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Methodology of assessment of adhesive composites' properties

Summary — The paper presents research proposition of methodology of adhesive composites' properties assessment, which was developed on the basis of numerous own researches and analysis of references. Using the proposed methodology, there were conducted experimental tests of a new Belzona 1831 adhesive composite, which can be applied on the wet and insufficiently cleaned surfaces. It appeared that the tested material exhibits much lower compression strength and creep resistance in connection to field repairs of military equipment, than previously tested adhesive composite of „super metal" group — Belzona 1111. Therefore, it does not seem to be useful with repair that guarantee long lasting effectiveness, but only temporary repairs with relative low level of load of repaired element. In contrast to Belzona 1111, the researched adhesive composite can be applied on the wet surfaces since it showed adhesion to steel wet surfaces.
Keywords: durability of materials, adhesive composites, mechanical properties of adhesive composites.

METODYKA OCENY WŁAŚCIWOŚCI KOMPOZYTÓW KLEJOWYCH
Streszczenie — W pracy przedstawiono autorską propozycję metodyki postępowania badawczego, mającego na celu określanie właściwości kompozytów klejowych, istotnych ze względu na naprawy polowe sprzętu wojskowego, z uwzględnieniem ich doraźności oraz trudnych warunków realizacji. Na pierwszym etapie postępowania badawczego określa się właściwości mechaniczne wykorzystując próbkę cylindryczną wykonaną z badanego kompozytu (rys. 1), na drugim zaś właściwości wytrzymałościowe próbek wałeczkowych obciążonych na odrywanie (rys. 2). Na trzecim, fakultatywnym etapie jest przewidziana ocena właściwości wytrzymałościowych badanego tworzywa, w odniesieniu do różnych specyficznych czynników, takich jak: rodzaj klejonego materiału, sposób przygotowania powierzchni lub temperatura utwardzania złącza klejowego. To badanie proponuje się realizować z wykorzystaniem próbek płaskich, obciążonych na ścinanie (rys. 3). Na podstawie zaproponowanej metodyki zbadano właściwości nowego materiału Belzona 1831 oraz porównano je z cechami znanego i przebadanego wcześniej kompozytu klejowego Belzona 1111. Wykazano, że zaproponowana metodyka oceny właściwości kompozytów klejowych wydaje się użyteczna dla potrzeb określenia ich przydatności do napraw polowych sprzętu wojskowego.
Słowa kluczowe: wytrzymałość materiałów, kompozyty klejowe, właściwości mechaniczne kompozytów klejowych.

INTRODUCTION

Adhesive composites are kind of multi-purpose adhesive materials, which form a special group used in repairs and regeneration of machines' and devices' parts. Their manufacturing is based on chemo-setting adhesives for metals (most commonly those are epoxy adhesives) and they contain relatively considerable amount of fillers and extenders (most commonly metallic fillers). These materials show thixotropic properties thanks to which they can be used to bond and; simultaneously, fill in joints' gaps, as well as, complement material defects of parts. Therefore, adhesive composites are materials between typical structural adhesives and gap filling adhesives. On one hand, the can be used to execute bonds of full value (they show better adhesion to metal surfaces and higher durability than traditional gap filling adhesives); on the other hand, they can be applied with thicker layers than in case of structural adhesives (gap filling, sealing) [1, 2].

Adhesive composites may play a significant part in the process of technical objects expedient (temporary) repairs where efficient and effective restoration of broken items to usability is an extremely important issue [3—7]. It is especially visible during different kind of combat operations, which dramatically increase intensity of weapon systems damages. Repairs carried out in these conditions are called field repairs, and they do not necessarily aim at permanent recreation of full durability of the repaired part or the assembly, but rather at quick restoration of equipment's efficiency in order to execute a task [8—10]. However, it should be noted that several essential issues apper when analysing the current state of research on determining operational and durability properties of the selected adhesive composites as well as their usefulness with regard to expedient repairs of technical objects.

Firstly, technical equipment repairs are more and more often taking advantage of structural bonding [11—15] (elements of aircrafts made of composite materials, sandwich structures), as well as, quick chemically setting materials; so-called, adhesive composites, which create new possibilities in the scope of expedient or permanent removal of different types of damages (*e.g.* cracks, cut-throughs, and lack of tightness) [16—20]. A broader implementation of the modern repair technologies connected with the use of adhesive materials for military technology repairs could considerably improve the process of field repairs [3, 21—23].

