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Effect of the Shape of Steel Fibers on Drying Shrinkage of Concrete

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Abstract:
This paper presents the experimental results of tests that were conducted to consider the effect of the shape of steel fibers on the drying shrinkage strains of concrete. Three different types of steel fibers differing in their shape (straight, hooked-end and crimped) and aspect ratios (l/d= 45, 65 and 80) were added to the concrete mixes with a volume content of (V_f= 1%). The main objective of this investigation was to clarify how the shape and aspect ratio of steel fibers can restrain the shrinkage strains of the concrete. Small prisms (75×75×200mm) were cast for six different concrete mixes and cured for 28 days, after which they were tested for up to 90 days. In general, the results showed that there were considerable reductions in drying shrinkage strains when the steel fibers were added to the concrete. The addition of crimped steel fibers led to the greatest decrease in shrinkage strain, by 22%, and the straight type recorded the lowest decrease 10%, in comparison with the plain concrete. In terms of the aspect ratio, it was observed that with increased diameters of the steel fibers, which decreased the aspect ratio, the strain caused by drying shrinkage was reduced.

Keywords: Concrete, Steel Fibers, Steel-Fiber-Reinforced Concrete, Drying Shrinkage.

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تأثير شكل الألياف الفولاذية على الانكماش الجاف في الخرسانة

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الملخص
يعرض هذا البحث نتائج معملية لاختبارات قد أجريت لدراسة تأثير شكل الألياف الفولاذية على انفعالات الانكماش الجاف في الخرسانة. تمت إضافة ثلاثة أنواع مختلفة من الألياف الفولاذية تختلف في نوعية شكلها (مستقيمة، معكوفة النهايات، ومجعدة)، حيث تم استخدام أنواع ألياف ذات نسب طول إلى قطر مختلفة بمقاس (l/d= 45, 65, 80) إلى الخلطات الخرسانية بمحتوى حجمي (V_f= 1%) . كان الهدف الرئيسي من هذا البحث هو توضيح كيف يمكن لشكل ونسبة الطول إلى القطر للألياف الفولاذية أن تمنع أو تحد من حدوث الانكماش الجاف للخرسانة. تم صب عينات علي شكل منشورات صغيرة بمقاس (75 × 75 × 200 مم) لستة خلطات خرسانية مختلفة وتمت معالجتها لمدة 28 يومًا، وبعد ذلك تم اختبارها لمدة تصل إلى 90 يومًا. وبشكل عام أظهرت النتائج وجود انخفاض كبير في إنفعالات الانكماش الجاف عند إضافة الألياف الفولاذية إلى الخرسانة. أدت إضافة الألياف الفولاذية المجعدة إلى أكبر انخفاض في قيمة الانكماش الجاف بنسبة 22%، كما

سجل النوع المستقيم أقل انخفاض بنسبة 10% مقارنة بالخرسانة العادية المصنوعة بدون ألياف. فيما يتعلق بتأثير نسبة الطول إلى القطر، لوحظ أنه مع زيادة أقطار ألياف الفولاذ وذلك بانخفاض نسبة الطول إلى القطر، انخفضت قيمة الانفعال الناتج عن الانكماش الجاف في الخرسانة.

الكلمات المفتاحية: خرسانة، ألياف الفولاذ، خرسانة الألياف الفولاذية، الانكماش الجاف.

Introduction

Steel fibers significantly increase the strength of concrete, which makes steel-fiber-reinforced concrete (SFRC) being used in more and more building applications worldwide. However, the effect of this addition of steel fibers on time-dependent deformations of concrete is not fully known and is the focus of many researchers in the field of developing concrete production and behavior.

Free shrinkage of concrete in the presence of steel fibers was investigated by Mangat and Azari [1]. For as long as 520 days, the authors tested various concrete mixtures, mortar, and cement paste in the laboratory. Steel fiber types of hooked-end, crimped, and melt extract were added to concrete mixtures at volume percentages ranging from 1 to 3%. Concrete shrinkage was shown to be reduced by up to 40% when deformed steel fibers were present, and the reduction increased with steel fiber volume. The authors revealed that the shape of steel fibers was important, and deformed fibers having a greater impact than straight and smooth ones. In 1985, the same authors also claimed that steel fibers had a minor effect on the creep of concrete [1].

