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Comprehensive Study for Impure and Pure Casts of Aluminum and Copper

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Abstract: Impure and pure casts have collected reasonable attentions over all the world. In this paper, Aluminum (Al) and Copper (Cu) cast alloys are considered to be studied. Multiple impure and pure Al-Cu cast alloys are established under the condition of very high temperatures. Then, all of the established alloys are examined by applying mechanical tests. More specifically, tests of hardness are exploited. Moreover, different quenching conditions are employed and analyzed. These are the water, air and oil. Consistent results are separately obtained for the impure and pure materials.

Key words: Casts, Aluminum, Copper, Mechanical Tests

1. Introduction

Cast alloys are essential materials that can be used in many fields. For example, manufacturing cars, trains, airplanes and trunks. A cast alloy refers to a mixed metal between two or more elements, where various ratios of elements are melted and combined to produce the certain alloy. The resulted cast alloy has different specifications that are completely different from essential characteristics of each component element. The cast alloys can be made by a combination between two or more elements of Aluminium (Al), Copper (Cu), Zinc (Zn), Magnesium (Mg), Manganese (Mn), Silicon (Si) and others [1]. Fig. 1 shows examples of various cast alloys.

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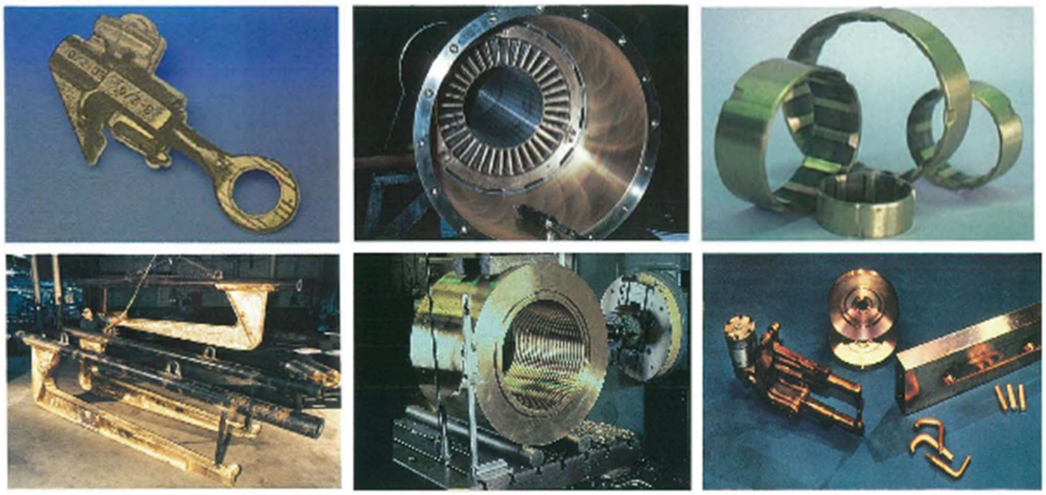

Figure 1: Examples of various cast alloys as provided in [2]

Al is reported as one of the most important elements. It abundant metal in the earth where it constructs about 8% of weighted solid earth surface. It generally uses in many purposes due to its weight ratio, good corrosion resistance, low density, good formability, high strength stiffness and recycling potential [3]. It has a Face Center Cubic (FCC) crystal structure and its ductility is taken at a very low temperature of approximately 660°C (or 1120° F) [4][5]. The Cu element is the most common series element. Its importance directly comes after the elements of gold, silver and platinum. It also has the same FCC crystal structure of Al and it is melted in 1080°C [2][6].

Combining between the Al and Cu can provide such interesting cast alloys. That is, their cast alloys may have significant mechanical properties such as hardness and high strength, and good machinability [7]. They are used in some important manufacturer such as bus bodies, beverage cans and automotive parts [1]. Al-Cu chain alloys can be utilized for the machine parts, aircraft materials and structural materials. Significant characteristics of high damage tolerance, high strength to weight ratio, cutting properties and good fatigue resistance are resulted [6].

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The aim of this paper is preparing cast alloys of impure and pure Al-Cu. Then, testing some important mechanical properties such as hardness. The advantages of this work can be exploited in very critical industries, for instance, manufacturing ships and airplanes.

The remaining sections after the introduction are organized as follows: Section 2 provides the related literature review, Section 3 illustrates the theoretical part of this study, Section 4 demonstrates the practical results and Section 5 clarifies the conclusion.

