ORIGINAL PAPER

MICROSTRUCTURE AND MECHANICAL PROPERTIES OF Al-Cd BINARY ALUMINIUM ALLOY

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Abstract. *This work is aimed at investigating the microstructure and mechanical properties of as-cast Al-Cd alloys system were prepared by casting technique. The Al-Cd binary aluminium alloy was analyzed by employing Rockwell hardness HRF, metallograph, XRD, SEM and EDS methods. Evolution of hardness confirmed that the studied alloys are age-hardenable alloys. The as-cast Al-2%Cd alloy is the one who present the mechanical properties (48,75HRF) improved compared to other studied alloy. The results of XRD and optical microscope revealed the presence of the one main phase α-Al of a crystalline structure CFC and there is no new phase formed.*

Keywords: *Al-Cd binary alloy, microstructure, mechanical property.*

1. INTRODUCTION

The use of aluminum alloys in industry is increasing owing to their high strength/density ratios and other advantage properties. Precipitation strengthening is applied to the some aluminum alloys. Precipitation strengthening is one of the most important hardening methods used to increase strength in aluminum alloys [1].

The representative precipitation-hardenable aluminum-base alloys for the applications are Al-Mg [2], Al-Si [3], Al-Sb [4], Al-Cu-Mg-Ag [5], etc. For example, Alloy 2024 is an aluminium alloy which contains copper, magnesium, manganese and some minor alloying elements; it is used in engineering applications such as aeroplane constructions, orthopaedic soles, rivet and pulling wheels [1].

Cadmium metal has specific properties that make it suitable for a wide variety of industrial application. These includes: excellent corrosion resistance, low melting temperature, high ductility, and high thermal and electrical conductivity [6]. Also, cadmium has been used in several alloys to improve mechanical properties. For example, Mg-Cd series alloy have been the focus of intense investigations in recent years due to their light weight and excellent high temperature strength satisfying the need of aerospace industry [7].

In the present paper, Cd was used to improve the property of Al-Cd binary alloy. Phase identification was performed using X-ray diffraction (XRD). Optical microscope was used to characterize the microstructure of the as-cast Al-Cd alloy and Rockwell hardness (HRF) used to study the evolution of mechanical properties.

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2. EXPERIMENTAL

2.1. Sample preparation

Elemental Al (99.9% purity) and Cd (99.9% purity) were used to prepare the four alloys of nominal composition Al-1%Cd,Al-2%Cd,Al-3%Cd and Al-4%Cd (all compositions quoted in this work are in wt.% unless otherwise stated).

The diagram of phase (figure1) of the binary system Al-Cd presents a eutectic stage to the temperature 650C°. The composition of the eutectic liquid is approximately 6.95% in weight of Cd. Thus it was chose compositions lower than the limit of solubility of cadmium: 1%, 2%, 3% and 4%.

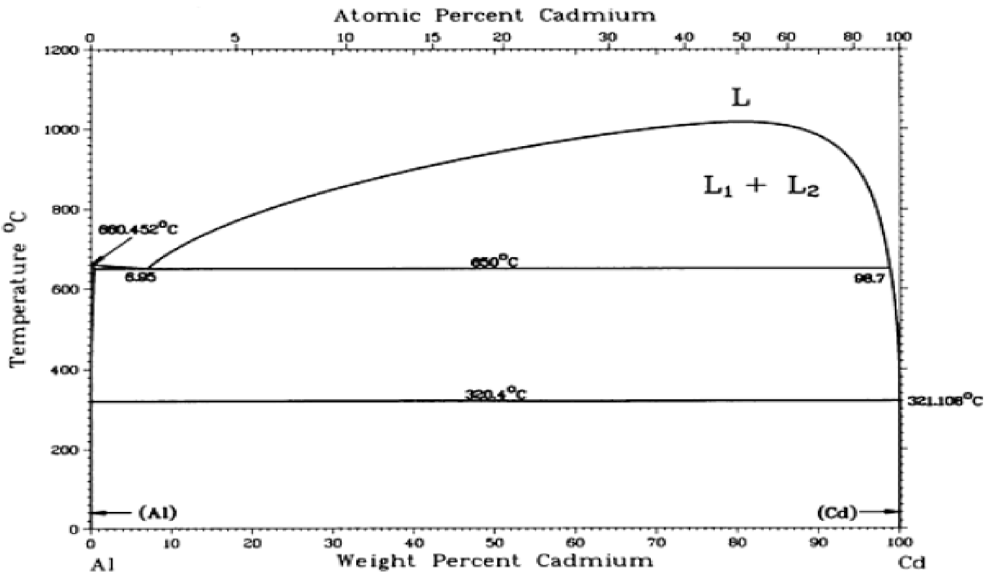

Figure 1. Phase diagram of binary system of Al-Cd [8].

The alloys are weighed according to the selected chemical composition. They are then introduced into a crucible out of alumina refractories of cylindrical form open in its top. The alloy is obtained by fusion in an oven with 750 °C during one hour. After fusion and total cooling, the unit “crucible and alloy” are soaked with water.

