Steel Fibers and Steel Fiber Reinforced Concrete in Civil Engineering

Jacek Katzer, Ph.D.

Department of Civil and Environmental Engineering, Laboratory of Building Engineering,
Technical University of Koszalin, Poland
http://www.wbiis.tu.koszalin.pl/ltb/
E-mail: katzer@tu.koszalin.pl

ABSTRACT

Since the beginning of applications of civil engineering materials based on clay, lime, and cement, there has been a need to find a way to decrease their brittleness. In ancient times, the problem was solved by modifying brittle clay bricks with the addition of fibers of an organic origin. These approaches can be examined through a reading of the descriptions of Roman baths construction (Vitruvius 1999). Today it is steel fiber which is mainly used to reinforce concrete and overcome the problem of brittleness. This paper describes the most interesting applications of steel fiber reinforced concretes (SFRC) all over the world. Firstly, the author presents the evolution of steel fibers and SFRC. Secondly, the paper covers the contemporary importance of SFRC in civil engineering.

(Key words: tensile strength, construction material, engineering technology).

INTRODUCTION

The long process of inventing modern steel fiber reinforced concrete started in 1874, when A. Bernard, in California, patented the idea of strengthening concrete with the help of the addition of steel splinters (Maidl 1995). Another 36 years passed before Porter in 1910 mentioned the possibility of applying short wire to concrete. This was supposed to improve homogeneity of concrete reinforced by thick wire. In 1918, in France, H. Alfsen patented a method of modifying concrete by long steel fibers, long wooden fibers, and fibers made of other materials. According to him, the addition of such fibers was to increase tensile strength of concrete (Maidl 1995). Alfsen was the first to mention the influence of coarseness of the surface of fibers onto their adhesiveness to matrix, and it was also he who paid special attention to the problem of anchorage of fibers.

After these first patents, there were numerous others, but generally they concerned different shapes and probable applications of ready made SFRC. For instance, the patent from 1927 worked out in California by G.C. Martin, regarded the production of SFRC pipes. In 1938, N. Zitkewic patented a way to increase the strength and impact resistance of concrete by adding cut pieces of steel wire (Jamrozy 1985). Steel fibers, patented in 1943 by G. Constancinesco, were already very similar to the ones used at present. The patent, apart from different shapes of fibers, contained information about the kind and dispersion of cracks during loading of SFRC elements and it made mentioned of the great amount of energy which is absorbed by SFRC under impact. The largest number of patents concerning the use of steel fibers to modify concrete have been submitted in the USA, France, and Germany in the years following. Wide applications of fiber reinforced composites in civil engineering were limited for a long time by lack of reliable methods of examination and mainly by the sudden progress of traditional rod reinforcement.

FIBERS

Currently in the world, there are about 30 major producers of steel fibers used for modifying concrete, and they offer over 100 types of fiber (Katzer 2003 and Odelberg 1985). Steel fibers for modifying concrete are produced not only in Europe and in the USA but also in such countries as the Republic of South Africa, Australia, and South Korea.

The oldest, and at the same time, the most basic type of steel fibers are straight fibers cut out of smooth wire. Unfortunately, such fibers do not ensure the full utilization of the strength of steel because of a lack of appropriate anchorage in the concrete matrix. Over 90% of currently produced fibers are shaped fibers. The shape of fibers is adjusted in such a way that it increases the anchorage of fibers in concrete. Throughout the last 40 years there have been produced twisted, crimped, flattened, spaded, coned, hooked, surface-textured, and melt-cast steel fibers. These steel fibers had circular, square, rectangular, or irregular cross-sections. Each of the types was additionally varied by diameters and length (Jamrozy 1985 and Maidl 1995). Sometimes, in order to modify concrete, waste steel shavings and chips of different shapes were used instead of produced fibers (Keyvani 1995).

