THE INFLUENCE OF NATURAL SEASONING ON THE LOAD CAPACITY OF CYLINDRICAL ADHESIVE JOINTS

Wpływ sezonowania naturalnego na nośność połączeń klejowych czopowych walcowych

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A b s t r a c t: The aim of the work was to investigate the influence of natural seasoning on the load capacity of cylindrical adhesive joints subjected to and not subjected to additional heat treatment. The adhesive joints ware made of ENAC-AlSi7Mg0.3 aluminum alloy (sleeve) and glass-epoxy composite (pivot). The elements were joined together using the Araldite 2014 adhesive composition. The adhesive joins were subjected to an axial shear test. The research was carried out for several variants of seasoning: seasoning for 6 months in the summer period, seasoning for 6 months in the winter period, seasoning for one year and two years. The test results show that the seasoning of samples not subjected to additional heat treatment increased the load capacity of the adhesive joints by 0.1-21.3%. On the other hand, in the case of samples subjected to additional heat treatment, seasoning contributed to the reduction of the load capacity of the joints by 0.6-24%. The analysis of significant differences (Student's t-test) showed that in the adopted range of variability of the input factors, the seasoning conditions did not have a significant impact on the load capacity of the adhesive connections. Only in the case of samples with additional heat treatment, seasoned for 2 years, the load capacity shows statistically significant differences compared to other variants (pv=0.23%). The results of correlation and regression analysis indicate that in the case of samples subjected to additional heat treatment, the load capacity of the adhesive joints decreases with the increasing duration of seasoning (r=-0.835). In the case of samples that have not been subjected to additional heat treatment, the load capacity of the joints increases with the increasing duration of seasoning (r=0.841).
K e y w o r d s: natural seasoning, cylindrical adhesive joints, heat treatment, EN AC-AlSi7-Mg0.3 aluminum alloy, glass-epoxy composite EP405-GE

S t r e s z c z e n i e: Celem pracy była ocena wpływu sezonowania naturalnego na nośność połączeń klejowych czopowych walcowych poddanych i niepoddanych dodatkowej obróbce cieplnej (dotwardzaniu cieplnemu). Złącza klejowe wykonano ze stopu aluminium EN AC-AlSi7Mg0,3 (tuleja) oraz kompozytu szklano-epoksydowego (czop). Elementy połączono ze sobą za pomocą kompozycji klejowej Araldite 2014. Połączenia klejowe poddano próbie ścinania osiowego. Badania przeprowadzono dla kilku wariantów sezonowania: sezonowania przez 6 miesięcy w okresie letnim, sezonowania przez 6 miesięcy w okresie zimowym, sezonowania przez jeden rok oraz przez dwa lata. Wyniki badań wskazują, że sezonowanie próbek niepoddanych dodatkowej obróbce cieplnej spowodowało zwiększenie nośności połączeń klejowych o 0,1-21,3%. Natomiast w przypadku próbek poddanych dodatkowej obróbce cieplnej sezonowanie przyczyniło się do zmniejszenia nośności złączy o 0,6-24%. Analiza istotnych różnic (test t-Studenta) wykazała, że w przyjętym zakresie zmienności czynników wejściowych warunki sezonowania nie miały istotnego wpływu na nośność połączeń klejowych. Jedynie nośność próbek z dodatkową obróbką cieplną sezonowanych przez okres 2 lat wykazuje istotne statystycznie różnice w porównaniu do pozostałych wariantów (pv=0,23%). Wyniki analizy korelacji i regresji wskazują, że w przypadku próbek poddanych dodatkowej obróbce cieplnej nośność połączeń klejowych maleje wraz ze wzrostem czasu sezonowania (r=-0,835). W przypadku próbek, które nie zostały poddane dodatkowej obróbce cieplnej, nośność złączy zwiększa się wraz ze wzrostem czasu sezonowania (r=0,841).
S ł o w a k l u c z o w e: sezonowanie naturalne, połączenie klejowe czopowe walcowe, obróbka cieplna, stop aluminium EN AC-AlSi7-Mg0.3, kompozyt szkło-epoksydowy EP405-GE

Introduction

Adhesive joints are widely used in various industries and in many cases they successfully replace mechanical joints. Compared to conventional mechanical joints, adhesive joints provide a more even stress distribution along the joint area, can be used to join various materials with different thermal expansion coefficients, are more resistant to corrosion and have good damping and sealing properties [10].

Due to the shape and mutual positioning of the joined elements, the adhesive joints can be divided into cylindrical and non-cylindrical connections. Among the cylindrical joints, there are non-tapered and tapered joints. The non-cylindrical joints are divided into flat (frontal and lap) and angular (T-shaped and corner) connections [17].

The most popular adhesive joints are lap joints, which are characterized by a very simple structure [12, 17].

