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Le Toumelin

A ferrocement schooner with a quarter century of successful service

by Antoine E. Naaman and Pierre Brenet

Le Toumelin is a schooner currently operating in the French West Indies, particularly around the island of Martinique located in the East Caribbean close to Dominica and St. Lucia. The main city of Martinique is Fort-de-France, and *Le Toumelin* anchors in the Trois Îlets (Pointe du Bout), a small holiday resort area located in the Fort-de-France bay.

A schooner (sometimes also called a *goélette*, as it's known in French) is a type of sailing vessel characterized by the use of fore-and-aft sails on two or more masts. Schooners were first used in the 16th century by the Dutch and were further developed and extensively used in Europe and the Americas for fishing and transportation; they are characterized by their speed, windward ability, and maneuverability.

Le Toumelin is a three-mast schooner, with nine sails totaling 480 m^2 (5170 ft^2) in area. What is most particular about it is that its structure (hull, deck, and all bulkheads) is entirely made out of ferrocement. Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small-sized wire mesh.[1-4] While numerous boats have been built with ferrocement and operated successfully in the past, very few have their service performance in seawater documented. At the time of this writing, *Le Toumelin* functions as a tourist charter vessel with day trips around Martinique or to the other nearby islands.

Fig. 1: *Le Toumelin* at sea with its sails on, and without them at port

Fig. 2: Illustration of the open-mold method of construction with successive wood frames used to provide the shape of the hull

Le Toumelin was built in a small shipyard located in Marseillan, a village close to the shipping harbor of Sète on the Mediterranean seashore of France. In 1989, it sailed from Marseillan to Martinique, a journey of almost 5000 nautical miles. Its ferrocement hull has been in service in seawater for more than 35 years and in the Caribbean for more than 20 years.

Le Toumelin is named after Jacques-Yves Le Toumelin, a sailor from Brittany, France, who, between 1949 and 1952, circumnavigated the globe alone without any engine or technical assistance in a 10 m (33 ft) long sailboat named *Kurun*. Now a classified historic monument, *Kurun* is located in the Museum Le Croisic in France.

Le Toumelin was the son and grandson of sailors and had built his own sailboat. At the time, he was the third known sailor to have accomplished this challenge. The story of his journey was published in the book *Kurun Autour du Monde*[5] (*kurun* means "thunder" in Breton). The book inspired Pierre Brenet (the second author) to pursue his interest in sailing and led to the construction of his own three-mast schooner, *Le Toumelin*.

The photos in Fig. 1 show *Le Toumelin* from different angles, with and without its full sails. The boat's beauty, grace, and fluidity prompted the authors to tell her story. To benefit the reader and future users of ferrocement, a summary of key information about *Le Toumelin* is presented herein.

It is observed that the construction of *Le Toumelin* did not entail the use of any high-technology process or equipment. To the contrary, it was carried out by Brenet, an amateur builder and craftsman following what was, at the time, the available technical recommendations for ferrocement and common-sense engineering.[6-10] It should be noted, however, that prior to undertaking his project, Brenet had practical training in industrial design, naval architecture, mechanics of materials, and naval structural carpentry. He was also a long-standing sailor who had practiced since childhood, and held several French Merchant Marine Certificates, including an engine room control certificate. Prior to completing *Le Toumelin*, he owned a smaller sailing boat with a steel hull.

Characteristics

As mentioned, *Le Toumelin* was built by the second author who, from a cement and concrete technical perspective, was an amateur builder, but knew a lot about sailing and naval procedures. So, when he decided to design and build his own boat (and given his past experience with different materials), he opted for ferrocement. Following are the main characteristics of *Le Toumelin*:

- Hull length: 23 m (75 ft);
- Overall length, including the bowsprit: 28.5 m (94 ft);
- Beam (that is, maximum width): 6.3 m (21 ft);
- Draft or distance between waterline and bottom of the hull (or load line): 3 m (10 ft);
- Weight: 75 metric tons (83 tons); and
- Ballast: 23 metric tons (25 tons).

Under deck, it has four cabins, each with a sink and toilet facility; there are also two showers. The ship can accommodate up to 10 passengers for sleeping. There is also one fully equipped cabin for the crew, and this could accommodate up to six people. Used as a day charter, *Le Toumelin* usually receives up to 46 passengers with food service.

