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RESEARCH INTO STRENGTH AND VIBROINSULATION PROPERTIES OF EPY PLASTIC

SUMMARY

The paper presents results of research into strength and vibroinsulation properties of the Polish make EPY plastic applied for foundation pads in installation of the ship main engines and auxiliary machines. Vast experience gained from many years of successful application of several versions of the EPY plastic pads in the Polish shipbuilding and ship repair industries is summarized. In consequence of the reported research more effective and rational usage of the plastic material is expected.

Introduction

Installation of the ship main engines (ME) and auxiliary machines on plastic pads cast of special, chemically hardening plastics are nowadays world-widely applied; the same concerns the Polish shipbuilding and ship repair industry. Very high requirements are imposed on pad materials, which are hard to satisfy. Such plastics, approved by the major classification societies and ship main engine makers, are at present produced in three countries only. Poland is one of the countries, apart from the USA and Germany. This is due to scientific research carried out systematically for 20 years at the Technical University of Szczecin as well as R&D works and practical applications performed by Polish firms acting in this field and cooperating closely with the University. To assure an appropriate progress and to keep pace with competitive foreign firms, producing plastics and installing machinery on plastic pads, there are further systematic R&D works performed on improvement of strength and technological properties of pad material and on better and wider utilisation of its valuable properties in practice. In this paper some results are presented of the research in strength and vibroinsulation properties of the EPY plastic, evidencing potential possibilities for more effective and rational application of this material and for obtaining additionally some technical and economical effects.

Standardized foundation bolted joint with cast plastic pad

The standardized foundation bolted joint with cast plastic pad is shown in Fig. 1a. The joint shown is characteristic in that the holding-down bolt 4 is loosely inserted into holes of the foundation bedplate 3, pad 2 and engine frame bedplate 1, but the pad with a sinkhead is cast as a whole in a mould. In temperature $T<10^{o}C$ pad hardening proceeds practically too slowly as to obtain appropriate strength properties in due time.

To shorten the pad hardening time and to reach the required strength properties, the pads are heated with use of external heat sources. Most often, hot air from appropriate heaters is blown into vicinity of pads. Heating of pads is arduous, energy consuming and long-lasting (from 18 to 72 hours), especially when high pads are heated throughout. A considerable amount of energy is lost for heating of engine surroundings, a thick foundation bedplate and bedplate of engine frame.

A way for improving pad properties and shortening their hardening time on board is casting of pads with prefabricated elements (item 5 in Fig. 1b; see also Patent Specification P-274874).

These elements are cast of the EPY plastic in advance and properly hardened in optimal workshop conditions. The prefabricated elements are fitted in a mould in such a way as to obtain from them mid-layers of cast pads after filling the void spaces in the moulds (abt.20%) with liquid plastic. In many types of holding-down bolted joints, especially those for ME and provided with side stoppers, it is needed to remove sinkheads from pads. The sinkheads play only an auxiliary role in casting of pads, and they do not transfer any service load. Removing the sinkheads becomes an easy operation, if perforated elements are placed in moulds

