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SOLDERABILITY OF AlSi FOAMS AND AlSi + SiC COMPOSITE FOAMS AND THE JOINTS PROPERTIES

ABSTRACT

The cellular structure and unique properties of aluminum foams are the reason of problems concerning their cutting and bonding. The content of the paper includes characterization of the essence of properties and application of aluminum foams, limitations and chances of aluminum foams soldering. The aim of the research is consideration of possibilities and problems of soldering AlSi foams and AlSi - SiC composite foams as well as mechanical properties. The possibility of soldering AlSi foams and AlSi - SiC composite foams using ZnAl solders was confirmed and higher tensile strength of the joint than the parent material was ascertained

Key words: AlSi foams, SiC composite foams, soldering, mechanical properties of soldered joint

INTRODUCTION

Aluminium foams, due to their high porosity, that in many cases exceeds 90%, are characterized by low density, high stiffness and capability to absorb acoustic waves, energy and mechanical vibration [1-4]. These properties determine their numerous applications in areas such as car industry, shipbuilding, architecture and general machine industry [5-6]. Among the range of foamed metals that have been introduced, aluminium foams are the ones that are most commonly used.

The application of aluminium foams in above mentioned examples requires efficient, cost- effective and reliable methods of joining. Possibilities of a practical application in a considered type of construction must also be considered. Foams can be joined in various ways, such as mechanical fastening [10] or through soldering, gluing or welding [7-12], similarly to non porous-materials.

In many cases, choice of soldering as a joining method of aluminium foam elements is justified. However, due to high porosity of these materials, when approximately 90% of their volume consists of voids, soldering may entail numerous technological difficulties.

Presumably due to the fact that aluminium foams are a relatively new type of materials, many of the problems have not been satisfactory solved yet. This research paper is an effort to satisfy the demand for solving these problems through presentation of experiment outcomes and discussion of the results.

Soldering non porous aluminum alloy elements is in many cases difficult process to solve. Much more difficult is the brazing of aluminum foams as the number of factors influencing the process increases due to phenomena resulting from the cellular structure. It can be estimated that the level of difficulty the process of aluminium foam soldering rises with the surface area, the decrease of weight and the rate of open porosity of parent material". This fact is directly related to high surface area of aluminium foam, which is covered by a thin layer of aluminium oxides, that, in case of mechanical damage immediately rebuilds and to the fact that the cell walls of the foam structure are relatively thin.

The aim of the paper is consideration of soldering of AlSi (9%Si) foams and AlSi + SiC (9%Si, 15%SiC) composite foams as well as definition of the joint mechanical properties.

SOLDERABILITY OF ALUMINIUM FOAMS

Preparation of aluminium foam edges for soldering requires removal of the possible residues from cutting, degreasing the surface and removing the layer of oxides. When foam structure is considered, the thorough cleaning of surfaces is not easy, because of its highly developed surface area. This limitation is especially noticeable when any type of mechanical cleaning is considered, where the direct contact of the surface that is processed with the tool is not always possible. In contrary, chemical cleaning can give satisfactory results.

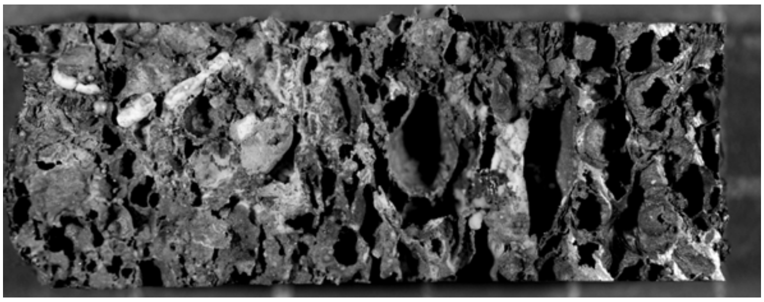
The further phenomenon that must be considered is the variable soldering gap that obviously results from the porous structure. Because of that, even distribution of flux and solder in a joint zone is nearly impossible. The capillary effect is greatly reduced or cannot be observed at all in a direct vicinity of pores. When the pores of the foam that is processed are mostly opened ones, the unintentional penetration of the flux into the structure may also be a problem, and therefore usage of fluxes must be limited to non corrosive, passive type ones.

The significant limitation of aluminium foam soldering is also the lack of a standardized methodology of examination of its mechanical properties as well as technical acceptance criteria. Besides the challenges resulting from the structure of foams, soldering of aluminium itself is considered a demanding process due to its relatively low melting point, high thermal coefficient and thermal conductivity. The degree of aluminium foam wetability in many cases determines the possibility to achieve a joint with required properties; therefore initially trials of spreading the solder over the foam surface were carried out. The experiments let to evaluate in what degree the surface is wetted at the selected process parameters. The description of the solderability was phenomenological in its nature. Fig. 1 - 5 show selected results of trials of spreading the solder over the surfaces of the aluminium foams.

The surfaces of the foams were mechanically cleaned with a wire brush and sand paper before the soldering. The traces that were left after machining in pores as well as any possible contaminations were removed in ultrasonic cleaner filled with ethyl alcohol. Finally, the specimens were dried up to a total evaporation of alcohol.

