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Manufacturing of small sized fibre reinforced concrete boats

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The use of fibre as reinforcement in concrete is receiving considerable attention and the activity level is not confined to laboratory research only. Its acceptance by the designer, specifier, owner and contractor is very positive in developed countries. Very thin section concrete having good mechanical properties and properties like impact abrasion resistance have been achieved using fibre reinforcement. This paper reports the outcome of experiments involving design and manufacturing of small boats using fibre reinforced concrete. It is seen from the study that, fibre reinforced concrete boats are less expensive and of improved quality in comparison with the wooden ones. The short term performance of the boats built with this material has shown no structural or material weakness. It is recommended that based on the outcome of the works, follow up actions be undertaken to establish the material as a viable alternative boat-building material. It is further emphasized that evolution of this material as alternative to wood in building small boats will help the boat owners and help preserve environment.

Country boats are essential to Bangladesh's transport needs. Traditionally, it is a part of culture of the people of Bangladesh. Almost four million people are directly employed in the industrial sector pertaining to these country boats, which is a means of livelihood for almost 10 million people in a country with a population of 120 million. In terms of value added to the economy, it is just second after agriculture. These have been the main mode of transport in the rural parts of the country, both for goods and passengers. In times of flood, these are indispensable for people's safety. The total number of various types of country boats is shown in Table 1 and the distribution of the number of boats based on the capacity is shown in Fig. 1. The present work is centered around hundreds of thousands of small country boats engaged in river crossing, short journeys and other household purpose throughout the country.

On the backdrop of scarcity and high price of the timber required for boat-building, the boatmen are resorting to use inferior quality wood. The result is a very high annual repair and maintenance cost, reduction in the income of the boatmen, increased consumption of timber and consequent faster deforestation. The whole situation has turned critical and a remedy was considered essential both for the welfare of the boatmen and the environment.

In this situation, various alternative materials for building such boats have been explored. The materials considered are ferrocement, aluminum, fibreglass reinforced plastic etc. and fibre reinforced concrete.

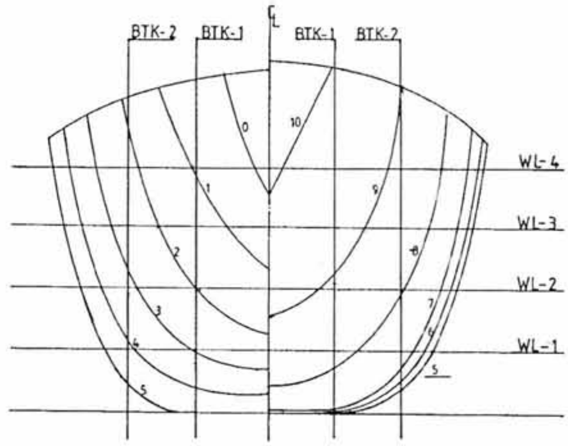

Fig. 1—Body plan of typical country boat (22×4.75×2.75 ft)

Table 1—Statistics of Country Boats (Source : BEBOA)

Type of Country boat	Total number in 1992-93	Per unit value added in 1993-94	Total value added in 1993-94
Passenger (non-mechanized)	6,42,322	0.04	23,547.52
Cargo/goods (non-mechanized)	3,45,866	0.04	14,966.32
Mechanized with shallow engine	1,74,385	0.06	10,783.27
	11,62,573		49,297.10

Ferrocement is too heavy for small boats, FRP is too expensive and aluminum fabrication required expensive infrastructure. Thus none of the commonly used alternative boat-building material appeared to be a feasible solution.

Fortunately, there have been tremendous advances during the last few decades in manufacturing thin concrete shells using fibre reinforcement imparting excellent impact and abrasion resistance. These properties are considered critical for small boats. Some experiments were carried out by the authors to establish technical viability of this low cost and durable material for use in building such small boats. The proposed material is a cement based matrix. It is contemplated that by utilizing the advancements achieved in this field, it may be possible to build very small boats (5 meter in length) which will be cheap and have a long life. Upon extensive investigations considering the initial cost, maintenance cost, longevity, manufacturing process, fibre reinforced concrete was considered to be the most promising one. Accordingly, a structural design of a typical boat was prepared for manufacturing with fibre reinforced concrete. Some specimen boats were manufactured and tested in limited practical operation.

