Advances in Mechanical and Materials Engineering

Volume 40, 2023, Pages 149-157
https://doi.org/10.7862/rm.2023.15

THE FACULTY OF MECHANICAL ENGINEERING AND AERONAUTICS
RZESZOW UNIVERSITY OF TECHNOLOGY

Original Research

Effect of Heating and Cooling of Aluminium-Based Fibre Metal Laminates on Their Tensile Strength

Kamil Boczar [1], Karol Wasłowicz [2], Andrzej Kubit [3], Dorota Chodorowska [4], Romuald Fejkiel [4,*]

[1] Nowy Styl sp. z o.o., ul. Pużaka 49, 38-400 Krosno, Poland; kamil.boczar12344@gmail.com
[2] Eba Sp. z o.o. Artykuły Metalowe, ul. Popiełuszki 86, 38-400 Krosno, Poland; karol.waslowicz@gmail.com
[3] Department of Manufacturing Processes and Production Engineering, Rzeszow University of Technology, al. Powst. Warszawy 8, 35-959 Rzeszów, Poland; akubit@prz.edu.pl
[4] Department of Mechanics and Machine Building, The State Academy of Applied Sciences, Rynek 1, 38-400 Krosno, Poland; dorota.chodorowska@kpu.krosno.pl (D. Chodorowska)

* Correspondence: romuald.fejkiel@kpu.krosno.pl

Received: 11 July 2023 / Accepted: 4 September 2023 / Published online: 11 September 2023

Abstract

The widespread use of composite materials in the construction of machines encourages to better understand their properties and the impact of various external factors on these properties. Fibre metal laminates (FMLs) consist of alternating layers of metal and a polymer matrix laminate reinforced with continuous fibres. The aim of this work was to investigate the effect of cyclical temperature changes and thermal shocks (heating the sample to a high temperature in a short time) on the strength properties of glass fibre and carbon fibre-reinforced AW-1050A aluminium laminates. The research concerns the determination of how cyclical temperature changes affect the tensile strength of FMLs. The results indicate that temperature changes have little effect on the tensile strength of the composites tested, with carbon fibre-reinforced aluminium laminates showing a tendency to delaminate.

Keywords: fibre metal laminates, FML, mechanical properties, tensile strength, thermal shocks

Nomenclature

c specific heat [J/kgK]
E Young's modulus [MPa]
R_m tensile strength [MPa]

Greek symbols

α coefficient of linear expansion [μm/mK]
ν Poisson's ratio
ρ density [kg/m^3]

1. Introduction

A composite material as a combination of two or more insoluble materials differing in species or chemical composition are usually produced to produce a structural material with suitable mechanical, electrical, thermal, tribological or other properties (Chandrasekar et al., 2017).They usually contain fibres or phase particles that are stiffer and more durable than the matrix. Many reinforcement materials also provide good thermal and electrical conductivity, a low coefficient of thermal expansion or good wear resistance (Costa et al., 2023). Fibre metal laminates (FMLs) consist of alternating layers of metal and a polymer matrix composite reinforced with continuous fibres. FMLs as hybrid materials are characterised by improved properties compared to the component materials. Due to their attractive properties, FMLs are widely used in the automotive industry (Kumar et al., 2022), aerospace (Etri et al., 2022), military (Pai et al., 2023) and marine applications (Raheem & Subbaya, 2023).

Fibre-reinforced composite materials are most commonly used to provide increased static and fatigue strength, including specific strength and stiffness (Yelamanchi et al., 2020), which is achieved by incorporating stiff fibres into a ductile matrix. The matrix transfers the applied load to the fibres (Dobrzański, 2016).

The characteristics of FMLs are excellent stiffness and strength in relation to density, high fatigue strength (Alderiesten, 2019), resistance to dynamic loads (Li et al., 2023; Vieira et al., 2022), compression (Kalfountzos et al., 2022) and stretching (Sun et al., 2023). In addition, they are characterized by high resistance to environmental conditions including corrosion. They can also be fire-resistant and highly durable (Bieniaś, 2018). A prerequisite for meeting the requirements for the fibre metal laminates is a sufficiently strong connection between the matrix and the reinforcing layer and a good adhesive joint between the metal and the composite (Fontes at al., 2023; Kabir et al., 2023). The selection of a composite material should begin with defining the requirements for its construction. Each material has different physical, chemical or mechanical properties. Not all materials can cooperate with each other, which results, among others, from their different electrical potentials or different values of thermal expansion coefficients. If the potential difference between the components of the composite is large, the galvanic cell phenomenon occurs, which may result in electrochemical corrosion inside the composite (Hamill et al., 2018; Verma et al., 2022). In the case of materials with different thermal expansion, delamination may occur, resulting in separation of the reinforced layer and the reinforcing layer (Kumaran et al., 2023; Sarfraz et al., 2021). The appropriate selection of fabrication method and the selection of individual components are largely responsible for increasing the laminate's resistance to destruction (Chen et al., 2023).

This article presents the results of strength tests of aluminium-based FMLs. The FMLs were made of AW-1050A aluminium sheet coated with a L285 resin matrix. The aluminium sheers were reinforced with one layer of twill weave glass fabric or one layer of twill weave carbon fabric. Lamination was done using the vacuum bag method. The samples were exposed to cyclical heating and cooling in the temperature range from −30°C to 90°C. Samples exposed to single heating and then slow cooling to temperatures of 150°C, 200°C and 250°C were also tested.