Cylindrical joints can be used, for example, as an alternative to interference fits connections [17]. One of the applications of cylindrical joints is joining composite pipes used for pipeline transport [22]. Another example of the use of this type of adhesive joints is hollow insulator. There are four types of such insulators: ceramic, glass, polymer (composite and resin) and hybrid [5]. Ceramics and glass are traditional materials used in the construction of insulators. These materials are characterized by durability, good mechanical properties and resistance to environmental factors. Their disadvantages are brittleness and low resistance to dirt [7]. In recent years, composite insulators have been gaining more and more popularity. The advantages of composite insulators are good mechanical properties, resistance to dirt, flexibility, low weight (compared to ceramic insulators), ease of transportation and installation. Due to the relatively short service life, and thus relatively small operating experience, composite insulators are still not fully tested in terms of long-term service life [8, 23]. Composite insulators are made of a glass-epoxy tube or a rod with metal fittings attached to the ends of it, and an insulating sheath made of silicone rubber. The element transmitting mechanical loads is a glass-epoxy composite tube. In the exemplary composite insulator (Fig. 1), metal fittings are attached to the pipe with epoxy adhesive. The insulating sheath protects the core against environmental influences. The shape of insulating sheath determines the electrical properties of the insulator. The insulating sheath may be formed by injection molding. Composite insulators, depending on the manufacturer, may differ in dimensions, the method of making the insulation sheath, material and execution of fittings, etc. [7, 8].

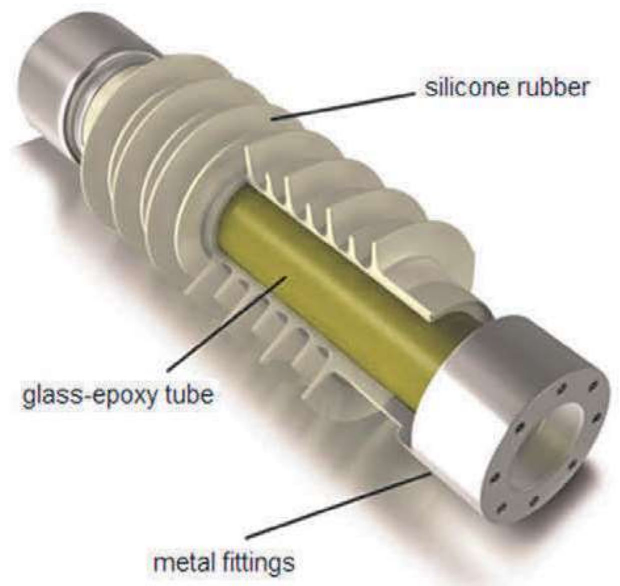


Fig. 1. The composite insulator [8]

Adhesive connections in composite insulators are exposed to environmental factors, such as cyclical temperature and air humidity changes. In the currently available literature, there are no results of research on the influence of natural seasoning in the Polish climatic zone on the strength of adhesive cylindrical joints used in composite insulators. Nevertheless, existing similar analyzes of the influence of temperature or aging time on the behavior of adhesive joints may be helpful in the design of adhesive joints in composite insulators.

The main components of adhesives are polymers. Therefore, the thermal properties of polymers largely determine the behavior of the adhesive joint at high, low or changing temperatures [9]. In the case of polymers (as well as adhesives), long-term exposure to elevated temperature leads to the so-called thermal degradation. As a result of degradation, macromolecules break down into smaller fragments. Additional cross-linking of the material structure in the first phase of degradation may contribute to the improvement of adhesive properties, including the increase of mechanical strength [18]. Nevertheless, further degradation can lead to a reduction in molecular weight or an excessive cross-linking of the structure, ultimately leading to deterioration of the strength properties. In the work [24], studies were carried out on the effect of additional heat treatment on a butt joint static strength at ambient temperature and elevated temperature. It has been shown that as a result of the heat treatment, the static strength of the joints tested at ambient temperature can be increased. However, in the case of joints created using compositions with an excess of hardener, which are additionally exposed to high temperatures, additional heat treatment may weaken such joints. Therefore, additional heat treatment cannot be treated as a universal method of increasing the strength of adhesive joints.

The process of structural changes occurring during degradation may be caused not only by long-term exposure to high temperature, but also by other external factors such as oxygen, ozone, high-energy radiation, light radiation, UV radiation, chemicals (including steam and water) and mechanical stress (in particular, cyclically changing dynamic stresses) [18].

In the case of long-term exploitation of adhesive joints, the adhesive bonds may be weakened as a result of moisture diffusion processes taking place at the interface between the adherent element and the adhesive joint. The method of protection the joints in this case may be coating the joints with special agents resistant to moisture adsorption [19].

Adhesives, as macromolecular materials with a spatially cross-linked structure, exhibit the characteristics of a viscoelastic body under long-term exploitation under load (they have both sticky and elastic properties). In the case of viscoelastic systems, the values or velocities of deformation depend on both the stresses and the duration of the load. As a result of viscoelastic properties the deformations change under the influence of constant stress, even when the stress is very small [19].

Another property that may affect the strength of adhesive joints is the value of the coefficients of thermal expansion of the joined elements. If the difference between the coefficients is large, then significant stresses may be constituted within the joint [9].