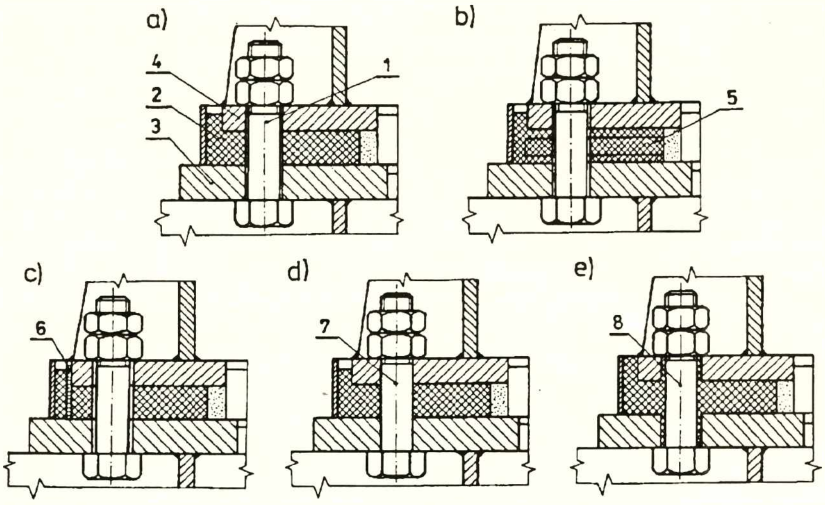

Fig. 1. The standard foundation bolted joint with the pad cast of EPY plastic (a) a nd its version (b, c, d, e).
1 - holding-down bolt, 2 - foundation pad, 3 - foundation bedplate, 4 - engine frame bedplate, 5 - prefabricated element, 6 - preforated element, 7 - fitting bolt, 8 - holding-down bolt fitted in the plastic.

(item 6 in Fig. 1c, see also Patent Specification P-278910). These elements are removed together with the sinkheads after gelating of the cast pads.

In the holding-down bolted joints for ME, a number of fitted bolts (item 7 in Fig. 1d) are often used. Fitting of bolts in a traditional way, consisting in grinding of bolt pins and reaming of holes, is labour-consuming, costly and arduous task when performing it on board. The same function is fulfilled by bolts fitted in the EPY plastic (Fig. 1e; see also Patent Specification 141627). Fitting of bolts in the plastic consists in inserting bolts with an adequate clearance into holes in the foundation bedplate and the frame bedplate of ME and filling moulds with the plastic up to the top of the frame bedplate of ME.

Experimental research

Plastics applicable for pads in the foundation joints of ship main engines and auxiliary machinery should hold the Product Type Approval Certificate issued by a classification society supervising construction or repair of a ship. Such certificates are issued on the basis of test results for a given plastic. The basic strength parameters of the plastic are determined in result of tests of standardized specimens having their cross-sectional area several tens or even hundreds times less than area of bearing surfaces of ME foundation pads. If the strength properties determined in consequence of the tests depend heavily on dimensions of specimens (or elements), then the scale factor should be introduced in calculations as follows:

$$\gamma = \frac{k}{k_p}$$

where:

k_p - strength of the standardized test specimen;
k - equivalent strength of an element (a large size specimen).

It is thus far assumed tacitly when calculating pads that $\gamma = 1$. To estimate how much specimen size influences its creep and compressive strength, tests of specimens of different size made of the EPY plastic, have been carried out. For test in compression cylindrical specimens of the equal height H = 25 mm and different diameters Dj have been used (Fig. 2a).

The specimens of the D_1 = 20 mm diameter are used in the standardized tests of creep and compressive strength of chemically hardening plastics. Diameters of consecutive specimens have been chosen in such a way as to obtain the end face area of a specimen of diameter D_{j+1} (j = 1,2,3,4) two times greater than the relevant area of the specimen of diameter D_j. The specimens tested have been prepared from a uniform plate cast of the EPY plastic.

Compressive strength Rc of the tested specimens has been determined from compression diagrams 1 - 5 shown in Fig. 2a and presented in Fig. 2b in function of the nondimensional area A_j/A_1. The results obtained have been approximated by the regression line expressed by the equation given in Fig. 2b.

State of stress in the standard test specimen of the EPY plastic and that in a cast foundation pad under compressive load applied to their end face areas would be different. How far it affects compressive strength is demonstrated by the following experiment.

The experiment has been carried out upon the cylindrical test specimens of the diameter D = 20 mm and the height H = 25 mm, hardened for 20 h in temperature 20°C and additionally for 2 h in temperature 45°C. The specimens were tested in compression. Three of them were compressed directly between the testing machine face plates; an example of compression diagram is shown in Fig. 2c (the curve a). The next three specimens were inserted successively into a hole in the steel plate 2 and then compressed by the punch 3, as shown in Fig. 2c. These specimens did not fail under the compressive load, causing axial stress three times greater than the compressive

