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Autor 1 H. M. Medrano-Prieto[1]
Dirección. Centro de Investigación en Materiales Avanzados (CIMAV), Laboratorio Nacional de Nanotecnología, Miguel de Cervantes No. 120, C.P. 31136, Chihuahua, Chih., México
Tel: 52 (614) 4391146
E-mail: hansel.medrano@cimav.edu.mx

Autor 2 C.G. Garay-Reyes[2]
Dirección. Centro de Investigación en Materiales Avanzados (CIMAV), Laboratorio Nacional de Nanotecnología, Miguel de Cervantes No. 120, C.P. 31136, Chihuahua, Chih., México
Tel: 52 (614) 4391146
E-mail: carlos.garay@cimav.edu.mx

Autor 3 C.D. Gómez-Esparza[3]
Dirección. Centro de Investigación en Materiales Avanzados (CIMAV), Laboratorio Nacional de Nanotecnología, Miguel de Cervantes No. 120, C.P. 31136, Chihuahua, Chih., México
Tel: 52 (614) 4391146
E-mail: cynthia.gomez@cimav.edu.mx

Autor 4 R. Martínez-Sánchez[4]
Dirección. Centro de Investigación en Materiales Avanzados (CIMAV), Laboratorio Nacional de Nanotecnología, Miguel de Cervantes No. 120, C.P. 31136, Chihuahua, Chih., México
Tel: 52 (614) 4391146
E-mail: roberto.martinez@cimav.edu.mx.

INFLUENCE OF SOLUTE ADDITION IN THE MICROSTRUCTURE AND HARDNESS OF THE AL-SI-CU ALLOYS

Abstract

Commercial aluminum alloys corresponding to Al-Cu-Si family are commonly used in casting and molding process because their high castability. The main characteristics of these alloys are the excellent weight/strength relation in conjunction with wear and corrosion resistance. Additionally, the mechanical properties of these alloys could be enhanced by heat treatment.

In Al A319 alloys, Cu and Mg are the main responsible to increase the mechanical properties after T6 heat treatment due to the precipitation of Al_2Cu and Mg_2Si and Al_2CuMg phase [1]. Combined effects of Ni and Cu improve strength and hardness at relatively elevated temperature [2]**,** Due to the low solubility of Ni in Al (0.04%), it has been reported the formation of $FeAl_9FeNi$-type intermetallic, which is not totally dissolved with the typical solution treatments used in aluminum alloys [3]. Hayajneh et al., found that increasing amounts of intermetallic compounds Al_3Ni, $Al_3(CuNi)_2$ and Al_7Cu_4Ni in Al-Cu alloy, the hardness increase [4].

The effect of Ni addition and solution treatment time on the microstructure and hardness of the Al A319 alloy are studied by Vickers microhardness (VHN), Rockwell B hardness (HRB), X Ray Diffraction (XRD), Optical Microscopy (OM), Scanning Electron Microscopy (SEM).

Introduction

The A319 Al alloy belonging to the Al-Si alloy system is commonly used in the automotive industry, due to its excellent combination of strength and ductility [6], moreover, of its high strength/weight ratio, corrosion resistance and excellent thermal conductivity [5]. Additionally, its high cast ability allows the casting of complex forms.

This alloy is generally heat treated to obtain optimum mechanical properties [5]. The effects of heat treatments have been studied by different techniques and authors [6, 7, 5, 8, 9, 1], where the following results highlight, the β-Mg_2Si and θ-Al_2Cu phases are dissolved during the solubilized treatment, but were not dissolved Fe-rich phases as, π-$Al_8Mg_3FeSi_6$ and α-$Al_{15}(Fe,Mn)_3Si_2$, only the β-Al_5FeSi phase is fragmented and gradually dissolved at high temperatures [5]. Through of addition of small amounts (~0.01%) of Na, Sr, Ca, or Sb during the solubilized treatment, were observed eutectic Si morphological changes since acicular to fibers or globules (spheroidization) [10, 7].The increase in the mechanical properties of hardness and mechanical strength is obtained by precipitating the θ-Al_2Cu phase during aging [5].
In Al alloys, the Ni, Fe, Ce and other transition metals, which, the main characteristic is their low solubility in Al (maximum of 0.01% to 0.03%), are employed to reduce the coefficient of thermal expansion [10]. The Al-Ni intermetallic compounds have excellent properties of resistance to temperature, due to their thermal stability, projecting to these intermetallic compounds as an excellent candidate for use in Al alloys [11]. The effect of Ni has been studied in Al-Cu alloys [2], improvement of mechanical strength and hardness at elevated temperatures, have been reported. Also, It was observed the formation of $FeAl_9FeNi$ Intermetallic compound, which was not dissolved during solution heat treatment [3]. By other hand, Hayajneh et al. [4] studied the effect of intermetallic compounds in the mechanical response in Al-Cu alloys; they reported that the presence of the Al_3Ni, $Al_3(CuNi)_2$ and Al_7Cu_4Ni intermetallic compounds have a direct relationship with mechanical properties. Higher amounts of intermetallic compounds higher hardness.