2. Materials and methods

2.1. Test material

Two types of the FMLs were used in the investigations. A 1-mm-thick AW-1050A aluminium sheet covered with a L285 resin reinforced with one layer of twill weave glass fabric of 190 g/m^2 (Fig. 1a) was used as test material. The second type of aluminium-based samples was reinforced with one layer of twill weave carbon fabric of 160 g/m^2 (Fig. 1b). Selected physical properties of AW-1050A aluminium sheet are presented in Table 1. Selected properties of the fabrics used are shown in Tables 2 and 3.

a) b)

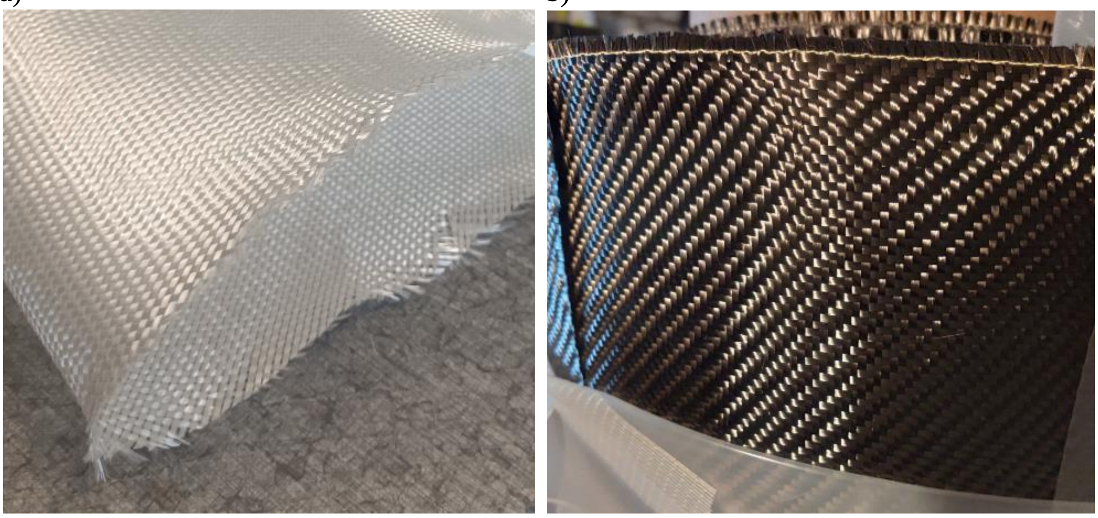

Fig. 1. a) twill weave glass fabric and b) twill weave carbon fabric.

Table 1. Physical properties of AW-1050A aluminium, prepared on the basis of AW-1050A (2023).

Density ρ, g/cm^3	**Young's modulus E, MPa**	**Poisson's ratio ν**	**Specific heat c, J/kg·K**	**Coefficient of linear expansion α, μm/m·K**	**Resistivity ρ , nΩm**	**Heat conductivity λ, W/m·K**	**Conductivity, %IACS**
2.70	69000	0.33	899	23.5	29	229	59.5

Table 2. Geometrical and physical properties of glass fibre (E-glass, 2023).

Type of fibre	**Shape of fibre**	**Length**	**Diameter μm**	**Cross section**	**Coefficient of linear expansion α, μm/m·K**	**Tensile strength R_m, MPa**	**Young's modulus E, GPa**
glass fibre	straight glass fibre	continuous fibres-	ϕ9 ±1.5	round	5.00	3450	72 GPa

Table 3. Geometrical and physical properties of carbon fibre (Toray, 2023).

Type of fibre	**Shape of fibre**	**Length**	**Diameter μm**	**Cross section**	**Coefficient of linear expansion α, μm/m·K**	**Tensile strength R_m, MPa**	**Young's modulus E, GPa**
carbon fibre	straight glass fibre	continuous fibres	ϕ7±1	round	0.41	3530	230 GPa

L285 (MGS) epoxy resin with relatively low reactivity polyamide hardener was used in the lamination process. Before lamination, the sheet was sandblasted and washed with isopropyl alcohol. Lamination was done using the vacuum bag method. After applying a layer of resin on the surface of the aluminium sheet using a sponge paint roller, the fabric was applied and carefully pressed in order to evenly distribute the resin. A transverse-longitudinal arrangement of the fabric fibres relative to the lateral edges of the laminated sheets was used. A seepage mat was then placed over the applied fabric. The composites prepared in this way were placed in a vacuum bag, which was sealed with butyl tape. After starting the vacuum pump (Fig. 2) the composites were left for 24 hours until the resin was cured.

Fig. 2. Lamination of glass fibre-reinforced aluminium laminates.

2.2. Experimental test

To determine the strength properties of AW-1050A-based FMLs, a static tensile test was carried out on flat specimens with dimensions 20 mm (width) × 280 mm (length). Tensile stresses are a representative type of loading on FML composites, in both tension and flexural elements. The samples were prepared using a KIMLA milling plotter equipped with a shank cutter. The diameter of the cutter was 3 mm.

Composite samples were divided into six groups. The samples of the first group were prepared for a static tensile test. These samples were not heat treated. The samples of the second group were exposed to cyclic heating and cooling in the temperature range between −30°C and 90°C, and the number of cycles was 100. The samples of the third group were exposed to cyclic heating and cooling in the temperature range between 30°C and 90°C, and the number of cycles was 400. The fourth, fifth and sixth groups were heated once and then slowly cooled down to 150°C, 200°C, and 250°C, respectively. Cyclical heating and cooling of FML samples was carried out using the TSE-12-A thermal shock chamber. All samples without heat treatment and after heat treatment were exposed to a uniaxial tensile test. A Zwick/Roell Z100 tensile testing machine was used to perform the uniaxial tensile test. Three replicates were used to obtain statistically significant results.