Decades of the experience had led to the production of the five most efficient steel fiber types. The efficiency of the currently produced fiber is based on both its effectiveness in concrete matrix and the simplicity of its production, which in turn has a significant influence on its price. These five most popular types of steel fiber are: traditional straight, hooked, crimped, coned, and mechanically deformed. The geometries of the non-straight fibers mentioned above are shown in Figure 1. Other types of fiber are rarely encountered and they are almost always produced for specific client orders.

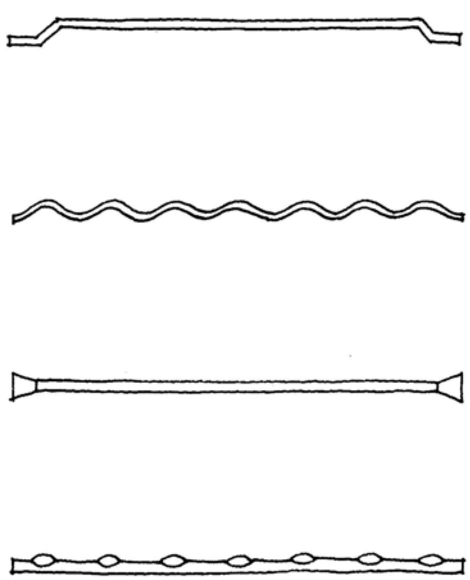

Figure 1: Fiber Profiles: Hooked, Crimped, Coned, and Mechanically Deformed.

A statistical analysis of the assortment produced in the world indicates that 67.1% of fiber consists of the hooked type. The other most popular fibers are: straight fiber (9.1%), mechanically deformed fiber (9.1%), crimped fiber (7.9%), and other fiber of different endings (6.6%).

The efficiency of dispersed reinforcement depends on numerous factors. However, the most important of them is the aspect ratio of the fibers, which influences the workability and spacing of fibers in fresh concrete mix. Because of workability, the concrete mix aspect ratio of steel fiber should not be higher than 150. A statistical analysis of the aspect ratio of produced steel fibers is shown in Figure 2 with the help of a frame chart.

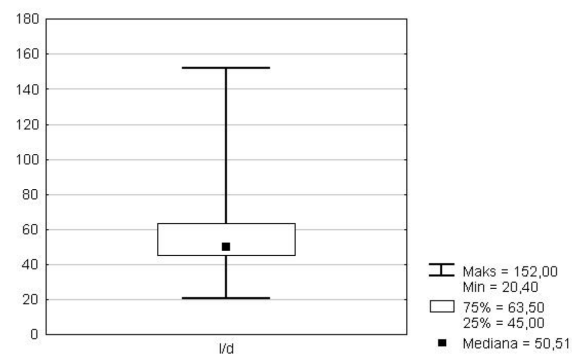

Figure 2: Aspect Ratio of Steel Fibers.

The aspect ratio of fibers available on the world market ranges from 20.4 to 152, which is indicated in Figure 2. In order to describe the frequency of a specific fiber aspect ratio, Figure 2 presents a frame showing a distance between the lower and upper quartile which is very narrow and encompasses the aspect ratio from 45 to 63.5. In other words, fiber of the aspect ratio from 45 to 63.5 constitutes 50% of the population of all types offered by producers of steel fiber used for modifying concrete.

APPPLICATIONS

The first serious civil engineering constructions with the application of SFRC were carried out in the 1960s. Nevertheless, the advantages of the material were not fully appreciated until a decade later. Since that time, SFRC has found numerous applications on a wider scale. Moreover, the application of SFRC is continually increasing. Firstly, SFRC was used to build runways of airports. In the USA, 28 runways built of SFRC modified by 0.3-2.0% of steel fiber of different kinds were finished between 1972 and 1980 (Lankard 1975). During these 14 years of observation of the construction projects, only scarce cracks and local damage were noticed. In the USA, fiber reinforced concrete is used to repair surfaces of motorways and airports as well as to build dams and canals (Lankard 1975). Recently it has been shotcrete with the addition of steel fiber which is gaining more and more popularity among constructors. Unstable slopes, landslides, and road embankments have been secured with shotcrete put on a previously stretched steel mesh.

