CZASOPISMO INŻYNIERII LĄDOWEJ, ŚRODOWISKA I ARCHITEKTURY
JOURNAL OF CIVIL ENGINEERING, ENVIRONMENT AND ARCHITECTURE
JCEEA, t. XXXV, z. 65 (3/18), lipiec-wrzesień 2018, s. 91-100, DOI:10.7862/rb.2018.46

Rafał GRZEJDA[1]

COMPARATIVE ANALYSIS OF SELECTED METHODS FOR SEATING OF MACHINES USING FOUNDATION BOLTED JOINTS

Finite element modelling of elements connected in foundation bolted joints applied in the case of seating of heavy machines or devices is presented. The study is focused on joints made with the use of three different types of chocks: a steel chock, a polymer chock and a polymer-steel chock. Stiffness characteristics of the joined elements for the adopted models of the foundation bolted joint at the assembly stage are described and compared. Conclusions of paramount importance to the engineering practice are created.

Keywords: seating of machines, foundation bolted joint, foundation chock, finite element method

1. Introduction

The dynamics of industrial buildings are influenced by machines and devices installed on their floors. To reduce the vibratory effect caused by the machines in buildings vibration insulation is commonly adopted [1, 2]. In the design of the vibration insulation the way of seating of the machine on the foundation should be taken into account.

Seating of heavy machines or devices on foundations is usually carried out by means of bolted joints. In such connections special foundation chocks are also used. There are three types of these chocks [3–6]:

- steel chocks,
- polymer chocks,
- polymer-steel chocks.

The earliest known way of machinery seating is the seating using steel chocks (rigid chocks, but less frequently also chocks made as wedge chocks or adjustable chocks [7]). This seating is associated with two disadvantages occurring during the assembly of the foundation bolted joint. The first one is the

[1] Rafał Grzejda, West Pomeranian University of Technology, Szczecin, Faculty of Mechanical Engineering and Mechatronics, 19 Piastów Ave., 70-310 Szczecin; tel. 914494969; rafal.grzejda@zut.edu.pl

need to ensure even distribution of contact pressure on all the chocks by matching their surfaces and abutment surfaces of the mounted machinery and the foundation. Such actions are difficult, tedious and laborious. Additionally, in case of seating applying the preload to foundation bolts brings on considerable contact deformations between the joined elements [8].

The second way of machinery seating is the seating on cast polymer chocks. In this case, precise machining surfaces of the joined elements is not necessary. In addition, direct casting chocks under the base of the machine ensures a close fit of these surfaces together. Inequalities resulting from the roughness of the joined surfaces are filled with polymer, whereby the pressure distribution on that surfaces is more favourable than in the case of the seating using steel chocks [9]. However, a disadvantage of seating on cast polymer chocks is their creep in the operational condition, evoking relaxation of the pretension in the foundation bolts [5, 10].

The third and newest way to perform machinery seating is the seating with polymer-steel chocks. It brings together advantages of seating according to two aforementioned methods and minimizes disadvantages occurring there. In the joints made of polymer-steel chocks the creep of the chocks is significantly reduced. At the same time, abutment surfaces of the joined elements adhere closely to each other and there is no need to matching them. Additionally, in the foundation bolted joint of this type steel chocks of the same thickness in the whole area of the connection can be applied.

Foundation bolted joints often have a significant impact on vibrations, reliability and durability of the entire mechanical systems. Therefore, to analyze the problems occurring in them, knowledge about their behaviour in the assembly and operational conditions is required. In order to know this behaviour usually the appropriate stiffness characteristics are determined.

Studies on foundation bolted joints with the steel chocks and the chocks made of polymer are described, inter alia, in [11–13]. In contrast, studies on foundation bolted joints with the polymer-steel chocks are presented for example in [5, 7]. The current paper is an extension of the research on foundation bolted joints, and its primary objective is to determine the stiffness characteristics of the elements joined in the foundation bolted joint in the case of the assembly condition for all the above-mentioned its types, taking into account the steel chock, the polymer chock, and the polymer-steel chock.

An object of research are some symmetrical segments of the foundation bolted joint in the form of two rectangular plates and a rectangular chock located between the plates. The chock can be in one of the three aforementioned types. So separated systems are modelled by the finite element method (FEM) to determine the stiffness characteristics for the joined elements in the assembly state. The EPY resin compound is used as the polymer material [12, 14]. The result of the work are conclusions of key and paramount importance to the engineering practice.

