DEVELOPMENT AND CHARACTERIZATION OF Al-Mg-V_2O_5 BY POWDER METALLURGY ROUTE

A Major Report

UNIVERSITY OF PETROLEUM AND ENERGY STUDIES

For the Degree of

BACHELOR OF TECHNOLOGY

IN

MATERIAL SCIENCE WITH SPECIALIZATION IN NANOTECHNOLOGY

UNDER THE GUIDANCE OF

Mentor

Dr. Sidharth Jain

(Signature)

Submitted By:-

Ishita Agarwal (R240211013)

Sahil Sehgal (R240211020)

ABSTRACT

Powder metallurgy route produces a wide range of compositional products, eliminates or minimizes machining, produces good surface finish, environment friendly parts with controlled porosity and provides option for heat treatment. Aluminium containing magnesium and vanadium pentoxide gives light weight and high strength to the component and vanadium pentoxide refines grains which add to the strength to the component. The heat treatment of the finished product can reduce the porosity of the final product, increasing its strength. This composite with light weight and high strength can be used in many applications such as pistons in car engine, gears etc. There are tests that can be conducted to check the product's strength. The microstructural properties are tested using metallurgical microscope and micro-hardness.

Certificate

This is to certify that the work contained in this major project report titled **"DEVELOPMENT AND CHARACTERIZATION OF Al-Mg-V_2O_5 BY POWDER METALLURGY ROUTE"** is being carried out by **Ishita Agarwal (R240211013) and Sahil Sehgal (R24021120)** under my supervision as a part of academic activity in B. Tech MSNT (fourth year.)

Dr. Sidharth Jain
Department of Mechanical Engineering
University of Petroleum Engineering and Energy Studies
Dehradun (248007)

Acknowledgement

We would like to express our gratitude to our mentor **Dr. Sidharth Jain,** our activity coordinator **Mr. Garimella V. Subrahmanyam and Dr. Suresh Kumar,** H.O.D of mechanical department and all the other faculty member of Mechanical Department (U.P.E.S) who gave us the golden opportunity to work on this project on the topic **"DEVELOPMENT AND CHARACTERIZATION OF Al-Mg-V_2O_5 BY POWDER METALLURGY ROUTE"** which also helped us in doing a lot of research and we came to know about many new things for which we are really thankful to them. We would also like to thank our friends who helped us a lot in finalizing this project within the limited time frame.

TABLE OF CONTENT

LIST OF FIGURES

Chapter 1. General Introduction

1.1 Introduction

Composite materials are made up from two or more constituent materials with significantly different physical or chemical properties, that when combined produce a material with different characteristics from the individual components. The two materials i.e., matrix and reinforcement work together to give the composites unique properties. The matrix surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. The individual components remain separate and distinct within the finished structure. The new material is stronger and lighter when compared to traditional materials.

Composites are generally classified in the various ways. These are as follows-

1. Classification based on matrix
2. Classification based on reinforcement.

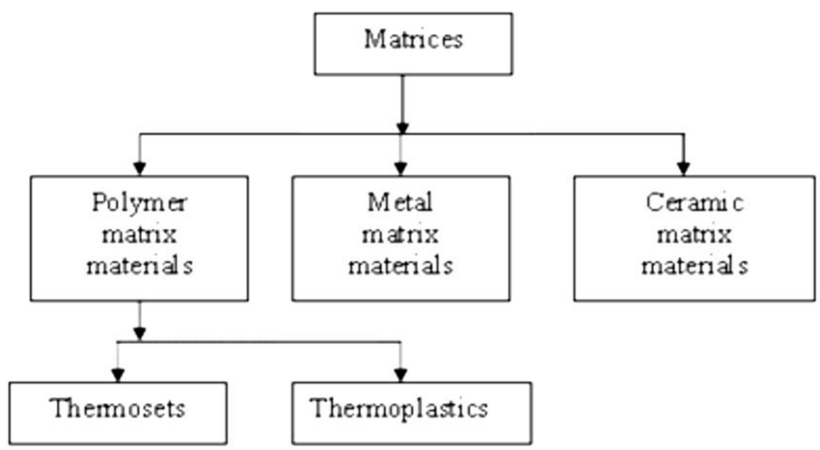


Fig: 1 Schematic representation of classification of composites based on matrix

1.2 Matrix – Metal Matrix Composite

Metal Matrix Composites is a composite material with at least two constituent parts, one being a metal. The other material may be different metal or another material, such as a ceramic or organic compound. MMCs are made by dispersing a reinforcing material into a metal matrix. The reinforcement surface can be coated to prevent chemical reaction with matrix. Most metals and alloys could be used as matrices and they require reinforcement materials which need to be stable over a range of temperature and non-reactive too. Most metals and alloys make good matrices.

For example, carbon fibers are commonly used in aluminium matrix to synthesize composites showing high strength. The carbon fibers are coated with nickel or titanium boride in order to prevent chemical reaction of carbon with aluminium matrix on the surface of fiber. Titanium, Aluminum and Magnesium are the popular matrix metals, which are particularly useful for aircraft applications.

Reinforced MMCs are produced by several processing routes such as powder metallurgy, spray deposition, mechanical alloying (MA) and various other casting techniques, i.e. squeeze casting, rheocasting and compo casting. These techniques are based on the addition of ceramic reinforcements to the matrix materials, which may be in molten or powder form. The scale of the reinforcing phase is limited by the starting powder size, which is typically of the order of microns to tens of microns and rarely below 1 mm. Main drawbacks that have to be overcome are the interfacial reactions between the reinforcements and the matrix, and poor wettability between the reinforcements and the matrix due to surface contamination of the reinforcements.

The properties of MMCs are controlled by the size and volume fraction of the reinforcements as well as the nature of the matrix ± reinforcement interfaces. An optimum set of mechanical properties can be achieved when fine and thermally stable ceramic particulates are dispersed uniformly in the metal matrix. Compared to the conventional MMCs produced by ex situ methods, the in situ MMCs exhibit the following advantages: (a) the in situ formed reinforcements are thermodynamically stable at the matrix, leading to less degradation in elevated-temperature services (b) the reinforcement ± matrix interfaces are clean, resulting in a strong interfacial bonding (c) the in situ formed reinforcing particles are finer in size and their distribution in the matrix is more uniform, yielding better mechanical properties.

1.3 Aluminium Powder Metallurgy

Aluminium P/M parts are used for their improved material characteristics or in some cases (e.g. complex shapes) because of their lower production cost. In most of the applications the P/M parts are used because of one (or more) of the following properties: higher Young's modulus, lower density, higher room temperature strength, better high temperature strength, better wear resistance.