Thanks to the application of steel fiber reinforced shotcrete (SFRS), the mesh, whose attachment and laying are time-consuming, may be abandoned. With traditional spraying of shotcrete onto mesh, it often happens that shotcrete is stopped by the mesh and spraying shadows appear. Apart from that, the mesh can vibrate as spraying causes grains of sand hit it. This in turn, hinders a good bond between the mesh and shotcrete. With the application of SFRS the loss of material during the laying phase is reduced by half in comparison with shotcrete without fibers (Jamrozy 2002). The application of SFRS allows one to avoid these technological problems and additionally creates a possibility of making thinner sprayed layers, which simultaneously are more resistant to cracks as is schematically shown in Figure 3.

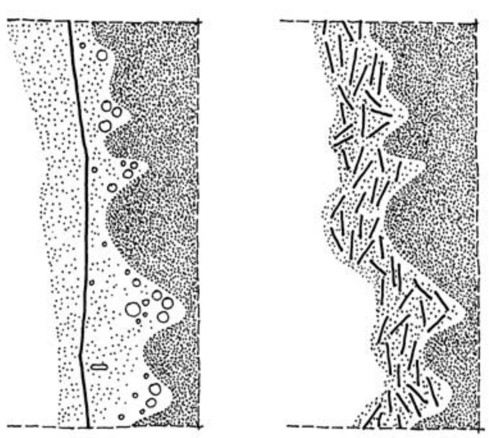

Figure 3: A Scheme of Securing a Rock Slide by putting Traditional Reinforced Concrete and SFRS.

SFRS also has greater early strength (after a three or seven day curing period) than traditional shotcrete on mesh. SFRS is more and more willingly applied to buildings, all kinds of new tunnels, and repaired older ones. Due to the employment of SFRS, it is possible to shorten the work time by half in comparison to the time needed to make the same application with the help of shotcrete sprayed on wire mesh.

SFRS enables a quick and effective regeneration of existing reinforced concrete elements. Such a regeneration of the coat of one out of four hyperboloid cooling towers was carried out at the Siersza Electricity Plant in Poland. The example of strengthening a concrete T-beam by spraying a layer of SFRS is shown in Figure 4. SFRS is also applied to build whole thin-walled constructions. Figure 5 shows a way in which a cylinder water tank is built by using fiber reinforced shotcrete. In this way the possibilities of achieving the most sophisticated and complex shapes of concrete elements are unlimited, which is displayed in an example of a fiber reinforced concrete shell shown in Figure 6.

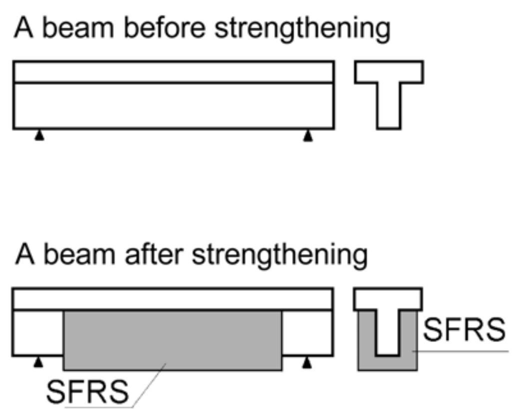

Figure 4: A Scheme of Strengthening a Concrete Beam by adding SFRS (Maidl 1995).

SFRC is more and more often employed to produce pre-cast elements (Shah 1985). The addition of steel fibers significantly decreases the risk of cracks of pre-cast elements or of their damage when transporting or assembling them. One of the first SFRC pre-cast elements produced in series were railway tunnel tubings. Beside the traditional solid pre-cast elements there are also produced thin-walled pre-cast elements made of SFRC.

