SYNTHESIS AND CHARACTERIZATION OF ALUMINIUM-TUNGSTEN METAL-METAL COMPOSITE THROUGH POWDER METALLURGY

[1]Mr. Kanakarao Arigela, [2]Dr.Srinivasu Rokkala

Associate Professor
Raghu Engineering College

***Abstract*: The scope of the research work is the production and characterization Al-W metal-metal composite were synthesized through powder metallurgy process. The produced composites were examined as far as their microstructure and mechanical properties (density, micro/macro hardness). Microstructure and its relationship with mechanical properties of the composite were also investigated. The result showed that with increasing Tungsten percentage micro hardness also got increased. And it is observed from the density calculations that even with increase in tungsten quantity in Al-W metal-metal composite there is minimum increase in density of the new composite.**

***Keywords*: Metal-Metal Composite, Aluminum, Tungsten, Microstructure, mechanical properties**

Introduction

It is necessary to have high machinery service life, operation reliability low friction in bearings, bushes, piston rings, brake pads, driving mechanisms, friction clutches, couplings, gears and moving parts etc. The working condition of these parts differs in various aspects like sliding speeds loads environmental conditions and other parameters. No single metal can meet all the required property so it is necessary to develop a composite material that could have all combinational property satisfying all our engineering requirements. Metal-metal composites were designed and fabricated to overcome the limitations with metal-ceramic composites. Thought has been given by Madhu et al, producing metal-metal combination system with restricted solubility, termed as Metal-Metal Composites [1]. Today aluminium based composite is on huge demand, due to its superior mechanical characteristics, for example; specific stiffness, wear resistance, hardness, high modulus and fatigue. These metal metal composites have been considered as excellent candidates, applied as structural materials to automobile industry and aerospace [2]. There are different manufacturing techniques for reinforcing composite such as spray decomposition, liquid metal infiltration, powder metallurgy, Squeeze casting, Mechanical alloying and compo casting [3]. Powder metallurgy is highly developed technique for manufacturing composites. Al-W composite material was prepared using powder metallurgy process. Why we have chosen powder metallurgy? Al-W prepared through Liquid Metallurgy (LM) process by the authors has reported following problems. The segregation in the A1/W composite processed through the LM technique is mainly caused by sedimentation (buoyancy) force and conventional convection. Very limited solid solubility between aluminium and tungsten and the formation of intermetallic compounds between tungsten and aluminium are observed [4]. Powder metallurgy process offers very distinct advantages compared to all other manufacturing processes. In powder metallurgy, composite powders are prepared at room temperature using Mechanical alloying method. The components prepared using this method have merits such as less residual voids, no dissolved gases in products, good interface bonding between inclusions and metal matrix, near-net shape of compacts.

II. METHODS AND MATERIALS

A. Material Used

The metals identified for the present study are
Aluminum:Al-99.0% purity, Size: 325 microns (Fig.1a)
Tungsten: W-99.3% purity, Size-2-5 microns (Fig.1b)

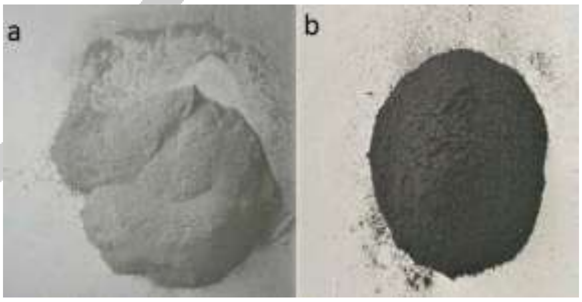


Fig. 1. a) Pure AlumnumPowder (Size 325 Microns)
b) Pure Tungsten Powder (Size 2-3 Microns)

B. FABRICATION TECHNIWUES

PowderMixing

Required amount of Aluminum and tungsten carbide were measured and taken as per the required weight percentage (0%, 5%, 10%, 15% & 20%)... The powders were mixed thoroughly in a mixing bowl, manually for obtaining homogeneity. Each sample was grounded for 30min in order to attain homogeneity in composition. Care was taken while grinding to avoid contamination of metal powders.