Aluminium P/M parts have been used for drive belt pulleys, hubs, and caps and connection collars. Other applications are found in automotive components. The need for light, corrosion resistant materials and for strong higher temperature materials promote the interest for P/M aluminium parts.

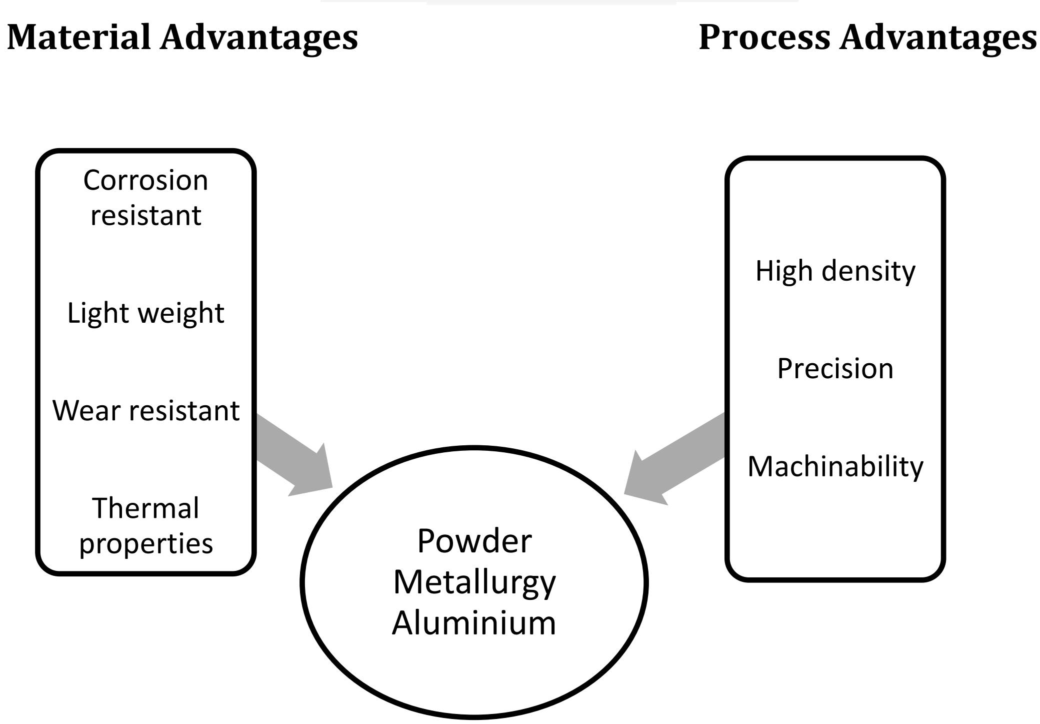


Fig:2 Schematic representation of advantages of Aluminium P/M route

The strong point of P/M aluminium parts is probably the wide variety of alloy compositions which can be prepared, offering in principle the possibility of achieving a desired combination of properties.

Powder metallurgy routes produces high-quality alloying powder which produces semi- finished PM products with a density of 100 percent for subsequent processing like rolling or forging. High-strength PM materials can be realized via an increase of the alloy contents and the formation of precipitations.

Aluminium P/M parts are currently used in low stress applications in marine transport, hand tools and office machinery and have started to penetrate the automotive industry.

Chapter 2. Literature Review

2.1 Introduction

During the literature review, an intensified research work is assessed on aluminum and its alloy – based metal matrix composites because of low density, good corrosion resistance and excellent mechanical properties for various engineering applications. The literature review provides an overview on the development of Aluminium matrix composites (AMC's) or aluminium alloy and characterization of AMC's with respect to microstructure and mechanical properties.

It is revealed that most of the works have concentrated on Al-SiC metal matrix composites produced using different techniques. Development of reinforced aluminium matrix composite materials has been reviewed to get an understanding of processing methods and properties evaluation of the metal-metal composite system with reactive interface.

Light metal matrix composite materials with ceramic particles as reinforcements have received widespread studies during the past decades because of their superior mechanical properties. Based, on the detailed literature survey the reinforcements such alumina, titania, zirconia when mixed with AMMCs fabricated by using powder metallurgy have good mechanical properties.

By using variety of reinforcements with different volume fractions it may be possible to optimize the wear and tear properties of the composites. Mazen and Ahmed and Arpon et.al while experimenting separately have examined that the ceramic reinforcements may contribute low coefficient of thermal expansion which in turn may increase hardness, stiffness and specific strength of the composites.

Some prominent applications for light metal MMC systems processed by squeeze casting have been reported as automotive wheels, gear blanks, Al- alloy automotive pistons, brass and bronze bushings (Vijayaram et al., 2006).

2.2 Powder Metallurgy Route of Aluminium

Fabrication technique of aluminium through powder metallurgy has increased its demand after the availability of all various alloy types. Aluminium Powder Metallurgy (P/M) offers components with equivalent mechanical and fatigue properties in comparison to wrought products of similar compositions. Lower density for overall weight reduction, corrosion resistance, with the ability of surface modification by coatings, high thermal and electrical conductivity, particularly useful in electronic packaging and thermal management of high frequency electronic equipment, excellent machinability with a good response to finishing processes are some of the benefits achieved (Marketing and the Technical and Standards Committees of the Pigments and Powder Division of The Aluminium Association, 1986). Classical benefits of powder metallurgy, primarily, higher material utilization alongwith lower energy consumption are not only retained in aluminium P/M but rather amplified on account of higher strength to modulus ratio (specific strength) of finished components. Aluminium P/M has been described as a versatile processing technique on account of its ability to modify alloy chemistry to suit specific functions whilst producing a near-net-shape product, wherein, important operating parameters include particle size distribution, blending techniques, pressing, and sintering (Kipouros et al., 2006).

2.3 Sintering of Aluminium

Sintering is one of the most important steps in powder metallurgy. It is the thermal treatment of a powder or compact at a temperature below the melting point of the main constituent for the purpose of increasing its strength by bonding together of the particles (The International Standard Organisation).

The sintering of metals and alloys is difficult due to the reaction between metals and alloys with the gases present in the environment even at room temperature, but more vigorously at higher temperatures.

The sintering of aluminium is not easy because of the presence of thermodynamically stable oxide shell on the particle surface which hinders wetting and solid-state diffusion (Kondoh, et al., 2001). A dew point of less than -140°C or an oxygen partial pressure of 10-50 atm. is required to reduce Al_2O_3 at standard sintering temperatures (Liu, et al., 2007; Lumley, et al., 1999; Schaffer, et al., 2005), such conditions are impossible to achieve by conventional means in either laboratory or industrial fabrication systems, hence, a controlled atmosphere is required for sintering of aluminium. Several aspects on the role of atmosphere, powder shape and size, alloying additions, sintering aids, liquid phase fraction, sintering time and temperature have been studied. They are summarized as below, to offer an understanding on the sintering behavior of pure aluminium and alloyed powder compositions.