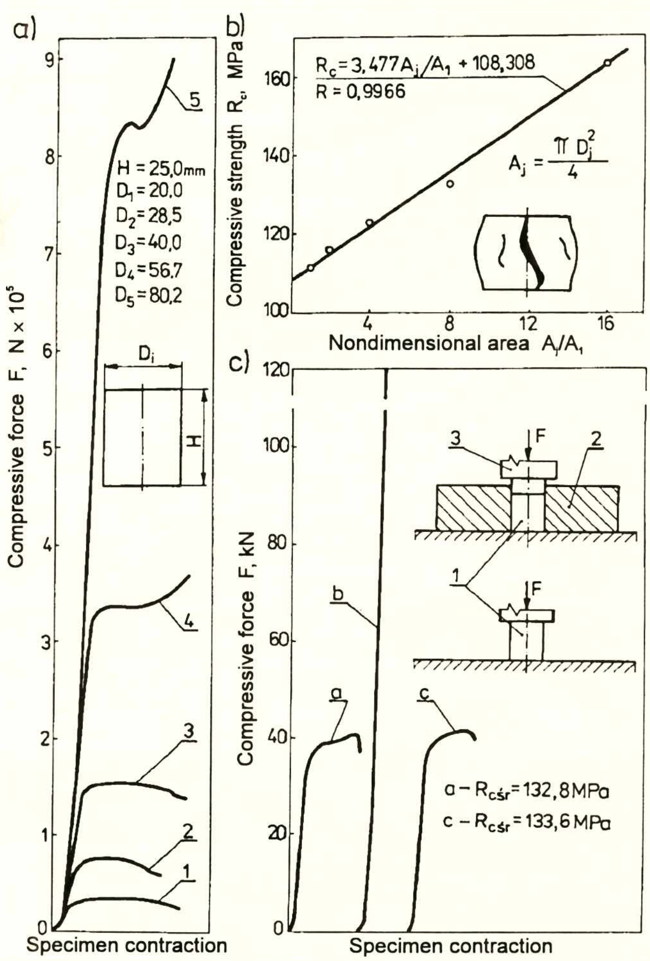

Fig. 2. Compressive test diagrams for the EPY plastic (a, c), and compressive strength-size relation for the plastic specimens (b).

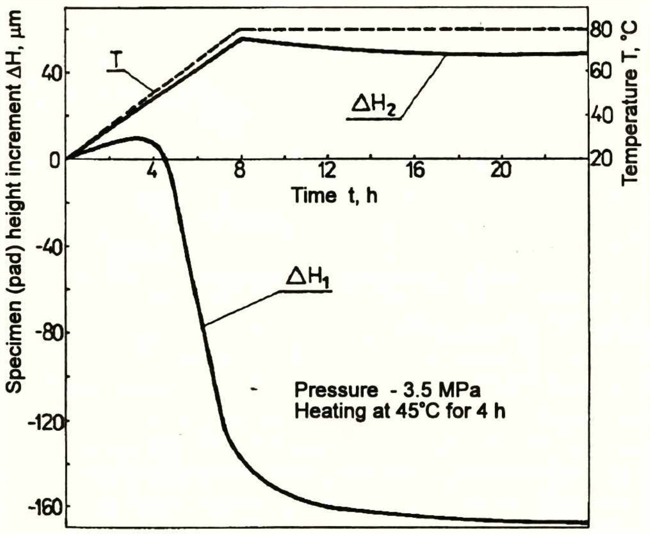

Fig. 3. Creep curves for the specimens and pad of the EPY plastic.

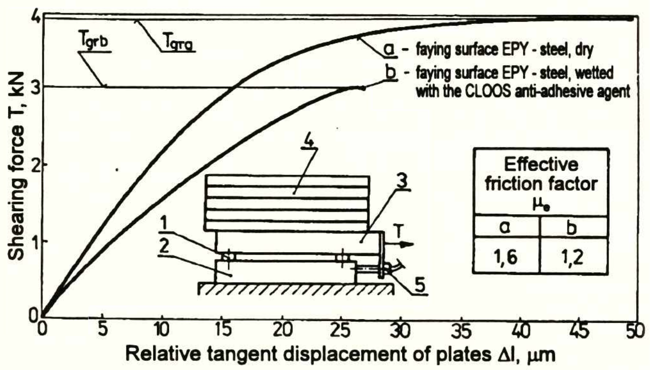

Fig. 4. Curves illustrating relationship of the shearing force T to the relative tangent displacement along the faying surfaces between the EPY plastic and steel.
1 - elements cast of the EPY plastic, 2 & 3 - steel plates, 4 - weight pads, 5 - displacement gauges.

strength of the free specimens, i.e. those compressed directly by the testing machine face plates. The specimens compressed in the hole of the plate 2 have demonstrated linear - elastic behaviour when deforming under load (Fig.2c, the curve b).