2.2. Hardness

Rockwell F hardness (HRF) tests were carried out on a Testwell durometer under a load of 60 kg using a 1.588-mm-diameter steel ball indenter. The sample surface was polished using 600-grade sandpaper, and each reported value of hardness corresponds to the mean of three points distributed over the entire cross section or the rolled surface of the samples.

2.3. Optical microscopy and scanning electron microscopy

To study the evolution of the microstructure of metal alloys should be used the micrographic observation. In this study we carried out the micrographic test of alloys using the two following tools: a micrographic microscope (OPTIKA B-500 TDK) equipped with a camera integrated of type “AIPTEK HD1080P” and scanning electron microscope (SEM) of type Philips XL30 ESEM coupled with a microanalysor with dispersion of energy (EDS) to allow a quantitative semi microanalysis of a given area.

With an aim of making microscopic observations, the samples are polished mechanically on papers abrasive (number 180 with the number 1200) and cleaned each time by distilled water. Surfaces were then attacked chemically by adequate etching solutions. In our case one used the Keller reagent to make a chemical attack whose composition of the reagent is the following one:

- distilled water (H_2O): 95.5 mL
- nitric acid (HNO_3): 2.5 mL
- hydrochloric acid (HCl): 1.5 mL
- hydrofluoric acid (HF): 0.5 mL

2.4. X-ray diffraction

Diffraction data were collected at room temperature on a D2 PHASER diffractometer, with Bragg–Brentano geometry, using CuKα radiation (λ=1.5418 Å) with 40KV and 10 mA). The patterns were scanned through steps of 0.01 (2 θ) in the 2θ range 10–100°.

3. RESULTS AND DISCUSSIONS

3.1. Al-2%Cd As-cast Structural

Figure 2 shows the XRD pattern of Al-2%Cd in the as-cast alloy. Figure 3 shows the microstructure of Al-2%Cd alloy. It can be seen from both figures that the matrix of Al-2%Cd binary alloy is α-Al phase solid solution. Al-2%Cd shows a distribution of non-uniform large block. The structure is homogeneously distributed over the matrix of aluminium. And that is in arrangement whit the previous work reported in the literature [9] which the morphology cadmium particles are spherical and aligned in rows inside the aluminium grains. The α-Al is gradually refined and distributed with uniform small grains. From Al-Cd binary phase diagram (Figure 1), Al and Cd can form uniform grain transition and can be infinitely dissolved forming a single-phase solid solution of α-Al and that is clearly confirmed from the XRD pattern in Figure 2 showing a single phase and stable phase of α-Al.

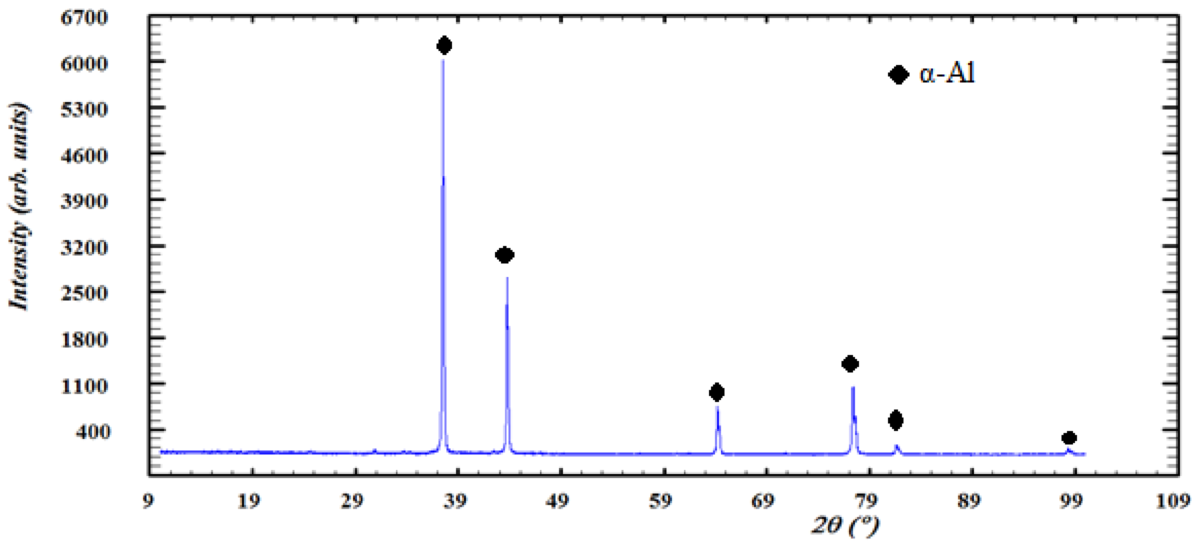

Figure 2. XRD pattern of as-cast Al-2%Cd alloy.

Also another observation can be obtained from this figure is that no new phase coming into being in Al-Cd binary aluminium alloy where the content of Cd is 2%. It is indicated that Cd completely solid dissolves in the Al matrix, because of solid solution strengthening and grain refinement of Cd.

