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DESIGN AND MANUFACTURING OF METAL MATRIX COMPOSITE GEAR USING POWDER METALLURGY

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***Abstract*— Due to its tremendous advantages, such as featherlight, high toughness, higher solidity, and less environmental assault, metal matrix composite (MMC) materials have lately been used to manufacture a range of technical components. MMC materials may be used in many applications, including power transmission gears. In this study, six samples of varying percentile compositions of SiCp – 5%, 10%, 15% (65m) and SiCp – 5%, 10%, 15% (35m) particles are reinforced with aluminium, and the properties of these materials are obtained, as well as the manufacturing of metal-matrix Al-SiC composite gears using the powder metallurgy method. UTM was used to test these gears under minimal breaking strength. This research suggests that MMC materials are well suited to the manufacture of gears capable of transmitting even huge amounts of power.**

Keywords *- Spur Gear, Powder Metallurgy, Metal matrix composite, Gear Die , Manufacturing*

I. INTRODUCTION

In the car industry, the rising need for low weight, fuel efficiency, and comfort has led to the development of new materials and optimal design. The growing need for featherlite materials with high specific strength in the space engineering and automobile industries has resulted in the creation and widespread usage of one type of composite: metal-matrix composites (MMCs). Because of its outstanding mechanical characteristics and wear resistance, MMCs are frequently employed in industry. MMCs have lately been used to manufacture a variety of technical components, including automobile high pressure die-cast bicycle sprockets, permanent mould cast pistons, investment cast engine cylinder inserts, disc brakes, hybrid electronic packages, brake rotors, and upper control arms. In this study, an attempt was made to manufacture MMC gears using powder metallurgy, as well as to examine and differtiate the performance of metal matrix composite gears with that of steel gears. Powder forging is particularly appealing because, in comparison to traditional castings and forgings, it combines cost and material savings via greater dimension and weight control. MMC gears have gradually replaced certain traditional steel gears in situations where weight and energy savings are key concerns while maintaining component strength. N.Ganesan et al. [1] evaluated the performance of MMC (Gr/Al and Al2O3/Al) power transmission gears to that of traditional steel gears. MMC gears and mild steel gears behave in a fairly similar way. The safety factor found for Gr/Al and Al2O3/Al gears is higher than for MS gears. The maximum stress of MMC gears falls significantly as the rim thickness lowers. Tamer Ozben et al. [2] investigated the toughness, impact hardness, and tensile stress properties of SiC-p reinforced AlSi7Mg2-MMC with 5, 10, and 15% SiC-p reinforcement ratios, as well as the effect of machining parameters such as density, feed rate, surface roughness and cutting depth on tool wear and cutting speed. D.R.Kumar et al. [3] investigated the effect of different percentages of Glass addition in Powder metallurgy preforms of Al-Glass composite on workability behaviour. Glass concentration varies between 0% and 8%, with a particle size of 60µm. Adding additional glass to the aluminium matrix as reinforcement increases the strength performance due to a reduction in pore size or a rise in relative density. Because pore size decreases and geometric work hardening decreases as the quantity of glass added rises, the strain hardening index value decreases. The analytical technique for dies with gear teeth is updated utilising FEM solution sets by O.Eyercioglu et al. [4]. Experiments are used to validate FEM analyses. During the experiment, it was discovered that the cylinder method was insufficient for forging dies. A simple set of formulas and nomograms for determining die and ring sizes, as well as radial interference, are provided. The composite is sintered from an alloy and metallic glass powder combination at a temperature slightly beyond the metallic glass particles' transition T, which is close to the Mg alloy's solidius temperature, according to D.V.Dudina et al. [5. When compared to Mg alloy alone, the Mg alloy-metallic glass composite formed has increased mechanical strength while maintaining flexibility. T.S.Srivatsan et al. [6] examine the tensile behavior, microstructure, and quasi-static fracture characteristics of a tool steel reinforced with titanium carbide particles. The elastic modulus of the composite was higher than that of the unreinforced matrix. According to the microstructure, the reinforcing titanium carbide particles were distributed uniformly throughout the metal matrix in the as-received composite. The composite's elastic modulus was 10% higher than the matrix alloy's elastic modulus without reinforcement.

II. MATERIAL SELECTION AND PROPERTIES

Material selection is one of the important factors in this work. The Aluminium and Silicon carbide powders has been selected for to manufacture a Metal Matrix Composite gear. The additives used for this process was Zinc stearate.