2. Related Literature Review

Many studies were presented for the Al-Cu cast alloys. In 2006, Wang *et al.* introduced a work for the Al-Cu-Mg alloys. Precipitation hardening was employed to be investigated. Differential Scanning Calorimetry (DSC) and Transmission Electron Microscopy (TEM) were applied [8]. In 2008, An *et al.* studied the utilizable ductility and high strength for the bulk ultrafine-grained of Cu–Al alloys. It was clarified that for providing engineering materials with high perfect ductility and strength hardness could be considered as a continuous challenging task for material scientists to satisfy different structural purposes [9]. In 2010, Min *et al.* explored the influence of returning the mechanical and microstructure characteristics of Al-Cu alloys. Conditions of heating and casting treatments were concentrated in order to attain the returns optimum quantity which might be added to the Al-Cu alloys [10]. In 2011, An *et al.* described the effects on the mechanical characteristics, by focusing on the Stacking Fault Energy (SFE). Nanostructured Cu and Cu–Al alloys were treated under a high-pressure condition [11]. In 2012, Hao *et al.* provided a work on the SFE. Compression Testing effects were considered for the Cu and Cu-Al Alloys. Deformation of twinning Cu-Al alloys was

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studied. Furthermore, the SFE plasticity, dynamic recovery and strength were analyzed for the Cu-Al alloys [12]. In the same year, Ayoola *et al.* investigated the influence of casting mould. Al alloy for the type of 6063 was utilized. Multiple mechanical characteristics were exploited such as metal mould, naturally-bonded sand mould and cement-bonded sand mould [13]. In 2016, Belov *et al.* presented theoretical and practical work for a range of Al alloys. Group of elements were used, these are the Al, Cu, Si and Tin (Sn). So, the Al and Cu alloys were parts of this study [14]. In the same year, Madhusudan *et al.* concentrated on the mechanical characteristics of Al and Cu elements. They both were taken as Composite Metallic Materials (CMMs). Hardness, microstructures and changing the Cu concentrations were carried out for the Al-Cu alloys [15]. In 2017, Stošića *et al.* utilized three elements of Al, Cu and Zn in alloys. Thermal and composition and treatments were provided. Shape-memory characteristics was analyzed [16]. In the same year, Bansal *et al.* exploited three elements of Al, Cu and Mg. Characterization and Synthesis of Al-Cu-Mg alloys were illustrated. Aging and deformation influences were studied on the characteristics of employed alloys [17]. In 2018, Bozorgi and Anders used cast alloys of the elements Al, Cu and Si. Mechanical characteristics were undertaken for the high Cu at elevated temperature. The Al-Cu-Si alloys were examined without including other expensive element such as Cerium (Ce), Cobalt (Co) and Silver (Ag) [18]. In 2019, Su and Young work with the material characteristics of high strength and normal Al alloys. Al alloys for the types of 6063-T5 and 6061-T6 were employed. Elevated temperatures were applied [19]. In the same year, Wang *et al.* considered multiple observations for a specific Al–Cu–Zn–Mg alloy. These observations are for the mechanical characteristics, corrosion manner and microstructure. Non-Isothermal Ageing (NIA) treatment was adopted [7]. In 2020, Soni and Mandloi explained tribological and mechanical properties of artificial age. The Al-Zn-Mg-Cu alloy was concentrated. Various aging temperatures were examined with the precipitation kinetics to enhance the tribological and mechanical characteristics. That is, over aging, optimum aging, under aging and pre aging were used [20]. Also in the same year, Puga illustrated forming and casting of advanced Al alloys. It has been highlighted that the competitiveness and quality of a casting are strongly based on the technique that is used to generate it and quality of the molten alloy. Furthermore, it has been cited that casting the Al alloy is a difficult process as it is prone to heterogeneous and dendritic structures, in addition to the hydrogen absorption during melting [21].

From the literature it can be noticed that many work were applied for Al alloys, as well as, for Cu alloys. However, they are still requiring more investigations. In this paper, comprehensive study is provided for impure and pure Al-Cu cast alloys by establishing many samples and applying effective treatments.

3. Theoretical Part

In this work, extensive processes are considered, each of which has reasonable theory. Fig. 2 shows the general block diagram of these extensive processes.

