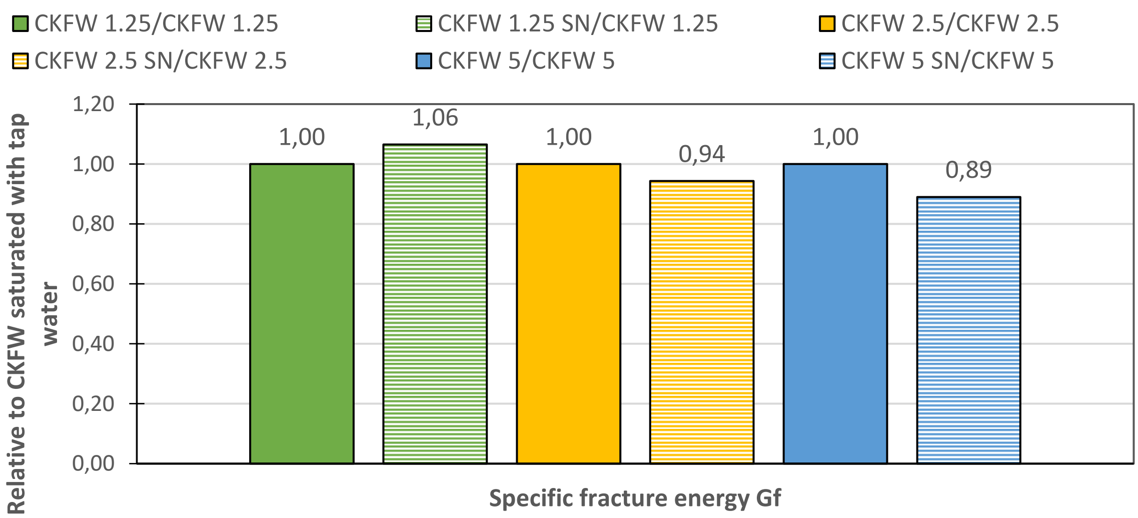


Figure 10. Specific fracture energy Gf of CKFW specimens relative to CKFW saturated with tap water specimens

To cover an area of 100 square meters with a cement screed reinforced with CKFW, as in this research, 3,1-12,5 kg of textile would be consumed, which certainly contributes to reducing this type of waste.

4 Conclusions

All the measured values of the compressive and flexural strengths indicate that incorporating CKFW into cement screed renders it suitable for practical implementation as a flooring element. When utilised as a flooring substructure in interior and dry spaces, weaknesses and defects typically associated with building materials, such as durability and low flexural strength, become almost irrelevant. Although compressive strength may decrease, it remains within acceptable limits compared to the prescribed thresholds. It may only be a constraining factor for high-load specialty areas, such as storage, industrial zones, manufacturing facilities, and similar spaces. The specimen with 2,5 % CKFW achieved higher compressive strength than the control screed. All the specimens reinforced with textiles achieved significantly higher specific fracture energies than the control specimen. It can be concluded that CKFW has no significant influence on the compressive and flexural strengths of the screed specimens; however, it contributes to a significant increase in ductility. Although an aqueous dispersion of polymer binders and additives that improve adhesion was used compared to tap water, it was found to be unfavourable for soaking textile pieces. In future studies, the usability of CKFW in cement screeds should be investigated in terms of abrasion resistance, adhesion strength, setting time, and impact resistance, as mentioned in the EU standard for screeds.

In addition to investigating material properties, it is crucial to consider the technological and architectural aspects of the production and implementation of building elements with CKFW. Two primary technological methods that incorporate CKFW are available for manufacturing cement screed. The first involves the *in- situ* installation of a fresh mixture, whereas the second method entails prefabricating screed boards by casting a fresh mixture into shallow moulds. These prefabricated boards can be transported to construction sites and installed at their final locations. The unique characteristics of this material, particularly when producing slabs in shallow moulds, warrant further investigation into several aspects. First, the thickness of the slabs must be carefully determined by considering factors such as the load requirements, installation methods, and specific locations. In addition, the formats of the rectangular, hexagonal, and complex geometric patterns should be optimised to maximise material potential. The possibility of cutting large-format plates and designing surface structures using relief moulds also requires thorough examination. Moreover, all these potential building elements should be reusable or disposable once the building life cycle ends, aligning with the overarching principles of industrial metabolism and circular economy.

Acknowledgments

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