BONDED JOINTS STRENGTH OF ARAMID-EPOXY AND GRAPHITE-EPOXY COMPOSITES

A. Rudawska[1*]

[1]*Department of Production Engineering, Lublin University of Technology, 36, Nadbystrzycka St., 20-618 Lublin, Poland*
*a.rudawska@pollub.pl

Keywords: bonded joints, strength, polymeric composites

Abstract
The article presents test results of bonded joints strength of certain epoxy composites. Due to numerous advantages, bonding technology is an established method of joining structural and plastic materials. The bonded joints were prepared from various kinds of epoxy composites: aramid-epoxy composite and graphite-epoxy composites. Three versions of bonded joints for a given polymer were studied: aramid-epoxy and aramid-epoxy composites; graphite-epoxy and graphite-epoxy composites; aramid-epoxy and graphite-epoxy composites. The aim of the research was the comparison of bonded joints strength of these composites. The type of an adhesive joint tested was a shear-loaded single-lap joint. Epoxy glue Loctite 3430 was used to create the adhesive joint. The surface of the composites was degreased prior to bonding (with Loctite7063 degreasing agent).

1 Introduction

Nowadays, composites are considered a very common structural material [1-3]. One of their essential qualities is the fact that their properties can be designed according to needs [4,5]. A wide variety of component types, shape and dimension variations of the strengthening material, and technologies are used for creating composites. Nevertheless, all structural composites share one property, namely high strength indices, which can be obtained through proper selection of components.

Composites are widely used in many branches of industry. This seems to result from the properties of composites, especially the fibre-strengthened ones, such as: light weight, resistance to corrosion, ability to damp vibrations, enhanced thermal and electrical resistivity, flexibility and high strength [3,5-7]. The examples of carbon fibers are presented in Fig 1.

These materials, used in various constructions, can be freely joined. Increasingly often, the need to join composite and metal arises (e.g. in aircraft, construction and automobile structures), occasionally, involving considerable differences in thickness and dimensions of joined elements. In such situations, adhesive technology is among few methods enabling creating such joints.

a) b) c)

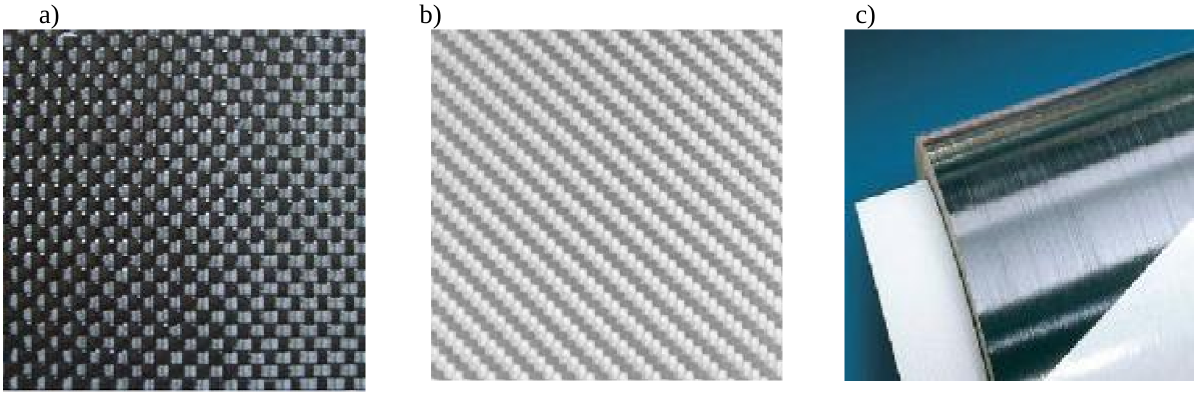

Figure 1. The examples of carbon fibers: a), b) carbon fiber fabric, c) carbon fiber fabric epoxy resin prepreg [8-10]

The increasing number of adhesive joints (including bonded joints) in different branches of engineering contributed to increased interest in the issues concerning adhesive joining technology. Such a trend must result from numerous advantages of this joint forming method, which include, e.g. the possibility of joining structural materials of different physical, chemical or mechanical properties (such as metal and polymer), as well as joining elements disproportionate in terms of dimensions (e.g. thickness) [1,11-13].