The construction plans for the boat were designed by the second author, following existing examples from French models of similar boats, and were certified by the French Admiralty Department in Marseille, France. As the boat was initially intended to operate as a charter for the Merchant Marine in the Mediterranean Sea, the construction of the hull was supervised by the French Marine Authorities of Sète, a nearby port, and certified for sailing upon its completion.

It should be noted that during the period it took to completely finish *Le Toumelin* on the inside and prepare it to sail long distance, 13 ferrocement hulls ranging in length from 12 to 23 m (39 to 75 ft) were also built for private customers by the second author, who was then a contractor and shipyard owner.

Construction Method

The hull of *Le Toumelin* was built using what is known as the open mold method of construction,[2-4,6] a traditional boat-building construction technique. In this method, an open mold is constructed using a stiff timber framework made of a succession of multiple frame sections acting as ribs and stiffeners and simulating the final shape of the hull. Among these framing sections are also some sections especially designed to accommodate future bulkheads. The heavier framing sections are then connected by a lattice of wood strips or ribbands (Fig. 2). Then, the reinforcement is added. The heavier framing (which is used to give the shape) is dismountable so that it can be removed and recovered later. The ribbands allow the mesh layers to be stapled to them for proper positioning,

until the whole reinforcing system is completed. Additional ties are used as needed to secure the various reinforcing meshes together each time a layer is added. The ribbands, spaced at 100 to 150 mm (4 to 6 in.), are largely removed before the mortar plastering to make it easier to plaster from the inside to the outside.

The reinforcement of the hull consisted essentially of three main layers, like a sandwich with two outer skins and a skeletal steel core in between. The first skin layer contained four layers of chicken wire mesh stacked on top of each other and regularly stapled to the wood frames and ribbands; it was followed by the core layer of skeletal steel made out of a grid of 8 mm (0.3 in.) deformed reinforcing bars spaced at about 50 mm (2 in.) center to center; and then the third layer, the outer skin, which contained four layers of chicken wire mesh.

For the skeletal core, the vertical bars were placed first and stapled to the wood frames, and then the horizontal bars were placed and tied to the vertical bars at every crossing joint. A typical cross section of the ferrocement structure that made the hull is shown in Fig. 3. The thickness of the hull is generally around 28 mm (1.1 in.), with a range from 26 to 31 mm (1.0 to 1.2 in.). The reinforcement prior to adding the mesh layers for the outer skin is illustrated in Fig. 4.

While many ties were used to secure the various layers of reinforcement during placing and construction, once the whole of the hull reinforcement was completed, wire ties were applied at every cross section of the skeletal grid through the entire depth of the reinforcement, thus binding the entire reinforcement together. It is estimated that 400,000 such ties were used over the entire surface of the structure. Particular care was taken to make sure that tie ends were buried inside the reinforcing skeleton and did not protrude from the surface.

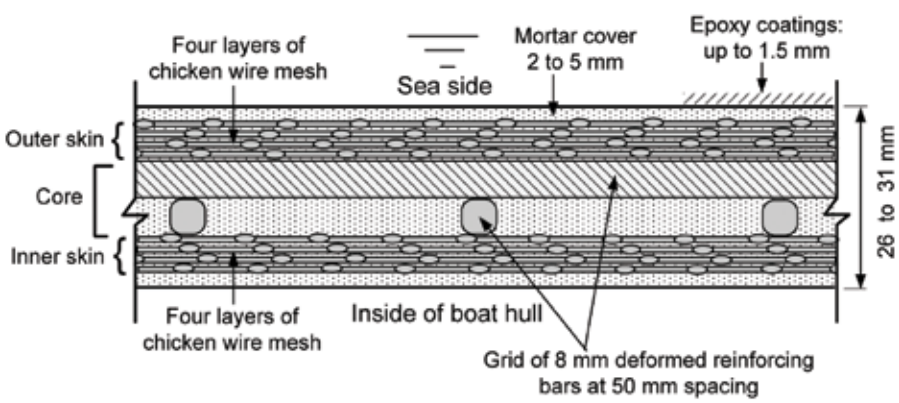

Fig. 3: Typical cross section of the ferrocement hull wall showing the different layers of reinforcement (Note: 1 mm = 0.04 in.)

