Design, fabrication of Powder Compaction Die and Sintered behavior of Copper Matrix Hybrid Composite

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Abstract – *An extensive research is being carried out to invent new materials to meet various requirements with respect to materials. Composite material is one such option that which can be explored and utilized in Manufacturing, aerospace, defence, automobile sectors. Therefore, in this research work a powder compaction die is designed and fabricated through WEDM process and synthesized Copper- 4 wt% TiC- 3 wt% Graphite matrix composite was reinforced with different percentages of SiC (3, 6 and 9 wt %) through blending, followed by compaction and sintering. Hardness and compressive strength results were carried out for those specimens and finally concluded that the hardness of the specimens increased with increase in SiC weight percentage in the composition and 6 wt% SiC shows the high compressive strength among remaining compositions. This copper matrix hybrid composite have extensive applications in manufacturing of bushes and bearings, heat transfer conductors, high conductivity electrical contactors and so on.*

***Key Words*: Hybrid Composite, Sintering, TiC, SiC.**

1. INTRODUCTION

Recently new materials have taken the important position in engineering field. Those materials fulfill the demand of almost all engineering applications maintaining tremendous mechanical and physical properties. In present situation, various scientists and researchers have developed the unavoidable compatible new engineering materials. Various materials have been combined with each other and give intended properties in each and every part of the world i.e. the development of new materials give another unique property and are different from their base materials.

1.1 Introduction to Composite Materials

A composite material can be defined as combination of two or more materials that results in better properties than those of the individual components used alone. In contrast to metallic alloys, each material retains its separate chemical, physical and mechanical properties. The two constituents are as reinforcement and a matrix. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part [1].

Metal matrix composite (MMCs) have attained growing importance because of their potential applications in the automobile, aerospace, sporting goods and general engineering industries due to their excellent properties (e.g., high specific strength, elastic modulus, specific stiffness, desirable coefficient of thermal expansion, elevated temperature resistance and superior wear resistance) [2].

1.2 Introduction to manufacturing of composites

There are some different manufacturing processes that are available to manufacture new type of composites. They are given below:

- Solid state processing
- Liquid state processing
- Plasma arc cutting
- Hand layup processing
- Spray up processing
- Resin transfer molding
- Pultrusion processing
- Pressure bag molding
- Compression molding.

1.3 Importance and Selection of Manufacturing Processes:

Manufacturing is a series of complex interaction between materials, machines, energy and people. It begins with creation of individual parts that are finally assembled to produce final product. Every method of production uses its own basic principles for impacting desired shape, accuracy and surface finish. There are many factors involved in selection of appropriate manufacturing process. However, the selection is usually made on the basis of the following considerations:

1. Materials to be used
2. Shape and size of the components
3. Accuracy and surface finish
4. Volume of production
5. Economy [3].

Though there are many different type of manufacturing processes, Powder metallurgy is the best option to manufacture this copper matrix hybrid composite because it satisfies below considerations.

- Efficient material utilization
- Enables close dimensional tolerance
- Good surface finish
- Manufacturing of complex shapes possible
- Environment friendly, energy efficient
- Suited for moderate to high volume component production.

2. Design and fabrication of Die for Powder compaction press:

Before going to fabricate the composite material, the die is needed for compaction process which is one of the major steps in powder metallurgy.

2.1 Design of the die:

Depending upon the work-structure the die, design has been carried out considering all the work-conditions. The design portion basically consists of the formulation of plan to satisfy the conditions for the given need. The plan results a product which is usable, safe, marketable, reliable and competitive. Usually a quite number of such characteristics are taken for consideration in design situation,

- Chemical composition and mechanical properties of material selected
- Maximum working load
- Green compact size
- Thickness of green compact [4].

Dimensions of Die:

- Die: 50mm of Outer diameter, 15mm of Inner diameter, 70mm of height of the die.
- Plunger: 15mm of diameter, height of 80mm.
- Pellet: 15mm of diameter, 5mm height.

