Mechanical Characterization and Machining of Mg-AZ91D/SiC/Al2O3MMC by Squeeze Cast Method

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Abstract: In the automotive industry, the high surface finish and superior mechanical property materials are prepared with the help of the squeeze casting process. The paper investigates on the chosen materials of MMC cast using magnesium alloy (Mg-AZ91D) reinforced with various %wt of silicon carbide (SiC) also aluminum oxide (Al2O3) of nano particulates (20 nm). The preferred squeeze casting technique produces magnesium matrix composites along with silicon carbide (SiC) and aluminum oxide (Al2O3) particulates direct to an absolute drenched inside the liquefy magnesium of hybrid metal matrix composite. Using CNC lathe and orthogonal array (L9), Magnesium metal matrix composites (Mg-AZ91D) are machined. To determine Metal Removal Rate (MRR) and Surface roughness (Ra) with various input parameters having the CNC lathe. Magnesium metal matrix composites (Mg-MMC) also, comparing the results with the unreinforced magnesium alloy with reinforcement of silicon carbide (SiC) and aluminum oxide (Al2O3) of nano particulates, Mechanical properties of the Magnesium metal matrix composite (Mg-MMC) and optimal machining parameters are evaluated.

1. Introduction
Magnesium based Hybrid metal matrix composites (Mg-HMMC) especially having sound fatigue resistance which is elementary or base materials for Automotives, because of its advanced assets like superior wear, corrosive resistance, high strength to weight ratio, lightweight, low density, high hardness, high temperature, thermal shock resistance, high specific modulus, and high fatigue strength. Turn to liquid also stirring techniques is used to make Hybrid metal matrix composites (HMMCs). This new edition has been greatly enlarged and updated to provide both scientists and engineers with a clear and comprehensive understanding of composite materials. In describing both theoretical and practical aspects of their production, properties, and usage, the edition crosses the borders of many disciplines. Incessant progressions contain amalgamated substance for the period of additional become wider your horizons function. In the present scenario more than 200 composite materials are available instead of as an average of 1600 engineering materials in the market, so the importance of composite materials for engineering applications day to day life increases [1]. In various industries like aircraft, aerospace, and automotive rapid demands for composite materials, because composites are wonder material with lightweight, high strength to weight ratio and stiffness property has come a long way in replacing the conventional materials like metals, wood, etc. Composite materials are promising predominantly into response toward unique consider as of expertise suitable in the direction in quickness progressive proceedings into engineering. When the ceramic particles added in the materials significant mechanical properties of composite have been improved and comparing many traditional engineering materials such as metals, have a low specific gravity that makes their properties particularly superior in strength and modulus. While a consequence of concentrated learning interested in the essential landscape of resources also enhanced appreciative of their composition possessions correlation, there is a possibility in the direction of making wider novel amalgamated possessions among enhanced properties are
mechanical also physical. Prepared novel concentrations are ceramic matrix composites, metal matrix composites having and Polymer matrix composites are having high performance amalgamated composites [2]. The selected works of Mg-HMMCs are manufacturers employing compress transmit along with its possessions also machining aptitude concert is premeditated.

M.R. Amin et. al. the author’s research work of unstable characteristic liquid run throughput into practice Prandtl combination distance end to end hypothesis. Individual foremost limitation consists of its effort be too into accumulation just before the constraints having of 2-D instead of 3-D model, it is applicable for a lightweight material like pure aluminum for the results cannot exist functional on behalf of aluminum alloys somewhere spongy region grown for the duration of solidification [3].

M. Hasan, L.Begum completed a follow a line of investigation taking place magnesium alloy AZ91 with A 3-D arithmetical simulation of an industrial-sized block caster. A magnesium alloy AZ91 has been carried out for the steady-state operational phase of the caster. While using of open-top liquefies discharge method built-in among a permeable sieve next to the hot-top with a simulated model, with a, superheat of 640 °C, a fixed inlet all parametric studies were performed, with help of temperature and velocity the results are obtainable illustratively. All final results are coming based on the crucible depth, thickness, mold shell thickness and axial temperature also considered and its speed of the casting processing through its homogeneous mixture of composite material. [4].