The test material for this article was aramid-epoxy and graphite-epoxy composites, both widely applied in e.g. aircraft industry [1,4]. Numerous publications [2,5,14-16] present various tests on the analysed composite materials. The aim of the research was to determine and conduct comparative analysis of the strength of adhesively joined composites in question, in the following configurations: aramid-epoxy and aramid-epoxy composite, graphite-epoxy and graphite-epoxy composite, aramid-epoxy and graphite-epoxy composite.

The presented test results constitute a part of a more extensive research regarding the constituting of adhesive joints in hybrid configurations.

2 Aramid-epoxy and graphite-epoxy composites

Composites may be strengthened with different kinds of fibres. As a result, certain strength indices of such a composite may be increased. Depending on the required strength, operating conditions, production processes employed and other factors appropriate type of composite components – fibre and matrix – are selected [3,7,13].

The matrix allows fibres to bind into surface elements, which then form a basis for the production of structural elements. It also functions as a protective coating for fibres and it partially transfers the load applied on the composite. Nowadays, epoxy resin, which belongs to the group of thermosetting materials, is most often used in composites. Epoxy resins are commonly used as the matrix for composites [7,13].

Different types of fibres, such as glass, carbon, boron, aramid, organic, metal or ceramic, can be used to strengthen composites [2,4,5]. Graphite fibres contain approximately 99% crystalline and highly oriented in structure carbon. Aramid fibres exhibit high fatigue strength, abrasive resistance and high failure energy. Moreover, they have good dielectric properties. Two basic types of aramid fibres are used for strengthening epoxy resins: Nomex and Kevlar [3,4,7]. Nomex fibres have excellent thermal resistance and low flammability.

The fundamental element of composite structure is a single layer called lamina. It is built of fibres joined together with resin. The fibre pattern in the layer may take various forms. The layer organisation (fibre orientation) in the laminate is determined according to the fibre angle (matrix) in each layer of the reference system. Laminate is a set of parallel layers (laminas) tightly bound together [7].

3 Experimental tests

3.1 Composite samples

The tests were conducted on aramid-epoxy composite samples, which consisted of two layers (2x0.30 mm) of aramid-epoxy fabric KV-EP 285 199-46-003. The layers were arranged at a 90^0 angle and subjected to the hardening process (in accordance with the technology).

Examples of the structure of the surface of the tested aramid-epoxy composite are shown in Fig. 2 [17].

