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Steel Fibres and Reinforced Concrete with Steel Fibers in the Field of Civil Engineering

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ABSTRACT

There has been an ongoing need to discover a solution to reduce the brittleness of civil engineering materials derived from clay, lime, and cement since their first usage. The ancients found a solution to the issue by adding organic fibers to fragile clay bricks. Reading about the building of Roman baths allows one to investigate these methods (Vitruvius 1999). To combat the material's brittleness, steel fiber is now the material of choice for reinforcing concrete. Worldwide, steel fiber reinforced concretes (SFRC) have found several very intriguing uses, which are detailed in this article. The author begins by outlining the history of SFRC and steel fibers. Second, the present relevance of SFRC to civil engineering is discussed in the article.

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

INTRODUCTION

In1874, a man from California named A. Bernard patented the concept of reinforcing concrete by adding steel splinters; this was the first step in the lengthy process that eventually led to the invention of contemporary steel fiber reinforced concrete (Maidl 1995). Porter didn't even bring up the idea of using short wire on concrete until 1910, a full 36 years later. The goal was to make the thick-wire-reinforced concrete more uniform in texture. H. Alfsen invented a technique for altering concrete in 1918 in France using long strands of steel, long fibers of wood, and other materials. The purpose of adding these fibers, in his view, was to make concrete more resistant to tensile stresses (Maidl 1995). The issue of fiber anchoring was initially brought to light by Alfsen, who also made note of the fact that the roughness of the fibers' surfaces affected their adhesiveness to the matrix.

There were a plethora of subsequent patents, although most of them were to variations in the form and potential uses of prefabricated SFRC. One example is the 1927 patent for SFRC pipes that was worked out in California by G.C. Martin. According to Jamrozy (1985), N. Zitkewic patented a method in 1938 for making concrete stronger and more impact resistant by using chopped bits of steel wire. G. Constancinesco invented steel fibers in 1943 that were quite close to the ones used today. In addition to describing various fiber forms, the patent detailed the kind and distribution of fractures that occur when SFRC elements are loaded, and also took note of the significant amount of energy that SFRC absorbs when subjected to impact. The United States, France, and Germany received the lion's share of patents pertaining to the modification of concrete using steel fibers in the years that followed. Many years passed before fiber reinforced composites found widespread use in civil engineering due to unreliable testing techniques and, most notably, the rapid development of conventional rod reinforcing.

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). Countries including South Korea, Australia, and the Republic of South Africa also contribute to the global supply of steel fibers used to alter concrete, alongside the United States and Europe.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. Shaped fibers account for more than 90% of all fibers manufactured today. 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. There was a wide variety of cross-sectional shapes represented by these steel fibers. Jamrozy (1985) and Maidl (1995) noted that the categories were further differentiated by their diameters and lengths. Sometimes, in order to modify concrete, waste steel shavings and chips of different shapes were used instead of produced fibers (Keyvani 1995). After decades of research and development, five distinct kinds of steel fiber were finally commercialized. 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.

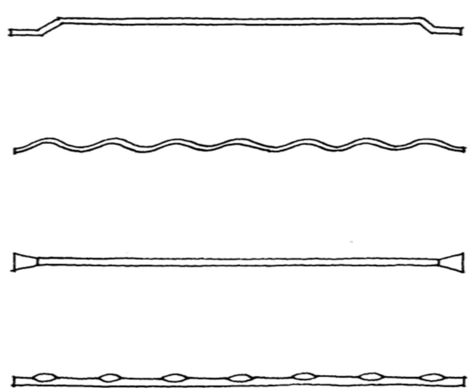

Figure 1: Fiber Profiles: Hooked, Crimped, Coned, and Mechanically Deformed.

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.

