Synthesis and characterization of copper oxide particulate reinforced aluminium matrix composite

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ABSTRACT

The need for advanced composite materials has become necessity for today's world due to greater mechanical and physical properties compared to the regular materials. In this research, a metal matrix composite (MMC) containing Aluminium (Al) and copper II oxide or cupric oxide (CuO) is synthesized using Powder Metallurgy Processing Technique and is then tested for hardness which is a predominant mechanical property for any metal matrix composite in all applications. Composite is synthesized using different compositions of participating components and then tested for hardness. Cupric oxide being an abrasive material is aimed to improve the hardness of the composite rather than using the Aluminium alone in applications. Morphology of the composite and phase composition will be evaluated using different hardness tests. Microstructure of the specimen will be observed for distribution of cupric oxide within the metal matrix which will be responsible for hardness enhancement of the material. Aluminium and cupric oxide being lower density materials, high strength to weight ratio, good mechanical properties will be very useful for many applications such as aerospace and are emphasized in this study.

Keywords: - *Metal matrix composite, aluminium, powder metallurgy, microstructure, hardness, mechanical properties*

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1. INTRODUCTION

Many metal matrix composites have been developed in past years, in which Aluminium composites have found various applications in many industries including aerospace. Particulate composites have been commercially produced in recent years for various applications. In automobile industry, Aluminium and silicon carbide composites have grown potential interest and soon expected in production. However, due to vastness of automobile industry, amount and cost of silicon carbide is expected to be barrier for widespread use of such composite in automobile applications. Therefore we are going to study synthesis and characterization of copper oxide-aluminium composite which will have potential of becoming low cost composite and also has wide variety of applications in industry. With use of composite materials, higher weight reduction is achieved without compromising the stiffness and strength due to high strength to weight ratio.

The objective of this project is to develop a low cost composite material with good mechanical properties using synthesis by powder metallurgy processing and study the characterization of the synthesized composite. This will include observation of microstructure of the synthesized samples for distribution of particulate within the matrix which will be responsible for improved mechanical properties. Also mechanical testing of the developed material will be done for hardness.

Synthesis of the composite samples is done using powder metallurgy processing technique. Powder metallurgy technique consists of distinct steps consisting mixing or blending, compaction, sintering and polishing or finishing. After synthesis, characterization and microstructure study is done using electronic optical microscope and later, hardness tests are done using standard testing techniques.

2. LITERATURE REVIEW

"Aluminium Properties and Physical Metallurgy" by John E. Hatch [1] describes all the metallurgical aspects of Aluminium. It consists of basic properties of pure aluminium to advanced uses of Aluminium and its alloys and compositions as well. It involves effects of impurities, constitution and microstructure of aluminium alloy powders, metallurgical and heat treatment aspects and even corrosion behavior of aluminium based products. It deals with Aluminium powder and powder metallurgy products. It also provides applications of aluminium powder metallurgy products which are discussed in further sections. It also involves various microstructure studies of aluminium powder metallurgy products and specimens.

Mehdi Rahimian et al. [2] worked on "The effect of particle size, sintering temperature and sintering time on the properties of Al–Al_2O_3 composites made by powder metallurgy". They studied the effects of the different particle sizes used in powder metallurgy as well as sintering temperatures for Aluminium matrix composite synthesis and their effects on the properties of the developed product material. It gives us the average particle size for alumina as 3, 12 and 48 μm and sintering temperature and time in range of 400 to 600°C for 30 to 90 minutes. The investigated properties of the samples include microstructure, density, hardness and mechanical properties. It is concluded that the variation in the properties of the samples are dependent on composition, sintering temperature and time.