2.3.1 Effect of sintering atmosphere

The presence of a very stable Al_2O_3 layer on the aluminium powder particles is a specific feature affecting the aluminium powder technology, particularly the sintering process, because the oxide cannot be reduced during sintering. (Pieczonka, et al., 2008) extensively studied the dilatometric shrinkage of 99.5% purity aluminium powder over a 600˚C sintering temperature for upto 150 min duration under flowing dry N_2-H_2 (maximum 5 vol.% H_2), N_2-Ar ; N_2, Ar, and vacuum. Initial findings pointed out to any noticeable shrinkage by N_2 only, addition of H_2, even in small amounts reduces the shrinkage, similar effect is observed with Ar, although at higher Ar content than H_2.

Only pure nitrogen is an active sintering atmosphere for aluminium, because it promotes shrinkage and sintered mechanical properties, as proved by bend test (Schubert, et al.).

Nitrogen and nitrogen based atmospheres are widely used in sintering of metals and alloys. It is used as a safely purge for flammable atmospheres. It is cheap and useful for replacing the costlier hydrocarbon atmospheres.

The nitrogen has following characteristics:

- It is vry dry with a dew point of less than -65°C.
- It is very pure with less than 10 ppm of oxygen.

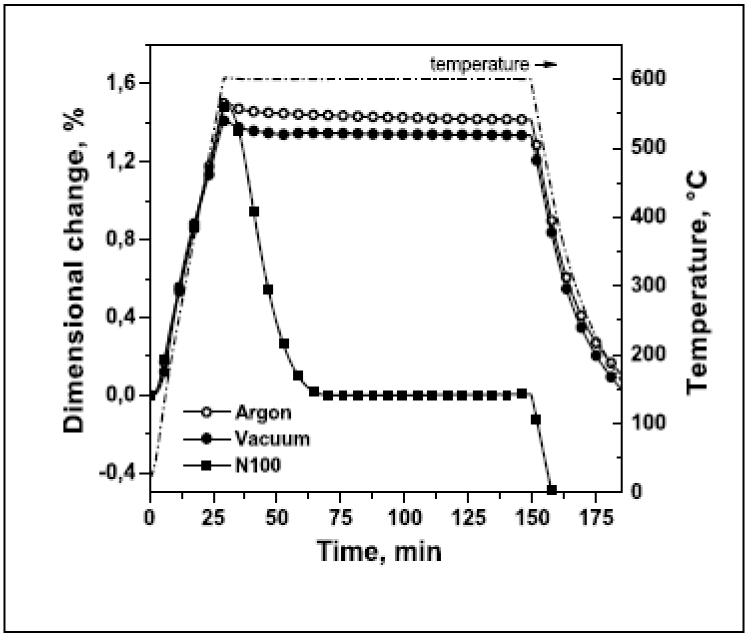


Fig.3 Graphical representation of sintering Al compacts in different atmospheres and vacuum (Pieczonka, T. Schubert, S. Baunack, B. Kieback)

It is evident that nitrogen is the only atmosphere producing shrinkage. The addition of hydrogen, even in small amounts, to nitrogen is detrimentally, because it strongly lowers sintering shrinkage. The higher purity Aluminium powder seems to be more sensitive for hydrogen. The addition of argon to nitrogen also reduces shrinkage, but only at much higher contents than hydrogen. Shrinkage may be quickly interrupted by the atmosphere change during sintering.

The nitriding of the powder particles will only occur if it is preceded by reduction or rather disruption of the Al_2O_3 layer, in this case, attributed to a self-gettering mechanism due to the presence of trace additions (as impurity) of Mg in the aluminium powder. This Mg content diffuses to the boundary of the particle and disrupts the Al_2O_3 film, exposing aluminium to N_2, as evident by the following reactions:

$3Mg + 4Al_2O_3 \rightarrow 3Al_2MgO_4 + 2Al$

$2Al + N_2 \rightarrow 2AlN$

This is a self-replicating reaction and is generally referred to as a self-gettering mechanism, wherein oxygen is removed from the Al_2O_3 layer by forming the spinel Al_2MgO_4 and AlN.

Dhokey, 2012 et al. has investigated that magnesium addition helps to reduce oxide film on aluminium by forming spinel of $MgAl_2O_4$ as confirmed by XRD as this is attributed to decrease dimensional growth till threshold value of 1% Mg and thus it limits the addition of magnesium in powder premix. Beyond this critical content, the surface finish of sintered compacts deteriorates.

2.4 Deformation Processing of Aluminium P/M Alloys

The quality of the product obtained through Powder Preform Forging (PPF) is very much influenced by the various process parameters such as forging temperature, initial preform density, alloying elements and flow stresses.

Chandramouli et al. analysed the influence of material flow constraints during cold forming on the deformation and densification behaviour of P/M steel ring preforms. They concluded that lower geometry ring preforms densify at higher rates under various modes of constrained deformations and under lower flow stresses.

Hot consolidation can be performed on sintered products or directly on cold compacted products. In many cases the product will first be degassed before hot consolidation. The most important techniques of hot consolidation are : forging, extrusion and hot isostatic pressing.

Forging is a high strain rate, hot deformation method which is used for the shaping and further densification of a precompacted and sintered preform.

2.5 Reinforcement V_2O_5

Aluminum alloys with transition metals such as Vanadium and titanium are promising base for fabricating super alloy which can be used for high temperature applications.Transition metals form strong interatomic bonding and low diffusivity in the solid aluminum due to the presence of d and f subshell.

Also vanadium have low density and melting temperature which is near to aluminium melting temperature. These properties of vanadium pentoxide provide uniform mixing and leads to strong bonding between them during sintering process.

It has also been investigated that vanadium pentoxide refines grains in aluminium matrix as it provides active nucleation sites for grain formation.

Chapter 3.Synthesis and Testing Methods

3.1 Powder Metallurgy

Powder metallurgy is a process of producing metal powders and making semi-finished or finished objects from individual, mixed or alloyed powders with or without the addition of nonmetallic constituents. Additives and lubricants are used before compaction. Highly porous parts, precise high performance components and composite material can be produced. It offers compositional flexibility, minimized segregation and the ability to produce graded microstructures. It is having variable physical and mechanical properties.

3.2 Steps in P/M route

The below is the flowchart of the steps of preparing a product through P/M route.