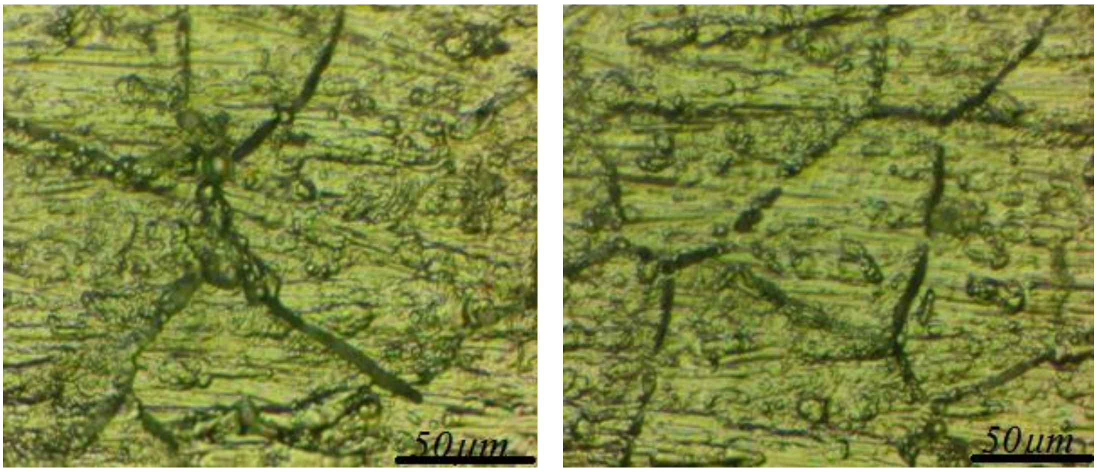

Figure 3. The optical microstructure of as-cast Al-2%Cd.

The SEM micrographic of microstructures of as-cast Al-2%Cd alloy is illustrated in Figure 4. It can be observed that de microstructure of as-cast Al-2%Cd alloy is uniform distribution of rich precipitate of Cd at the grain boundaries and the solute segregation of Cd is formed in solid solution. It is also indicated that Cd in the α-Al matrix forms a large number of enrichment zones in or near the grain boundaries, and then the segregation of Cd comes into being, which brings largely constitutional supercooling, hindering the grain growth of α-Al phase. Grain of α-Al is accordingly refined.

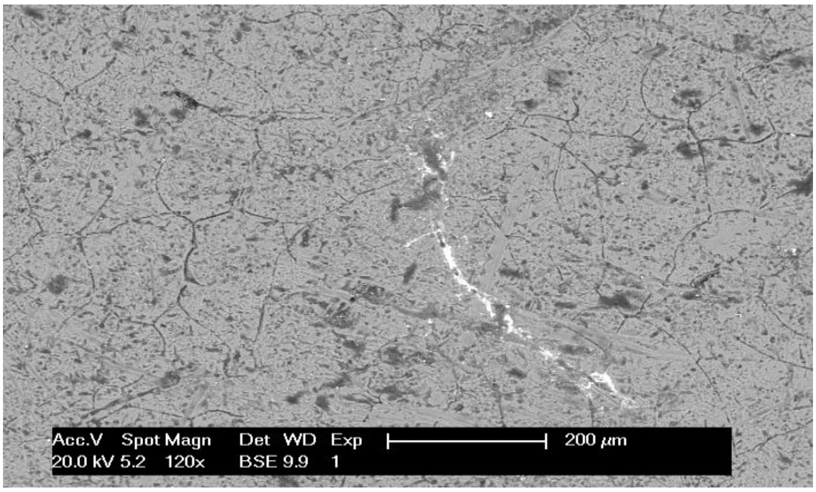

Figure 4. SEM micrographic of as-cast Al-2%Cd .

Cd is known to behave like Pb, Bi and In which have low melting point inclusions, are not very soluble in solid aluminum and are very dense, were abnormally distributed in a very heterogeneous way, and were most often present in the form of globules or crystals with sizes larger than 20 micrometers and sometimes larger than 1mm [10]. The microstructures presented by the researchers are very similar to those observed by us although the scale of microstructure is finer in our case. Furthermore, The EDS analysis is done in two different zones, marked by A and B in Figure 5 and Figure 6 respectively. According to the result of analysis by EDS, the dominantly phase are α-Al and cadmium only.