3. Results and discussion

Figure 3 shows the results of tensile test of aluminium sheets. Initially, there is a large increase in the tensile force until the yield point is reached. The plastic flow range is characterized by increasing strain with a constant or slightly decreasing amount of tensile force. Sample failure occurs at a sample elongation of approximately 5.5%. This graph shows the response of an aluminium sample exposed to a static tensile test taking into account the work hardening effect. The average ultimate tensile strength R_m was equal to 107.8 MPa.

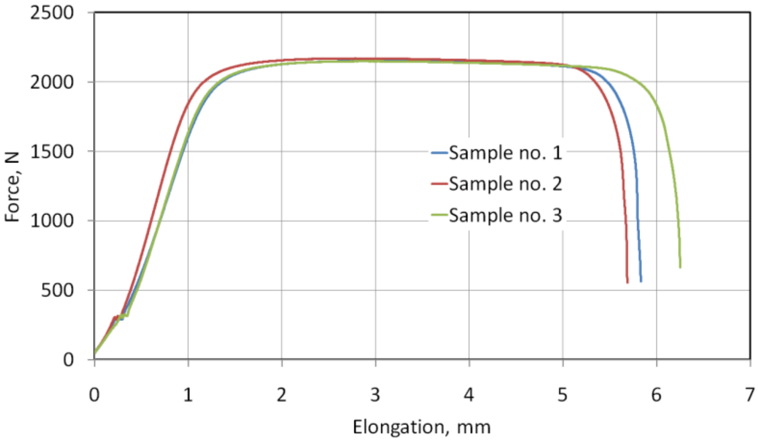

Fig. 3. Tensile curves of the AW-1050A aluminium sheets.

Figure 4a shows the results of the tensile test of glass fibre-reinforced aluminium laminates that have not been exposed to thermal shocks or heating and cooling cycles. Comparing these tests to the testing of aluminium sheet samples, a much higher maximum force can be observed. At the elongation value of about 4.5%, the fabric breaks without delamination of the composite (Fig. 5a). Gradual tearing of the fibres (breaking of individual fibres of the glass fabric) was observed. This translated into a sudden reduction in the force acting on the sample. In this way, the total tensile force was transmitted through the aluminium sheet until the necking was initiated and then the tensile force suddenly decreased. The force causing the breaking of the glass fibres is about 3600 N. With further stretching of the sample, the change in tensile force is typical for an aluminium sample.

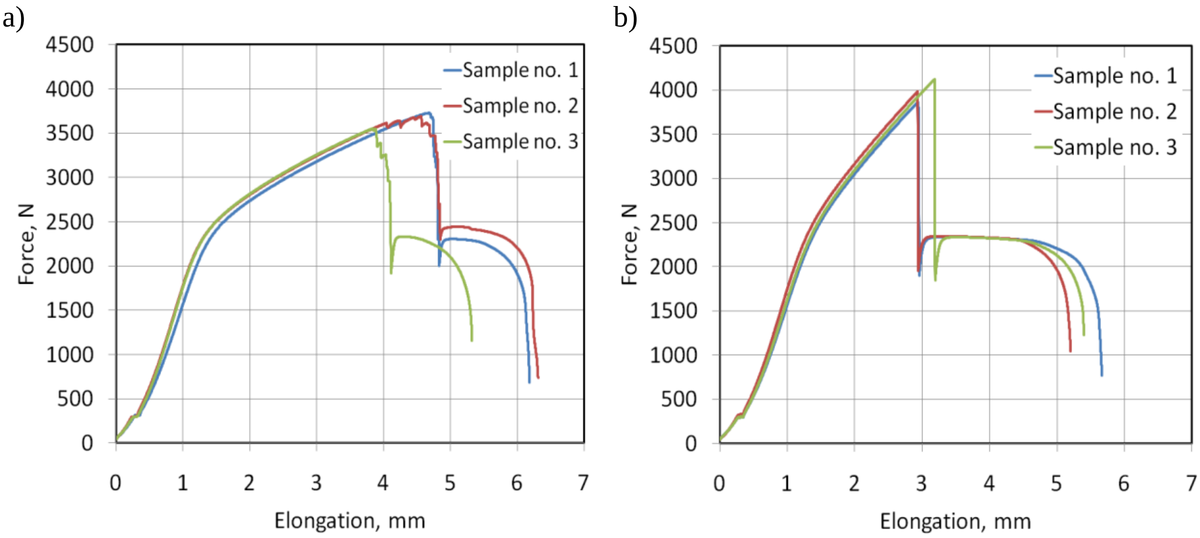

Fig. 4. Tensile curves of a) glass fibre-reinforced aluminium laminates and b) carbon fibre-reinforced aluminium laminates non exposed to thermal shocks and cycles

Figure 4b shows the tensile test results of carbon fibre-reinforced aluminium laminates that have not been exposed to thermal shocks or heating and cooling cycles. Comparing these results with the results for glass fibre-reinforced aluminium laminates (Fig. 4a), an increase in the maximum tensile force (3800-4100 N) can be observed. The delamination of carbon fibre-reinforced aluminium laminates (Fig. 5b) occurs at a much lower elongation (3 mm) compared to the elongation of glass fibre-reinforced aluminium laminates (min. 3.8 mm) (Fig. 4a). The breaking force of the carbon fibre fabric is almost twice as high as that of the aluminium sheet (Fig. 3).