It consists of multiple steps. Firstly, collecting the materials of Al and Cu in their two categories: impure and pure. The impure Al and Cu have been acquired from recycled and wasted materials, this may benefits in recycling and cleaning environment. On the other hand, the pure AL and Cu have been purchased as Al saturation of 98% and Cu saturation of 99%. Secondly, grouping both the Al and Cu into two groups of impure and pure, where each group is separately processed. Thirdly, changing percentages of weights are applied for the Al and Cu. Table 1 shows the prepared weights and ratios for the

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impure Al and Cu. Whereas, Table 2 provides the employed weights and ratios for the pure Al and Cu.

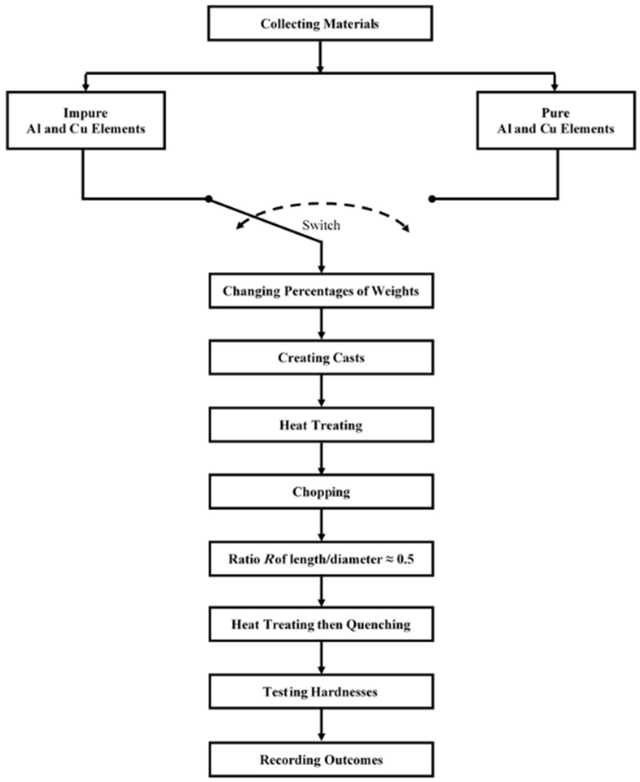

Figure 2: The general block diagram of the applied extensive processes

Table 1: The prepared weights and ratios for the impure Al and Cu

Index	Al(gm)	Cu(gm)	Al(%)	Cu(%)
1	15	10	60	40
2	16.25	8.75	65	35
3	16.75	8.25	67	33
4	17.5	7.5	70	30
5	18.75	6.25	75	25
6	25	0	100	0
7	0	25	0	100

Table 2: The employed weights and ratios for the pure Al and Cu

Index	Al(gm)	Cu(gm)	Al(%)	Cu(%)
1	15	10	60	40
2	16.25	8.75	65	35
3	16.75	8.25	67	33
4	17.5	7.5	70	30
5	18.75	6.25	75	25
6	25	0	100	0

4. Fourthly, establishing multiple cast alloys between the Al and Cu according to the exploited weight ratios that are given in Tables 1 and 2. Each cast alloy has been prepared by applying very high temperature to melt the Al and Cu. With more illustration, the Cu has been melted under the high temperature in a gas furnace, then, the Al has been added and mixed to the Cu in the same gas furnace. So, both are melted and carefully mixed together until being homogenous where a cast alloy of Al-Cu is finally established. These processes have been repeated many times where different cast alloys of Al-Cu are acquired. Fifthly, the cast alloys are treated by heating inside an electric furnace to operate concretions. Consequently, the cast alloys are stayed inside the electric furnace after turning it off for about one day. Sixthly, acquired cast alloys are chopped. Seventhly, a cutting ratio (*R*) is considered by rubbing each cast alloy, where: *R* is define as length divided by diameter. In this study, the cutting ratio is taken as *R*≈0.5. Eighthly, heat treating is used once more again for the cast alloys inside the electric furnace (with 1 hour at 500°C) to examine different quenching conditions. Subsequently, treated cast alloys are quenched by oil, water or air. Ninthly, the measurements of hardness are applied. Hardness measurement method of Vickers Hardness (HV) is utilized according to the following equation [22]:

$$\boldsymbol{HV_N = \frac{2\,P\,sin(\frac{\emptyset}{2})}{D_{mean}^2} = 1.854\,\frac{P}{D_{mean}^2}} \quad (1)$$

where: HV_N is the HV measurement for *N* number, *P* is the load in (Kg), Ø=136º, $sin\left(\frac{\emptyset}{2}\right)$=0.927 and D_{mean}^2 is the squared average between the length and width of pressured diamond head.

