Design and Construction of a Reinforced Plastic Oar for Use in Competitive and Recreational Rowing

JOHN H. PRINSEN

Industrial Materials Research Institute
National Research Council Canada
Boucherville, Québec, Canada J4B 6Y4

and

GRAHAM WILKINS

Paluski Boats
Peterborough, Ontario, Canada

In 1982 Paluski Boats with the assistance of the National Research Council of Canada, embarked on a project to design a reinforced plastic oar. The problems to be solved involved not only the construction of a shaft of sufficient strength, but also the development of a light and durable F.R.P. blade, as well as fixing to the pole a suitable strong and adjustable pivot point. The shaft was manufactured, borrowing techniques developed for ski poles and windsurfing masts, in the form of a tapered epoxy and carbon-fiber pole. The blade was formed with an outer shell of epoxy and fiberglass laminate which was then filled with a two-part structural foam. The pivot point, or 'collar/sleeve assembly' was made by molding around the shaft a solid section of polyurethane. The new plastic oars are lighter, less-expensive, need no regular maintenance and are practically impossible to break.

INTRODUCTION

The use of reinforced plastics has made radical changes in the design of equipment for many sports as a replacement of traditional, usually wood products. Skis and ski poles, sailing hulls and masts, poles for pole vaulting are examples. Tentative steps have been made to introduce plastics in the manufacture of rowing boats and equipment, and the purpose of this paper is to describe the development of a reinforced plastics oar.

In general terms, the problem is to determine how to apply the technology of reinforced plastics to the manufacture of high quality, precision designed oars for competitive, training, and recreational use at low capital and maintenance costs.

The traditional method of oar construction is to laminate wood strips into a single piece that is then turned and shaped into an oar. Extensive handwork is required in the manufacture and finishing and the result is an expensive product with a number of definite weaknesses. The fragile blade is easily chipped or broken and the shaft requires constant upkeep in the form of sanding and refinishing to retain the necessary stiffness. Repairs of laminated wood oars are difficult and blade replacement virtually impossible.

This paper describes the design and construction of a high performance racing oar using both carbon fibers and fiberglass reinforcements. This product was made possible through the financial and technical assistance of the National Research Council of Canada. Subsequently prototypes of more economic all fiberglass oars for training and recreational use were made. A reinforced plastic oar basically consists of a reinforced plastic tube, a wooden handle, a reinforced plastic blade, and a plastic collar/sleeve assembly.

BASIC DESIGN CONSIDERATIONS

A typical oar is shown in *Fig. 1*. The most crucial part of an oar is the long central part. To analyze the mechanical properties of an oar, it may best be considered as a beam fixed at the pivoting point and loaded at the free end.

The average stiffness of the central part of a wooden oar, which is the part that corresponds to the reinforced plastic tube of the reinforced plastic oar, was determined experimentally and found to be typically 8,000 Nm^2. Hence, the stiffness of the reinforced plastic tube should be at about the same value. The relationship between stiffness, bending moment, and amount of deflection for a beam is the well known formula (1):

$$EI \frac{d^2y}{dx^2} = M \qquad (1)$$

Where:

E = modulus of elasticity, MPa
I = moment of inertia, m^4
x = distance from fixed point, m
y = deflection, m
M = bending moment, Nm

For a cylindrical tube, I is constant and *Eq 1* can easily be integrated, yielding:

$$Y_m = \frac{PL^3}{3EI} \qquad (2)$$

Where:

Y_m = maximum deflection at the free end, m
P = force executed at the free end, N
l = length of the tube, m

If we compare the plastic tube with the wooden oar, and we want the same stiffness for the two, then it is obvious from *Eq 2* that the following condition should be met:

$$(EI)_{tube} = (EI)_{wood} = 8{,}000\ Nm^2$$

The following design procedure was followed. Consider a range of tube diameters and tube wall thicknesses and calculate for each combination (a) the modulus required to arrive at $(EI)_{tube}$ = 8,000 Nm^2, and (b) the weight of the tube using fiberglass or carbon fibers or a combination thereof in an epoxy matrix.

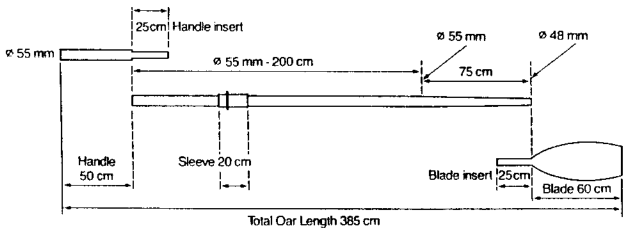

Fig. 1. Reinforced plastic oar/component parts.

