Comparative study on antiballistic behaviour of AlMg10-SiCp type cellular ultralight composite metal materials

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Abstract. This paper presents a study done on metallic materials composite ultralight cell type AlMg10-SiCp, obtained by two methods, chosen to assume minimal costs of production: a method based on melt bubbling with a reactive gas and a method based on using various salts powders particles, soluble in suitable solvents. First method is suitable for obtaining ultralight composite with open and semi-open cell. By the second one we achieved ultralight porous composite materials, with a metal foam structure characterized by generally semi-open cells. There are presented both technological flows for obtaining ultralight cell type composites. The porosity of these materials increases with the percentage of added SiC particles, no matter of used method of achievement. The antiballistic behavior refers basically to the impact of a small/medium caliber bullet shot on a light armor built on the base of obtained AlMg-SiC metallic cell composites. Thus, a 35 mm thick armor was achieved by using only cellular or porous composites of AlMg10 with 15% SiC. These proved to be effective enough for a 9 mm projectile not to pass through, with the minimum penetration depth observed for the porous composite. It has been observed that up to a speed of about 320 m/s the projectile is braked more efficiently by the cellular composite material, which can be explained on the basis of the microstructure and the dependence of the coefficient of friction on the density of the material.

1. Introduction
The complex needs of contemporary society have determined a continue development of industries for a sustained improvement of the materials quality and for the discovering of others with superior properties, by developing new synthetic materials, passing thus from simple or complex metal alloys to high-tech materials.

In the mentioned above materials category we can include ultralight metallic composite materials with particle, materials with an increasingly important role in scientific and technical progress. We are dealing with a class of materials that are placed between composites and metal cellular/foam materials, borrowing properties from both, but developing also new ones, fact that allowed their use for a wide range of applications from, for example, bioengineering to the aerospace industry.

Metal cellular materials/foams are materials that have a porous structure, thereby causing a remarkable combination of properties: mechanical strength, stiffness, energy absorption, thermal and electrical conductivity, stability in harsh (aggressive) environments.

Metallic cellular materials can be classified into two categories: closed-cell and open-cell ones. Cellular closed cell materials/foams have good mechanical properties and are used primarily for structural and load-bearing applications. The open porosity is mainly used for thermal applications, filtration, electrochemistry, sound absorption and porous implants.
In order to characterize antiballistic behaviour of ultralight composite materials are taken into account peculiarities of behaviour and mechanical properties of the composite such as: the existence of several deformation mechanisms, which activate at high and very high impact velocities. These can produce totally different effects on the size and nature of the deformations produced by the impact because, due to the high impact velocity, a composite armor is subjected to different stress conditions which will result in varying elastic, visco-elastic behaviour or elasto-visco-plastic composites; dependence of mechanical properties on some geometric and physical stress parameters: very high impact velocities, time variation of fragmentation load, temperature, etc.; the dependence of mechanical properties on the conditions of production of the composite material, the reinforcement elements of the matrix, the thermal treatment applied, etc.; he dependence of the mechanical properties on the nature and characteristics of the matrix cell reinforcement elements, the density and the total volume of the reinforced material, the morphology of the particle / matrix interface and the input materials introduced to modify the shape and size of the cells of the composite [1].

2. Production methods

Based on the general methods for preparing ultralight metal composites with particles and on the material type used for the base and particles [2-7], I have focused on two production methods, chosen because of their low cost applicability in industry. We chose AlMg10 alloy for the material base and SiC for inserted particles (with 120 micrometers medium size).

First method (M1), which lead us to ultralight cellular composite type AlMg10 with different amounts (5, 10 and 15%) SiCp, with small and medium size open and semi-open cells, it is based on the reactive gas (butane) bubbling of a metal melt. This method involves the addition of silicon carbide in the melted aluminum alloy, a vigorous agitation of the formed mixture simultaneously with it bubbling.

The second method (M2) allowed us to obtain ultralight porous composite AlMg10 - SiCp (5, 10 and 15% SiCp), with a structure close to metal foams, with generally semi-open cells. This method is based on the use of particles of various salts, in the form of powders, which are soluble in suitable solvents. The method adopted by me used as soluble salt particles of sodium chloride and water as solvent and is based on the introduction in the molten metal alloy of a mixture of powders of sodium chloride and silicon carbide, followed, after cooling, by the dissolution of the sodium chloride in water.

The technological flow for obtaining ultralight cellular composite materials type AlMg10-SiCp by butane bubbling, involves the following steps:
- heating the oven to 710°C and maintaining it at this temperature for all butane bubbling period;
- crucible loading with AlMg10 alloy;
- addition of silicon carbide particles in the required amount (5, 10 and 15%) in the melted aluminum alloy;
- butane bubbling (under 1.2 atm pressure) of the continuously stirred metal melt, for 5 minutes;
- power off the furnace and air cooling of the obtained material;
- removal from the crucible of the obtained composite material.

In order to obtain ultralight cellular composites using soluble salts, we used an aluminum alloy AlMg10, SiC powder and sodium chloride powder (grain size of approx. 1.6 mm). In order to obtain a uniform grain size of sodium chloride, it was sieved with a vibrating granulometer.

After sifting and weighing, the NaCl powder was kept for 60 minutes in an electric oven at 300°C temperature in order to remove absorbed water from atmosphere. After cooling, sodium chloride was packed in polyethylene bags, which were sealed air-tight in order to avoid rehydration.

