ORIGINAL PAPER

MODELING OF MAGNESIUM INFLUENCE UPON THE MECHANICAL PROPERTIES OF ALUMINUM-COPPER ALLOYS

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Abstract. *Although aluminum is sometimes used alone, we often add to it small amounts of other metals in order to obtain alloys with specific qualities. Some elements of the alloy increase the mechanical resistance or the resistance to corrosion. Other improve: the aptitude to manufacturing; malleability; weldability and; the resistance to high temperatures.*

Since the range of diverse alloys is very extended, so allows to find that which is most suitable to the envisaged use constraints. Therefore the mechanical properties of aluminum can be modified by the addition of other metals, notably magnesium which considerably contribute to the improvement of mechanical typical features of various alloys and significantly improves the aptitudes to the manufacturing of realised parts.

The current study consists of modeling the mechanical properties of the AlCuMg alloys as well as studying the addition effect of magnesium upon the cooling process and upon the evolution of the properties in question.

Keywords: *Mechanical properties, modeling, the AlCuMg alloys.*

1. INTRODUCTION

Aluminum has many qualities such as lightness and resistance, it also processes a great capacity for recycling. The growing need of environment respect and technological innovations, make of aluminum a metal with prospects .It benefits by a strong potential of growth in the equipments of transport, while coming within a viewpoint of lasting development.

Whether in its pure forme or in alloys, aluminum seems to be one of the most useful metals upon the surface of the planet. Its polyvalency never ceases of astonishing. Its future is bearer of great developments still undreamt of; nevertheless an important part of research and development aims at the innovation of new aluminum alloys.

As it is the case with all pure metals, the typical features of pure aluminum are feeble, notably its mechanical properties. The commercially pure aluminum has in its annealed state, some mechanical weak properties; however one can improve considerably these properties by means of cold hammering, addition of alloy elements or thermic treatment, it all depends on the individual case[1].

This work aims at the modeling of the mechanical properties of the AlCuMg alloys as well as at the study of the addition effect of magnesium upon the cooling process and upon the evolution of the properties in question.

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Usually, the microstructure and the mechanical behavior of the AlCuMg alloys are straight away impacted by certain parameters such as composition and speed of cooling.

2. MATERIALS AND METHODS

The works concerned with the solidification modeling are essentially focused upon the calculus of the evolution of the thermic field in casting. This temperature field is obtained via the resolution of the equation of heat diffusion.

The whole sphere is made up of a solid and liquid, and the problem of heat diffusion with stage transformation may be expressed by the following formula [2]:

$$div\left(K\overrightarrow{grad}T\right) + \dot{Q} = \rho c_p.\frac{\partial T}{\partial t} \quad (1)$$

with:

- K is the thermic conductivity;
- ρ is the voluminal density;
- c_p is the specific heat ;
- $\dot{Q}$ is the source term bound to the liberation of melting latent heat:

$$\dot{Q} = \rho L.\frac{\partial f_s}{\partial t} \quad (2)$$

with:

- L is the melting latent heat;
- f_s is the solid fraction.

The speed of a solution diffusion increases with temperature (network vibration) and expresses itself as follows [3]:

$$D_i = D_i^0 \,.\exp\left(-\frac{Q_i}{RT}\right) \quad (3)$$

with:

- D_i^0 is the pre-exponential term ;
- Q_i is the activation energy ;
- R is the perfect gases constant;
- T is the temperature expressed in Kelvin.

It is necessary to perfectly study the balance diagram between Al-Cu, Al-Mg and Mg-Cu phases in order to know the phases susceptible of being encountered.

AlMg system: The magnesium has a high solubility of 17.4% in weight at 450°C within solid aluminum. The presence of magnesium increases the resistance to corrosion, gives a goo finish to the work at cold because of the ductility it imparts to various alloys and heightens the features of solders made of aluminum alloys[4].