"Fundamentals of aluminium metallurgy - Production, processing and applications" by Roger Lumley [3] gives information about basic fundamentals of Aluminium metallurgy as well as rigorous information about the production, processing and also the applications of the metal in various fields. Its different sections on production of primary, secondary aluminium and its products, processing of aluminium based alloys and composites and applications give distinctive information for the synthesis of our sample. The "aluminium powder metallurgy" section deals with all the process parameters of aluminium based powder metallurgical products such as compositions, compaction pressures, sintering temperatures and time etc. also it sheds light on future trends and probable applications for aluminium based metal matrix composites. It also involves various case studies for applications of aluminium and its alloys in various fields and regions of industries.

"International Journal of Powder Metallurgy – volume 46, edition 2" [4] gives various recent trends in the powder metallurgy field. Its focus is on "Microminiature Powder Injection Molding process and its applications". It also involves other recent developments of nitriding responses on powder metallurgical products of Titanium, high strength powder injection moulded stainless steel and aluminium products". It also gives us latest advancements and techniques used in powder metallurgy processing. Importance of sintering temperature and time and also correct compaction parameters are emphasized in this issue.

R. Q. GUO et al. [5] worked on "Preparation of aluminium–fly ash particulate composite by powder metallurgy technique". It includes analysis of powder metallurgical products of aluminium with various compositions and parameters of fly ash. Effect of increasing the composition of fly ash was found out and also its limitations. The major contribution of this study is the density, strength and hardness of the sintered samples were the function of the amount of particulate ash involved concluding the effect of the particulate reinforcements in aluminium based composite products. Although the hardness seemed to increase as the fly ash amount was increased, it was observed to decrease beyond 10% of particulate composition.

Mehdi Rahimian et al. [6] worked on "The effect of production parameters on microstructure and wear resistance of powder metallurgy Al–Al_2O_3 composite". They worked on the effect of production factors on properties and wear resistance of Aluminium based composites. Various particle sizes combinations are tested as well as sintering temperature and time is also varied. Resultant hardness, wear resistance, structure and density and homogenization of the microstructure is studied. A finer grain size is observed at low size and higher amount of the reinforcement particles within the testing combinations.

ASTM Standard Designation: B243 – 13 dealing with "Standard Terminology of Powder Metallurgy" [7] is used for understanding purposes and standardization of the powder metallurgy processing technique.

3. METHODOLOGY

Following methodology has been adopted for the study.

3.1 **Process Flow-**

Flowchart shown in Fig. 1 indicates the step by step methodology adopted for the study.

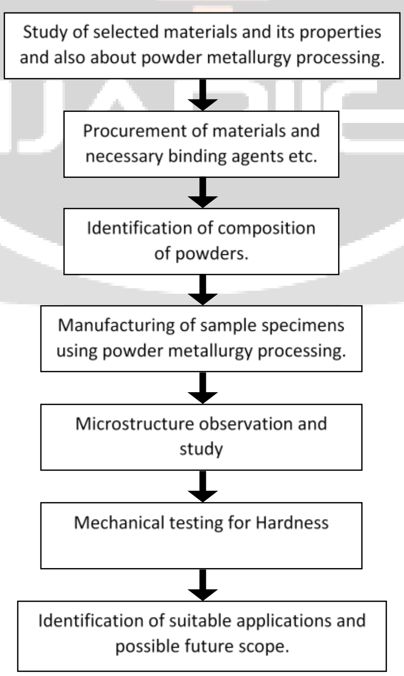

Fig. 1- Process Flow

3.2 Powder metallurgy processing

It is a technique of processing various materials in powder form to produce a new product with enhanced mechanical and physical properties. It consists of blending or mixing fine powdered materials, compacting them in applicable shapes, and then sintering in a controlled environment to bond the sample. Powder metallurgy is also used in "3D printing" of metals. Basic powder metallurgy process is as shown in fig. 2.

