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Strength properties of repair glue composite Belzona 1111

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Summary. This article presents the most important, in terms of field repair of military equipment, results of glue composite Belzona 1111 defining characteristics, which are not provided by the manufactures. This paper presents strengths and functional characteristics of the composite and possibility of using it in repairs.
Keywords: strength of materials, glue composite, field repair, strength and functional properties of glue composite
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Introduction

Immediate repair of modern military equipment is not possible without the use of BDR technology (c)[1]. One of the elements of this technology is the use of adhesive plastic (construction glues, sealers, glue composites, etc.) [1]. More and more often constructional gluing is used in repairs (e.g. structures of airframes made of composite materials, separating structures, etc.). Quick-binding chemo-hardened materials: the so-called glue composites offer new opportunities in the scope of reparations of various types of damage (e.g. cracks, perforations, leaks) [2]. Wider introduction of modern technologies related to the use of corrective

[1] Battle Damage Repair — repair of combat damage, which is a quick and often ad hoc (not permanent) repair, is performed at the location of the troops (field conditions) and aims at rapid return of the damaged equipment to operation. The repair is characterized by limited access to spare parts and is carried out on the basis of basic rearing tools. Any scheduled works should be performed in a simple way and may not require complex preparation and finishing [1].

adhesive plastic to repair military technology can significantly improve the process of carrying out repairs in field conditions [3, 4, 5].

Due to the specificity of field repairs of military equipment, the repair performed should ensure the sustainability of the repaired item for several hundred hours, because after completion of combat operations damaged components can be exchanged for new ones or regenerated at stationary repair workshops with methods recovering their original strength and functional properties.

Macromolecule plastics, which are adhesive plastics, have relatively low durability. Such materials are characterized by time-limited strength, which is the ability to carry permanent burdens in time and limited fatigue strength — an ability to carry variable burdens [6]. Without knowledge of these properties, the use of these materials in repairs brings a risk of damage in a relatively short period of time after carrying out repairs. In addition, macromolecule plastics are a subject to aging process during storage of components, and after the application (combination of components and hardening). With time their adhesive and cohesive properties change relatively quickly [7, 8]. During the process of field repairs of military equipment, aging phenomenon is less significant due to the fact that its effects are visible after a period of time measured in months.

Taking into account the fact that producers of glue composites inform only about basic strength proprieties of their products, it was decided to comprehensively assess and determine the properties of the selected glue composite in following aspects:

— mechanical and adhesive properties;
— static time durability;
— fatigue durability.

The aim of this assessment was to turn the attention to the functional properties of glue composite.

Research methodology

A variety of adhesive materials, suitable for BDR type of repairs are currently available on the market. Material with universal functional properties and relatively high strength properties has been selected for the research. It was glue composite from the group of so called "super metals"-Belzona 1111. The tests were carried out by using samples made of tested composite (to determine its mechanical properties), as well as using glued samples (in order to determine the strength of joints made of tested composite). The basic methods of preparing the surface of samples for gluing were sandblasting and washing with an agent recommended by the manufacturer. The use of extraction naphtha was also possible.

The following indicators assessing properties of selected material have been presented in this paper:

- stress-strain curves and longitudinal elasticity modulus E [MPa] [2];
- tensile strength Rm [MPa] — set during tension of flat samples (with a cross 20 × 3 mm) made of the tested material. The research was conducted on a testing machine Instron 8501. Before marking, the sample had been seasoned at a temperature of around 18°C for 72 hours;
- shear strength Rt [MPa] — was set on the basis of the norm PN-69/C-89300. Elements of samples made of steel S235JR or aluminum alloy AW 2017T4. The research was conducted on a testing machine ZD-10;
- compress strength Rc [MPa] — was set basing on the norm PN-83/C-89031. Samples in cylindrical shape were made with a diameter of 12.6 mm and 31.5 mm in length. Six samples were made for each batch. The hardening of material has been carried out at a temperature of about 18°C for a period of 96 hours. The research was conducted on a testing machine ZD-10;
- impact strength a_n [Ncm/cm^2] — was set in accordance with the norm PN-68/C-89028. The impact strength of the samples was defined using the DYNSTAT type of camera produced by the German company Louis Shoper. Ten samples with dimensions of 15×10×3.5 mm have been used for each series. Samples had been seasoned before marking for a period of 72 hours at temperatures of around 18°C;
- tensile strength R_o [MPa] — was taken from [2] (samples are presented in Fig. 1);
- shear strength at a higher temperature was determined by measuring the strength of glue joints at the ambient temperature and at the temperatures of: 60, 100, 140 and 180°C. The studies involved the high temperature chamber, inside which the temperature was regulated with an accuracy of ±2^{o}C. The sample had been heated at the desired temperatures for 8 minutes, and then torn off. The tests for strength of joints were carried out on a testing machine ZDM at constant joint strain speed 6 mm/s;
- shear strength of ageing joints in natural climatic conditions — research carried out for steel sheet (S185) and aluminum alloy (AW 2017T4). Joints were aged in two places. The first can be characterized by intense sunlight and variable temperature and occasional precipitations. The second was a shady place, characterized by intensive and long-term effects of moisture and variable temperature. Given the temporarily character of field repairs, joints have been aged for 6 months in the first place and 12 months in the second place. The exposure of samples started in spring;
- shear strength of joints subjected to heating at high temperatures — made of sheet steel (S185). Joints soaked at a temperature of 100°C for a period of 50, 150, and 500 hours;
- dependence of shear strength of joints made of tested composite using different methods of preparation of the glued surface, for instance by ap-