Figure 6a shows the results of the tensile test of the glass fibre-reinforced aluminium laminates, which were exposed to one hundred thermal cycles. These tests, compared to the samples not exposed to thermal cycles (Fig. 4a), are characterized by very similar results for the maximum tensile force. The use of heat treatment resulted in an increase in the elongation corresponding to the maximum tensile force, compared to the samples not exposed to heat treatment (Fig. 4a). This proves that the stiffness of the composites is reduced as a result of thermal treatment.

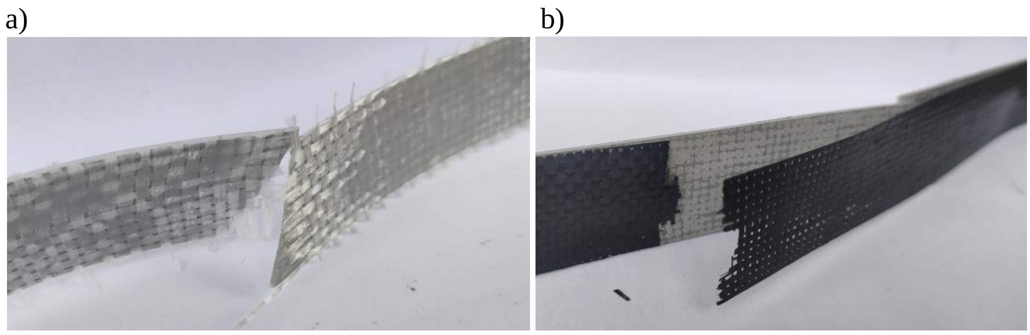

Fig. 5. Samples after tensile test a) tearing of glass fibre-reinforced aluminium laminate and b) delamination of carbon fibre-reinforced aluminium laminate.

Tensile test results of carbon fibre-reinforced aluminium laminates exposed to 100 cycles of thermal shocks show less stable results compared to samples not exposed to thermal shocks (Fig. 6b). In the elongation range between 2 and 5 mm, the carbon fibre fabric breaks. The degree of delamination of the samples due to the cyclic heating and cooling may have an impact on a large variation in maximum tensile force. In the case of sample no. 3, it is difficult to distinguish any differences from the test of samples not exposed to thermal cycling. Sample no. 1 was particularly weakened after heating and cooling cycles. The destruction of the carbon fibre fabric in the case of this sample occurred at a maximum force of 2500 N.

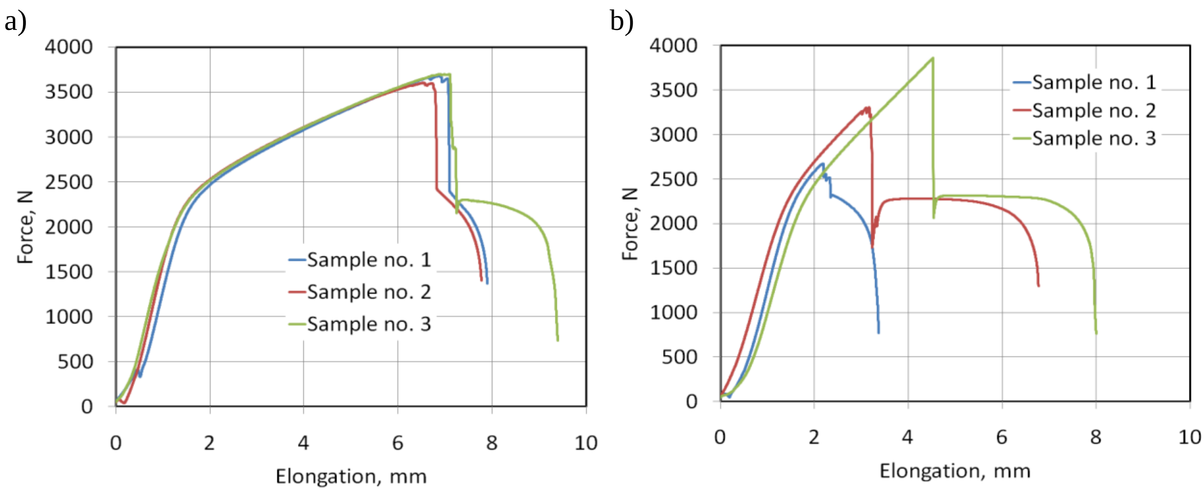

Fig. 6. Tensile curves of a) glass fibre-reinforced aluminium laminates and b) carbon fibre-reinforced aluminium laminates exposed to 100 cycles of thermal shocks.

Fig. 7a shows the results of the tensile test of glass fibre-reinforced aluminium laminates that were exposed to 400 thermal cycles. These tests, compared to the samples not exposed to thermal cycles (Fig. 4a) and to the samples exposed to 100 thermal cycles (Fig. 6a), show very similar results of the maximum tensile force. For samples exposed to 400 cycles, a high repeatability of results can be observed, especially in the case of samples 1 and 2. In this case, the breaking force of the fabric is about 3700 N, while for sample 3 the maximum tensile force is about 3500 N. Tests of samples exposed to 100 thermal cycles (Fig. 6a) showed a slightly lower elongation of the samples corresponding to the maximum tensile force, compared to the samples exposed to 400 thermal cycles (Fig. 7a).