Furthermore, additional hardness measurements are computed. These are the Hardness Brunel (HB) and Tensile Strength (TS). HB measurement has been collected from the Hardness Conversion Table (HCT) [22]. TS measurement can simply be calculated as follows [22]:

$$TS_N = 3.45 \times HB_N \quad (2)$$

where: TS_N is the TS measurement for N number and HB_N is the H.B measurement for N number.

It is worth mentioning that the eutectic point, two nearest points around it and two far points of hypoeutectoid and hypereutectoid have been considered in this study. The eutectic point is defined as a smallest measured point that refers to easy melt of casted elements. Furthermore, the hypoeutectoid and hypereutectoid points are denoted as the measured points which positioned in locations less and high than the eutectic point, respectively [22].

Finally, outcomes of the employed measurements for established cast alloys are recorded and compared.

4. Practical Part with Discussions

First of all, multiple Al-Cu cast alloys have been established. In each alloy a Cu was firstly melted under very high temperatures by using a gas furnace. Consequently, the Al was secondly added to the melted Cu in the same gas furnace. So, the Al was gradually melted too. Both were carefully mixed by using a rod of Carbon (C). Then, the mixed liquid was spilled into a mold of steel and concreted. These processes were repeated many times where 13 samples of Al-Cu cast alloys have been created.

The established samples are divided into two main groups (impure and pure). The impure group consists of 7 samples for various Al and Cu percentages of weights[(1)]. On the other hand, the pure group consists of 6 samples for various Al and Cu percentages of weights too. The prepared weights and ratios for the impure Al and Cu are given in Table 1. Whilst, the prepared weights and ratios for the pure Al and Cu are given in Table 2.

The created cast alloys have been treated by heating for the 1st time in order to operate recrystallization, where an electric furnace was used. The established cast alloys were spent an 1 hour at high temperature of 500°C. Subsequently, the electric furnace was turned off and the cast alloys were left inside for around 24 hours. Then, the established cast alloys have been chopped with a R of rubbing that approximately equal to 0.5. Each sample has been carefully covered and labeled. Fig. 3 shows examples of these samples.

Heat treating has been applied for the 2nd time in order to examine different quenching conditions, where the same electric furnace was utilized. Similar time and temperature treatments (1 hour at 500°C) were employed. The difference between the 1st and 2nd times of heat treating is that the 2nd time did not consider leaving the created cast alloys inside the electric furnace for about 24 hours. However, they are quenched by oil, water or air.

Hence, the hardness has been measured for all the established cast alloys. More specifically, the hardness measurements of HV, HB and TS have been applied. For evaluating the HV, the WOLPERT device of type (V-Testor 2) with P=1Kg and Equation (1) have been exploited. For assessing the HB, the HCT [22] has been utilized. For computing the TS, Equation (2) has been employed. Tables 3 and 4 show the details and measurements of the Al-Cu cast alloys for both impure and pure groups, respectively.

[(1)] Weight Percentage (wt%) can be converted to Atomic weight Percentage (At%).

Figs. 4 and 5 demonstrate relationships between the HV measurements and Cu wights(100-Al wights) with the different quench types of the Al-Cu cast alloys for both impure and pure groups, respectively.