The outcome of the experiments along with the outcome of the limited practical operation is presented in this paper. However, this phase is confined to establish the basic feasibility of manufacturing hulls using the proposed material. The real life test of such boats will be studied in a future phase once the on-going phase is completed before concluding that feasible boat hulls can be constructed using this material.

Literature Review

An extensive review of various literature on the related topics was carried out. It is observed that various types of materials in fibre form have been used so far in reinforcement of concrete for a wide range of applications. The materials used ranges from wood pulp to amorphous metallic fibres. However, synthetic materials like polypropylene and polyethylene are the most common. Using these materials in various methods and manners and in various proportions in various forms of concrete, improvements in the characteristics and properties of concrete in various ways have been achieved. Improvements in the tensile strength, compressive strength, flexure strength, toughness, impact resistance, abrasion resistance, fatigue resistance etc. have been achieved in various degrees in different cases. These reported advances can be treated to be sufficient to conclude that it is worthwhile to explore the feasibility of use of this material for building small boats. A brief review of such improvements obtained is presented below:

Impact Strength:

Using polypropylene fibres at a volume fraction of 0.1%, some improvement in the strength has been achieved but at a volume fraction of 0.5% 1/2" long fibres, the impact resistance increased dramatically[1].

Using fibrillated polypropylene with conventional steel reinforcement, the impact resistance increases with increase in fibre volume. An addition of up to 0.5% of this fibre has virtually no effect on the impact strength but lead to a considerable increase in fracture energy[2].

Using polypropylene fibre reinforced with high volume fly ash shotcrete, it was found that for initial crack, the impact strength was unaffected but for ultimate failure, the number of blows required was more[3].

Polyethylene—Polyethylene fibres at 0.05% volume fractions produced impact strengths comparable to those of polypropylene fibres at 0.1% volume fraction; the impact strengths of polyethylene fibre reinforced concrete materials with 0.025% and 0.1% fibre volume fractions were, respectively, inferior and superior to those of polypropylene fibre reinforced concrete with 0.1% fibre volume fraction. With 0.1% volume fraction of polyethylene fibres, the average impact strengths were increased by 5.8 times. All the fibre reinforcement conditions considered by various studies produced considerable improvements in the impact resistance of concrete [2]. Both polyethylene pulp and fibre tend to increase the impact resistance of cementitous materials. Combined use of the two fibres lead to higher test results[4].

Aramid fibre—Impact strength of the concrete reinforced with aramid fibre improves substantially[5].

Carbon fibre—The impact strength of the carbon fibre reinforced concrete was found experimentally 33 blows with a standard error of mean 4 blows[6].

Cellulose fibre—Considerable improvements can be reached with the kraft pulp. Some improvements can be reached with mechanical pulp[7].

Steel fibre—The performance of resistance to fatigue and impact of high strength concrete is raised greatly by the composite effect of silica fume and steel fibre[8].

Brittleness

By using polypropylene fibre and polyethylene fibre in high volume fractions, the brittle post-peak failure pattern of high strength concrete can be reduced significantly.

The continuous reinforcement given by **Retiflex** is not brittle as in the case of asbestos and can withstand overloading even when the matrix is broken. For this reason a broken **Retiflex** cement sheet can even withstand the weight of four people[9].

Bond Strength

The following improvements were obtained in bond strength of concrete by using fibrillated polypropylene with conventional steel reinforcement[2].

Increase in fracture energy was much greater than the sum of the effects of polypropylene fibres and reinforcing bars considered separately. A 0.5% volume was the optimum fibre content that can be employed without major adjustment to mix the design. In experiments involving reinforced concrete beams, it were observed that due to the additional fibre surface area with higher volumes, the slump decreased as the fibre content increased. The fracture energies increase markedly, particularly at 0.5% fibres. Increasing the fibre content appeared to increase the displacement range over which the beams can support the maximum load. With 0.5% fibres, however, the beams generally maintained a greater integrity. While they too were heavily damaged, there was little sapling of the concrete, and the resulting beam deflections were smaller than for the lower fibre content beams. This is probably due to the effects of the fibres "bridging" across some of the cracks and thus tying the entire beam together. Slip is much less with 0.5% fibres.

