Characterization and Mechanical Properties of Al-Al_3V in-situe composite from reduction of V_2O_5 using aluminium

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***Abstract*—Al-V composite has been obtained by reduction of vanadium pentoxide by molten aluminium. The processing parameters affecting the preparation process were investigated. Some tests such as chemical analysis, X-ray diffraction microstructure examination, mechanical properties and wear testing were carried out on the produced Al-V composit. The results obtained indicate that the produced alloys containing up to 8.6% V in the form of Al_3V intermetallic compound and can be used as a master alloy or composite material. The recovery of vanadium in the prepared composite is reached to 8.6%V and it has proved certainly by introducing many evidence using XRD, SEM, EDS, DTA and X ray mapping that, this compound is Al_3V intermetallic compound. The presence of this compound in the aluminium matrix enhanced and improvement the mechanical properties of the prepared composite. The effect of increasing the vanadium content from 0 wt.% to 8.2 wt.% significantly improves the hardness 84 % (where Hardness increased from 50 to 92 HB, improves the yield strength by 100 % (where yield strength increased from 50 to 100 MPa) and improves of ultimate tensile strength by 108% (where yield strength increased from 103 to 215 MPa). The decrease in wear weight loss with increasing percentage of vanadium from 0 to 8.2% due to the presence of hard Al_3V intermetallic compound particles adhered to the composite matrix. In addition, the wear weight loss increases as the wear velocity increased.**

Keywords—Composite Materials, Al-V alloys, Vanadium pentoxide, Mechanical properties, and Wear.

I. Introduction

Metal matrix composites (MMC) reinforced with ceramic particles, whiskers, or fibers have been commonly used in automobile, aeronautical and space industries. This due to their high strength, superior wear resistance and other excellent mechanical properties [1,2]. Mechanical and physical properties of pure aluminium are enhanced with the addition of alloying elements. Aluminium-transition metal alloys exhibit superior mechanical properties such as vanadium and titanium. These alloys have high thermal stability and corrosion resistance, accordingly, these alloys can be applied for wide range of aerospace applications, missiles and air frame structure [1] Therefore, the intermetallic compounds of Al-Zr, Al-Ta, Al-Nb, Al-W and Al-Mo in Al matrix could reduce the differences of the thermal expansion coefficient of the composite. These intermetallic compounds have high hardness and Young's modulus. Al-V alloys is being produced to meet the highest quality and reliability requirements of the aerospace industry. It is an alloy that can be strengthens titanium which is used in critical parts of aircraft as a result, the alloy must meet rigid quality standards [2]. The raw materials of vanadium include vanadium pentoxide, ferrophosphorus slag, petroleum residues, spent catalysts, utility ash, and vanadium bearing iron slag [6,7]. Vanadium pentoxide (V_2O_5) is perhaps vanadium's most useful compound. It is used as a catalyst in certain chemical reactions and in the manufacture of ceramics. Generally, transition-metal tri-aluminide intermetallic could provide the kind of reinforcement for light metal matrices. These intermetallics having low densities and high elastic modulus are good candidates for in-situ reinforcement of light metal matrices based on aluminium alloys [10]. However, to our knowledge, no studies have been reported on the fabrication of Al-V master alloys with more the 2%V. The importance of Al-V master alloys for many industries specially in aerospace applications and biomaterials and the production it is not available in open literatures encourage us as main target to attempt for producing these alloys. Also, an attempt to study the different factors affecting the producing of Al-V alloys reinforced by intermetallic compound Al_3V and characterization of these alloys for microstructure, mechanical and wear behavior.

II. Experimental Work

The used materials were commercial aluminum, vanadium pentoxide V_2O_5, powdered Aluminium.

Experiments procedure

The materials used in this work were: Pure Al (99.9 %) and V_2O_5 (99.5 %) powders (average particle size 59 μm, and 178 μm, respectively) and bulks Al were used. A 30 g V_2O_5 was mixed with Al powder at different weights of Al powder, 7.5, 15, 22.5 g. The powders were uniformly mixed in cylindrical polyethylene bottle using a ZrO_2 ball with ball-to-powder ratio of 6:1 using horizontal mixing machine (Mechanical mixer, ABB ACS100), 150 rpm speed mixing time 6 hours. The experiments were preformed in a vertical muffle furnace with temperature controller, and it contains silicon carbide crucible. A 99.7% purity of aluminium was melted at elevated temperature varied from 700-850 ^oC; then a calculated amount of the mixed powder that previously prepared was added to the molten aluminium with manual stirring maintained for 5 minutes followed by skimming the formed slag before pouring into suitable cast iron moulds to carry out some tests.