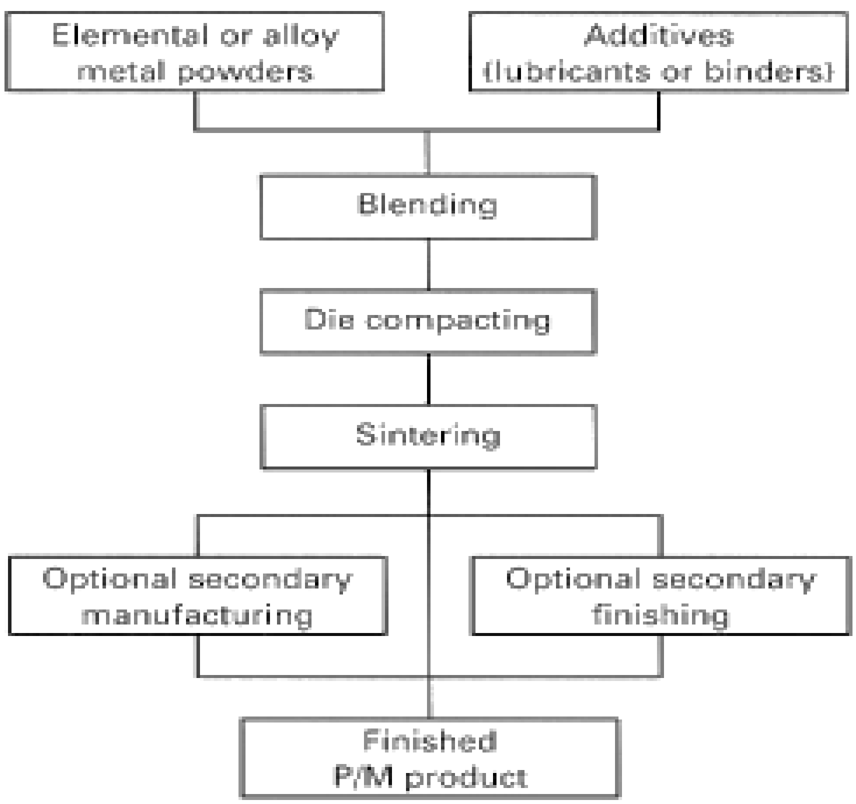


Fig. 4 Schematic represenation of steps involved in Powder metallurgy route

1. **Powder production**–the raw materials for P/M components is the powder. These powders are engineered materials in the sense they are manufactured to precise specifications to facilitate subsequent processing. The powders used can be pure elements, elemental blends or pre-alloyed powders. Powders having desired size range, shape and other characteristics are chosen to obtain the properties required for the end use.

   Powders along with additives are mixed thoroughly using mixers. Lubricants may be added prior to mixing to facilitate easy injection of the compact and to minimize the wear of compaction tool. Typical lubricants include waxes or metallic stearates, graphite and stearates.

2. **Compaction**- compaction of mixed powders is generally carried out using dies machined to close tolerance. Equipment used for compaction includes mechanical or hydraulic presses. The powder type and its characteristics influence the compaction pressure. The purpose of compaction is to produce a green compact with sufficient strength to withstand further handling operations.

3. **Sintering** – sintering of the green compact is carried out in a furnace under a controlled atmosphere to bond the particles metallurgical. Sintering is carried out at atmosphere about 70% of the absolute melting point of the material. Basically, bonding occurs by diffusion of atoms, giving integrity to the compact.

4. **Secondary processes** –

   - **Forging**–it is a process in which unsintered, pre-sintered, or sintered powder preforms are hot formed in confined dies. Powder forging is a natural extension of the conventional press and sinter process. In essence, a porous preform is densified by hot forging with a single blow.

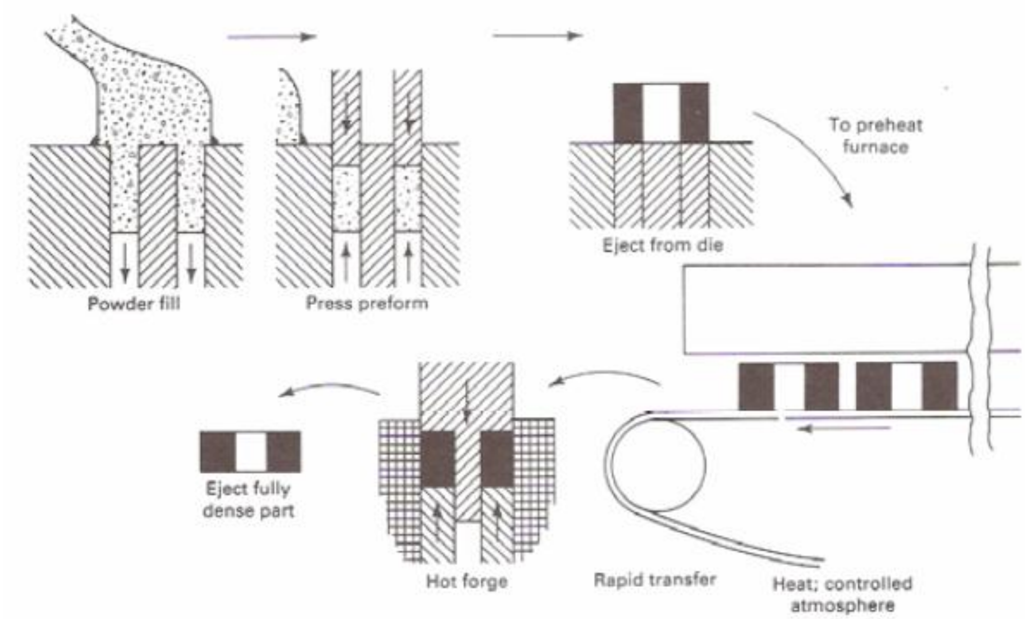


Fig. 5 Schematic of mechanism of hot forging process

3.3 Advantages

Powder Metallurgy has many advantages over other manufacturing processes due to which it is gaining importance.

It has advantages in different aspects such as:

- Process Advantages
- Metallurgical Advantages
- Commercial Advantages

3.3.1 Process Advantages

Various process advantages of Powder Metallurgy are:

- Eliminates or minimizes machining.
- Efficient materials utilization
- Enables close dimensional tolerances.

- Produces good surface finish.
- Provides option for heat treatment.
- Facilitate manufacture of complex shapes.
- Suited to moderate to high volume component production process.
- Produce components in pure form.
- Energy efficient
- Environment friendly

3.3.2 Metallurgical Advantages

Various metallurgical advantages of Powder Metallurgy are:

- Powders with uniform chemical composition with desired characteristics.
- Elemental and pre alloyed powders.
- Unique compositions including non-equilibrium compositions.
- Parts with controlled porosity.
- Materials with improved magnetic property.

3.3.3 Commercial advantages

Powder Metallurgy technique has many commercial advantages as well:

- Ferrous and non-ferrous metallurgy parts can be oil impregnated to function as self-lubricated bearings. Similarly, parts can be resin impregnated to seal interconnected porosity to improve density.
- Parts can be heat treated and plated if required.
- Cost effective production of simple and complex parts.