The influence of seasoning conditions or temperature on the strength of adhesive joints was analyzed in various studies [4, 6, 11, 13-15, 20, 21]. The paper [10] presents the results of research on the influence of the curing and seasoning time on the strength of single-lap 1H18N9T stainless steel adhesive joints. The joints were made with three different compositions consisting of Epidian 53 epoxy resin and PAC, Z1 or TFF hardener. Curing was carried out in cold conditions, in one stage for 7 days at the temperature of 22±2° C and the humidity of 32%. After curing, the samples were seasoned for 14 or 28 days. It was shown that in the case of joints made with Epidian 53 + Z1 composition, the seasoning resulted in a reduction of the shear strength of the connections.

The subject of work [20] was the analysis of the influence of temperature and aging time on selected mechanical properties of four different adhesive compositions. The following variants of seasoning were used: seasoning for one month, two months, five months and eight months at a temperature of 24±2°C, seasoning for one month at a temperature of -10±2°C, and seasoning for five months first at negative temperature and then at a temperature of 24±2˚C. Cylindrical samples, made of adhesive mass, were subjected to compressive strength tests. It was found that in the case of seasoning at the temperature of 24±2°C, the compressive strength of the samples increased with the increase of the seasoning time. The samples were especially sensitive to the effects of negative temperature. The negative temperature made the epoxy compounds brittle. Variable seasoning conditions had a slight effect on the compressive strength of the samples.

The paper [14] presents the results of research on the effect of thermal shocks on the strength of lap and butt joints made of steel and aluminum alloy. Two types of adhesives were used in the research - one of them was characterized by stiffness and the other by increased flexibility. The tests were carried out for 500 cycles of temperature changes. The minimum temperature was -20˚C and the maximum 38˚C. It was observed that the strength of butt and lap joints slightly increased in the initial stage of aging and then began to decline.

The subject of the work [4] was the analysis of the influence of temperature on the shear strength of lap joints made of aluminum alloy. The glass transition temperature (Tg) of the tested adhesive composition was 155°C. According to the test results, the samples tested at a temperature slightly lower than the Tg were characterized by a higher shear strength than the joints tested at room temperature. According to the authors of the study, the higher strength of joints at elevated temperatures resulted from the increase in the plasticity of the adhesive and the reduction of maximum stresses at the ends of the overlap. However, at temperatures above Tg, the adhesive behaved like rubber and the shear strength dropped drastically.

The work [6] searched for methods to increase the strength of adhesive joints at elevated temperatures. The authors of the study showed that nanofillers in the form of nanosilica have a positive effect on the strength of joints exposed to high temperature.

The authors of the paper [11] looked for a method to increase the strength of joints exposed to both low and high temperatures. The solution proposed by the researchers was to make the connection using two types of adhesive compositions - brittle in the middle of the joint (transferring loads at high temperatures) and plastic at the ends of the joint (transferring loads at low temperatures).

To sum up, the problem of the influence of natural seasoning on the load capacity of adhesive joints is very important when designing adhesive structures. A method that can be used to improve mechanical properties of adhesive joints is additional heat treatment. In the literature, there are analyzes of the influence of additional heat treatment or seasoning conditions on adhesive joints. However most of the analyzes, are carried out for lap joints and concern relatively short seasoning times. Therefore, it is justified to carry out further research on the influence of the seasoning conditions and additional heat treatment on the load capacity of the cylindrical adhesive joints used, among others, in composite insulators. Accordingly, the aim of the research presented in the article is to assess the effect of natural seasoning on the load capacity of the cylindrical adhesive joints made of EN AC-AlSi7-Mg0.3 aluminum alloy and glass-epoxy composite EP405-GE subjected and not subjected to additional heat treatment.

Methodology

The analysis was carried out for cylindrical adhesive joints. The sleeves were made of EN AC-AlSi7-Mg0.3 aluminum alloy (Table 1), while the pivots were made of glass-epoxy composite EP405-GE (manufacturer: KUVAG ISOLA Composites GmbH).

The adhesive joints were made using the two-component composition Araldite 2014 (manufacturer – Huntsman). Araldite 2014 is an epoxy-based construction adhesive. This adhesive is resistant to temperatures up to 120˚C (248˚F). It withstands exposure to water and different chemicals. It is suitable for bonding metals, ceramics, GRP, electronic components and other parts which may be exposed to aggressive environments or elevated temperatures [2].

The surfaces of the sleeves and pivots were mechanically treated in order to develop the appropriate geometrical structure and, as a result, to increase the strength of adhesive bonds. The sleeves were turned using the LZ-360 universal lathe (Fabryka Maszyn Tarnów, Poland). The surfaces of the pivots were ground. Grinding was

Table 1. Chemical composition of ENAC-AlSi7Mg0.3 aluminium alloy [1]