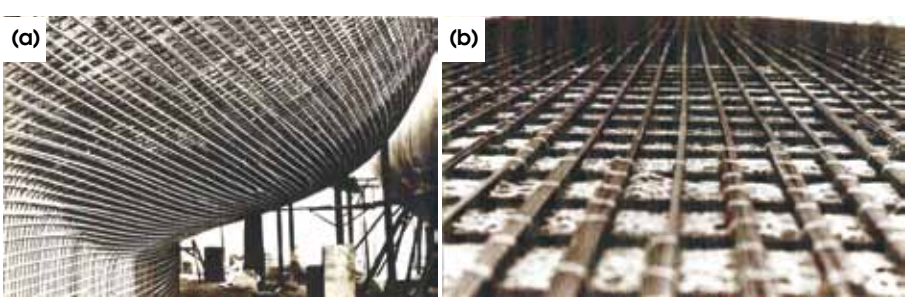

Fig. 4: The first two layers of reinforcement: (a) inner skin; and (b) skeletal reinforcement, prior to adding the outer skin made with four layers of chicken wire mesh

For all elements other than the hull, such as bulkheads, crossbeams, and floor stiffeners, the ferrocement composite used the same sandwich construction as for the hull; however, each skin contained three layers of wire mesh instead of four, and the skeletal steel had 80 mm (3 in.) grid spacing. These elements were meant to be less rigid than the hull to provide some flexibility in case of large deformation.

Six bulkheads provided the lateral rigidity of the structure. Each acted as a frame as well as a floor beam for both the deck and the bottom hull. Moreover, where appropriate, specific reinforcement was added in the bulkheads to prepare the locations receiving the masts.

The thickness of the total reinforcement (that is, the sandwich of wire mesh and skeletal steel grid) for the hull was about 24 mm (0.9 in.) while, for the remaining elements, such as bulkheads and deck, it varied from 18 to 22 mm (0.7 to 0.9 in.). When mortar was added, the thickness of the hull varied from about 26 to 31 mm (1.0 to 1.2 in.), the lower values occurring in areas where the mesh layers were strongly compacted.

After the reinforcement was completed, plastering of the mortar was carried out in three main steps, each separated by a period of time to allow proper curing at 100% relative humidity (using a simple vaporizer while the structure was covered by plastic sheets), and strengthening of the mortar matrix. The bulkheads were plastered first, then the hull, and finally the deck leading to a monolithic structure.

When there was interruption of mortar application, a latex-based bonding agent was used prior to application of new mortar. A photo illustrating a typical mortar application is shown in Fig. 5(a). Note that for plastering the hull, the wood ribbands were first removed, and the mortar was applied from inside the hull, forcing it through the reinforcement system toward the outside; it was then

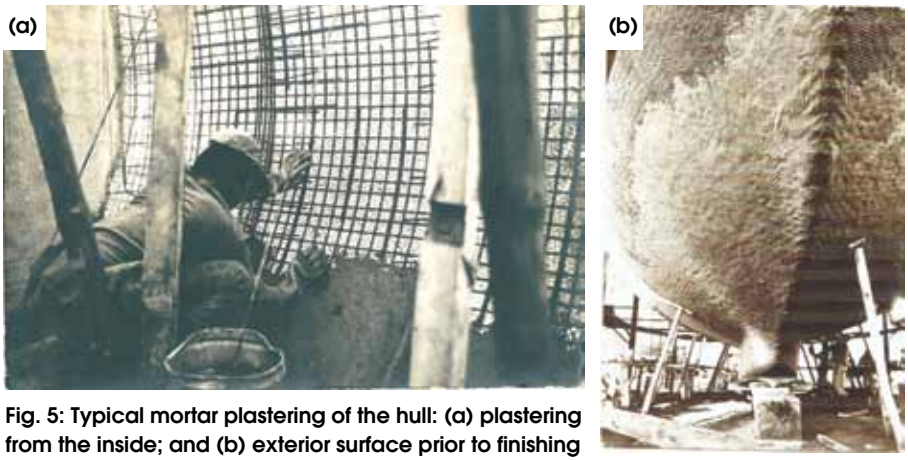

Fig. 5: Typical mortar plastering of the hull: (a) plastering from the inside; and (b) exterior surface prior to finishing

Fig. 6: The finished hull after epoxy coating and polyurethane application

finished from both sides (Fig. 5(b)). This essentially required a two-person team. To create a stronger joint and facilitate the connection with the deck, a band of about 100 mm (4 in.) at the periphery of the deck was plastered simultaneously with the hull.