AlCu system: Copper is one of the most important elements for aluminum, because of its appreciable solubility and strengthening effect. Many commercial alloys contain copper, either as the major addition or among the principal alloying elements, in concentrations of 1 to 10%. It is used frequently in combination with magnesium [5].

MgCu system: The phase diagram for MgCu presented in Fig. 3 is characterized by the presence of two intermediate phases: β or $MgCu_2$ (16.1% de Mg) and γ or Mg_2Cu (43.3% de Mg). The β phase occupies a relatively wide area, indicating that MgCu2 compound is non-stoichiometric and can dissolve a certain amount of Cu or Mg. By contrast, the γ phase is represented by a vertical: this phase is perfectly stoichiometric. This equilibrium diagram can be subdivided into three separate diagram, each having a eutectic transformation Cu-$MgCu_2$, $MgCu_2$-Mg_2Cu and Mg_2Cu-Mg [1].

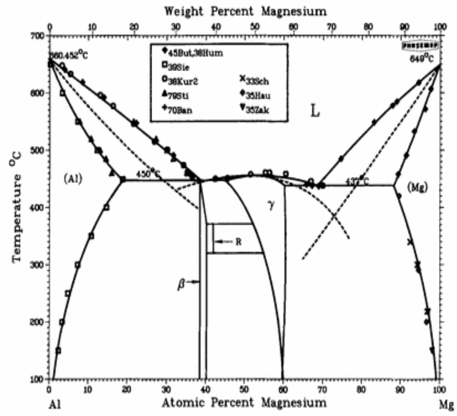

Figure 1. Al-Mg phase diagram [6].

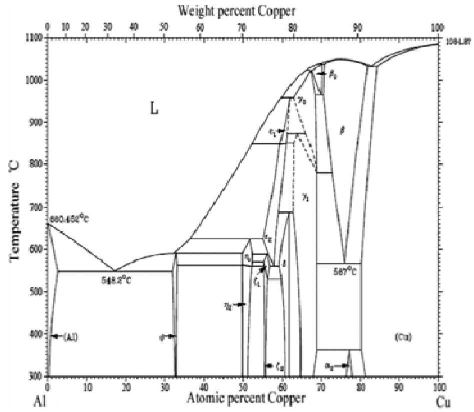

Figure 2. Al-Cu phase diagram [7].

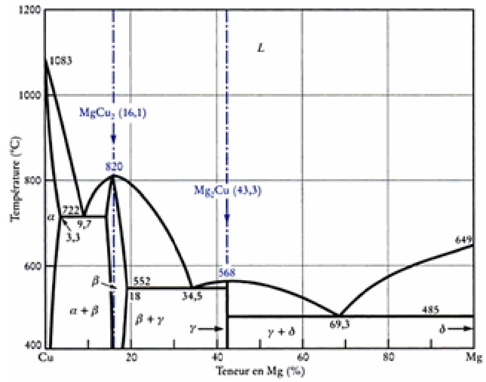

Figure 3. Mg-Cu phase diagram [1].

Because of the limits of solubility of alloy elements, we shall restrict the study of the balance diagram to fields of chemical composition contained between 0 and 4% in weight for the following elements: Cu and Mg.

3. RESULTS AND DISCUSSION

3.1. THE AlCuMg ALLOYS LIGHTLY LOADED WITH COPPER

3.1.1. Cooling velocity

Fig. 4 presents the cooling curves of the following alloys: Al2%Cu[8], Al2%Cu0.12%Mg, Al2%Cu2%Mg, Al2%Cu3%Mg and Al2%Cu4%Mg, representing temperature according to time. The curves of thermic analysis evolve according to the composition of each alloy.

As it is illustrated in the figure, we obviously find again the linear initial cooling of the liquid. After 631s, we notice the existence of a bearing at 670°C for Al2%Cu[8] alloy corresponding to a phase change (L↔L+α) a non-isothermal transformation, the increase in the solid part takes place while temperature diminishes. A second change of gradient representing the crossing of the area α is recorded at 560°C, under which temperature goes on evolving.