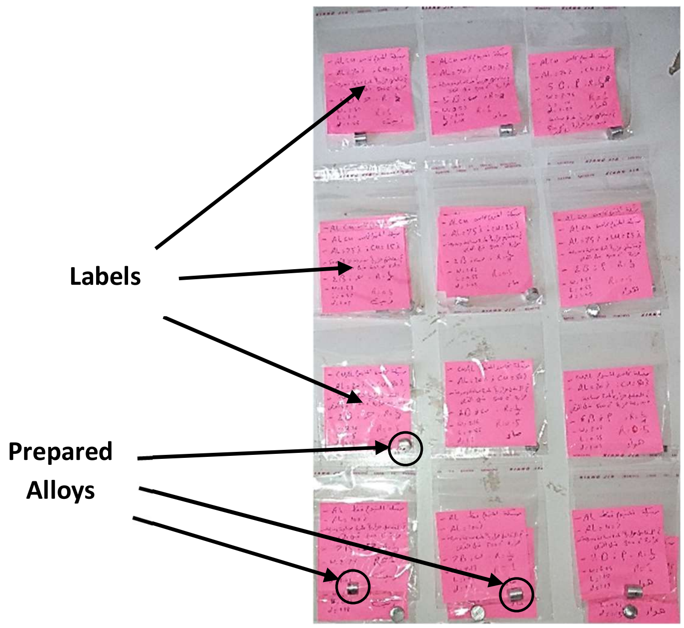

Figure 3: Examples of the established cast alloys, where each sample has been carefully covered and labeled

It can be seen that five main points have been assigned in this work, as mentioned. These are the eutectic point, two near points around it and two far points of hypoeutectoid and hypereutectoid.

First of all, the measured HV, HB and TS values for the impure cast alloys are more fluctuated than the pure cast alloys. This is due to the effects of other embedded elements in the impure cast alloys.

Reasonable outcomes can be observed from Table 3 and Fig. 4. That is, in all samples of the Al-Cu cast alloys impure group for the HV measurements to all quenched conditions, the eutectic point is located in the value when Cu weight is equal to 33%. The hardness

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in this point can be considered as very low in all the measured cases. For the point that is positioned near from the eutectic in the value when Cu weight is equal to 30%, the hardness in this point has attained the highest HV in all the measured cases. Likewise, these results are consistent with other employed measurements of HB and TS as shown in Table 3.

Interested outcomes can be investigated from Table 4 and Fig. 5. To illustrate, in all samples of the Al-Cu cast alloys pure group for the HV measurements to all quenched conditions, the eutectic point (when Cu weight is equal to 33%) or a point near from it (when Cu weight is equal to 35%) has obtained the highest HV. For the hypoeutectoid point that is positioned far from the eutectic in the value when Cu weight is equal to 0% and Al weight is equal to 100%, the hardness in this point has attained the lowest HV in all the measured cases. Similarly, these results are consistent with other employed measurements of HB and TS as shown in Table 4.

The main difference between the impure and pure performance is that in the impure measurements the eutectic points have achieved low HV, HB and TS evaluations, whilst, in the pure measurements the eutectic points have achieved high HV, HB and TS evaluations. This is reasonable as the performances of impure cast alloys are affected by other embedded elements. The results of pure measurements can be used as standards because no other embedded elements could influence the performances.

Table 3: Details and measurements of the Al-Cu cast alloys impure group

Quench Type	Al(%)	Cu(%)	D_{mean}(mm)	Measurements		
				HV(Kg/mm2)	HB(Kg/mm2)	TS(Mpa)
Air	60	40	0.085	256.6	244.28	842.76
Oil	60	40	0.083	269.1	255.28	880.716
Water	60	40	0.08	289.6	274.6	947.37
Air	65	35	0.088	239.4	227.4	784.737
Oil	65	35	0.083	269.1	255.2	880.7
Water	65	35	0.08	289.6	274.6	947.37
Air	67	33	0.158	74.2	---	---
Oil	67	33	0.15	82.4	---	---
Water	67	33	0.145	88.18	84.1	290.4
Air	70	30	0.077	312.7	296.4	1022.6
Oil	70	30	0.075	329.6	312.6	1078.4
Water	70	30	0.072	357.6	338.6	1168.4
Air	75	25	0.1	185.4	176.4	608.5
Oil	75	25	0.095	205.4	195.4	674.1
Water	75	25	0.09	228.8	217.8	751.4
Air	100	0	0.122	124.5	118.5	408.8
Oil	100	0	0.25	29.66	---	---
Water	100	0	0.114	142.6	135.6	467.8
Air	0	100	0.153	79.2	---	---
Oil	0	100	0.122	147.7	140.7	485.4
Water	0	100	0.11	153.2	145.8	503.01