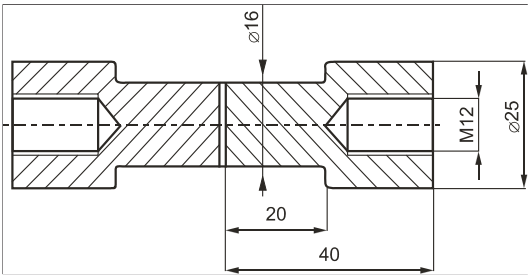

Fig. 1. The shape and dimensions of the sample subjected to stretching [2]

plying a degreasing agent. Composition of the glue and thickness of gluing joint were also an important factor;

— static time durability enabled the estimation of limit stress value, at which the glued joints, made of the test material were able to withstand at least 500 hours at a temperature of 60°C. The working time of joint was taken considering temporary character of the repair and the temperature. The assumption also included the possibility of the effects of sunlight on military equipment (e.g. overheating) and elements absorbing heat while working, such as engines. A detailed methodology for testing is described in the work [2];

— research on fatigue durability of adhesive materials made it possible to estimate the joint stress limits burdened with variables forces. Due to the time-consuming character of research and taking into account the specificity of ad hock repairs, in fatigue studies, the test was interrupted after carrying out 250.000 stress cycles. A detailed research methodology is described in the work [2].

The results of the tests and their analysis

A stress-stain curve is set during the static tensile test, in which the maximum stresses are equal to ad hoc strength of the test material [12]. In the case of glues and glue composites a problem occurs, because they were applied in the form of thin layers (joints) or shells. Basing on the results of research [13] it was assumed that with sufficient precision, mechanical properties of joints can be set using samples cast from tested adhesive plastic.

Due to the fact that such samples subjected to stretching do not achieve the level of strain occurring in thin joints, stress-strain were set in compression tests for cylindrical samples of dimensions φ = 12.5 mm and l = 25 mm [14], in which much greater strain can be achieved. Such tests allow us to specify the cohesive strength of plastic but also the value of the longitudinal elasticity module of tested

material. The tests were carried out on a testing machine ZD-10 at a speed of the burden rise of about 500 N/s. Results of the tests are given in Fig. 2.

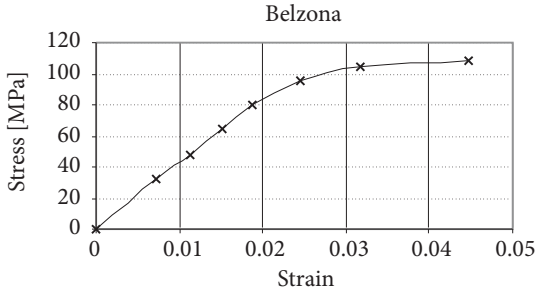

Fig. 2. Exemplary compression curve for glue composite Belzona 1111 [2]

Basing on the results of the tests a conclusion can be made that mechanical properties of tested composite are characterized by compression strength of around 120 MPa and the value of longitudinal elasticity module about 4400 MPa. Testing results for strength properties of glue composite Belzona 1111 are shown in Table 1.