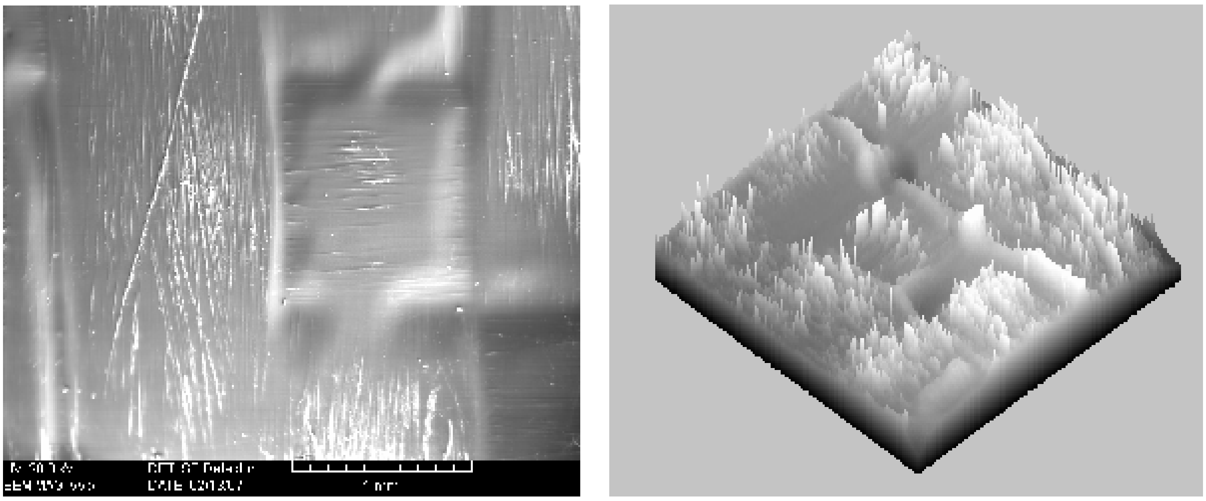

Figure 2. The surface of aramid-epoxy composite no. 3, SEM, x 55

Graphite-epoxy composite constituted the second type of composite samples. Examples of the structure of the surface of the tested graphite-epoxy composite are shown in Fig. 3 [17].

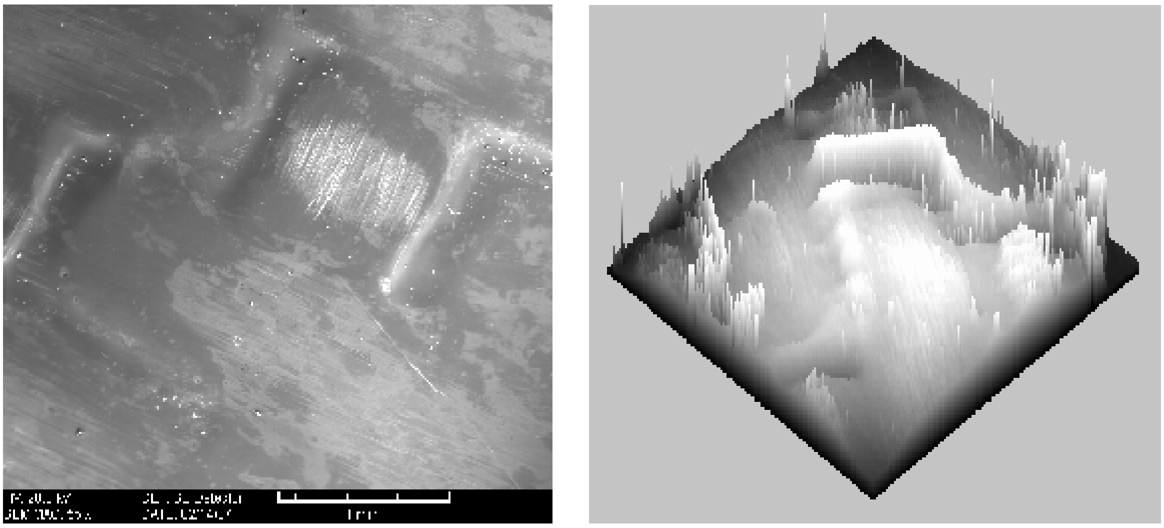

Figure 3. The surface of graphite-epoxy composite no. 6, SEM, x 55

This composite consisted of two layers (2x0.33 mm) of graphite-epoxy fabric GR-EP 199-45-003. The layers were arranged at a 90^0 angle and subjected to the hardening process (in accordance with the technology).

3.2 Adhesive joints

The following adhesive joint variants were used in the tests:

1) aramid-epoxy composite – aramid-epoxy composite,
2) graphite-epoxy composite – graphite-epoxy composite,
2) aramid-epoxy composite – graphite-epoxy composite

The third type of adhesive joints analysed was a combination of both types of the tested composites. The models and shapes of adhesive joints of the polymer composites in question are presented in Fig. 4.