During application of the solder onto the surface of AlSi and composite AlSi + SiC foams, two sources of heat were used: flame of propane burned in air and hot air. Regardless of the heating method, AlSi + SiC composite foam showed no wettability by the solders that were used: ZnAl22, ZnAl4, ZnAl2 and Castolin 198 FCW (Tab. 1). During the solder application process the soldering alloy that was applied to the surface formed drops and was pushed off the foam by the air stream (Fig. 1).

a)



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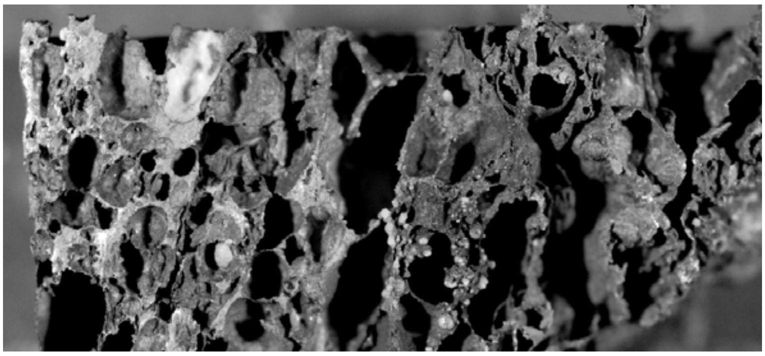

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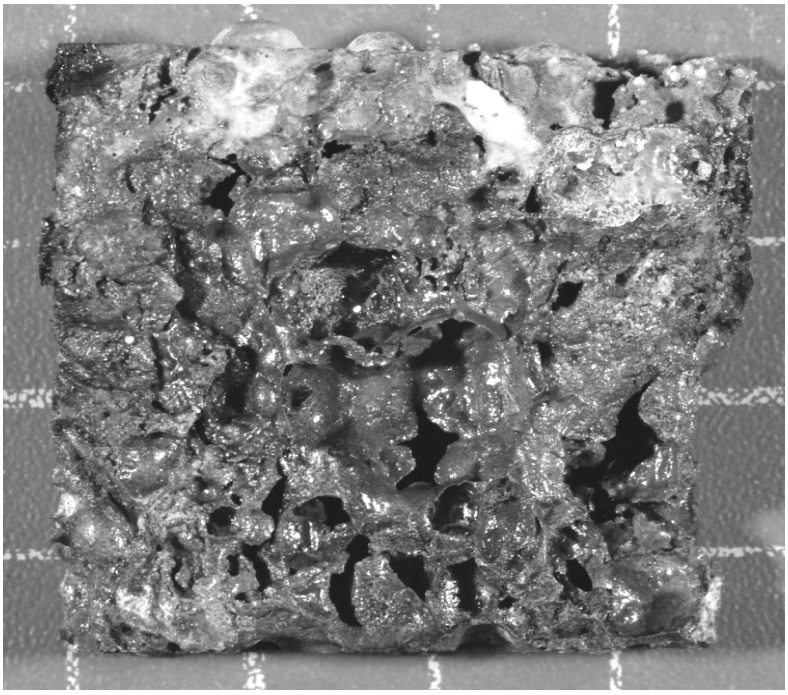


Fig. 1. Surface of AlSi + SiC composite foam used for solder wettability investigation, solders that were used: a) ZnAl22 with a flux inside a core b) ZnAl4 with TLA-4 flux c) Castolin 198 FCW with Castilin 192 FX flux that was diluted in a dedicated 190 Al diluter

When the flame was pointed in a direction perpendicular to the foam surface, the drops of soldering alloy were not blown off; they coagulated into bigger drops instead. The shapes of the drops reaffirm the lack of wettability of the composite foam by the solders that were used (Fig. 2). In the face of failing to achieve wetting with hot air as a heat source, the trials with the propane torch were abandoned. Soldered joints were therefore made using hot air as a heat source only; the hot air gun model was Pro - 4, capable of providing a temperature of 500 - 600 degrees, which is lower than the temperature of burning propane in the air, but still sufficient for the discussed application.

***Table. 1**. Aluminium solders*

Solder alloy	Composition, %			Melting point range	Working temperature	Recommended flux	Solder characteristic
	Zn	Al	Rest	°C	°C		
ZnAl2	98	2	-	377-385	385	not required	wire, flux in a wire core
ZnAl4	96	4	-	385-418	410	TLA-4	wire
ZnAl22	78	22	-	426-485	485	not required	wire, flux in a wire core
Castolin198 FCW	80	5	Ag, Sn	385-418	410	Castolin 192 FX	wire, flux in a wire core

