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Investigation of Multi-Cold Rolling Passes on Mechanical Characteristics and Surface Quality of AlCuV

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ABSTRACT

In this study, the effect of rolling angle orientation namely; 0°, 45°, and 90° degrees, and three rolling passes on the mechanical behavior of Al-Cu after vanadium addition were investigated. Al-4%Cu and Al-4%Cu-0.1%V sheets were produced and rolled from 4 mm to 3 mm followed by 3 to 2 mm, and finally from 2 mm to 1.3 mm. After each pass, the tensile test was performed in three directions from which the maximum tensile force, deformation energy, microhardness, and average surface roughness (Ra) were determined. A pronounce finding is that the addition of both additions of 0.1% vanadium to Al-4%Cu alloy and multi-rolling passes resulted in reducing the deformation energy by 85.4, and the maximum tensile forces reduced by 56.6%, this resulted in reduction of production cost of AlCuV alloys, furthermore, it resulted in reducing the anisotropy of AlCuV alloy. Additionally, the average microhardness was enhanced for Al-Cu and AlCuV alloy, whereas the Ra was in maximum enhanced for AlCuV alloy of about 64.9%.

Keywords: materials processing; surface roughness; rolling passes; angle orientation; vanadium; copper.

INTRODUCTION

Rout demonstrates that the rolling process is a bulk metal forming process, where metal flows plastically between two rollers, rotating in opposite directions, by which the thickness is reduced and there is an enhancement in the properties of materials such as toughness, strength, and surface morphology. Rolling is the most widely used forming process, which produces products such as plate, billet, bloom, slab, strip, and sheet, [1]. Nwachukwu Revealed that the mechanical properties of St60Mn steel were affected by rolling process parameters; rolling strain rate, % total deformation, and finish rolling temperature, the optimum occurred at $6.10388 \cdot 10^3$ s^{-1} strain rate, 99% total deformations, and finish rolling temperature of 958 °C [2]. Rout demonstrates to increase the followability of the metal during rolling, working at high temperature is preferable, as this will reduce the needed loads. In a study of high-temperature effects on metal microstructure, [1]. Zhao investigated the effects of heating rate on the hardness and microstructure of Al-Cu and Al-Cu-Zr-Ti-V alloys they reported that as the heating rate change the microstructure and microhardness of both alloys can be controlled, [3]. Rout reported just only in the last two decades a lot of research work has been performed on the change in the direction of rolling during rolling, [1]. Najib discussed the effect of three different angles (0°, 45°, and 90°) on the tensile properties of aluminum alloy AA5083 dog-bone specimens, they reported that as the angle of orientation increases UTS will be increased. Furthermore, they find that as the work hardening increase the ductility will be increased, [4]. Medjahed Observed the tensile properties along the various tensile angles were influenced by an Al-Cu-Li-Mg-X alloy as an effect of changing the rolling direction, [5]. Also, Wang for Mg-5Li-1Al-0.5Y alloy reported that the change in rolling directions will refine the grains, [6]. Tu revealed that the rolling speed from 0.1 to 0.4 m/s affects the mechanical properties of AZ31 magnesium alloy sheets at 550 °C and after annealing and resulted that the processed AZ31 sheets exhibiting rolling direction increasing the rolling speed, [7]. On the other hand, Radhi and Jabur showed that the increase in roller diameter results in decreasing the rolling process time, also it has a significant effect on the effective friction coefficient (EFC) than roller speed, [8]. (Mei studied the tensile results after Al-Mg-Si alloys with and without pre-aging treatment were subjected to cryo-rolling, warm rolling, and subsequent aging and they found that the strength and ductility of the cryo-rolled alloy were simultaneously enhanced, [9]. (Wang found that the shape of the grains is elongated along the rolling direction after the cold rolling of AA 5052 aluminum alloy. Additionally, when cold rolling was applied on AA2519 alloy, [10]. Zuiko and Kaibyshev demonstrated that the density of lattice dislocations increases by a factor of 100 and cell structure evolves after a 40% reduction, [11]. Rao conduct a study of the cryo-rolling effect followed by warm rolling (CR+WR) on the strength and ductility of Al-Mg-Si alloys was conducted and resulted in simultaneous improvement in strength (290 MPa) and ductility (15%) in Al 6063 alloys, [12]. Magalhaes presented results from the effects on the microstructure and mechanical strength of AA1050 Al alloy, pure Cu, and Cu-15Zn alloy being processed by cryogenic rolling up to a true strain (ε) equal to 2.5, [13]. Zuiko reported that aluminum alloys are attractive in transportation applications due to their strength-to-weight ratio, formability, and high corrosion resistance, [14]. Shafiei and Dehghani revealed that the force of rolling increases as the radius of the roll increase and the coefficient of friction is also increased, [14]. Mandal and Mitra studied the mushy state, rolling transforms the rosette-shaped microstructure of the as-cast in situ composites (Al-4.5wt. %Cu-5wt. %TiB2) into a gradient microstructure, an increase in microhardness and Dynamic recrystallization appears, [15]. Huo reported another effect on the hardness, average surface roughness, and microstructure, [16]. Also, Zou proved that Cu-1.6Ni-1.2Co-0.65Si-0.1V alloy obtains excellent combination properties including electrical conductivity, hardness, and tensile strength which are produced by the addition of vanadium (V), [17]. Machinery parts will be affected by some degrees of impact, friction, wear or corrosion in their working process. Especially under the action of long-term alternating load, fatigue failure of parts will occur, which will not only reduces mechanical efficiency but also increase power consumption and shorten service life of mechanical equipment [18–20]. Li [21] thought that cold deformation helped to reduce the activation energy of the second precipitation for the subsequent aging and to improve microstructure and mechanical properties of Al–Cu-(Mg) alloy.