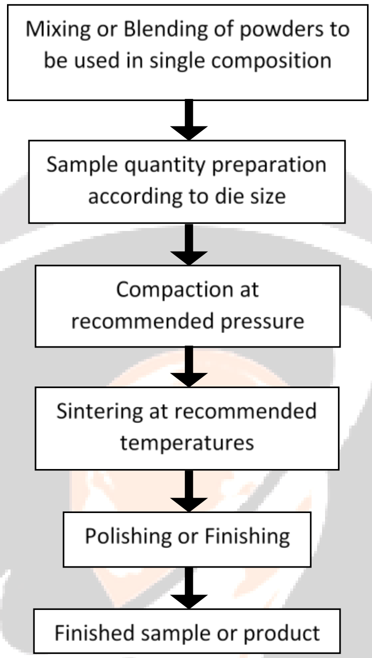

Fig. 2- Powder Metallurgy Process

3.3 Material characteristics

In this study, cupric oxide is used as particulate which is reinforced into aluminium matrix. Both the constituents have been used in fine powder form. Key properties of the aluminium powder used are given in table no. I below from manufacturer's catalogue.

Table 1. Properties of AL. Powder

Property	**Value**
Purity	98%
Grade	Extra pure
Colour	Grey powder
Melting point	660°C
Auto ignition temperature	760°C
Boiling point	2327°C
Density	2.7 g/cm^3

Similarly, key properties for cupric oxide are given in table no. II below.

Table 2. Properties of CuO powder

Property	**Value**
Colour	Black powder
Melting point	1326°C
Boiling point	2000°C
Density	6.3 g/cm^3

Key advantages of usage of Aluminium in powder metallurgy-

- Light weight (Density - 2.7 kg/m^3)
- Excellent compressibility
- High strength (up to 700 MPa)
- High thermal and electrical conductivity.
- Good corrosion resistance

In this study, composite material containing cupric oxide and aluminium is synthesized using powder metallurgy processing. Later, these samples are subjected to microstructure characterization and hardness testing. Also comparative study is done using pure aluminium form and particulate inclusion form. Samples with 4 varying compositions are synthesized as 5%, 10%, 15% and 20% particulate inclusion within aluminium matrix. These are compacted at 120 to 150 MPa [2][3] pressures and sintered at 450°C for 1 hour each [2][3].

4. EXPERIMENTAL SYNTHESIS

Samples of varying compositions are prepared using powder metallurgy processing technique. Various stages in the synthesis are given below-

4.1 Blending or mixing

Blending is a very important process in the powder metallurgy processing. Proper and uniform mixture of the constituent powders is of key importance for a proper and reliable sample preparation. In order to make the proper and fine mixture of the constituents, aluminium powder and cupric oxide powder, each composition powder mix i. e. 5%, 10%, 15% and 20% particulate mixtures are properly mixed and then blended using planetary ball milling machine for 1 hour each as shown in fig. 3 below.

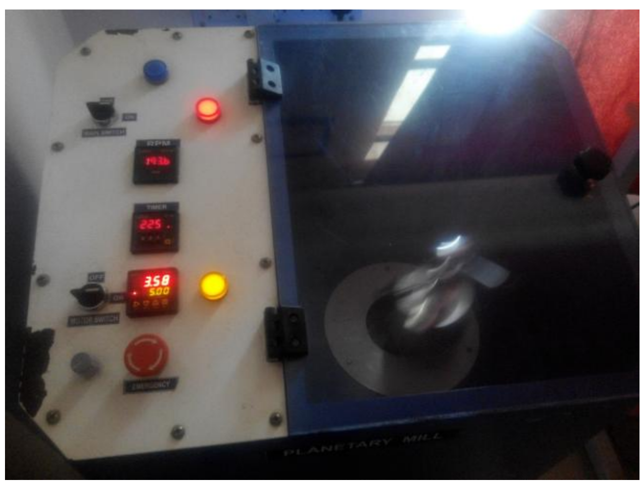

Fig 3- Planetary ball milling operation

Specifications of the planetary ball milling machine are given in table no. 3 below-

Table 3. Specifications of planetary Ball mill

Name	Planetary Ball Mill
Make/Model	VBCC
Feed materials	Soft, hard, fibrous, dry or wet
Size reduction principle	Impact, friction
Material feed size	< 10 mm
No. of grinding stations	1
Final fitness	< 1 μm
Grinding jar size	250 ml

4.2 Compaction

It is the process of pressurizing the blended mixture of powders into die cavity for sample preparation. Standard circular die of 10 mm internal diameter and 50 mm height is used for sample preparation. Compaction die is shown in fig. 4 below. [8]

Fig 4- Compaction die

According to the density of sample and die limitations, 1.5 gm. of the mixture is poured into the die cavity. Compaction is done at pressure of 135 MPa in standard pneumatic compaction machine as shown in fig 5 below.