The samples of carbon fibre-reinforced aluminium laminates exposed to 400 cycles of thermal shocks (Fig. 7b) showed a very similar maximum force needed to break the fabric compared to glass fibre-reinforced aluminium laminates (Fig. 7a). The elongation of the sample corresponding to the failure of the fabric is much smaller in the case of carbon fibre-reinforced aluminium laminates compared to glass fibre-reinforced aluminium laminates (Fig. 7a).

Figure 8a shows the results of tensile test of the glass fibre-reinforced aluminium laminates exposed to soaking in an oven for 5 minutes at a temperature of 150°C. The samples behave in a similar manner to previous tests showing a maximum fabric breaking force of approximately 3600 N. The elongation at maximum tensile force is approximately 6.3 mm (samples no. 2 and 3 in Fig. 8a). The increased elongation in the graph showing the results for sample number 1 is due to slippage of the sample in th*e* grippers of the testing machine. Therefore, this test cannot be considered significant.

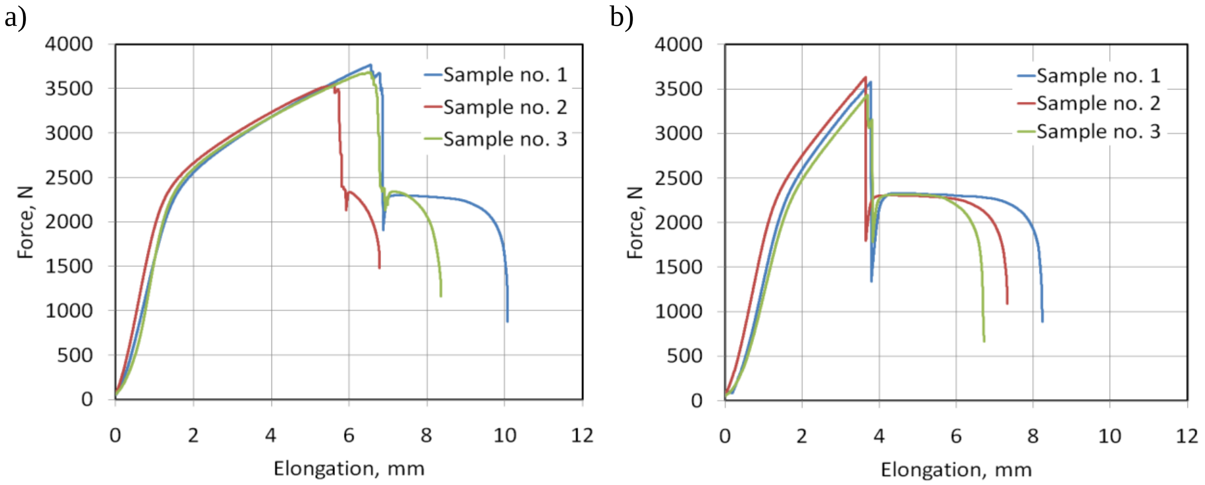

Fig. 7. Tensile curves of a) glass fibre-reinforced aluminium laminates and b) carbon fibre-reinforced aluminium laminates exposed to 400 cycles of thermal shocks.

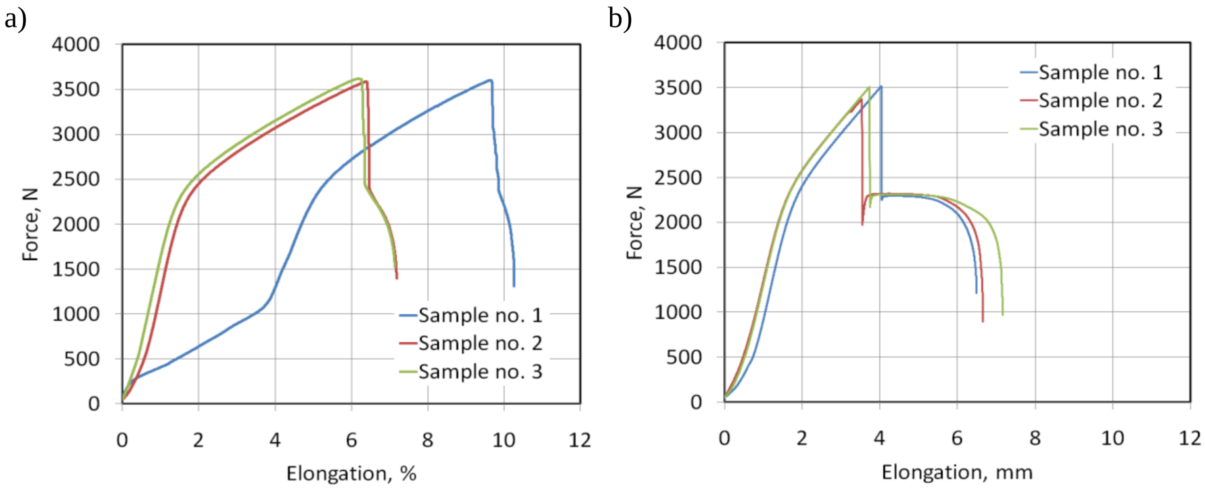

Fig. 8. Tensile curves of a) glass fibre-reinforced aluminium laminates and b) carbon fibre-reinforced aluminium laminates exposed to soaking at 150°C.