In this study the main aim is to investigate the influence of rolling angles namely; 0^o, 45^o, 90^o, and three rolling passes on the maximum tensile force, deformation energy, microhardness, and the average surface roughness (Ra) of AlCuV alloy, where the rolling directions are shown in Fig. 1 below.

MATERIALS AND METHODS

Materials

A set of metallic materials used in this study are presented in Table 1, where the chemical composition of the pure aluminum is; 0.09% Fe, 0.05% Si, 0.005% Cu, 0.004 Mg, 0.004% Ti, 0.008% V, 0.005% Zn, 0.001% Mn, 0.005% Na, and the reset is Al.

Equipment

In this work, different machines and instruments were used namely; an Electric resistance furnace(Nabertherm) with 0-1750 °C, a Microhardness tester (Falcon 400), an Instron machine of 100 KN capacity (Quasar 100), a NIKON 108 microscope, CNC milling machine

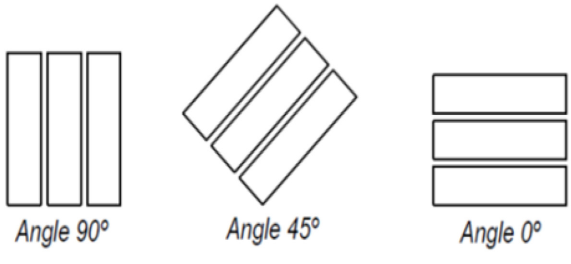

Fig. 1. Rolling directions schemes

Table 1. Main specifications of used materials in this study

Material	Purity (%)	Density (gm/cm³)	Melting point °C	Crystal structure
Aluminum	99.85	2.82	659	FCC
Copper	99.99	8.96	1085	FCC
Vanadium	99.80	9.11	1910	BCC

(Excel type) was used to prepare the sheet metal before the rolling process, A surface roughness tester was used to determine the average surface roughness (Ra) based on cut-off distance = 0.8 mm and ISO 13565 (Rk) and a sample of the test is shown in Appendix Figure. A1. To cast the workpieces (sheet plate of 160×45×5 mm) a casting die was designed and manufactured as shown in Figure 2.

Experimental procedures

At the beginning aluminum is prepared to melt, cut into small pieces, and cleaned by using 3M HCl dilute by water (to get a higher level of purity of aluminum), then fill the graphite crucible with the pre-calculated amount of aluminum and insert it in the furnace at 750 °C for 30 min under the protection of argon gas, while aluminum becomes liquid phase, the calculated amount of copper was added, then steering the mixture for 2 min and return the crucible for 5 min, get the crucible out and add the pre-calculated amount of Al-5%V master alloy to the melt and steering for 2 min. and return it for 5 min. A brass die was used to be used for casting the required workpiece of 152 mm length, 45 widths, and 4.9 mm thickness as shown in Figure 3a, where the rolling passes are shown in Table 2 and Figure 3b.