3.4 Testing

3.4.1 Porosity–

Porosity is inherent to most of the P/M parts. The green compact prior to sintering can be treated as a two phase material consisting of powder particles and porosity. This porosity may or may not be removed during sintering. The sintered products are less or more porous and this has an influence on the properties of the sintered compact.

Porosity present in P/M products depend on a variety of factors such as

i. Compaction pressure and time.
ii. Compaction temperature
iii. Shape of the part
iv. Powder particle characteristics such as size and shape.
v. Material constitution: composites show different sintering characteristics than metals and densification accordingly varies.
vi. Sintering temperature and time: sufficient temperature and time are needed for good densification.
vii. The type and amount of lubricants used have a influence on the level of porosity in the sintered part. Presence of lubricant affects sintering and the dissociation products from lubricant can lead to porosity.

3.4.2 Microstructure –

When a polished flat sample reveals traces of its microstructure, the image is captured using macrophotography. More sophisticated microstructure examination involves higher powered instruments: optical microscopy, electron microscopy, X-ray diffraction and so on, some involving preparation of the material sample (cutting, microtomy, polishing, etching, vapor-deposition etc.). The methods are known collectively as metallography.

3.4.3 Micro hardness-

The **Vickers hardness test method**, also referred to as a micro-hardness test method, is mostly used for small parts, thin sections, or case depth work. The Vickers method is based on an optical measurement system. The Micro-hardness test procedure specifies a range of light loads, using a diamond indenter to make an indentation which is measured and converted to a hardness value. It is very useful for testing on a wide type of materials. A square base pyramid shaped diamond indenter is used for testing in the Vickers scale. The load ranges from a few grams to one or several kilograms. The Micro-hardness methods are used to test on metals, ceramics, and composites.

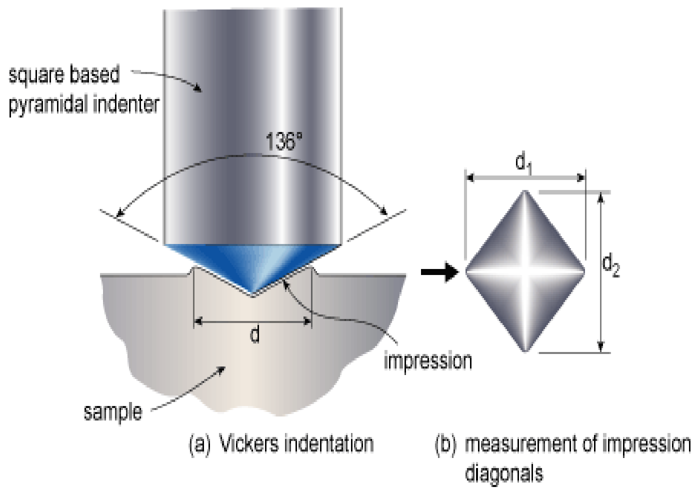


Fig. 6 Schematic of mechanism of indentation of Vicker's Hardness Test

Chapter 4. Experimental Procedure

4.1 Objective

1. To incorporate fine Vanadium powder (1-5 wt.%) in Al-Mg hypoeutectic pre-alloyed powder alloy by conventional blending for further cold compaction and sintering.

2. To determine the effect of sintering temperature on phase evolution, microstructure, hardness and density.

3. To characterize the metallographic properties such as micro-structures and mechanical properties such as micro-hardness.

4.2 Component formation procedure

1. **Powder composition**- The powders were mixed with different composition such as

samples	**Al**	**Mg**	**V_2O_5**
Pure Aluminium	100	0	0
Al-Mg	99.5	0.5	0
Al-Mg-1V_2O_5	98.5	0.5	1
Al-Mg-5V_2O_5	94.5	0.5	5

2. **Blending** – The most important factor in P/M is the particles size, on which the physical and chemical properties of the component depend. Therefore, the powder mixture is blended using the bearing balls of 2mm and 4mm diameter respectively. The balls crushes the powder particles and make them fine and of uniform size.

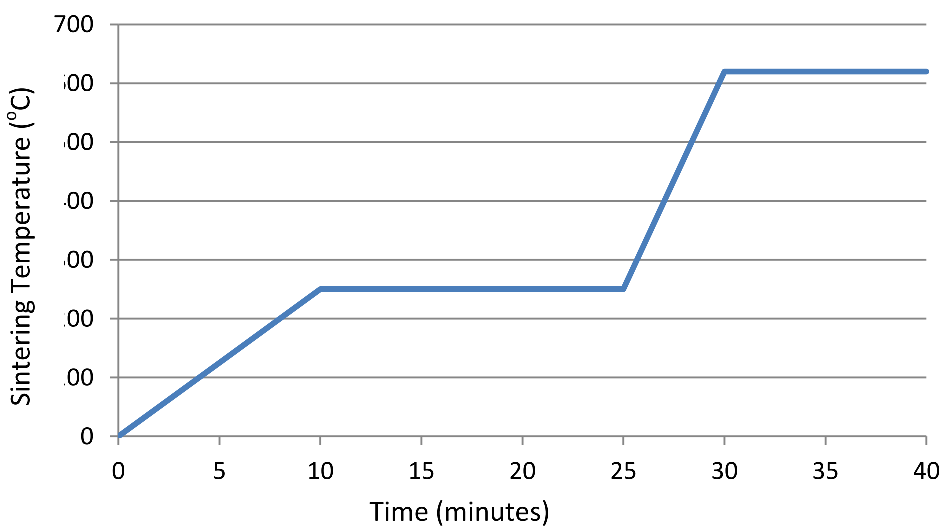
   The blending process is done in a 3D motion mixture, in which the powder mixture and balls are added and is rotated for 40 minutes at 40 rpm.

3. **Compaction**– The blended powder mixtures are cold compacted in a hydraulic press. After compaction a semi-finished product is obtained, in which the particles are bonded just by mechanical force applied by hydraulic press. The product we get is known as 'green compact'. The green compact is very weak and fragile to be handled, so after compaction, sintering is done to make the chemical bonds between the particles.

   The maximum load of hydraulic press used is 100 ton and the load applied on the powder is 22 ton. The releasing load after compaction is 1.5-2 ton.

4. **Sintering** – After compaction, sintering is an essential process to give strength to compacted component. The sintering is done in a chamber at an elevated temperature of maximum 620^{o}C. During sintering the powder particles make bonds with each other and provide strength to the component.