According to the results of Swamy and Stavrides [2], it can be concluded that adding 1.0% by volume of steel fibers reduced the drying shrinkage of normal and lightweight aggregate concrete by roughly 15-20%. Additional experimental findings by Chern and Young [3] also demonstrated that steel fibers concrete shrank less than typical plain concrete under uniaxial compression load.

Grzybowski and Shah [4] studied the differences in cracking that occurred during shrinkage under restrained conditions of concrete samples that had been reinforced with steel fibers (25mm in length) compared with polypropylene fibers (19mm in length). The steel fiber contents tested were 0.25%, 0.5%, 1% and 1.5%, and those of polypropylene fibers were 0.1%, 0.25%, 0.5% and 1%. The conclusions of this research were that the presence of the steel fibers considerably reduced the widths of cracks that formed during restrained shrinkage and that the restraining effect of the steel fibers was greater than that of the polypropylene fibers.

Tan et al. carried out an experimental investigation of the shrinkage and creep deformations of SFRC in 1994 [5]. Concrete cylinders and prisms with varying steel fiber contents (0%, 0.5%, 1%, 1.5%, and 2%), were cast, prepared, and cured for this study. Compressive creep and drying shrinkage strains were measured. It was determined that both the creep coefficient and shrinkage strains significantly lowered with an increase in the content of steel fibers.

Erena and Mararb [6] investigated the effect of the addition of different volumes and aspect ratios of hooked-end steel fibers on the plastic shrinkage cracking behavior of normal and high-strength concrete. They studied two different compressive strengths, 56 and 73MPa, and found that the presence of steel fibers significantly reduced plastic shrinkage cracking in the concrete. According to their findings, increasing the amount of fibers in concrete resulted in improved control over plastic shrinkage cracking, a decrease in the rate of shrinkage contraction, and a reduction in both the total crack area and the maximum crack width.

In 2016, Sryh and Forth [7] conducted laboratory experiments to investigate the impact of adding steel fibers and recycled aggregate on the drying shrinkage and creep deformations of concrete. The findings demonstrated that the inclusion of 0.5% by volume of steel fibers resulted in decreases in these strains (drying shrinkage, compressive creep, and tensile creep) by 7%, 3%, and 10% correspondingly. The inclusion of 1.0% fiber content resulted in reductions of 15%, 5%, and 20% in deformations, respectively. The records show that the steel fibers had a significant impact on tensile creep and shrinkage, but only a moderate effect on compressive creep.

The study conducted by Yousefieh et al. [8] aims to examine the impact of various fibers on the drying shrinkage and cracking of concrete that occurs when it is restrained. The researchers examined the efficacy of both polymeric and metallic fibers in concrete. Three different types of fibers were used in this study: polypropylene, polyolefin, and steel fibers. The researchers determined that the extent of drying shrinkage was strongly impacted by the fibers' modulus of elasticity, and that the physical characteristics of the fibers directly affected the decrease in cracking widths.

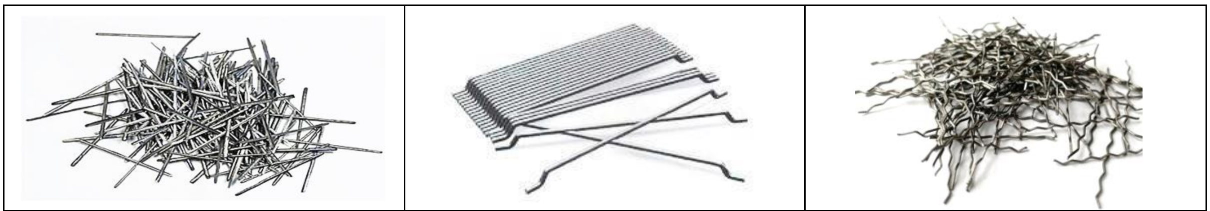
Based on these studies and other published results on this topic [9-16], this study was designed to investigate experimentally the effect of the shapes and aspect ratios of steel fibers on restraining the drying shrinkage of concrete.

Experimental Programme

Six concrete mixes were designed for the experimental programme of this study. Four small prisms (75×75×200mm) of each mix were prepared, cast, cured for 28 days and tested for a period of 90 days. The properties of the materials, mix proportions, sample preparations, curing, and test methods are described in the following sections.