Once the mortar had reached its strength, the exterior surface of the hull was ground and sanded to smooth it and prepare it for the final coatings. This task was extensive and rather time-consuming, but it also allowed for checking the surface for air pockets or other irregularities and repair them using a rich mortar and the latex-based bonding agent.

To apply the mortar of the deck, a formwork of plywood boards was used and plastering was carried out from the exterior.

Upon satisfactory final inspection, five films of epoxy coating (liquefied enough to facilitate penetration) were applied to the hull at intervals, each allowing full curing of the epoxy, followed by three coats of polyurethane paint for the final finish. Figure 6 illustrates the quality and glossy smoothness of the finished hull. It is estimated that the epoxy layers and coatings added about 1.5 mm (0.06 in.) of protection to the outer cover and allowed perfect watertightness.

Materials

The reinforcing mesh was a galvanized chicken wire with an opening of about 19 mm (0.7 in.) and a wire diameter of 1 mm (0.04 in.). A total of 4400 m^2 (47,360 ft^2) of wire mesh was used for the project. The skeletal core bars were of the "Rumi type" (French-made) with an X-like square cross section, 8 mm (0.3 in.) to each side and yield strength close to 600 MPa (87,000 psi). A total of 18,000 m (59,000 ft) was used.

The rather fine mortar matrix consisted of cement, sand, and water (one part cement, two parts sand, and about 0.4 to 0.5 part water). The cement was a typical Type V cement produced by Lafarge for seawater environments. The sand originated from the Drome River, with a grain size ranging from 90 microns to 3 mm (0.004 to 0.1 in.). Particular attention was given to making sure that the sand had a good distribution of particle sizes, averaging 1.5 mm (0.06 in.)—two parts by weight, 900 microns (0.04 in.)—one part, 400 microns (0.02 in.)—one part, 200 microns (0.008 in.)—one part, and 90 microns (0.004 in.)—one part. The compressive strength of the mortar was about 35 MPa (5080 psi) at 7 days and was expected to reach a design strength of about 75 MPa (10,880 psi). When finishing the outside of the hull, only 200 and 90 microns (0.008 and 0.004 in.) average sands were used.

Hauling, Cleaning, Inspection History, and Milestones of Survival

Upon completion, the ferrocement hull stayed in seawater from 1975 to 1984, during which time the boat interior was worked on leisurely. Its hull was hauled in 1984, cleaned, and appeared at the time to be in excellent condition. Between 1984 and 1989, *Le Toumelin* was finished with its full mechanical (a diesel engine of 260 hp

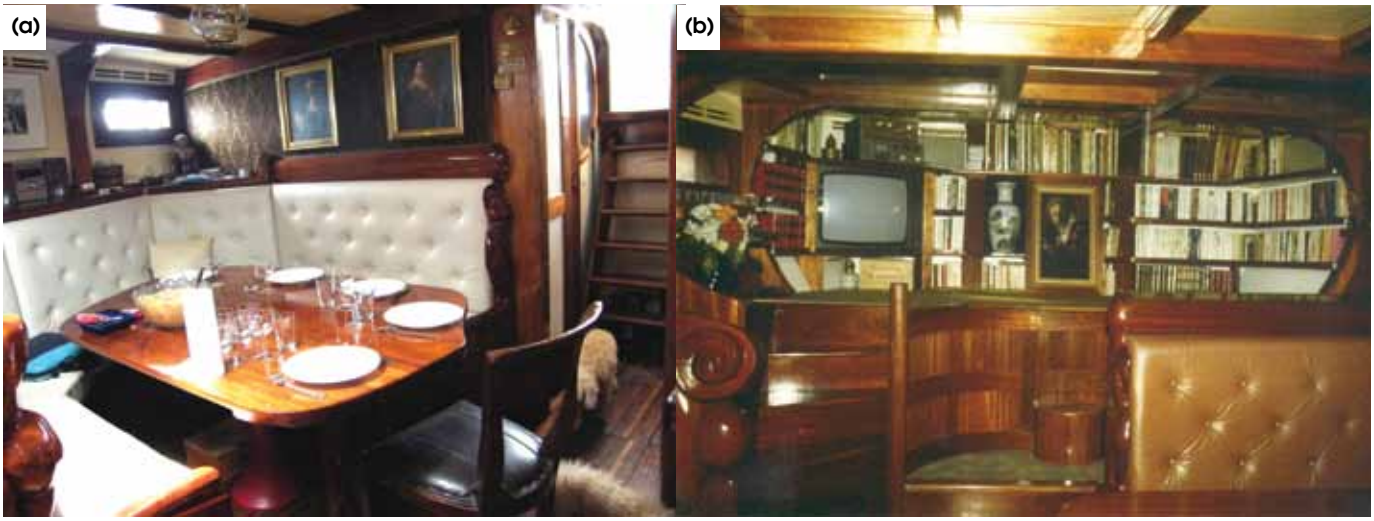

Fig. 7: The interior quarters of *Le Toumelin* finished with African mahogany wood: (a) dining area; and (b) library and map room