It can be seen from this literature review that not many research works have been done to investigate the effect of Ni on Al-Si-Cu alloys. The objective of this

research is the study of the effect of Ni additions, solution time and aging heat treatments on microstructure and hardness. The variation of general microstructure, precipitates morphology and hardness is presented and discussed as a function of Ni % and aging time.

Experimental procedure

The raw materials were A319 commercial aluminum alloy and Al-20%Ni master alloy. The commercial A319 alloy is melted on a LINDBERG BLUE electric furnace at 740 °C. The Al-20%Ni master alloy is added in different proportions to obtain A319-1.0% Ni and Ni-A319-2.0% alloys. Thereafter, each alloy is degassed for 5 minutes with argon gas (20 psi), using a graphite propeller at 490 rpm and finally Al-5Ti-1B grain refiner is added. The alloys were cast into steel molds preheated at 260 °C. Solution heat treatment at 495 °C during 5 and 7h were done in LINDBERG-BLUE electric furnace followed by a quenching in water at 60°C. Aging heat treatments were done in a FELISA furnace at 170°C for different period of time (0.5, 3, 5, 10 and 96 h), followed by quenching in fresh water.

The microstructure of prepared samples, before and after heat treatments was characterized by X-ray diffraction (XRD), optical microscopy (OM), scanning electron microscopy (SEM). Observations by OM were done in a Olympus PGM-3 optical metallographic microscope. XRD analyses were performed in a Panalytical X'Pert PRO diffractometer (40 kV, 35 mA) with Cu Ka radiation (λ = 0.15406 nm). Analyses by SEM and TEM were carried out in a JEOL JSM5800-LV (operated at 20 kV). For OM and SEM samples were prepared by conventional metallographic techniques.
Hardness tests were carried out in a Wilson Rockwell device using Rockwell B scale. Microhardness test were done in a Future Tech FM-7 Microhardness Tester, the load used was 100 gf. The average of 10 indentations is reported.

Results and Discussion:

Optical Microscopy (OM)

The variations in microstructure as a function of solution time are shown in Figure 1. Fragmentation of Si, dissolution of Cu phases and the modification of dendritic microstructure are observed. Figure 1a shows the as-cast condition. In this figure a dendritic morphology is observed, in which it is observed dendritic aluminum arms, Si-rich platelets, Al-Cu phases and intermetallic containing Fe, Si and Mn.

The microstructure of the samples after of solution treatment at 495 °C for 5 and 7 h is show in Figs. 1b and 1c, respectively. In these figures is observed how the Si-rich phase changes its morphology from irregular continuous platelets to rounded fragments after solution treatment. In addition, phases with morphology of needles and Chinese script type are observed, these phase has been identified before as βFe (Al_5FeSi) and αFe

$Al_{15}(Fe,Mn)_3Si_2$, respectively [6, 8]. These phases have a high thermal stability due to the Fe content [5, 1] and they are not dissolved during solution treatment. However, fragmentation and a reduction in size have been observed.

