# Effect of Quenching Medium on the Properties of the Hybrid Composite AlSi7Mg03-SiC-Graphite

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**Abstract**
The aim the of paper is to analyse the influence of the graphite content and quenching media on the structure and mechanical properties of hybrid composites, with AlSi7Mg03 based matrix reinforced with 10% SiC and 1.5% or 3.0% copper coated graphite. The samples obtained by stir casting were subjected to a solution heat treatment to 530°C for one hour, followed by cooling in air, water and ice + water followed by aging at 170°C for four hours. The hardness tests revealed the advantages of cooling in ice relative to the other cooling.

**Keywords**
composites, solution heat treatment, aged treatment, quenching medium

## 1. Introduction

Composite materials consist of several distinct components, the combination of which gives the assembly properties that none of the component elements taken separately possess.

The properties of composite materials, anisotropic by nature, are superior to those of conventional monolithic, isotropic materials: high resistance relative to their density, high rigidity, stability at high temperatures, low crack propagation speed, corrosion and wear resistance [1, 2, 3, 4, 5]. An important aspect is that composite materials can be moulded for a given application so as to ensure maximum performance.

Composite materials are innovative solutions for high end applications such as aeronautics, machine building, electronics and heat management [6, 7].

Wide applicability is offered by composites with reinforced multilayer metal matrix, called hybrid composites, symbolized by MMCH, as they provide mechanical and heat properties supporting their use in the aeronautical and aerospace fields.

The paper studies the microstructure and the hardness variation after quenching heat treatment in various media (air, water, brine, ice water) for the AlSi7Mg03 alloy matrix hybrid composite, reinforced with 10% SiC and 1.5% or 3% graphite, obtained by stir casting.

## 2. Experimental Research

### 2.1. Material used

The experimental research was conducted on the hybrid composite material (MMCH) with matrix of aluminium based alloy, reinforced with silicon carbide and graphite.

The chemical composition of the analysed material is presented in Table 1.

Table 1. The chemical composition of the composite material

| Material | Matrix | SiC [%] | Graphite [%] |
|---|---|---|---|
| MMCH 1 | AlSi7Mg03 | 10 | 3 |
| MMCH 2 | AlSi7Mg03 | 10 | 1.5 |

### 2.2. The matrix material

Aluminium alloys are attractive for the metal matrix composites (MMC) because of their low density and ability to be precipitation hardening, as well as because of their good corrosion resistance, high heat and electrical conductivity, good workability and weldability.

The mechanical properties of the AlSi7Mg03 alloy depend on several variables such as: the casting technique, the use of modifiers, the alloy purity, the porosity levels and the heat treatment.

The characteristics of the aluminium alloy used as the matrix of the composite are shown in the Tables 2 and 3.

Table 2. Mechanical properties of the matrix material [EN.1706:2010]

| Casting method | Temper | Yield strength $R_{p0.2}$ [MPa] | Tensile strength $R_m$ [MPa] | Young's modulus [GPa] | Hardness [HB] | Elongation % |
|---|---|---|---|---|---|---|
| S | F | 80-140 | 140-220 | 75 | 45-60 | 2-6 |

S- static cast,   F- without treatment.

Table 3. Physical properties of the AlSi7Mg03 matrix material

| Density [g/cm$^3$] | Linear expansion coefficient x10$^{-6}$ [K$^{-1}$] | Thermal conductivity [W/mK] | Solidification range [$^o$C] | Poison's coefficient |
|---|---|---|---|---|
| 2.680 | 22 | 150-180 | 625-555 | 0.33 |

### 2.3. Reinforcing elements

The reinforcing materials frequently used in MMCH include SiC, $Al_2O_3$, $B_4C$, TiC, graphite, because these provide an optimal balance between rigidity, resistance and density [1, 2, 3, 4, 5, 6].

In the assessed case, the reinforcing element used was silicon carbide (SiC) in proportion of 10% and graphite in proportion of 1.5 and 3% covered with copper (for good wettability). The choice of silicon carbide as reinforcing element is justified by its physical and mechanical properties, shown in Table 4, as well as by its physical and chemical compatibility with the aluminium alloy based matrix.

Table 4. Physical properties of silicon carbide   [6, 8]

| Material | Density [g/cm$^3$] | Linear expansion coefficient x10$^{-6}$ [$^o$C$^{-1}$] | Poisson's coefficient | Thermal conductivity [W/mK] |
|---|---|---|---|---|
| SiC | 3.21 | 4.7 | 0.19 | 180 |

Graphite is known as a solid lubricant, and its presence as reinforcing element in the matrix of the aluminium alloy influences the wear behaviour and reduces density.