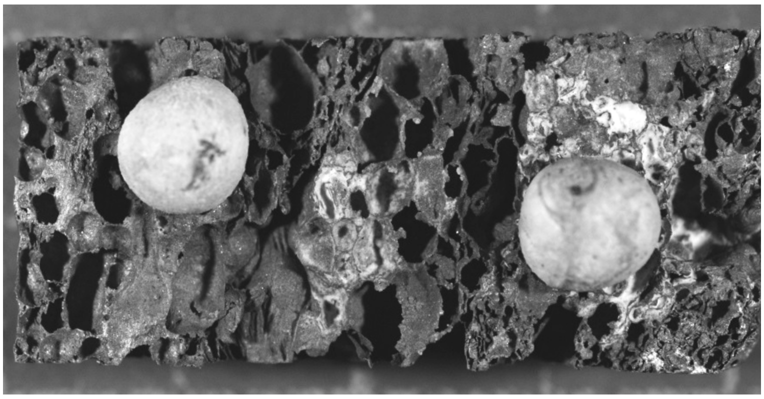


Fig. 2. Surface of AlSi + SiC composite foam used for solder wettability investigation, ZnAl22 solder was used

The experiment that followed showed that liquid drops of ZnAl2 solder with a flux in a core can be spread over the Al + SiC foam surface using a flat metal spatula (Fig. 3). It was however ascertained, that resultant layer can be easily peeled away from the foam surface.

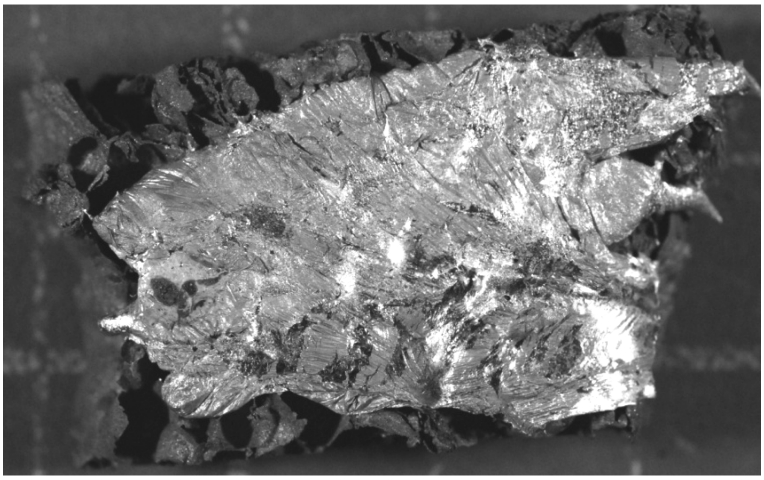


Fig. 3. Surface of AlSi + SiC composite foam used for solder wettability investigation, ZnAl2 solder with a flux in a core was used

The trials of spreading the solder over the AlSi + SiC foam surface showed that the best results can be achieved when ZnAl4 alloy without a flux is used (Fig. 4). While the most favourable among the considered variations, the result cannot be considered satisfactory as the spreading capability was not sufficient and it had to be assisted by using a flat spatula.

On the contrary, ZnAl22 - using an alloy with a flux in a core (Fig. 5a) in combination with AlSi foam, gave acceptable results. The solder exhibited good wettability and spreadability over the AlSi foam surface. During the hot air heating, the solder spread without any mechanical assistance, creating a continuous, tight adjoined layer that filled the surface pores (Fig. 5b).

Good wettability and spreadability of the solder over the AlSi foam surface was confirmed during the soldering. Hot air was used as a heat source. The soldering gap was entirely filled with the solder (Fig. 6b). In Tab. 2, the results of the soldering where various parameters were used are presented

Table 2. *The influence of the process parameters and additional material type on solderability of AlSi and AlSi + SiC foams*

Heat source	Solder					Parent material
	ZnAl2	ZnAl4 without a flux	ZnAl4 + flux	ZnAl22	Castolin 198 FW	
Gas torch	-	-	+	+	+	AlSi
Hot air	+	N	-	+	N	
Gas torch	-	+/-	-	-	-	AlSi + SiC
Hot air	+/-	-	-	-	N	

N –trial was not carried out, „+" - soldering is possible, „-" – results were not acceptable