The results are shown in *Table 1*. Since the total weight of the oar, including handle and blade should not exceed the weight of a wooden oar, i.e., 4.0 kg, the weight of the tube alone should not exceed 2 to 2.5 kg. Typical moduli for carbon and fiberglass reinforced epoxy are 80,000 and 30,000 MPa respectively (2). Based on these restrictions we can right away exclude the all fiberglass tube. An all carbon tube of 50 mm diameter and 2 mm thick is possible, but not very practical because of poor impact and high cost. Only two acceptable combinations remain, namely a diameter of 50 mm with a wall thickness of 3 mm, and a diameter of 60 mm with a wall thickness of 2 mm, using a 50/50 mixture of carbon and glass. The average of these two combinations, namely an outside diameter of 55 mm and a wall thickness of about 3 mm was chosen because it constitutes a good compromise considering various factors such as weight, impact, cost and, last but not least, acceptance by the rowing community.

The maximum tensile and compressive stresses occur at the fixed end of the oar and may be calculated from the following equation:

$$stress\ max = \frac{Ms}{I}$$

Where:

s = distance from the neutral plane.

The typical force applied by a rower using his two arms is evaluated at 830 N (3) which corresponds to a bending moment M = 1080 Nm. For a wall thickness of 3 mm and a diameter of 50 mm this results in a maximum stress of 180 MPa, which is well below the maximum allowable level of 500 MPa for carbon reinforced epoxy.

Since the maximum stresses would be much lower toward the free end of the oar, a tube with a slight tape, toward the end was finally chosen

Table 1. Required Modulus *vs.* Weight for a 2.75 m Long Reinforced Epoxy Tube.

Diameter	Wall Thickness (mm)	Moment of Inertion (m^4)	Modulus Required (MPa)	Weight of Tube (Kg)		
				Fiberglass	50% glass/ 50% carbon	Carbon fiber
40	1	2.5×10^{-8}	318,000	0.74	0.65	0.57
	2	5.0×10^{-8}	159,000	1.48	1.31	1.14
	3	7.5×10^{-8}	106,000	2.24	1.99	1.72
	5	1.2×10^{-7}	63,000	3.72	3.28	2.85
50	1	4.9×10^{-8}	162,000	0.93	0.82	0.72
	2	9.8×10^{-8}	81,000	1.86	1.64	1.42
	3	1.4×10^{-7}	54,000	2.80	2.47	2.14
	5	2.4×10^{-7}	32,000	4.64	4.10	3.56
60	1	8.4×10^{-8}	94,000	1.11	0.98	0.85
	2	1.6×10^{-7}	47,000	2.24	1.98	1.72
	3	1.5×10^{-7}	31,000	3.35	2.96	2.57
	5	4.2×10^{-7}	18,000	5.57	4.92	4.27

in order to gain maximum weight savings. More complex calculations show that this taper has a positive be it rather marginal effect on the stiffness of the tube.

CONSTRUCTION

From *Fig. 1* we can see that the oar was constructed using four separate components: the shaft, the blade, the sleeve/collar, and the wooden handle. As a result four different construction methods were developed.

The *shaft* was made on the filament winding machinery used by Exel Canada to manufacture ski poles and sail boarding masts. The shaft comprised four different fiber layers, each layer using a vinyl-ester epoxy resin, as shown in *Fig. 2*. The first layer of glass-fibers was pulled along the longitudinal axis. The second and third layers were also glass-fibers wound in opposite directions around the shaft. It was with these two layers that extra reinforcement was added to the shaft wall in those areas requiring maximum strength, namely at those points were the other three components were attached. *Figure 3* shows how the speed of the winding machine is varied to obtain this effect. The final layer was made of carbon-fibers pulled along the longitudinal axis. A constant ratio of 75/25 percent fiber to resin was maintained by wrapping the exterior of the shaft with a polypropylene tape, which was later removed. The required stiffness was attained with an almost equal amount of carbon and glass fibers.

The *blade* required had some severe design restrictions. It had to maintain the stiffness achieved in the shaft, have additional impact strength as it was the "working" part of the oar and most likely to be damaged, and it had to have a thin cross-section for clean entry into the water. These requirements were achieved by hand laminating into cold molds exterior skins of glass cloth with epoxy resin. Before these exterior layers had hardened in the molds, the molds were clamped together and the interior cavity was filled with a low density structural foam. To further stiffen the blade in the longitudinal direction a 12 mm hollow fiber tube was inserted into the cavity and encapsulated into the foam core.

The *sleeve* was needed so that the oar had a "flat" side that was at the same angle as the front edge of the blade, (see *Fig. 4*). This flat edge was needed for a distance of 20 cm along the shaft to allow for the adjustment of the collar (this allows for the adjustment of the oars pivot point). Given that the outside diameter of the shaft at this point was 55 mm and the maximum outside diameter of the sleeve was 65 mm it was found that a suitable core could not be made to achieve a suitable strong sleeve. It was found that thermosetting polyurethane plastic could, however, be hand poured into molds that clamped together around the shaft.

