AN INVESTIGATION OF THE INFLUENCE OF NANO-COBALT OXIDE ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF 7075 ALUMINIUM ALLOY

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ABSTRACT

Aluminium Alloy AA7075 is the strongest heat-treatable aluminium series. For that they have suitable properties and tremendous applications, especially in the aviation and aerospace industries. The effect of a minor Nano-cobalt oxide on the microstructures and mechanical properties of AA7075 was investigated in this work. The investigation was carried out as a cast AA7075 with 0.2, 0.4, 0.6 and 0.8% Nano-cobalt. The optical microscopy demonstrates that the grain size of alloys was decreased with the increasing of Nano -cobalt oxide content. The Scanning electron microscopy and EDX show that the cobalt oxide present between the grains at the grain boundary. Moreover, there are Al-Zn-Mg, Al-Fe-Cu, Si-Al-Zn, Al-Fe-Cu-Co-Zn, and Al-o-Si-Zn-Cu compounds. The mechanical properties examination shows that the hardness decreased and yield stress, increased with an increasing in the Nano-cobalt content. The ultimate tensile stress and modulus elasticity also increased with the increase of Nano-cobalt content, except alloy with 0.8% Nano-cobalt which decreased to 5.87 GPA.

KEYWORDS: Aluminium Alloy (7075), Nano-Cobalt Oxide, Micro Structural; Mechanical Properties & Aerospace Aluminium Alloys

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INTRODUCTION

Metals matrix composites (MMC) reinforced by Nano ceramic particles have received considerable importance because of their superior mechanical properties over metals matrix. So that in the last years, metal matrix composites with nano-sized reinforcements have become progressively composites because they have another strengthening mechanisms as compared to that in the composites with micro-sized reinforcements. Consequently, interested properties have been achieved from the Nano metric particulate reinforced composites.

Aluminium-based reinforced have received a considerable attention as a result of their high modulus, increased wear resistance and improved strength, over conventional aluminium alloys.

It was reported that the yield strength of the pure aluminium was increased two times by introducing only 4vol. % Al_2O_3 Nano particles [1]. The addition of 1% of the carbon Nano tube to 2024 Al-Cu alloy increased the strength and Young's modulus about 35% [2]. The factors that affect the properties of MMC are homogeneity, volume fraction, microstructure, and isotropy of the system [3].

AA 7075 alloy is the best alloy for manufacturing aircraft structural parts because it has low density and excellent mechanical properties [4-6].

Many researches have been carried out on AA7075 to produce alloy with the best properties. Chen et al studied the effect of Nanoparticle Al_2O_3 addition on microstructure and mechanical properties of 7075 alloy. They have found that the yield strength, ultimate tensile strength and 0.2 compressive yield strength of the alloy with 1.5% Nanoalumina were increased by 74%, 57 and 100% respectively [7].

The wear and high temperature creep resistance were increased with the addition of SiC nanoparticles (50nm) [8]. The effect of carbon-coated silver (Ag-C) nanoparticles on mechanical properties of AA7075 alloy was studied by Capos et al. It was detected that the Vickers hardness increased with an increasing in the content of Ag-C Nanoparticles as a result of refining of crystal structure [9]. The influence of Al_2O_3 nanoparticles injected by argon in the melt of AA7075 has effectively improved ultimate tensile strength, compression strength and hardness of metal matrix composite after extrusion of the composite alloy [10-11]. Mechanical and physical properties were investigated on the two types of AA7075 composites. One alloy was manufactured by introducing 2 wt.% Nano alumina particles (avg. particle size 30–50 nm) in the molten AA 7075 alloy by squeeze casting with a pressure of 101 MPa. And the other alloy was fabricated by stir casting and reinforced by 4%SiC and 2%, 4% Nano alumina [12].

In this work the effect of Nano Cobalt oxide (CoO) particles on the mechanical properties of AA7075 alloy by liquid casting was studied. The Nano metal matrix composite alloys were prepared by introducing 0.2%, 0.4% and 0.6% NanoCoO in the melt of AA7075 alloy.

