An Analysis on some thermal characteristics of AlMg10-SiC ultralight composite materials

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Abstract. The paper presents the determination of the specific heat, thermal conductivity and thermal expansion coefficients of some composites of the type AlMg10-SiC with the help of a differential scanning calorimeter. For the experiment we will use several types of composites with different concentrations of SiC (5%, 10%, 15%, with 120 micrometres medium size). One sample category was obtained by melt bubbling method (A) and the other one by soluble salt method (B). We obtained cellular composites using A method and porous composites using B method. The paper presents by comparison the thermal properties of the two categories of materials. The paper also presents the equipment used, as well as its operation. We used a differential scanning calorimeter for the specific heat and thermal conductivity determinations and thermomechanical analyser equipment for linear expansion coefficients. Based on the values obtained for the thermal characteristics of the investigated composite materials, those directions of applications can be suggested, which can be based on the absorption characteristics of the deformation energy of these composites, even at temperatures above 100°C, a situation for which, for example, in general, polymeric composites cannot be used.

1. Introduction
In the literature we found no characterization of cellular/porous ultralight metallic materials, based on AlMg-SiC, in terms of thermal properties, absolutely necessary to be known in case of their use in various practical applications. Because the materials mentioned above can be, structurally, cellular or porous, in our experiments we analyse [1, 2] two sets of samples, each set being obtained by a different method, because each one leads to a different structure.

In order to obtain ultralight composites we used AlMg10-SiC type composites [3], with a SiC addition of 5, 10 and 15%. The A method involves a forceful agitation [4-7, 9] of the aluminum alloy and SiC mixture, combined with gas bubbling (we used CH₄ as the reactive gas) [8].

Method B involves the dissolution in water of the sodium chloride [4-7] contained in the AlMg10-SiC solid composite. The occurrence of NaCl in the structure of the material is due to the introduction of sodium chloride and silicon carbide powders mixture in the molten material.

The A method leads to a cellular structure of the composite and the B method to a porous one (like metal foams).

2. Experimental results
The specific heat and thermal conductivity of the composites obtained in the experimental program were determined using a differential scanning calorimeter, the DSC 404 F3 Pegasus (figure 1).
The operation of this calorimeter is based on the accurate measurement of the heat flow from a homogenous heated/coolied sample, in a thermal range from –150°C to 2000°C. In order to eliminate measurement and unwanted phenomena errors the sample chamber is purged with inert/oxidizing gas.

The design of the equipment and also the proprietary software allows to determine: the beginning/end of transformation, the maximum/minimum and of the inflection critical points; the automatic search for peaks and their analysis; transformation enthalpies, specific heats; glass transition points; degree of crystallinity; assessment of oxidation time and so on.

The determined specific heat is practically constant (table 1 and figure 2), regardless of the percentage of SiC (5, 10 or 15%) or of the obtaining method of the composite (in the latter case, therefore, it does not depend on the relative density or porosity, size and distribution of cells in the material). The average values of this characteristic are 0.904 J/kgK for the composite with 5% SiC, 0.8975 J/kgK for the composite with 10% SiC and 0.8905 J/kgK for the composite with 15% SiC, the average value for this investigated ultralight cellular composite materials being 0.8973 J/kgK, value quite close to that of aluminum (about 0.9 J/kgK).

The thermal conductivity of the investigated composite materials (table 2 and figure 3) is a function of both the percentage of silicon carbide and the method of production, which will ultimately dictate the type of material: cellular (A method) or porous (B method). Thus, compared to the thermal conductivity value of the starting alloy AlMg10 (λ = 217.424 W/mK), the value of this characteristic decrease with increasing percentage of silicon carbide and relative porosity for the A method samples (up to about 23% for the composite with 15% SiC). However, even greater variations are observed in the samples from porous composite materials (method B), when the decrease of thermal conductivity compared to the control sample from AlMg10 alloy exceeds 70% for the sample with 15% SiC. The phenomenon is explained by the high relative porosity of the respective composite, the existing cells behaving as a thermal barrier. We can thus conclude that this type of material can be used under certain conditions in insulating structures, fact that may represent a future research direction.

**Table 1.** Specific heat of AlMg10-SiC composites according to the percentage of silicon carbide and the obtaining method.

| Sample obtaining method | Specific heat, J/kgK | 5% SiC | 10% SiC | 15% SiC |
|-------------------------|---------------------|--------|--------|--------|
| A                       |                     | 0.905  | 0.897  | 0.890  |
| B                       |                     | 0.903  | 0.898  | 0.891  |

Figure 1. DSC 404 F3 Pegasus differential scanning calorimeter [2].
The linear expansion coefficients were determined using a TA Instruments 2940 Thermomechanical Analyzer (figure 4) [2]. It can be used to measure different properties of materials (in solid form, films, fibers or powders), such as coefficient of thermal expansion, melting temperature, glass transition temperature, behavior at thermal expansion or creep and so on, under varying conditions of temperature, force, atmosphere or time. It also allows the analysis of the behavior of the materials from the thermomechanical point of view, in a thermal gap of (–150 ÷ 1000)°C, with a heating speed between 0.01 and 200°C/min. The sample with dimensions of maximum 10 mm in diameter and length of maximum 15 mm is placed in a quartz support, being then introduced into the heating / cooling chamber, the analysis being done in air or in an inert atmosphere. The device measures the dimensional changes of the sample in relation to a standard quartz sample, with an accuracy of 100 nm, and the related software allows the calculation of the thermal characteristics and, possibly, the representation of their variation with temperature.