The physical properties of graphite are shown in Table 5.

Table 5. Physical properties of graphite [6]

| Material | Density [g/cm$^3$] | Linear expansion coefficient x10$^{-6}$ [$^o$C$^{-1}$] | Poisson's coefficient | Thermal conductivity [W/mK] |
|---|---|---|---|---|
| Graphite | 2.28 | 4.3 | 0.23 | 150 |

### 2.4. Preparing the material

The experimental research was carried out on the hybrid composite (MMCH) with an AlSi7Mg03 aluminium alloy based matrix, reinforced with 1.5-3% copper coated graphite and 10% SiCp (45 μm), obtained using the classic stir casting technique.The copper coating of the graphite provides good wettability and incorporation into the molten matrix.

The parameters of the stir casting process were: temperature of the liquid aluminium alloy of 780°C; preheat temperature of the reinforcement elements of 200°C; stirring speed of 200 rpm; stirring time of 10 minutes; pouring temperature of 720°C; steel die was preheated to 500°C.

## 3. Investigation Techniques

### 3.1. Metallographic analysis

The structural changes of the composite material are evidenced by metallographic analysis.

The specimens were polished with abrasive paper (400-3000 grit) and etched with Keller's reagent.

For characterization OMNIMET-BUEHLER System, with NIKON Metallurgical Microscope [NIKON ECLIPSE MA 100] was used.

### 3.2. Hardness

The Brinell hardness test was performed according to the ASTM-E10 standard.

Two parallelepiped samples, 25×25×10 mm, were made from each group of composite material with 10%SiC and 3% Graphite, differentiated by treatment type. Considering the inhomogeneity of the material, three tests were performed for each sample.

### 3.3. Heat treatment

The hybrid composites with aluminium alloy matrix containing silicon carbide and graphite are characterized by good heat treatment behaviour and thus their properties can be optimized [8, 9].

The heat treatment process is chosen according to the nature of the material and the product's functions, being defined by temperature, duration and cooling medium.

The heat treatment was carried out in an oven with electrical resistors with a maximum heating temperature of 1000°C. The influence of the cooling rate on the composite material properties was monitored by modifying the cooling medium after solution heat treatment.

Metallographic analysis, and hardness tests were carried out on unheated and heat treated specimens.

Considering the strains generated by high cooling rates, the choice of the cooling medium correlates with the functional analysis of the product.

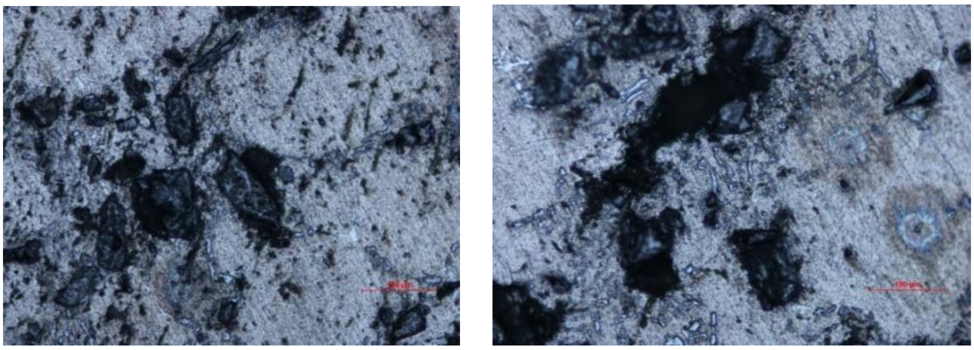
The treatment scheme is shown in Table 6.

Table 6. Parameters of the heat treatment

| No. | Treatment type | Parameters | | |
|---|---|---|---|---|
| | | Temperature [°C] | Time [hours] | Cooling medium |
| 1 | Solution heat treatment | 530 | 1 | air |
| 2 | | | | water |
| 3 | | | | ice + water |
| 4 | Artificial aging | 170 | 4 | air |

## 4. Results and Discussions

The micrographs performed for the initial, cast state highlight the embedded SiC particles as well as the quasi-dispersive graphite arrangement areas around them (Figure 1). The porosity of the analysed composite material and the pore size was determined using a porosimeter Pascal 140. The results are summarized in Table 7. There is a decrease in the composite material density with the increase in graphite content and an increase in porosity and pore size.



a b

Fig. 1. Microstructure of as cast composite
a) AlSi7Mg03/10%SiC/1.5%Gr; b) AlSi7Mg03/10%Si/3%Gr

Table 7. Density and porosity of as cast composite material

| Material | Theoretical density [g/cm3] | Experimental density [g/cm3] | Average pore diameter [μm] | Porosity [%] |
|---|---|---|---|---|
| AlSi7Mg03 | 2.568 | 2.6873 | 51.577 | 8.8165 |
| AlSi7Mg03-10%SiC-1.5% Gr | 2.624 | 2,646 | 51.577 | 8.8165 |
| AlSi7Mg03-10%SiC-3.0% Gr | 2.618 | 2.5068 | 65.843 | 11.788 |

During solution heat treatment (SHT), after heating at 530°C, an oversaturated, homogenous solid solution is obtained by dissolving both the existing phases in the matrix and the ones formed by the interaction between the matrix and the reinforcement material.