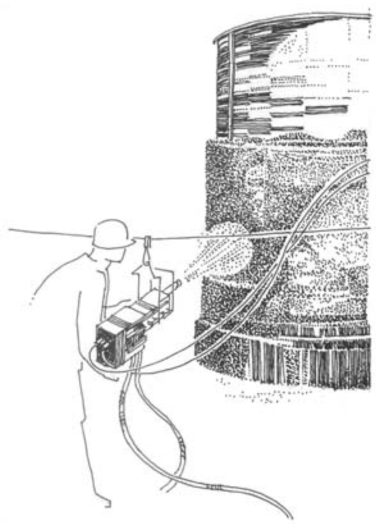

Figure 5: Building of a Cylinder Water Tank Employing Shotcrete Techniques (Shah 1985).

Figure 6: A Storage Room made by Employing Shotcrete Techniques (Shah 1985).

In Poland, there currently is production of curtain wall pre-cast elements made of SFRC (Shah 1985). Such an element consists of two SFRC outer layers which are 12-18mm across and the thermo-insulation layer which is 160-230mm across. The described elements (presented in Figure 7) are very light, durable and cheap to produce. In Kenia, SFRC thin-walled pre-cast concrete elements are produced with foamed polystyrene core. These elements (presented in Figure 8) are used to build living shelters (Boer 2004). Such pre-cast elements (whose sizes are 147.5cm ·20cm·40cm and mass equals 100kg) are very simple in production and later assembling.

An interesting example of thin-walled SFRC pre-cast elements are Swedish ones of a trapeze section (Shah 1985). A single prefabricate is 7m long (of a diameter from 1.2 to 1.8m) and weighs 6 tones. These elements are used to build a seaport harbor or breakwaters. Six elements in an upright position shaped in a semicircle forms the head of a single breakwater, which is shown in Figure 9. The interior of the positioned elements is filled with ordinary concrete.

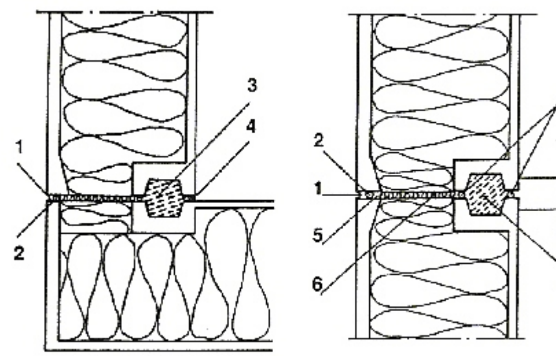

Figure 7: A Vertical joint of Precast Wall Elements (1- Sealing Compound; 2-gasket; 3-Cement Mortar; 4- Sealing Compound; 5- Air Canal; 6- Rock Wool).

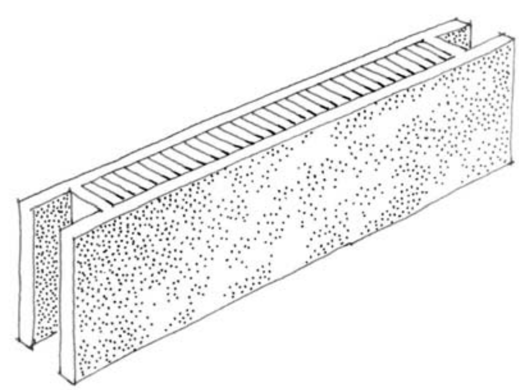

Figure 8: A Thin-Walled Element Made of SFRC with Foamed Polystyrene Insulating Core (Boer 2004).

A rare example of a SFRC application is the reconstruction of foundations under a hammer 200kN of a percussive action described by Jamrozy (1983). The foundation in question used to crack every few years. After a subsequent removal of the cracked part of the foundation as deeply as four meters, the part was reconstructed with SFRC. The basis of the foundation was 12·14m. A layer of ordinary concrete was covered with a one meter thick layer of SFRC situated directly under the anvil.