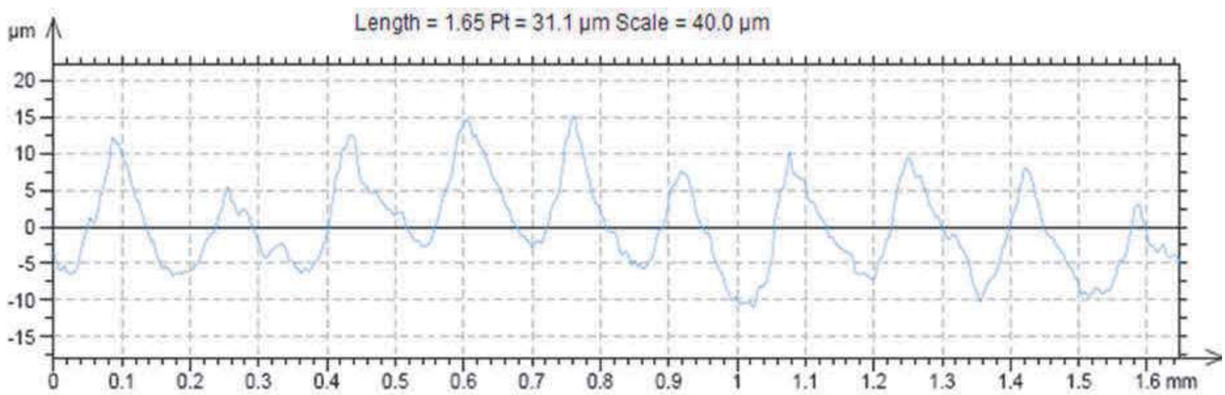
Fe	Si	Mn	Ti	Cu	Mg	Zn	Others	
max 0.19	6.5 - 7.5	Max 0.1	Max 0.25	Max 0.05	0.25 - 0.45	Max 0.07	each 0.03; total 0.1	Al - balance

performed using a RUP-280 roller grinder (Fabryka Maszyn Tarnów, Poland) with an MVBE 45 grinding wheel with dimensions of 400x50x107 mm.

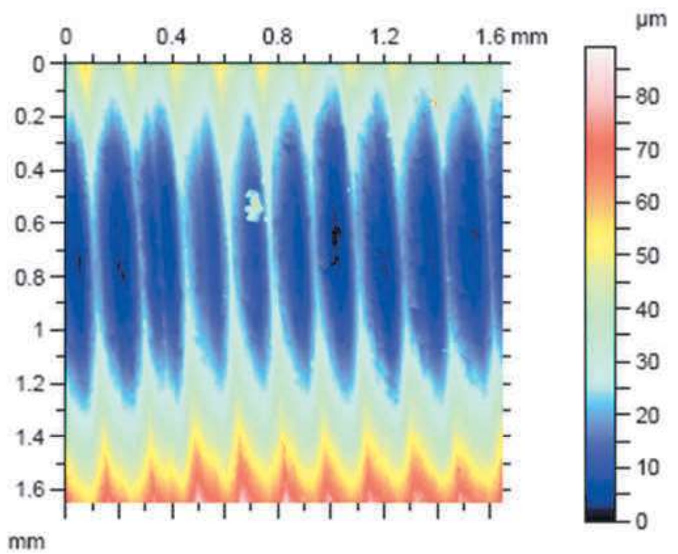
The next step was to measure the surface roughness of the sleeves and pivots. The surface roughness measurements were carried out using the Talysurf CCI Lite optical profilometer (manufacturer: Hobson) which scans surfaces and allows to perform measurements in 2D and 3D. Table 2 presents the results of surface roughness measurements.

Table 2. Results of surface roughness measurements

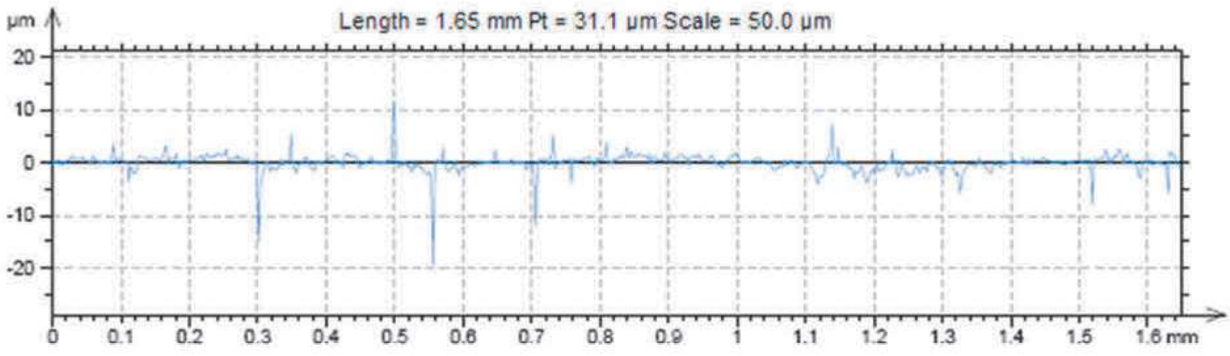
SLEEVE (turned)								
2D parameters								
Rp	Rv	Rz	Rc	Rt	Ra	Rq	Rsk	Rku
11.8 µm	7.51 µm	19.4 µm	17.7 µm	20.9 µm	4.64 µm	5.46 µm	0.579	2.00