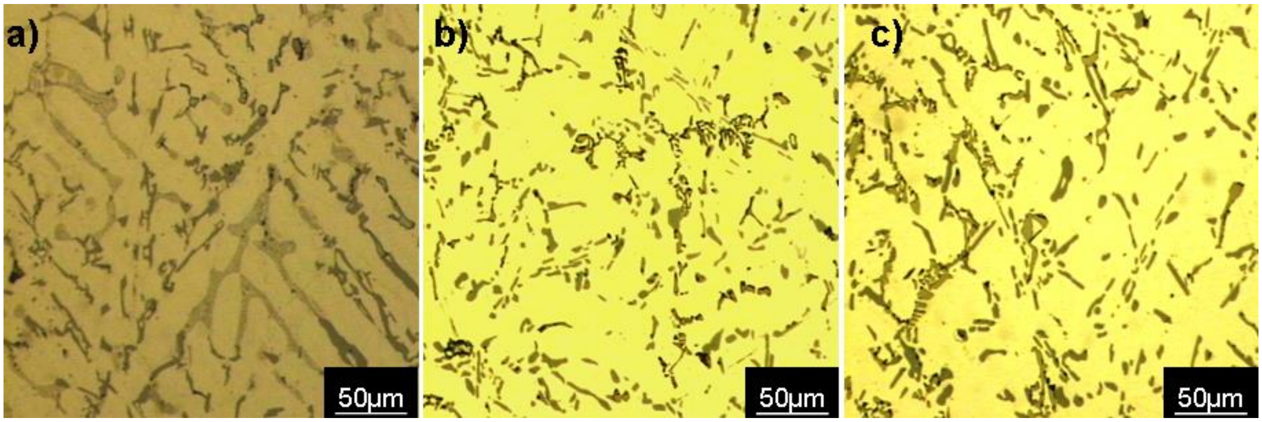

Fig. 1 OM micrographs of the A319 alloy: a) as-cast and after solution treatment at 495 ºC for b) 5 h and c) 7 h.

Figure 2 show the microstructure in as-cast conditions in samples modified with Ni additions.

There are many effects of heat treatments; one of them is the variation of microstructure. The degree of this modification of microstructure is influenced by the alloying elements and the temperature selected.

The microstructure of as-cast condition A319 alloy after Ni additions is shown in Fig. 2. There is observed a variation in dendrites morphology, as well as, the interdendritic phase has been changed its morphology. Additionally, platelets like

phases are present; these variations in morphology and presence of new phases are due the addition of Ni.

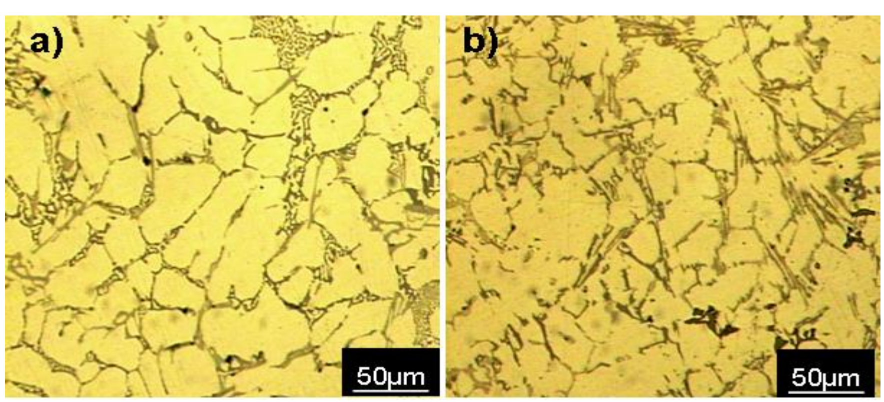

Fig. 2 OM micrographs of A319 alloy modified with Ni additions in the as-cast condition: a) 1 wt% Ni and b) 2 wt% Ni.

Scanning Electron Microscopy (SEM)

The Ni effect over microstructure was kept after solution treatment. The effect of solution treatment in alloys was different if there Ni presence. Additionally to the modification of dendrites morphology by Ni additions, the formed phases containing Ni are thermally stables at least at solution temperature. The microstructures of the A319 alloy modified with 1 wt% Ni and solubilized for 5 and 7 h, are showed in Figs. 3 and 4, respectively. Distribution of the main alloying elements (Al, Si, Cu, Fe, Mn and Ni) is included. Both figures show the presence of Si-rich, Al-Fe-Mn-Si and Al-Cu-Ni phases, with rounded, elongated needles and Chinese script type morphologies, respectively (Fig. 3). Additionally, Al-Ni phases with plate morphology can be observed in Fig. 4. However, the αAl(FeMn)Si phase (Chinese script) was not easily observed after longer solution times (7 h). This phase has a direct effect over mechanical properties in Al-Si alloys [9]; partial dissolution or morphological modification could be enhancing physical properties.