The dimensions of the analysed adhesive joints were the following:

- sample length: 1=100 mm,
- lap length of l_z adhesive joint was determined depending on the thickness of the material, l_z was the same for all the variants, and it equalled 8 mm;
- sample thickness: g_b, combination-dependent, equalled 0.60 mm for aramid-epoxy composite and 0.66 mm for graphite-epoxy composite,
- adhesive layer thickness: g_k = 0.1 mm,
- sample width b = 20 mm

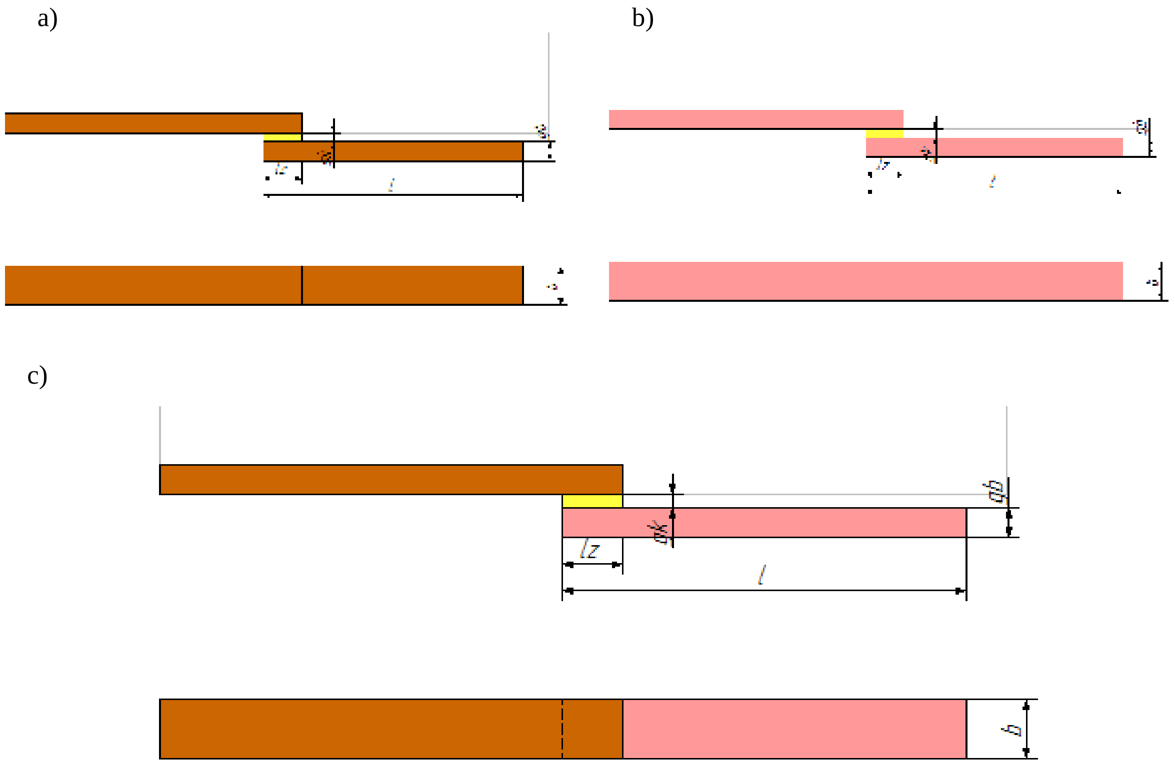

Figure 4. Adhesive joint models: a) aramid-epoxy composite, b) graphite-epoxy composite, c) aramid-epoxy and graphite-epoxy composites

Adhesive joint forming conditions were as follows:

- surface preparation – degreasing with Loctite 7063 degreasing agent;
- a two component epoxy adhesive was applied – Loctite 3430;
- hardening time – 48 hours;
- humidity – 48±2%;
- pressure – 0.02 MPa.

Adhesive joint shear strength tests were conducted on the joints in accordance with DIN EN 1465 standard [18]. The aforementioned norm of the samples shape and certain dimensions was adopted for the shear strength tests. Tests were performed using a testing machine Zwick 100.

4 Test results

4.1 Strength test results

The strength test results of shear-loaded single-lap adhesive joints of polymer matrix composites are presented in Tables 1-2.