![Figure 2](image-url) 

**Figure 2.** Specific heat variation curves of AlMg10-SiC composites with the SiC percentage and the obtaining method of the ultralight composite material; SA-n - composite samples obtained by method A, SB-n - composite samples obtained by method B, n = 1, 2 or 3 (corresponding to 5, 10 or 15% SiC).

| Sample obtaining method | Thermal conductivity, W/mK |
|-------------------------|---------------------------|
|                         | 5% SiC        | 10% SiC       | 15% SiC       |
| A                       | 183.197       | 176.269       | 167.837       |
| B                       | 107.189       | 77.431        | 62.108        |

**Table 2.** Thermal conductivity (λ) of AlMg10-SiC composites according to the percentage of SiC and the obtaining method.

The temperature variation of the absolute linear thermal expansion (figure 5) is approximately linear for all composite material samples, regardless of the type of composite (cellular or porous) or the percentage of silicon carbide, unnoticing any discontinuities that can indicate transformations in analyzed temperature range (up to about 400°C). The coefficient of thermal expansion (table 3 and figure 6) shows a slight decrease with the percentage of silicon carbide, regardless of the type of composite (cellular A or porous B), the values obtained being lower than that of the starting alloy AlMg10, \( \alpha = 22.98 \cdot 10^{-6} \text{ K}^{-1} \). However, based on the increased porosity of the porous composite...
samples compared to the cellular ones, it was observed important differences between the obtained values of the coefficient of thermal expansion (about 30%).

Figure 3. Thermal conductivity variation curves of AlMg10-SiC composites with the SiC percentage and the obtaining method of the ultralight composite material; SA-n - composite samples obtained by method A, SB-n - composite samples obtained by method B, n = 1, 2 or 3 (corresponding to 5, 10 or 15% SiC).

Figure 4. Thermal analysis device TA Instruments 2940 [2].

Figure 5. Variation of absolute linear thermal expansion with temperature for the AlMg10-15% SiC cell composite sample.
Table 3. Coefficient of thermal expansion (α) of AlMg10-SiC composites according to the silicon carbide percentage, obtaining method and the measurement direction (M - the average of the values measured on the three directions; measurements made at 300 K).

| Obtaining method | 5%SiC | 10%SiC | 15%SiC |
|------------------|-------|--------|--------|
|                  | X     | Y      | Z      | M      | X     | Y      | Z      | M      |
| A                | 19.35 | 19.25  | 19.42  | 19.34  | 18.45 | 18.55  | 18.63  | 17.85  |
| B                | 13.24 | 13.14  | 13.22  | 13.20  | 12.38 | 12.44  | 12.28  | 11.91  |

Figure 6. The coefficient of thermal expansion variation curves of AlMg10-SiC composites with the SiC percentage and the obtaining method of the ultralight composite material; SA-n - composite samples obtained by method A, SB-n - composite samples obtained by method B, n = 1, 2 or 3 (corresponding to 5, 10 or 15% SiC).

3. Conclusions

Based on the values obtained for the thermal characteristics of the investigated composite materials can be suggested those directions of applications which are based on the deformation energy absorption characteristics of these composites, even at temperatures above 100°C, for which, for example, in general, polymeric composites cannot be used.

The thermal conductivity of the investigated composite materials is a function of both the percentage of silicon carbide and the method of production. Thus, compared to the thermal conductivity value of the starting alloy AlMg10 (λ = 217.424 W/mK), there was a significant decrease of this parameter for the cell samples (up to about 23% for the composite with 15% SiC), with increase in the percentage of silicon carbide and relative porosity. However, even greater variations are observed in the samples from porous composite materials, when the thermal conductivity decrease, compared to the AlMg10 alloy control sample, exceeds 70% for the sample with 15% SiC. The phenomenon is explained by the high relative porosity of the respective composite, the existing cells behaving as thermal barriers. We can thus conclude that this type of material can be used under certain conditions in insulating structures.

The temperature variation of the absolute linear thermal expansion is approximately linear for all composite samples, regardless of the type of composite (cellular or porous) or the percentage of SiC. The coefficient of thermal expansion shows a modest decrease with the percentage of SiC, regardless of the type of composite.
4. References

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