Fig. 2. Brass casting die of a cavity of (160×45×5 mm)

RESULTS AND DISCUSSION

Average grain size after copper and vanadium additions to pure aluminium

As can be seen from Figure 4 below the grain size of Al is 124 µm, adding 4% copper has resulted in a reduction in the grain size by 58.1%, whereas adding 0.1 % V resulted in a further reduction of 123.8%, and it is clear from the same figure that the grain shape changed from columnar structure to equiaxed grain which can be explained by the formulation of $Al_{21}V_2$ after 0.1% V addition which hinders the grain growth. Al-qawabah presented the effect of 0.1% V addition to Al-9% Cu on the mechanical characteristics of commercially pure aluminum in the as-cast and after the upsetting process, which result in the reduction of the average grain size to 45 µm. on the other hand, in this study the effect of 0.1 % V addition to Al-4% Cu results in an extra reduction of the average grain size to 19 µm, [18].

Table 2. The reduction in thickness after the rolling process

Pass No.	Thickness before (mm)	Thickness after (mm)	Reduction in thickness (mm)
1	4	3	1
2	3	2	1
3	2	1.3	0.7

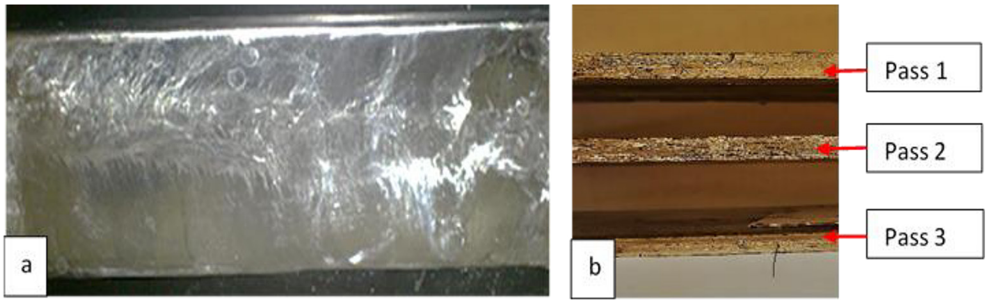

Fig. 3. (a) Sheet metal after casing process (160*45*5 mm), (b) first pass (3 mm), second pass (2 mm), and third pass (1.3 mm)

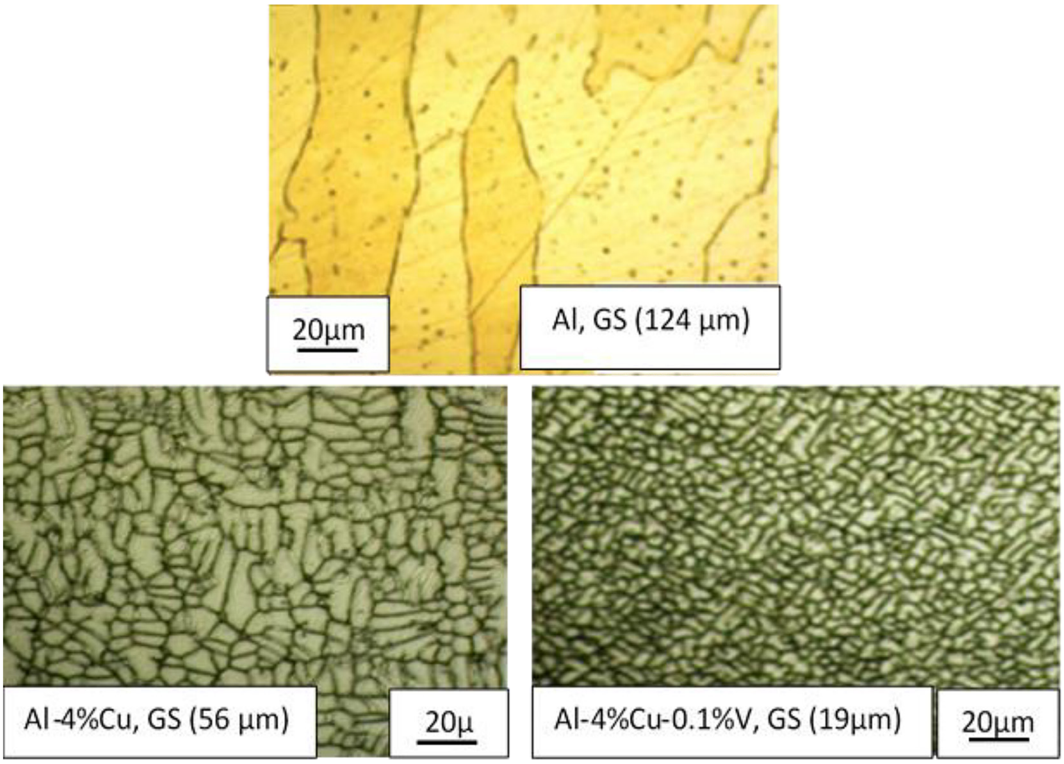

Fig. 4. Micrographs of aluminum alloys show the grain size after copper and vanadium additions at 200X [20]