The described SFRC was based on the addition of 65kg/m^3 of steel fibers. The length of the mentioned fibers was 25mm with the diameter of 0.25mm.

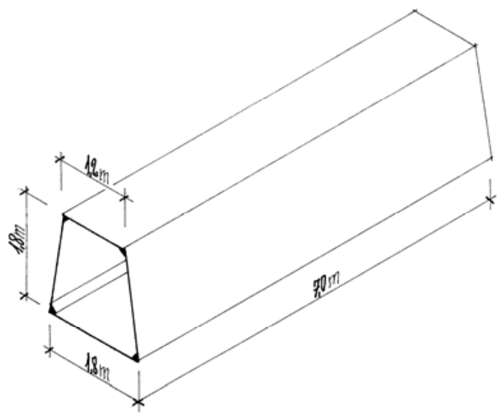

Figure 9: A View of a Thin-Walled SFRC Element used to build a Seaport Harbor (Shah 1985).

While working, the hammer causes stress inside the foundation from +0.2 MPa to -0.7MPa. The foundation was examined two years after the hammer started working. The hammer was taken off in order to uncover the whole surface of the foundation. During the inspection, no damage was found and the rebound hammer test showed a considerable growth of compressive strength of the examined concrete. Figure 10 shows a scheme of the foundation of the described hammer with marked areas in which ordinary concrete and SFRC were used in its renovation.

In Russia and Ukraine, SFRC is used to build and renovate industrial concrete chimneys. A chimney, apart from being exposed to severe weather conditions, is also exposed to considerable temperature difference between its outer surface (e.g. frost -30^{o}C) and inner side, which can be heated up to +250C by the fumes.

The application of steel fibers allowed increased flexural strength of the chimney elements by 250%. The increased strength stopped the appearance of micro-cracks and fast degradation of chimneys previously caused by water penetration into the chimney barrel.

The addition of steel fiber to fireproof concretes turned out to be extremely effective. Moreover, the usually brittle fireproof concrete became resistant to cracks caused by sudden temperature changes up to 1,500C and mechanical blows (Jamrozy 1983).

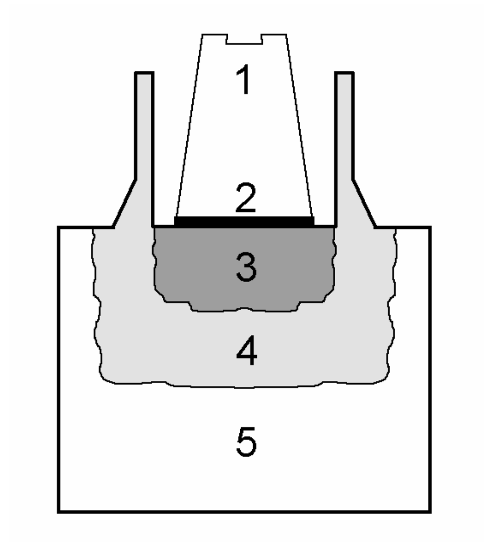

Figure 10: A Scheme of a Foundation Under a Hammer Reconstructed with SFRC (1- Anvil, 2- Shock Absorption Pad, 3- SFRC, 4- Ordinary Concrete, 5- Old Concrete Block) (Jamrozy 1983).

Besides for the civil engineering applications of SFRC presented above, there are also examples of fiber reinforced pipe production. The first patent for SFRC pipes was filed in 1927, in California, by G.C. Martin (Maidl 1995). In 1978, a successful production of pre-cast SFRC pipes and masts was established in Sweden (Sallstrom 1985).

These elements, of a length up to 13 meters, are produced with the help of spinning and axial moving forms. The advantages of this rotating manufacturing process lie in the significantly higher strength and lower permeability of the SFRC as compared to conventionally produced SFRC pipes and masts.