M. Mounib et. al. completed his follow a line of investigation scheduled presentations on MMCs (metal matrix composites) truly powerfully scheduled the allocations of a constituent part in the metal matrix while moreover lying on the substance responses are occurs next to the phase transformations stage. The present learning the substance responses within the selected base materials constituent part of (Al2O3) and (Al2O3) through Mg-AZ91D along with EL21, correspondingly, moreover present work was the distributions of the selected reinforcement in the composites. Dissimilar processes are differential scanning calorimetric (DSC), as well as XRD be bringing into play en route for the best part of the selected substance responses with near recognize yield. Transmission electron microscopy (TEM), [5].

R. Sunil al. completed his follow a line of investigation going on SMMCs (Surface metal matrix composites) be a cluster of advanced materials for engineering anywhere the external surface of metals are customized with scatter inferior stage within the outline of constituent part otherwise filaments with the central part are not affected of chemical composites of materials along with its structure. These materials are exactly suitable for the automobile field, airbuses, power industries also recent trends for biomedical. Newly, (FSP) friction stir processing practices have been in advance broad fame into manufacturing exterior amalgamated into unyielding circumstances. Selected AZ19D life forms complex in the direction of procedure metals and contains effective progression with friction stir processing practices (FSP) in the direction of manufactured surface metal matrix composites (SMMCs) [6].

S. Aravindan et. al. completed his follow a line of investigation going on (Mg-AZ91D) amalgamated resistant employing (SiC) silicon carbide constituent part among wt% based or volume percentage at different sizes be manufacture through stir casting process consist of two steps based on the various sizes reinforced particles are added in the Mg-AZ19D, to evaluate the characteristics of the MMCS in while transmit also (T6) temperature environment. Obtained results while compared with available standards properties. Allocations of the selected constituent part also cracked exterior be deliberate during the SEM images [7].

A. Dey and K. M. Pandey, completed his follow a line of investigation based on the composite materials with Magnesium be probable resources designed for different appliances like aerospace with protection association suitable in the direction of along with low down compactness, good quality physical along with mechanical properties. Advancements are wear behavior, specific strength, damping behavior, stiffness, creep employing low energy possessions be considerably predisposed in adding particles together interested in the metal matrix composites also conventional engineering materials. Present investigation summary lying on magnesium with different
combinations of reinforcement and its alloy along with limitations and advantages [8]. Finished lines of investigation on amalgamated are fabricated employing the squeeze casting method, Mg-AZ91D matrix material. The selected reinforcement constituent part must be alive physically dominant as well as rigid than the matrix material, as a result, headed for turn out the estimated intensification consequence. But, the mixture of substance, type, and size along with wt% of the reinforcements as well as its interactions with the matrix is essential to obtain desirable properties. Among high-quality thermal stability, ceramic particles as reinforcements are the most desirable due to high hardness, strength, and melting point. Among suitable concern on cost as well as functions are on mind SiC, Al₂O₃ reinforcements are fashionable into magnesium composites. Huge research information is available on SiC particle reinforced magnesium MMC. If SiC considers in magnesium composites, having highly brittle by nature. While Al₂O₃ particles have the advantages of low cost, exhibit high specific stiffness and excellent oxidation resistance. Al₂O₃ particles can exist in many crystalline phases and produce the most stable hexagonal alpha. The machining procedure is completed through a computer-controlled lathe machine (CNC). With help of Surface roughness testing equipment evaluate the Surface roughness of the machined surface. Parametric study be accomplished intended for the material removal rate (MMR), surface roughness (Ra). Brinell hardness machine is used to know the Hardness number, with help of a universal tensile test rig to know the tensile strength.

2. Materials and Methods

A base material magnesium, the most widely used die-cast alloy (AZ91D), having a tremendous amalgamation of its oxidation confrontation, mechanical properties, and casting ability. The Mg-AZ91D of magnesium alloy having a lesser concentration, higher specific modulus and unit weight to load-carrying capacity situate good heights, also used for huge potency are not essential. Whereas higher stiffness or a thick, light desired form are needed. As the exact quantity of three metallic impurities like iron, copper, and nickel are inbuilt in the Mg-AZ91D of magnesium alloy, So oxidation confrontation is attained with putting into effect extremely severe restrictions. For the production of this alloy, it is essential to bring into play principal magnesium next to a very squat echelon adding together. Instances of complex parts manufacturing are used in the designing of aircraft or housing in addition to reciprocating or rotary machine components.