In a foundation pad, in regions far enough from its edges, a stress state prevails close to that found in the specimen compressed in the hole of the plate 2. After removing specimens from the holes in the plate 2 and compressing them again, this time directly by the face plates of the testing machine, it has been found that compressive strength of the specimens has been the same as those specimens not compressed previously in the hole of the plate 2 (Fig. 2c, the curve c).

In testing the EPY plastic a lot of attention has been paid to determination of its creep in compression. Among other things comparative tests of standard specimens and foundation pads were carried out.

Test specimens and a pad were cast of one and the same lot of plastic, and in the same thermal conditions. Then they were hardened for 48 h in 20°C and additionally in 45°C temperature for 4 h. The specimens and the pad were of the same height H = 25 mm, but their respective cross-sectional areas were 314 mm^2 and 55222 mm^2. The pad was loaded in an universal testing machine, but specimens - in a specialized creep-testing machine applying load, exerting pressure of 3.5 MPa. After 24 h temperature of the plastic was gradually increased (Fig. 3, the curve T). Increments in height of the specimens and the pad were simultaneously measured. On this basis the curve ΔH_1 (for the specimens) and ΔH_2 (for the pad) were drawn (see Fig. 3).

During the first eight hours, when temperature was growing linearly, a change in height of the specimens and the pad resulted from superposition of effect of transient creep and thermal expansion of the plastic. Increments in height of the specimens and the pad due to thermal expansion are the same. It means that difference in pattern of the ΔH_1 and ΔH_2 curves has resulted from creep. Creep developed in a different way in the small size specimens and in the much larger foundation pad, in spite of the same pressure exerted and identically changing temperature. State of stress, different in each of the two cases, is responsible for that result. Within the pad, except of its free edges, the three dimensional state of stress has appeared, similar to that existing in the specimen compressed in the plate hole (see Fig. 2c). The research contained also determination of the effective friction factor μ_e for the EPY plastic against steel. It has been defined as the ratio of the limiting shearing force T_{gr}, causing macro-slip of a plastic element over a steel element to appear, and the force N, pressing both elements together. Four elements 1 of the dimensions Φ = 13.2 * 4 mm were cast of the EPY plastic between the steel plates 2 and 3 (see Fig. 4). The elements were symmetrically placed with respect to the plate axis. The plates have been machined (Ra = 9.6 μm). The weight pads 4 set on the plate 3 exerted the compressive force N = 2500 N. The shearing force T was measured with use of an extensometric system, but relative displacements of the plates 2 and 3 with use of the displacement gauges 5 (GIMETRAMI). Then, values of the effective friction factor were determined from the curves a and b registered (Fig. 4).

Research in the dynamic properties of the plastic

It has been always aimed to reduce as much as possible mechanical vibrations and noise in mechanically propelled ships [1]. Along with technological developments, higher and higher demands in this respect have been made, addressed to ship machinery makers. Vibration trouble-shooting has become nowadays one of the key problems in shipbuilding and ship operation.

There are many vibration sources in ships, and of different vibration frequencies. Unbalanced forces and moments, acting in the main engine, generate fundamental, low frequency vibrations (up to 60 Hz). Besides, they excite also vibrations of higher frequencies.

Moreover, there are many other installations generating vibrations in ships. For ship crews and passengers, vibrations of higher frequencies (of the 1000 Hz order) are of a particular nuisance.