2. Basics of the analysis

One of the important issues considered in the case of calculations of foundation bolted joints is the stiffness analysis of its elements. Treating the bolts as linear elements, their elastic flexibility can be determined by the instructions given in the standard VDI 2230 [15] or by using the simplified method [16]. There is no equally easy way to set down the elastic flexibility of elements joined in foundation bolted joints [13]. Therefore, to accurately determine it the finite element method is usually applied.

To analyze the above methods of seating, calculations were executed for the following models:

- FEM-S – the model with the steel chock,
- FEM-P – the model with the polymer chock,
- FEM-PS – the model with the polymer-steel chock.

In the paper, a single bolted connection separated from the foundation bolted joint, with the geometry shown schematically in Figs. 1–3, is examined. The bolted connection is created by two steel plates (2) and (4) corresponding to fragments of the machine base and the continuous footing. The chock (3) or (6), suitable for the applied method of seating, is located between the plates. Because the objective of the paper is the stiffness analysis of the joined elements, in the connection the full bolt model is not included (for a review, see [17]). The bolt is represented by a pair of steel stamps (1) and (5), by means of which the pressure from the head of the bolt and the nut is introduced. The diameter of these stamps is equal to 46 mm and it is adjusted according to the pressure area from the M30 nut.

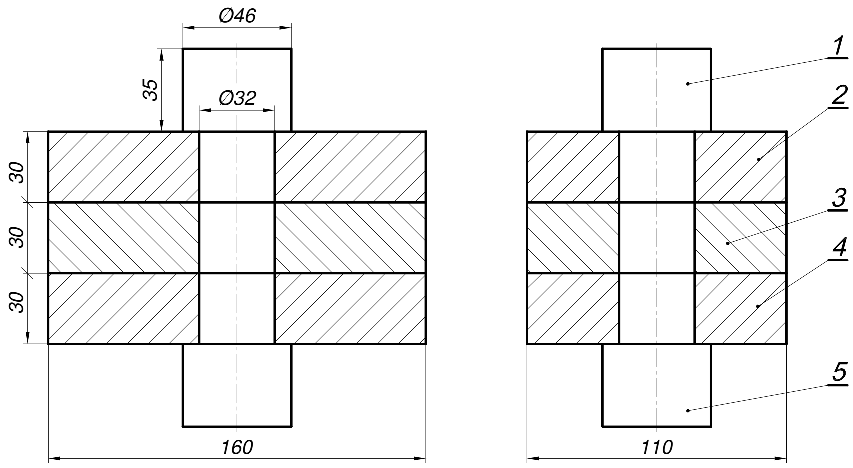


Fig. 1. Geometry of foundation bolted joint model with the steel chock: 1 – top pressure stamp, 2 – top plate, 3 – steel chock, 4 – bottom plate, 5 – bottom pressure stamp

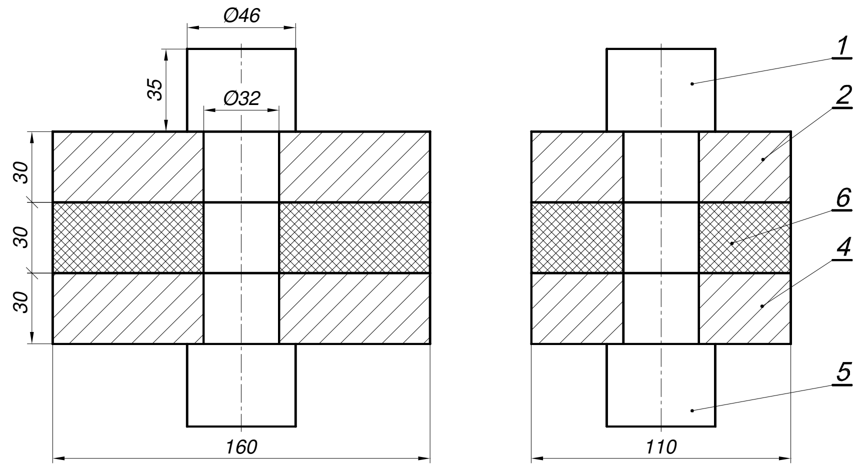


Fig. 2. Geometry of foundation bolted joint model with the polymer chock: 1 – top pressure stamp, 2 – top plate, 4 – bottom plate, 5 – bottom pressure stamp, 6 – polymer chock