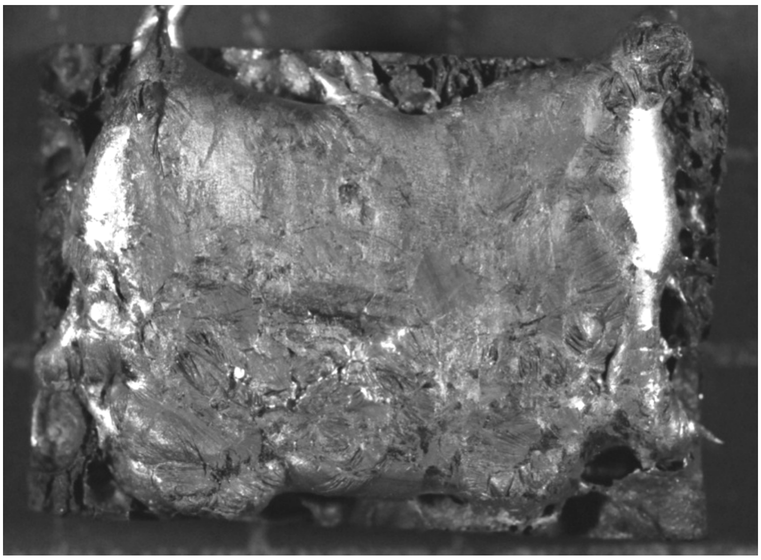
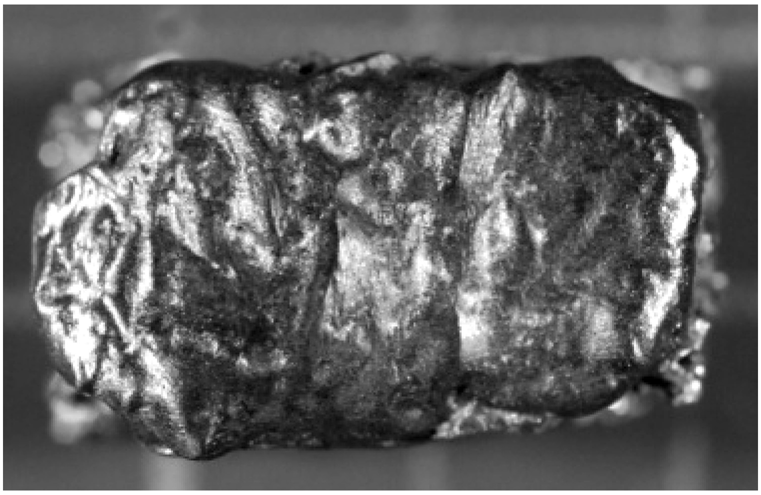


Fig. 4. Surface of AlSi + SiC composite foam used for solder wettability investigation, ZnAl4 solder without a flux was used

a)



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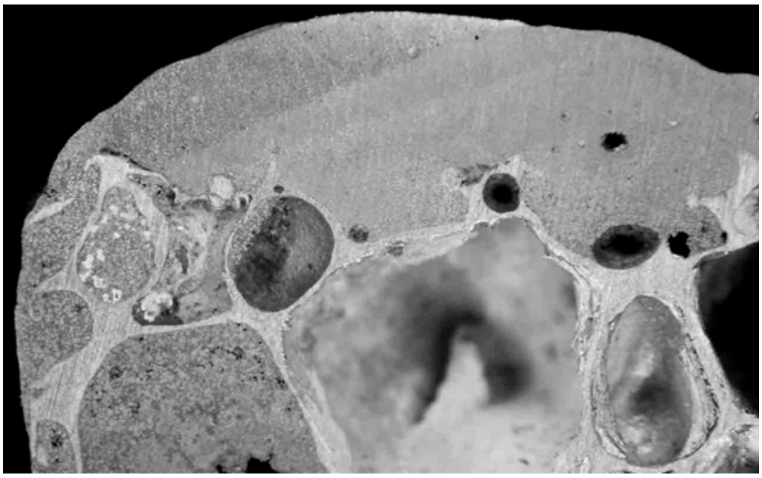
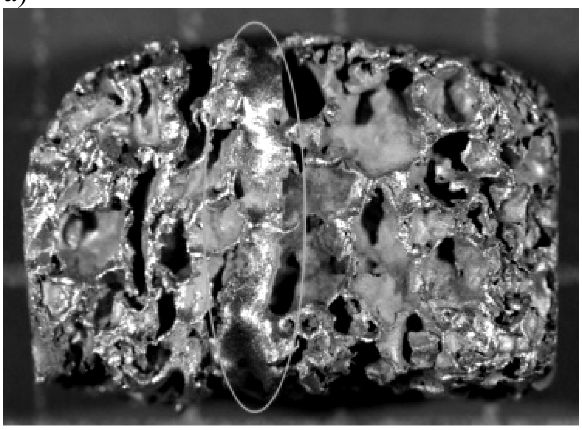


Fig. 5. AlSi foam used for solder wettability investigation, ZnAl22 solder with a flux in a core was used a) surface of the specimen b) cross section of the specimen

a)



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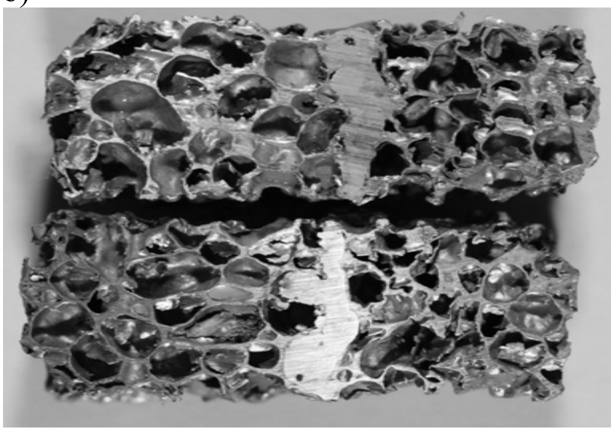


Fig. 6. AlSi foams used for solder spreading investigation; ZnAl22 solder with a flux in a core was used: a) joint face marked with a white line, b) cross section of the joint