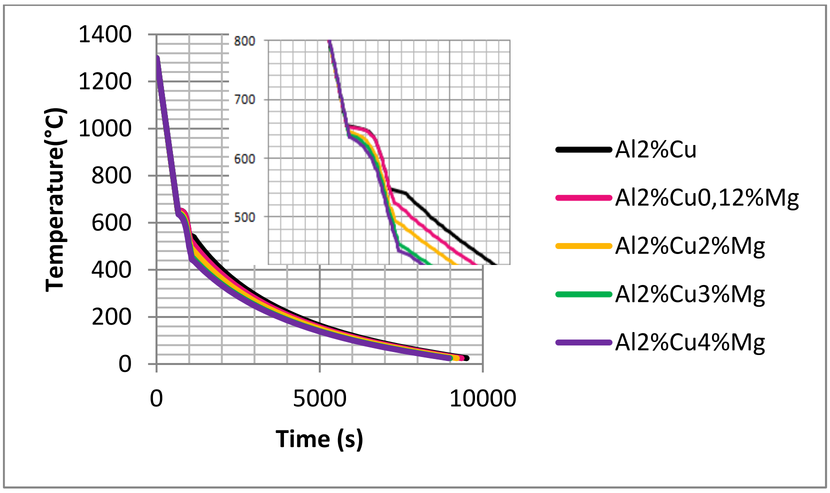

Figure 4. Cooling curves of the following alloys: Al2%Cu, Al2%Cu0.12%Mg, Al2%Cu2%Mg, Al2%Cu3%Mg and Al2%Cu4%Mg.

The curve of Al2%Cu4%Mg alloy containing more magnesium presents its first inflexion point at 645°C after 661s, therefore the addition of magnesium has an impact upon temperature as well as upon transformation time. Magnesium slows down the cooling process and its effect is rendered by a slight increase of time and temperature of solidification .

3.1.2.Studies of mechanical properties

- **Proof stress**

The underneath figure shows the evolution of elasticity according to the cooling velocity of the following alloys: Al2%Cu[8], Al2%Cu0.12%Mg, Al2%Cu2%Mg, Al2%Cu3%Mg and Al2%Cu4%Mg.

We notice that elasticity progressively augments as fast as the cooling velocity increases whatever may be the added magnesium percentage. We also note that the alloys containing more magnesium have the highest values of elasticity: the Al2%Cu4%Mg alloy takes the value of 244MPa at 100C/s whilst for this same speed, the Al2%Cu[8] alloy, which contains no magnesium, does not exceed 59MPa.

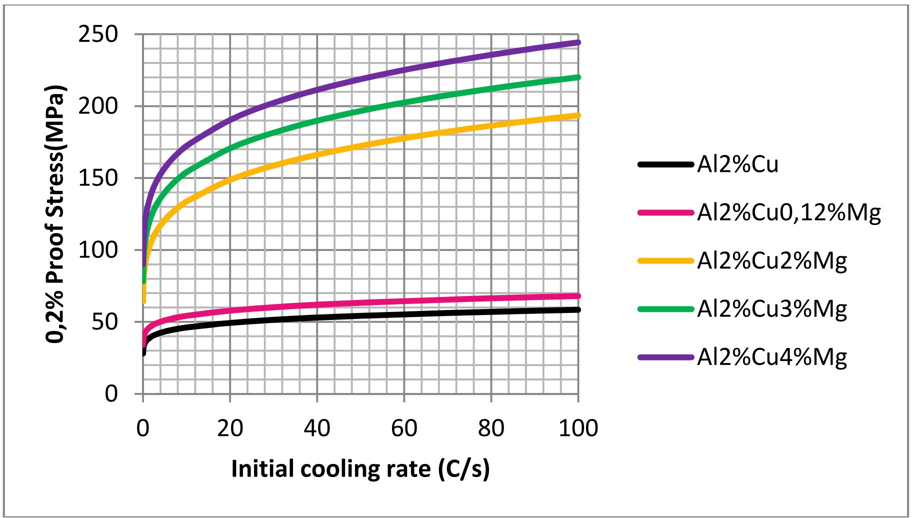

Figure 5. Evolution of proof stress according to cooling speed of such alloys as: Al2%Cu, Al2%Cu0.12%Mg, Al2%Cu2%Mg, Al2%Cu3%Mg and Al2%Cu4%Mg.