Table 4: Details and measurements of the Al-Cu cast alloys pure group

Quench Type	Al(%)	Cu(%)	D_{mean}(mm)	Measurements		
				HV(Kg/mm2)	HB(Kg/mm2)	TS(Mpa)
Air	60	40	0.105	168.1	160.1	552.3
Oil	60	40	0.099	189.1	180.1	621.5
Water	60	40	0.095	205.4	195.4	674.1
Air	65	35	0.1	185.4	176.4	608.5
Oil	65	35	0.085	256.6	244.2	842.7
Water	65	35	0.077	312.7	296.4	1022.6
Air	67	33	0.091	223.8	212.8	734.4
Oil	67	33	0.089	234.06	222.6	768.1
Water	67	33	0.085	256.6	244.2	842.7
Air	70	30	0.097	197	187.3	646.1
Oil	70	30	0.095	205.4	195.4	674.1
Water	70	30	0.093	214.3	203.9	703.5
Air	75	25	0.104	171.4	163.2	563.2
Oil	75	25	0.1	185.4	176.4	608.5
Water	75	25	0.098	193	183.7	633.7
Air	100	0	0.32	18.1	---	---
Oil	100	0	0.215	40.1	---	---
Water	100	0	0.2	46.3	---	---

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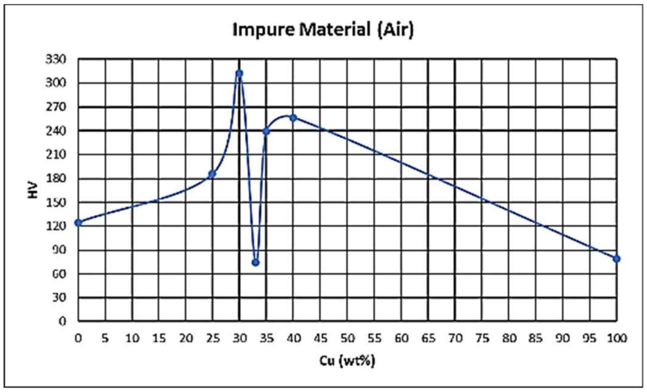
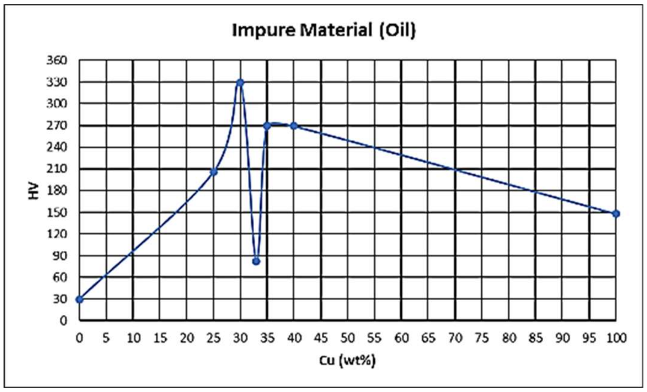


(a)



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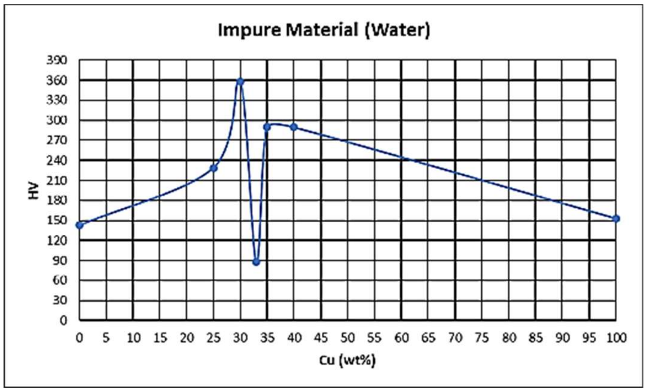

(c)

Figure 4: Relationships of the Al-Cu cast alloys impure group between the HV measurements and Cu wights(100-Al wights) for the quench type (a) air, (b) oil, and (c) water

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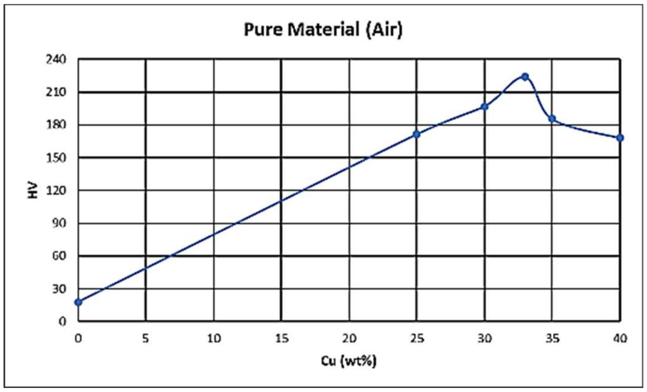