MECHANICAL PROPERTIES OF SOLDERED AlSi FOAM JOINTS

Basing upon the evaluation of wettability described above it can be assumed, that a combination of ZnAl22 solder and AlSi foam as a parent material should allow to obtain a joint of satisfactory mechanical properties. To confirm it, specimens for strength tests were made and the static tensile and bending tests were carried out. In the Fig. 7a a soldered specimen, consisting of AlSi foam being the main part and two pieces of Al sheet metal serving as gripping parts were used, ZnAl22 solder was used to join the elements. The tests were carried out on Instron 5585H universal testing machine (Fig. 7b). A specimen after the test is shown in Fig. 7c. The destruction occurred in the foam zone. Fig. 8, 10 and 12 show load- displacement curves, the construction of the specimens is shown in the Fig. 7, 9 and 11, accordingly. In case of the first specimen (Tab. 3), dividing maximal tensioning force F_m = 380 N by the transverse cross section area S_o = 335.4 mm^2, led to a result of nominal tensile strength- R_{mn} = 1.1 MPa. Real tensile strength of the specimen, considering the porosity of 90% equals R_{mr} = 11.3 MPa. For three specimens that followed, the results were similar (Fig. 8, 10, 12). Only small quantitative differences, that were presumably caused by non uniform shape and distribution of pores, were ascertained (Tab. 3). The results range between 0.8 MPa to 1.1 MPa. The interpretation of the static tensile strength curves (Fig. 8) leads to a conclusion that basically throughout all the applied load range the specimens deform in a non-linear way. Only the specimen number 4, where the soldered joint was tested for shear strength (Fig. 12) shows elastic at first, then in a combined, elastic- plastic behaviour.

a)

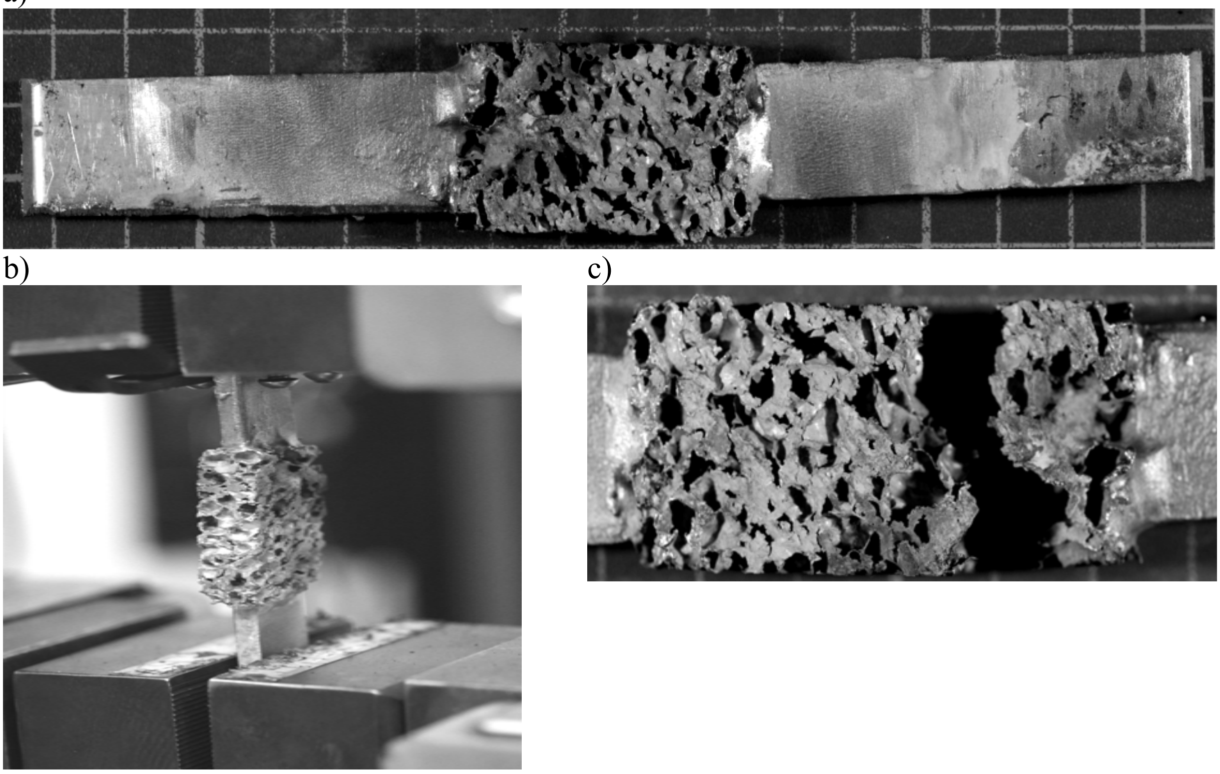


Fig. 7. Soldered AlSi foam - Al sheet metal specimen for static tensile testing: a) specimen construction b) a specimen mounted in universal testing machine fixings, c) specimen destructed during the test