The addition of up to 0.5% fibrillated polypropylene fibres to concrete containing conventional steel reinforcing bars led to a considerable increase in fracture energy, particularly for 0.5% fibre concrete. For all of the fibre volumes tested, there was sufficient bond between the fibres and the matrix to minimize fibre pullout.

Fibrillated polypropylene fibres in conventionally reinforced concrete beams improved the cracking resistance under impact loading and appear to inhibit debonding of the reinforcing steel from the matrix[2].

The standard **Retiflex** net is consists of 12 adhering fibril layers, 8 of which are in the main direction and 4 in perpendicular. Retiflex net produced in this way can really reinforce in both directions. However, net can be produced with different combinations for special applications. The size of the mesh depends on the type, and is different according to the aggregate used. The usual dimensions of mesh are shown in Table 1.

As the Retiflex® net has a large specific surface it binds very well with the mixture[9]. Using **steel fibres** in concrete, the following conclusions can be drawn regarding the bond behaviour of fibre reinforced concrete with and without silica fume: (1) The pullout failure type is usually obtained for #3 bar specimens with or without steel fibres. (2) While an explosive splitting of concrete type of failure occurs for bar diameters greater than 16 mm (#5) without steel fibres, this failure becomes more ductile with the inclusion of steel fibres. (3) The addition of steel fibres contributes a little to the bond strength of specimens with small bar specimens, (9.0 mm [#3]), because the failure is due to the collapse of compression struts not greatly strengthened by steel fibre. But the presence of steel fibres, giving an effect comparable to confining concrete, has a more effective contribution to the bond strength of larger bar specimens (#5 and up). (4) The presence of silica fume enhances the bond strength. (5) The slip value corresponding to the maximum pullout load increases with the addition of steel fibre[10].

Identification of Scopes of Application of Fibre for Reinforcement of Concrete

As mentioned earlier, the concept behind fibre reinforcement of concrete has been used in a wide range of applications. While such reinforcement has the potential of improving the property of concrete in various manners, the engineers must be judicious in such applications and should not treat fibre reinforcement to be magic solution to every problem, limitation and shortcoming in concretes. There are also some major features that must be taken seriously into cognizance while contemplating the use of fibre reinforcement in concretes. Some of the major features of fibre reinforced concrete and its application are briefly elaborated below: (a) Fibre reinforced concrete can be used as alternative to welded wire fabric or non-structural temperature reinforcement. This is a very important characteristics of this material for use in boat manufacturing. Results of the laboratory test indicate that substituting synthetic fibre in place of welded wire fabric at a rate of 0.65 kg/cubic meter of concrete yield an equivalent flexural strength capacity of the slab and equivalent load deflection relationship. (b) Although use of fibre in concrete results in a synergistic with structural,