Type of adhesive joint	Failure force [N]		Strength [MPa]
	2178,94		
Aramid-epoxy	1634,12		
composite	2531,91		
adhesive joint	2396,32	2070,08	12,94
	1226,68		
	2452,48		
	Standard deviation	525,2018	
	Variance	275836,8855	

Table 1. The strength of aramid-epoxy composite adhesive joints

Type of adhesive joint	Failure force [N]		Strength [MPa]
	2715,82		
Graphite-epoxy	2615,83		
composite	2543,75		
adhesive joint	3075,10	2875,43	17,97
	3061,15		
	3240,95		
	Standard deviation	286,6510	
	Variance	82168,80643	

Table 2. The strength of graphite-epoxy composite adhesive joints

The comparison of test results of shear-loaded single-lap adhesive joints of the analysed composites is presented in Fig. 5.

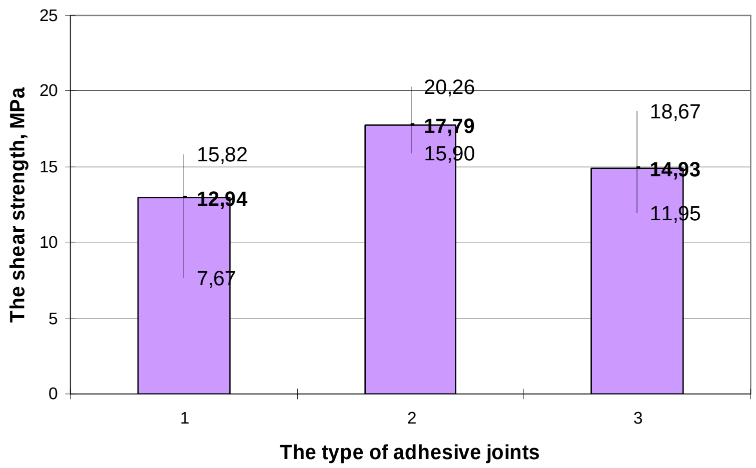

Figure 5. Polymer composites adhesive joints strength: 1) aramid-epoxy composite, 2) graphite-epoxy composite, 3) aramid-epoxy and graphite-epoxy composites

Based on the test results it can be observed that in adhesive joints of the same type of composites, aramid-epoxy composite adhesive joints obtained the lowest strength value, namely 12.94 MPa. Graphite-epoxy composite adhesive joints exhibited the highest strength (17.79 MPa). Adhesive joints of aramid-epoxy and graphite-epoxy composites combination equalled 14.93 MPa.

4.2 Test results analysis

The combination of two analysed composites: aramid-epoxy and graphite-epoxy, led to an increase of adhesive joints strength when compared to composites that exhibited lower strength. The increase amounted to approx. 15% and, in some applications (structures), may be considered significant. The adhesive joint strength of aramid-epoxy and graphite-epoxy composites combination is lower than in graphite-epoxy adhesive joint by approx. 19%. When comparing these types of joints it can be observed that combining two types of materials is less beneficial (results in lower strength) when taking into consideration materials that exhibited higher strength.

These results were obtained in identical structural and technical conditions. Equal dimensions of joints were adopted: the lap length, width (adhesion area) and thickness of the adhesive layer. The only variance was applied in thickness of joined elements and it equalled 0.06 mm. The adhesive, surface preparation, hardening and strength tests conditions were the same.

During the joint formation process, particular attention was given to the correctness of both the process and strength tests. At the final stage of the adhesion process – joint control, the visual method was applied. It allows, inter alia, to determine whether the geometric dimensions of the joint are proper and whether the hardening process was carried out correctly. For that reason, not all of the joints were accepted for the strength tests.

Basic statistical analysis of the test results provides additional information, as it, for instance, determines the spread of results of adhesive joints failure force. Graphite-epoxy composite adhesive joints exhibited the best repeatability (the lowest standard deviation).

5 Summary

Adhesive joints (especially bonded joints) appear in increasing numbers in many branches of engineering and an increase of interest in different adhesive technology issues can be observed. One of those issues is joining different types of materials or materials differing geometrically (e.g. thickness). Polymer composites applied, among others, in the aircraft industry, were the subject of this article. Three variants of the adhesive joints of composites were formed, one of which included a combination of the tested composites. The aim of forming such joints is to join materials different in terms of their properties and dimensions. Frequently, it is adhesive joining exclusively which provides technology allowing formation of such a joint.