- **Tensile stress**

Fig. 6 shows the evolution of the traction constraint according to the cooling speed of the following alloys Al2%Cu[8], Al2%Cu 0.12%Mg, Al2%Cu 2%Mg, Al2%Cu 3%Mg and Al2%Cu4%Mg.

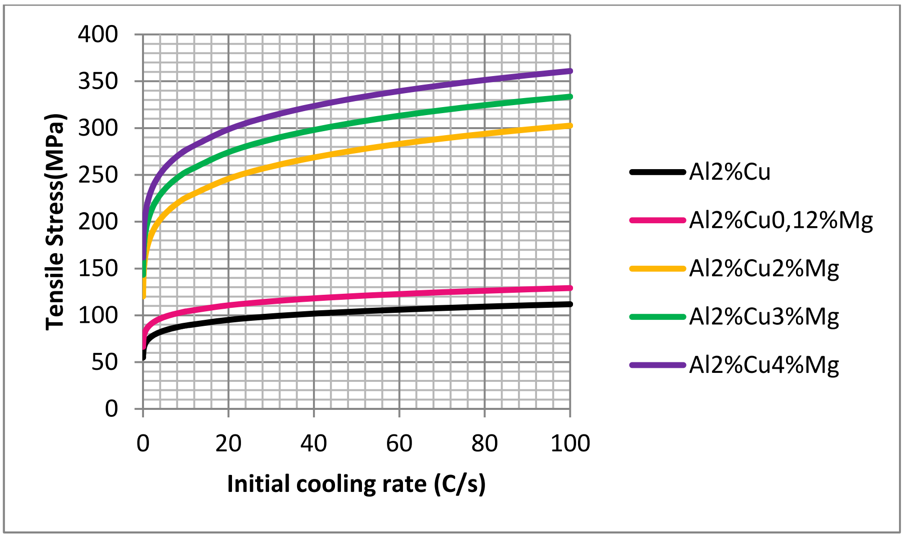

Figure 6. Evolution of tensile stress according to cooling speed of such alloys as: Al2%Cu, Al2%Cu 0.12%Mg, Al2%Cu 2%Mg, Al2%Cu 3%Mg and Al2%Cu4%Mg.

We notice that the traction constraint increases progressively as fast as the cooling speed augments whatever may be the added magnesium percentage. We also notice that the alloys containing more Mg have the highest values of the traction constraint: the Al2%Cu4%Mg alloy takes the value of 360MPa at 100C/s whereas for this same velocity the Al2%Cu[8] alloy which contains no Mg does not exceed 112MPa.

- **Hardness**

Fig. 7 shows the evolution of hardness according to the cooling speed of the following alloys: Al2%Cu[8], Al2%Cu0,12%Mg ; Al2%Cu2%Mg ; Al2%Cu3%Mg et Al2%Cu4%Mg.