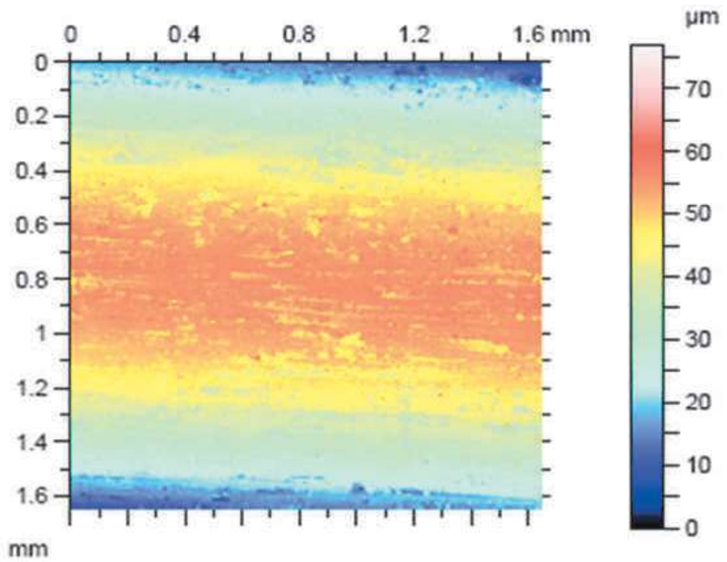
3D parameters						
Sq	Ssk	Sku	Sp	Sv	Sz	Sa
16.1 µm	0.853	3.10	63.1 µm	26.3 µm	89.5 µm	13.0 µm



PIVOT (ground)								
2D parameters								
Rp	Rv	Rz	Rc	Rt	Ra	Rq	Rsk	Rku
9.88 µm	8.75 µm	18.6 µm	4.16 µm	18.6 µm	0.599 µm	1.14 µm	0.635	29.4



3D parameters						
Sq	Ssk	Sku	Sp	Sv	Sz	Sa
12.6 µm	-0.597	2.21	36.2 µm	40.8 µm	77.0 µm	10.8 µm



Subsequently, the surfaces of the sleeves and pivots were degreased in order to remove fatty impurities and machining residues. Degreasing was carried out in an EMMI-40HC ultrasonic cleaner (manufacturer: EMAG, Poland) filled with acetone. The degreased elements were placed in the washer for 5 minutes. After this time, the elements were removed from the washer and allowed to dry. Degreased and dried elements were joined using Araldite 2014 composition. The scheme of the cylindrical adhesive joints created in this way is shown in Figure 2.

The adhesive was applied to the inside surface of the sleeve and the center surface of the pivot with a spatula. The pivots were then placed in the sleeve in such a way that the sleeve was in the middle of the pivot. The thickness of the adhesive layer was 1 mm. After removing the adhesive flashes, the samples were placed in a special device (jigging fixture). As a result, the desired position of

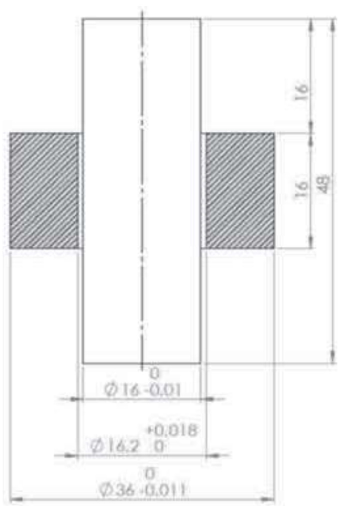


Fig. 2. Dimensions and shape of the cylindrical adhesive joints

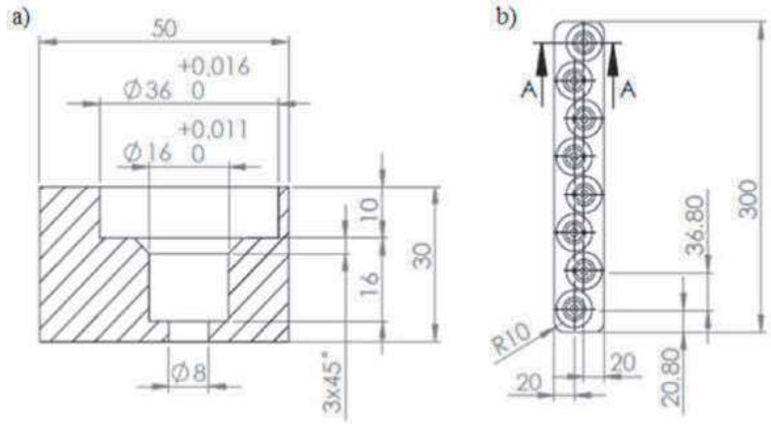


Fig. 3. Scheme of the device

Table 3. Seasoning variants

Variant description	Variant – without heat treatment	Variant – with heat treatment
Without seasoning	**0M**	**0M-HT**
6 months of seasoning started in the summer period (01.07.2013 – 31.01.2014)	6MS	6MS-HT
6 months of seasoning started in the winter period (10.01.2014 –10.07.2014)	6MW	6MW-HT
1 year of seasoning (01.07.2013 – 30.06.2014)	12M	12M-HT
2 years of seasoning (01.07.2013 – 30.06.2015)	24M	24M-HT

the connection elements was maintained (including the central position of the pivot in the sleeve, which ensures the same thickness of the adhesive layer throughout the cross-section). The cross-linking time of the samples in the device was 48 h, and the temperature was 21±1˚C. The scheme of the device is shown in Figure 3.