Effect of rolling passes on the surface roughness

It is obvious from the histogram of Figure 5 that a slight increase in the surface roughness (Ra) after pass 1 and pass 2 followed by a slight decrease in the surface texture after pass 3 for Al-4%Cu, so this small change in surface texture is negligible compared to the enhancement in the mechanical characteristics. Where in the case of AlCuV there is an enhancement in the surface quality after pass 1 and pass 2 to by 64.9%, however, it increased to 0.98 μm after pass 3, but it is still lower than before rolling stage, and this consistency with other researchers, [1].

Effect of angles orientation on the maximum tensile force

It was obvious from the histogram of Figure 6 that there is a slight change in tensile force as the angle increase from 0^o to 90^o after pass 1, where there is a pounce increase in the tensile force of about 16% after rolling pass 2, however, this can be attributed to the anisotropy that resulted from the direction of applying force. After rolling pass 3 it is clear that the anisotropy increases the tensile force by about 56.6%, this can be explained that the shape of the grain i.e. the grain diameter elongated in the 0^o and reduced in the 90^o direction. It is obvious in Figure 7 that there is a small change in the maximum tensile

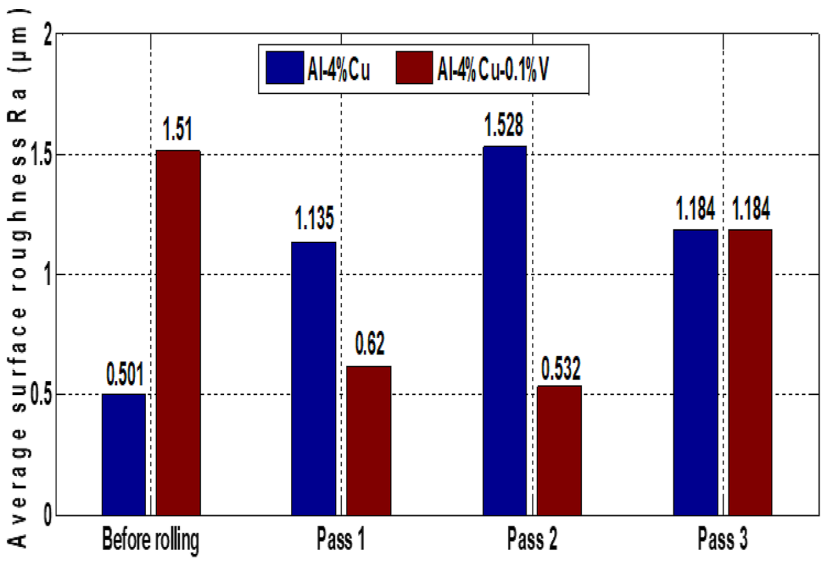

Fig. 5. Average surface roughness (Ra) after each pass for AlCu and AlCuV

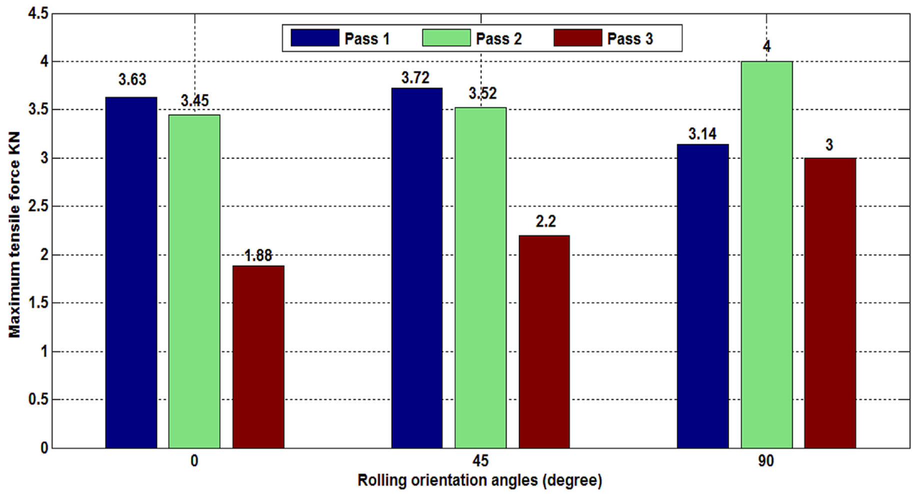