   The gas used in the chamber during sintering is Nitrogen. The Nitrogen is used as it gives a great shrinkage to the component. The sintering processes is shown in graph below -

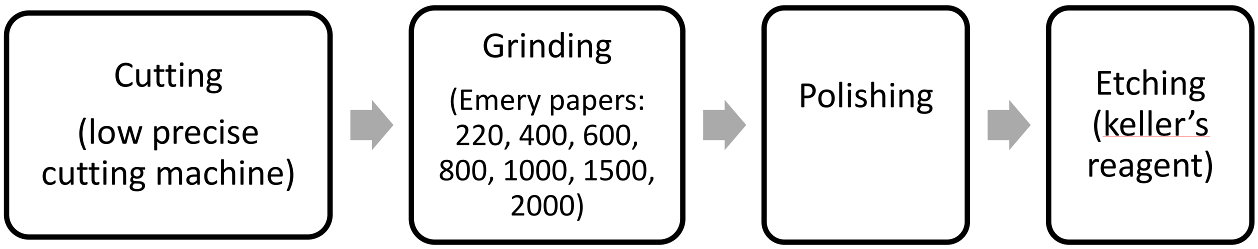


4. **Hot Forging** – The heat treatment process gives the component high strength and hardness. The sintered component is heated in a pre-heated furnace upto 475^{o}C and then holded for about 45 minutes. After holding, the heated component is again compacted in the hydraulic press under the load of 49 tons. The hot forged component results in reduced cross-section.

4.3 Characterization procedure

After sintering, the products formed are characterized. The characterization techniques adopted are microstructure and micro-hardness. The processes involved are as follows –

1) **Sample preparation** –



Cutting cast specimen

Small piece of the cast sample was cut using manual hacksaw.

Grinding

Cast samples were made flat with proper geometry using belt grinder for making the surface flat.

Then by using emery paper of following grades 220,400.600,800,1000,1500,2000 the surface was made exactly flat and severe scratches were removed.

Polishing

During polishing the sample was rotated in exactly 90° after polishing of one side stroke, using diamond polishing, for polishing operation wet cloth was clamped over the wheel, 0.3 micron angular sided diamond paste solution was applied. Specimen was held firmly n hand against the rotating cloth. After which the specimen was washed with water and dried.

Etching

After polishing the component, the polished surface is etched with a specified etchant. For aluminium the etchant used is Keller's reagent. The reagent is prepared as follows –

Keller's reagent –

- 95ml of distilled water
- 2.5ml HNO_3
- 1.5ml HCl
- 1ml HF

After sample preparation, the microstructures are seen through optical microscope and micro-hardness is calculated by vicker's hardness method.

4.4 Optical Microscope –

Metallurgical microscope is used to determine the microstructure, grain size of the mounted specimen. In a typical metallurgical microscope, a horizontal beam of light from the light source is reflected by means of a plane glass reflector downwards through the microscope objective on the surface of the specimen. Some of these incidents light reflected from the specimen surface will be magnified and passing through the plane glass reflector and magnified again by upper lens system of the eye-piece.

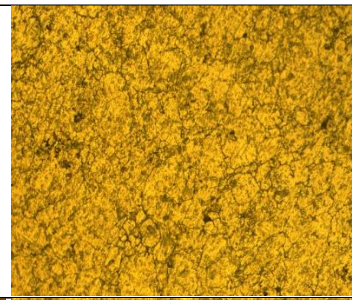
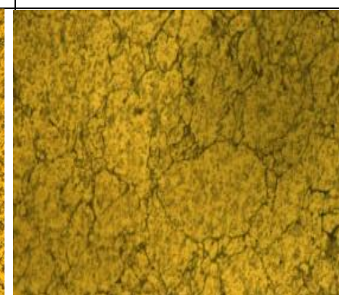
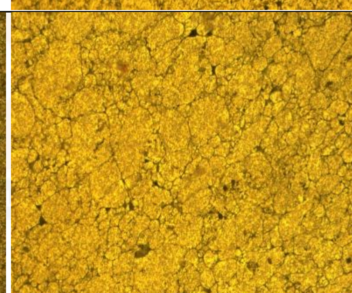
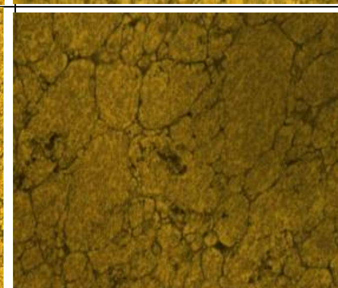
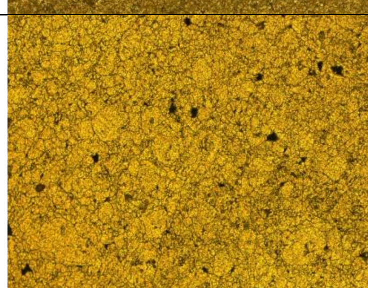
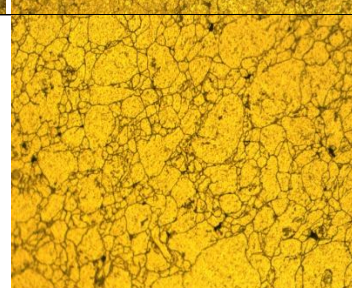
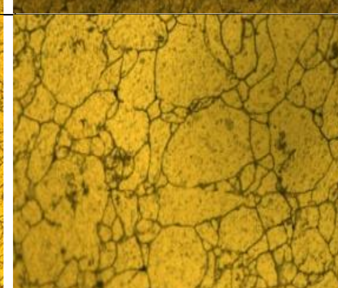
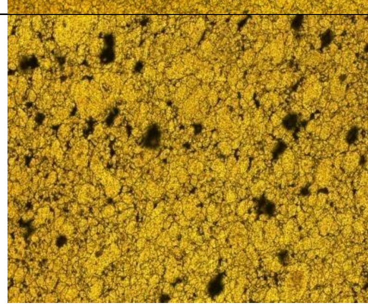
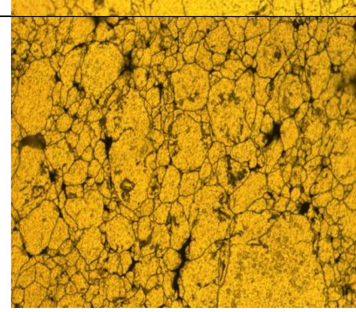
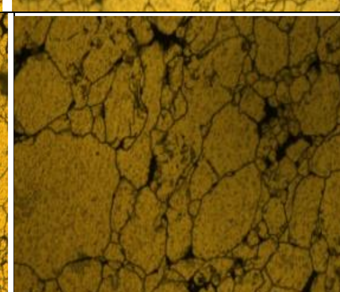
Components of optical microscope –

Components	**Description**
Source	Illuminating source
Condenser	Collimated light source
Aperture diaphragm	Controls the amount of light
Field diaphragm	Area of specimen