In the case of carbon fibre-reinforced aluminium laminates exposed to soaking at 150°C, the maximum force was lower compared to the untreated samples (Fig. 4b). The force reaches a maximum of 3500 N (Fig. 8b), which is a result similar to the samples exposed to 400 cycles of heating and cooling (Fig. 7b).

The tensile results of the glass fibre-reinforced aluminium laminates exposed to soaking for 5 min at 200°C indicate breakage of the glass fabric at a force of 3700-3800 N (Fig. 9a) and at an elongation similar to the results of tests of samples processed at other temperatures. After breaking the glass fibres, the aluminium alloy sheet is not strengthened again, as shown in Figs. 4a, 6a and 7a.

The maximum tensile force of carbon fibre-reinforced aluminium laminates exposed to soaking at 200°C is similar to that of carbon fibre-reinforced aluminium laminates exposed to soaking at 150°C (Fig. 8b). In the case of the sample no. 2 slipping of the sample in the gripper of the testing machine was observed (Fig. 9b).

Test results of glass fibre-reinforced aluminium laminates exposed to heating in an oven for 5 minutes at 250°C indicate breaking of the glass fabric at a force of 3700-3800 N (Fig. 10a). The behaviour of carbon fibre-reinforced aluminium laminates exposed to soaking at 250°C was similar to the previously presented results for this type of samples (Fig. 10b). However, the elongation of the samples corresponding to fabric failure was almost two times lower compared to glass fibre-reinforced aluminium laminates exposed to soaking at 250°C (Fig. 10a). The deformation of the aluminium sheet takes place practically at a constant value of the tensile force, which corresponds to a weak work hardening of the material. A similar effect was observed in the case of carbon fibre-reinforced aluminium laminates exposed to soaking at 200°C (Fig. 9b).

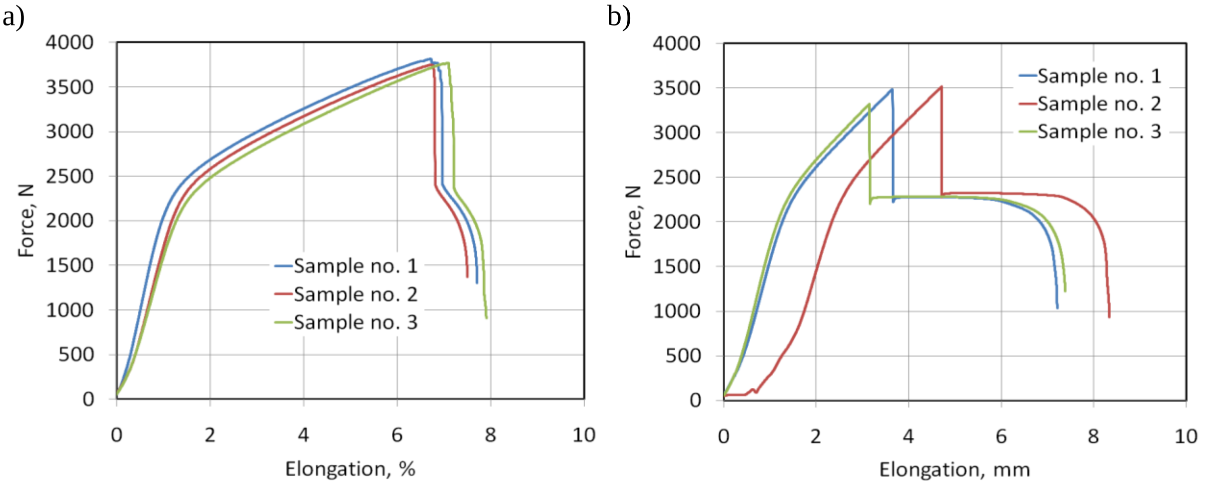

Fig. 9. Tensile curves of a) glass fibre-reinforced aluminium laminates and b) carbon fibre-reinforced aluminium laminates exposed to soaking at 200°C.

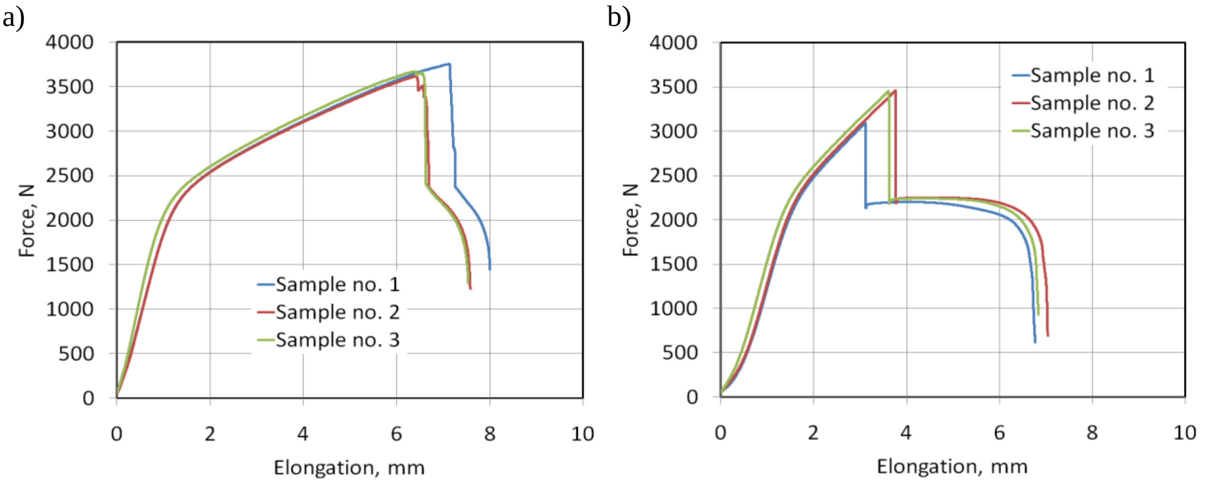

Fig. 10. Tensile curves of a) glass fibre-reinforced aluminium laminates and b) carbon fibre-reinforced aluminium laminates exposed to soaking at 250°C.