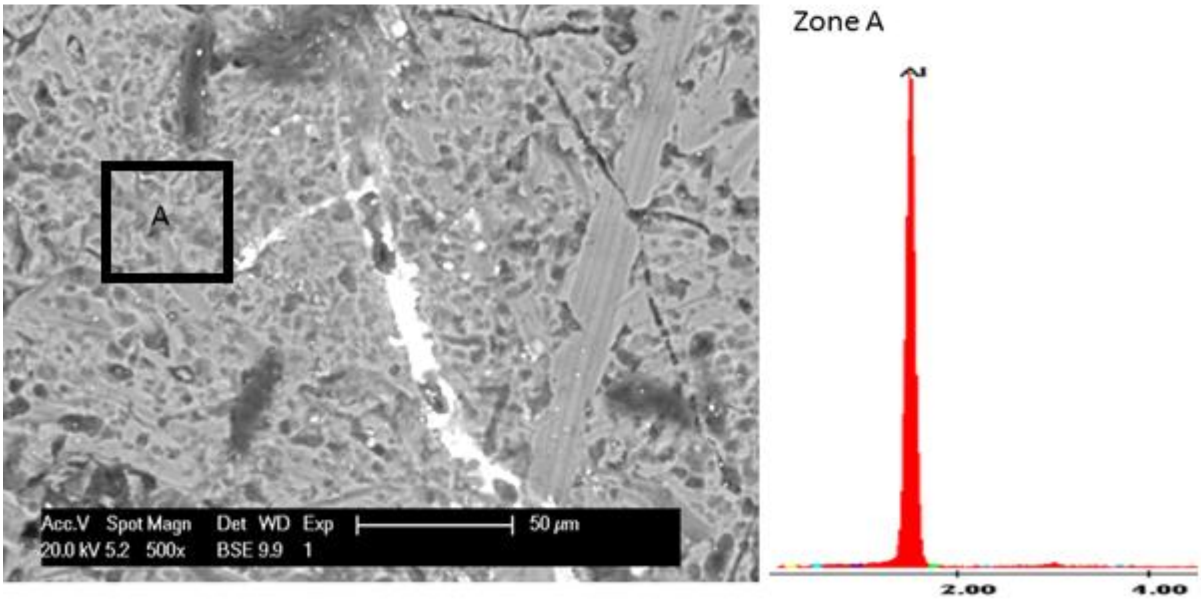

Figure 5. EDS spectra of morphology of microstructure of as-cast Al-2%Cd at the position A.

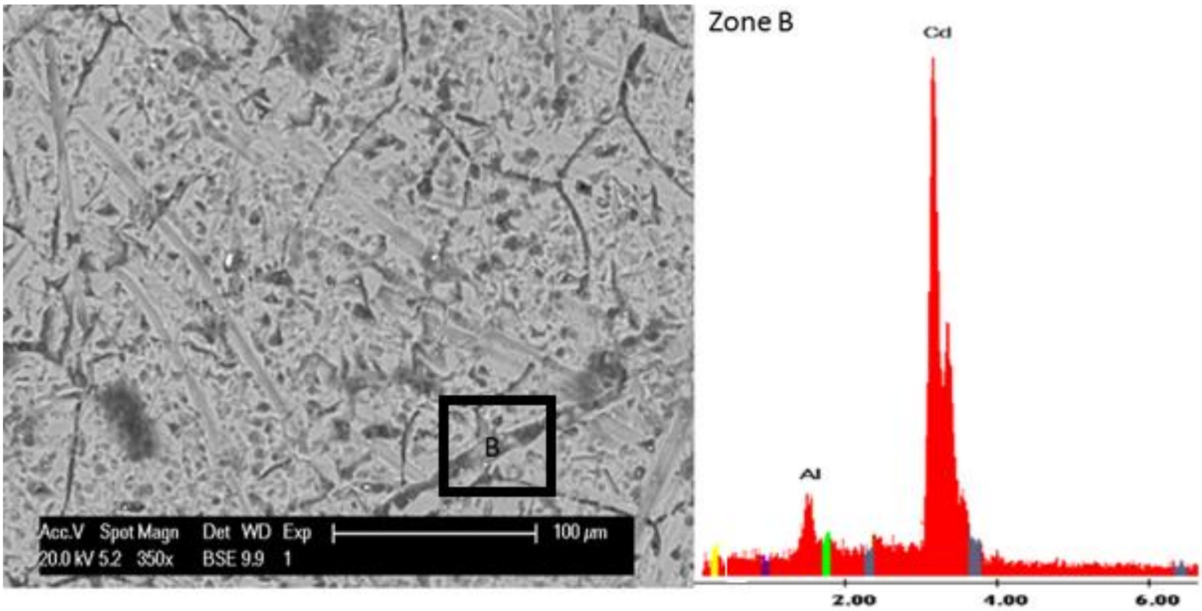

Figure 6. EDS spectra of morphology of microstructure of as-cast Al-2%Cd at the position B.

3.2. Hardness measurement of Al-2%Cd in the as-cast alloy

After quenching in cold water the series of microstructural transformation are manifested on the aging and over-aging of the alloys Al-1%Cd, Al-2%Cd, Al-3%Cd and Al-4%Cd until the equilibrium state of as cast alloys. Those transformations can be predicted from the hardness evolution, the remarkable changes in hardness are used as an index to confirm that the studded alloys are age-hardenable alloys.