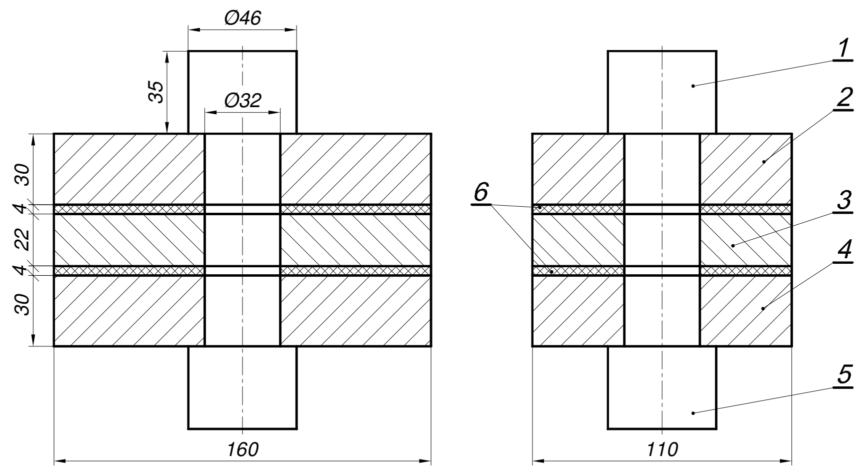


Fig. 3. Geometry of foundation bolted joint model with the polymer-steel chock: 1 – top pressure stamp, 2 – top plate, 3 – steel chock, 4 – bottom plate, 5 – bottom pressure stamp, 6 – polymer chock

3. Computational models

Calculations were performed for dimensions of the joined elements given in Figs. 1–3. On the basis of works [18, 19], it is assumed that the EPY resin compound is a linear material. Material constants for the materials used in the models are collected in Table 1.

Table 1. Characteristics of materials used for the foundation chocks

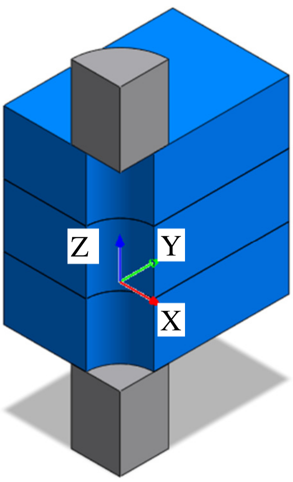
Parameter	Steel	EPY compound
Young's modulus, E [GPa]	210	7.5
Poisson's ratio, ν	0.3	0.376

In the view of two planes of symmetry occurring in the considered fragment of the foundation bolted joint, only a quarter of the connection shown in Fig. 4a, has been taken into account in the calculations.

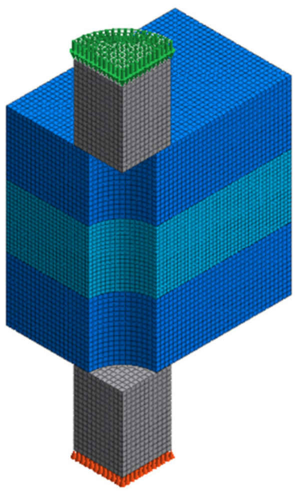
The discrete models of the connection created in the Midas NFX 2017 R1 program is presented for all the adopted methods of seating in Figs. 4b and 5. Pursuant to results described in [13], between the steel joined elements and the steel chock the "general" model of the contact connection is applied (for a review, see [20]). Simultaneously, between the steel joined elements and the polymer layer the "welded" model of the contact connection is used. The models are fixed in the nodes on the back side of the bottom pressure stamp in the direction of the bolt axis and loaded in the nodes on the upper surface of the top pressure stamp with normal forces.

Additionally, appropriate degrees of freedom (translational and rotational) are removed in the nodes lying on the symmetry planes of the foundation bolted joint. Due to such application of boundary conditions and load, the elements joined in the foundation bolted joint models are subjected to compression, which is consistent with the actual work of these connections.

Calculations were performed using a nonlinear solver in ten steps with the incrementally increasing preload F from 0 to 200 kN.