The conducted tests proved that joining two types of composites: aramid-epoxy and graphite-epoxy increases adhesive joint strength in comparison with adhesive joint strength of aramid-epoxy composite. The strength of such a hybrid joint is, however, lower than graphite-epoxy composite adhesive joint. Therefore, both positive and negative results of forming hybrid joints can be observed. On the one hand, combining aramid-epoxy composite with graphite-epoxy composite is beneficial, as strength of such a joint is higher than of aramid-epoxy composite joint. However, when comparing the strength of hybrid joints with the strength of graphite-epoxy composite joints, a negative result of joining this composite with another one can be observed. Therefore, it seems that many different factors, such as design basis, should be analysed when designing and forming adhesive joints.

The presented tests constitute a part of research into adhesive joints of different structural materials, however, some interrelation between combining different materials and the strength of adhesive joints can be observed.

An article written under the ministerial research projects no. 3T10C02730 and no. N N507 592538 The Ministry of Science and Higher Education

References

[1] Adams R.D., Comyn J., Wake W.C. *Structural Adhesive Joints in Engineering*. Chapman&Hall, London 1997.
[2] Bernard Q., Fois M., Grisel M., Laurens P. Surface treatment of carbon/epoxy and glass/epoxy composites with an excimer laser beam. *Int. J. Adh. Adhesives,* **26,** 534, 2006.
[3] Żuchowska D. *Polimery konstrukcyjne*. WNT, Warszawa 2000.
[4] Boczkowska A., Kapuściński J., Lindemann Z., Witembeg-Perzyk D., Wojciechowski S. *Kompozyty*. Oficyna Wyd. Politechniki Warszawskiej, Warszawa 2003.
[5] Wang C., Huang Y. D., Wang B. Study on heat-resistant property of adhesive/carbon-carbon composite joints. *Int. J. Adh. Adhesives,* **26,** 206, 2000.
[6] Lee J., Drzal L.T. Surface characterization and adhesion of carbon fibers to epoxy and polycarbonate. *Int. J. Adh. Adhesives*, **25,** 398, 2005.
[7] Czub. P., Bończa-Tomaszewski Z., Pęczek P., Pieluchowski J. *Chemia i technologia żywic epoksydowych*. WNT, Warszawa 2002.
[8] http://www.carbonfiberschina.com/carbon-fiber-fabric/493241.html
[9] http://www.carbonfabricsource.com/shop/carbon-fiber-fabric-wrap-silver
[10] http://www.directindustry.com/prod/sgl-group/carbon-fiber-fabric-epoxy-resin-prepregs-39873-348786.html
[11] Ebnesajjad S. *Adhesives Technology Handbook*. Wiliam Andrew, Norwich, NY, USA 2008.
[12] Brockmann W., Geiß P.L., Klingen J., Schröder B.: *Adhesive Bonding*. WILEY-VCH, Germany 2009.
[13] Park S.-J., Cho M.-S., Lee J.-R. Surface treatment of carbon/epoxy and glass/epoxy composites with an excimer laser beam. *J .Colloid Interface Sci*., **226**, 60, 2000.
[14] Wang C., Huang Y. D., Wang B. Study on heat-resistant property of adhesive/carbon-carbon composite joints. *Int. J. Adh. Adhesives,* **26,** 206, 2006.
[15] Kaye R., Heller M. Finite element-based three-dimensional stress analysis of composite bonded repairs to metallic aircraft structure, *Int. J. Adh. Adhesives*, **26,** 261, 2006.
[16] Doxsee L.E., Janssens W. JR., Verpoest I., De Meester P. Strength of Aramid-Epoxy Composites during Moisture Absorption. *Journal of Reinforced Plastics and Composites,* **10**, 645, 1991.
[17] Rudawska A. Swobodna energia powierzchniowa i struktura geometryczna powierzchni wybranych kompozytów epoksydowych, *Polimery,* **53**, 452, 2008.
[18] DIN EN 1465. *Adhesives - Determination of tensile lap-shear strength of bonded assemblies (*2009).