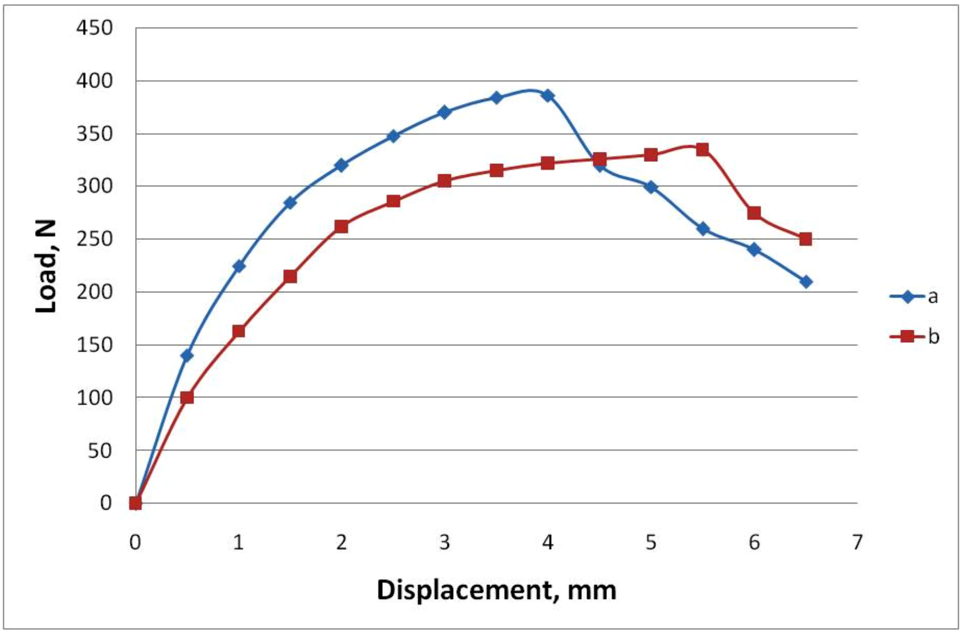
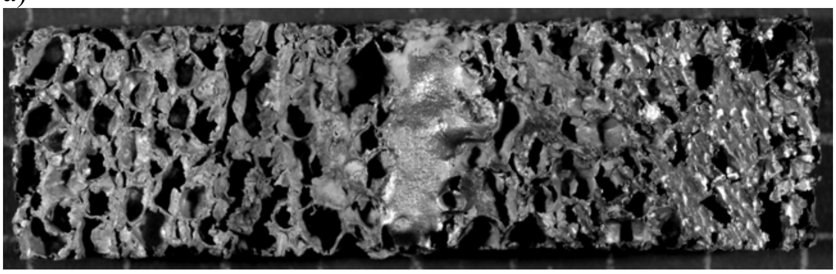


Fig. 8. Load- displacement tensile test curves of soldered specimens: a) AlSi foam with porosity 82% – non porous Al sheet (specimen shown in Fig. 7), b) AlSi + SiC foam with porosity 85% – non porous Al sheet

Static tensile tests were also carried out on specimens of different construction, namely two profiles made of AlSi foam that were soldered using the same alloy as above- ZnAl22. During the test, the destruction occurred in a foam zone (Fig. 9b). The resultant strength was 1.0 MPa, what is in agreement with previous outcomes. In case of both types of specimens, the resultant strengths basically represent the strength of the foam itself as the destruction occurred away from the joint.

a)



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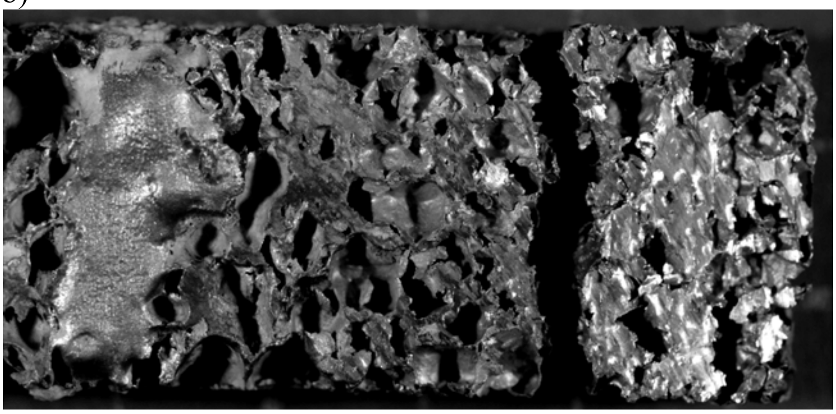


Fig. 9. Specimen for static tensile testing of two AlSi foams butt soldered: a) specimen construction, b) specimen destructed in the test

In the third case, the tensile test was carried out on specimens that consisted of two AlSi foam elements that were soldered to Al sheet metal, making up a lap joint (Fig. 11a). The lengths of laps on the left and right side were determined in such a way, that nominal area of sheared cross section was higher and lower, accordingly, than the nominal cross section of the foam itself. The trials confirmed that the strength of the soldered joints is sufficient for the examined material. The destruction occurred away from the joint zone (Fig. 11b). Tab. 3 presents the results of static tensile strength tests of the specimens with lap joints.

