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Suplementary Information:

Design and Selection of Paddle Materials for High-level Rowing Competition Applications Using Multi-Criteria Decision Analysis

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Appendix 1. Formula derivation

The goal of the material selection of the handle is to reduce weight:

$$m = (A)\ Z\ \rho \tag{1}$$

$$A = \frac{m}{Z\rho} \tag{2}$$

Assume the requirements of the design requirements (Z) and geometric solid square (b):

$$m = (b^2)\ Z\ \rho \tag{3}$$

Material performance indications are determined based on the primary function and selected critical constraints. These functions and constraints can be expressed as two stiffness formula and one strength formula:

Stiffness, (S)

$$S = \frac{F}{\delta} = \frac{CEI}{L^3} \tag{4}$$

$$S(L^3) = CEI \tag{5}$$

Where,

$$A = b^2 \tag{6}$$

$$I = \frac{b^4}{12} = \frac{A^2}{12} \tag{7}$$

The first Materials Performance Index, Equations (2) and (7) are substituted for Equation (5):

$$S(L^3) = CE\left(\frac{A^2}{12}\right) \tag{8}$$

$$S(L^3) = \frac{1}{12}(CE)\left(\frac{m}{Z\rho}\right)^2 \tag{9}$$

$$m^2 = \frac{12\, SL^3 Z^2 \rho^2}{CE} \tag{10}$$

$$[m^2]^{1/2} = [\frac{12\, SL^3 Z^2 \rho^2}{CE}]^{1/2} \tag{11}$$

$$m = \underbrace{[\frac{12\, SL^3}{C}]^{1/2}}_{\text{Structural Index}} (Z) \underbrace{(\frac{\rho}{E^{1/2}})}_{\text{Material Index}} \tag{12}$$

$$M_1 = \frac{E^{1/2}}{\rho} \tag{13}$$

Assume the design requirements (Z) and geometric of the beam (b, h):

$$m = (b)(h)\, Z\, \rho \tag{14}$$

Where,

$$A = (b)(h) \tag{15}$$

$$I = \frac{b(h)^3}{12} = \frac{A^3}{12} \tag{16}$$

The second Material Index can be defined as:

$$S(L^3) = CE\, (\frac{A^3}{12}) \tag{17}$$

$$S(L^3) = \frac{1}{12}\, (CE)\, (\frac{m}{Z\rho})^3 \tag{18}$$

$$m^3 = \frac{12SL^3 Z^3 \rho^3}{CE} \tag{19}$$

$$[m^3]^{1/3} = [\frac{12SL^3 Z^3 \rho^3}{CE}]^{1/3} \tag{20}$$

$$m = \underbrace{[\frac{12\, SL^3}{C}]^{1/3}}_{\text{Structural Index}} (Z) \underbrace{(\frac{\rho}{E^{1/3}})}_{\text{Material Index}} \tag{21}$$

$$M_2 = \frac{E^{1/3}}{\rho} \tag{22}$$

Design requirements assume requirements and cylinder Rod (r, L):

$$m = (\pi r^2 L)\, \rho \tag{23}$$

Where,

$$A = \pi r^2 \tag{24}$$

$$I = \frac{\pi r^4}{4} = \frac{A^2}{4\pi} \tag{25}$$

The Third Material Index can be defined as:

Flexure strength (σ_f), Flexure moment (M).

$$\sigma_f = \frac{(M)(C)}{I} \tag{26}$$

$$c = r \tag{27}$$

$$\sigma_f = \frac{(M)(r)}{\frac{\pi r^4}{4}} \tag{28}$$

$$\sigma_f = \frac{4M}{\pi r^3} \tag{29}$$

$$(\sigma_f)(\pi r^3) = 4(M) \tag{30}$$

$$r^3 = \frac{4M}{\pi\,(\sigma_f)} \tag{31}$$

$$[r^3]^{1/3} = \left[\frac{4M}{\pi\,(\sigma_f)}\right]^{1/3} \tag{32}$$

$$r = \left[\frac{4M}{\pi\,(\sigma_f)}\right]^{1/3} \tag{33}$$

Substitution of Equation (33) to Equation (23):

$$m = \pi\, L\, \rho \left(\left[\frac{4M}{\pi\,(\sigma_f)}\right]^{1/3}\right)^2 \tag{34}$$

$$m = \pi\, L\, \rho \left[\frac{4M}{\pi\,(\sigma_f)}\right]^{2/3} \tag{35}$$

$$m = [4\,(M)\,(\pi)^{1/3}]\,(L)\,\left[\frac{\rho}{\sigma_f{}^{2/3}}\right] \tag{36}$$

Structural Index — Material Index

$$M_3 = \frac{\sigma_f{}^{2/3}}{\rho} \tag{37}$$