The factors affecting the recovery of vanadium in the produced composite were studied, these factors are: Bath temperature; V_2O_5; powdered Al / V_2O_5 weight ratio (R) and reaction time. The optimum processing parameters were: Bath temperature 850; V_2O_5% 10-15%; powdered Al / V_2O_5 weight ratio 0.5 and reaction time 15 min. these results were published in another paper [3]. Some of the specimens were selected from the produced composite by the previous process with different vanadium contents as shown in Figure1. These specimens were characterized using XRD; SEM, EDS, Mechanical and wear behavior.

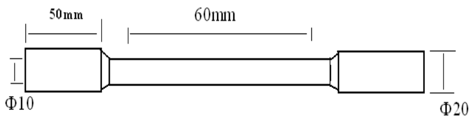


Figure 1 Dimension of tensile specimen according to ASTM.

III. Results and Discussion

Characterization of the produced alloys

1. XRD results

The X-ray diffraction analysis for the produced Al-V composite containing 8.2%V was carried out from 20 to 70 degree. Figure 2 shows the XRD pattern, the phase identifications for this pattern indicated that only two phases were appeared; pure Al and Al_3V. According to the Al-V phase equilibrium diagram Figure 3, the compounds $Al_{21}V_2$, $Al_{45}V_7$ and $Al_{23}V_7$ are metastable over temperature 736^{o}C. But the compound Al_3V is a stable compound until 1420 ^oC, also from Figure 3, it can be noticed that the composition of Al_3V contains about 39 Wt.% V and 61 Wt.% Al [12, 13]

From X-ray diffraction data obtained using PDF2, programs, the crystal structure of Al_3V is body-centered tetragonal tI8 space group is (I4/mmm) lattice parameters are: a, b is 3.78 Angstroms, and c is 8.322 A^o, and the density is 3.65.

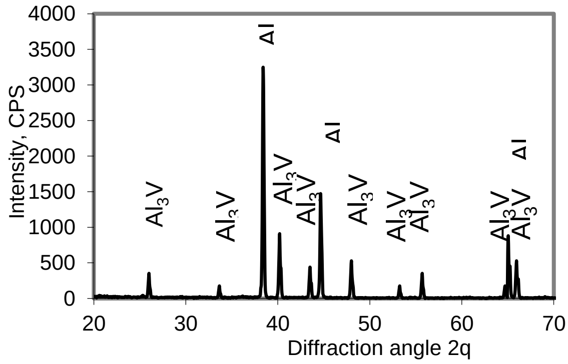


Figure 2 X-ray diffraction pattern for the produced composite containing 8.2 Wt.% V

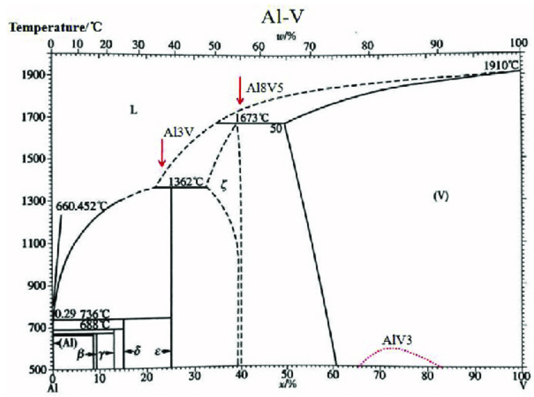


Figure 3 Phase diagram of Al-V system.

2. SEM analysis

Figure 4 shows the backscattered electron SEM micrographs for the prepared Al_3V composite. From this Figure it can be noticed that a homogeneous distribution Al_3V compound (white phase) like cotton with in the aluminium matrix (black). This is confirmed with the mentioned above in both XRD. The distribution of Al_3V within Al matrix may reinforcement the matrix and improvement the mechanical properties.