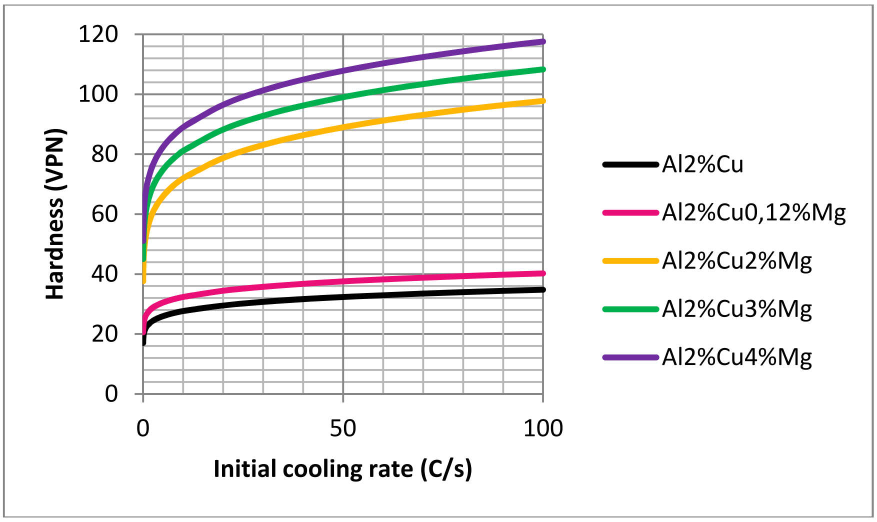

Figure 7. Evolution of hardness according to cooling speed of such alloys as: Al2%Cu, Al2%Cu 0.12%Mg, Al2%Cu 2%Mg, Al2%Cu 3%Mg and Al2%Cu4%Mg.

We notice that hardness increases progressively as fast as the cooling speed augments whatever may be the added magnesium percentage. We also notice that the alloys containing more Mg have the highest values of hardness: The Al2%Cu4%Mg alloy takes the value of

117VPN at 100C/s whilst for this same speed, the Al2%Cu [8] alloy that contains no Mg, does not exceed 35VPN.

3.2. THE AlCuMg ALLOYS STRONGLY LOADED WITH COPPER

3.2.1.Cooling velocity

Fig. 8 presents the cooling curves of the following alloys: Al4%Cu[8]; Al4%Cu0,12%Mg; Al4%Cu2%Mg; Al4%Cu3%Mg and Al4%Cu4%Mg representing temperature according to time. The curves of thermic analysis evolve according to the composition of each alloy.

As it is illustrated in the figure, we obviously find again the linear initial cooling of the liquid. After 658s, we notice the existence of a bearing at 650°C for Al4%Cu[8] alloy corresponding to a phase change (L↔L+α) a non-isothermal transformation, the increase in the solid part takes place while temperature diminishes. The curve of the Al4%Cu4%Mg alloy containing more magnesium exhibits its first inflexion point at 630°C after 648s below which temperature goes on evolving. Therefore the addition of magnesium has an effect upon temperature as well as upon transformation time. The magnesium slows down the cooling process and its impact is rendered by a slight augmentation of time and temperature of solidification.

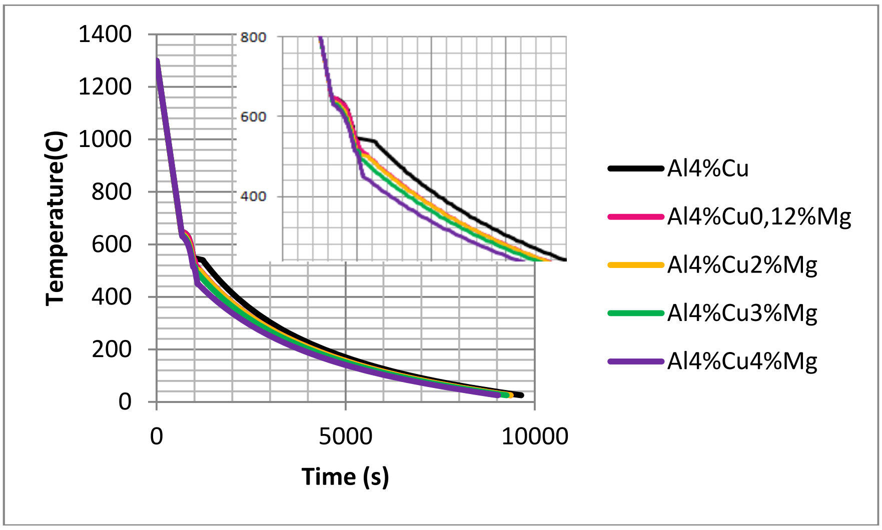

Figure 8. Cooling curves of the following alloys: Al4%Cu, Al4%Cu0.12%Mg, Al4%Cu2%Mg, Al4%Cu3%Mg and Al4%Cu4%Mg.