4. Summary and conclusions

Based on the results of uniaxial stretching FMLs the following conclusions can be drawn:

- Carbon fibre fabric exhibits a completely different thermal expansion than AW-1050A aluminium. When when the aluminium sheet expands under the influence of temperature, the fibre does not change its dimensions and the sample delaminates due to difference in the length of individual materials. The second reason for avoiding this carbon fibre-reinforced composites is the phenomenon of the galvanic cell, which leads to the formation of oxide layers on the metal-carbon fibre interface. This phenomenon occurs due to the different corrosion potentials of these materials. In the case of glass fibres, this problem does not occur, these fibres are characterized by greater flexibility than carbon fibres.

- Glass fibre-reinforced aluminium laminates showed high resistance to delamination. The glass fibre samples did not delaminate even after they were broken - the glass fabric was very firmly connected to the matrix.
- The soaking of the samples also had an impact on their strengthening. It is assumed that the resin hardened even more during the soaking process and this process became responsible for the strengthening of the samples compared to non treated specimens.
- For the glass fibre reinforced specimens, the maximum destructive force of the laminate reinforcement after each heat treatment increased from 3600 N to 3700-3800 N.
- For the carbon fibre reinforcement after heat treatment, a decrease in the maximum breaking force was observed from 3800 N to 3700 N for 100 cycles of temperature variation down to 3500 N after the specimens were heated to 250ºC.
- An increase in the elongation of the heat-treated specimens was observed until the maximum failure force occurred. In the case of glass fibre reinforcement, 2-3 mm, and for carbon fibre reinforcement, 1-1.5 mm.
- The tests were aimed at presenting the influence of alternating heating and cooling cycles and thermal shocks on the properties of selected types of FMLs. Subsequently, the same tests should be carried out, but for sandwich composites consisted additional layers of carbon and glass fabric. It should be analysed whether the phenomenon of delamination of the metal at the metal/fabric interface occurs with a larger number of laminate layers. Another aspect is the use of fibres with a different density and a different type of weave. The use of an electrochemical method of surface processing should be explored, which would translate into a better bonding of the laminate.

References

Alderiesten, A. (2019). Fatigue in fibre metal laminates: The interplay between fatigue in metals and fatigue in composites. *Fatigue & Fracture of Engineering Materials & Structures*, *42*(11), 2414-2421. https://doi.org/10.1111/ffe.12995

AW-1050A. (2023, June 20). *AW-1050A.* https://www.kronosedm.pl/aluminium-a1-aw-1050a/

Bieniaś, J. (2018). *Kształtowanie stanu powierzchni rozdziału metal-kompozyt w laminatach metalowo-włóknistych z włóknami węglowymi*. Politechnika Lubelska.

Chandrasekar, M., Ishak, M.R., Jawaid, M., Leman, Z., & Sapuan, S.M. (2017). An experimental review on the mechanical properties and hygrothermal behaviour of fibre metal laminates. *Journal of Reinforced Plastics and Composites*, *36*(1), 72-82. https://doi.org/10.1177/0731684416668260

Chen, Y., Yang, Y., Wang, Z., Wang, H., Li, J., & Hua, L. (2023). Accurate simulation on the forming and failure processes of fiber metal laminates: A review. *International Journal of Lightweight Materials and Manufacture*, 6(3), 344-356. https://doi.org/10.1016/j.ijlmm.2023.02.003

Costa, R.D.F.S., Sales-Contini, R.C.M., Silva, F.J.G., Sebbe, N., & Jesus, A.M.P. A. (2023). Critical review on fiber metal laminates (FML): From manufacturing to sustainable processing. *Metals*, *13*, 638. https://doi.org/10.3390/met13040638

Dobrzański, L.A. (2016). *Podstawy nauki o materiałach i metaloznawstwo*. Wydawnictwa Naukowo-Techniczne.

E-Glass. (2023, September 1). *E-Glass Fiber*, *Generic*. MatWeb. https://www.matweb.com/search/DataSheet.aspx?MatGUID=d9c18047c49147a2a7c0b0bb1743e812&ckck=1

Etri, H.E., Korkmaz, M.E., Gupta, M.K., Gunay, M., & Xu, J. (2022). A state-of-the-art review on mechanical characteristics of different fiber metal laminates for aerospace and structural applications. *International Journal of Advanced Manufacturing Technology*, *123*, 2965–2991. https://doi.org/10.1007/s00170-022-10277-1

Fontes, A., & Shadmehri, F. (2023). Data-driven failure prediction of fiber-reinforced polymer composite materials. *Engineering Applications of Artificial Intelligence*, *120*, 105834. https://doi.org/10.1016/j.engappai.2023.105834

Hamill, L., Hofann, D.C., & Nutt, S. (2018). Galvanic corrosion and mechanical behavior of fiber metal laminates of metallic glass and carbon fiber composites. *Advanced Engineering Materials*, *20*(2), 1700711. https://doi.org/10.1002/adem.201700711

