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Optimization of Drilling Parameters on Surface Roughness of Al 1200-SiC Composites Using Taguchi Analysis

Krishnaprakasha[1], Pavitra Ajagol [2]
[1]M.Tech Student, Department of Mechanical Engineering.
[2] Assistant Professor, Department of Mechanical Engineering.
[1, 2] Sahyadri College of Engineering and Management, Mangalore.
Corresponding author: Krishnaprakasha

Abstract: *In present study, the matrix material Al 1200 reinforced with various percentages (5% and 10%) of SiC particles. Stir casting method employed for producing AlSiC MMCs since it is simple and cheapest method used for producing Aluminium Matrix Composites (AMCs). Main purpose of this investigation is to study the effects of drilling parameters (Spindle Speed, Feed Rate and Depth of Cut) on Surface Roughness. Drilling carried out using CNC Vertical Machining Centre for varying drilling parameters. Surface roughness found out around drilled hole circumferences using surface roughness tester. Taguchi method and Analysis of Variance (ANOVA) employed for finding optimal drilling parameters values on minimizing surface roughness and also to find out most effective drilling parameter on minimizing surface roughness. It was found that Depth of cut is the most effective parameter for 5% AlSiC MMC and Spindle speed is the most effective parameter for 10% AlSiC MMC.*
Keywords*- Metal Matrix Composites, Stir Casting, Surface Roughness, Taguchi, ANOVA.*

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I. Introduction

Scientists are looking for improving various properties of engineering materials so that newly generated materials will have more engineering applications compared to individual components. Newly generated materials are called composites. Composites have superior properties such as high strength to weight ratio, modulus of elasticity, light weight, low coefficient of thermal expansion, high corrosion and wear resistance, high stiffness etc. Composites consist of two phases, a continuous phase and a non-continuous phase. Continuous phase is generally termed as matrix phase and non continuous phase is generally termed as reinforcement. Normally in any composites, matrix phase acts as a soft phase and reinforcing agent acts as hard phase which increases strength and modulus.

When a matrix phase is composed of a metal then the composite formed is termed as Metal Matrix Composites (MMC). Metal Matrix Composites possess significantly enhanced properties such as higher strength, light weight, specific modulus, damping capacity, stiffness, good wear resistance, high temperature stability, good corrosion resistance, low density, high electrical & thermal conductivity, adjustable coefficient of thermal expansion, weight savings etc. Disadvantage of MMC is that high cost of fabrication and of reinforcement materials. Aluminium, magnesium, copper, titanium, titanium aluminides, nickel, nickel aluminides, nickel-based super alloys and various alloys of iron can be used as matrix materials. Among all the matrix materials available, Aluminium alloy is widely used as a matrix material because of its properties such as high strength, excellent corrosion resistance, low density, low weight, high malleability, ease of machining, high damping capacity, good electrical & thermal conductivity etc [1]. So many reinforcements are used such as Silicon Carbide (SiC), Aluminium Oxide, Titanium Carbide, Boron Carbide etc. Out of all listed reinforcements, SiC particle is widely used as reinforcement in order to make Al MMC because SiC reinforcement increases tensile strength, hardness, density, wear resistance, high thermal conductivity, corrosion resistance of Aluminum and its alloys [2]. SiC have properties such as less expensive, high yield strength and elastic modulus at little expense of ductility.

Stir Casting is a simple method used for fabricating Aluminium Matrix Composites (AMCs) because it is less expensive, attractive, flexible and used for mass production. In stir casting method, major difficulty is the settling of fine reinforcement particles during the formation of composite.]. There is a need to improve the distribution of non continuous phase. The distribution of reinforcement can be improved if matrix phase is in semi solid condition. Other factors which improve the distribution of reinforcement are temperature of melt, mechanical stirrer speed, way of stirring, particle size and its density, design of the mold, proper gating system, temperature of mold before pouring etc. In this method of fabricating the composite, the main aim is on the wetting of the particles by the liquid (molten) metal otherwise there are potential areas which could lead to fatal deterioration of the material [3-4]. There are many ways to enhance the wetting of the particles which includes the surface coating of the particles before pouring into the liquid melt. In this way the coating not only minimizes the interfacial energy but also the chances of the chemical interaction between the particles are reduced [5-6]. Another way is by using wetting agents. Before pouring reinforcement into liquefied metal, wetting agent has to be poured into melt in order to increase the wettabilty of reinforcement in the melt. Elements such as Mg, Li, Zr, Ti, Ca and P can be used as wetting agents in order to improve wettability of reinforcements in molten melt. Normally Magnesium is used as a wetting agent.

AlSiC MMC is widely used in automobile, aerospace and automotive fields. Due to high hardness and abrasive nature of SiC particles, AlSiC MMC is very difficult to machine. Hence different machining operations such as turning, facing and drilling are involved while manufacturing components from AlSiC MMC. Taking machining of AlSiC into account, many researchers have been focused on turning, facing but drilling has got less attention. Early studies gave lesser importance on effects of machining parameters on drilling of AlSiC MMC (5 & 10% Volume fraction). More influential drilling parameters on cutting force, surface roughness and torque are spindle speed and feed rate. Due to wide application of AlSiC MMC it is important to use appropriate method to solve problems regarding cutting force, surface roughness, torque etc when drilling is taking into account. Drilling can be used in various industries such as Medical and Electronic Equipment Industries, Aircraft and Aerospace, Automotive, Home Appliance, Dies/Molds.