The technological flow for obtaining ultralight cellular composite materials type AlMg10-SiCp by soluble salt method, involves the following steps:
- sodium chloride sifting in order to obtain particle powder with 1.6 mm size and it dehydration;
- achieving and homogenization of NaCl și SiCp mixture;
- crucible loading with;
- heating the oven to 710°C and maintaining it till AlMg10 alloy is melted;
- addition of NaCl and SiCp mixture;
- homogenization;
- power off the furnace and air cooling of the obtained material;
- removal from the crucible of the obtained composite material;
- introducing and maintaining composite in water for dissolving sodium chloride.

From the macrostructural point of view it can be observed a clear difference between the first set of samples (figure 1) and the second one (figure 2), the samples from the second having larger and interconnected pores, the material approaching to a metal foam [1].

![Figure 1. Macrostructure of cellular samples obtained by M1 method (a) 5% SiC, (b) 10% SiC, (c) 15% SiC.](image)

![Figure 2. Macrostructure of porous samples obtained by M2 method (a) 5% SiC, (b) 10% SiC, (c) 15% SiC.](image)
3. Antiballistic behavior

In the experiment a 9 mm caliber bullet was directed on an armored area, made of AlMg10-SiCp composite (15%SiCp) [8], one with cellular structure and one with porous one, both of 35 mm thickness.

It can easily be seen from figure 3 and table 1 that a 30 mm armor made of AlMg10-15% SiC cellular or porous ultralight composite is sufficiently effective for a 9 mm projectile, the minimum penetration depth being observed in the case of porous composite. We used the following notations: P1-3 - cellular composite with 15% SiC, P2-3 - porous composite with 15% SiC, T1-3 and T2-3 - theoretical values corresponding to the two types of composite material (cellular and porous, respectively.

![Figure 3](image_url)

**Figure 3.** Penetration depth variation of a 9 mm and 15 g mass projectile in an ultralight composite armor, made from AlMg10-SiC (15% SiC), 30 mm thick, depending on the projectile speed.

**Table 1.** Penetration depth variation based on projectile speed and composite material type.

| Projectile speed m/s | Penetration depth, mm |
|-----------------------|-----------------------|
|                       | P1-3 | P2-3 | T1-3 | T2-3 |
| 250                   | 9.8  | 10.7 | 10   | 11   |
| 274                   | 12.4 | 14.3 | 12   | 15   |
| 310                   | 16.6 | 17.3 | 16   | 17   |
| 340                   | 21.2 | 19.9 | 22   | 19   |
| 367                   | 29.1 | 25.5 | 28   | 26   |

It can be observed that up to a speed of about 320 m/s (which is part of the transonic sonic speeds - between 0.8 and 1.2 Mach), the projectile is braked more efficiently by the cellular composite material, compared to the porous one having the same amount of silicon carbide (the Mach number is a dimensionless number showing how many times the projectile's speed is higher than the speed of the sound; it is about 340 m/s for a projectile in air).

Cellular materials behave differently to impact with the projectile in relation to porous composites because, at supersonic speeds, the kinetic energy of the projectile and impact energy, respectively,
greatly increase. This can be explained by the fact that the dynamic properties of the solid at very high deformation velocities are greatly influenced by the higher volume instability of the cellular composite compared to the same type of composite but having a porous structure. In addition, there is a significant increase in the coefficient of friction of the projectile, passing through the composite, as the density increases.

The above-mentioned behaviour adds the strictly ballistics aspect, which refers to the fact that for supersonic velocity projectiles there appears also a shock wave (i.e. a ballistic wave), which additionally creates a strong volumetric shock which can easily destroy the cellular material. In this case, the decomposition in the armor of destructive forces, that are transmitted into the material volume, is made very quickly, especially by association with a shock wave, which is in fact an additional energy carrier. Therefore, destructive energies are much higher at supersonic speeds, cellular composite material resisting less than the porous material.

Similar results to those presented in the paper were published by various authors [9-11].

There was also a good concordance of the modeling performed on the basis of the finite element analysis with the results obtained by ballistic analysis of the impact area. The error between experimental measurements and those determined by calculus [1, 8] does not exceed 4.7%. It is worth noting that almost all the values obtained for the absorbed impact energy are located in the active protection zone provided by the composite armor.

The issue of launching projectiles and setting the required anti-ballistic level of protection for absolute safety leaves no room for errors. For this reason, all modeling and simulation approaches for anti-ballistic and armor safety components must be viewed with utmost responsibility, making multiple tests on the computer thus becoming a mandatory activity alongside polygon tests.

4. Conclusions
The methods we used for making ultralight metal composite materials lead to cellular materials with outstanding features. Thus, the bubbling method leads to ultralight composite with semi-open and open cell, the soluble salts method allowing us to obtain ultralight porous composite materials with a metal foam structure (generally, with semi-open cells).

The production process has a major influence on the macro and microstructure (e.g. relative density and pore distribution in the material, porosity type, pore size and specific pore size, cell wall size) and thereby the properties of the material obtained.

The addition of SiC particles in the AlMg10 alloy matrix aims at stabilizing cell walls and thus improving the mechanical properties of the material. It should be noted that a major influence on the mentioned characteristics has both the shape and size of the particles and their distribution in the material volume.

The increase of the proportion of SiC causes a decrease of composite material density due to porosity rising and equalization of cell size and distribution in the composites volume.

A 30 mm armor made of AlMg10-15% SiC cellular or porous composite is sufficiently effective for a 9 mm projectile, the minimum penetration depth being observed in the case of porous composite. Up to a speed of about 320 m/s, the projectile is braked more efficiently by the cellular composite material, compared to the porous one having the same amount of silicon carbide.

It was observed a good concordance between experimental data obtained by ballistic analysis and those which results by finite element modeling of the impact area.

For these types of composites there is a wide range of applications, especially for anti-ballistic blinds, especially for military vehicles.

5. References
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