Table 1

Strength properties of glue composite Belzona 1111

Parametr	Belzona 1111
Tensile strength Rm	29.6 [MPa]
Shear strength Rt — for steel plates St3 — for aluminum plates PA7T4	 18.14 ±0.28 [MPa] 11.78 ±0.69 [MPa]
Compression strength Rc	122.2 ±0.7 [MPa]
Impact strength a_n	13.2 ±0.11 [Ncm/cm^2]

In the case of shear strength testing, the destruction of joints made of composite Belzona 1111 had cohesive character, which demonstrates a very high adhesion of the material to the ground. The research also shows that the tested material reveals greater shear strength in terms of steel sheets than the ones made of aluminum alloy. This is in line with the expectations, and it is a result of higher value of longitudinal elasticity module of steel than aluminum.

Tensile strength was defined for three types of ground: aluminum, steel and brass. Results of tests are given in Fig. 3.

Tested composite shows a different peel strength and adhesion to a variety of metal alloys, after preparation of their surface for gluing with sand-blasting. The

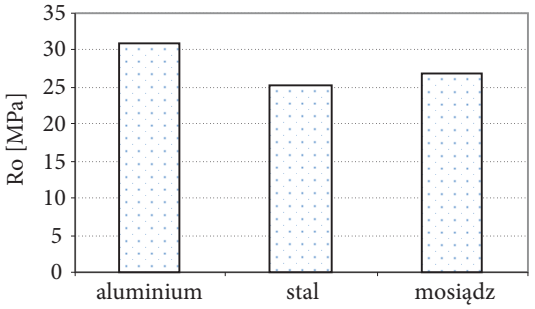

Fig. 3. Tensile strength of glue composite Belzona 1111 [2]

strongest adhesion was observed on the alloy of aluminum and steel, where only cohesive destruction of material occurred. In the case of brass adhesive-cohesive destruction occurred, reflecting a slightly lower adhesion on the material using the tested composite. Shear strength at high temperature of joints made with the use of glue composites was an important factor, because this type of material can be used to repair components, which are heated in operation to a temperature higher than 100°C (e.g. engine body, pipes inside engine such as cooling and lubrication systems).

Results of tests are presented in Fig. 4.

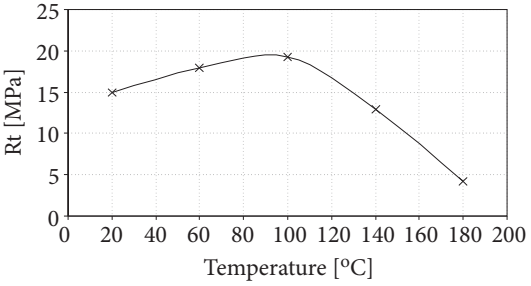

Fig. 4. Shear strength at higher temperature of joints made with the use of glue composite Belzona 1111

Analysis of the results indicates that the test material is characterized by relatively high shear strength at higher temperature. Research shows that the tested composite may be used for a short period of time at a temperature of 120°C. An increase in shear strength at a temperature of 60°C and 100°C was also found. It was probably caused by drop in longitudinal elastic module of tested plastic at higher temperature.

In order to verify the impact of natural climate factors on change of strength properties of glue composite Belzona 1111 in time, two overlapping batches made of

an alloy of aluminum and steel were glued. Sheet surfaces for gluing were prepared by aloxite sandblasting and washing with extraction naphtha. From each batch consisting of 12 units, 6 were randomly selected and their immediate strength was defined. The remaining samples were placed on the roof of the building, where they were exposed to the effects of weather conditions (changes of temperature, rainfall and the impact of sunlight). The strength of samples aged in natural conditions was determined after six months. There is a comparison of shear strength of samples tested immediately after gluing and after a period of six months aging process in Table 2.

Table 2

Comparison of the effects of natural aging on shear strength of glue composite Belzona 1111

Material	Aging time [months]			
	Samples of aluminum		Samples of steel	
	t = 0	t = 6	t = 0	t = 6
Belzona 1111	11.78 ±0.69	13.40 ±0.63	18.14 ±0.28	16.88 ±2.09

No signs of corrosion on samples of an alloy of aluminum were noticed. The surfaces of steel samples were covered with rust. Taking into account the value of confidence limits, six-month aging resulted in an increase in the strength of joints Belzona 1111 for aluminum samples and 7% decline in the strength of steel samples.

In addition, joints made with the use of tested composites of steel sheet (S185) have been naturally aged for a period of 12 months inside an empty body of a fighting vehicle. The samples were not directly subjected to the sun's rays. They were subjected to a lengthy and intensive impact of water, moisture, and variable temperature. Joint have been kept in such conditions for a period of 3, 6, 9, and 12 months. The results of this testing can be found in Fig. 5.