Then, half of the prepared cylindrical adhesive joints were subjected to additional heat treatment. The samples were heated in a chamber furnace (Polish producer Kepka Group) at 120˚C for 60 minutes. After removal from the furnace the samples were cooled at room temperature.

The next stage was the natural seasoning of the adhesive joints. The seasoning was carried out in several variants, differing in the length of the seasoning and the period in which it was carried out. Each variant consisted of 5 heat treated and 5 non-heat treated samples. The seasoning variants are shown in Table 3.

The samples were seasoned in Rzeszow (Podkarpackie Voivodeship, Poland) in urban conditions and were exposed to the sun and other weather conditions (rainfall, snow). The temperature and relative humidity distribution during the 24 months of seasoning shown in Figure 3 was taken from the weather archive [25–26].

a) b)

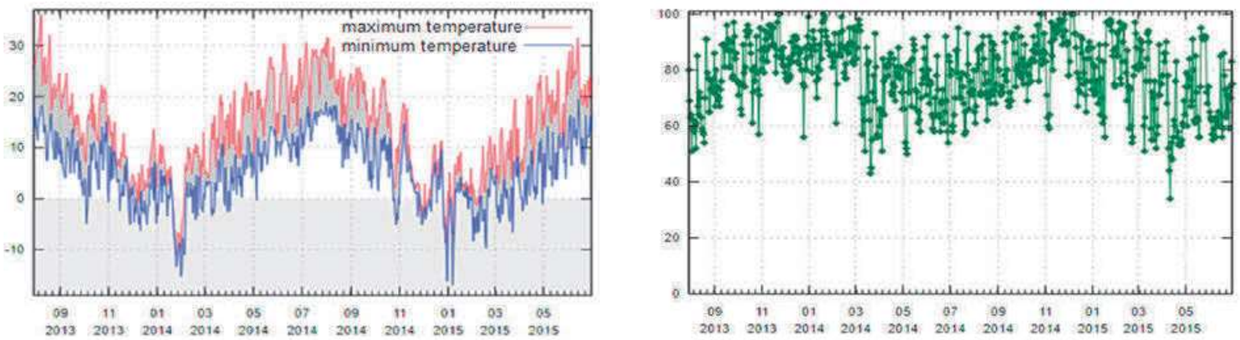


Fig. 4. Graphs showing the distribution of temperature (4a) and relative humidity (4b) during the 24 months of seasoning (01.07.2013 – 30.06.2015) [25–26]

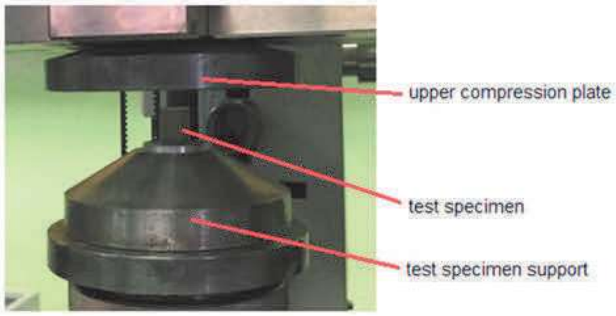


Fig. 5. The sample placed in the handle of the machine

The last step was testing the strength of the cylindrical adhesive joints. For this purpose, the samples were subjected to an axial shear test on a Zwick/Roell Z100 testing machine (manufacturer: Zwick Roell GmbH & Co. KG, Germany). Figure 5 shows a sample placed in the handle of the machine.

The test was performed in accordance with the standard PN-EN ISO 10123:2019-07 (Adhesives - Determination of shear strength of anaerobic adhesives using pin-and-collar specimens) [16].The pin-and-collar test is applied to compare the shear strength of adhesives. This test can be used for quality control purposes and not for joint design. The sample consists of two elements glued together: a cylindrical pin and a slip collar. The sample is placed in the test machine in such a way that the collar is supported on the ring on a compression plate. A compressive load is applied to the top end of the pin and forces the pin through the collar. The force required to shear the adhesive joint is used to calculate the shear strength of the adhesive [3, 16].

During the shear test, an initial force of 50 N, a test speed of 5 mm min and a maximum deformation of 15 mm were assumed. The testXpert software from Zwick/Roell was used for the tests.

Results and discussion

Table 4 and Figure 6 show the results of strength tests for cylindrical adhesive joints differing in the seasoning variant and the presence of additional heat treatment.