Diepreparation

The composite powder has to be compacted into cylindrical perform of diameter 10mm and 60mm heights. The performs were prepared for two different aspect ratios. Die was made from HCHC (High carbon high chromium) D3 steel.D3 Die steel in order to meet the above requirements. Die is made of cylindrical shape of dia. 10mm and length 70mm. It is of split type and can be fixed with 4 Allen bolts shows in Fig 2. Punch is made of SS (stain less steel) with a length of 120mm and dia. 9.6mm. Graphite Powder was used for the die wall lubrication for the easy removal of the compacted performs.

Fig. 2.HCHC-D3 steel Die and Punch

Sintering

The compacted performs were then placed in a muffle furnace for sintering. Sintering is usually carried out below the melting point of the lowest melting metal which in this case is aluminum (melting point=660ºC). Sintering is essentially a process of bonding solid bodies by atomic forces. Sintering forces tends to decrease with increase in temperature. Since bonding particles is greatly affected by surface films, the formation of undesirable surface films, such as oxides, must be avoided. Sintering is done at a controlled Argon atmosphere in order to prevent oxides formation of Al and W. samples were placed inside the furnace in particular order and furnace was made air tight seal with Glass Wool. Purging was done for 20min with argon gas at high pressure to remove any traces of other gases and to create inert atmosphere inside the furnace. Temperature was set at 560°C. Samples were soaked for 10hrs. At that temperature and allowed to cool within the furnace at inert atmosphere for 8hrs.

Microstructure:

Microstructures of the alloy samples were observed under computerized optical microscope (Model: Olympus BX51, Essex, UK). The Al-W samples of different weight composition, Etching was done using the Keller's reagent.. The micrographs of the samples were obtained

Vickers Hardness Test

The hardness tests of all the samples have been done using a Vickers's hardness testing machine. The applied load during the testing was 30 kgf, with a dwell time of 15s. Obtained values were tabulated.

Yield Strength and Ultimate Strength

The relation between flow strength and hardness for Al alloys for fine grained and ultrafine grained can be expanded as follows.

Hv = (σY/ 3)(0:1)^-n* ----(1)

Hv = (σUTS/ 2:9)(1- n*)[12.5 n*/ (1- n*)]^n* -- (2)

Where

Hv- Vickers hardness number

σY- yield strength, σUTS-ultimate tensile strength

n*- modified hardening component for (pure Al and Al alloys n* value is .114

Considering the n* values for Al and Eqs.(1) and (2), the evolutions in the yield stress and ultimate tensile strength on the bases of indentation hardness data can be calculated.

Density and porosity analysis

Density was analyzed using Archimedes principle. Samples were weighted first in air, then in water. Volume of the composite is calculated using following relation.

$$\mathrm{Vc} = \frac{\mathrm{Wa} - \mathrm{Ww}}{\rho \mathrm{w}}$$

The actual composite density can be calculated by

$$\rho \mathrm{c} = \frac{\mathrm{Wa}}{\mathrm{Vc}}$$

And the theoretical composite density can be calculated by using

Where:

V_C: volume of the composite sample;

W_A: the weight of the sample in air;

W_L: the weight of the sample in liquid;

$\boldsymbol{\rho}_w$: the density of liquid.

The actual composite density $\boldsymbol{\rho}_c$ can be calculated by:

and the theoretical density could be calculated by:

$\boldsymbol{\rho}_{th} = 1 / [(W_{fp}/\boldsymbol{\rho}_p) + (W_{fm}/\boldsymbol{\rho}_m)]$

where W_{fm} and W_{fp} are weight fractions of the matrix and the particles respectively; $\boldsymbol{\rho}_m$ and $\boldsymbol{\rho}_p$ the density of the matrix and the particles respectively.