Working load (F) - 15 KN

- Stress developed in plunger due to applied load of 15 KN:

Area, A = $\frac{\pi}{4}d^2 = \frac{\pi}{4}(15)^2 = 176.715\ mm^2$.
Stress, $\sigma_1 = \frac{Load}{Area} = \frac{15000}{176.715}$ = 84.88 MPa (i.e., 15KN is the safe load for plunger).

- Stress developed in die due to load applied on plunger:

$\sigma_2 = \sigma_1 \left[\frac{r_o^2 + r_i^2}{r_o^2 - r_i^2}\right] = (84.88)\frac{25^2 + 7.5^2}{25^2 - 7.5^2}$ = 101.669 MPa (Die is also in safe condition).

Where r_o, r_i are the internal and external radius of die.

The ultimate yield strength and ultimate tensile strength of D2 tool steel are 2200 MPa and 2000 MPa respectively. So, the die tends to withstand the given load with ease i.e., 15KN.

2.2 Fabrication of Die:

Material selected for die: Cryogenically Treated D-2 Tool Steel (High Carbon High Chromium tool steel).

Cryogenic treatment: It is the process of treating material to cryogenic temperatures (i.e. below -190^{0}C) to remove residual stresses and improve wear resistance on steels.

Table -1: Chemical Composition of D-2 Tool Steel

Chemical Composition of D-2 Tool Steel	
Element	**Percentage %**
C	1.4-1.6
Mn	0.6
Si	0.6
Co	1.0
Cr	11-13
Mo	0.7-1.2
Fe	Balance

Table -2: Mechanical Properties of D-2 Tool Steel

Mechanical Properties of D-2 Tool Steel	
Young's Modulus	210GPa
Density of Material	7.7 x 1000 kg/cm^3
Poisson's ratio	0.277
Yield strength	2200 MPa

Machining Process selected: EDM and CNC wire-cut electric discharge machining (WEDM).

Fig. -1 Fabricated die

The process parameters selected for the fabrication of die during WEDM process are given in table 3. These parameters are selected for minimum value of surface roughness or maximum surface quality [5].

Table -3: Process Parameters Selected during WEDM[5]

Process Parameters Selected during WEDM		
Control Factors	**Symbol**	**Value**
Pulse on-Time	Ton (μs)	105
Pulse off-time	Toff (μs)	25
Spark Gap Voltage	SV (SV)	30
Peak Current	IP (A)	188

3. Powder Metallurgy

Powder metallurgy is the process in which fine powdered materials are pressed into a die of the desired shape. The powder particles interlock to form a green compact. This compact is ejected from the die and sintered at high temperature in a controlled (neutral or reducing) atmosphere to establish desired properties in a component.

3.1 Experimental procedure:

3.1.1 Materials

In the experimentation process, the materials are chosen below 100 micron size. These micron sizes are based on mesh. Copper obtained from electrolytic process and with 200 mesh with a purity of 99.5% and 5-15 microns of TiC with a purity of 99.5% and SiC, flaky graphite are of 325 mesh respectively.

3.1.2 Sample Preparation

Initially the powder was filled in the die which in order to know the quantity of powder required for each sample. The filled powder is measured in an electronic weighing machine. Later Cu-4 wt% TiC-3 wt% Graphite as matrix and the reinforcement x wt% SiC was varied (x=3, 6, and 9 %).

3.1.3 Steps involved in Powder Metallurgy

There are four major steps involved in powder metallurgy process. They are:

- Powder production
- Blending
- Compacting
- Sintering.

3.1.3.1 Powder Production

Three dimensional matrix solid parts are converted into the tiny powder through mainly of any of the two processes, 1.Atomoization, 2.Electrolytic, 3.Chemical process. Copper powder was taken which is readily available obtained by electrolytic process.