Aluminium is a face-centered cubic metal with low strength and high ductility that is mostly used as a powder for pyrotechnics, explosives and rocket fuel. Table 1 lists the characteristics of the aluminium powder used in the tests.

TABLE 1. Al powder properties

Sl. No.	**Properties**	**Al**
1	Elastic Modulus (E)	71×10^3 MPa
2	Poisson's ratio(γ)	0.35
3	Density(ρ)	2700 kg/m^3
4	Melting Temperature(T)	660 ºC

Silicon carbide (SiC), also called carborundum, is a silicon-carbon compound. It's a rigid, stiff, oxidation-resistant polymorphic chemical that's also a semiconductor. Sintering may join silicon carbide grains together to form very hard ceramics, which are commonly used in applications that need a lot of endurance, such as vehicle brakes, clutches, and bulletproof vest ceramic panels. Table 2 lists the characteristics of the silicon carbide powder utilised in the tests.

Zinc stearate is one of the more frequently used applied organometallic lubricants used to minimize compaction tool wear via a reduction in the ejection force, it is especially used for ferrous materials.

TABLE 2. SiC powder Properties

S.No	**Properties**	**SiC**
1	Elastic Modulus (E)	4.14×10^5 MPa
2	Poisson's ratio(γ)	0.192
3	Density(ρ)	3145 kg/m^3
4	Melting Temperature(T)	2700 ºC

Zinc stearate is a fatty acid that typically has two 18-carbon chains coupled to zinc oxide – the chemical formula is $Zn(C_{18}H_{35}O_2)_2$. Table 3 lists the characteristics of zinc stearate powder utilised in the tests.

TABLE 3. Zinc Stearate Powder Properties

S.No	**Properties**	**Zinc Stearate**
1	Density	1095 kg/m^3
2	Melting Temperature	130 ºC

III. Modeling Of Gear

The most difficult aspect of modelling the spur gear was parametrically defining the involute tooth shape and the tooth undercut. The initial attempt at accurately defining the involute curve necessitated the meticulous dimensioning of a sequence of curves in order to get a close approximation of the full involute. The parametric equation of the involute of a circle was the most crucial finding we made when designing the spur gear.

Equations with Parametric Involutes:

$$x(t)=rb(\cos(t)+t*\sin(t))$$
$$y(t)= rb(\sin(t)-t*\cos(t))$$

These equations were helpful in defining dimensions for designing the gear in SolidWorks CAD programme. As a result, the needed solid model of the gear is created, as illustrated in Figure 1. Table 4 lists the parameters for spur gear.

Spur gears, also known as straight-cut gears, are the most basic type of gear. While they are not straight-sided (they are usually of a certain form to produce a constant drive ratio, such as involute), the edge of each tooth is straight and oriented parallel to the rotating axis. These gears can only mesh correctly when they are placed on parallel shafts.

Gears are toothed mechanical components that convey power or motion in a variety of industrial applications, from heavy equipment to precise instruments. The smaller gear in a gear set is called the pinion, while the bigger gear is termed the gear or wheel, regardless of which one is driving the other.

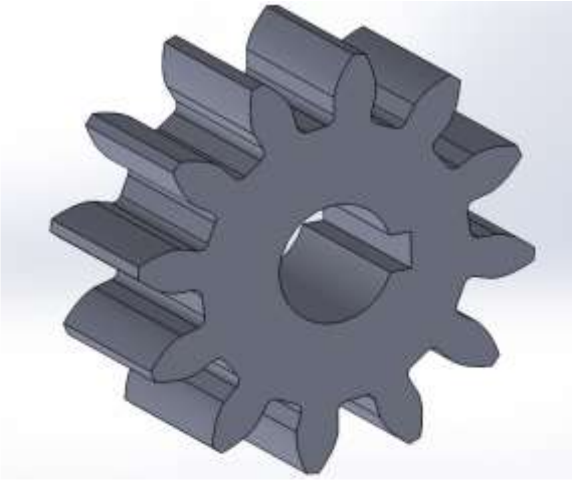

Fig. 1 Gear model

TABLE 4. Specifications for Spur Gear

Sl No.	**Parameter**	**Value**
1	Profile	Involute
2	Pressure angle	20 degree
3	Pitch circle diameter	48mm
4	No of teeth	12
5	Module	4mm
6	Addendum	4mm
7	Dedendum	5mm
8	Face width	22mm
9	Root fillet radius	1.2mm
10	Rim thickness	5mm
11	Outside diameter	56mm
12	Root diameter	38mm
13	Base diameter	45.11mm
14	Angular thickness	15 degree
15	Bore Diameter	14mm
16	Keyway	5×5

IV. GEAR DIE MODELING AND MANUFACTURING

The powder metallurgy gear die was created using the powder metallurgy press as a starting point. The tonnage of the press determines the die's strength. Perforation is the most extreme procedure in a die. Because the punch press uses pressures ranging from a few tonnes to over 1000 tonnes, this is the case.