Fig. 6. Rolling orientation angles across maximum tensile force for AlCu alloy

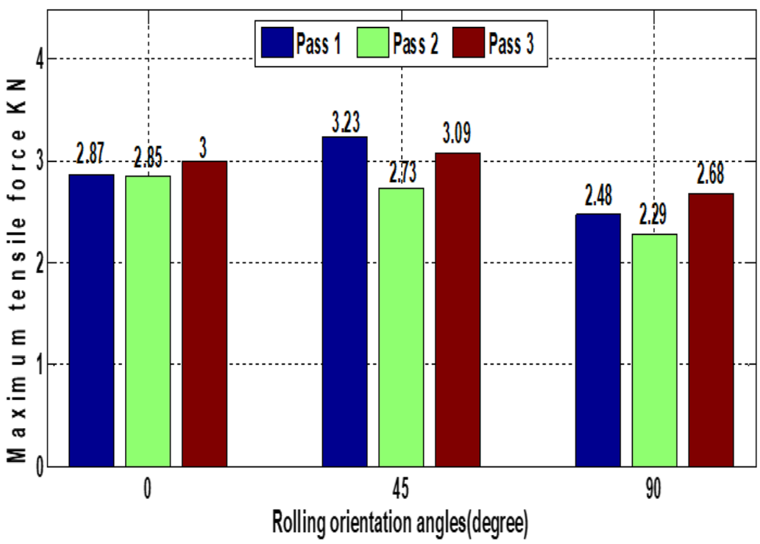

Fig. 7. Rolling orientation angles across maximum tensile force for AlCuV alloy

force in AlCuV alloy for all passes, and it is clear that the material becomes nearly isotropic after 0.1% Vanadium addition, this finding is so important to the metal forming processes that affected by anisotropy i.e. deep drawing process, where the type of residual stress change from tensile to compressive after rolling process [1].

Effect of angle orientation on the deformation energy

Effect of angles orientation on the deformation energy for AlCu

Figure 8 shows the energy consumed during the tensile test after each rolling passes, the pronounce finding that there is a reduction in the energy of deformation after pass 3 for all angle directions, the maximum is 85.4 79.6 %, 77.1% respectively. It is expected that after the rolling pass 3 that the material enters the superplastic range by which the material becomes easy to deform, this is consistent with a previous study performed, [12].

Effect of angles orientation on the deformation energy for AlCuV

Figure 9 shows a huge reduction in the deformation energy after vanadium addition and cold rolling passes, this reduction will reduce the cost of production, this reduction is consistent with results obtained in Figure 7, that as the tensile force decrease the energy consumed in deformation is decreased.