Figure 7 show the hardness evolution of the as cast Al-2%Cd (wt %) alloy at room temperature. The initial hardness value is similar to pure aluminum hardness (45 HRF), indicating that the alloy don't have any transformation during solidification. After 100 min of aging, the hardness increases from 45 HRF to 46 HRF. This increase indicates the beginning of the formation of the GP zones. Then we observe a linear increase, and quite slow of hardness (46.5 HRF) after 42 h. After 10 days, we see a remarkable increase to maximum value of hardness 48,75HRF indicating the formation of a significant amount of GP zone during this period. The G.P. zones are found to be spherical and lead to a precipitate-free zone near grain/cell boundaries [9]. Then hardness decreases according to time to reach a value of 45, 5 HRF after 14 days. The drop in hardness explained by the dissolution of the GP zones and the formation of the phase of equilibrium during fairly slow cooling .Moreover, the aging kinetics is very slow unlike the kinetic over-aging which is very fast.

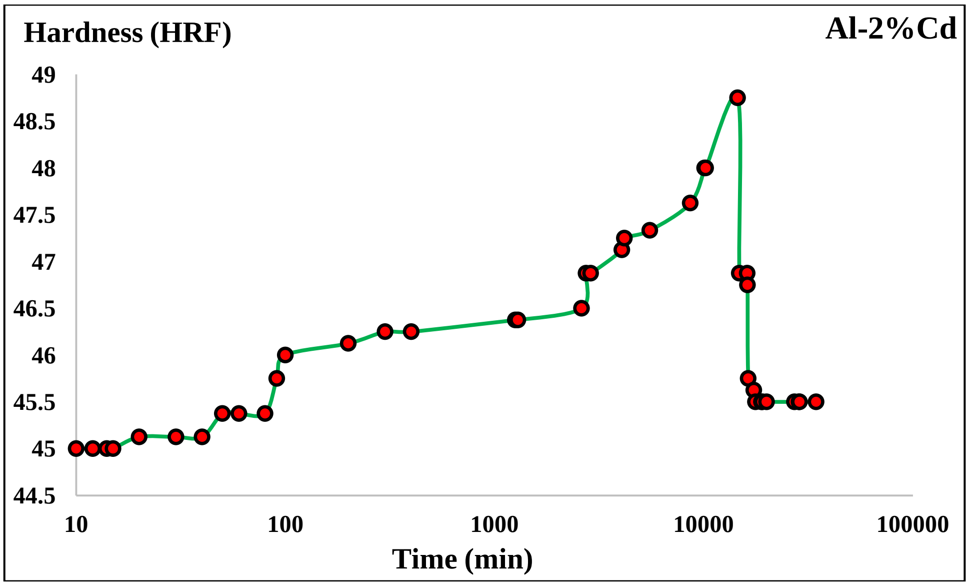

Figure 7. The hardness values of as-cast Al-2%Cd alloy.

3.3. Microstructure and mechanical properties of Al-Cd alloy with different Cd content

To study the effect of the Cd on the mechanisms of structural hardening of Al-Cd alloys, we worked on four different compositions: Al1%Cd, Al2%Cd, Al3%Cd and Al4%Cd. The evolution of the hardness is presented in Figure 8. This figure shows the plot of Rockwell hardness (HRF) vs. Cd content in the Al-Cd alloy at room temperature. The hardness of Al-1%Cd in the as-cast believes gradually and reaches a maximum value which is about 48 HRF after 7 days. After it, decreases quickly to reach value 45 HRF after 13 days of ageing. For Al-3%Cd in the as-cast, the hardness increases linearly and reaches the maximum value of 48.6 HRF after 6 days then it decreases quickly to reach the end value (45.125 HRF) after 14 days of ageing. For Al-4%Cd in the as-cast alloy, the maximum value of hardness 48 HRF is reached after 4 days. Then hardness decreases to reach 45 HRF after 14 days of ageing.

The increase in the hardness of the Al-1%Cd, Al-3%Cd and Al-4%Cd aluminium alloys to the maximum values 48HRF, 48,6HRF and 48HRF respectively can be explained by the formation of GP zones. And the drops in hardness explained by the dissolution of the GP zones and the formation of the phase of equilibrium during fairly slow cooling.

Shan et al. studied the effect of Cd addition on the microstructure and properties of Mg-Cd binary alloy and they noted that With the Cd content increasing, the mechanical properties of Mg-Cd magnesium alloy are improved accordingly [7].

By comparing the hardness variation of four alloys worked out with different compositions from Cd, we notices that a strong Cd concentration accelerates the kinetics of the reaction of hardening and increases hardness. Indeed, in the case of cadmium alloy strongly charged, maximum hardness 48 HRF is reached after only 4 days, contrary to Cd alloy slightly charged (Al2%Cd), maximum hardness is 48.75 HRF is reached after 10 days. And that is in arrangement whit the previous work reported by Shan et al.