3.1.3.2 Blending

The powders get mixed in either of the available millers, 1.Ball miller, 2.Bowl miller, 3.Pestle electric motor, 4.Agate, so in this blending process agate was chosen as a mixer and mixed the sufficient amount of powder for around 40 minutes.

3.1.3.3 Compaction

The mixed powder gets compacted in any one of the following presses. 1. Mechanical press, 2. Hydraulic press, 3. Isostatic press. These presses are based on the loads.
In this compaction process, mechanical press was used to compact the powder was filled into die and applied the load of 15KN on the plunger of the die and the green pellet was ejected carefully and is ready for next step of Powder metallurgy i.e., sintering.

3.1.3.4. Sintering

The compacted green pellet is gets sintered in any one the furnaces and those are 1.Muffle furnace, 2.Tubular furnace, 3.Microwave furnace, 4.Vaccum furnace.
In this experimental work muffle furnace was chosen for sintering process. The compacted green pellets were sintered in muffle furnace at an optimized sintering temperature of 850^{0}C for a soaking time of 60 min.

4. Results & Discussion

4.1 Rockwell Hardness Test

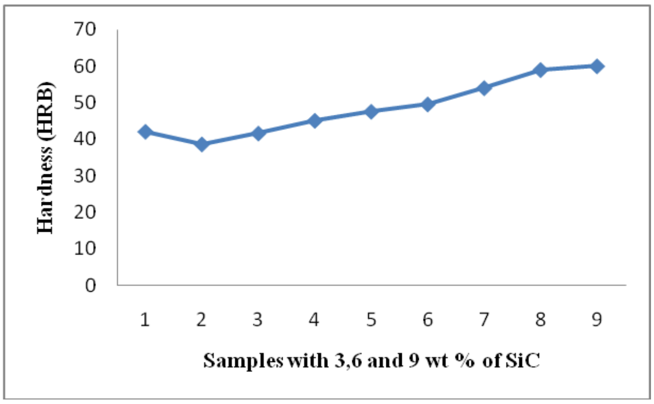
The Rockwell scale is a hardness scale based on indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. There are different scales, denoted by a single letter, that use different loads or indenters. The result is a dimensionless number noted as HRA, HRB, HRC, etc., where the last letter is the respective Rockwell scale.

Fig -2: Rockwell Hardness Tester

When testing metals, indentation hardness correlates linearly with tensile strength. This important relation permits economically important nondestructive testing of bulk metal deliveries with lightweight, even portable equipment, such as hand-held Rockwell hardness testers. The determination of the Rockwell hardness of a material involves the application of a minor load followed by a major load. The minor load establishes the zero position. The major load is applied, and then removed while still maintaining the minor load. The depth of penetration from the zero datum is measured from a dial, on which a harder material gives a higher number. That is, the penetration depth and hardness are inversely proportional. The chief advantage of Rockwell hardness is its ability to display hardness values directly, thus obviating tedious calculations involved in other hardness measurement techniques [14].

Table -4: Hardness test results

S. No	Sample (Cu-4 TiC-3 Gr- *x* SiC), *x*= wt%	Hardness test HRB
1	3	42
2	3	38.5
3	3	41.5
4	6	45
5	6	47.5
6	6	49.5
7	9	54
8	9	59
9	9	60



Graph -1 Composition Vs Hardness

From the above table and graph of Hardness test values, it was observed that the Hardness of the copper composite increased with increase SiC wt% in the composition.

4.2 Compression Test

When a specimen of material is loaded in such a way that if the material compresses and shortens it is said to be in compression. On an atomic level, the molecules or atoms are forced together in compression. Since atoms in solids always try to find an equilibrium position, and distance between other atoms, forces arise throughout the entire material which oppose both tension and compression. The phenomena prevailing on an atomic level are therefore similar.