Kabir, S., Shahed, C.A., Ador M.S.H., Choudhyry, I.A., & Ahmad, F. (2023). Review of the developments in composite materials over the last 15 years. *Reference Module in Materials Science and Materials Engineering*. https://doi.org/10.1016/B978-0-323-96020-5.00044-3

Kalfountzos, C.D., Bikakis, G.S.E., & Theotokoglou, E.E. (2022). Postbuckling and secondary buckling of rectangular fiber-metal laminates and glass-fiber reinforced composites under uniaxial compression. *Engineering Structures*, *267*, 114663. https://doi.org/10.1016/j.engstruct.2022.114663

Kumar, K.A., Prabu, R., & Arulraj, R. (2022). Development and characterization of fiber metal laminates (FML) using aluminium and Kevlar fibre for automobile applications. AIP Conference Proceedings 2413(1), 050002. https://doi.org/10.1063/5.0091668

Kumaran, D., Antony, J.M.; Lokeshwaran, G., Srinivasan, P.S., Vigneshwar, S.R.M., Ramnath, B.V., & Kumar, R.S. (2023). Investigation of flexural, inter delamination and impact behaviour of fiber metal laminate composite. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2023.05.624

Li, K., Qin, Q., Cui, T., Han, Q., Peng, J., Sha, Z., & Zhang, W. (2023). Soft impact of GLARE fiber metal laminates. *International Journal of Impact Engineering*, *178*, 104607. https://doi.org/10.1016/j.ijimpeng.2023.104607

Mohammad-Zaheri, F., Mohammadi, B., & Taheri-Behrooz, F. (2023). Prediction of stress distribution and stiffness degradation in fiber metal laminates containing matrix cracking. *Composite Structures*, *311*, 116820. https://doi.org/10.1016/j.compstruct.2023.116820

Pai, A., Kini, C.R. Hegde, S., & Satish, S.B. (2023). Thin fiber metal laminates comprising functionally graded ballistic-grade fabrics exposed to mechanical and damping characterization. *Thin-Walled Structures*, *185*, 110628. https://doi.org/10.1016/j.tws.2023.110628

Raheem, A., & Subbaya, K.M. (2023). Performance evaluation of hybrid polymer composite materials in marine applications: A review. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2023.01.346

Sarfraz, M.S., Hong, H., & Kim, S.S. (2021). Recent developments in the manufacturing technologies of composite components and their cost-effectiveness in the automotive industry: A review study. Composite Structures, 266, 113864. https://doi.org/10.1016/j.compstruct.2021.113864

Sun, J., Xu, S., Lu, G., Ruan, D., & Wang, Q. (2023). Mechanical response of fibre metal laminates (FMLs) under low to intermediate strain rate tension. *Composite Structures*, *305*, 116493. https://doi.org/10.1016/j.compstruct.2022.116493

Toray. (2023, September 1). *Toray T300 Carbon Fiber*. MatWeb. https://www.matweb.com/search/datasheet.aspx?matguid=86d0be5b80514c66b2c91e3357c57a1f&ckck=1

Verma, E., Gajera, H., Ramani, D., Bist, N., Sircar, A. (2022). Corrosion in the light of electrochemistry. *Materials Today: Proceedings*, *62*, 7057-7061. https://doi.org/10.1016/j.matpr.2022.01.138

Vieira, L.M.G., Dobah, Y., dos Santos, J.C., Panzera, T.H., Campos Rubio, J.C., & Scarpa, F. (2022). Impact properties of novel natural fibre metal laminated composite materials. *Applied Sciences*, *12*, 1869. https://doi.org/10.3390/app12041869

Yelamanchi, B., MacDonald, E., Gonzalez-Canche, N.G., Carrillo, J.G., & Cortes, P. (2020). The mechanical properties of fiber metal laminates based on 3D printed composites. *Materials*, *13*, 5264. https://doi.org/10.3390/ma13225264

Wpływ Nagrzewania i Chłodzenia Laminatów Metalowo-Włóknistych na Bazie Blachy Aluminiowej na ich Właściwości Wytrzymałościowe

Streszczenie

Coraz powszechniejsze zastosowanie materiałów kompozytowych w konstrukcji maszyn skłania do podejmowania działań mających na celu lepsze poznanie ich właściwości, oraz wpływu różnych czynników zewnętrznych na te właściwości. Kompozyty metalowo-włókniste (ang. Fibre Metal Laminates) składają się z naprzemiennie ułożonych warstw metalu oraz laminatu o osnowie polimerowej wzmacnianego włóknami ciągłymi. Celem pracy było zbadanie wpływu cyklicznych zmian temperatury oraz szoków termicznych (nagrzanie próbki do wysokiej temperatury w krótkim czasie) na właściwości wytrzymałościowe laminatów metalowo-włóknistych wykonanych na bazie blachy aluminiowej AW-1050A pokrytej jednostronnie laminatem wzmocnionym włóknem szklanym lub włóknem węglowym. Badania dotyczyły ustalenia jak zmiany temperatury, w tym przede wszystkim zmiany cykliczne, wpływają na właściwości wytrzymałościowe laminatów. Wyniki wykazały mały wpływ liczby cykli obciążeń cieplnych na wytrzymałość kompozytów na rozciąganie. Laminaty wzmocnione włóknem węglowym wykazywały tendencję do rozwarstwienia.

Słowa kluczowe: kompozyty metalowo-włókniste, FML, właściwości mechaniczne, wytrzymałość na rozciąganie, szoki termiczne