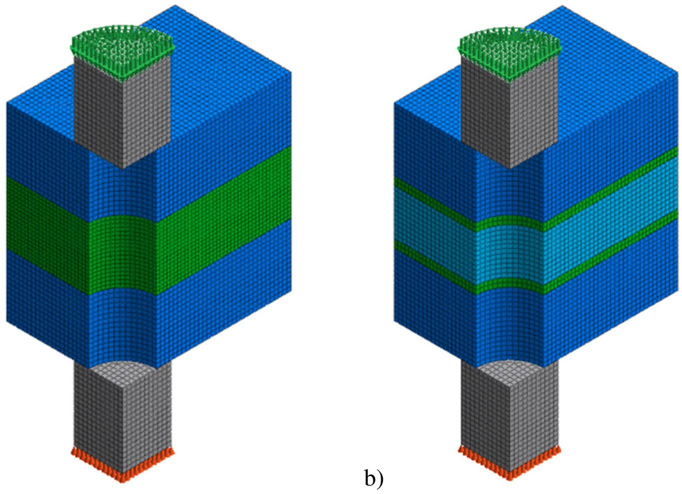


a)



b)

Fig. 4. Foundation bolted joint models – calculation model (a) and FEM-S model (b)



a) b)

Fig. 5. Foundation bolted joint models – FEM-P model (a) and FEM-PS model (b)

4. Results of calculations and their comparison

Examples of the calculation results for adopted FEM-models in the form of displacements in the Y0Z plane under the preload F equal to 200 kN are shown in Fig. 6.

In order to conduct comparative analysis of the calculation results respective statement of these results obtained for the tested connection and all their FEM-models is performed (Fig. 7).

In the next step, displacements of elements joined in the foundation bolted joint ΔH corresponding to the maximum value of the preload F is designated. The final parameter adopted for quantitative comparison of the computational models is the stiffness of joined elements k, calculated as [13]:

$$k = \frac{F}{\Delta H} \tag{1}$$

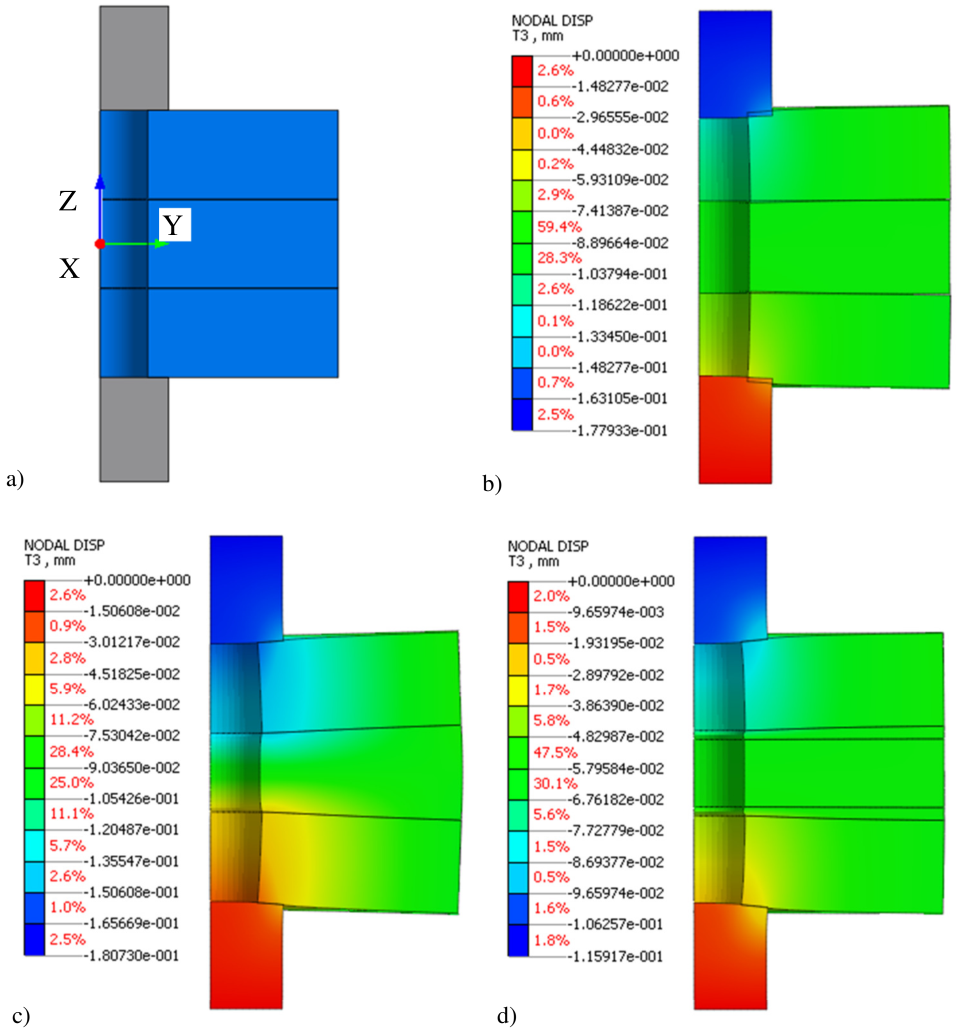


Fig. 6. Results of calculation – scheme of the model (a) and displacements in the Y0Z plane of the foundation bolted joint models loaded by the force F = 200 kN for: FEM-S model (b), FEM-P model (c), FEM-PS (d)

The stiffness values of the joined elements obtained for the adopted foundation bolted joint models are summarized in Table 2. In the case of the FEM-P and FEM-PS models as a result of the calculations linear stiffness values are given, whereas in the case of the FEM-S model stiffness value determined from the nonlinear stiffness characteristic for preload F equal to 200 kN is included.

Table 2. Stiffness values of the elements joined in the foundation bolted joint

Model	**FEM-S**	**FEM-PS**	**FEM-P**
k [kN/μm]	3.14	3.15	1.57

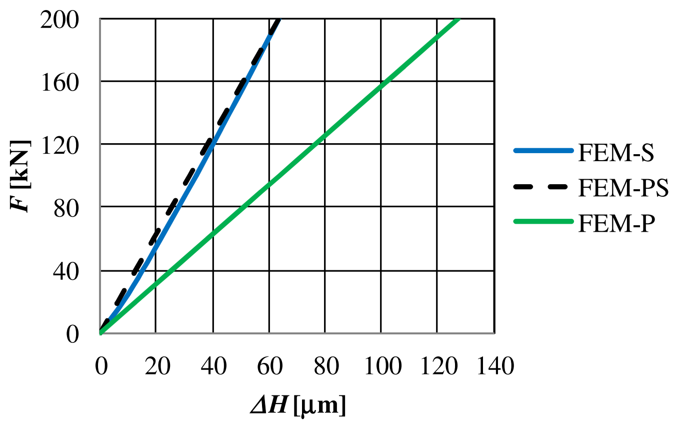


Fig. 7. Stiffness characteristics of the elements joined in the foundation bolted joint

Based on the calculation results for adopted models of the foundation bolted joint it should be stated that the use of the polymer-steel chock can lead to:
– significant improvement of foundation bolted joint stiffness in relation to the connection with the chock made of polymer,
– obtaining the foundation bolted joint with the stiffness similar to the stiffness of the connection with the steel chock.

From observation of stress maps for the FEM-P and FEM-PS models, it follows that the normal stresses for the EPY resin compound did not exceed the compressive strength values for this material [21].

5. Conclusions

In the paper foundation bolted joints made by seating in three ways is analyzed. It has been shown that the foundation bolted joint with the polymer-steel chock can have the stiffness characteristics close to the foundation bolted joint with the steel chock. At the same time, these joints are characterized by advantages appropriate for the joints with the polymer chock, among which the most important is an exact mach and strict adherence the chock to rough surfaces of the joined elements of the machinery and the foundation around the all nominal contact area.

The study should be continued in order to determine the effect of the thickness of the polymer layer in the polymer-steel chock on the stiffness characteristics of elements joined in the foundation bolted joint made with such a chock.

References

[1] Mak C.M., Yun Y.: A study of power transmissibility for the vibration isolation of coherent vibratory machines on the floor of a building, Applied Acoustics, vol. 71, no. 4, 2010, pp. 368–372.

[2] Yun Y., Mak C.M.: Assessment of the stability of isolated vibratory building services systems and the use of inertia blocks, Building and Environment, vol. 45, no. 3, 2010, pp. 758–765.

[3] General guidelines for marine chock designers, Technical Bulletin 692D, ITW Polymer Technologies, Montgomeryville 2005.

[4] Grudziński K., Grudziński P.: Tradycyjny i nowoczesny sposób posadawiania ciężkich sprężarek tłokowych na fundamentach betonowych, Przegląd Mechaniczny, nr 5, 2009, s. 15–21.