Secondly, with regard to a specific character of the field repairs to the military equipment, a performed repair should guarantee a working life of repaired object within the range from several dozen to several hundred hours, until the moment when a task is executed or a combat operation is terminated and damaged subassemblies can be replaced with new ones or regenerated in stationary repair workshops with the use of methods that restore their original durability and utilitarian properties [7, 21, 24, 25].

What is more, the adhesive materials show relatively low durability. These materials are very sensitive to repair's conditions, as well as, they have got limited shear and long-term strength; that is, an ability to transfer constant loads in time, and limited fatigue life — an ability to transfer changing loads [26—31]. Without familiarity with these properties, the application of adhesive materials in repairs is burdened with the risk of damage of a repaired element in a relatively short time after the performed repair. Furthermore, these materials are subject to aging process both during components' storing and after their application (components' bonding and setting). Their adhesive and cohesive properties change relatively fast with the elapse of time [32—36].

Another issue concerns effective methods of conclusive evaluation that would enable to examine usefulness of the particular adhesive material with regard to its use in the process of the expedient repair of military equipment. In the literature on the subject one could find an enormous number of different kinds of experiments concerning different types of adhesive materials. The most considerable amount of research concerns structural adhesives, which can be used to paste composite patches to damaged airframe structures of aircrafts [11, 14, 37—39].

When summing up the previous analyses, one should notice that the great potential within the scope of the use of adhesive materials in order to remove combat and utilization failures of military equipment is; currently, considerably limited by the specific characteristics of adhesive materials. These are, among others: aging processes, limited long-term strength, limited fatigue life, and low thermal stability. Since manufacturers of adhesives and adhesive composites advertise their products usually by only giving their shear strength, it is difficult to decide whether or not the particular material fulfils the requirements of expedient (temporary) field repair. In this context, the main research objective of this work is to find a correlation between the conducted experiments; on the basis of previous research on adhesive composites, in the aspect of development a simplified methodology of determining usefulness of the specific material for the military purposes.

EXPERIMENTAL

Methodology of adhesive composites research

The executed so far assessment of features of adhesive composites makes it possible to select the limited range of research, which will be sufficient enough to allow researchers to determine the properties of new, untested materials, with regard to their use in expedient (temporary)

Methodology of assessment of adhesive composites' properties

1. Determining mechanical properties of the material:
- compression loaded cylinder specimens,
- determining a compression curve $\sigma = \sigma(\varepsilon)$,
- determining compression strength R_c, MPa,
- determining the modulus of longitudinal elasticity E, MPa,
- determining a creep curve $\varepsilon = f(t)$.

2. Determining strength properties of the material in joints:
- tensile loaded frontally joined specimens,
- determining tensile strength (max breaking stresses) R_o, MPa,
- determining a type of destruction (adhesive, cohesive or mix),
- determining the relationship between forces of adhesion and type and method of surface preparing for joining.

3. Determining specific utilitarian properties:
- shear loaded lap specimens,
- determining shear strength R_t, MPa,
- determining strength in conditions specific for the particular type of composite or for conditions of its use, *e.g.* temperature conditions of curing or operational conditions.

Scheme A. Suggested methodology of adhesive composites research field repairs. Simultaneously, it is assumed that these tests should be as easy as possible to carry out and their costs and duration should be minimised.

Scheme A presents the proposed methodology of research on adhesive composites.

In the first stage one should determine mechanical properties of an adhesive composite as a material, as $\sigma = \sigma(\varepsilon)$ relationship course, compression resistance R_c (MPa) and a modulus of longitudinal elasticity E (MPa). As numerous experiments proved for this type of adhesive materials, it is most advantageous to execute this kind of determination by means of a compression loaded cylindrical specimen since specimens undergoing stress and strain do not reach the level of deformations occurring in thin bonds [1, 40]. Cylindrical specimens of ϕ = 12.5 mm and l = 25 mm dimensions can be carried out by means of standardised syringes, which guarantee identical dimensions of specimens, as well as, low costs and easy execution (Fig. 1). During the execution of specimens one should make sure that there is no air bubble inside them;

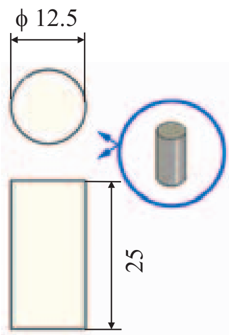


Fig. 1. The specimen used for mechanical properties of adhesive composite determination

therefore, a greater amount of adhesive composite should be placed inside a syringe and then the excessive amount should be squeezed out by means of syringe's piston. The right length of specimens should be kept by turning their ends by means of a lathe, which also guarantees that bases of cylinders are perpendicular towards their walls. Similar cylindrical specimens can be also used to determine creep curves of the examined material in normal and increased temperatures [$\varepsilon = f(t)$].