A portion of these vibrations is emitted to the surrounding air and results in aggravating and health damaging noise. The remaining portion of vibration energy, in the case of stiff joints, is transferred to the foundation supporting a given machine or to other objects connected to it, and then is transmitted as material-borne sound to all, even remote, structural components. In result of propagation of this material-borne sound, highly unwanted secondary phenomena may arise, e.g. aggravating noise, caused by vibration of bulkheads and various shields in the engine room as well as in other compartments, and forced secondary vibrations (even often resonant ones) of other installations and equipment etc. Counter-measures against propagation of vibration consist usually in applying rubber pads as well as specialized vibroinsulators. These means are not always possible to be used, as it is necessary to precisely position objects being fastened, as well as due to considerable increase of costs and substantial technical difficulties in applying vibroinsulators.

Application of the foundation pads cast of plastic, apart from many advantages concerning technique of assembling, results also in positive effects in damping and insulation of vibration, which is usually felt by ship crews. Plastics used for foundation pads better suppress mechanical vibration than steel, traditionally used to that purpose. On the other hand, their contact surface with steel forms a substantial barrier for propagation of material - borne sound. To perform a comparative analysis of materials used for foundation pads, special tests on dynamic mechanical properties of the EPY plastic and steel have been carried out. The tests have been performed with use of the torsional pendulum complying with the PN-83/C-89042 standard. Values of the logarithmic decrement of mechanical damping and of the dynamic shear modulus for the material tested have been experimentally determined. In Fig. 5, characteristics of vibration amplitudes versus time are presented for the material tested, determined in $20^{o}C$ temperature, but in Fig. 6 - diagrams illustrating the relationship of both the logarithmic decrement of damping D and the dynamic shear modulus G' to temperature, determined for the EPY plastic.

It is clearly visible from Fig. 5, that the rate of fading of free vibrations for the EPY plastic is, in the same conditions, much greater than for steel. The ratio of the logarithmic decrement of damping for the EPY plastic to that for steel: D/D_s equals 0.1326:0.0413 = 3.21. This means that the vibration damping coefficient of the EPY plastic used for foundation pads is more than three times greater than that for steel. The dynamic shear stiffness of the EPY plastic is, of course, much smaller than that of steel. The ratio of the two stiffnesses (at $20^{o}C$) is G_t'/G_s' = 2511:80000 = 0.0314. This is a meaningful advantage of the plastic in comparison with steel. High elastic deformability of the plastic pads and, simultaneously, high friction factor on their surfaces faying in with the bedplates of the machine and foundation, allow for substantial, thermal, and structural deformation of the machine to occur without any slip on the pads. The end faces of the pads do not wear off and due to that a tendency for loosening holding-down bolts is much smaller than in the case of steel pads.

An important tool for analysis of the problem of insulation of material-borne sound is acoustic impedance. This is a measure of resistance, offered by a medium against propagation of material-borne sound. It is a known phenomenon [2,3], that acoustic waves propagate in different media with a different velocity. If an acoustic wave propagating in a given medium impacts into a medium having a different acoustic impedance then flow of energy will be highly ineffective. For a plane or spherical wave situated at a considerable distance from its sound source a value of the specific acoustic impedance R of a solid, liquid or gas body may be calculated from the following expression [2,3]:

$$R = \rho \cdot v$$

where:

ρ – density of a medium, kg/m^3;

v – velocity of acoustic wave propagation in the medium, m/s.

Velocity of sound propagation in a material considered depends on its elasticity and density. For a longitudinal wave propagating in a solid body specific acoustic impedance may be calculated from the following expression [4]:

$$R = \sqrt{E \cdot \rho}$$

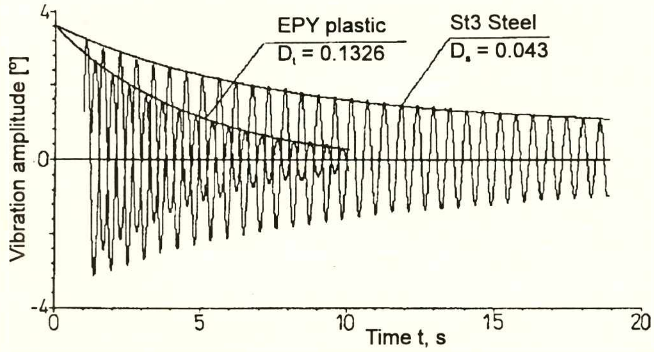

Fig. 5 Vibration amplitude-time response characteristics for the EPY plastic and the St3 steel at 20°C.