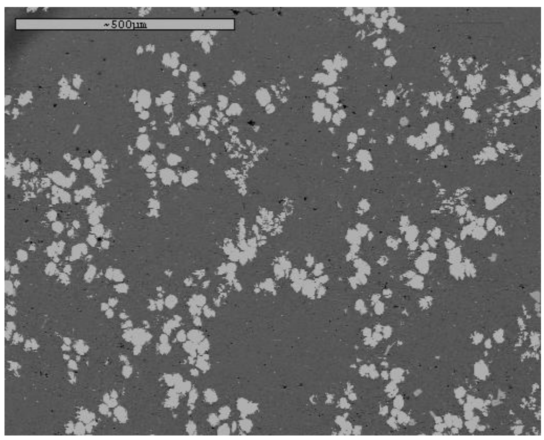
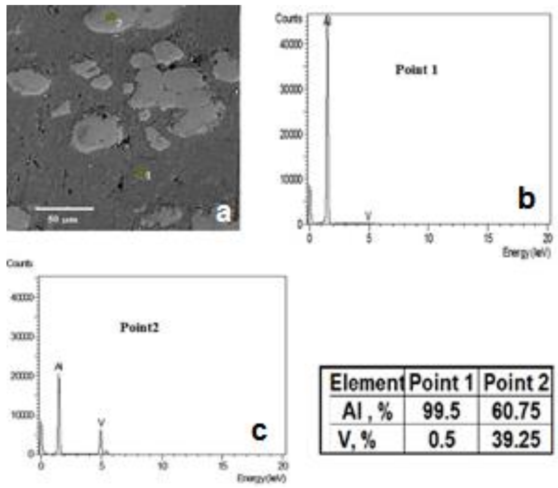


Figure 4 Backscattered electron SEM micrographs of the prepared Al-V composite

3. EDX analysis results

Figure 5a indicates the point analysis of the dark gray phase at point 1 and light gray at point 2 using energy dispersive spectrometer (EDS). From Figure 5 b indicates the light gray at point 2 is 39.76 Wt% vanadium and 60.24 aluminium this is closed with the composition of Al_3V intermetallic compound as mentioned before. But the composition at point 1 is 0.3 Wt% vanadium and 99.7 aluminium this is pure Al as see in Figure 5c. This means that the light gray phase point 2 is Al_3V and the dark gray phase point 1 is aluminium matrix.

Figure 6 indicates the X-ray mapping images and the distribution of Al, and V in the Al-V composite prepared at 850 ^oC. From this Figure, it can be seen that SEM photograph containing Al_3V within the aluminium matrix as indicated in Fig 6a. But the right micrograph Figure 6b indicates the only Al particles or atom (blue color) and the place of vanadium particles (black) like shadow. The bottom micrograph Figure 6c indicates only vanadium particles (red color) and the place of aluminium particles black color. It cloud be seen that the white gray nodules is mix of aluminium particles and vanadium particles form Al_3V and the dark gray is aluminium matrix, this confirmed with the results mentioned before. The all matrix analysis using EDX proved that the analysis of aluminium is 91.59 wt% Al and the vanadium is 8.41 Wt% V. The same EDX mapping micrographs for Al-V alloy containing 8.6% V.



Element	Point 1	Point 2
Al , %	99.5	60.75
V, %	0.5	39.25

Figure 5 SEM micrograph for the produced Al_3V.

4. Light microscopy

Also, Figure 7 shows light microscopy image indicates the distribution of Al, and V in the prepared Al_3V. The same results are obtained from this figure, the nodules Al_3V (black) dispersed in aluminium matrix dark gray and this more evidence to indicate that the phase appear in the aluminium matrix is absolutely Al_3V intermetallic compound and may reinforcement the aluminium matrix

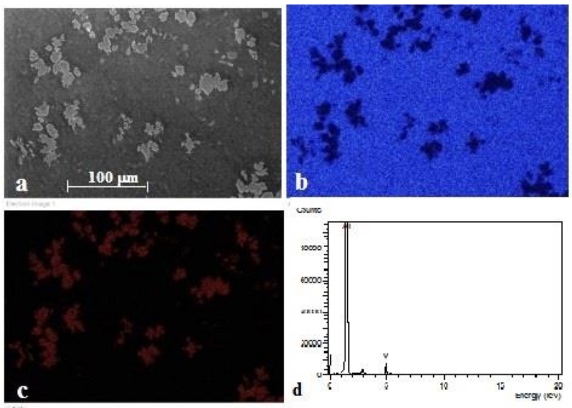


Figure 6. X-ray mapping images indicates the distribution of Al, and V in the prepared Al_3V