Fig 5- Pneumatic compaction machine

4.3 Sintering

After compaction, the samples are then heat treated for sintering purpose. Sintering temperature is taken 450°C as recommended for aluminium matrix composites. Samples are kept in sintering furnace for 1 hour curing period. Sintering furnace and process is shown in fig. 6 below.

Fig 6- Sintering furnace

Specifications of furnace are given in table no. IV below-

Table 4. Furnace specifications

Name	Muffle Furnace – Box type
Make	INDFURR
Area	150x150x300 mm
Maximum temperature	1050°C
Voltage	230V/Single phase 50Hz/3.5 kW

After sintering, samples are taken out and kept at room temperature for cooling purpose.

4.4 Summary

In powder metallurgy processing technique, for good microstructure morphology, proper compaction pressure and sintering temperature with curing is very important. In our composite material, chemical etching is not required as there is no molten matrix material involvement. In the table no. V below, the sample preparation data is summarized along with pure aluminium sample [8].

Table 5. Sample preparation data

Sl. No.	Aluminium (%)	Copper Oxide (%)	Compaction Pressure (MPa)	Sintering Temperature (°C)
1	100	0	120	470
2	95	5	135	450
3	90	10	135	450
4	85	15	135	450
5	80	20	135	450

Phase composition microstructure and morphology is evaluated from different hardness tests. In this study, microstructure study is done using optical electronic microscope with 100x zooming as shown in fig. 7 below.

Fig 7- Optical Electronic Microscope

Along with microstructure study, Brinell hardness and Micro-Vickers hardness are evaluated for each composition sample.

5. RESULTS AND DISCUSSION

5.1 Microstructure Study

Microstructure for pure aluminium sample (100% aluminium without reinforcement) [6] is shown in fig. 8 below-

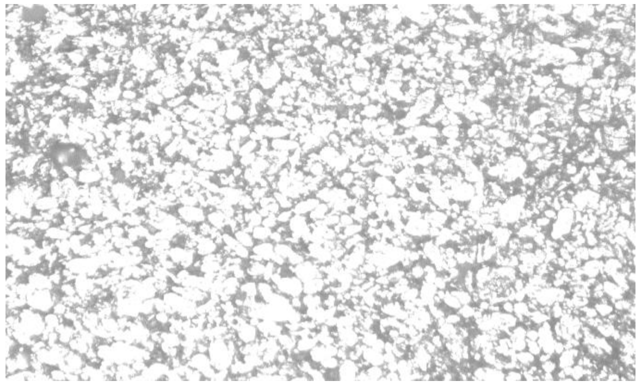

Fig 8- Pure Aluminium sample (100x) [8]

Similarly microstructure study for different compositions i. e. 5%, 10%, 15% and 20% reinforcement is shown in fig. 9, 10, 11 and 12 respectively.

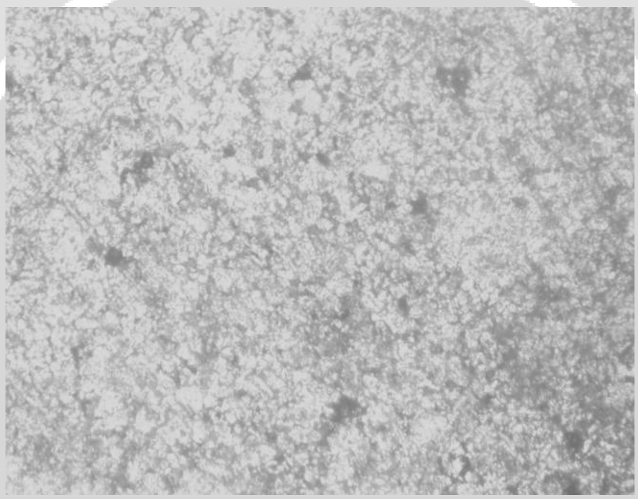

Fig 9- 5% CuO reinforcement (100x)