EXPERIMENTAL WORK

The present work was carried out on AA7075 alloy prepared by traditional casting. Five alloys were prepared in 100 g weight. Each alloy was melted in silicon carbide clay bonded crucible at 780°C in the electrical resistance furnace (with accuracy of $\pm 5^\circ\text{C}$). The pure aluminium was melted, then the alloying elements were added to the melt, A 0.2%, 0.4% and 0.6% and 0.8% Nano cobalt oxide (30nm and 99.9% purity) were added to the alloys (S1, S2, S3 and S4) respectively, and poured in 14mm diameter and 200 mm length gray cast iron mold (preheated to 200°C). The chemical composition carried out by optical emission spectrometer type (SPECTROMA) as in the Table 1. The samples were prepared for hardness, tensile strength; dry were resistance and microscopy examination according to the standards. The microscopy was accomplished by using (Tescan Vega 3 SEM and EDX). Tensile strength was achieved by the universal tensile strength. The Brinell's hardness test was done using universal hardness. The chemical composition carried out by optical emission spectrometer type (SPECTROMA) as in the Table 1.

Table 1: The Chemical Composition of Alloys (wt%)

No.	Si	Fe	Cu	Mg	Cr	Ni	Zn	Ti	Nano CoO	Al
S0	0.086	0.212	1.740	2.860	0.205	0.043	6.040	0.084	0.001	Bal
S1	0.072	0.203	1.722	2.847	0.201	0.040	5.943	0.083	0.224	Bal
S2	0.073	0.206	1.735	2.838	0.198	0.038	5.892	0.084	0.398	Bal
S3	0.082	0.198	1.732	2.832	0.199	0.036	5.889	0.081	0.604	Bal
S4	0.079	0.199	1.738	2.821	0.202	0.039	5.821	0.083	0.789	Bal

RESULTS AND DISCUSSIONS

The present work was carried out on AA7075-O aluminium alloy and the influence of Nano cobalt oxide on its properties.

Microstructures of the alloys revealed that the alloy with 0.2% NanoCoO (S1) had a non-homogeneous and fine grain structure, (Figure 1a).

As shown in the Figure 1a coarse inter metallic compound precipitated on the grain boundaries and other inter metallic compound deposited independently. In microstructures of alloys S2 the grain size slightly increased with increasing the Nano cobalt oxide content to 0.4% as in figure 1b. Moreover the inter metallic compound increased on the grain boundary zone and the independently deposits also increased. Figures 1c and 1d reveal a very homogeneous equiaxed grain structure and more inter metallic precipitates. From microstructures in the Figures 1a, 1b, 1c and 1d, it can be observed that the homogeneity of the microstructure increases with the increase in the percentage of nanoparticles of cobalt.

Figure 1: Optical Microscopic Structures
(a) Alloy AA7075 with Addition of 0.2% Nano CoO Alloy S1,
(b) Alloy AA7075 with Addition of 0.2% Nano CoO Alloy S2,
(c) Alloy AA7075 with Addition of 0.2% Nano CoO Alloy S3,
and (d) Alloy AA7075 with Addition of 0.2% Nano CoO Alloy S4

**Figure 2: SEM Microstructure and EDX Graphs of Alloy S1,
 (a) SEM Microstructure of Alloy S1,
 (b) EDX Graph at 11 Which Shows the Composition Consists of Al-Zn-Mg,
 (c) EDX Graph at Point 12 which Consists of Al-Zn-Mg but with another Content, and
 (d) EDX Graph at Point 13 Which Consists of Al-O-Zn-Si-Mg**

Figure 2 reveals the SEM microscopic image and EDX graphs of alloy S1. The main constituents of compounds are determined by EDX mostly on behalf of (Al-Zn-Mg) at point (11) near the grain boundary. Figure (2-a) shows the SEM microscopic image with points (11, 12, and 13) and reveals the compound near and at the grain boundaries.

Figure 2-b displays the chemical composition at the point (11) which consists of Al-Zn-Mg with contents (5.8%Zn and 1.6%Mg). Figure 2-c shows a deposition of a phase Al-Zn-Mg consists of both zinc and magnesium with a percentage higher than those in point 11 (6.1% Zn and 2.1% Zn)

As shown in the Figure 2-d, the laminated phase is composed of Al-O-Zn-Si-Mg. precipitated at grain boundaries.

Figure 3 reveals the SEM microscopic image and EDX graphs of alloy S1. Figure 3a shows the SEM microscopic image with points (14, 15, and 16) that reveals the compounds near and at the grain boundaries. Figure 3b displays the chemical composition at the point (14), that consists of Al-Fe-Cu.

Figure 3: SEM microstructure and EDX graphs of alloy S2.