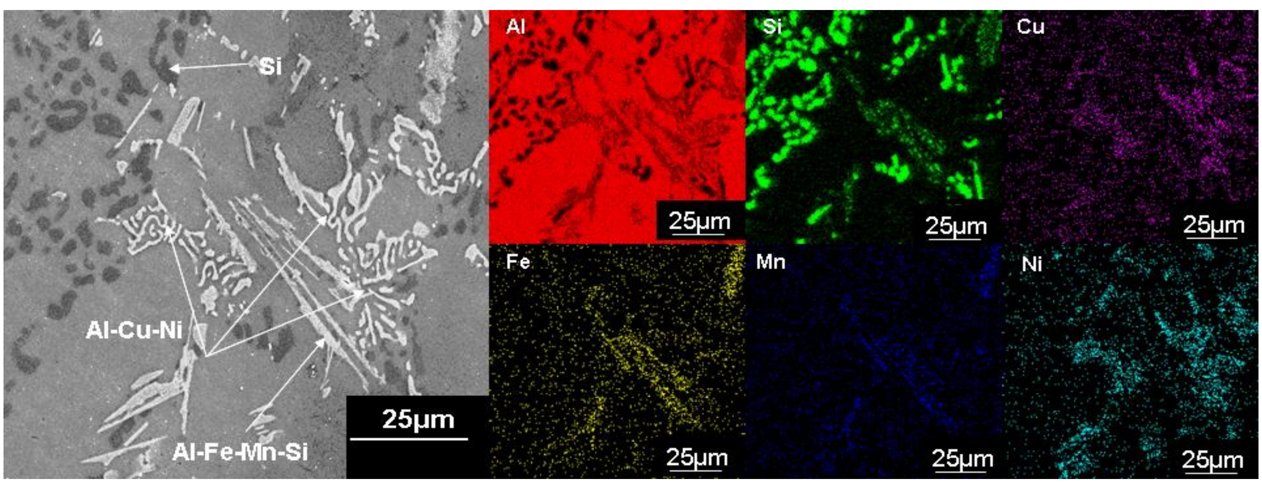

Fig. 3 SEM micrograph and elemental mapping of the A319 alloy with 1 wt% Ni after solution treatment for 5 h.

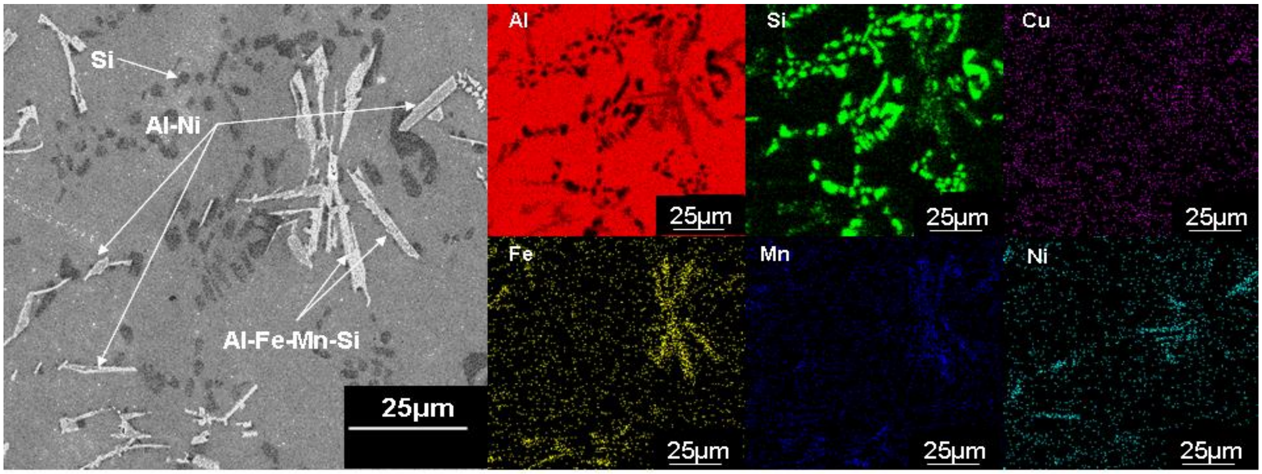

Fig. 4 SEM micrograph and elemental mapping of the A319 alloy with 1 wt% Ni after solution treatment for 7 h.