load bearing, moment steel but should not be used as replacement of conventional reinforcing steel reinforcement. (c) Since typical temperature steel is included in most of the designs as non-structural secondary reinforcement, high strength synthetic fibres can be used as alternative to temperature steel in concrete structures. (d) In some cases, steel reinforcement is used both for structural purpose and strengthening of the matrix. Synthetic fibre reinforcement in concrete should not be used as an alternative to this combination steel since the fibres can only fulfill the functions of strengthening of the matrix, not the structural ones. (e) Synthetic fibres can be used in slabs on grade as an alternative to welded wire fabric. In fact, the synthetic fibre is in some respect superior to the welded wire fabric in this purpose. This is because the welded wire fabric does not carry structural load but prevents or restricts the cracks occurring in the top surface. Thus the welded wire fabrics would have best served the purpose would it have been placed just on the surface. For practical reasons, welded wire fabrics cannot be placed so. However, the synthetic fibres can be placed just on the surface and also randomly oriented in all directions effectively preventing and resisting cracks in all directions. (f) Extruded concrete can benefit from synthetic fibre reinforcement by retaining the vertical alignments of the freshly extruded concrete. Synthetic fibres used in this type of application should be chosen for their ability to uniformly mix throughout the concrete and provide the needed vertical alignment, while providing all the benefits of a quality engineering synthetic concrete reinforcing fibre. However, the implication of this characteristics in manufacturing of concrete boats with the help of guniting is not yet clearly understood. Apparently, some features indicate that this property is going to positively influence the end product while it is feared that if most of the fibres remain in vertical direction (direction of extrusion), it may somewhat curtail the crack resisting property. (g) Synthetic fibres may be used as an alternative to welded wire fabric in composite metal deck assemblies where the welded wire fabric is designed as temperature reinforcement. However, this should be done only after proper testing. (h) Synthetic fibres for concrete construction in pumping process, addition of such fibres may provide additional lubrication, reduce segregation and decrease bleeding when appropriate admixture is added. This is a property considered helpful for boat-building process. (i) Temporary structures gain the plastic and hardened concrete benefits of synthetic fibres reinforcement of concrete while in service and are often easier to dismantle, because that fibre aids in holding broken concrete prices intact for disposal. (j) Shotcrete and gunite applications benefit in additional ways besides the plastic and hardened concrete perks of synthetic concrete reinforcing fibres. Thicker one pass application and less rebound are achieved with synthetic fibre concrete reinforcing application. (k) The special mix design in the pre-cast industry or low or no slump, quick mixing times and fast stripping practice require the appropriate synthetic fibre selection for concrete reinforcement. (l) The abuse concrete is subjected to in marine environments is best remedied with the use of synthetic concrete reinforcing fibres as secondary reinforcement. Welded wire fabric in marine environment is contaminated and deteriorates rapidly exposure to the salt spray, continual saturation and marine flora. Most of the synthetic concrete reinforcing fibres are chemically inert. (m) Shatter resistance and added toughness are two of the major contributions to tilt-up construction synthetic concrete reinforcing fibres offers. All the plastic and hardened concrete attributes to synthetic fibre reinforcements of concrete aid tilt-up concrete. (n) Neither integral nor surface colour is hampered by the synthetic fibres. (o) The dual use of the primary reinforcement (rebar) and synthetic fibres delays the time of initiation and amount of rebar corrosion as well as providing the benefits of both systems. This characteristic of the synthetic fibres makes it a very strong candidate for use in improvements in conventional ferro-cement. (p) Tapping applications are generally improved with the use of synthetic fibre reinforcement on concrete. This is due to the fibres' multidimensional uniform distribution. The single phase contribution of the welded wire fabric makes it almost impossible to properly locate within a thin topping slab. This feature of synthetic fibre reinforcement of concrete makes it suitable for boat-building purpose. (q) All synthetic fibres may be used in exterior concrete. Synthetic concrete reinforcing fibres are chemically inert and the concrete encapsulated fibres are unaffected by the long-term exposure to the elements. (r) Synthetic fibre reinforcements in vertical walls can replace welded wire fabric when the welded wire fabric has no negative moment assigned to the design. The uses of synthetic reinforcing fibres in vertical walls provide reduction in plastic shrinkage, lowered permeability, added toughness and all the other attributes of

synthetic fibre concrete reinforcement. (s) Foamed concrete is a very light and cellular concrete manufactured with the addition of a prepared foam or by the generation of gas within the hardened concrete. Foamed concrete requiring reduced plastic cracking, increase shatter, abrasion and impact resistance and reduced permeability should use synthetic fibres for reinforcement. (t) Fibres used in masonry cement aids in better bond of the mortar to the masonry unit. Appropriate synthetic fibres for concrete reinforcement designed for masonry use are typically recommended for this application. (u) Test data indicate that synthetic fibres help the wells and early handling concrete block. Also, synthetic fibres aid in better bond of concrete mortar to the unit. Application of synthetic concrete reinforcing fibres results in increased freeze-thaw resistance, reduced plastic crack formation, increased cohesion and increased shatter resistance with added toughness when used in plastering. When applied to scratch coat and concrete finishing, synthetic concrete reinforcing fibres also yields similar benefits.