Fig. 6. Average values of the load capacity of cylindrical adhesive joints and standard deviation values

Based on Table 4 and Figure 6, it can be concluded that in the case of joints that were not subjected to additional heat treatment, the six-month seasoning started in summer (variant 6MS) contributed to an increase in the load capacity of the joints. High summer temperatures could have increased the cross-linking and stiffness of the joint. The joint may have strengthened naturally under the influence of the sun. The six-month seasoning started in winter (variant 6MW) did not increase the load capacity of the connections. The lower winter temperatures did not allow the connections to strengthen. After one-year seasoning (12M variant), the strengthening effect has stabilized. The two-year seasoning (variant 24M) contributed to the highest strengthening of the joints. To sum up, the test results show that in the accepted range of

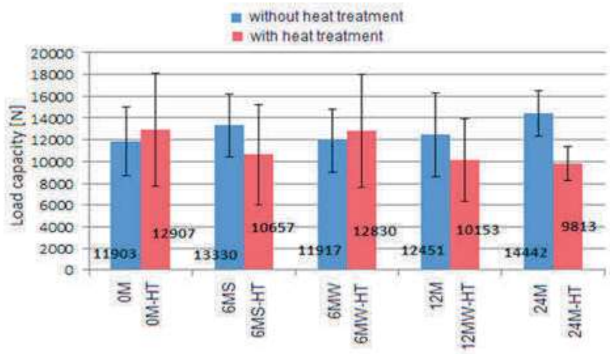


Fig. 6. Average values of the load capacity of cylindrical adhesive joints and standard deviation values

Table 4. The results of strength tests

Wariant	Load capacity – sample no 1	Load capacity – sample no 2	Load capacity – sample no 3	Load capacity – sample no 4	Load capacity – sample no 5	Load capacity – average	Change in load capacity	Standard deviation	Range $R=P_{max}-P_{min}$	Percentage error $(0.5 \cdot R):P_{śr}$
	P_1 [N]	P_2 [N]	P_3 [N]	P_4 [N]	P_5 [N]	$P_{śr}$ [N]	ΔP [%]	σ [N]	R [N]	B [%]
0M	14760	15383	10073	11412	7886	11903	---	3162	7497	31
0M-HT	9284	12230	9526	21886	11609	12907	---	5180	12602	49
6MS	10236	11931	16890	15933	11661	13330	12.0	2905	6654	25
6MS-HT	6061	17771	11651	10589	7213	10657	-17.4	4599	11709	55
6MW	7917	13748	10573	15412	11937	11917	0.1	2889	7495	31
6MW-HT	10668	11731	10523	21914	9315	12830	-0.6	5150	12599	49
12M	8595	11702	17161	9096	15701	12451	4.6	3855	8566	34
12M-HT	14332	10043	12432	9631	4328	10153	-21.3	3771	10004	49
24M	16746	11457	14367	15912	13726	14441	21.3	2055	5288	18
24M-HT	10742	10126	10175	7084	10937	9813	-24.0	1565	3853	20

input factors variability, the seasoning of joints that were not subjected to additional heat treatment resulted in an increase in the load capacity of the connections.

In the case of joints that were subjected to additional heat treatment, the six-month seasoning started in July (variant 6MS-HT) resulted in a decrease in the load capacity of the connections. The probable cause of the reduction in load capacity was excessive degradation which could result in a reduction in molecular weight or excessive cross-linking of the structure. The six-month seasoning started in winter (variant 6MW-HT) contributed to the decrease in the load capacity of the connections to a lesser extent. The one-year (12M-HT variant) and two-year (24M-HT variant) seasoning also resulted in a decrease in the load capacity of the connections. The difference in the load capacity of the connections between the one-year and two-year variants was small. Summarizing, it can be concluded that the seasoning of adhesive joints subjected to additional heat treatment resulted in a decrease in the load capacity of the joints. This decrease is the highest in the case of 12-month seasoning (12M-HT variant) and the lowest in the case of 6-month seasoning started in winter (6MW-HT). Moreover, by comparing the obtained values of the load capacity of the joints, it can be stated that higher values of the standard deviation were obtained in the case of samples subjected to additional heat treatment (variants 12M-HT and 24M-HT are the exception).

The results of the research on the load capacity of cylindrical adhesive joints were statistically analyzed using the Student's t-test. Statistical significance α=0.05 was assumed for the analyzes. In the first step, the Student's t-test was used to analyze the significant differences between the load capacity of connections subjected or not been subjected to additional heat treatment (Table 5).

Table 5. The results of the analysis of significant differences between the load capacity of joints subjected and not subjected to additional heat treatment

Compared variants		Pv [%]
0M	0M-HT	36.15
6MS	6MS-HT	15.47
6MW	6MW-HT	37.39
12M	12-HT	18.43
24M	24M-HT	0.23

Based on Table 5, it can be concluded that the pv probability values are in most cases higher than 5%. This means that in the assumed range of variability of input factors, the load capacities of joints subjected and not subjected to heat treatment do not differ significantly. A statistically significant difference is revealed only in the case of two-year seasoning (pv = 0.23%). Therefore, only in this case the additional heat treatment has a significant impact on the load capacity of the adhesive joints.

Student's t-test was also used to analyze significant differences between the load capacities of connections seasoned in different time periods. These analyzes were carried out for joints that were not subjected to heat treatment (Table 6) and for joints that were subjected to heat treatment (Table 7).