Chapter5. Results and Discussion

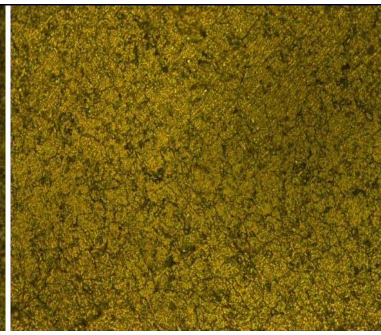
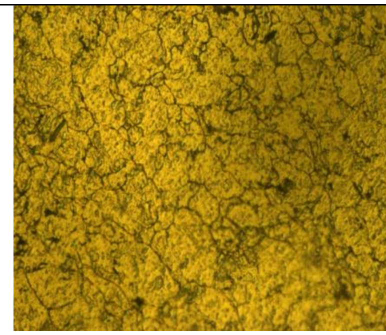
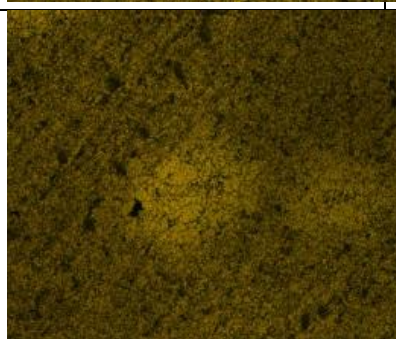
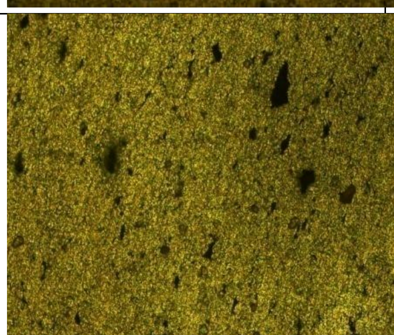
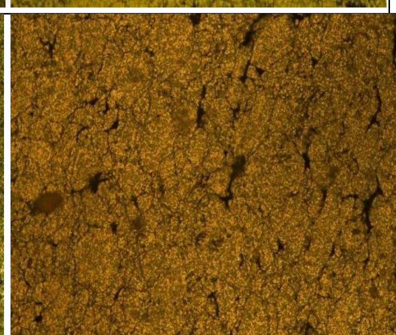
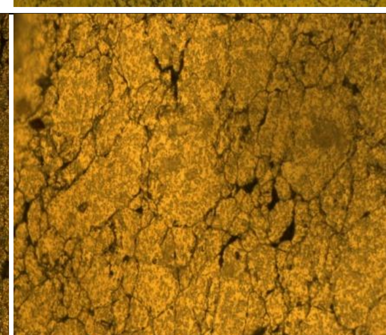
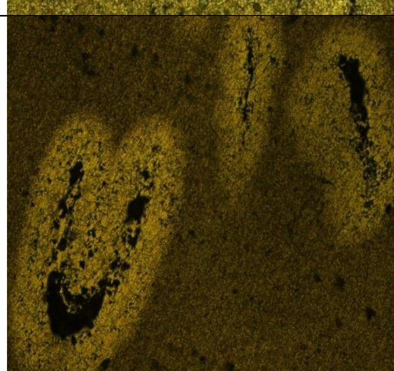
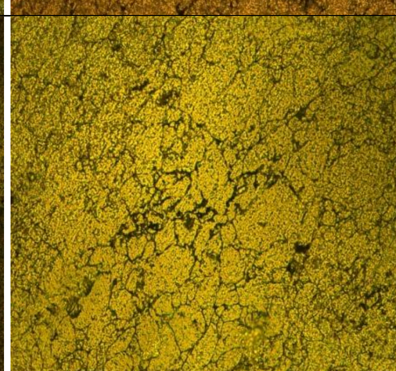
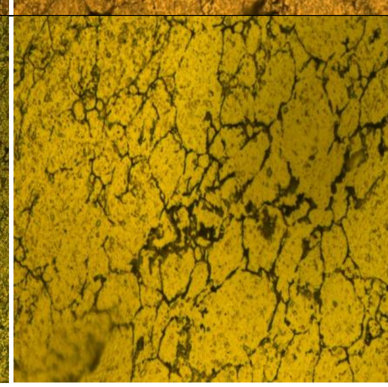
5.1 Microstructure of Sintered Component

Microstructures of the sintered components are viewed under metallographic microscope. The results of produced samples are as follow:

Sample	Microstructure (20X)	Microstructure (50X)	Microstructure (100X)
Pure Al			
Al- 0.5 Mg			
Al- 0.5 Mg- 1 V_2O_5			
Al- 0.5 Mg- 1 V_2O_5			

4.2 Microstructure of Forged Component

Microstructures of the sintered components are viewed under metallographic microscope. The results of produced samples are as follow

Samples	Microstructure (20X)	Microstructure (50X)	Microstructure (100X)
Pure Al			
Al- 0.5 Mg			
Al- 0.5 Mg- 1 V_2O_5			
Al- 0.5 Mg- 5 V_2O_5			

5.3 Porosity

It is easy to calculate porosity based on density of the component.

Formula Used-

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\text{Volume} = \text{Length} \times \text{Breadth} \times \text{Height}$$

For pure Al-

Length (mm)	Breadth (mm)	Height (mm)	Mass (gm)
73.54	12.25	11.20	25.2129

Volume = 73.54 x 12.25 x 11.20

= 10809.25 mm^2 = 10.80925 cm^2

Density = $\frac{25.2129}{10.80925}$ = **2.3895 gm/cm^2**

For Al-0.5 Mg-

Length (mm)	Breadth (mm)	Height (mm)	Mass (gm)
73.64	12.25	11.32	25.6605

Volume = 73.64 x 12.25 x 11.32

= 10.21166 cm^2

Density = $\frac{25.6605}{10.21166}$ = **2.51286 gm/cm^2**

For Al-0.5 Mg- 1V_2O_5-

Length (mm)	Breadth (mm)	Height (mm)	Mass (gm)
73.59	12.24	11.62	25.9826

Volume = 73.59 x 12.24 x 11.62

= 10.4666 cm^2

Density = $\frac{25.9826}{10.4666}$ = **2.4824 gm/cm²**

For Al-0.5 Mg-5V_2O_5-

Length (mm)	Breadth (mm)	Height (mm)	Mass (gm)
73.55	12.26	11.67	25.8283

Volume = 73.55 x 12.26 x 11.67

= 10.80925 cm^2

Density = $\frac{25.8283}{10.80925}$ = **2.3895 gm/cm²**

Theoretical Density (g/cm^3)	**Calculated Density (g/cm^3)**
Pure Aluminium D= 2.69	D= 2.4989
Al- Mg D= 2.68268	D = 2.51286
Al-Mg-1V_2O_5 D **=** 2.68808	D = 2.4824
Al-Mg-5V_2O_5 D = 2.7099	D= 2.3895

It is observed that with increase in the weight percentage of V_2O_5 the porosity of the produced composite decreases.