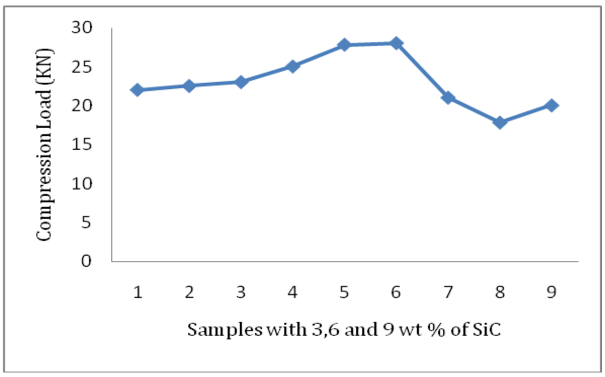
The "strain" is the relative change in length under applied stress; negative strain characterizes a compressive stress that shortens an object. Compression tends to amplify deflection into buckling. Compressive strength is measured on materials, components, and structures. By definition, the ultimate compressive strength of a material is that value of uniaxial compressive stress reached when the material fails completely. The compressive strength is usually obtained experimentally by means of a compressive test.

The apparatus used for this experiment is the same as that used in a compaction. As can be imagined, the specimen (usually cylindrical) is shortened as well as spread laterally. The diameters of the pellets after compression are different before compaction. A Stress–strain curve is plotted by the instrument and would look similar to the following:

The compressive strength of the material would correspond to the stress at the red point shown on the curve. In a compression test, there is a linear region where the material follows Hooke's Law. Hence for this region $\sigma = E\varepsilon$ where this time E is refers to the Young's Modulus for compression. In this region, the material deforms elastically and returns to its original length when the stress is removed.

This linear region terminates at what is known as the yield point. Above this point the material behaves plastically and will not return to its original length once the load is removed [15].

The heights and diameters of the sintered pellets are measured by using vernier calipers and the readings are obtained as shown in the table 5.



Graph -2: Composition Vs Compression Load

Table -5: Compression test values

S. No	*SiC, x*= wt%	Height (mm)	Top Dia. (mm)	Bottom Dia (mm)	Compr-ession Load (KN)
1	3	18.5	12.5	14.5	22
2	3	20.2	13.2	13.5	22.5
3	3	20.2	13	13.4	23
4	6	19.8	13	13.7	25
5	6	20.1	12.5	14	27.8
6	6	23	13	13.5	28
7	9	15	13	13.5	21
8	9	17	13	13.1	17.8
9	9	20	13.3	13.8	20

From the above table and graph of Compression test values, it was observed that the maximum compression load is obtained for the composition of 6 wt. % SiC among the remaining compositions.

5. LITERATURE REVIEW

Several researchers have fabricated copper matrix hybrid composite and gave many suggestions through research papers. The literature review presented given below regarding this copper matrix hybrid composite:

Kamal Kumar Jangra, Tilak Raj, Neeraj Sharma gave some data regarding design and development of die as Depends upon the work-structure the die design has been carried out considering all the work-conditions. Die has to be developed for powder compacting press. The design portion basically consists of the formulation of plan to satisfy the conditions for the given need. The plan results a product which is usable, safe, marketable, reliable and competitive. The design include following steps.

- Create alternate solution.
- After analysis and test, reproduce and calculate the performance of each substitute, retain satisfactory alternative, and remove unacceptable once.
- Choose the better alternative discovered as an approximation to optimality.
- Implement the design **[4].**

C.Parswajinan et al., gave the information as Die design is one of the most important steps in Powder Metallurgy process because the shape and attributes of the die will directly affect the final component. Die design has a number of steps and considerations to be made before fabrication. Their project is an attempt to design and fabricate a die for cold compaction process used in the powder metallurgy process. Their project includes design and fabrication of a die for the fabrication of a rectangular specimen, which used to test the impact strength of the specimen using Izod impact test and Charpy impact test. The die is designed according to the standards of ASTM B925 with the die being made of AISI D3 tool steel with the punch material being AISI D2 steel. This project also includes the design considerations, calculations, 2-D drawings, 3-D model and processes involved in fabrication of the die **[9].**