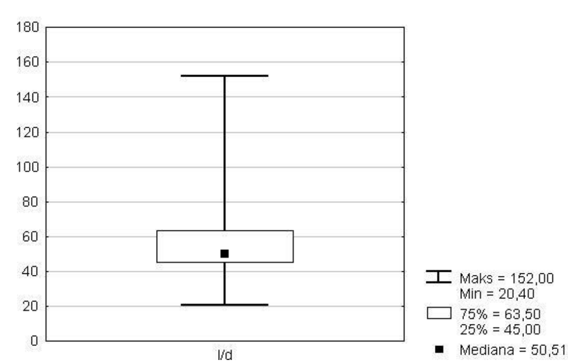

Figure 2: Aspect Ratio of Steel Fibers.

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 to63.5. 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

In the 1960s, SFRC was used for the first time in significant civil engineering projects. However, it took another decade before the material's benefits were recognized. Many more widespread uses of SFRC have emerged since then. More than that, SFRC is being used more and more increasing. The runways of airports were the first to make use of SFRC. Between 1972 and 1980, according to Langard (1975), 28 runways in the United States were constructed using SFRC that had been amended with 0.2 to 2.0 percent of various types of steel fiber. Throughout the fourteen years that we monitored the building sites, we found very few cracks and localized damage. Repairing highway and airport surfaces, as well as constructing dams and canals, are all examples of American infrastructure projects that make use of fiber reinforced concrete (Lankard 1975). A new material that is quickly becoming a favorite among builders is shotcrete reinforced with steel fiber. Road embankments, unstable slopes, and landslides have all been stabilized using shotcrete applied on stretched steel mesh. The mesh, which requires time to connect and lay, may be removed with the use of steel fiber reinforced shotcrete (SFRS). Traditional shotcrete spraying onto mesh often results in spraying shadows because the mesh stops the shotcrete. As an additional feature, the mesh has the ability to vibrate when sand grains impact it after spraying. Consequently, the mesh and shotcrete are unable to form a strong link. Using SFRS instead of shotcrete without fibers cuts material loss in half during the laying phase (Jamrozy 2002). As seen schematically in Figure 3, using SFRS not only helps to circumvent these technical issues, but it also opens the door to the prospect of producing spray layers that are both thinner and more crack-resistant.

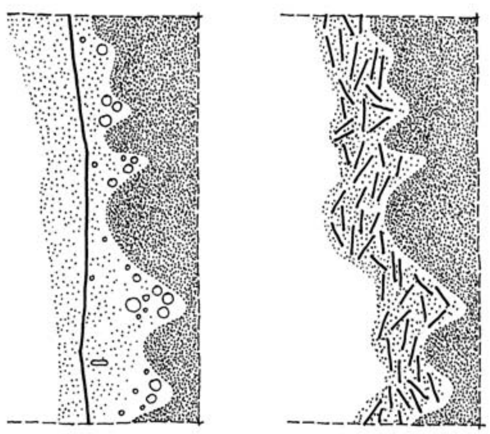

Figure 3: A Scheme of Securing a Rock Slide by putting Traditional Reinforced Concrete and SFRS.SFRS also has greater early strength (after a three or seven day curing period) than traditional shotcrete on mesh. SFRS is more and more willingly applied to buildings, all kinds of new tunnels, and repaired 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.

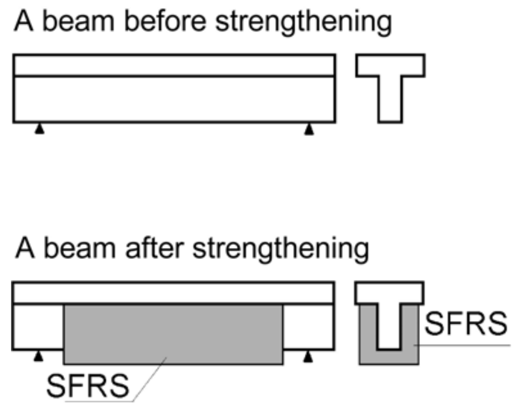

Figure 4: A Scheme of Strengthening a Concrete Beam by adding SFRS (Maidl 1995).

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.