The porosity can be estimated using the following formula:
Porosity = $(\boldsymbol{\rho}_{th} - \boldsymbol{\rho}_c) / \boldsymbol{\rho}_{th}$

C. RESULTS AND DISCUSSION

Different tests like microstructure, macro hardness test, density test, porosity test on Al-W alloys were carried out. The results obtained from these tests are reported

Microstructure

Microstructures obtained from computerized optical microscope are shown in Fig.3

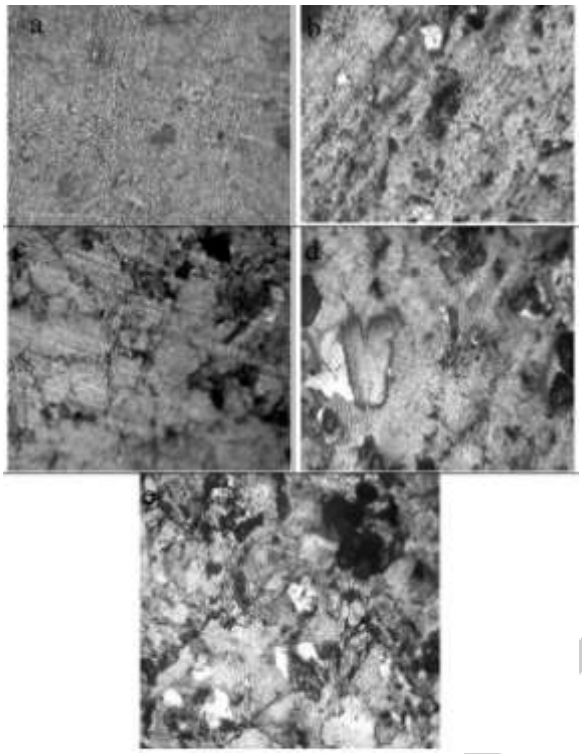
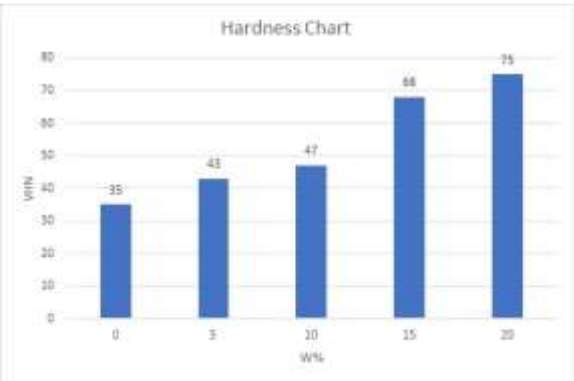


Fig. 3. Optical Microstructure of a) pure Aluminum, b) Alumnium-5% W, c) Aluminum – 10%W , d) Aluminum – 15%W, e) Aluminum – 20%W

The above microstructures reveal that there is a uniform distribution of tungsten particles in the matrix of aluminium. It also depicts that there is good bond between Al & W particles without melting

Vickers Hardness Test

Graph 1 shows the Vickers hardness numbers for pure Al, Al-5% W, Al-10% W, Al-15% W and Al-20%W were found to be 35, 43, 47, 68, and 75 VHN respectively. The hardness with Al-20%W was almost 115% more, comparatively to pure Aluminium. This shows that hardness of the Al-W metal-metal composite increases with the increase in the weight percentage of tungsten. This may be due to the increment of tungsten amount.



Graph 1. VHN vs % of W

Yield and ultimate strength results

Yield and ultimate strengths of Al-W composites were obtained by using Hardness-strength relation as mentioned before. Results were tabulated below.

Model Calculations:

For pure Al:

Hv = (σY/ 3)(0.1)^-n*

Hv = (σUTS/ 2:9)(1- n*)[12.5 n*/ (1- n*)]^n*

σY = (35*3)/ (0.1)^(-.114) = 80.75 Mpa

σUTS = (35*2.9)/ (1- .114)[12.5 * 0.114/ (1- 0.114)]^0.114 = 121Mpa.