Higher Ni additions have an important effect over microstructure. The effect of solution time is different for each Ni concentration. At higher Ni contents the morphology of Al-Fe-Si-Mn phases is observed different. Additionally, was observed during elemental analyses that this phase present important Ni concentrations, this incorporation of Ni could be a factor that change the morphology, before platelets and now noodles-like. The microstructure of the A319 alloy with 2 wt% Ni after solution treatment at 495 °C for 5h is presented in Fig. 5.

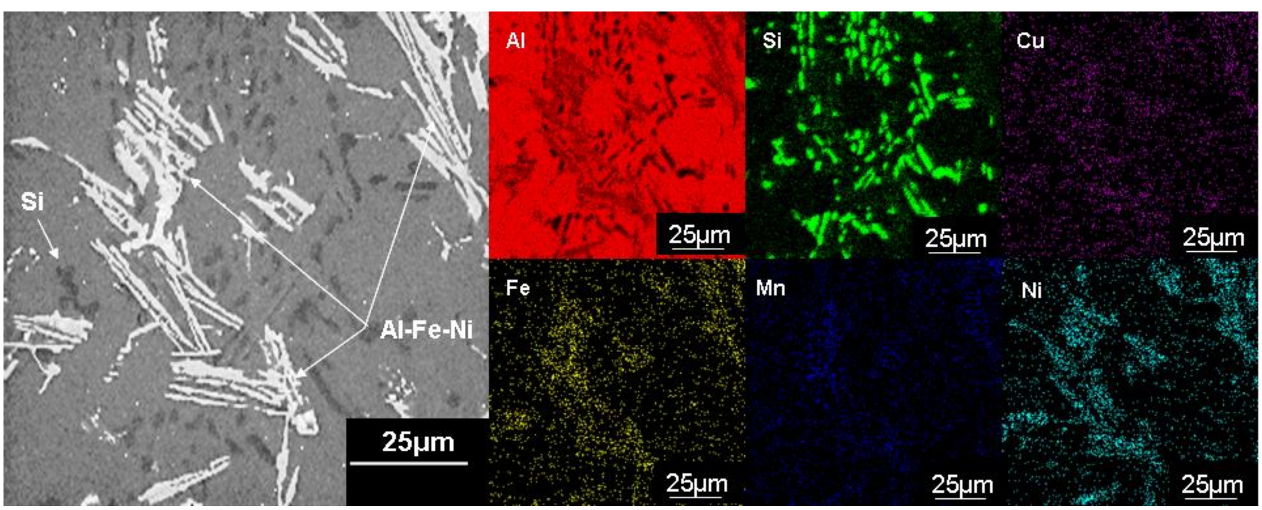

Fig. 5 SEM micrograph and elemental mapping in the A319 alloy with 2 wt% Ni after solution treatment for 5h.

X-Ray Diffraction

The phase's identification was done by XRD analyses. In accord with the peak intensities, the more evident phases present are, the aluminum matrix and Si interdendritic phases. However, other phases are present in accord with XRD pattern, in which, the characteristic reflections of these phases, even with low intensities, are present. The effect of Ni additions in phases present in AA319 aluminum alloy is presented for as-cast and after solution treatment in Figs. 6 and 7, respectively.
Fig. 6 shows the XRD patterns from A319 and additions of 1.0 % Ni and 2.0 % Ni in the as-cast condition. In the XRD pattern corresponding to reference sample, Al rich and interdendritic Si-rich phases are identified. Minor intensity presents Al_2Cu Al_2CuMg and $AlCu_2Mn$ phases. Whit 1% of Ni additions the incipient presence of Al_3Ni is apparently observed, as well as Al_2FeSi and a complex phase identified as $Al_8FeMg_3Si_6$. In Sample with 2% of Ni additions Al_3FeSi_2 phase is observed with low intensities. The phases, Al_3Ni and $Al_8FeMg_3Si_6$ present a higher number of peaks.

The effect of solution time is observed in Fig. 7. Dissolution of Al_2Cu is the more important variation; however the presence of new phase ($Al_{75}Ni_{10}Fe_{15}$) because the longer diffusion times, is observed. Phases identified in as-cast condition are present after solution heat treatment [5, 1], which indicate that these phases

present high thermal stability. The presences of the phases identified with XRD are in accord with the elemental mapping showed in Fig. 4.