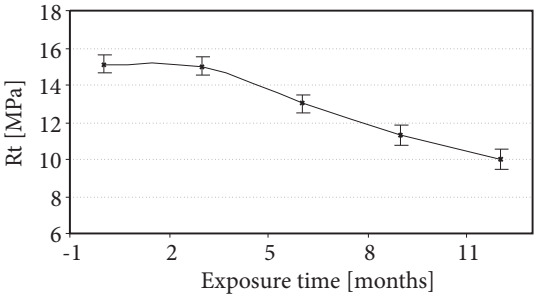

Fig. 5. Change of the shear strength of joints made with the use of composite Belzona 1111, aged in natural climatic conditions

On the basis of research results, it can be concluded that the strength of steel joints aged in a humid environment with unstable temperatures (Fig. 4) was gradually declining along with extension of the aging time. After 12 months of aging process, reduction in shear strength by about 33% was observed. Observation of broken joints indicated that the ground material (S185), despite the fact that it was covered with gluing material, corroded. It demonstrates that tested composite did not sufficiently protect the ground against corrosion, especially in term of the long-term impact of water and moisture.

While examining the results of long-term impact of high temperature on the shear strength of steel joints glued with composite Belzona 1111 (Fig. 6), a significant increase in strength in the first phase had been observed. It has been followed by a slight decline in the second phase. The process of hardening of glue composite was the probable cause of this phenomenon.

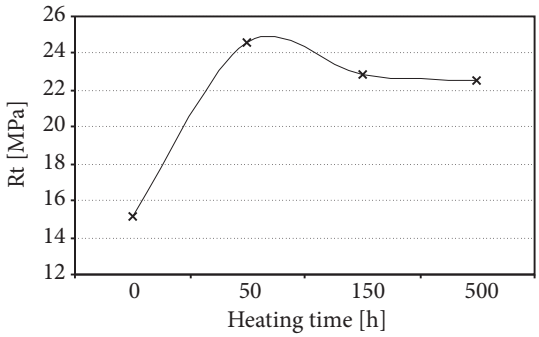

Fig. 6. Change of shear strength of joints subjected to long-term effects of high temperature (100°C)

The PN-69/C-89300 standard is the most commonly used designation of adhesive joints. Patterning upon this standard, the effect of selected factors related to the preparation of surfaces of sheets and gluing mass on strength properties of glue composite Belzona 1111 was tested. Results of the research are presented in Figs. 7-10 [15].

The performed research demonstrates that glue composite Belzona 1111 shows the best adhesion to the surface of aluminum alloys prepared with etching or sandblasting method (Fig. 7). The use of a brand remover is the most appropriate method for washing sandblasted surfaces of steel sheets (Fig. 8). Improper measurement of individual components of gluing mass adversely affects shear strength of the tested composite. The shortage of hardener affects it even more (Fig. 9). In the case of glue joints operating on a wall, the highest value of strength for composite Belzona 1111 was obtained for joint thickness of 0.15 and 0.20 mm (Fig. 10).

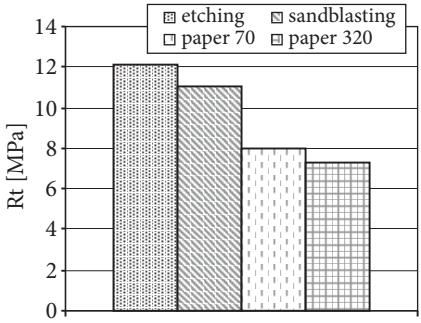

Fig. 7. Influence of surface preparation on joint strength [15]

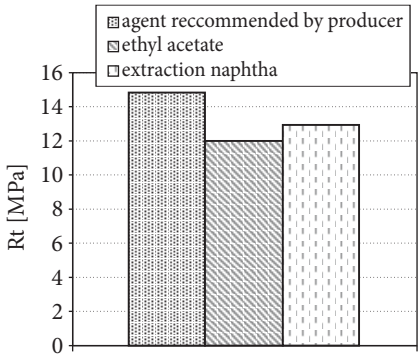

Fig. 8. Influence of surface cleaner on joint strength [15]

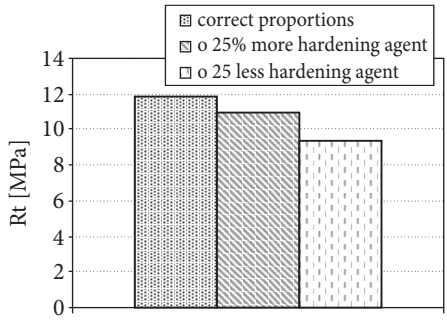

Fig. 9. Influence of gluing mass composition on joint strength [15]