CONCLUSIONS

Over 40 years ago, Romualdi, Baston, and Mandel published the papers (Romualdi & Baston 1963, Romualdi & Mandel 1964) that brought SFRC to the attention of academic and industrial research scientists around the world. In the ensuing four decades, SFRC has been constantly examined and its technology was continually developed. Today, SFRC is a commercially available and viable construction material.

REFERENCES

Boer, S. and Groeneweg, T. and Leegwater, G., and Pieterse, I. 2004. *Low-cost Housing in Kenia.* Delft University of Technology.

Odelberg, G. 1985. “Producing and Promoting of Swedish Steel Fibers to the Market”. Steel Fiber Concrete US-Sweden Joint Seminar, Stockholm 3-5 June, 1985.

Jamrozy, Z. 1983. *Mechanika Kompozytów Betonopodobnych.* Zakład Narodowy Imienia Ossolińskich, Wydawnictwo Polskiej Akademii Nauk.

Jamrozy, Z. 1985. *Drutobeton.* Wydawnictwo Politechniki Krakowskiej. Kraków.

Jamrozy, Z. 2002. “Betony ze Zbrojeniem Rozproszonym”. XVII Ogolnopolska Konferencja Warsztat Pracy Projektanta Konstrukcji. Ustron.

Johnston, C. D. 2001. *Fibre Reinforced Cements and Concretes.* Gordon and Breach Science Publishers.

Katzer, J. 2003. “Wlokna Stalowe Stosowane do Modyfikacji Betonu”. *Polski Cement.* (3/2003).

Kayvani, A. and Saeki, N. and Shimura, K. 1995. “Applying Waste Shavings in Concrete”. *Proceedings of the Eleventh International Conference on Solid Waste Technology and Management.* Philadelphia, PA,USA.

Lankard, D.R. 1975. *Fiber Concrete Applications.* Rilem Symposium. The Construction Press, LTD.

Lankard, D. R. 1985. “Preparation, Properties and Applications of Cement-based Composites Containing 5 to 20 Percent Steel Fiber”. Steel Fiber Concrete US-Sweden Joint Seminar. Stockholm.

Maidl, B.R. 1995. *Steel Fibre Reinforced Concrete*. Ernst & Sohn.

Romualdi, J.P. & Baston, G.B. 1963. “Mechanics of Crack Arrest in Concrete”. *Proc. ASCE.* 89 EM3.

Romualdi. J.P. & Mandel. J.A. 1964. “Tensile Strength of Concrete Affected by Uniformly Distributed Closely Spaced Short Lengths of Wire Reinforcement”. *ACI J. Proc.* 61(6)

Sallstrom, I. 1985. “Products Made of Steel Fiber Reinforced Concrete on the Scandinavian Market”. Steel Fiber Concrete US-Sweden Joint Seminar, Stockholm 3-5 June, 1985.

Shah, S. P. and Skarendahl, A. 1985. *Steel Fiber Concrete.* Elsevier Applied Science Publishers. London, UK.

Vitruvius. 1999. *De Architektura Libra Decem*. Prószyński i Spółka. Warszawa.

ABOUT THE AUTHOR

Jacek Katzer, Ph.D., M.Sc., B.Sc. is a headmaster of the Laboratory of Building Engineering at Technical University of Koszalin. He earned his B.Sc., M.Sc., and Ph.D. from the Technical University of Koszalin in 1994, 1994, and 2000, respectively. He is a member of Concrete Society of Southern Africa and International Society for Concrete Pavements. He is a former headmaster of Division of Civil Engineering and Building Materials at the Technical University of Koszalin. His research interest focuses on concrete technology and especially on steel fiber reinforced concrete.

SUGGESTED CITATION

Katzer, J. 2006. “Steel Fibers and Steel Fiber Reinforced Concrete in Civil Engineering”. *Pacific Journal of Science and Technology*. 7(1):53-58.

Pacific Journal of Science and Technology