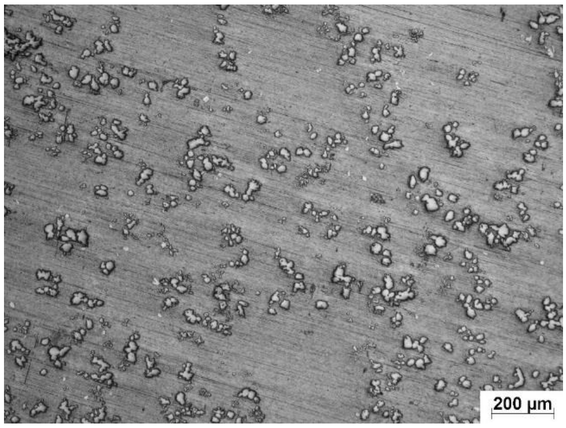


Figure 7 Typical microstructure of a produced Al-V alloy containing about 6.0%V., X 100

5.Mechanical properties

5.1 Hardness results

The hardness test carried out using Brinell hardness (load 5 Kgf, $^1/_{16}$ inch ball diameter and average three hardness reading taken. Figure 8 shows the effect of V recovery on the Brinell Hardness of the prepared composite reinforced by Al_3V intermetallic. From this Figure the relation between Brinell hardness (HB) of the prepared composites reinforced by Al_3V intermetallic compound and vanadium recovery. The hardness significantly increased by 84 % (where Hardness increased from 50 to 92 HB) as vanadium recovery increased from 0 to 8.2% V. This increasing may be because the strengthening of aluminium matrix by the founded Al_3V intermetallic compound. The amount of formed Al_3V intermetallic compound which is the main reinforcements in the Al- Al_3V composites increases as vanadium recovery increased. The relation between hardness (HB) of the prepared composites and vanadium recovery can be obtained from the following equation:

$$\text{Hardness, } HB = 5.0283\ V\% + 49.096 \qquad (1)$$

$$R^2 = 0.993$$

V% is the contents of vanadium recovery in the produced composite.
R^2 Root mean square.

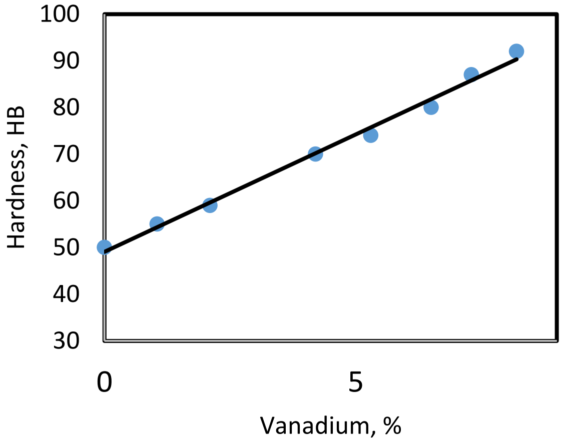


Figure 8 The relation between Brinell hardness (HB) of the prepared composites and V%.

From the previous results, it can be said that the technique for preparation of Al-Al_3V composites had been successful. The presence of the Al_3V intermetallic compound in the aluminium matrix enhanced and improvement the mechanical properties of the prepared composite

5.2 Tensile results

The tension test is widely applied to provide the basic design information about the ultimate tensile strength, Yield strength and elongation. It provided strength of the materials and as an acceptance test for the specification of materials. The relation between the vanadium contents in the produced Al-V composite and the values UTS and YS at different percentages of V recovery were investigated as shown in Figure 9. It can be observed that both yield strength (MPa) and ultimate tensile strength of the Al-V composite increase linearly as the percentage of V% in the produced alloys increased
The effect of increasing the vanadium content from 0 wt.% to 8.2 wt.% significantly improves the yield strength by 100 % (where yield strength increased from 50 to 100 MPa). These results compared with the improvement of ultimate tensile strength by 108% (where yield strength increased from 103 to 215 MPa). The increasing. The results of both yield strength and ultimate tensile strength (MPa) against the contents of vanadium recovery in the produced composite were correlated as the following equations:

$$UTS = 13.414\ V\% + 101.53 \quad (4)$$

$$R^2 = 0.992$$

$$YTS = 5.521\ V\% + 51.337 \quad (3)$$

$$R^2 = 0.9748$$

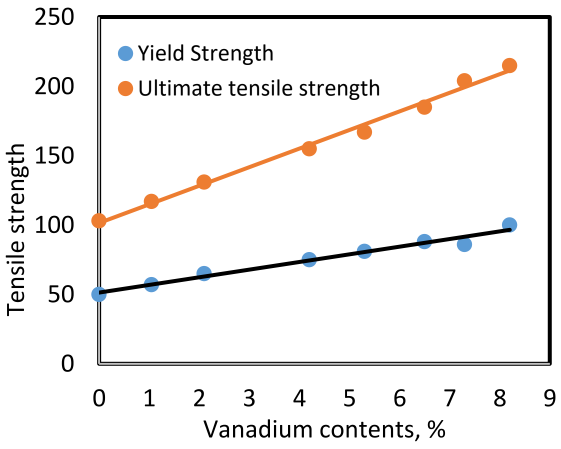


Figure 9 The relation between the vanadium contents and the values UTS and YS.