Experimental Work to Develop the Skill and Techniques in Manufacturing Section with Fibre Reinforced Concrete

Enriched with the findings on fibre reinforcement of concrete, attempts were made for manufacturing and testing of some fibre reinforcing concrete boats using this technology. It is emphasized that before a boat can be built, various design exercises have to be carried out. However, a fundamental requirement was the development of skill and techniques required for producing a concrete matrix possessing the required properties. A fibre reinforced concrete that is to be used for any practical purpose must possess the following properties: (i) The fibres, which are generally available in lumps, must be separated from one another so that it does not make a lump in the concrete matrix. If lump formation is not avoided, this will not only fail to produce the required reinforcement but will also create internal flaws in the matrix. (ii) The fibres must be uniformly dispersed in the matrix in all directions. This is essential to achieve one of the basic objectives of use of the synthetic fibres; enabling the concrete to resist/restrict cracks in all directions. (iii) The good dispersion of fibres in the concrete must be achieved with the water-cement ratio ensuring the highest strength of the concrete. Generally, use of water in higher proportion results in better dispersion of fibres and also good workability but that makes the concrete too weak. Thus this concrete must be manufactured with the minimum amount of water-cement ratio. (iv) There are a number of types of fibres used for concrete reinforcement. The properties like viscosity, surface roughness, cohesion, adhesion of these fibres are different. Thus, mixing and dispersing various types of fibres in concrete requires various care and precaution to be taken. This was considered essential that the technicalities special to each of the fibre types that will be tested must be clearly understood before the actual boat-building is done.

Although various types of cements have been used along with fibre reinforcements, the experiments in the study have been restricted to ordinary portland cement (OPC). This is because one of the basic objectives of the study is to evolve a material, the raw material of which is as easily available as possible. Since none of the fibres used for concrete reinforcement is easily available in Bangladesh, nothing can be done about it. However, since OPC is readily available, it will be most beneficial if the raw material can be confined to this type of cement. With the above objective in mind, work was undertaken with various types of fibres by manufacturing various test slabs.

It may also be mentioned that in the most common applications of the synthetic fibres, there are huge amount of concrete works and massive equipment are used in the process. The machines used for mixing the fibres with the concrete is also large. Whereas in this case, the volume to be handled is small and the machines and systems ordinarily used in fibre reinforced concrete construction cannot be used. Thus the mixing process has to be done by hand to ensure proper dispersion of the fibres.

The experimental slabs were broken and examined under magnifying glass to observe the dispersion of fibres and then was tested for strength. The mechanical strength was in line with the different results published by various authors referred in this paper. However, no conclusion can be derived from the results since the specimen were of different concentration and types of fibres and the water-cement ratio was also varying. Hardly two specimen were of the same specification. Also, the main objective was to ensure segregation of the individual fibres from the bundles and uniform dispersion in the matrix. Also optimum water-cement ratio was aimed at. The observations from the experience are summarized as below: (a) The polyethylene fibres

(0.5 inch and 10-15 microns) can be easily separated by rubbing by hand a polythene bag containing the fibres. Occasional striking of the bag is helpful. Extreme care has to be taken that the bag is not exposed to environment firstly because the fibres being too small will be lost in air and secondly, the fibres being injurious to the respiratory system, this may cause damage to the workers due to inhaling the same. (b) The polypropylene fibres (0.75 inch and 12-16 microns) are more cohesive and thus has to be rubbed with hand if the lumps are to be loosened for mixing with concrete. Other care has to be same as in the case of polyethylene. (c) It is easier to mix the fibre with the sand-cement mixture than with the cement or sand only. The fine grains of the cement creates dust when attempt is made to mix fibres with the same. It is easier to mix the fibres with the complete dry sand but practically speaking it is difficult to find a sand in this condition. With little moisture in the sand, it becomes very difficult to move fibres from places where it first comes into contact with the sand. The sand-cement mixture removes most of these problems. (d) Water-cement ratio is a prime factor behind the strength of the concrete. But this matter is somewhat elusive. Actually, the moisture content in the sand is an important factor. Practically, no sand can be found free from water, but this moisture content is never taken into account when calculating water-cement ratio. Thus experience based judgment remain the most useful tool. (e) Dispersion of the fibres in the matrix has been found to be most easily achieved for a water-cement ratio of 0.70. The adhesion force between the matrix and the fibres appears to be minimum in this case. However, this water cement ratio has been considered poor from the point of view of strength. (f) For a mixture of 10 kg of cement, 20 kg of sand, 5 kg of water and 1.5% of polyethylene fibre, satisfactory mixing of the fibre with the matrix has been achieved in 15 min mixing by hand. Whereas this mixing time is found to be 23 min for polypropylene fibres in the same proportion and other ingredients remaining same. (g) Due to absence of a vibration suitable for the application, manual measures have been found to be inevitable for avoiding voids in the matrix. Extreme care has to be adopted during the casting. Voids are mostly observed in the central region of the casting and in the middle layer.

