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TESTING THE UNCONVENTIONAL; THE ERGONOMIC PADDLE SHAFT

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Abstract: The use of composite materials in sports equipment has enabled design engineers to revolutionise their products. This is seen in all sports from cycling to skiing, climbing to kayaking. Along with performance enhancement products are also being designed with ergonomic considerations that reduce athlete stresses and support injury prevention.

One aspect of product innovation seen to lag behind some radical new designs are the techniques to test or measure the equipment performance. A product that falls into this category is the ‘Crank’. The ‘Crank’ is an adaptation of the kayak paddle shaft which has been designed to relieve stress in the wrists and forearms of the paddler.

This work investigates standard mechanical methods used to test flexural properties of the paddle shaft and then looks at adapting this standard to the ‘Crank’.

This investigation shows that use of a symmetrical loading test is not suitable given the geometry of the ‘Crank’. The unsymmetrical test method proposed here in conjunction with the improved testing apparatus is proven to be suitable for use as a standard testing regime.

The test method used here would be suitable for providing mechanical data comparable for custom shafts such as the crank and could be further developed as a tool for both performance and product benchmarking.

Key words: Crank, innovation, kayak paddle shaft, mechanical properties, testing method.

1- Introduction

Paddle shafts are traditionally tested using a three point bend setup, either with or without the blades attached. This provides an indicative measure of the mechanical properties of each paddle and/or shaft. As the flexural test creates both tensile and compressive stress within the shaft it is the ideal method to be used for destructive or non-destructive testing and will also approximate in use loading. Current quality control and performance assessment methods utilise the expertise of the manufacturer and were often developed in-house over a number of years. These in-house methods may not be conducive to innovation and product development, especially where unconventional shaft designs and composite materials are used.

2- Background

Kayak paddles were conventionally made from wood using lamination and/or solid fabrication techniques that allow the grain to run longitudinally along the shafts axis. Wooden paddles are still being manufactured today and while some paddlers consider them outdated others still prefer the look and feel, especially for canoeing and rafting where there is only one blade attached to the shaft. Aluminium is widely used in shaft production and was once the material of choice but has since been relegated to entry level paddle construction only. Glass fibre reinforced thermoset composite; the material of choice in the 1980s was quickly superseded by the superior specific properties offered by carbon fibre. Glass fibre is still the main shaft material and is widely utilised, in combination with advanced reinforcement materials such as carbon and aramid fibre, due to its impact resistance when used in thermoset resins. Elite sports people will generally specify full carbon for its lightweight and stiffness regardless of reduced durability and the extra costs.

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3- Technical problem

Conventional paddle shafts are straight thin walled tubes with a round cross section uniform through the entire length. They may also be ergonomically formed to have an elliptical section with the ends feathered to aid the natural paddling action. A more recent adaptation of the paddle shaft (Figure 1) improves the ergonomic factor by cranking the shaft, at the hand grip position, relative to the main axis of the shaft. It is said that by cranking the shaft the wrist is kept straighter which reduces the strain on the forearm, improves performance and reduces fatigue [D1]. The tension in the tendons that run from the fingers, across the wrist, and connect to muscles in the forearm (Figure 2) is also reduced.

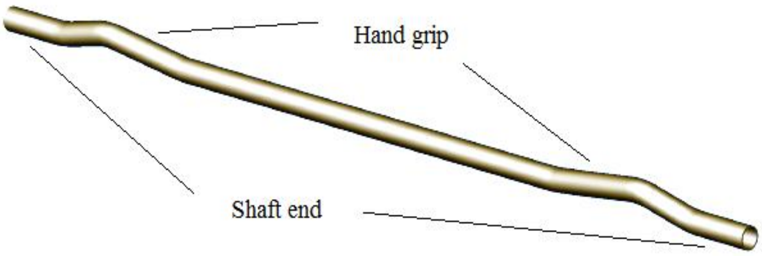

Figure 1. 'Crank' paddle shaft

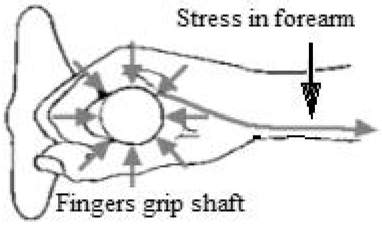

Figure 2. Clamping pressure on the paddle shaft creating stress in the forearm tendons [D1]