5.3 Elongation results

Elongation values (E) of the Al-V alloys at different percentages of V% from 0 to 8.2 as shown in Figure 10. It can be observed that the elongation % of the Al-V composite increase linearly as the percentage of V% in the produced alloys increased. The effect of increasing the vanadium content from 0 wt.% to 8.2 wt.% significantly improves the elongation by 20 % (where the elongation increased from 8.9 to 10.8%).The results of the elongation against the contents of vanadium recovery in the produced composite were correlated as the following equation:

$$\text{The elongation, } \% = 0.22\ V\% + 8.7971$$

$$R^2 = 0.943$$

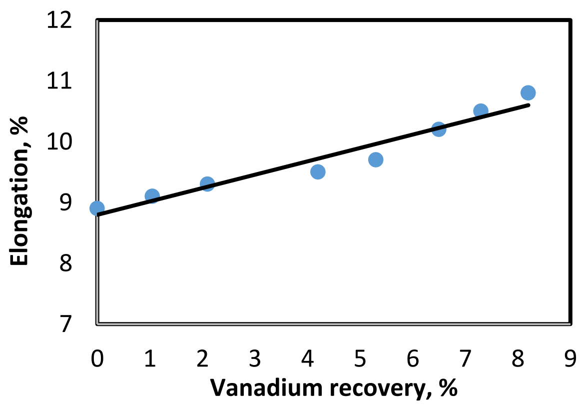


Figure 10 the relation between elongation (E) and vanadium recovery.

5.4 Wear testing results

5.4.1 Effect of wear time

The wear test for the produced Al-V composite specimens using the reduction of vanadium pentoxide by aluminium was carried out using pin on disk apparatus under load 0.866 kgf, sliding speed 1.83 m/s (250 rpm) at different time (0-7 hours with interval time 0.5 hour). The results in Figure11 indicated that as the wear time increases the wear weight loss increased too. At constant wear time, the wear weight loss reduces with increasing the vanadium contents in the produced Al-V alloys. This Figure shows that, the wear weight loss after 7 hr wear time in pure aluminium was 3.037 g and reduced to 0.1 g after 7 hr wear time in Al-V composite containing 8.2% V. The decrease in wear weight loss with increasing percentage of vanadium can be due to the presence of hard Al_3V intermetallic compound particles adhered to the composite matrix. The predicted wear rate at any V contents in the produced composite from Figure 11 from the slope of the trend line of weight loss of this content.

Figure 12 shows the relation between the wear rate with the vanadium contents. It can be indicated that, the wear rate decrease as the V% increase reached to the minimum wear at vanadium contents 8.2%. The wear rate as a function of V contents could be correlated according to the following:

$$\text{Wear rate, g/hr} = 0.006V^2 - 0.1\,V + 0.43 \quad (6)$$

Where:
V is V% contents in the produced composite.

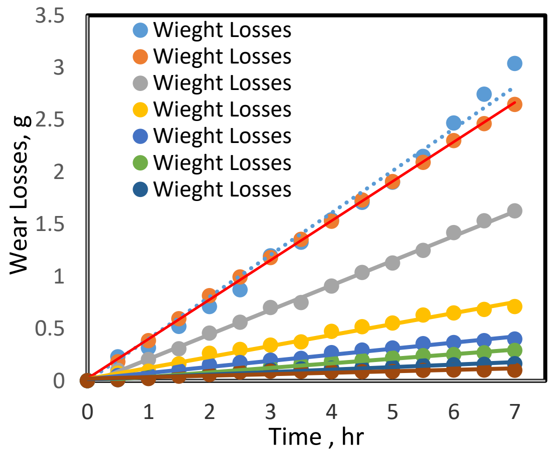


Figure 11 Wear weight loss of the produced Al-V composite against wear time at different V% contents