Silicon carbide (SiC), it occurs in nature as the extremely rare mineral moissanite. A small particle of silicon carbide can tie simultaneously employing hard pressing with sintering machine set up headed for extremely structured rigid ceramic objects. Those are extensively employing into relevance’s needs elevated continued existence, such seeing that automobile coaster brake, vehicle clutches also ceramic plates into bullet evidence upper part body particles, besides that acknowledged while carborundum(hard block solid), be a complex as a chemical formula SiC of silicon and carbon.

Aluminum oxide (Al₂O₃) (or) aluminum oxide is a chemical compound of aluminum and oxygen with the chemical formula Al₂O₃. It is the most commonly occurring of several aluminum oxides. It occurs naturally in its crystalline polymorphic phase α-Al₂O₃ as the mineral corundum, as an abrasive owing to its hardness, and as a refractory material owing to its high melting point. It is also used in microdermabrasion, both in the machining process available through dermatologists and estheticians, and as a manual dermal abrasive used according to manufacturer directions.

2.1. Squeeze casting of Mg-AZ91D/SiC/Al₂O₃ Composites -

As liquid metal forging is a Squeeze casting, be a part of the grouping of transmitting as well as falsify course of action. At the bottom of the test set up having pre-heated die through this molten metal is poured into the chosen die. When the molten metal gets start solidification, the pressure is applied on the upper half die and it closes with help of hydraulic pressure in terms of tons, it
happens at the solidification process. The applied pressure or force is slightly less than the forging force, along with components having enormous specify be capable of subsisting are formed. Mechanical properties are enhanced when the metal matrix composite is having less porosity. Through this transmit and pressure applied method like squeeze techniques en route for manufacture the ferrous and non-ferrous materials.

| %   | Al   | Cu   | Fe   | Ni   | Zn   | Mn   | Si   | Mg   |
|-----|------|------|------|------|------|------|------|------|
| Mg-AZ91D | 8.3-9.7 | 0.03 | 0.005 | 0.002 | 0.35-1.0 | 0.15-0.5 | 0.1 | Bal |

2.2. **Mg-AZ91D/SiC/Al2O3 Composites Fabrication Procedure**

The aluminum oxide (Al2O3), Silicon carbide (SiC) with a Size of 20 (nm), and magnesium alloy AZ91D be stimulated inside a crucible shown in Figure 1. At 800°C magnesium, alloy AZ91D is heated in the furnace beginning. In Pre-heater at 400°C alumina in addition to boron carbide are as well preheated.

![Fig.1. Stir casting setup with Squeeze](image)

With a suitable load of 400KN applied on the molten with help of a hydraulic die having a mixture of molten metal is coming from the crucible with the bottom gate. Table 2 shown the wt% of materials is solidification the essential profile, as well as the dimension of the hybrid metal matrix composite materials, are obtained.

| Samples | Materials in terms of wt.% |
|---------|----------------------------|
|         | Mg-AZ91D | SiC | Al2O3 |
| 1       | 100       | 0.0 | 0.0   |
| 2       | 94        | 3.0 | 3.0   |
| 3       | 91        | 6.0 | 3.0   |
| 4       | 88        | 9.0 | 3.0   |

2.3. **Orthogonal array (L9)**

The orthogonal array (L9) is intended on behalf of realizing the consequence of 4 autonomous dynamics every one contains 3 dynamic rank standards. At the same time as here be various regular orthogonal ranges presented, each of the ranges is preordained on behalf of a particular numeral indent of autonomous intend unpredictable’s also ranges. At the same time as in various cases, there is nothing communication representation hypothesis is valid, present exist various cases someplace here be a plain indication of communication. The selections of array imagine to here be zero communication in between selected factors of any two. The communication connecting the temperature also material properties would be alive a classic interaction bond. The below table 3
shown obtained values with the selected orthogonal array of 3 variables. In support of illustration, condition individual requirements en route for carrying out experimentation in the direction of identity with the authority of four dissimilar autonomous changeable employing every changeable contains three lays down standards, after that orthogonal array (L9) may be the accurate selection.