Manufacturing of some Practical Hulls of Conventional Country Boat Geometry using Fibre Reinforced Concrete

Applying the findings and experiences described above, attempts were made to manufacture some boats of practical size using the fibre reinforced concrete under various configurations. It was also decided to manufacture boats of exactly the size and shape of boats lying in the Sadarghat area of Dhaka. Prior to deciding the details of the boat, a typical model boat (body plan is shown in Fig. 1) was purchased for detail measurement of the shapes, offsets, reinforcement details etc.

The production of the boat was preceded by a detail design as shown in Fig. 2. As regards the shape of the boat is concerned, the traditional shape was maintained for several reasons. Firstly, this traditional hull shape is an outcome of hundreds of years of tradition. There can be no basis in apprehending that the hull shapes developed by the 'illiterate' boat-builder is a faulty one. There can be some scopes of improvements in the design of the hull but that has to be identified by thoroughly investigating the existing design. This has to be followed by evolvement of measures to offset the identified drawbacks in the existing design. Moreover, it has to be ensured that the suggested remedy does really work in all practical respect in the real life. Thus, no attempts were made to change the hull shape, rather only the material of construction.

The boats built for the study were of 1100 kg capacity. The hull of the boats was approximately 12-15 mm thick. The cement sand ratio was 1:2 and water cement ratio was 0.50. Although water-cement ratio of 0.35 was treated optimum from the point of view of strength and 0.70 was found optimum from the point of view of fibre dispersion as well as workability, a compromise was reached at a ratio of 0.50.

During the manufacturing of the boats, convex moulds were used. This was because it was considered to be the easiest and also convex moulds are also used in FRP boats since the reinforcement in forms of ribs are to be inside the hull. The boats were lifted from the mould after 15 days of curing and were floated in water then. The shell of both the boats are smooth from both inside and outside. Thus the hull is a pure shell without any shape reinforcement i.e., ribs. The length, breadth and depth of the boats are 22 feet ×4.75 feet ×2.75 feet respectively. Photographs of the

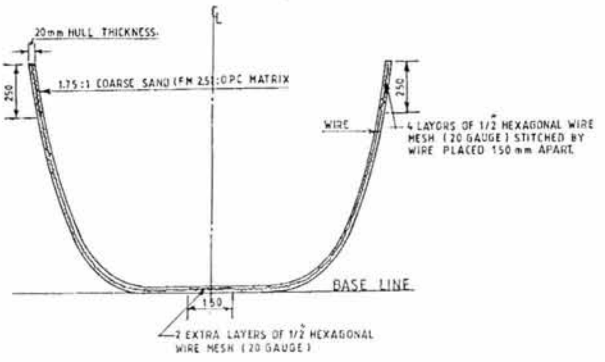

Fig. 2—Section of the fibre reinforced concrete boat (22×4.75×2.75 ft)

boats are shown in Fig. 3. The features of the individual boats are elaborated below:

Boat no. 1 developed problems during lifting from the mould and serious cracks in line of the stitch of the nets in the transverse direction. This happened apparently due to poor penetration of the matrix in these locations. The boat ultimately broke into pieces. The lightweight of the boat was within +10% of the wooden boats if same size and shape.

Boat no. 2 showed some signs of very light leakage in the midship portion of the hull after about one-month in water. Upon investigation, it was revealed that some stress might have developed in the boats due to improper handling during lifting from the mould. A concrete fender fitted showed signs of major cracks and thus a wooden fender may be recommended.

Due to higher cement concentration used, **boat no. 3** had a slightly more self-weight. Locations of some extra reinforcement showed signs of slight water ingress. The impact resistance showed much improvement. Some cracks were developed at the root of the goloi which was taken care of in the later boats. The strength at the root of the goloi in **Boat no. 4** did not prove remedial even after extra strengthening with high-tension wires. Since very careful application of mortar resulted in lighter hull thickness, the self-weight was about 5% higher in this boat compared to wooden boats. Still there were no signs of cracks or water leakage.