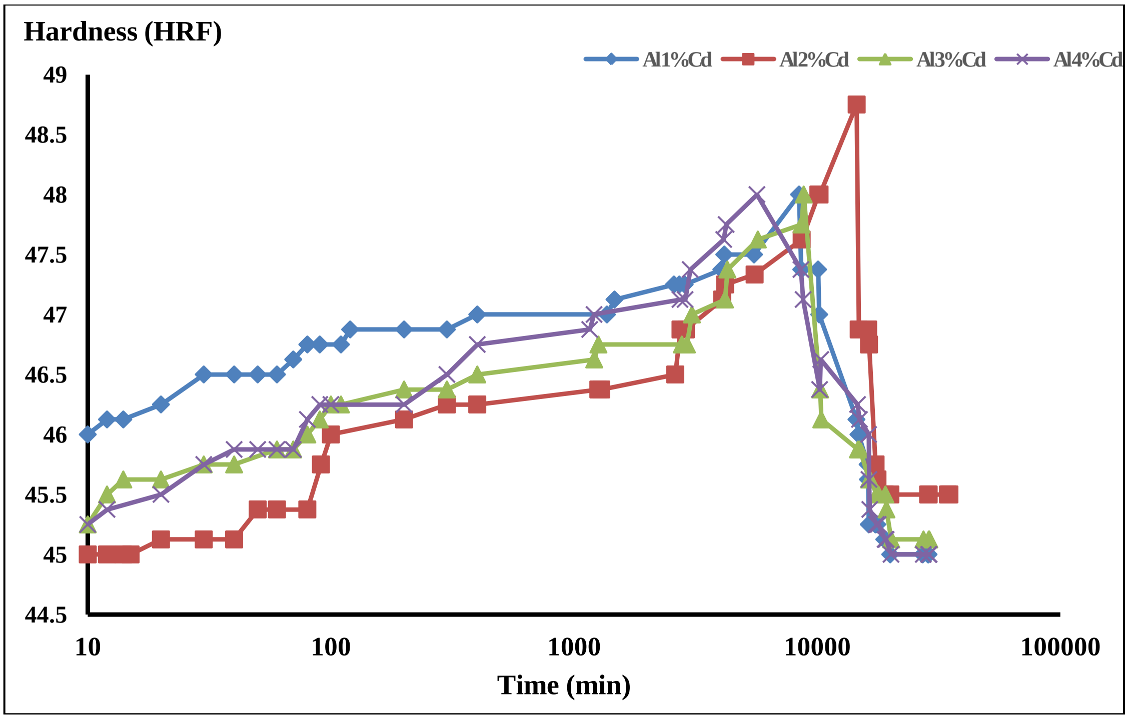

Figure 8. Hardness values of as-cast Al-1%Cd, Al-2%Cd, Al-3%Cd and Al-4%Cd alloys vs. time at room temperature.

Figure 9 shows the XRD pattern superposition of as-cast Al-1%Cd, Al-2%Cd, Al-3%Cd and Al-4%Cd alloys at room temperature. It can be observed that the microstructure of as-cast Al-1%Cd, Al-2%Cd, Al-3%Cd and Al-4%Cd alloys are single-phase currents of solid solution rich in Al. the most intense peak of all developed alloys is (111) located in the well-defined angular positions. The XRD revealed the presence of the one main phase α-Al of a crystalline structure CFC, and this finding is coincident with the Al-Cd phase diagram [8]. This results of XRD proves that there is no new phase for Al-1%Cd,Al-3%Cd and Al-4%Cd aluminium alloy.

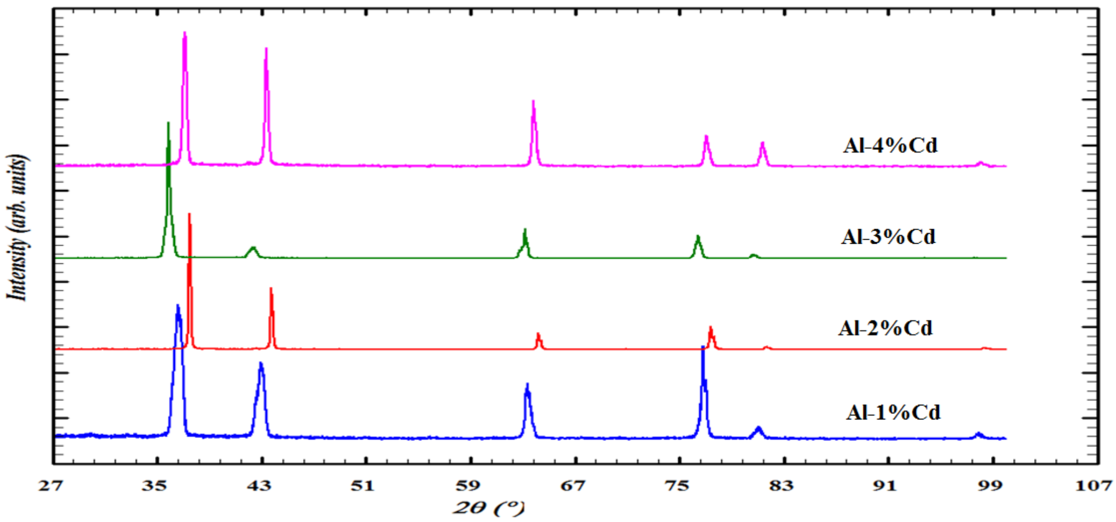

Figure 9. XRD pattern superposition of as-cast Al-1%Cd, Al-2%Cd, Al-3%Cd and Al-4%Cd alloys at room temperature.