3.2.2.Studies of mechanical properties

- **Proof stress**

The figure below shows the evolution of elasticity according to the cooling velocity of the following alloys: Al4%Cu[8]; Al4%Cu0,12%Mg ; Al4%Cu2%Mg ; Al4%Cu3%Mg et Al4%Cu4%Mg.

We notice that elasticity progressively augments as fast as the cooling velocity increases whatever may be the added magnesium percentage. We also note that the alloys containing more magnesium have the highest values of elasticity: the Al4%Cu4%Mg alloy takes the value of 294MPa at 100C/s whereas for this same speed, the Al4%Cu[8] alloy, which contains no magnesium, does not exceed 60MPa.

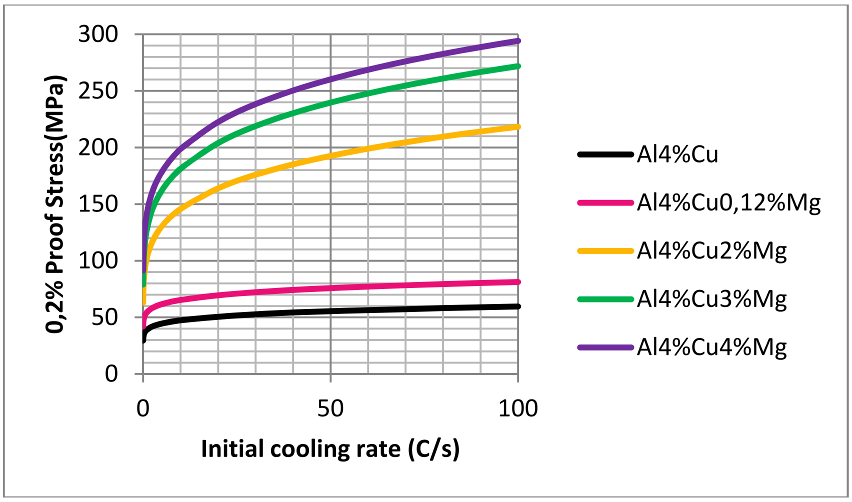

Figure 9. Evolution of proof stress according to cooling speed of such alloys as: Al4%Cu, Al4%Cu0.12%Mg, Al4%Cu2%Mg, Al4%Cu3%Mg and Al4%Cu4%Mg.

- **Tensile stress**

The figure number 10 shows the evolution of the traction constraint according to the cooling speed of the following alloys Al4%Cu[8]; Al4%Cu0,12%Mg ; Al4%Cu2%Mg ; Al4%Cu3%Mg et Al4%Cu4%Mg.

We notice that the traction constraint increases progressively as fast as the cooling speed augments whatever may be the added magnesium percentage. We also notice that the alloys containing more Mg have the highest values of the traction constraint: the Al4%Cu4%Mg alloy takes the value of 413MPa at 100C/s whilst for this same velocity the Al4%Cu[8]; alloy which contains no Mg does not exceed 114MPa.