Fig. 10. Load-displacement tensile test curve of soldered AlSi foam – AlSi foam specimen (specimen shown in Fig. 9), foam porosity 82%

a)

b)

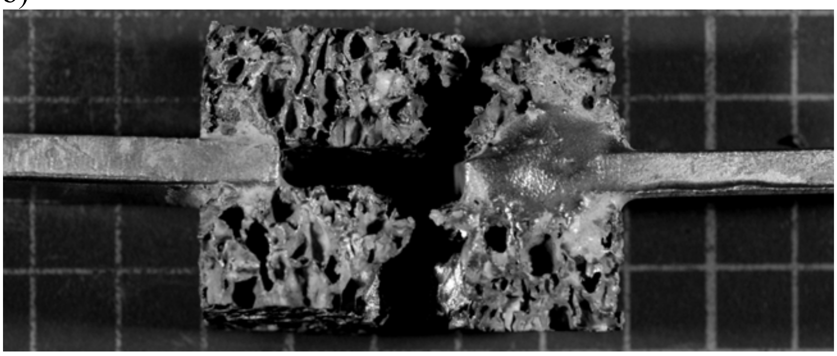


Fig. 11. Specimen for shear testing by tensioning, AlSi - Al sheet metal lap joints a) specimen construction b) specimen destructed in the test

Table 3. *The results of static tensile testing of AlSi foam specimens, soldered with ZnAl22 alloy*

Specimen number	Nominal dimensions of the specimen cross section a x b, mm/mm	Nominal area of the specimen cross section S_{on}, mm^2	Real area of the specimen cross section- taking into account 90% porosity S_{or} mm^2	Maximal force F_m, N	Nominal static tensile strength $R_{mn} = F_m/S_{or}$, MPa	Real static tensile strength taking into account 90% porosity $R_{mr} = F_m/S_{or}$, MPa	Fracture place
1	13.0x25.8 (joint acc. Fig. 7)	335.4	33.5	380.0	1.1	11.3	AlSi foam
2	13.9x23.1 (joint acc. Fig. 7)	321.1	32.1	320.0	1.0	10.0	AlSi + SiC foam
3	20.0x14,0 (joint acc. Fig. 9)	280.0	28.0	280.0	1.0	10.0	AlSi foam
4	(13.5x18.0)x2 (joint acc. Fig. 10)	486.0	48.6	480.0	1.0	9.9	AlSi foam

In case of welded joints, the bending test is the most commonly conducted one, allowing to evaluate its properties. The authors of the article performed this test to examine the properties of soldered AlSi foam joints. The specimens that were subjected to the bending test failed away from the joint zone, at an angle below 25° (Fig. 13b). The failure zone shows minor plastic deformation, which can be observed only in a close vicinity of the failure surface. If the structure of the foam was continuous and homogenous, the failure would be expected to occur in a cross section that bears the highest tension. This, however, did not happen. It is clearly seen, that in case of aluminium foam bending, the location of the failure area depends on a local structure of cells (Fig. 13). Each void behaves as a notch, where concentration of tension occurs, growing up to a initiation of a crack. Fig. 14 shows three bending test curves of the specimens – AlSi foams soldered with ZnAl22 solder. The horizontal axle represents values of displacement of the pivot, while the vertical - applied load. The cracking initiation was observed at a displacement of about 2.5 mm and pivot load of about 80 N. The results of the bending test are presented in Tab. 4.

Table 4. *Results of the bending test of ZnAl22 soldered AlSi foam – AlSi foam specimens, diameter of bending pivot - 12 mm*

Specimen number	Specimen dimensions a x b, mm	Bending angle, o	Tensioned surface
1	25.2x12.2	24	the joint bottom
2	25.1x11.9	22	the joint bottom
3	25.1x12.0	25	the joint bottom