Following the design and implementation of the 'crank' paddle shaft it has been found that conventional testing methods are not suited to the new design. While some testing agencies may provide performance verification after manufacture there is no benchmarking available to determine a comparative standard to the conventional shafts. Employing an external testing agency can also be extremely expensive for the manufacturer and prohibitive where tests for the conventional are conducted in-house.

4- Proposed solution

The performance of the 'crank' paddle shaft needs to be equal or better than the conventional shaft in order to provide a high performance alternative worth any increased cost. Although it has been shown that improved performance is not merely a mechanical property, even an improvement perceived by the athlete can provide the advantage needed for competition [RJ1] [RJ2]. Regardless of subjective aspects of equipment assessment, performance based on mechanical properties should still be considered essential in product design for which mechanical testing is the only objective means of measurement.

Throughout the paddling action the greatest loading on the shaft is seen when the paddle blade is perpendicular to the plane of the water surface, this is called the power phase of the stroke. The force normal to the paddle blade becomes equal to the horizontal force (Figure 3) [Nd1]. For the conventional shaft this loading will produce quasi-linear stress distribution throughout the shaft length. However, the stress distributions through the crank will not be regular due to the geometry at the hand grip area.

Because of the unconventional 'crank' shaft geometry it is essential that testing closely resembles end use. This will ensure that any weaknesses not be evident in the design are quickly identified and eliminated prior to production and/or further iterations. To do this an adjustable shaft test kit (Figure 4) was made that could mimic the loading of the paddle shaft during use. The shaft test kit was designed to enable the loading apparatus to swivel which would enable the test kit to conform to the irregular shape of the 'crank'. The span length was also made fully adjustable.

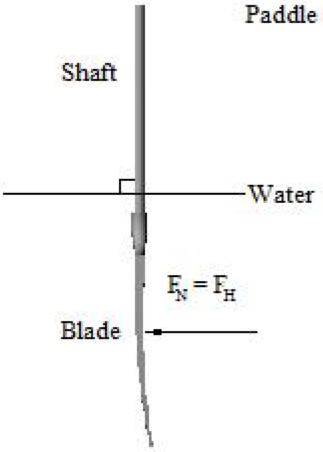

Figure 3. Angle of greatest resistance during paddle action

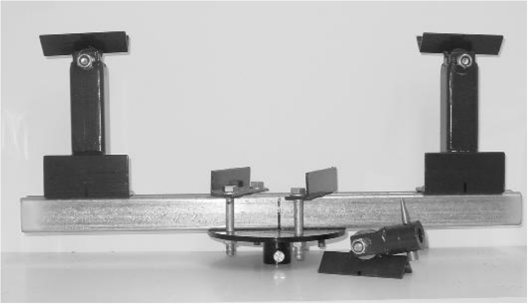

Figure 4. Shaft test kit.

5- Method

Conventional and crank paddle shafts were centrally loaded over a 500mm span to produce initial deflection of 1-2mm. Final load to break was also applied to each shaft tested (Appendix I). Tested using Lloyd LR30C Universal testing machine, Calibration certificate No. ERN8905.

6- Discussion and results

The flexural test using conventional three point bend test apparatus is ideal for the conventional paddle shaft. However it is not suitable for the crank shaft where the cranked hand grip could not be loaded due to the rigid constraints of the load adaptor causing misalignment. When the loading adaptor was allowed to swivel the crank could be tested with a central load in a three point configuration. It was further considered that although the crank could be tested with a central load this did not represent the in-use situation.

