

height demonstrate good agreement with the experimental data and can be applied in the design of pouring systems and in developing casting regimes for molds with low height-to-width ratios.

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Protsenko V., Kasyan O.

(KhNTU, Kherson-Khmelnytskyi)

METHODOLOGY FOR DETERMINING THE COST OF PRODUCTS MADE FROM NEW COMPOSITE MATERIALS

E-mail: eseu@ukr.net

A significant number of studies in the field of materials science has led to the development and investigation of properties of new materials. However, the implementation of these materials is often hindered by the resource intensity of the composition, the energy consumption or labor intensity of the proposed technology, and the poor operational performance of the finished products. Considering the clear research gap in the field of technical and economic justification for the feasibility of using new polymer composite materials, which is underscored by the absence of such justification

in a large number of defended dissertations on materials science, there is a need to develop a methodology for conducting such an analysis. This is essential to move new materials from the laboratory to the sphere of practical application.

The total manufacturing ($C_{product}$) cost of a composite product (UAH/unit) is the sum of the material cost (C_{mat}) and the processing cost (C_{proc}) (1).

$$C_{product} = C_{mat} + C_{proc} \quad (1)$$

he cost of materials (for the case of composites based on liquid resins) (2) includes the cost of matrix material (C_{matrix}), the cost of hardener material ($C_{hardener}$), the cost of filler material (C_{filler}), the cost of reinforcement material (C_{reinf}), and the cost of the mold (C_{mold}), minus the cost of waste material (C_{waste}) (in the case of disposal costs, these expenses must be added).

$$\begin{aligned} C_{mat} &= \sum_{i=1}^n C_i - C_{waste} \\ &= C_{matrix} + C_{hardener} + C_{filler} + C_{reinf} + C_{mold} - C_{waste} \end{aligned} \quad (2)$$

The processing technology may involve the influence of stationary (thermal, electrical, force, etc.) or variable (magnetic-pulse, ultraviolet, etc.) physical fields on the product, as well as mechanical processing by cutting, pressure, and so on, across a total of n operations, with corresponding costs ($C_{proc.s}$), ($C_{proc.v}$), ($C_{proc.mech}$) (3).

$$C_{proc} = C_{proc.s} + C_{proc.v} + C_{proc.mech}. \quad (3)$$

After substituting (2) and (3) into (1), we will obtain expression (4).

$$\begin{aligned} C_{product} &= \{C_{matrix} + C_{hardener} + C_{filler} + C_{reinf} + C_{mold} - C_{waste}\} + C_{proc} \\ &+ C_{proc.v} + C_{proc.mec} = \{C_{matrix} + C_{hardener} + C_{filler} + C_{reinf} + C_{mold} - C_{waste} \\ &+ \sum_{j=1}^n C_{proc.j}\} = \{C_{mat} + C_{mold} - C_{waste}\} + \sum_{j=1}^n C_{proc.j} \end{aligned} \quad (4)$$

The cost of materials can be estimated as:

$$C_i = m_i \times P_i, \quad (5)$$

where m_i – is the mass of the i -th material (matrix, hardener, filler, reinforcement, waste), in kg;

P_i – is the price of the i -th material, in UAH/kg.

In the case of using composites where the mass fractions of each component q_{mi} , their price, and their density p_{mi} are given, the cost of the composition can be calculated using the following expression:

$$\left\{ \begin{array}{l} C_{mat} = C_{matrix} + C_{hardener} + C_{filler} + C_{rein} = p_r + V_r + P_r ; \\ p_r = \sum_{i=1}^n p_{mi} q_{mi} / \sum_{i=1}^n q_{mi} ; \\ P_r = \sum_{i=1}^n P_{mi} q_{mi} / \sum_{i=1}^n q_{mi} . \end{array} \right. \quad (6)$$

The cost of processing C_{proc} for the j -th operation is generally the sum of the worker's labor cost C_{labor} , the cost of electricity C_{elec} , equipment depreciation D_{equip} , and operational expenses C_{op} (technical maintenance and repair of equipment, tools, fittings, consumables, etc.). Other workshop expenses $C_{ws_{other}}$ must also be added here (for the upkeep and maintenance of production areas, occupational safety, etc.).

$$C_{proc\ j} = C_{labor\ j} + C_{elec\ j} + D_{equip\ j} + C_{op\ j} + C_{ws_{other}\ j}. \quad (7)$$

$$C_{labor\ j} = \frac{12 \times S_{avg\ j} + C_{leave\ j}}{T_{fund\ j}} \times \frac{t_{setup\ j}}{60N_{sim}} \times \left[1 + \frac{USC}{100} \right] \quad (8)$$

$$C_{elec\ j} = \frac{P_{mech} \times t_{proc\ j}}{60N_{sim}\eta_j} \times p_{elec\ j} \quad (9)$$

$$D_{equipj} = \frac{C_{equipj}}{T_{lifej} \times F_{eyj}} \times \frac{t_{proc}}{60N_{sim}}, \quad (10)$$

where P_{mech} – power consumed for mechanical processing, kW;

t_{proc} – main processing time, min;

N_{sim} – number of products processed simultaneously, pcs;

η_j – equipment efficiency factor;

p_{elec} – price of electricity, UAH/(kW·h);

S_{avgj} – average monthly salary of the respective worker, UAH;

C_{leavej} – amount of a worker's paid leave, UAH;

T_{fundj} – worker's annual working time fund, h/year;

t_{setupj} – calculated time (includes operational time and preparatory-final time for equipment setup), min;

$USC = 22\%$ – unified social contribution for private entrepreneurs;

C_{equipj} – cost of equipment (including tools and fittings), UAH;

T_{lifej} – equipment useful life, years (e.g., for metal-cutting machines, it is usually taken as 6...10 years);

F_{eyj} – equipment's annual working time fund, h/year.