Glue joints are characterized by a limited time static durability and change of strength in time. This means that glue joint can be destroyed under the influence of permanent load, lower than that set in immediate strength test, after a certain period of time. To determine the static time durability of tested glue composite in

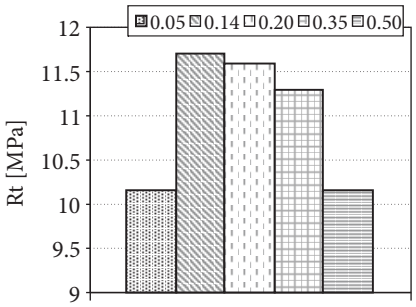

Fig. 10. Influence of joint thickness on joint strength [15]

the first phase, deep curves in a compression test for cylindrical samples were set. They were the subject of a permanent burden giving normal negative stress of 10, 20, and 30 MPa [2]. Due to time-consuming character, the testing was limited to 1000 h. The test results are presented in Fig. 11.

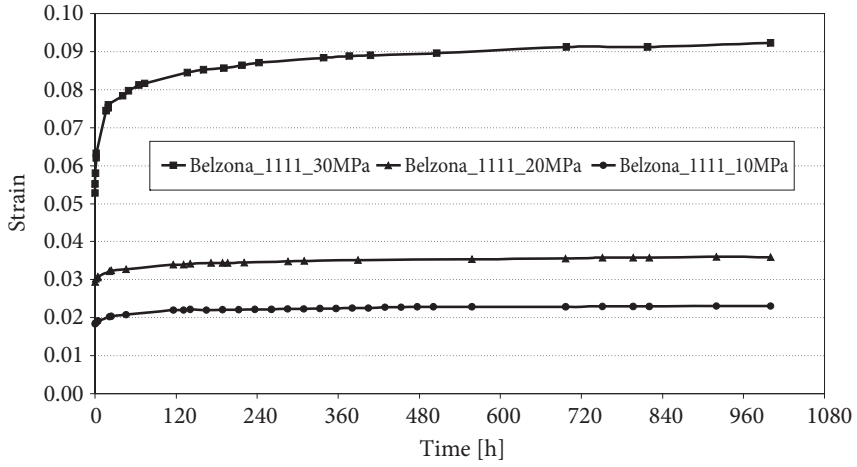

Fig. 11. Creep curves of composite Belzona 1111 obtained for various stresses at a temperature of 60°C [2]

Static time durability of composite Belzona 1111 was set by burdening one of the samples with a load of 60% Pn (Pn — an average strength destroying the sample) and placing it in a heat chamber at the temperatures of: 60°C, 80°C, and 100°C. Given the temporary character of field repairs, testing was interrupted after 500 hours. At a temperature of 60°C, none of the five samples glued with Belzona 1111 was seriously damaged or destroyed during the assumed time. At a temperature of 80°C, one of the samples was destroyed after 48 hours of being burdened. The remaining samples were not affected by the high temperature.

At a temperature of 100°C, all the tested samples have been destroyed during the first 24 hours.

Limited static time durability of glue joints made using Belzona 1111 demonstrated in the tests, confirmed the need of taking into account rheological properties of glue composite while designing such joints.

It should be taken into account that when using adhesive plastics in repairs of military equipment, the repaired area may be subjected to fatigue burden. Therefore it is necessary to be aware of possible transfer of variable burdens through repairing material. Due to the limited time of research and temporary character of field repairs only the level of fatigue durability was measured. Tests were carried out for composite as material and joints of glue composite Belzona 1111. In durability tests for material itself, cylindrical samples were burdened with stress compression from-zero-pulsating with a value of 55 MPa, i.e., equal to a half of compression strength with a frequency of 20 Hz. Testing was stopped after about 750 000 cycles due to the fact that no sign of damage was found.

Fatigue durability of joints glued with the tested composite was also determined during the research. A batch of 10 one-overlapping samples made of aluminum alloy AW2024T4 [2] was glued, 5 of which were subjected to immediate strength. An average destructive power of P = 2450 ±248 N has been set. Other samples were then subjected to the following fatigue durability tests and the results are presented in Table 3.