Present study involves fabricating AlSiC MMC using stir casting method and then finding out optimal values of drilling parameters (spindle speed, feed rate and depth of cut) on minimizing surface roughness by applying Taguchi method and also to find out most effective drill parameter on minimizing surface roughness.

AlSiC MMC possess wide range of physical and mechanical properties such as high strength, high specific modulus, improved stiffness, low density, light weight, high corrosion resistance, fatigue resistance, increased wear resistance, low thermal shock, high electrical and thermal conductivity, high temperature properties, controlled thermal expansion coefficient, good damping capacity etc. AlSiC MMC is used in various fields like aerospace, fuselage skins of high performance aircrafts, underwater, automobile, substrate in electronics, golf clubs, turbine blades, brake pads, automotive applications such as engine piston, brake disc etc.

II. Literature Survey

The purpose of literature review is to provide background information on the issues to be considered in this investigation and to emphasize the relevance of the present study.

Riaz Ahamed et al. have studied the drilling of hybrid Al–5%SiCp– 5%B4Cp metal matrix composites and have used high speed steel as a tool material. They have found that, the lower feed and speed produce better surface with low tool wear [7].

Shivaprakash et al. focused on multiple response optimization of drilling process for composite Al-TiBr2 to minimize the damage events occurring during drilling process. Taguchi method with grey relational analysis was used to optimize the machining parameters with multiple performance characteristics in drilling of MMC Al-TiBr2 and found that the maximum feed rate, low spindle speed are the most significant factors which affect the drilling process and the performance in the drilling process can be effectively improved by using this approach [8].

Rajmohan et al. used Taguchi method with grey relational analysis to optimize the machining parameters with multiple performance characteristics in drilling hybrid metal matrix Al356/SiC-mica composites. Experiments were conducted on a CNC vertical machining center and L18 orthogonal array was chosen for the experiments. The drilling parameters namely spindle speed, feed rate, drill type and mass fraction of mica were optimized based on the multiple performance characteristics including thrust force, surface roughness, tool wear and burr height (exit) and found that the feed rate and the type of drill were the most significant factors which affect the drilling process [9].

Haq et al. implemented a new approach for the optimization of drilling parameters on drilling Al/SiC metal matrix composite with multiple responses based on orthogonal array with grey relational analysis. Experiments are conducted on LM25-based aluminum alloy reinforced with green bonded silicon carbide of size 25 µm. Drilling tests were carried out using TiN coated HSS twist drills of 10 mm diameter under dry condition. Drilling parameters viz. cutting speed, feed and point angle were optimized with the considerations of multi-responses such as surface roughness, cutting force and torque [10].

Davim investigated the influence of cutting parameters (cutting velocity and feed rate) and cutting time on drilling of metal matrix composites. Taguchi based experiments were performed on controlled machining with cutting conditions prefixed in work pieces. Correlation between cutting velocity, feed rate and the cutting time with the evaluator the tool wear, the specific cutting pressure and the holes surface roughness was established by using multiple linear regressions analysis [11].

Ahamed et al. focused on drilling of Al-5% SiCp-5% B4Cp hybrid composite with high-speed steel

(HSS) to minimize tool wear and improve surface finish. It was noticed that drilling of Al-5%SiC-5%B4C composites with HSS drills was possible with lower speed and feed combination [12].

Mahesh Babu et al. have studied the characteristics of the surface quality on machining of hybrid (Al–SiC–B4C) composites. They have asserted that the feed rate is the most influential parameter followed by cutting speed, which influences the surface roughness [13].

III. Methodology

3.1 Selection of Materials:

Al 1200 was used as a matrix material and various percentages of SiC particles (5% & 10%) were added as reinforcement to prepare AlSiC MMC. Al 1200 has chemical composition (% by weight) as Al=99 max, Fe and Si=1 max, Mn=0.05 max, Ti=0.05 max, Cu=0.05 max, Zn=0.1 max and others=0.15 max. To increase the wettability of SiC in molten Al, 1wt % of Magnesium (Mg) was added into the molten Al. Green bonded SiC particles of size 40µm (400 mesh) were used as reinforcement.