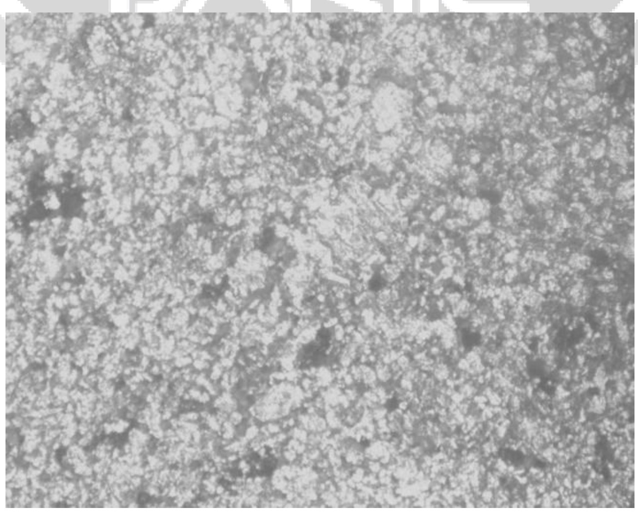

Fig 10- 10% CuO reinforcement (100x)

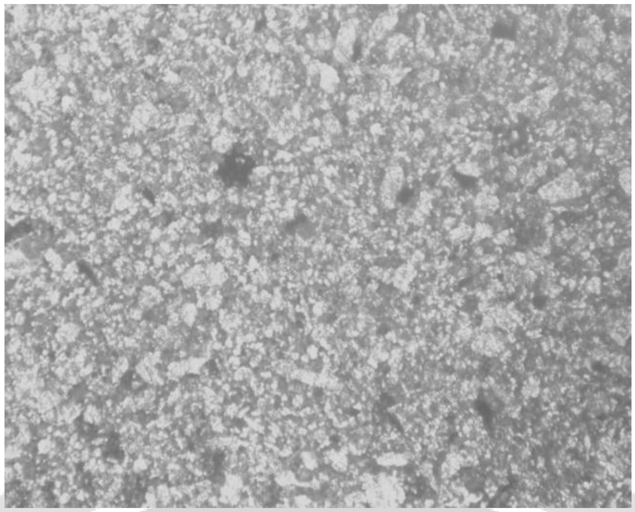

Fig 11- 15% CuO reinforcement (100x)

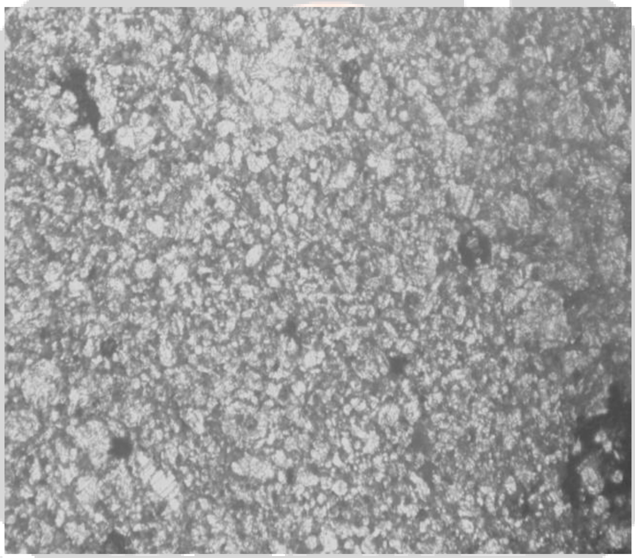

Fig. 12- 20% CuO reinforcement (100x)

The reinforcement used is cupric oxide which is black in color, the black inclusions in the microstructure identifies the distribution of cupric oxide within the shiny aluminium matrix which goes on increasing as the proportion of reinforcement is increased from 0 to 20% as shown in above fig. 9 to 12.