Table 1 and Table 2 shows the variation of the crystallographic parameters of the worked alloys compared with the crystallographic parameter of aluminium in the as-cast.

Comparing the crystallographic parameters of the developed alloys: Al-1%Cd (a=0,418nm), Al-2%Cd (a=0,410nm), Al-3%Cd (a=0,417nm) and Al-4%Cd (a=0,412) with those of aluminium (a=0,4049nm) [11], we notice the expansion of the crystal lattice of the elaborate alloys. This is due to the conditions of development where fast solidification at room temperature acts by a fast crystallization of the surroundings of material towards its heart in fusion, subjecting the crystal lattice to constraints of external surfaces.

Table 1. Crystallographic parameters of as-cast Al-1%Cd and Al-2%Cd alloys.

As-cast Al [11] a=0,4049 nm		**Al-1%Cd**			**Al-2%Cd**		
hkl	**2θ**	**2θ**	**d (hkl)**	**a (nm)**	**2θ**	**d (hkl)**	**a (nm)**
(111)	38.92	36.50	2.46	4.26	37.41	2.40	0.415
(200)	45.16	43.005	2.11	4.22	43.68	2.07	0.414
(220)	65.48	63.186	1.48	4.17	64.30	1.45	0.410
(311)	78.52	76.72	1.24	4.10	77.36	1.23	0.407
(222)	82.76	80.97	1.18	4.08	81.64	1.18	0.408
(400)	99.32	91.813	1.07	4.28	98.38	1.02	0.408
Parametera (nm)		0.418			0.410		
Volume (nm^3)		0.07303			0.06892		

Table 2. Crystallographic parameters of as-cast Al-3%Cd and Al-4%Cd alloys.

As-cast Al [11] a=0.4049 nm		**Al-3%Cd**			**Al-4%Cd**		
hkl	**2θ**	**2θ**	**d (hkl)**	**a (nm)**	**2θ**	**d (hkl)**	**a (nm)**
(111)	38.92	35.83	2.50	0.433	37.03	2.42	0.42
(200)	45.16	42.34	2.13	0.426	43.27	2.09	0.418
(220)	65.48	63.2	1.47	0.414	63.98	1.45	0.409
(311)	78.52	76.46	1.245	0.412	77	1.237	0.41
(222)	82.76	80.71	1.185	0.410	81.37	1.18	0.408
(400)	99.32	97.6	1.02	0.408	97.97	1.02	0.408
Parametera (nm)		0.417			0.412		
Volume (nm^3)		0.07251			0.06993		

Figures 10-12 show the optical microstructure of as-cast Al-1%Cd. Al-3%Cd and Al-4%Cd alloys at room temperature. It can be observed that the microstructures of as-cast Al-1%Cd. Al-3%Cd and Al-4%Cd alloys are similar with the microstructure of as-cast Al-2%Cd alloy. The structure is homogeneously distributed over the matrix of aluminium. The α-Al is gradually refined and distributed with uniform small grains. The microstructures are equiaxed.

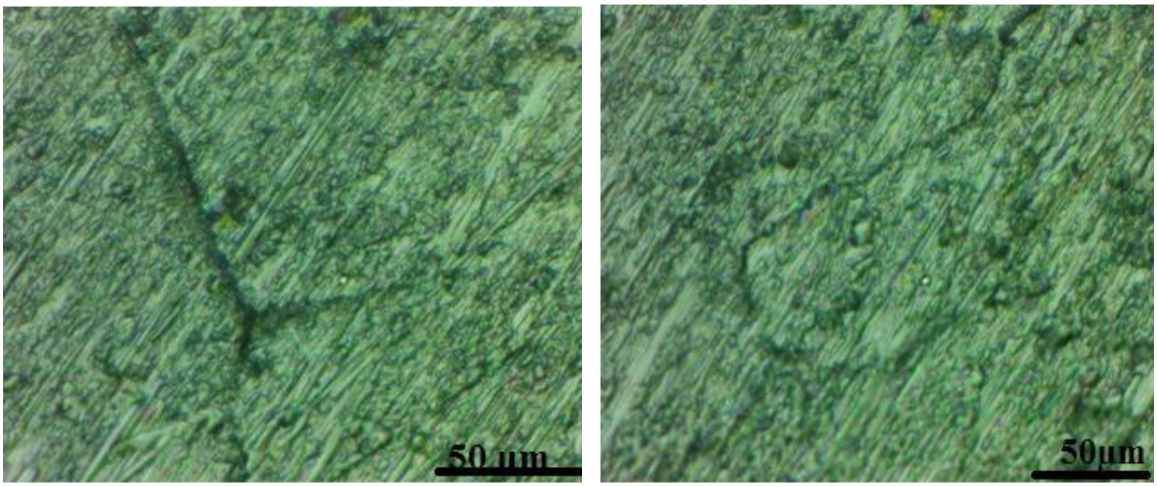

Figure 10. Optical microstructure of as-cast Al-1%Cd.