J Abhilash, M Govindaraju, S L Narasimha Reddy and K Srikanth worked on design and develop a Hydraulic power pack of 1.2 Ton capacity for lifting a powder metallurgy component Die. Design of the components in the assembly are done considering the explicit conditions by the industry and the implicit conditions, i.e., inherent to all hydraulic units design and powder metallurgy components. The parts was be modeled in Solid Works and the core components will be subjected to structural analysis in ANSYS. As a result of design and analysis, the dimensions are finalized with the tolerances and mating conditions. The designed components of Hydraulic Die ejector will be manufactured in lathe machines as per the given specifications. The components will be assembled and tested in practical environments of the industry. The design and fabrication is considered to be cost effective **[10].**

K.Rajkumar and S.Aravindan said that gives that hardness of hybrid composites is higher than the unreinforced copper. Electrical sliding contact material requires not only good electrical conductivity, high wear resistance and self-lubricating property but also requires high temperature strength related properties. So, the copper based hybrid metal matrix composites reinforced with ceramic and solid lubricant materials can fulfil such requirements of electrical sliding contact application. Self-lubricant reinforcement like graphite can act as good or improves anti friction properties due to its lamellar structure. But though the addition graphite is necessary for the lead free copper based contact materials but it decreases the strength of the composites. So, available reinforcements like titanium carbide, silicon carbide and alumina are to be added. He also said that increased content of harder reinforcement (TiC) in the hybrid composites leads to enhancement in hardness. Wear rate and coefficient of friction of hybrid composites and unreinforced copper increases with increase in normal load and Wear rates and coefficient of friction of hybrid composites are lower than those of unreinforced copper. Wear rate of hybrid composites is reduced with increasing % TiC or % SiC and % graphite, due to the cooperative effect offered by both the reinforcements. Coefficient of friction of hybrid composites is decreased with increase in % graphite reinforcement **[11].**

Basvarajappa S, Chandramohan G and Mahadevan A suggested that addition of Sic and graphite improves the tribological performance of the composites. The extent of the subsurface deformation in Al-SiC-Gr hybrid composites was lower than Al-SiC composites **[12].**

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R. Noor Ahmed and C S Ramesh said that copper and its alloys have found extensive applications in manufacture of bushes and bearings, heat transfer conductors, high conductivity electrical contactors and so on. In this direction, researchers have focused their attention on improving the strength and the tribological properties by reinforcing copper with hard ceramic reinforcements such as Silicon carbide and Titanium carbide. The major drawbacks of these copper based composites are reduced conductivity and poor machinability **[6].**

Akshay Kumar and Anubhav Singh Parihar gave a review on the mechanical and tribological properties of stir cast copper matrix composites containing silicon carbide reinforcement. Addition of Sic in copper has shown an increase in its hardness and wear resistance **[7]**.

Pushkar JHA, R K Gautham, Rajesh TYAGI investigated on Friction and wear behavior of Cu - 4 wt.% Ni - TiC composites under dry sliding conditions and concluded that the addition of 4 wt% TiC showed the optimum performance in terms of friction and wear caused by its higher hardness and ability to hold a transfer layer of a relatively larger thickness compared to the other materials **[2]**.

SHAAZ ABULAIS, VIKRANT YADAV, ANIRUDDHA MULEY said that the basic reason of metals reinforced with hard ceramic particles are improved properties than its original material in terms of strength, stiffness, hardness, electrical conductivity **[13]**.

5. CONCLUSION

Die was designed and fabricated according to the working load. Literature review helps in the selection of material and parameters for processing of the selected material.

Copper matrix hybrid composite was fabricated successfully by blending, followed by compaction and sintering.

- Hardness of the copper composite increased with increase SiC wt% in the composition.
- 6 wt% SiC in the composition shows the higher compressive strength among remaining compositions.

This copper matrix hybrid composite have extensive applications in manufacturing of bushes and bearings, heat transfer conductors, high conductivity electrical contactors and so on.

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