5.2 Brinell hardness testing

After microstructure study, Brinell hardness testing is done on “Rockwell come Brinell hardness testing machine” as shown in fig. 13 with sample under indenter in fig. 14 For Brinell hardness test, load is taken as 100kgf as recommended for aluminium matrix composites with scale “B” and indenter used is 1/16” ball indenter.

Fig. 13- Brinell Hardness Testing Machine

Fig. 14- Sample under indenter for Brinell hardness test

For each composition sample, 3 test readings are taken and average hardness value is taken for consideration. The results for the Brinell hardness test are given in table no. 6 below.

Table 6. Brinell Hardness test results

Sl. No.	Composition (Al%+CuO%)	Brinell hardness number
1	100+0	B48
2	95+5	B58
3	90+10	B71
4	85+15	B79
5	80+20	B89

As seen from the Brinell hardness values for different composition samples, the hardness is increasing as we go on increasing the proportion of reinforcement i. e. cupric oxide into aluminium matrix.

5.3 Micro-Vickers hardness testing

Micro-Vickers hardness testing machine is shown in fig. 15 below with sample under indenter in fig. 16.

Fig. 15- Micro-Vickers hardness testing machine

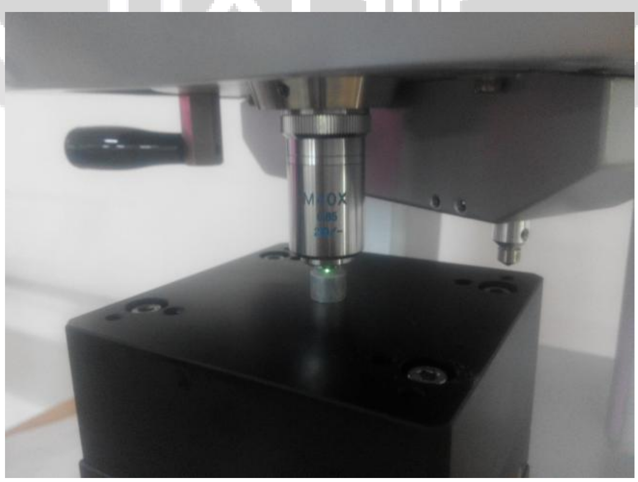

Fig. 16- Sample under microscope/indenter for Micro-Vickers hardness test

This testing is done with use of microscopic identification of the deformation which occurs after the sample is loaded. In this testing, Vickers diamond indenter is used with 10 sec. hold time. Following are the results of the test shown in table no. 7 below.

Table 7-Micro-hardness test results

Sl. No.	Composition (Al%+CuO%)	L1	L2	Lavg	Micro-Vickers Hardness value
1	95+5	124.72	123.26	123.99	24.1
2	90+10	117.14	118.25	117.69	25.8
3	85+15	111.08	113.85	112.46	29.3
4	80+20	110.77	109.12	109.94	31.2

The values L1, L2 and Lavg given in table no. 7 above are the microscopic length values of the indentation on the sample under testing after load is applied. L1 represents the horizontal deformation and L2 represents the vertical deformation in the diamond shaped indentation on the sample while Lavg being the average value of L1 and L2. Fig. 17 below illustrates the sample indentation and the calculations.