During use, the paddle shaft is held at the hand grips with the submerged paddle blade having the resistance from the water. While the blades are not considered in this work the test should be valid for the crank shaft with supports at one end of the shaft and the opposite hand grip with loading at the adjacent hand grip. To enable both ends of the crank to be tested to destruction the shaft support is moved to give a span length of 500mm. When the unsymmetrical loading was tested it was found that misalignment of the central shaft and shaft ends could also benefit from the supports being able to swivel. The test method Appendix II was then produced to represent the unsymmetrical loading seen during use.

The initial testing was done using small deflections (< 2mm) so the shaft is not damaged during testing therefore this method would be suitable as a quality control post manufacturing. The destructive testing followed the same process as above but the loads and the deflections needed for breaking the shafts were considerably higher.

From the data (Appendix I) it can be seen that the non-destructive tests show considerably higher loading must be applied to the crank to produce the deflection of 1.5mm. It is also shown that the cranks break at higher loads than the conventional shafts as would be expected given the greater tube thickness.

7- Conclusion

While there is currently no testing standard specific to the testing of the crank shaft the method investigated here should be suitable as an in-house standard. The application of the test method (Appendix II) using non-destructive loads and deflections not exceeding 1.5mm give easily comparable results that could be used as a quality control method to monitor both the manufacturing process and material supply of the crank shaft. Although there is no direct comparison shown for the different shaft designs it would be suitable for providing mechanical data comparable for custom shafts such as the crank and could be further developed as a tool for both performance and product benchmarking.

Acknowledgments

Kilwell Fibretube, Rotorua, New Zealand

Sunspots Kayaks, Rotorua, New Zealand

Technology New Zealand

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Appendix I

Shaft	Test	Span [mm]		500 with 170 offset		
Crank	**Plane of crank**			**A**	**B**	**C**
		OD	**[mm]**	27.5	27.3	31.6
		ID		22.5	22.7	27.8
	NDT*	**Load**	**[N]**	502.3	453.3	555.5
		Mod bending	**[Gpa]**	78.6	60.7	61.5
	Destructive	**Load**	**[N]**	3793	4051	5320
		Mod bending	**[Gpa]**	86.1	73.1	76
		Deflection	**[mm]**	9.9	11.2	10.0
	Plane of blade			**A**	**B**	**C**
	NDT*	**Load**	**[N]**	433.8	423.0	446.3
		Mod bending	**[Gpa]**	60.4	58.3	44.1
	Destructive	**Load**	**[N]**	4382	3304	4971
		Mod bending	**[Gpa]**	77.4	62.0	59.2
		Deflection	**[mm]**	12.8	20.0	12.6
Conventional		**Symmetrical**		**C1**	**CK**	**G**
		OD	**[mm]**	28.5	29.6	29.0
		ID		26.5	27.0	26.5
	NDT*	**Load**	**[N]**	277.4	309.9	261.5
		Mod bending	**[Gpa]**	59.0	46.1	42.4
	Destructive	**Load**	**[N]**	3070	3861	2700
		Mod bending	**[Gpa]**	40.4	33.0	30.2
		Deflection	**[mm]**	23.1	24.15	20.9

A, B and C (Full carbon crank)
C1 (Full carbon conventional)
CK (Carbon/ aramid conventional)
G (Full glass conventional)
*** Deflection 1.5mm**

Appendix II.

Proposed method for paddle shaft only testing:

1. Test conventional carbon fibre and glass fibre shafts within their elastic limit to determine load and elastic modulus. Span 500mm, load point at 170mm from shaft end.

   Each shaft tested to deflection of 1.5mm at up to six positions around main axis.

   The position with the lowest load value was then reset and the shaft was tested until failure.

2. Test carbon and carbon kevlar crank shafts within their elastic limit to determine load and elastic modulus. Span 500mm with load point at 170mm to coincide with hand grip.

   Each shaft tested to deflection of 1.5mm at four positions around main axis for each end. Start in line with plane of crank then turn 90 degree.

   The position with the lowest load value was then reset and the shaft was tested until failure. One end was used to measure the crank plan the other measured the flat plane.