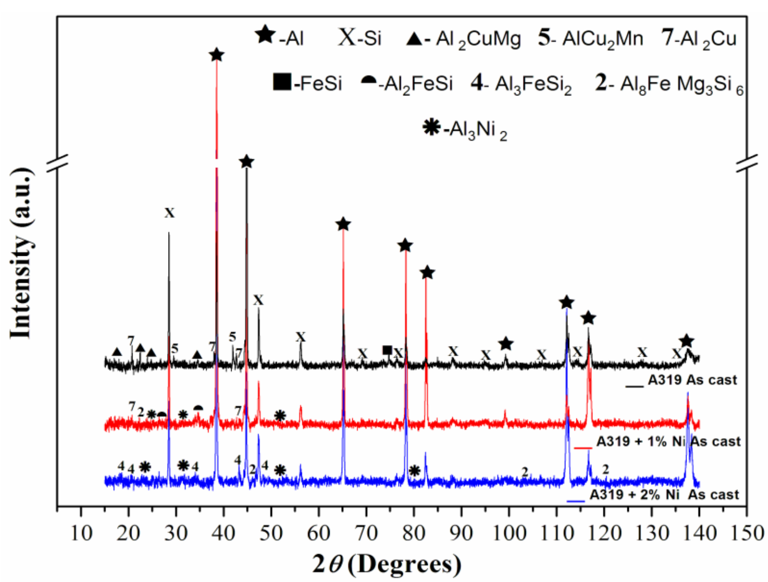

Fig. 6 XRD pattern obtained from as-cast condition in the A319 alloy with and without Ni additions.

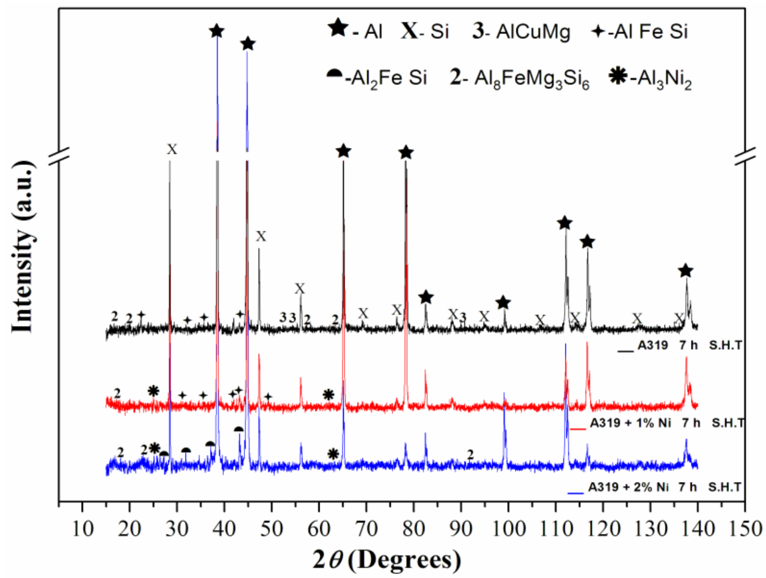

Fig. 7 XRD pattern obtained after solution treatment at 495 °C for 7h in the A319 alloy with and without Ni additions.

Rockwell B Hardness [HRB]

The effect of Ni addition and precipitation heat treatment on the Rockwell B Hardness (HRB) in the A319 alloy is shown in Fig. 8. By this test is possible evaluate the effect of all present phases, including the new formed due heat treatment. In general way it is observed an increase in the hardness value up to a maximum and then decrease in relation to the aging time. This is a typical behavior in aging hardenable (heat treated aluminum) alloys. All hardness values in Ni modified alloys are higher than those found in reference sample. For the A319 alloy, is observed a maximum value of hardness of 70 HRB in the sample aged for 300 min (5 h); while, in samples modified with additions of 1 and 2 wt% Ni, are obtained maximum hardness values of 75.9 and 77.2 HRB, respectively, in samples aged for 180 min (3h). With Ni additions it is possible obtain higher hardness values at shorter aging times.

According to several authors [5, 1] the θ' Al_2Cu (Semi-coherent) phase is the main responsible for the increase in hardness, and θ Al_2Cu (Incoherent) phase is responsible for the decrease. Ni additions have a direct effect over the θ' Al_2Cu (Semi-coherent) phase, which is the main responsible of hardness increment by heat treatment. However this influence is different in each alloy system. Increment in hardness and stabilization of mechanical properties is reported for Al-Cu alloys when are modified with Ni [4].