Table 3. Orthogonal Array (L9)

| CNC Machine Inputs Variables | Mg-AZ91D/SiC/Al2O3 of materials |
|-----------------------------|----------------------------------|
| Spindle speed (rpm)         | S-1     S-2     S-3     S-4     S-5     S-6     S-7     S-8     S-9 |
| 350                         | 550     750     550     750     350     750     550     350     |
| Depth of cut                | 0.2     0.3     0.4     0.2     0.3     0.4     0.2     0.3     0.4 |
| Tool Feed rate              | 0.1     0.1     0.1     0.2     0.2     0.2     0.3     0.3     0.3 |

2.4. **CNC Machining**

The below figure is shown as a machined and unmachined workpiece with help of a CNC Lathe machine. The main aim to study the amount of material removal rate and amount of surface roughness of the Magnesium metal matrix composite of Mg-AZ91D/SiC/Al2O3, if Al2O3 is constant wt.% in all samples and SiC % varying at wt.% in twice in sample 3 and sample 4.

![Fig.2. Mg-AZ91D/SiC/Al2O3](image)

3. **Results with Discussion**

3.1. **Metal Removal Rate (MRR)**

The Desirable MRR values are shown in table 4. There are two ways to evaluate the amount of materials removal rate of Mg-AZ91D/SiC/Al2O3, one is a weight basis and the other one is volume-based. The Material Removal Rate (MRR) also known as the immediate material removal rate as the rate at which the cross-section area of material being removed moves through the workpiece. Another way is the measurement of how much material is removed from a part in a given period.

Table 4. Mg-AZ91D/SiC/Al2O3 Metal Removal Rate and Surface Roughness values

| CNC Machine Inputs Variables | Mg-AZ91D/SiC/Al2O3 of materials |
|-----------------------------|----------------------------------|
| Spindle speed (rpm)         | S-1     S-2     S-3     S-4     S-5     S-6     S-7     S-8     S-9 |
| 350                         | 550     750     550     750     350     750     550     350     |
| Depth of cut                | 0.2     0.3     0.4     0.2     0.3     0.4     0.2     0.3     0.4 |
| Tool Feed rate              | 0.1     0.1     0.1     0.2     0.2     0.2     0.3     0.3     0.3 |
| MRRx10⁴(m/Sec)              | 2.19    3.42    5.22    4.41    6.42    8.21    7.34    4.11    1.32 |
| Ra(µm)                      | 0.45    0.56    0.58    1.89    1.78    1.92    4.23    5.39    6.42 |

3.2. **Ra (Surface Roughness) test**

The Ra is deliberate by using the SURFTEST machine set up shown in figure 3. Surface Roughness (Ra) is a constituent of exterior consistency. Surface roughness is enumerating through the variations into the track of the customary vector of a real exterior from the surface’s ultimate outward appearance. However variations are big, the exterior surface as of rough; meanwhile, they are little, the exterior face is smooth.
Table 5 represents measured values of the samples’ surface roughness through the surface testing machine. Surface roughness (Ra) is characteristically believe headed for being present high occurrence, short-wavelength elements of surface measurements’ (observe exterior metrology). Other than, during the observation surface roughness is frequently essential headed for recognizing together the frequency and amplitude in the direction of making certain with the purpose of an exterior be in shape intended for an intention.