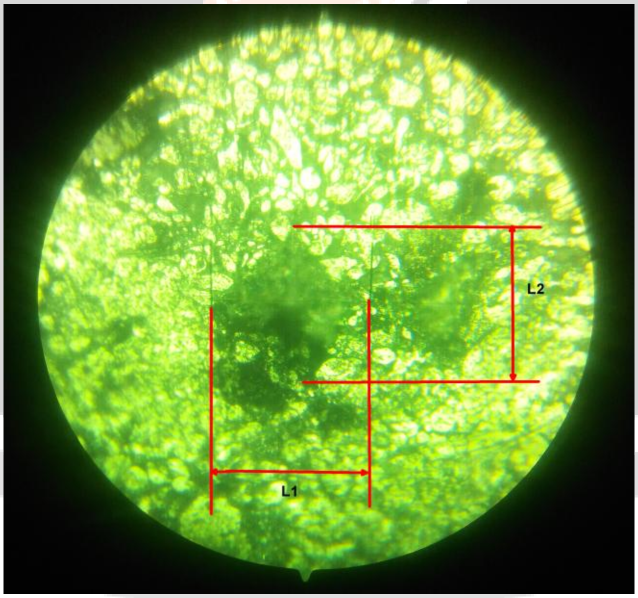

Fig. 17- Indentation parameters in micro-hardness testing

5.4 Summary

Microstructure study has been completed using optical-electronic microscope with 100x zooming for different composition samples as shown in fig. 9 to 12 above. Also morphology and hardness testing is done using Brinell harness testing machine and micro-Vickers hardness testing machine and results are given in table no. VI and VII respectively.

Graph between different hardness values vs. the increasing proportion of reinforcement (cupric oxide) in the aluminium matrix is shown in chart no. 1 below.

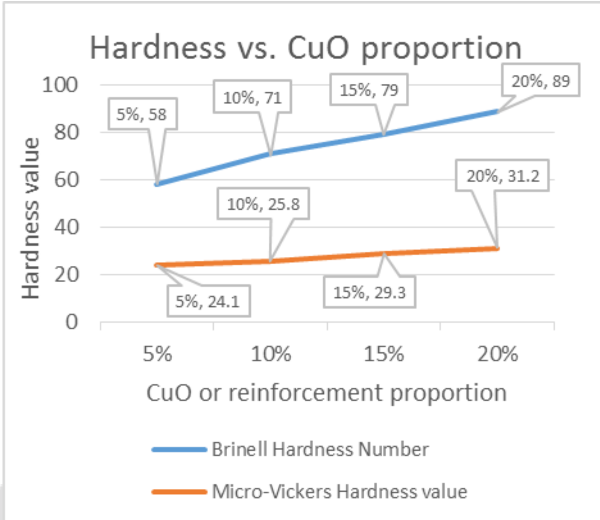

Chart 1- Hardness vs. CuO proportion

As seen from above chart, hardness of the synthesized material is increasing with the amount of reinforcement added to the aluminium matrix. Increased hardness for similar material is a useful advantage in many applications. Major application of metal matrix composites such as this cupric oxide reinforced aluminium matrix composite is in aerospace industry. Aluminium is greatly useful with high strength to weight ratio in aerospace and this increased hardness with no major contribution to cost is a considerable advantage for such. Also, recently automobile industry is also trending towards different composite materials for use in many areas such as leaf springs in suspension etc. with higher strength to weight ratios. This composite material will be useful in automobile industry.

6. CONCLUSIONS

Aluminium being one of the metals which is used very widely in broad spectrum of all industries, improvement in the physical properties without significant addition of cost or appearance, the cupric oxide reinforced aluminium matrix composite is a very useful outcome. With addition of reinforcement as cupric oxide, hardness of the synthesized material is increased with respect to the pure aluminium metal. As further reinforcement proportion is added, the increasing trend continues till 20% and beyond up to certain limit which can be evaluated with further experiments. At the 20% proportion of reinforced cupric oxide in aluminium gives up to 86% increase in the hardness compared to pure aluminium as confirmed through Brinell hardness testing. Aluminium being a light weight material with good mechanical properties, addition of copper oxide improves the hardness further which is very effective advantage in various applications such as aerospace industries or automobile industries etc. where higher strength to weight ratio is an optimal requirement.

6. REFERENCES

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BIOGRAPHIES (Not Essential)

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