1. Materials and mix proportions:

In this experimental investigation, all the designed samples were cast using the same type of cement, specifically high-strength cement with a grade of C52.5. The target compressive strength for the samples was set at 40 MPa. Uncrushed, natural coarse aggregate with a maximum size of 20mm and natural fine aggregate with a maximum particle size of 5mm were utilized. All the mixes were produced using potable tap water, and a high-range-water-reducing concrete additive was added as a superplasticizer to meet the workability requirements. Steel fibers with a straight, hooked-end, and crimped shape were incorporated at a volume content of 1.0%, as illustrated in Figure 1. Different aspect ratios of the hooked-end fiber type (length/diameter (l/d) = 45, 65 and 80) were used to investigate the effect of this parameter on restraint of the drying shrinkage of concrete. Using fibers with reduced diameter while maintaining the same length resulted in fibers with higher aspect ratios.



Straight	Hooked-end	Crimped

Figure 1: Types of steel fibres.

Table 1 Concrete mix proportions.

Mix	Specimen	Shape of steel fibres	Fiber length (mm)	Aspect ratio (l/d)	Mix proportions (kg/m3)				
					W/C	W	C	FA	CA
M1	NC	-	-	-					
M2	ST-SFC	Straight	35	65					
M3	HE-SFC-65	Hooked-end	35	65	0.42	177	422	754	1024
M4	CR-SFC	Crimped	35	65					
M5	HE-SFC-45	Hooked-end	35	45					
M6	HE-SFC-80	Hooked-end	35	80					

W/C= water to cement ratio, **W=** weight of water, **C=** weight of cement, **FA=** weight of fine aggregate, **CA=** weight of coarse aggregate

2. Specimen preparation, casting, and curing:

The concrete mixing process, which involved the preparation of materials, batching, and mixing, was carried out following the guidelines of British standard 1881-125 [17]. Each mixture was made by weighing and combining the components in the designed quantities. The ingredients were sequentially added to the drum mixer in the following order: first, half of the required amount of coarse aggregate; next the entire amount of fine aggregate; next, the complete weight of cement; and finally, the remaining quantity of coarse aggregate. The components were initially mixed in a dry state for one minute to achieve batch homogenization. Subsequently, the superplasticiser was introduced into the water, and the resulting mixture was subsequently transferred into the drum mixer. The wet mixing process was conducted for a few minutes, after which the steel fibers were incorporated, and the mixing process was continued until a uniform mixture was obtained.

The workability of the fresh concrete was assessed using the slump test. As soon as the concrete was determined to be manageable, it was quickly poured into the prepared moulds. The concrete samples were put into moulds in layers following the specified specifications. The compaction process was promptly implemented following the addition of each layer, utilizing a vibrating table for a brief duration. This procedure was carried out to prevent the segregation of the concrete. The samples were shielded with wet rugs and plastic sheets to prevent water from evaporating and were left for a minimum of 24 hours. Following this duration, the specimens were extracted from the moulds and sent to the controlled fog room for a curing period of 28 days until the day of testing, as shown in Figure 2.

Figure 2: Casting and curing of specimens.

3. **Test Methods:**

After 28 days of curing process, four prisms (75x75x200mm) were prepared for each mix and tested for drying shrinkage. Demec points were located on two of the opposite long sides of the specimens and a digital, hand-held strain gauge was used to take the readings, as shown in Figure 3. Specimens were stored in a room with a humidifier to ensure constant, controlled environmental conditions: a temperature of 20ºC±0.5ºC and relative humidity of 45%±5%. The final amounts of shrinkage strains were calculated based on the average of the readings for samples of each mix.

Figure 3: Drying shrinkage test

Results and discussion

Drying shrinkage refers to the gradual changes in volume of concrete over time when it is exposed to drying environmental conditions. In this study, shrinkage strains were taken after 28 days of curing process and for a period of 90 days. Figures 4 and 5 illustrate the impact of various shapes and aspect ratios of steel fibers on the fluctuations in shrinkage strains over time.

1. **Effect of the shape of steel fibers:**

Figure 4 shows the relationship between the shrinkage strains that were taken during drying over up to 90 days and the shape of steel fibers that were used in the concrete mixes. Based on the recorded results, it is clear that as the deformation and waviness of the steel fibers increase, the drying shrinkage strain decreases. A decrease in drying shrinkage strain of 10% was recorded when straight steel fibers were used, a decrease of 15% when hooked-end fibers were used, and a decrease of 22% with crimped steel fibers. All these results were in comparison with those for normal concrete samples that did not contain fibers. The reductions can be attributed to the restriction that is imposed by the presence of the fibers on volumetric changes in the concrete as it dries and the high modulus of elasticity and stiffness of the steel fibers. Also, as the fibers deform and their waviness increases, their surfaces become roughened, and this enhances their resistance to the occurrence of this type of strain in concrete. These findings and reasons match some of that mentioned by other researchers in the literature [1,13].