The alignment of the press is critical. While die set can help with alignment during operation, it can't compensate for bad press alignment. Modeling of the gear die components was done with Solidworks CAD software. The gear die components are heat treated to a hardness of 50 HRS before being manufactured using a Wire Cut EDM.

Fig. 2 Wire Cut EDM

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EN24 steel was used to make the gear die pieces such as the top plate, punch, punch holder, base plate, die cover plate, and core rod. Table 3 and Table 4 show the usual composition and characteristics of EN24 material.

TABLE 5. Typical Chemical Composition of EN24

BS970 of 1955 EN24	
Carbon	0.36 – 0.44 %
Silicon	0.10 – 0.35 %
Manganese	0.45 – 0.70 %
Nickel	1.30 – 1.70 %
Chromium	1.00 – 1.40 %
Molybdenum	0.20 – 0.35 %
Sulphur	0.035 max %
Phosphorus	0.040 max %
Iron	Remaining

TABLE 6. Mechanical properties of EN24

Mechanical Properties	
Tensile Strength N/mm^2	850 / 1000
Stress N/mm^2	700
Fracture Toughness (Izod)	54
Proof Stress 0.2% N/mm^2	680
Brinell Hardness	248 / 302

Figures 3-7 show how Wirecut EDM was used to make the gear die parts, such as the die cavity, gear punch, gear punch holder, base plate, and core rod.

Fig.3 Gear Die Cavity

Fig.4 Gear Punch

Fig.5 Gear Punch Holder

Fig.6 Base Plate **Fig.7** Core Rod

V. MANUFACTURING OF GEAR

The powder metallurgy technique was used to make the MMC gears. Powder metallurgy is a manufacturing technology that entails three primary stages: First one is the creation of metal powder, Second is the compaction and shape of the powder, and third and last one is the consolidation and fusing of the powder into a solid metal component at high temperatures and pressures.

1 . Blending of Powders

The metal particles were mixed in a ball mill. Blending is the process of mixing powders that have the same nominal content but various particle sizes. Metal powder is blended to provide a consistent distribution of particle sizes and to intermingle lubricant with powders to change metal-powder interaction during compaction and make compaction easier. In this experiment, Al and SiC powders were mixed in a ball mill for different weight fractions.

TABLE 7. Weight Fraction of Metal Powders

Combination	Al	SiC
Al	89	-
Al-5%SiC	84.5	4.5
Al-10%SiC	80	9
Al-15%SiC	76	13

The roller ball mill has been used for blending metal powders. The ball mill contains 3 steel balls. The balls having various shapes as shown in figure 9.

Fig. 8 Ball mill

Ball 1 Ball 2 Ball 3

Fig. 9 Steel Balls

2 . Compaction of Metal Powders

The goal of compaction is to create metal powder compacts of the required shape that are strong enough to survive ejection from tools and subsequent handling until sintering is complete without breaking or damage. As illustrated in Fig. 10, the metal powders were compacted using a hydraulic press. The press has a maximum capacity of 60 tonnes. The capacity of the die cushion is 20 tonnes.

3 . Sintering

In Powder Metallurgy, sintering is one of the most essential processes. It is the process of compacting a loose powder aggregate or a green compact with the required composition under controlled temperature and time conditions.

The sintering process is usually carried out at temperatures between 0.7 and 0.9 Tm (Tm is the melting point temperature of the metal or alloy).

Fig. 10 Hydraulic Press used for Die Compaction

Solid state sintering is used for metal and alloy powders. There are several types of sintering processes. Densification occurs in solid state sintering as a result of atomic diffusion in the solid state. As illustrated in Fig. 11, the sintering process was carried out using a vacuum sintering furnace.

Fig. 11 Vacuum Sintering Furnace

The final MMC gear has been manufactured and shown in Fig. 10

Fig. 12 Al-SiC Composite Gear

V. CONCLUSION

The Metal Matrix Composite gears has been manufactured based on design considerations and desired specifications. The weight of the MMC gears has been reduced compared to steel gears. These gears can be used in automobiles and aerospace applications and to achieve the required performance criteria.

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