- (a) SEM microstructure of alloy S2,
(b) EDX graph at the point (14) which shows the composition consists of Al-Fe-Cu,
(c) EDX graph at the point (15) which consists of Al-Zn, and
(d) EDX graph at the point (16) which consists of Al-O-Zn-Cu-Mg. contents (14.9%Fe and 7.1%Cu)

Figure 3c shows a composition of Al-Zn compound contain of (4% Zn) without any other elements

In the Figure 3d can be detected (Al-O-Zn-Cu-Mg) precipitated compound at the boundaries of the grains. The Cu rich eutectics are converted into S (Al_2CuMg), and (Al-Cu-Fe) compounds precipitate as $\text{Al}_7\text{Cu}_2\text{Fe}$ particles [13]. It is clearly distinct that the (Al-O-Zn-Cu-Mg) phase deposited on the grain boundary and, Cu and Mg elements are reduced in areas far from the grain boundaries.

Figure 4 shows the microstructure and EDX graphs of alloy S4. The EDX graph at points (17) clearly reveals the composition Al-Zn-Mg compound. The point (17) located far from the grain boundary.

Mechanical Properties

Room temperature (RT) tensile properties of the cast alloys are given in the Figure 5.

The tensile stress of alloy with Nano CoO content 0.2% is 85 MPa by increasing the Nano CoO content to 0.4 the tensile stress increases to 92MPa as in the alloy (2).

The tensile stress of alloys (3 and 4) was also increased to 111 and 131 MPa respectively, meant that, the tensile stress increased proportionally with the Nano cobalt oxide contents.

Figure 4: SEM Microstructure and EDX Graphs of Alloy S4.
 (a) SEM Microstructure of Alloy S4,
 (b) EDX Graph At Point (17) Which Shows the Composition Consists of Al-Zn-Mg,
 (c) EDX Graph At Point (18) Which Consists of Si-Al-Zn, and
 (d) EDX Graph At Point (19) Which Consists of Al-Fe-Cu-Co-Zn

Figure 5: Tensile Stress of as Cast 7075 Aluminum Alloys with 0.2, 0.4, 0.6, and 0.8 Nano CoO Particles

This increment of tensile stress as the result of the effect of Nano cobalt oxide which act as nuclei centers during solidification process of melt and refine the microstructure of the alloys. Moreover the precipitated phases like T-(Al₂Mg₃Zn₃), S-(Al₂CuMg) and (Al-Cu-Fe) which act as composite with the matrix of aluminium. These phases act as obstacles for dislocations during a tensile test [14].

Figure 6: Yield Stress of as Cast 7075 Aluminium Alloys with 0.2, 0.4, 0.6, and 0.8 Nano CoO Particles

Figure 6 reveals the effect of NanoCoO on the yield stress. As appears in the figure 6 yield stress also proportionally increased by increasing the Nano cobalt oxide contents. The yield stress increased from 53 to 75 MPa. The reason for this increment in the yield stress belong to the refinement effect of Nano particles and obstacle effects of the precipitated phases which act as a composite material with aluminium matrix. Figure 7 shows the effect of Nano cobalt

oxide particle on the modulus of elasticity of the alloys.

As illustrated in the figure 7 the modulus of elasticity increases at a high rate from 4.8GPa in the alloy of 0.2% Nano CoO to 7.78GPa in the alloy of 0.4% Nano cobalt oxide particles, but the rate decreases at alloy of 0.6% Nano CoO particles, and then decreases to 5.87GPa in alloy of 0.8% Nano CoO particles. The reason may be because the high homogeneity of the microstructure and precipitated phases which effect on the strain and then the modulus of elasticity.

Figure 7: Modulus of Elasticity of as Cast 7075 Aluminium Alloys with 0.2, 0.4, 0.6, and 0.8 Nano CoO Particles

Figure 8 shows the effect of Nano cobalt oxide on Brinell's hardness of alloys. The hardness of alloy of 0.2 has 93MPa hardness but the hardness increased by increasing the Nano cobalt oxide in the alloy of 0.4% NanoCoO.

Figure 8: Brinell Hardness of as Cast 7075 Aluminium Alloys with 0.2, 0.4, 0.6, and 0.8 Nano CoO Particles

The hardness of alloys of 0.6 and 0.8% Nano CoO also increased. The hardness increased proportionally with the increase of Nano cobalt oxide. The reason for that as mention in the other above mechanical properties is the refinement effect of Nano particles and the precipitated phases.

CONCLUSIONS

It can be concluded from the results above that:

The addition of nanoparticles of cobalt oxide increases the mechanical properties of the 7075 alloy. The tensile stress, yield stress, modulus of elasticity and hardness proportionally increased with the increasing of Nano cobalt oxide content, except the modulus of elasticity of alloy with 0.8% Nano particles was lower than the other alloys.

The homogeneity of the microstructure increases with the increase in the percentage of nanoparticles of cobalt.

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