was added) and navigation equipment and readied for use in high seas. In 1989, prior to crossing the Atlantic, *Le Toumelin* was again hauled and its hull was cleaned, fully inspected, and given a clean bill of health. Photos illustrating the completed interior of the boat and its rich African mahogany wood are shown in Fig. 7.

Since 1990, the boat has been hauled every 1 or 2 years for cleaning and inspection. Three events of interest should be noted because they illustrate the strength and qualities of the ferrocement composite and hull structure.

In 1993, while taking off the masts for maintenance, the cable of the lifting crane broke and the cable end block (about 200 kg [440 lb]) fell down from about 12 m (39 ft) in height directly onto the deck. While the impact was strongly felt, it did not produce a hole in the deck but it did create extensive cracking around the impacted zone. Later, the cracked mortar was removed, the skeletal reinforcing bars were realigned, the chicken wire mesh was replaced, the area was cleaned, and a new mortar was applied; this was a very cost-effective repair.

In 1996, the hull was again hauled and sandblasted for a full inspection. Two sites showed slight discoloration on the inside due to corrosion: where the chain of the anchor penetrated the hull and at the toilet intake of seawater, each about 1 m^2 (11 ft^2) in area. These were repaired by removing the mortar, cutting off the corroded portions of bars, welding replacement bars to the remaining ones, adding the layers of wire mesh for both the inner and outer skins, tying the whole to the existing skeletal steel, troweling a rich mortar containing an adhesive agent, and finishing with the epoxy coatings.

In 2004, a fire broke out in the engine room due to a gas-oil transfer mistake. Fortunately, although the fire lasted 15 to 20 minutes, it did not spread; it was then contained and the hull did not sustain any short- or long-term damage.

These milestones confirm several known advantages of ferrocement, including ductility, resiliency, and impact and fire resistance.

Concluding Remarks

No tests were carried out to check any of the materials and mechanical properties of the ferrocement composite used to build *Le Toumelin*. However, based on the information described previously, it is estimated that the total volume fraction of steel reinforcement in the hull was close to 9%, of which about 2/3 were contributed by the skeletal steel reinforcing bars. Based on a design chart given in Reference 3 developed for typical ferrocement plates, the modulus of rupture (MOR) (nominal strength in bending) of such a composite is estimated to be around 45 MPa (6500 psi) and its direct tensile resistance is about 20 MPa (2900 psi). Material properties have evolved significantly since the construction of *Le Toumelin*. MOR values exceeding 120 MPa (17,000 psi) were reported in References 4, 11, and 12 for ferrocement plates using unidirectional, very-high-strength steel meshes made with fine strands. Most recently, using an ultra-high-performance fiber-reinforced concrete with steel fibers combined with very-high-strength steel strands, a record-breaking value of MOR close to 230 MPa (33,000 psi) was obtained from tests on 12.5 mm (0.5 in.) ferrocement plates containing about 10% total steel reinforcement.[13] Given that ultra-high-performance concrete also offers the benefit of high durability under an aggressive environment, such information suggests that the next generation of ferrocement boats, catamarans, or schooners could be significantly larger and more efficient than *Le Toumelin*.

Summary

Le Toumelin has been in seawater for more than 35 years and has been sailing in the East Caribbean Sea for more than 20 years. At the time of this writing, its

ferrocement structure is still in very good condition. Given what we know today about advanced materials available for future ferrocement structures, such as ultra-high-performance fiber-reinforced concrete and very-high-strength steel wires, strands, or textiles,[11,12] the success story of *Le Toumelin* is very encouraging. Indeed, it is hoped that it will not only inspire future naval architects and boat builders to consider ferrocement as a viable and competitive material in their projects but also entice the engineering community to evaluate the application of ferrocement in terrestrial structures, including residential structures, water tanks, silos, and other light agricultural structures.

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