Table 3

Fatigue durability of joint glued with the composite Belzona 1111

Sample No	Load	Result
1	— 0.1-1.3 kN (about 0.53 of destructive load)	— after 654 000 loading cycles the test was interrupted
2	— 0.1-1.3 kN (about 0.53 of destructive load)	— after 434 000 loading cycles the test was interrupted
3	— 0.1-1.5 kN (about 0.61 of destructive load)	— after 303 000 loading cycles the test was interrupted
4	— 0.1-1.5 kN (about 0.61 of destructive load) — the load was increased 0.1-1.7 kN (about 0.69 of destructive load)	— after 302 000 loading cycles the test was interrupted — after 903 cycles the sample was destroyed
5	— 0.1-1.7 kN (about 0.69 of destructive load)	— after 58 634 loading cycles the sample was destroyed

At fatigue loads, with a maximum value equal to 0.6 of immediate strength, fatigue durability of joints lasted longer than 300 000 cycles.

Conclusions

On the basis of performed tests, it is possible to formulate general conclusions about strength properties and limits of the tested glue composite Belzona 1111:

1. Taking into account the results of the static time durability tests and fatigue durability of glue composite, it can be stated that immediate strength cannot be the only criterion for assessing the usefulness of the tested material for making joints in responsible structures.
2. Glue composite Belzona 1111 shows a high compression strength and adhesion to the ground and the relatively low longitudinal elasticity module (compared to other composites from the "super metal" group, which were researched in [2]). In the case of shearing joints, the highest level of strength has been achieved for steel grounds with thickness of the glued joint at 0.15-0.20 mm.
3. In the case of short-term static loading, the maximum temperature of joints made with Belzona 1111 should not exceed 120°C for load at Rt = 15 MPa.
4. It should be noted that even six months aging process in conditions of high humidity reduces the strength of joints of steel sheets made with the use of tested composite.
5. Long term (500 hours) exposure to a high temperature (100°C) does not adversely affect its strength properties.
6. Numerous researches show [2], that the best method to prepare the surface of steel sheet for gluing with Belzona 1111 are sandblasting and washing with an agent recommended by the manufacturer. The use of extraction naphtha is also possible.
7. During the research, it was found that at a temperature higher than 80°C, the static time durability of joints made of composite Belzona 1111 has been sharply reduced.
8. Due to the specificity of repairs carried out in field conditions, fatigue durability of glue joints above 300 000 cycles can be considered in most cases as sufficient one. Secure value for maximum fatigue burdens ensuring such durability equals 0.6 of destructive load in immediate static strength tests.

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T. SMAL

Właściwości wytrzymałościowe klejowego kompozytu naprawczego Belzona 1111

Streszczenie. W artykule przedstawiono najistotniejsze, z punktu widzenia doraźnych napraw polowych sprzętu wojskowego, wyniki badań jednego z powszechniej wykorzystywanych w naprawach — kompozytu klejowego Belzona 1111. W artykule zamieszczono wyniki wieloletnich badań własnych oraz dla pełnego zobrazowania cech badanego kompozytu, dołączono wybrane wyniki badań realizowanych przez innych badaczy. Zaprezentowane w pracy badania określają właściwości mechaniczne, takie jak krzywa ściskania (rys. 1), wytrzymałościowe, takie jak: wytrzymałość na rozciąganie, ściskanie, ścinanie, udarność i trwałość zmęczeniowa (tab. 1, rys. 3) oraz użytkowe, takie jak: wytrzymałość na ścianie w podwyższonej temperaturze, wpływ naturalnego starzenia na wytrzymałość na ścianie, wpływ długotrwałego wygrzewania złączy na ich właściwości wytrzymałościowe, wpływ sposobu przygotowania powierzchni i kompozycji klejowej na właściwości wytrzymałościowe i krzywą pełzania (tab. 2, rys. 4-11) rozpatrywanego klejowego kompozytu naprawczego. Podkreślić należy fakt, że przeanalizowane w pracy właściwości nie są podawane przez producenta materiału, a ich znajomość wydaje się niezbędna w aspekcie ewentualnego wykorzystania badanego kompozytu do realizacji doraźnych napraw sprzętu wojskowego, które są wykonywane w warunkach polowych.

Na podstawie zrealizowanych i przytoczonych badań określono ogólne właściwości wytrzymałościowe i ograniczenia dotyczące zastosowania klejowych kompozytów naprawczych oraz szczegółowe zalecenia dotyczące zastosowania kompozytu klejowego Belzona 1111.
Słowa kluczowe: wytrzymałość materiałów, klejowy kompozyt naprawczy, naprawy polowe, właściwości wytrzymałościowe i użytkowe kompozytu klejowego
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