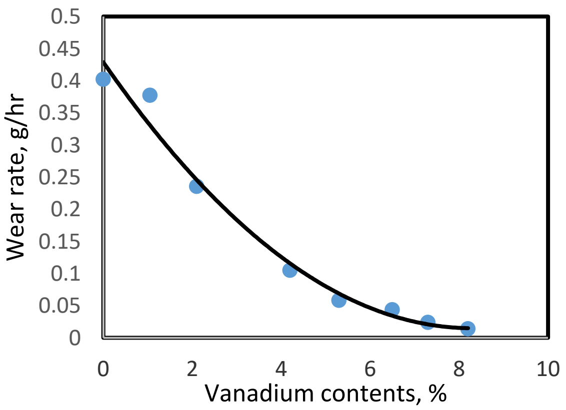


Figure 12 The relation between the wear rate with the vanadium contents

5.4.2 Effect of wear velocity

Figure 13 shows the relationship between the weights losses and wear velocity with different vanadium contents in the produced Al-V composite. This Figure indicates that the wear weight loss increases as the wear velocity increased. At constant wear velocity, the wear weight loss reduces with increasing the vanadium contents in the produced Al-V composite. Also, it shows that, the wear weight loss at velocity 3.05 in pure aluminium was 0.771 g and reduced to 0.083 g at velocity 3.05 in Al-V composite containing 8.2% V. The decrease in wear weight loss with increasing percentage of vanadium can be due to the presence of hard Al_3V intermetallic compound particles adhered to the composite matrix. The predicted wear rate at any V contents in the produced composite from Figure 13 from the slope of the trend line of weight loss of this content.

Figure 14 shows the relation between the wear rate with the vanadium contents. It can be indicated that, the wear rate decrease as the V% increase reached to the minimum wear at vanadium contents 8.2%. The wear rate as a function of V contents could be correlated according to the following:

$$\text{Wear rate (g/hr)} = 0.0031V^2 - 0.0585\,V + 0.2893$$

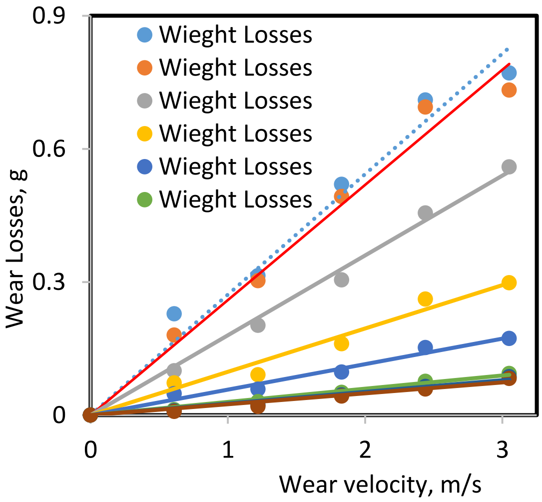


Figure 13 Wear weight loss of the produced Al-V alloys against wear velocity.

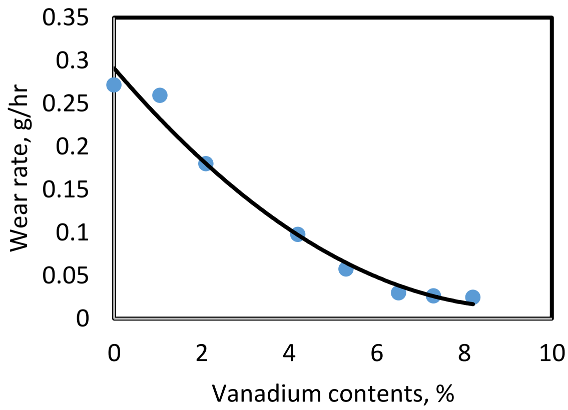


Figure 14 Effect of V% contents of Al-V alloys on the wear rate.

Conclusion

In this work, an advanced method for preparation of Al-V composite from reduction of V_2O_5 by powdered aluminium within a bath of molten aluminium has been proposed. The main results were concluded as follows:

1. Although the Al_3V intermetallic compound is unknown compound in open literature, But, it has proved certainly by introducing many evidence using XRD, SEM, EDS, DTA and X ray mapping that, this compound is Al_3V intermetallic compound.
2. The presence of this compound in the aluminium matrix enhanced and improvement the mechanical properties of the prepared composite.
1. As vanadium recovery increased from 0 to 8.2% V, The hardness significantly increased by 84 %, improves the yield strength by 100 %, improves of ultimate tensile strength by 108% and improves the elongation by 20 %.
2. The decrease in wear weight loss with increasing percentage of vanadium can be due to the presence of hard Al_3V intermetallic compound particles adhered to the composite matrix. In addition, the wear velocity increases as the wear weight loss increased.

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