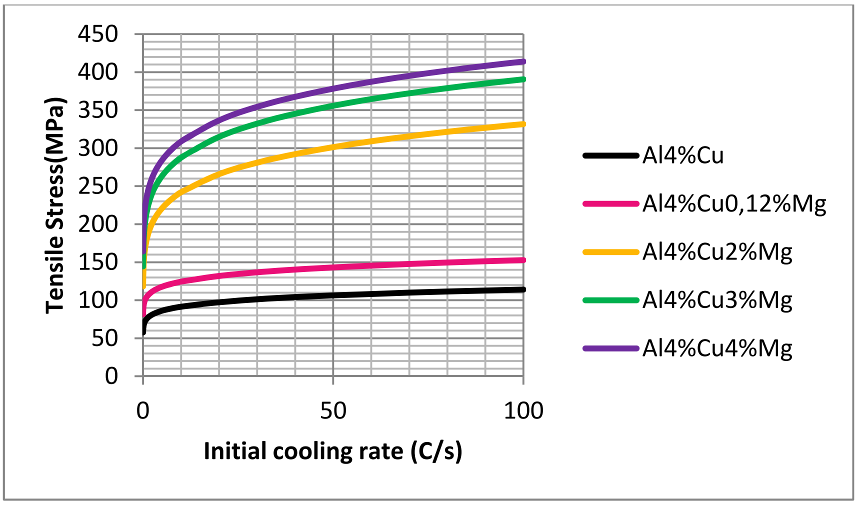

Figure 10. Evolution of tensile stress according to cooling speed of such alloys as: Al4%Cu, Al4%Cu0.12%Mg, Al4%Cu2%Mg, Al4%Cu3%Mg and Al4%Cu4%Mg.

- **Hardness**

Fig. 11 represents the evolution of hardness according to the cooling speed of the following alloys: Al4%Cu[8]; Al4%Cu0,12%Mg; Al4%Cu2%Mg; Al4%Cu3%Mg and Al4%Cu4%Mg.

We notice that hardness increases progressively as fast as the cooling speed augments whatever may be the added magnesium percentage. We also notice that the alloys containing more Mg have the highest values of hardness: The Al4%Cu4%Mg alloy takes the value of 135VPN at 100C/s whilst for this same speed, the Al4%Cu[8] alloy that contains no Mg, does not exceed 36VPN.

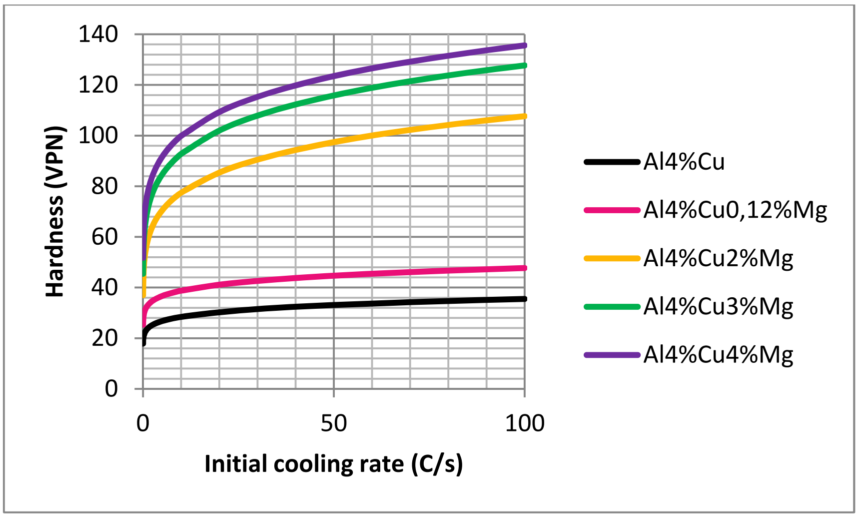

Figure 11. Evolution of hardness according to cooling speed of such alloys as: Al4%Cu, Al4%Cu0.12%Mg, Al4%Cu2%Mg, Al4%Cu3%Mg and Al24Cu4%Mg.

4. CONCLUSIONS

According to to this study, we notice that magnesium slows down the cooling process, and its effect is rendered by a slight increase of the solidification time and temperature.

For both cases of aluminum alloys: weakly and strongly laden with copper, we notice that the tree parameters increase progressively as fast as the cooling speed increase whatever may be the added magnesium percentage; maybe, all this is owing to the impact of the cooling speed upon the alloy microstructure and more precisely upon the grains size, which increases with the cooling speed subsiding.It is mainly the magnesium addition and especially the porosity reduction that is responsible for the strong increase of the mechanical properties previously studied.

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