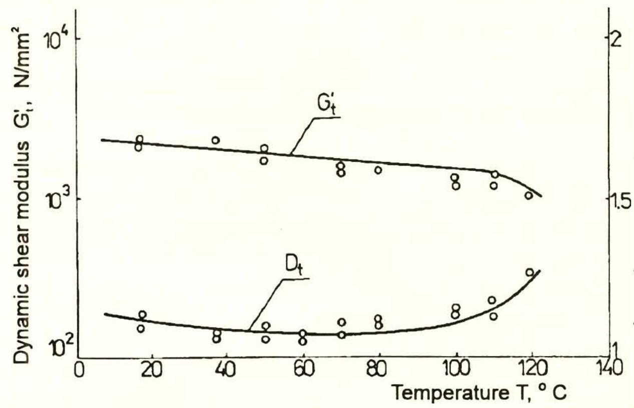

Fig. 6 Relationship of the logarithmic decrement of damping D and dynamic shear modulus G'_t to temperature for the EPY plastic.

where:

E – modulus of longitudinal elasticity.

Material-borne sound propagating in a material when reaching the end face of the plastic is to a large degree reflected and only a small portion of it penetrates the plastic. A fraction of the portion converts into heat and is then dispersed, but the rest of it is transmitted to the other side of the plastic pad where it reaches again a barrier from which it is to a large degree reflected off. Having assumed the values of parameters, appropriate for steel and plastic:

$E_1 = 2\times10^{11}$ kg/ms^2, ρ = 7800 kg/m^3, $E_2 = 4915\times10^6$ kg/ms^2, ρ = 1590 kg/m^3 , and substituted them into the expression (2), the following values of the specific acoustic impedance for the materials considered will be obtained:

- for steel $R_1 = 39.50\times10^6$ kg/m^2s,
- for the EPY plastic $R_2 = 2.85\times10^6$ kg/m^2s.

Acoustic energy entering into a body 2 from a body 1 through their faying surface, may be calculated from the following expression [2,3]:

$$P_{1,2} = \frac{4 R_1 \cdot R_2}{(R_1 + R_2)^2}$$

If it is taken into account that acoustic energy emitted from a steel engine through a pad of the EPY plastic to a steel foundation must surmount two faying surfaces, then an acoustic energy passing to a foundation 3 out of the engine may be evaluated from the following formula:

$$P_{1,3} = \left[\frac{4 R_1 \cdot R_2}{(R_1 + R_2)^2}\right]^2$$

Having substituted the above assumed data into the formula (4), the following will be obtained:

$$P_{1,3}=\left[\frac{4\cdot 39.5\cdot 10^6\cdot 2.80\cdot 10^6}{(39.5\cdot 10^6+2.90\cdot 10^6)^2}\right]^2=0.061$$

The estimation presented above concerns only the flow of acoustic energy through a pad into a foundation. Many other factors influence also noise propagation within a ship. Engines and equipment placed on plastic pads are fastened to a foundation by steel bolts, through which a portion of acoustic energy flows without any significant obstacle (loss). The amount of this energy depends on the diameter and length of the bolts as well as on the construction and stiffness of the joint between the engine and its foundation.

Therefore, problems which concern damping and insulation of vibrations as well as an optimal usage of plastics applicable for foundation pads, require more complex research to be further performed and relevant structural solutions elaborated. It should be, however, explicitly mentioned that the plastics used for fastening ship engines and installations have not been initially provided for vibroinsulation purposes, but to notably facilitate assembling process of these objects. Their beneficial influence on insulation of vibrations, especially those of high frequencies, is an additional, significant advantage which is the case for using this material and this method of fastening ship engines and installations.

Conclusions

The research results and many years of failure-free operation of several thousands of objects, including more than 280 ship's main engines developing from 736 to 16192 kW and fastened on the pads made of the Polish plastic, may serve as a proof that the Polish plastics are in no respect inferior to the foreign plastics produced for these purposes. The test results obtained for the EPY plastic indicate that a physical basis (high strength, good damping and vibroinsulation properties) exists for more effective and rational usage of the material in shipbuilding and ship repair as well as in other fields of engineering.

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