Thus, the first stage of research enables to define not only cohesive strength of material but also a value of its modulus of longitudinal elasticity. As it is commonly known, strength of shear loaded adhesive joints, that is, the most often used joints, is especially dependent on this mechanical property of bond [30, 32, 41—43]. What is more, determined strength properties of adhesive composite are indispensable with carrying out possible simulations and numerical calculations by means of the finite-element method. On the other hand, determination of creep curve gives possibility to evaluate creep resistance of an examined composite; in other words, its ability to transfer long-lasting static loads.

In the subsequent (second) stage of research strength properties of discussed adhesive composites in joints are determined. As it results from the conducted experiments, this determination is the most advantageous by examining tensile strength of adhesive composites R_o (MPa). It is recommended to conduct examination of this type by means of cylindrical specimens of ϕ = 16 mm dimension which are frontally joined and axisymmetrically loaded. In joints of this kind of specimens there is stress similar to uniaxial tension (Fig. 2). Depending on a type of destruction of adhesive bond (adhesive or cohesive);

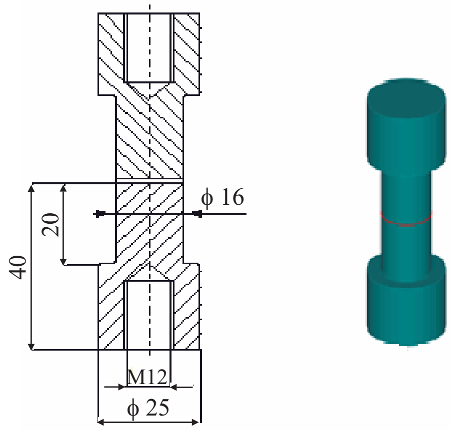
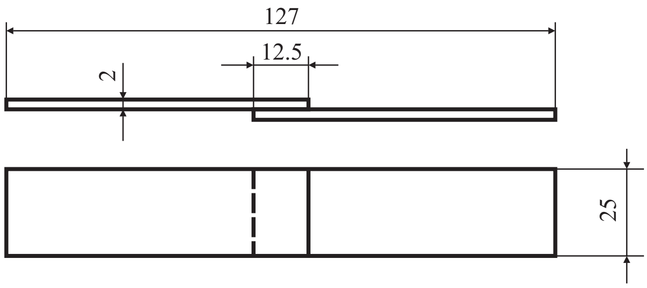


Fig. 2. The specimen used to determine strength properties of adhesive composite

by means of these specimens, one can determine a value of generalized destructive forces of adhesion or cohesive strength of examined material of bond (short term strength). Therefore, determination recommended in this stage enables to define general strength properties of an examined adhesive composite, and also to compare adhesive resistance of different materials and determine whether their destruction is of adhesive or cohesive type. If adhesive destruction is found, it means that an examined material showed low adhesion to a base material and it can show lower static long term and fatigue resistance. This fact should be also taken into consideration during possible numerical calculations; alternatively, there is no such need [44]. The proposed determination also enables to define dependence of the particular material's adhesion forces on the method of preparing a surface for joining.

The final proposed stage of research is optional. It can be used when there is a necessity to determine additional properties of adhesive composite connected with defining its strength in the conditions specific for the particular type of adhesive composite or conditions of its application, *e.g.* determining the influence of temperature conditions of joint curing or operation on its strength, or de-



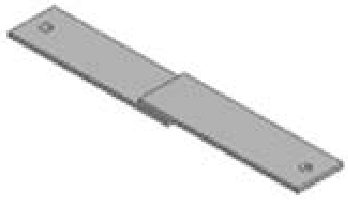


Fig. 3. The specimen used to determine utilitarian properties of adhesive composite

termining the influence of natural aging on its strength properties. In this kind of research, the use of shear single lap joints which enables generalized assessment of strength properties of tested material, seems to be the most advantageous. It is recommended to conduct this research in accordance with PN-EN 2243-1:1999, in which length of a lap is 12.5 mm, and its width is 25 mm (Fig. 3). In the research of this type one should use a method of preparing surface for joining that would correspond with actual conditions of repair.