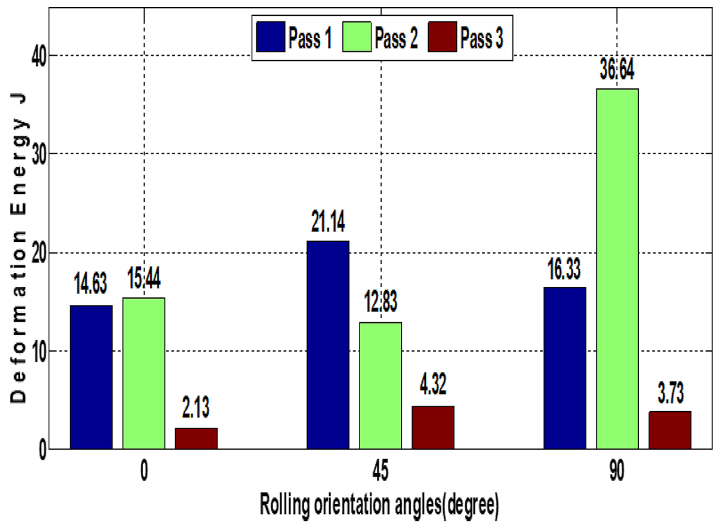

Fig. 8. Deformation energy after three cold rolling passes for AlCu alloy

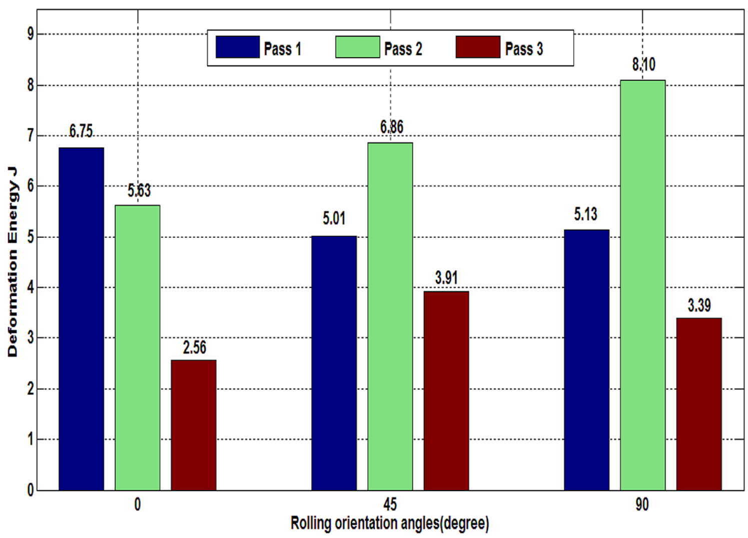

Fig. 9. Deformation energy after three cold rolling passes for AlCuV alloy

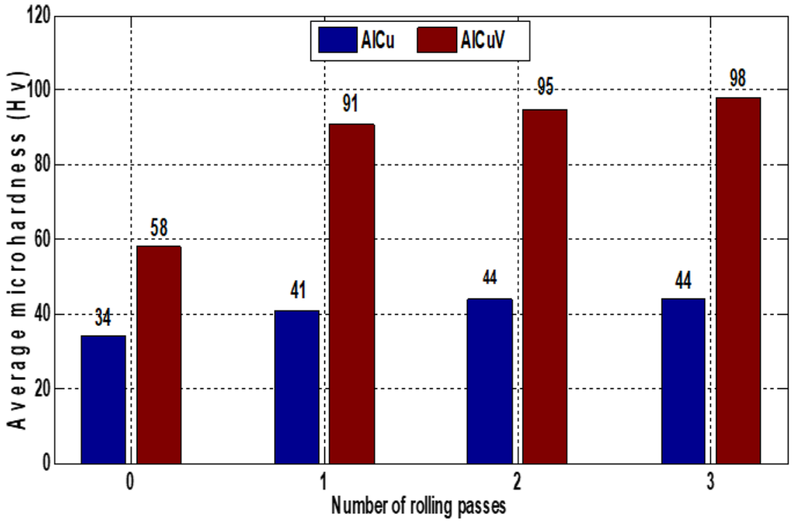

Fig. 10. Average micro-hardness after rolling passes for AlCu and AlCuV alloys respectively

Effect of angles orientation on the micro-hardness

It can be seen from Figure 10 that the average microhardness of both AlCu and AlCuV after three rolling passes, it obvious that there is a slight change in microhardness for Al-Cu, on the other hand, it is clear that is a pronounced increase in hardness after rolling passes for AlCuV of about 63.8%, it is due to severe plastic deformation that performed on the workpiece and to the added vanadium. The addition of vanadium of 0.1% form intermetallic compounds like Al21V2, is consistent with the previous finding that reported by [18, 19].

Limitations of this study

There important limitation in this study:
- amount of vanadium addition should not exceed 0.1%, if it happened no pronounce enhancement will have attained and resulted in increasing the cost, i.e. the cost of vanadium is very expensive.
- in each rolling stage the strain not to exceed the strain at instability for both alloys, if it exceeds the rolled material will have failure.

CONCLUSIONS

The following can be classified that rolling process increases hardness by 68.9% for AlCuV. Rolling process enhances 29.4% in hardness for AlCu alloy. Adding 4% copper and 0.1% V resulted in grain refinement of pure aluminum. There is a reduction in the energy of deformation for Al-4%Cu after the third rolling pass for all angle directions, the maximum is 85.4%, 79.6%, 77.1% respectively. There is a pronounced increase in micro-hardness after rolling passes for AlCuV of about 63.8%. The addition of both the Addition of 0.1% vanadium to Al-4%Cu alloy and the multi-rolling passes resulted in reducing the deformation energy and the maximum tensile forces that will reduce the cost of production of AlCuV alloys. The average surface roughness (Ra) was enhanced for AlCuV and increased for AlCu alloy. It recommended in the future to study the mechanical and surface properties after other method, i.e. micro-oxidation process.

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