The aging treatment at 170°C results in the precipitation of the phases, and increase hardness. The nucleation and the growth of these precipitates depend on the temperature of the solution heat treatment, on the cooling rate and the aging kinetics.

Several researches showed that the aging behaviour of the composite with ceramic reinforcement in the form of particles is different from the one of the matrix alloys; the reinforcement elements accelerate the precipitation process. Forming and stabilizing the intermetallic precipitates ($Mg_2Si$) during ageing process contributes to increased hardness after thermal treatment [9].

The cooling rate after solution heat treatment, affects the kinetics of precipitation process, the volumetric fraction of the precipitated phases, bonding between ceramic particles and matrix and the final hardness [9, 10].

The hardness values obtained after the solution heat treatment and aging for the MMCH composite with 10% SiC and 3% Graphite are presented in Table 8. The hardness of the unheated specimen was 68 HB.

Table 8. Brinell hardness values for the analysed composite

| No. | Material | Treatment type | Quenching medium | Hardness $HB_{250, 5, 15}$ |
|---|---|---|---|---|
| 1 | AlSi7Mg03 +10% SiC +3% coppered graphite | Solution heat treatment at 530°C and aging at 170°C | air | 79 |
| 2 | | | water | 87 |
| 3 | | | ice + water | 94 |

Solution heat treatment and aging causes an increase in final hardness, decreasing of porosity and increased cohesion between the matrix and SiC.

The cooling rate after solution heat treatment, affects structure and final hardness. Air cooling after solution heat treating is done at a relatively slow rate and the hardness after aging is lower in comparison with samples cooled in water and ice + water.

The micrographs of the heat treated samples are presented in Figure 2. Micrographs and hardness tests were carried after aging treatment.

## 5. Conclusions

Increased graphite content leads to increased porosity and decreasing hardness.

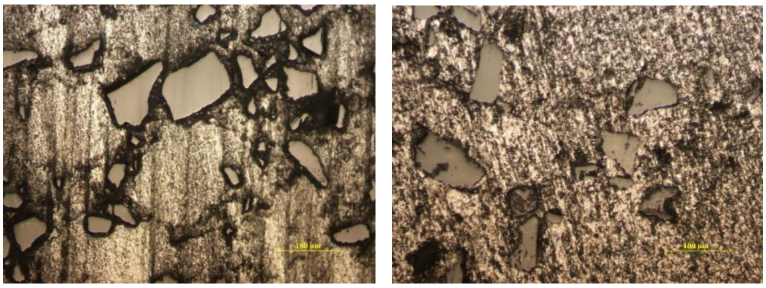
By applying thermal treatment the porosity decreases and cohesion between the matrix and SiC increased.

The rapid cooling from the solution heat treatment temperature favours obtaining a saturated, homogeneous solid solution and allows the increase of hardness after aging.

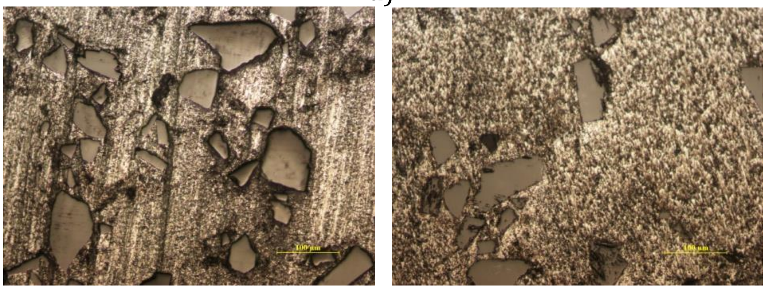
The final value of the hardness is the combined effect of the heat treatment and reinforcement elements.

Heat treatment enhances hardness of composites and in the case with ice quenching result in maximum value.

Cooling in ice + water causes an increase in hardness after aging by 12.8% compared to cooling in the air.



a)



b)

Fig. 2. Microstructure of composite material, AlSi7Mg03 +10% SiC+3graphite
after the solution heat treatment and quenching in water and aging (a) in ice + water and aging (b)

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