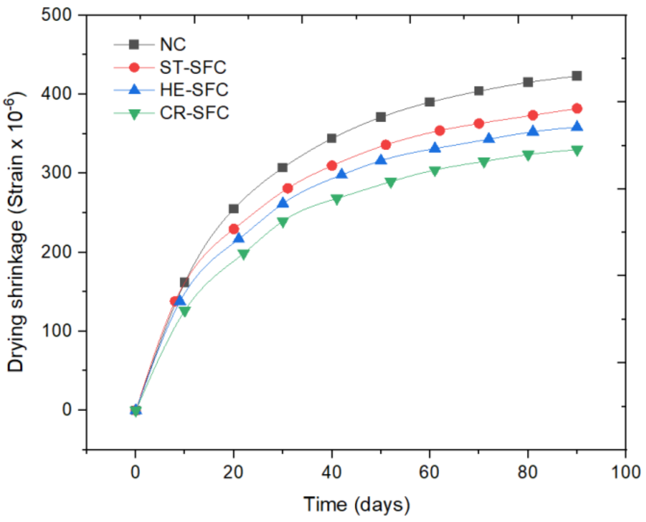


Figure 4: Effect of the shape of steel fibres on drying shrinkage of concrete**.**

2. Effect of the aspect ratio of steel fibers:

Figure 5 shows the relationship between the drying shrinkage strain that was recorded over time (up to 90 days) and the aspect ratio of the hooked-end steel fibers. It is clear from the graph that reductions in aspect ratios by increasing the diameters of steel fibers led to reduced drying shrinkage strains. The drying shrinkage strain was decreased by 12% when hooked-end steel fibers with an aspect ratio of 80 were added to the concrete; by 15% when hooked-end steel fibers with an aspect ratio of 65 were added; and by 20% when hooked-end steel fibers with an aspect ratio of 45 were used. These results were in comparison with those found with a normal concrete mix that had no fibers. The reason behind this effect is that fibers of increased diameter are harder than thinner fibers, which increases their resistance to deformation, this is also what discussed by some previous studies [1,16]. In summary, it can be stated that the presence of steel fibers significantly reduces the drying shrinkage strain of the concrete. This effect is increased with the deformation and waviness in the shape of the steel fibers, and with increased diameter of the fibers, which decreases their aspect ratios. In addition, the effect of the presence of the fibers on the drying shrinkage of the concrete remained constant in this study and no changes in the percentages of reduction were observed as the concrete aged.

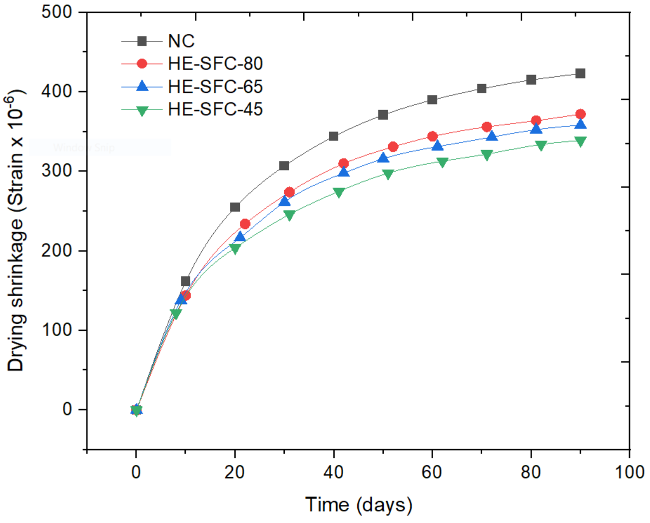


Figure 5: Effect of the aspect ratio of steel fibres on drying shrinkage.