Table 5. Surface Roughness Test Experimental values

| CNC Machine Inputs Variables | Mg-AZ91D/SiC/Al₂O₃ of materials |
|-----------------------------|----------------------------------|
| Spindle speed (rpm)         | S-1  | S-2  | S-3  | S-4  | S-5  | S-6  | S-7  | S-8  | S-9  |
|                            | 350  | 550  | 750  | 550  | 750  | 350  | 750  | 550  | 350  |
| Depth of cut                | 0.2  | 0.3  | 0.4  | 0.2  | 0.3  | 0.4  | 0.2  | 0.3  | 0.4  |
| Tool Feed rate              | 0.1  | 0.1  | 0.1  | 0.2  | 0.2  | 0.2  | 0.3  | 0.3  | 0.3  |
| Ra (μm)                     | 0.45 | 0.56 | 0.58 | 1.89 | 1.78 | 1.92 | 4.23 | 5.39 | 6.42 |

3.3. Hardness
The Brinell scale characterizes the indentation hardness of materials through the scale of penetration of an indenter, loaded on a material test-piece. It is one of several definitions of hardness in materials science.

The volume fractional percentage of SiC/ Al₂O₃ nano particulates fashioned as increasing the hardness value of metallic matrix composite results are shown in Fig.4a. The percentage of SiC/ Al₂O₃ of in Mg-AZ91D had to escalate the proportion of SiC/ Al₂O₃ through the stiffness assessment enhances in the same way. Whereas pure Mg-AZ91D (magnesium alloy) had not had such hardness while evaluates among Magnesium/SiC/ Al₂O₃ (MMC) amalgamated.

3.4. Tensile
With the consequence of SiC/ Al₂O₃ wt% in Mg-AZ91D MMC, the tensile strength is scrutinized, along with the results are plotted in Fig.4b. Tensile strength increases with an increase in the weight fraction of reinforced nanoparticles of SiC/Al₂O₃. The Tensile strength of fabricated hybrid Magnesium/ SiC/Al₂O₃ (MMC) also increases with an increase in weight fraction of reinforced particles SiC/Al₂O₃. The tensile strength of fabricated 9 wt% SiC+ 3wt% Al₂O₃ – Mg-AZ91D MMC is 224MPa which is 1.3 times of Mg- Matrix.
Fig. 4. (a) wt% SiC/Al$_2$O$_3$ in Mg-AZ91D V/S Hardness of composites, (b) wt% SiC/Al$_2$O$_3$ in Mg-AZ91D V/S Tensile Strength, (c) wt% SiC/Al$_2$O$_3$ in Mg-AZ91D V/S Density, (d) wt% SiC/Al$_2$O$_3$ in Mg-AZ91D V/S Wear

3.5. Density

Fig. 4c, Represents the density of the prepared samples determined utilized the relation as follows: 
$$\rho = \frac{w_1 (\rho_w) - w_2}{w_1 - w_2},$$
where $\rho_w$ is the density of water, $w_1$=sample weight in the air, $w_2$= sample weight in water, $\rho$ = density of prepared cast Mg-MMC sample. Based on Archimedes’s principle, the density of the prepared SiC/Al$_2$O$_3$ wt% in Mg-AZ91D MMC samples are determined.

3.6. Wear

By using the pin on disc test rig the selected or sample specimens are performed wear tests. In Fig.4.d stated lower wt% of SiC/Al$_2$O$_3$ added in Mg-AZ91D as a reinforcement the extent of reduction is higher if higher wt% of SiC/Al$_2$O$_3$ added in Mg-AZ91D wear rate decreases because the wear rate decreases with increases the SiC/Al$_2$O$_3$ wt% in Mg-AZ91D as reinforcement, for the reasons is thermal stability and hardness of the reinforcement are more than the Mg-AZ91D alloy.

3.7. Performance Measures with the effect of Machining Parameters

With considering the process parameters of spindle speed, Depth of cut(DOC), Tool feed rate, Metal Removal Rate (MRR), Surface Roughness (Ra) also reinforcement proportions (%Ref) be considered to drown the graph based on the experimental assessment.
From Fig. 5.a, the depth of cut increases, the surface roughness values are to some extent increased also there are no identical variations due to tool feed rate and spindle speed. Fig. 5.a stand for the chart contains an X-axis depth of cut whereas Y-axis consists of surface roughness. From Fig. 5.b X-axis taken as the reinforcement (%Ref) added in the Mg-AZ91D of 3%, 6%, and 9% of SiC moreover 3% of Al2O3 in addition to the Y-axis consists of surface roughness. Its experimental results observed that % of reinforcements are increased in Mg-AZ91D; it increases the hardness of the composite material, so the surface roughness value decreases with the good surface finish of the components. However, the friction-free components are fabricated and it becomes suitable for the automobile industry. Fig. 5.c contains the X-axis tool feed rate and Y-axis Material removal rate (MRR). Concerning tool feed rate increases up to a certain level the material removal rate also increased. Further tool feed rate increased the material removal rate decreased. From Fig. 5.d consists of speed to materials removal rate, X-axis consists of speed, and Y-axis consists of material removal rate. When spindle speed increases to obtained more material removal rate. It’s not considered DOC and tool feed rate.