Table 1 Yield and Ultimate strength

Composite	VHN	σY (Mpa)	σUTS (Mpa)
Pure	35	80.75	121
Al-5% W	43	99.2	133.3
Al-10% W	47	108.5	146
Al-15%W	68	157	211
Al-20%W	75	173	232.6

Graph. 2 show that with the increase in weight percentage of tungsten in Al-W composite material yield strength and ultimate tensile strength are showing increasing sign. Yield strength of pure Al is 75 Mpa, 99.2 Mpa for 5%W,108.5 Mpa for 10%W,157Mpa for 15%W and 173Mpa for 20%W. Ultimate tensile strength of pure Al is 121Mpa, Al-W composite with 5%W is 133.3 Mpa, with 10%W is 146 Mpa, with 15%W is 211Mpa and with 20%W is 232.6 Mpa respectively. The yield strength with 20%W was almost 115% more, and ultimate strength was 92% more, comparatively to pure Aluminium. Thus the above results show that with increase in the W quantity in the Al-W composite, yield and Ultimate strengths were also increasing.

Density and porosity calculations:

Model calculations:

For 5% W

ρact = weight of sample / volume of sample

2.93/1.1 = 2.67 gm/cc

ρth = 1 / [(W_{fp}/ρ_p) + (W_{fm}/ρ_m)]

= 1 / [(0.05/19.27) + (0.95/2.7) = 2.82 gm/cc

Porosity = $(\rho_{th} - \rho_c) / \rho_{th}$

Porosity = (2.82-2.67)/2.82 = 5.36%

Table 2 Density and Porosity results

Composition	Actual density (gm/cc)	Theoretical density (gm/cc)	Porosity (%)
Pure Al	2.6	2.7	3.7%
Al-5% W	2.67	2.82	5.36%
Al-10% W	2.73	2.95	7.5%
Al-15% W	2.8	3.1	9.67%
Al-20% W	2.91	3.26	10.74%

Discussion

Theoretical density of the Al-W composite was calculated using above formula and the values are 2.7gm/cm^3 for pure Aluminium, 2.83gm/cm^3 for 5%W, 2.95gm/cm^3 for 10%W, 3.1gm/cm^3 for 15%W and 3.26gm/cm^3 for 20%W respectively. Whereas actual densities which are calculated using Archimedes law are as follows: 2.6gm/cm^3 for pure Aluminium, 2.67gm/cm^3 for 5%W, 2.73gm/cm^3 for 10%W, 2.8gm/cm^3 for 15%W and 2.91gm/cm^3 for 20%W respectively. All these results were plotted on the graph 3. It was observed from the above graph that there is some difference between theoretical density and actual density. That difference is might be because of loose compaction. These density variations can be justified with the result of porosity. Porosity values were found to be 3.7%,5.35%,7.5%,9.67% and 10.74% respectively shows in Graph 4

Graph. 4. Yield & UTS vs %W

Conclusions

1) A series of Al-W metal-metal composites were produced through powder metallurgy process successfully.
2) Large amount of tungsten up to 20% by weight was incorporated successfully through powder metallurgy process.
3) Al-W metal-metal Composite was synthesised successfully without using any binder.
4) Prepared Al-W metal-metal composites with uniform distribution of tungsten particles throughout the matrix of aluminium with good bonding between them.
5) Hardness of the Al-W metal-metal composite increases with the increase in amount of tungsten present.
6) Mechanical properties such as yield strength and ultimate strength were found to be increasing with the increase in tungsten quantity of composites.
7) Theoretical and actual density calculations were done for Al-W metal-metal composites with varying weight percentage of tungsten. Density calculations have revealed there are considerable variations in theoretical and actual densities which were justified by Porosity results.

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