Scope and methods of the research

Using the proposed above methodology of research, the usefulness of new Belzona 1831 adhesive composite was verified in connection to field repairs of military equipment. According to the manufacturer (English Belzona company) it can be applied on wet and insufficiently cleaned surfaces. In the first step compression and creep curves in the ambient temperature of examined adhesive composite were determined. Secondly, in order to assess the specific property of the composite mentioned by the manufacturer, the composite's tensile strength was defined for steel (S235JR) and brass specimens, as well as, wet steel specimens, and steel specimens covered with oil (WD-40). For the sake of comparison, similar research on thoroughly examined adhesive composite of „super metal" group — Belzona 1111 was presented. Finally, the examined material's shear strength tests were conducted for specimens made of steel (S235JR) and aluminium alloy (AW2017T4).

Compression and creep curves

Compression [$\sigma = \sigma(\varepsilon)$] and creep curves [$\varepsilon = f(t)$] were gained in a compression of cylinder specimens presented in the Figure 1. The measurement of strains' increase was conducted with the use of a micrometric sensor. The compression curves were defined with the use of Instron material testing machine at the speed of 2 mm/min in the ambient temperature. The creep curves were determined with the usage of devices presented in the work [21], where the loading element was a pressed spring. The experiment was conducted at the temperature of 20 °C, using a lab drier with thermo-circulation. During the creep curves determining, the specimens were loaded, and as a result there was a normal negative stress of 30 MPa.

Tensile strength of frontally joined specimens

Tensile strength was determined with the use of ZD-10 material testing machine at the ambient temperature. The tests were conducted with the use of cylindrical specimens presented in the Figure 2, which surface where prepared to bonding by use of abrasive-blast treatment and recommended cleaner. Determination was obtained using 6 specimens (the remaining specimens were used to investigate static long-lasting life). The results were verified by statistic methods in confidence level $1 - \alpha = 0.95$.

Shear strength of lap joints

Load capacity of shearing loaded lap joints was determined with the use of ZD-10 material testing machine at the ambient temperature. The tests were conducted according to PN-EN 2243-1:1999 with the use of lap joints presented in the Figure 3, but the surface of specimens were prepared for bonding by abrasive-blast treatment and recommended cleaner. The test was carried out using 6 specimens (the remaining specimens were used to investigate static long-lasting life). The results were verified by statistic methods in confidence level $1 - \alpha = 0.95$.

RESULTS AND DISCUSSION

Compression curves

The data presented in Fig. 4 shows that the discussed adhesive composite demonstrates compression strength of R_c = 80 MPa and the modulus of longitudinal elasticity at the level of E = 4100 MPa. In relation to the examined composites of „super metal" group, it is characterized by considerably lower value of compression resistance and similar modulus of longitudinal elasticity; therefore, in adhesive joints of short term load it should be characterized with similar value of strength; however, it can be less useful for reconstructing compression elements of machines.

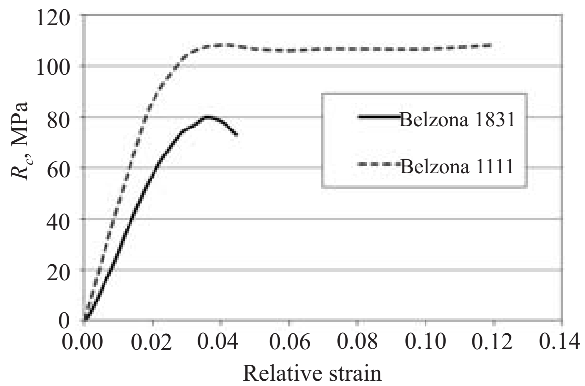
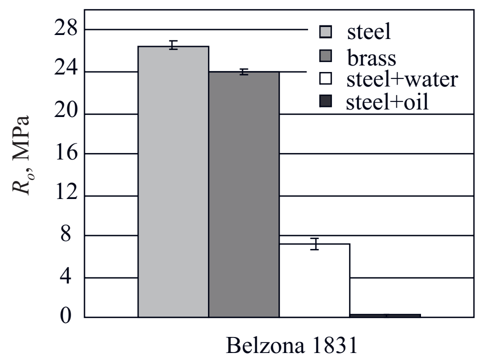


Fig. 4. Exemplary compression curves obtained for Belzona 1831 and Belzona 1111 adhesive composites



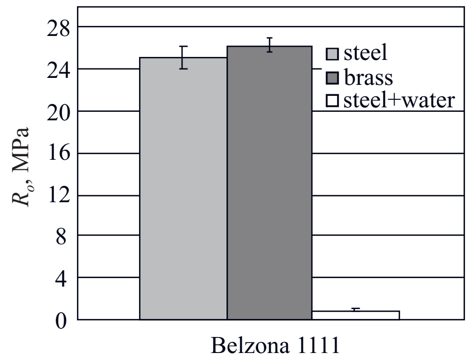


Fig. 6. Tensile strength of Belzona 1831 and Belzona 1111 adhesive composite for steel, brass, wet steel, and covered with oil steel specimens

Creep curves

The determined creep curves of Belzona 1831 composite proved that; under long-lasting load at the level of 30 MPa, this material exhibited a rapid increase in strain (Fig. 5). The applied load was less than 40 % of the material short term compression strength. Therefore, this composite does not seem to be useful with repairs that guarantee long lasting effectiveness, but only with temporary repairs with relatively low level of load of a repaired element.