4. Conclusion
In this investigation, squeeze castings techniques are used to build magnesium metal matrix (Mg-MMC), made-up with make use of for the fabrication of hybrid Mg-AZ91D/SiC+ Al2O3-MMC.
The dissimilar weight fractions of hard reinforced particulates SiC and Al₂O₃ are utilized to fabricate hybrid Mg-MMC samples. The different tests are conducted on cast hybrid Mg-MMC samples to identify the various physical and mechanical properties.

The following conclusions are based on the fabrication and machining of Mg-AZ91D/ SiC/Al₂O₃ composite material.

➢ With help of the squeeze casting technique, Mg-AZ91D with reinforcement’s nanoparticles of SiC/Al₂O₃ distributions are easily done.
➢ The density of hybrid Mg-MMC increases with an increase in weight fraction of SiC/Al₂O₃ nano particulates as SiC/Al₂O₃ both have a higher density over Mg-matrix. Investigation results reveal that the density of Mg-MMC with 9wt% SiC + 3% Al₂O₃ is about 1.77 times of Mg-AZ91D. The hardness increases with an increase in weight fraction of hard reinforced nano particulates with SiC/Al₂O₃ (8 & 3 wt %) respectively - MMC is 104HV, whereas the hardness of Mg-AZ91D is only 62.8HV.
➢ Tensile strength increases with an increase in weight fraction of reinforced nano particulates SiC/Al₂O₃. The incorporation of SiC/Al₂O₃ nano reinforcement particulates to Mg-AZ91D alloy increases the wear resistance of the composite.
➢ The purposes of L9 array selection to reduce the number of tests are conducted through the CNC Lathe machine. It generates great values of measurable performance conducted on Mg-AZ91D/ SiC/Al₂O₃ composite materials.
➢ Since the reinforcement percentages increase in magnesium composites of Mg-AZ91D/SiC/Al₂O₃, the surface roughness are decreases. The observed variations concerning tool feed and spindle speed.
➢ They both selected output responses purely depend on the depth of cut whereas compared to other input process parameters in CNC lathe.

5. References

[1] L. M. Manocha, A. R. Bunsell, Advances in composite materials, Pergamon Press, Oxford, 2 (1980), 1233-1240.
[2] G. Fisher, Composite: Engineering the ultimate material, American Ceramics Society, 63 (2005), 360-364.
[3] M.R.Amin, A. Maharajn, Modeling of turbulent heat transfer during the solidification process of continuous casting, I. Mater. Process. Tech. 174(2006) 155-166.
[4] M. Hasan, L. Begum, Modelling of magnesium DC casting process using a 3D turbulent CFD model, Advanced Material Processing, 28(2012), 145.
[5] M. Mounib, M. Pavese, C. Badini, W. Lefebvre, H. Dieringa, Reactivity, and microstructure of Al2O3-reinforced magnesium-matrix composites, Advances in Materials Science and Engineering, 39 (2013), 1-7.
[6] B. R. Sunil, Developing surface composites: A comparative survey, International Journal of Advances in Materials Science and Engineering, 4(3) (2015) 1-8.
[7] S. Aravindan, P. V. Rao, K. Popanna, Evaluation of physical and mechanical properties of AZ91D/SiC composites by two-step stir casting process, Advanced Engineering Material, 6(2015), 1-11.
[8] Dey, K. M. Pandey, Magnesium metal matrix composites-a review, Indian Foundry Journal, 57(2015), 35-40.