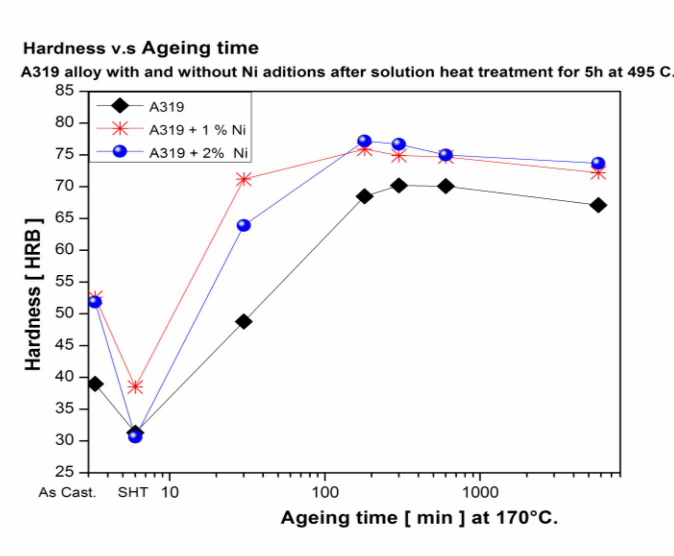

Fig. 8- Graph of hardness versus aging time for the A319 reference alloy and those modified with Ni additions, after solution treatment at 495 °C for 5h.

Vickers Microhardness [VHN]

The effect of heat treatments and Ni additions on aluminum matrix was evaluated by micro-hardness. By this test is evaluated only the effect of solid solution and hardening precipitation mechanisms. The variation on micro hardness Vickers as a function of aging time for different concentrations is presented in Fig 9. Vickers microhardness behavior is similar to that observed for Rockwell B Hardness. All hardness values in Ni modified alloys are higher than those found in reference sample. For A319 alloy, a maximum value of 131.23 VHN is obtained in samples aged for 5h, similar to the value of ~ 133 VHN-reported by Tavitas-Medrano et al. [7]. For the A319 alloy with additions of 1 and 2 wt% Ni, maximum values of 139.47 and 140.92 VHN are obtained in samples aged for 3h. It is also observed that increasing the Ni content in the A319 alloy, increases hardness and retards the formation of incoherent precipitates, which agrees with reported by Hayajneh et al. [4].

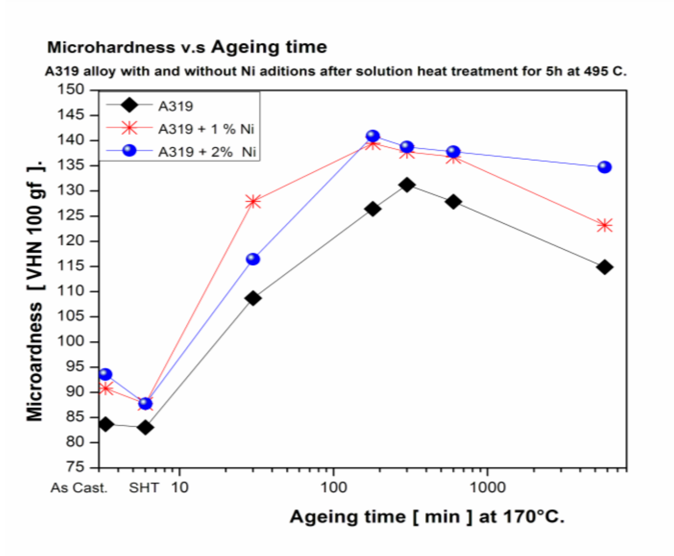

Fig. 9 Vickers microhardness as a function of aging time for the A319 reference alloy and those modified with Ni additions, after solution treatment at 495 °C for 5h.

Conclusions

The Ni addition between 1 and 2 wt. % to the A319 aluminum alloy favored the formation of the Al-Fe-Ni, Al-Cu-Ni and Al_3Ni_2 intermetallic phases and delayed the formation of incoherent precipitates. The formation of intermetallic phases increases the hardness being the highest values obtained in the A319 alloy with 2 wt% Ni.

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