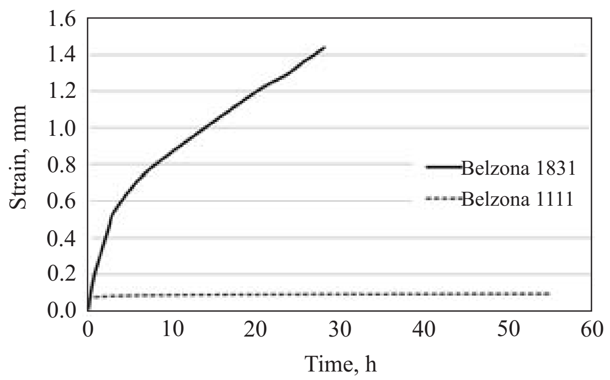


Fig. 5. Creep curves obtained for Belzona 1831 and Belzona 1111 adhesive composite at the temperature of 20 °C with load causing normal stresses of 30 MPa in the tested specimen

Tensile strength of frontally joined specimens

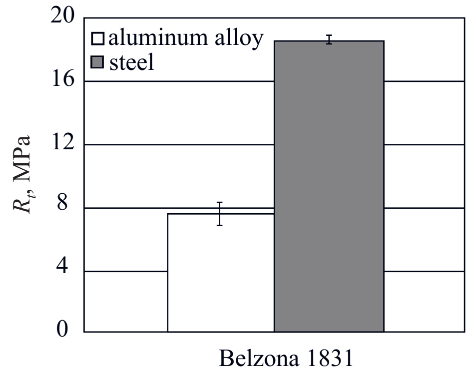
According to expectations based on the analysis of compression curves, the tested composite showed high parameters of short term strength in tear off loaded adhesive joints (Fig. 6). These are even slightly higher than those of composites of „super metal" group. What is more, it was stated that the examined composite; as opposed to other types of materials, showed adhesion to steel wet surfaces; still, it cannot be applied to undegreased surfaces. Therefore, it can be used for short-term removal of damages on spots where it is impossible to remove water before repair, *e.g.* in case of cracked pipeline or radiator repairs.

Shear strength of lap joints

The research on shear strength of Belzona 1831 composite for different base materials indicated its much higher adhesion to steel surfaces than to aluminum alloys (Fig. 7).

CONCLUSIONS

Based upon presented in the paper results, one can assume that methodology of research on adhesive composites enables to assess their usefulness for expedient field repairs of weapon system in a relatively simple and quick way. By means of several simple tests one can define the most significant parameters of studied material, such as: cohesive and adhesive short term strength, modulus of longitudinal elasticity, type of destruction, relationship between adhesion forces and a type and method of preparing of a surface, and an influence of other, freely selected factors on the material's strength properties. On the other hand, the determined creep curve gives possibility to predict; in a qualitative way, the material's durability to long-lasting constant and changing load — the materials of greater creep resistance enable to obtain joints of more considerable static long term and fatigue strength.



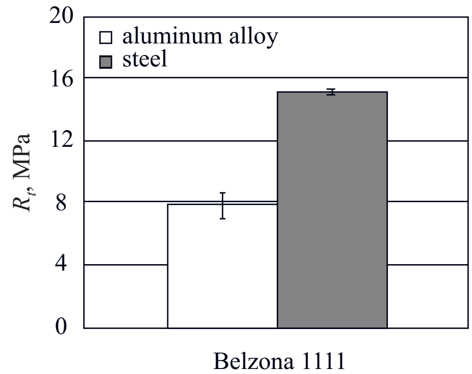


Fig. 7. Shear strength of Belzona 1831 adhesive composite for aluminium and steel specimens

The conducted research proved that the new Belzona 1831 adhesive composite exhibits much lower compression strength and creep resistance, in connection to field repairs of military equipment, than previously tested adhesive composite of „super metal" group — Belzona 1111. Therefore, it does not seem to be useful for repair that guarantee long lasting effectiveness, but only temporary repairs for relative low level of load of repaired element. However, in contrast to Belzona 1111, it can be applied on the wet surfaces since it showed adhesion to steel wet surfaces.

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