Boat no. 5 was tried with a new type of amorphous metal fibres used with concrete in civil engineering applications. The characteristics of the fibres were somewhat plastic in apparent nature but had a very high elongation at rupture. Due to the size of the fibres, hand laying was used. The average thickness of the hull was 19 mm. However, the boat

Fig. 3—Photographs of some manufactured fibre reinforced concrete boats.

disintegrated few days after manufacturing. It was later identified that due to improper acid washing required before suing the fibres, there were serious problems related to the adhesion between the fibres and the matrix and thus the specimen disintegrated quickly.

In the case of **Boat no. 6,** the thickness was of an average of 21 mm, slightly more than the previous boats, apparently due to one added layer of mesh. The strengthening of the connections with the goloi,

however, remained same and did not show any improvement. Cracks initiate very soon. There were also no appearances of seepage in the hull. Any improvement in the strength of the hull due to the one additional layer of wire mesh could not be verified within such a short period.

In the **Boat no. 7**, a basic change in the design of the goloi showed some improvement in anti-crack strength. The connecting section was replaced with strong shells strengthened with two additional layers of wire mesh further strengthened by more compact weaving with the help of high-tension wires. However, any future design must take care of any users in this aspect.

Short Term Performance of the Boats

The final success of the exercises will be established once the boats perform successfully in long term and in real life conditions. However, it may be recalled that this phase of the exercise was aimed at establishing the viability of manufacturing boat hulls with an acceptable self-weight and initial strength. Once this is established, further experiments may be undertaken to manufacture a considerable number of boats to be operated in real life environment for a significant duration. The performances are to be recorded and analyzed systematically. However, within the short time available under the time frame of the study some indications of its time-based performance have been achieved which are reported below: (i) The impact and abrasion resistance did not show any deterioration up to two years after its manufacturing. However, the time available is not enough to make any conclusive judgment. Some local damages were observed in places of heavy impacts. Some systematic recordings are required for a considerable span of time and the same needs to be compared with the wooden boats to compare the same as common platform. (ii) There has been no evidence of weakness in the overall strength of the boats. (iii) The matter of strength at the root of the goloi needs to be studied and experimented more carefully. (iv) Some impacts have caused local damages in the hulls. This can, hopefully, be remedied by some structural redesigning to improve the local strength. Necessary repairs have been made by using fibre concrete. It is also to be examined if such repairs can be done without use of fibres since this material is not available everywhere. If any repair is possible without fibre, it may be preferred even if the resulting strength is somewhat less than the fibre added option because of lack of availability of the same in remote places. However, this may be treated to be a temporary solution and major repairs may be undertaken at a convenient place and time. (v) Some deterioration in the sheer (upper side edge) line has been detected. This can also be remedied by trying various alternatives. (vi) Sufficient time has not been available to record the long-term performance of the strength situation at the goloi. (vii) The necessity has been felt for providing some extra strengthening at the places rowing attachments are to be fitted. (viii) The necessity of a broadened sheer line was felt which is required to facilitate the operator to move from one end of the boat to another when there are passengers on board. This can be achieved by bolting a wooden bar of required thickness that can work as a fender as well. (ix) Even with the high abrasion resistance achieved in the boats built, there will always be some abrasions just below the sheer line of the boats. There may be a necessity of some re-working after 2-3 years. An appropriate method for the repair, preferably with fibre reinforcement, is to be evolved. (x) Some temporary seating arrangement of passengers were made in these experimental boats by making extended support bases for the beams. While this may be a temporary solution, an efficient and dependable means have to be evolved. (xi) It has been suggested to employ bolting for connections of many of the fittings with the hull. The method of such bolting have to be examined, especially in terms of local strengths. (xii) The, performance of the fibres especially in sunlight and exposed environment or its chemical reaction is not required to be investigated since the fibre reinforcement is meant for such situations. (xiii) The durability of the fibres in the concrete is not a point of concern since fibre reinforced concrete is in use for more than 20 years. (xiv) However, any dependable evaluation of long term performance of the boats must be based on systematic and long-term recording assessment of a real life performance of these boats. A second phase of the study may be taken up to undertake the same.