Operational C_{op} and other workshop expenses $C_{ws_{other}}$ (depending on the level of thriftiness and production organization) are approximately 75...150 % (at enterprises with a less advanced production process, this percentage may be higher) of the worker's labor cost, C_{labor} [1-4]. Considering this, expression (7) for calculating the processing cost at the j -th operation is presented in a form convenient for practical use:

$$C_{procj} = (1,75 \dots 2,50)C_{laborj} + C_{elecj} + D_{equipj}. \quad (11)$$

Using the presented methodology, the cost of bushings for stern tube bearings of ships with the following parameters was calculated: $d = 100$ mm, $D = 132$ mm, $l = 270$ mm. The materials used were: caprolon PA-6MG, filled with graphite [5] (MI);

caprolon PA-6MDM, filled with graphite and molybdenum disulfide [6] (*M2*); and epoxy composite EKM-3 [7] (*M3*).

For materials *M1* and *M2*, the processing was assumed to be only mechanical, in a single operation ($j = 1$) on a lathe, comprising two setups. This included facing the end, external turning of diameter D , drilling, reaming, and boring of hole d , cutting the part from the rod, and facing the opposite end. For material *M3*, the process involved mold fabrication, polymer composite production according to the technology in [7], and mechanical processing on a lathe. The cutting modes for all materials were considered identical. To compare the practical value of the analyzed materials, we used the results from studies [5-7] on their wear intensity when paired with steel shafts. We also calculated the number of repairs requiring bushing replacement over the total service life of the ships (25 years). The results of these calculations are summarized in Table 1.

Table 1 – Main characteristics of model stern tube bearing bushings made from the analyzed materials

Material designation	Coefficient of friction, f , with water lubrication	Manufacturing labor intensity, t_{setup} , min	Manufacturing duration, min	Manufacturing cost of C_{product} , UAH	Number of vessel repairs over service life, N_r
M1	0,020	54	54	1573	9
M2	0,016	54	54	1877	4
M3	0,038	312	3314	1829	23

The data in Table 1 indicate that using material *M3* for manufacturing the bushings will lead to the highest number of repairs and, consequently, due to the longest downtime and repair costs, the highest specific costs per tonne of cargo transported by the vessel. This will ultimately reduce the profits from operating a vessel equipped with these bushings. Bushings made from material *M3* will also cause the greatest friction losses in

the stern tube bearing, thereby increasing fuel costs and further raising transportation expenses.

The manufacturing labor intensity of bushings from material *M3* is almost 6 times greater than that of bushings from materials *M1* and *M2*, while the manufacturing duration is more than 60 times longer. The manufacturing cost of a bushing from material *M1* is $C_{product} = 1573$ UAH, from material *M2* is $C_{product} = 1877$ UAH, and from material *M3* is $C_{product} = 1829$ UAH. The results obtained make the choice of material for stern tube bearing bushings more well-substantiated and convincingly argue in favor of using materials *M1* or *M2*.

Thus, the presented calculation methodology for determining the main costs that form the prime cost of such products makes it possible to perform practical calculations and simplifies decision-making when selecting composite materials.

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Smetankina N.¹, Misiura Ie.², Misiura S.^{1,3}

(¹Anatolii Pidhornyi Institute of Power Machines and Systems of the NAS of Ukraine, Kharkiv; ²S. Kuznets KhNUE, Kharkiv; ³NTU “KhPI”, Kharkiv)

**DEFORMATION MODELING OF COMPOSITE PLATES WITH
COMPLEX SHAPE UNDER IMPACT LOADING**

E-mail: misuraeu@gmail.com

The widespread use of structures made of composite materials is due to their improved, relatively homogeneous characteristics. Due to their high strength properties combined with low weight, composite materials are widely used in space, aircraft and shipbuilding, and transport engineering [1, 2]. The issues of static deformation of composite structural elements and their free oscillations are the most studied [3]. Transient processes in such structures are less studied [4, 5]. The complication of the operating conditions of modern composite structures associated with impulse and shock loads, the variety of shapes of structural elements, and the use of new materials lead to the fact that the development of methods for solving problems on the stress-strain state of composite elements of arbitrary shape is an urgent problem of structural dynamics.

A methodology is proposed for studying the processes of unsteady deformation of layered composite elements of aerospace structures under impulse loading and impact with a solid body. The elements are considered that are made in the form of plates with a complex plan form. The plate consists of orthotropic layers of constant thickness and occupies a single-connected region on the coordinate plane, which is bounded by a curved contour. It is assumed that the Timoshenko type hypothesis is fulfilled for the package of layers. The stresses in the layers are determined by Hooke's law for an orthotropic body.