Conclusion

The effect of the shape and aspect ratio of steel fibers on the drying shrinkage of concrete to which they were added was investigated in this laboratory study. According to the experimental results, the following conclusions can be drawn:

- In general, the addition of steel fibers significantly reduces the drying shrinkage strain of concrete.
- This effect increases with the deformation and waviness in the shape of the steel fibers increases.
- The presence of crimped steel fibers reduces the drying shrinkage of concrete more than does the presence of hooked-end or straight types.
- The drying shrinkage strain decreases further with increased diameter and therefore decreased aspect ratio of the fibers.
- Once drying shrinkage of concrete begins to occur, the rate of decrease in shrinkage strains continues steadily as the age of the concrete increases.

References

[1] Mangat, P.S., and Azari, M.M., (1984). A theory for the free shrinkage of steel fiber reinforced cement matrices. *Journal of Materials Science*, *19*(7), 2183-2194.

[2] Swamy, R.N., and Stavrides, H., (1979), March. Influence of fiber reinforcement on restrained shrinkage and cracking. *Journal Proceedings*, *76*(3), 443-460.

[3] Chern, J.C., and Young, C.H., (1990). Factors Influencing the Drying Shrinkage of Steel Fiber Reinforced Concrete. *Materials Journal*, *87*(2), 123-139.

[4] Grzybowski, M., and Shah, S.P., (1990). Shrinkage cracking of fiber-reinforced concrete. *Materials Journal*, *87*(2), 138-148.

[5] Tan, K.H., Paramasivam, P., and Tan, K.C., (1994). Instantaneous and long-term deflections of steel fiber reinforced concrete beams. *ACI Structural Journal-American Concrete Institute*, *91*(4), 384-393.

[6] Eren, Ö., and Marar, K., (2010). Effect of steel fibers on plastic shrinkage cracking of normal and high strength concretes. *Materials Research*, *13*, 135-141.

[7] Sryh, L., and Forth, J., (2016). Effect of steel fibers and recycled aggregate on drying shrinkage and creep deformations of concrete. *The 9th International Concrete Conference on the Environment, Efficiency and Economic Challenges for Concrete*, 4-6.

[8] Yousefieh, N., Joshaghani, A., Hajibandeh, E., and Shekarchi, M., (2017). Influence of fibers on drying shrinkage in restrained concrete. *Construction and Building Materials*, *148*, 833-845.

[9] Rahmani, T., Kiani, B., Bakhshi, M., and Shekarchizadeh, M., (2012). Application of different fibers to reduce plastic shrinkage cracking of concrete. *7th RILEM International Conference on Cracking in Pavements: Mechanisms, Modeling, Testing, Detection and Prevention Case Histories*, 635-642. Springer, Netherlands.

[10] Kim, D.J., Kim, S.H., and Choi, W.C., (2021). Characteristics of restrained drying shrinkage on arched steel fiber-reinforced concrete. *Applied Sciences*, *11*(16), 7537.

[11] Fang, C., Ali, M., Xie, T., Visintin, P., and Sheikh, A.H., (2020). The influence of steel fiber properties on the shrinkage of ultra-high performance fiber reinforced concrete. *Construction and Building Materials*, *242*, 117993.

[12] Bandelj, B., Saje, D., Šušteršic, J., Lopatic, J., and Saje, F., (2011). Free shrinkage of high-performance steel fiber reinforced concrete. *Journal of Testing and Evaluation*, *39*(2), 1. Ehbahani, H. P., Nematollahi, B., & Farasatpour, M. (2011). Steel fiber reinforced concrete: a review.

[13] Naaman, A.E., Wongtanakitcharoen, T., and Hauser, G., (2005). Influence of different fibers on plastic shrinkage cracking of concrete. *ACI materials journal*, *102*(1), 49.

[14] Su, P., Li, M., Dai, Q., and Wang, J., (2023). Mechanical and durability performance of concrete with recycled tire steel fibers. *Construction and Building Materials*, *394*, 132287.

[15] Afroughsabet, V., and Teng, S., (2020). Experiments on drying shrinkage and creep of high-performance hybrid-fiber-reinforced concrete. *Cement and Concrete Composites*, *106*, 103481.

[16] Yazıcı, Ş., İnan, G., and Tabak, V., (2007). Effect of aspect ratio and volume fraction of steel fiber on the mechanical properties of SFRC. *Construction and Building Materials*, *21*(6), 1250-1253.

[17] BS 1881-125, Testing Concrete, (2013). Methods for Mixing and Sampling Fresh Concrete in the Laboratory. *British Standards Institute*.