5.4 Micro-hardness

Using vicker's hardness test, the micro-hardness of the produced component are as follow:

Applied Load = 50 gf

Loading Time = 5 sec.

Resolution= 50X

5.4.1 Micro-hardness of Sintered Product

For pure Al-

	D_1	D_2	HV
1.	59.16	60.54	25.88
2.	67.99	66.84	20.40
3.	60.59	57.97	26.38

For Al - 0.5 Mg-

	D_1	D_2	HV
1.	80.44	81.36	28.33
2.	76.42	82.00	29.55
3.	56.31	59.64	27.59

For Al – 0.5 Mg – 1 V_2O_5 –

	D_1	D_2	HV
1.	57.74	57.84	27.76
2.	53.20	54.75	31.83
3.	52.94	52.97	33.32

For Al – 0.5 Mg – 5 V_2O_5 –

	D_1	D_2	HV
1.	55.40	59.00	28.34
2.	49.69	55.78	33.34
3.	50.47	54.88	33.41

5.4.2 Micro-hardness of Hot Forged Product

For pure Al-

	D_1	**D_2**	**HV**
1.	45.93	47.69	42.32
2.	45.93	46.91	43.02
3.	45.54	44.86	45.38

For Al – 0.5 Mg-

	D_1	**D_2**	**HV**
1.	45.80	44.47	45.51
2.	45.15	44.22	46.44
3.	41.13	46.40	48.41

For Al – 0.5 Mg – 1 V_2O_5-

	D_1	**D_2**	**HV**
1.	41.26	44.73	50.16
2.	44.24	44.99	46.58
3.	41.26	41.64	53.96

For Al – 0.5 Mg – 5 V_2O_5 –

	D_1	**D_2**	**HV**
1.	46.19	43.96	46.64
2.	42.30	43.83	50.00
3.	40.42	39.23	55.91

Chapter 6. Conclusion

The synthesis and characterization of the components by P/M route give results about the physical and chemical properties. The conclusions made from the results are as follows –

- After sintering –

1. From the microstructures it can be seen that with increase in the concentration of vanadium pentoxide, the size of the grains decreases (Fig.) and thus the strength of the component increases.

2. From the comparisonof the theoretical and calculated density of the component, it is observed that with increase in vanadium pentoxide concentration, the difference between the calculated and theoretical density increases, and thus the porosity increases.

3. From vicker's hardness test it is seen that, with increase in the concentration of vanadium pentoxide the micro-hardness also increases.

- After hot forging –

1. The grains are found more refined than the sintered components with increase in vanadium pentoxide concentration. Thus the heat treatment helps in the grain refinement and thus increases in strength.

2. The vicker's hardness is also increased compared to the sintered components.

References

1. Abdel-Rahman M., and El-Sheikh, M. (1995). Workability in forging of powder metallurgy compacts. Journal of Materials Processing Technology, (54), 97–102.
2. Abouelmagd, G. (2004). Hot deformation and wear resistance of P/M aluminium metal matrix composites. Journal of Materials Processing Technology, (155-156), 1395– 1401.
3. Neubing H., Sinteraluminium – Der konsequente Weg vom Pulverprodukt zum Leichtbauteil, *Pulvermetallurgie in Wissenschaft und Praxis*, Hagen, 20(2004), 3-29.
4. Dudas, J.H., C.B. Thompson, C.B., Improved sintering procedures for aluminium P/M parts, *Aluminium Company of America* Form F38-12964 (1970), 1-12
5. Schaffer G.B. and B.J. Hall, The Influence of the Atmosphere on the Sintering of Aluminium, *Metallurgical and Materials Transactions A*, 33A(2002), 3279-3284.
6. Pieczonka T., Gácsi Z., Kretz F. and Kovács J., Sintering behaviour of Al-SiC powder mixtures controlled by dilatometry, *Proc. of Euro PM2004*, compiled by H. Danninger, EPMA, Shrewsbury, UK (2004), vol. 2, 95-100.
7. Agarwala, R. C., Agarwala, V. and Garg, L.M. (1998) production of reinforced castings containing stainless steel wires in Aluminium alloy BergUndHuttenmannischeMonatshefte, . (143) 3 86–.89
8. Agarwala, V., Satyanarayana, K. G., and Agarwala, R. C. (1999). Studies on the development of aluminium alloy–mild steel reinforced composite. Materials Science and Engineering: A, 270(2), 210–218.
9. Aghajanian, M., and Rocazella, M. (1991). The fabrication of metal matrix composites by a pressureless infiltration technique. Journal of Materials Science, (26), 447–454.
10. Alahelisten A., Bergman F., Olsson M. and Hogmark S. (1993). On the wear of aluminium and magnesium metal matrix composites. Wear, 165(April), 221–226.
11. Alsaran, A., Çelik, A., and Karakan, M. (2005). Structural, mechanical and tribological properties of duplex-treated AISI 5140 steel. Materials Characterization, 54(1), 85–92.
12. Alpas, T., and Zhang, J. (1994). Effect of microstructure (particulate size and volume fraction) and counterface material on the sliding wear resistance of particulate-

reinforced aluminium matrix composites. Metallurgical and Materials Transactions A, 25(5), 969– 983.

13. Arsenault, R. J. (1988). Relationship between strengthening mechanisms and fracture toughness of discontinuous SiC/Al composites. Journal of Composites Technology and Research, 10(4), 140–145.

14. Asgharzadeh H., and Simchi, A. (2008). Hot deformation of PM Al6061 alloy produced by sintering and powder extrusion. Powder Metallurgy, 51(4), 354–360.

15. ASM International. (1990). ASM Handbook–Volume 1: Properties and Selection: Irons, Steels, and High Performance Alloys. ASM International. ASM International, Materials Park, OH, USA

16. Ibrahim, I. A., Mohamed, F. A., Lavernia, E. J., 1991, "Metal Matrix Composites" A Review Journal of Material Science, Vol.26, pp.1137 – 1157.

17. Park, B. G., Crosky, A. G., Hellier, A. K., 2001, "Material Characterization and Mechanical Properties of Al2O3-Al Metal Matrix Composites" Journal of Material Science, Vol. 36, pp. 2417 – 2426.

18. N. Nagendra, B.S. Rao, V. Jayaram, Microstructures and properties of Al2O3/Al-AlN composites by pressurless infiltration of Al-alloys, Materials Science and Engineering A269 (1999) 26-37.