[5] Piaseczny L.: New types of washers and foundation bolts for seating marine diesel engines, Combustion Engines, vol. 48, no. 3, 2009, pp. 23–27.

[6] Guidelines for the seating of propulsion plants and auxiliary machinery, Germanischer Lloyd AG, Hamburg 2010.

[7] Piaseczny L.: Marine engine seating on polymer-metal chocking, Combustion Engines, vol. 47, no. 4, 2008, pp. 3–13.

[8] Grudziński P., Konowalski K.: Experimental investigations of normal deformation characteristics of foundation chocks used in the seating of heavy machines and devices, Part 1: Theoretical fundamentals and investigations of a steel chock, Advances in Manufacturing Science and Technology, vol. 38, no. 1, 2014, pp. 63–76.

[9] Piaseczny L.: Designing of power plant rechocking using a pourable polymer on example of ship's power plant, Eksploatacja i Niezawodnosc – Maintenance and Reliability, vol. 4, no. 2, 2002, pp. 26–38.

[10] Kawiak M., Kawiak R.: Dobór materiału na fundamentowe podkładki maszyn, Inżynieria Materiałowa – Materials Engineering, vol. 36, no. 6, 2015, s. 528–531.

[11] Piaseczny L.: Analysis of main propulsion engine seatings in ship power plants, Journal of Polish CIMAC, vol. 5, no. 1, 2010, pp. 135–142.

[12] Grudziński K., Grudziński P., Jaroszewicz W., Ratajczak J.: Assembling of bearing sleeve on ship propulsion shaft by using EPY resin compound, Polish Maritime Research, vol. 19, no. 2, 2012, pp. 49–55.

[13] Grudziński P., Grzejda R.: Wyznaczenie charakterystyk montażowych modeli fundamentowych złączy śrubowych z podkładką stalową i odlaną z tworzywa, Przegląd Mechaniczny, nr 5, 2016, s. 34–38.

[14] Urbaniak M., Ratajczak J.: Modernizacja posadowień maszyn i urządzeń okrętowych oraz przemysłowych z zastosowaniem tworzywa chemoutwardzalnego EPY, Część 1: Praktyczne zastosowania tworzywa, Inżynieria Materiałowa – Materials Engineering, vol. 36, no. 6, 2015, s. 532–536.

[15] Schaumann P., Kleineidam P., Seidel M.: Zur FE-Modellierung von zugbeanspruchten Schraubenverbindungen, Stahlbau, vol. 70, no. 2, 2001, pp. 73–84.

[16] Bouzid A.-H., Beghoul H.: The design of flanges based on flexibility and tightness, In Analysis of bolted joints, Proc. of the 2003 ASME Pressure Vessels and Piping Conference, Cleveland, Ohio, 20-24 July 2003, pp. 31–38.

[17] Grzejda R.: New method of modelling nonlinear multi-bolted systems, In Advances in Mechanics: Theoretical, Computational and Interdisciplinary Issues, Proc. of the 3rd Polish Congress of Mechanics (PCM) and 21st International Conference on Computer Methods in Mechanics (CMM), pp. 213–216, CRC Press/Balkema, Leiden 2016.

[18] Grudziński P.: Analiza odkształceń i naprężeń w fundamentowych złączach śrubowych, Część 2: Złącze śrubowe z podkładką z tworzywa, Modelowanie Inżynierskie, nr 52, 2014, s. 72–79.

[19] Grudziński K., Jaroszewicz W., Grudziński P., Ratajczak J.: 40 lat stosowania polskich tworzyw w posadawianiu maszyn i urządzeń na fundamentach, Przegląd Mechaniczny, nr 4, 2015, s. 26–35.

[20] Grzejda R.: Designation of a normal stiffness characteristic for a contact joint between elements fastened in a multi-bolted connection, Diagnostyka, vol. 15, no. 2, 2014, pp. 61–64.

[21] Urbaniak M., Grudziński K.: Wpływ szybkości odkształcania na charakterystyki mechaniczne tworzywa epoksydowego EPY® poddanego obciążeniom ściskającym, Kompozyty, nr 4, 2006, s. 24–28.

Przesłano do redakcji: 12.03.2018 r.
Przyjęto do druku: 25.09.2018 r.