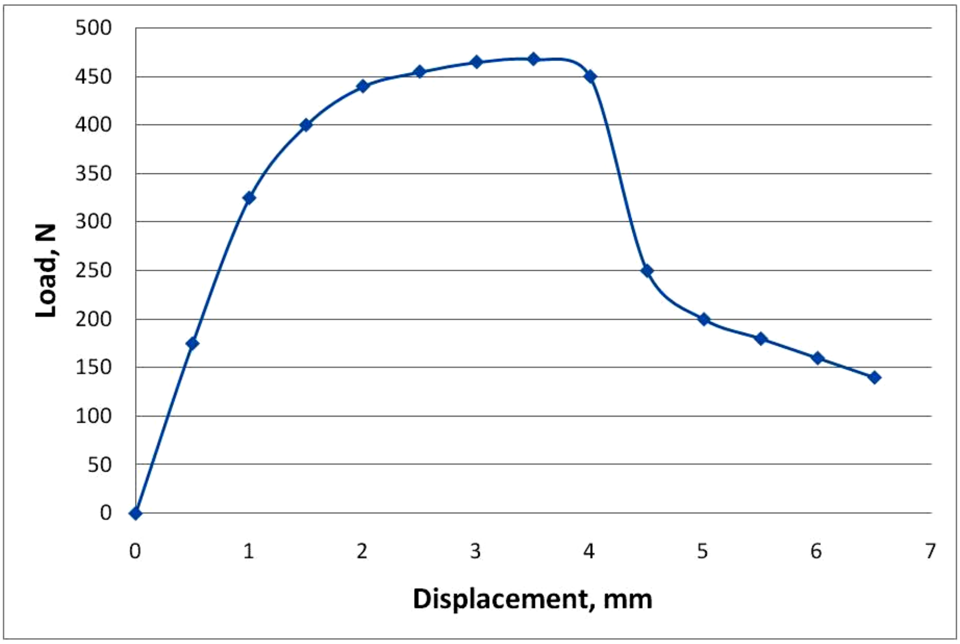
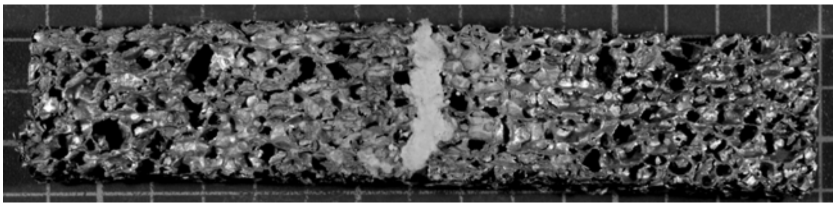


Fig. 12. Load - displacement shear test curve of lap soldered AlSi specimen (specimen shown in Fig. 11), foam porosity 82%

a)



b)

Fig. 13. A bending test of ZnAl22 soldered AlSi foam specimen a) specimen construction b) specimen during the test

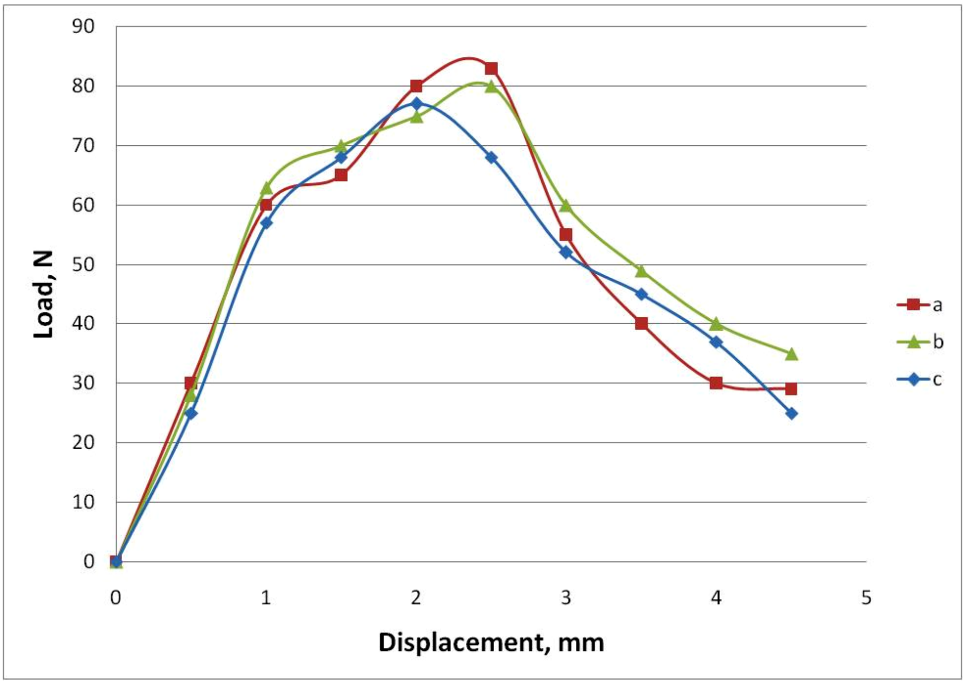


Fig.14. Load – displacement bending test curves of ZnAl22 soldered AlSi foam – AlSi foam specimens, foam porosity: a) 84%, b) 90%, c) 94%

CONCLUSIONS

Manufacturing of an element that consists of a single piece of foam, when its desired shape is complicated or the dimensions are large is not always economically justified . While many methods can be used for joining aluminium foams, soldering proved to be a reliable and effective one. The conducted research showed, that AlSi foams can be soldered using commonly used solders such as ZnAl2, ZnAl4 or Castolin 198 FW. The strength parameters of soldered joints that were achieved are better than the properties of the parent material - AlSi foam. Static tensile and bending tests showed that the failure occurs in the foam zone.

Trials of soldering composite Al + SiC foams must be considered to be not as successful as only marginal wettability of the substrate by the solder was achieved. To solve the problem, further research is planned to be carried out. Traces of local adhesion that were observed during the test of spreading the ZnAl2 and ZnAl4 solders without the use of flux over the Al + SiC foam surface gives prospects for obtaining a joint if the preparation and process parameters are modified. The aim of further investigations will also be the optimization of AlSi foam soldering, especially concerning the solder alloy and process temperature selection. The strength parameters of the soldered joint should exceed the strength of parent material in a limited extent only.

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