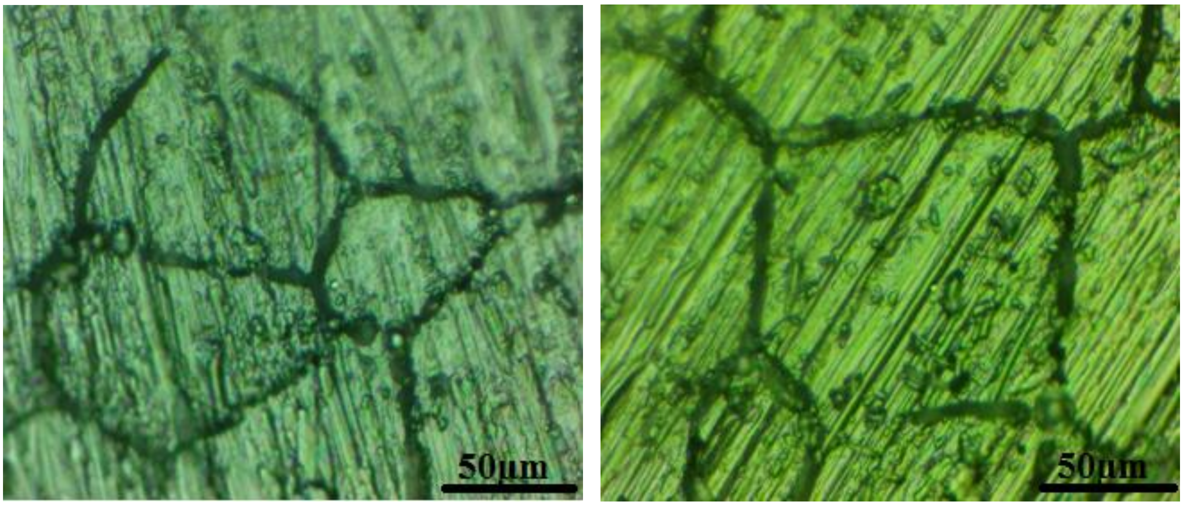

Figure 11. Optical microstructure of as-cast Al-3%Cd.

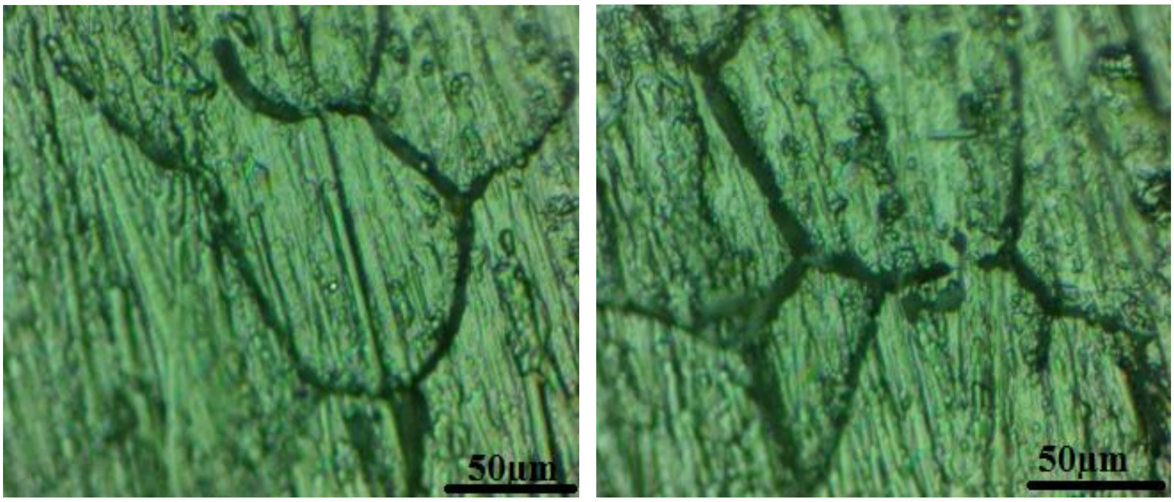

Figure 12. Optical microstructure of as-cast Al-4%Cd.

4. CONCLUSION

The mechanical properties and microstructure of as-cast Al-1%Cd. Al-2%Cd. Al-3%Cd and Al-4%Cd alloys were investigated. The significant results and conclusions of the present work are as follows: the mechanical test of hardness confirmed that he studdied alloys are age-hardenable alloys explained by the evolution of the hardness with time. The as-cast Al-2%Cd alloy present the mechanical properties improved relative to other object of this study; the XRD show that the microstructures of four studied alloys are single-phase of solid solution CFC rich in Al. Cd can completely solid dissolves into Al-Cd aluminium alloy. It forms neither new phase; the observation of optical microscope and EDS shows that the microstructures of as-cast Al-1%Cd. Al-2%Cd. Al-3%Cd and Al-4%Cd alloys are singular with only one phase which is the phase solid solution CFC Al. reveals that the texture of surface is homogeneous with regular distribution of dense grains. The structures are equiaxed.

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