Costing of the Boats

The average cost of the boats as incurred in the study is shown in Table 2. It may, however, be remembered that this cost is not the realistic cost of the boat in real market condition. Being an experimental study, there were many trials and errors. There was wastage as well since the workers were not acquainted with the works. Many labour hours were

lost in trying to do the things in various ways. Once the boats are established to be economically viable and the construction methods and techniques are standardized, the cost will be coming down significantly. In such a situation, the materials can be ordered bulk with the price advantage due to the scale of the purchase. The price of the boats under such a manufacturing process is indicated in Table 3. The price of an equivalent wooden boat using various types of timbers is shown in the Table 4 as well. This table also shows that a fibre reinforced concrete boat would cost 4% more compared to a boat built with mango timber (most inferior quality of timber). On the other hand, the concrete boat would cost 43% less compared to a wooden boat made with garjan wood (the best quality timber for the purpose with a price of Tk. 800/cft.). The comparison with some other types of timber is also given in the Table 4. The figures shown in Table 4 are the initial cost of only the hull. There are some other fitting required, mainly the passenger platform, which is essential for operation. However, the main cost benefit that is expected to be derived from these proposed boats, if found otherwise technically viable, is the extremely low repair and maintenance cost. The benefits of the low cost timbers is vanished very fast and major repairs costing more than 50% of the initial cost is required within 2-3 year of operation. In the case of these boats, the cost of annual maintenance is insignificant.

Conclusions

The results achieved in the study have adequately

Table 2—Direct material and labor cost incurred for each boat under the study

Item	Quantity	Unit	Unit Price (Tk.)	Cost (Tk.)
Cement	6	Bags	250	1,500
Sand	13.5	Cft	22	297
Hexagonal wire mesh	505	Sft	6.5	3,283
High tension steel wire	2	Kg	50	100
Polypropylene fibres	0.45	Kg	900	405
Semi-skilled labor (man-days)	10	man-days	100	1,000
Miscellaneous				200
Total				6,785

Table 3 —Costing of the boats in a commercial boat building yard

Item	Quantity	Unit	Unit Price (Tk.)	Cost (Tk.)
Cement	3.5	Bags	250	875
Sand	10	Cft	18	180
Hexagonal wire mesh	360	Sft	4	1,440
High tension steel wire	2	Kg	40	80
Polypropylene fibres	0.35	Kg	800	280
Labor (semi-skilled)	3	man-days	100	300
TOTAL DIRECT COST				3,155
Overhead and miscellaneous (25%)				789
TOTAL INCLUDING OVERHEAD				3,944
Profit (10%)				394
TOTAL INCLUDING PROFIT				4,338

Table 4—Costing of a traditional timber boat using various timbers and comparison with fibre reinforced concrete boats

Item	Mango @ Tk. 375/cft	Jackfruit @ Tk. 550/cft	Sundari @ Tk. 650/cft	Garjan @ Tk. 800/sft
Timber (7.5 cft.)	2625	4125	4875	6000
Patam, Gajal, coal tar	500	500	500	500
Labor (7 days @ Tk. 150/day)	1050	1050	1050	1050
TOTAL	4175	5675	6425	7550
Cost of a fibre concrete boat (-less or +more)	4%	-24%	-32%	-43%

demonstrated that the fibre reinforced concrete is a viable material for manufacturing of small boats. The overall, impact and abrasion resistance has been found to be satisfactory. The technical viability is mere the first step towards establishing such viability. The follow up steps are the economic viability over its entire life cycle. The users' satisfaction, their response, acceptability etc. are vital components of such viability.

The study has established the primary technical viability for the material considered. With the success achieved, it may be recommended to undertake the follow-up investigations. Such an investigation should consist of manufacturing of considerable number of boats that should be put into real life operation. The performance of such boats is monitored to obtain the following feedback information.

- The technical performance of the boats in terms of local and overall strength, impact and abrasion resistance, ease of operation etc.
- Response of the boat operators and the passengers.
- Improvements felt useful or necessary by the passengers and boat operators.
- Acquisition of data on economic performance in terms of repair and maintenance costs.
- Development of means for further improvement in design and construction of the boats so as to make them stronger and cheaper.
- Any other item considered important.

The success in evolving a viable alternative will help hundreds of thousands of boat owners of the country on one hand and will help reduce cutting of trees for manufacturing such boats and this help protect the environment.

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