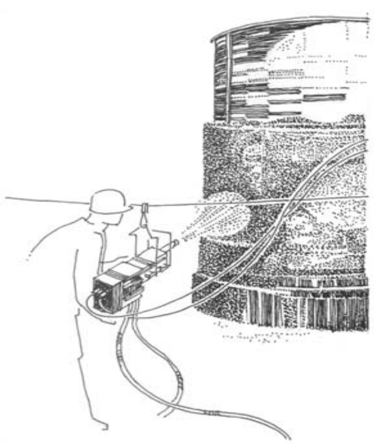

Figure 5: Building of a Cylinder Water Tank Employing Shotcrete Techniques (Shah 1985).

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.

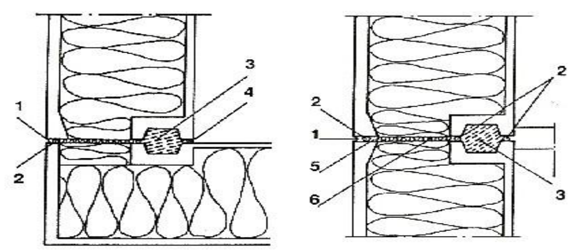

Figure 7: A Vertical joint of Precast Wall Elements (1- Sealing Compound; 2-gasket; 3- Cement Mortar; 4- Sealing Compound; 5- Air Canal; 6- Rock Wool).

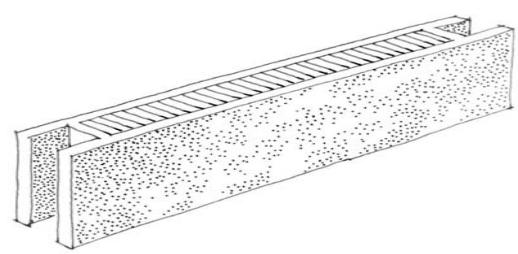

Figure 8: A Thin-Walled Element Made of SFRC with Foamed Polystyrene Insulating Core (Boer 2004).

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, thepart 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.

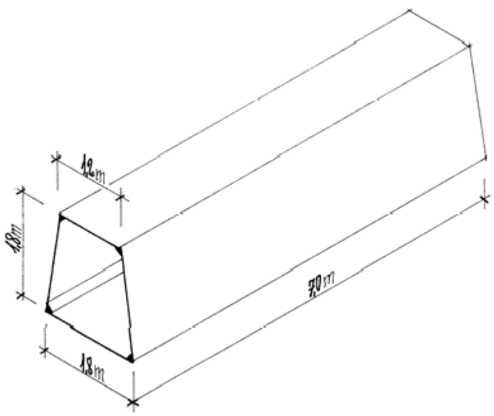

Figure 9: A View of a Thin-Walled SFRC Element used to build a Seaport Harbor (Shah 1985).

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 -30ºC) 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).

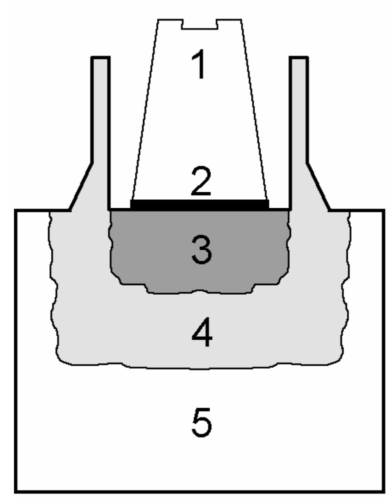

Figure 10: A Scheme of a Foundation Under a Hammer Reconstructed with SFRC (1- Anvil, 2- Shock Absorption Pad, 3- SFRC, 4- Ordinary Concrete, 5- Old Concrete Block) (Jamrozy 1983).

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

The three authors—Romualdi, Baston, and Mandel—first brought SFRC to the notice of researchers in academia and industry more than 40 years ago with their publications (Romualdi & Baston 1963, Romualdi & Mandel 1964). Over the next forty years, SFRC has been the subject of ongoing research and technological advancement. In modern times, SFRC has become a practical and marketable building material.

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