Table 6. The results of the analysis of significant differences between the load capacities of adhesive joints not subjected to heat treatment and seasoned in different time periods

Pv [%]	0M	6MS	6MW	12M	24M
0M	X	23.94	50.00	40.61	8.84
6MS		X	23.94	34.77	23.35
6MW			X	40.61	8.84
12M				X	17.35
24M					X

Table 7. The results of the analysis of significant differences between the load capacities of adhesive joints subjected to heat treatment and seasoned in different time periods

Pv [%]	0M-HT	6MS-HT	6MW-HT	12M-HT	24M-HT
0M-HT	X	24.43	48.94	18.36	13.01
6MS-HT		X	23.35	42.73	35.69
6MW-HT			X	19.21	13.75
12M-HT				X	42.94
24M-HT					X

Based on tables 6 and 7, it can be concluded that all probability pv values are greater than 5%. Therefore, in the adopted range of variability of input factors, the seasoning conditions (seasoning variant) do not have a significant impact on the load capacity of the adhesive joints.

The test results were subjected to regression and correlation analysis. The input factor was the duration of seasoning (SL): 0 months, 6 months (summer period), 12 months and 24 months. The resulting factor was the load capacity (P[N]) of adhesive joints. The analyzes were carried out for joints subjected to and not subjected to additional heat treatment. Regression equations showed a relationship between the seasoning time and the load capacity of adhesive joints. The calculated values of the Pearson correlation coefficient determined the degree of linear dependence between the studied variables. The results of the regression and correlation analysis are presented in Table 8.

According to the results presented in Table 8, it can be stated that in the case of samples subjected to additional heat treatment, the load capacity of the adhesive joints decreases with the increasing duration of seasoning. Moreover, there is a strong negative linear correlation of –0.835 between the load capacity of the joints

Table 8. The results of correlation and regression analysis

Variant	Linear regression equation	Pearson correlation coefficient r	Determination coefficient R^2 [%]	p-value
Adhesive joints subjected to heat treatment	$y_P = 12075 - 114\ x_{SL}$	-0.835	70.8	0.165
Adhesive joints not subjected to heat treatment	$y_P = 12075 + 91\ x_{SL}$	0.841	69.8	0.159

subjected to heat treatment and the seasoning duration. In the case of samples that have not been subjected to additional heat treatment, the load capacity of the joints increases with the increasing duration of seasoning. The obtained value of the Pearson correlation coefficient in this case also indicates a strong linear correlation (r = 0.841) between the seasoning duration and the load capacity of the connections.

Conclusion

1. Seasoning of samples not subjected to additional heat treatment, started in the summer period, resulted in an increase in the load capacity of the adhesive joints. The load capacity of connections seasoned for 6 months increased by 12.0%, while the load capacity of connections seasoned for 24 months increased by 21.3%. The increase in load capacity of joints that were not subjected to additional heat treatment can be explained by the fact that high summer temperatures may have increased the cross-linking of the adhesive-bonded joint. Under the influence of solar radiation, the adhesive-bonded joint may have naturally post-hardened and the connection may have strengthened.
2. Additional heat treatment of the cylindrical adhesive joints increased their load capacity by 8.4% in comparison to the samples not subjected to heat treatment. The increase in load capacity was caused by the increase in cross-linking of the adhesive-bonded joint. Seasoning of the joints subjected to additional heat treatment, commenced in the summer period, resulted in a decrease in their load capacity by 17.4% after 6 months, by 21.3% after 12 months and by 24.0% after 24 months of seasoning. On the other hand, the 6-month seasoning started in the winter period resulted in the reduction of the load capacity by only 0.6%. The obtained test results indicate that more cross-linked adhesive-bonded joints of connections subjected to additional heat treatment are more sensitive to changes in stresses caused by deformations of the joined elements at higher temperatures.
3. The analysis of significant differences between the load capacity of adhesive joints subjected to and not subjected to additional heat treatment showed that within the adopted range of variability of input factors, only in the case of two-year seasoning, additional heat treatment had a significant impact on the load capacity of the adhesive joints. In the case of two-year seasoning, the load capacity of joints not subjected to additional heat treatment was 32% higher than the load capacity of connections subjected to heat treatment.
4. The analysis of significant differences between the load capacity of joints seasoned in different periods and lengths of time has shown that, within the adopted range of variability of input factors, the seasoning variant did not have a significant impact on the load capacity of adhesive joints (both for joints subjected to and not subjected to additional heat treatment).
5. The regression and correlation analysis showed that there is a strong linear relationship between the duration of the seasoning and the load capacity of the tested adhesive joints. In the case of joints not subjected to additional heat treatment, the load capacity increased with the increase in the duration of the seasoning and the linear correlation coefficient was 0.841. In the case of samples subjected to additional heat treatment, the extension of the seasoning time reduced the load capacity of the adhesive joints and the linear correlation coefficient was –0.835.
6. The obtained results of tests of the cylindrical adhesive joints made of EN AC-AlSi7-Mg0.3 aluminum alloy and glass-epoxy composite EP405-GE bonded with Araldite 2014 adhesive showed that natural aging over a period of 24 months does not cause statistically significant changes in their strength properties, therefore the adhesive technology can be successfully used in the production of composite overhead insulators.

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