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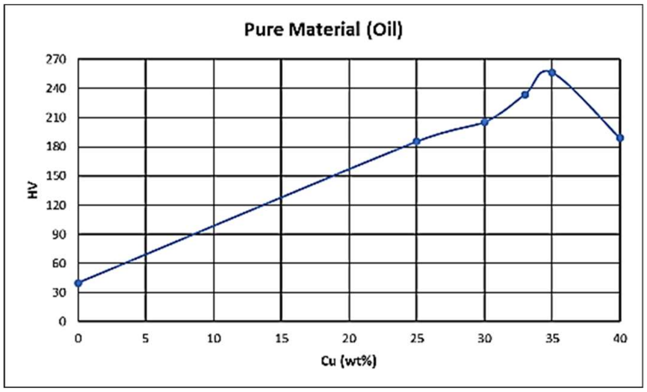

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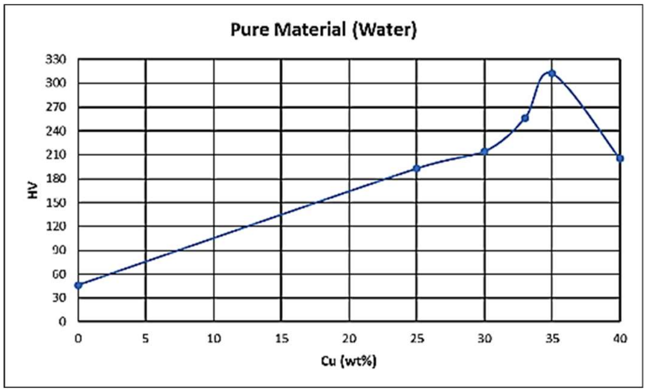

(c)

Figure 5: Relationships of the Al-Cu cast alloys pure group between the HV measurements and Cu wights(100-Al wights) for the quench type (a) air, (b) oil, and (c) water

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Another main issue that is worth to be highlighted is that the impure cast alloys are less affected by the quenched conditions of air, oil and water than the pure cast alloys. This is also expectable because the pure cast alloys are sensible to the quenched conditions. However, the influences of different quenched conditions to the pure cast alloys are slight not significant. With more explanation, the highest measurement value is when Cu weight equal to 33% after quenching by air and it is when Cu weight equal to 35% after quenching by the other conditions (oil and water). This is due to the sensitivity of pure cast alloys to the different quenched conditions, where using air provides slow quenching time than oil and water.

The suggested processing steps in this paper can be considered to be worthy as other suggested processing steps in [23-83].

5. Conclusions

This paper offered a comprehensive study for impure and pure casts of Al and Cu. It consisted of multiple steps, these are: collecting Al and Cu materials, grouping them into impure and pure, changing percentages of mixed Al and Cu weights, establishing multiple Al-Cu cast alloys, treating them by heating inside an electric furnace, chopping the cast alloys, repeating the heat treatments followed by quenching with various conditions (oil, water or air), applying effective measurements (HV, HB and TS) and considering multiple essential points (eutectic point, two nearest points around it and two far points of hypoeutectoid and hypereutectoid), and extensively discussing and comparing the essential outcomes.

First of all, the measured HV, HB and ST values for the pure cast alloys are more smoother than the impure cast alloys. This is because of the influencing of other embedded elements in the impure cast alloys.

The results were attained such promises, reasonable and interesting outcomes. The HV, HB and ST measurements yielded that the eutectic point has obtained very low values and the point which is located near from the eutectic has achieved very high values for the Al-Cu cast alloys impure group in all quenched conditions. On the other hand, the same employed measurements exhibited that the eutectic or a point near from it has obtained very high values and the hypoeutectoid point which is located far from the eutectic has achieved very high values for the Al-Cu cast alloys pure group in all quenched conditions.

The contradictory between the performances of impure and pure cast alloys can be explained. The impure cast alloys are influenced by other embedded elements, whereas, the pure cast alloys are not affected by such elements. Moreover, the pure cast alloys are more sensible to the quenched conditions of air, oil and water than the impure cast alloys.

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