The *handle* was turned to the required shape from kiln dried sections of Ontario poplar. The length of the insert was varied in order to obtain a well balanced oar, with the center of the gravity at the same point as for a wooden oar, which is just about in the middle.

TESTING OF THE OARS

The plastic oar was designed to replace the strongest wooden oar available. As *Fig. 5* illustrates, wooden oars usually are very "stiff" when first constructed and as they are used gradually allow greater amounts of flex. Typically, new wooden oars are used by the strongest, heavier crews and then passed on to the lighter crews as their flex increases.

Our test was designed not only to measure the performance of the oar but also to gage the

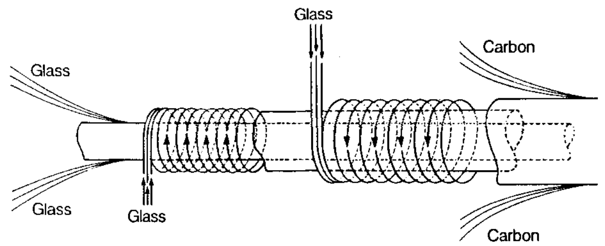

Fig. 2. Shaft construction showing three layers of fiberglass and final layer of carbon fibers.

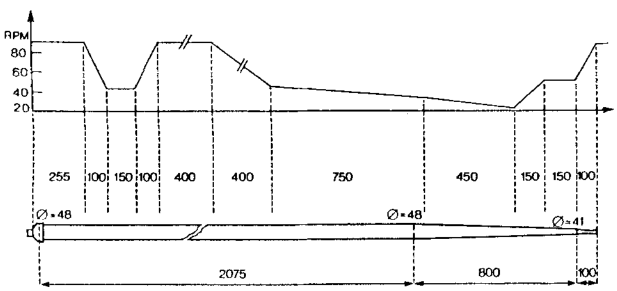

Fig. 3. Density of two cross wound layers of fiberglass is varied to obtain local extra reinforcement.

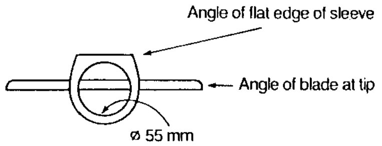

Fig. 4. Blade/sleeve angle.

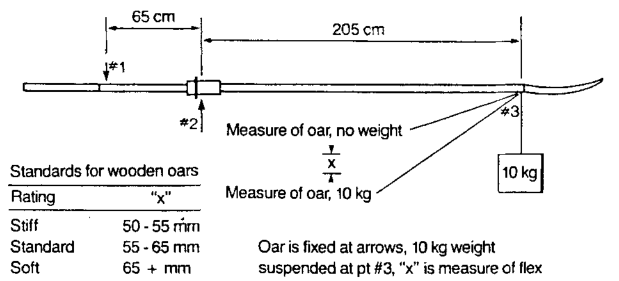

Fig. 5. Flex test for rowing oars-standard results.

reaction of the competitive rowing community. Of the 44 oars tested, half were used by heavier stronger crews and half by lighter and less experienced crews.

The oars were visually examined regularly and the standard flex test explained in *Fig. 5* was repeated regularly. Also the oars were checked to determine if any twisting had occurred, that is that the angle between the blade and the sleeve had remained constant.

During the time of a regular rowing season none of the oars showed any noticeable increase in flex. One oar was found to have an increasing angle between the blade and the sleeve—the fault in this instance was found to be in the laminated blade, which was replaced. A second blade had to be replaced on one oar that had been damaged as a result of a collision.

The athlete's reactions to the oars were very interesting. Although we knew from measuring that the oars were anywhere from 0.25 to 0.5 kg lighter than wooden oars, a persistent initial comment was that the oars "looked heavy". The extreme stiffness of the oars also re-enforced this observation, especially for the crews more accustomed to oars with greater flex. Also the wooden oar is built with a more pronounced taper than the shaft we used. This athlete "resistance" seemed to wear off quite rapidly and the oars were used for the entire rowing season and were especially appreciated for their durability.

CONCLUSION

The construction of a reinforced plastic oar proved to be a valuable and successful project. For each design problem an effective and cost efficient solution was found. The oar performed as expected and appears to provide a better alternative for the fragile wooden oars presently being used.

REFERENCES

1. J. G. Williams, "Stress Analysis of Polymers," 2nd Ed., Ellis Horwood Limited.
2. John Delmonte, "Technology of Carbon and Graphite Fiber Composites," Van Nostrand Reinhold Company.
3. Unpublished experimental study done at the Ecole Polytechnique de Montreal.