3.2 Preparation of AlSiC MMC:

AlSiC Metal Matrix Composites were prepared by stir casting method. A stir casting setup consists of a pre-heater, an electrical furnace with crucible made up of graphite and also a stirrer made up of graphite. Temperature range of the furnace is 1000ºC and of pre-heater is about 800ºC. During processing, first required quantity of cut solid Al pieces were taken in the graphite crucible placed inside the furnace. Desired amount of Al and SiC particles weights were measured by using digital balance. Based on the capacity of the furnace, amount of Al was defined. Temperature of the furnace was set at 830°C. Al started melting as furnace temperature increases. Solid Al started converting to liquid Al. It took around 2 hours for melting completely inside the furnace. To measure the temperature of the melt, a digital temperature connected to a chromel-alumel thermocouple was used. After complete melting of molten metal (liquid Al reached at 750°C), 1 wt % of Mg was added to the melt in order to improve the wettability of SiC reinforcements in Al matrix. After adding Mg into the melt, known percentages of heat treated SiC particles of size 40µm (5% and 10%) were added to the melt through funnel. Along with SiC particles, Hexachloroethane tablets were added to the melt for the purpose of degassing the molten metal and to prevent porosity in cast composites. SiC particles were preheated at 800°C for about 1 hour to eliminate gases and moisture from the surface to ensure homogeneous mixing and intimate dispersion. An electrical resistance furnace assembled with mild steel impeller was then lowered into the melt reinforcement mixture and mechanical mixing carried out. Stirring of liquid reinforcement mixture was carried out for 10 minutes at an rpm of 500. Uniform stirring of liquid metal reinforcement mixture was done to get vortex formation which helps to uniformly distribute the reinforcements throughout the matrix. To measure the constant stirring speed, a non contact type speed sensor was used. Impeller was immersed up to a depth approximately 2/3 of height of molten metal from the bottom of crucible. Composite mixture prepared by various percentages of SiC particles (5% & 10%) was poured to preheated mild steel metal molds at 670°C to get desired shape of the specimen. AlSiC MMCs were cast in Flat die of dimension 230 × 100 × 15 mm and cylindrcal and Cylindrical die of dimension 24mm diameter × 190 mm length. Finally the casted product was allowed to solidify in the molds with the help of air to minimize the settling time of reinforcements in matrix and also to avoid oxidation.

Table 1: SiC and Al Composition.

Material Designation	1T	2T
Percentage of Al 1200 Matrix	95	90
Percentage of SiC added	5	10

Fig.1: Stir Casting Setup.

Fig. 2: Vortex Formation of Melt.

Fig.3: Prepared Composites.

3.3 Machining of Composites:

Drilling test was carried out on prepared composites to know about the machining characterization of AlSiC MMCs. For drilling of composites, a specimen from each composite prepared according to required dimensions of 100mm × 50mm × 12mm. Samples were prepared by using vertical milling machine. Kerosene used as coolant. High Speed Steel (HSS) of 11mm diameter used as a drill tool material. Drilling carried out for various drill speeds (1000 RPM, 2000 RPM, 3000 RPM), feed rates (0.05 mm/rev, 0.10 mm/rev, 0.15 mm/rev) and various depths of cut (1 mm, 1.5mm, 2mm). Experiment was carried on CNC vertical machining center. Synthetic 68 used as coolant during drilling operation.

Fig. 4: CNC Vertical Machining Center.

Fig. 5: Drilled Specimens.

In drilling operation quality of hole produced plays an important role. Getting required hole dimensions, roundness and also surface finish along the length of the hole are very important to industries. The present study comprised of finding out surface roughness after performing drilling on AlSiC MMC. To characterize the surface quality, surface roughness was used. Average surface roughness value (R_a) was taken as many industries uses the same for their study. Surface roughness value found out around the hole circumference with 0.8 mm cut off length by using SURFTEST SJ - 201. Direction of measuring surface roughness was perpendicular to the circumference of drilled holes. Surface roughness reading found out as the average of three circumferential readings.

Fig. 6: Device for Measuring Surface Roughness.

IV. Results And Dıscussıons

4.1 Measurement of Surface Roughness and Signal to Noise (S/N) Ratio:

Surface Roughness (R_a) measured using Surftest SJ-201 on prepared composites around the hole circumference. For each hole, two trials have been performed and average surface roughness value was calculated. Taguchi method performed using MINITAB 17 software in order to optimize process parameters like spindle speed, feed and depth of cut for minimum surface roughness obtained from the experimental study and also to find out most effective drilling parameter on surface roughness. L9 orthogonal array with three parameters and levels used to carry out Design of Experiment (DOE). S/N ratio calculated on the basis of output parameter surface roughness value. Smaller the Better type category used to find out S/N ratio. Optimized machining parameters for minimizing surface roughness will find out on the basis of main effect plot drawn for S/N ratio. Result of S/N ratio on surface roughness is shown below.

Signal to Noise ratio for smaller the better type is given by the formula,

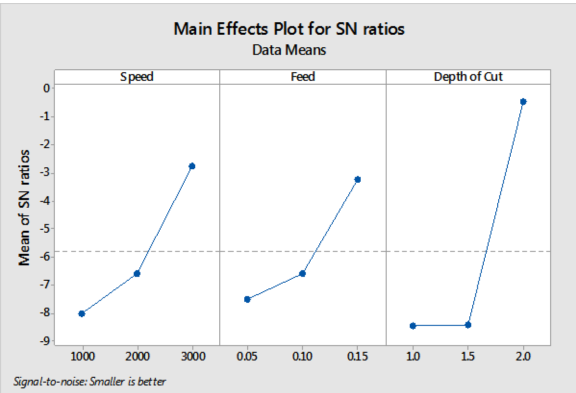
$$S/N = -10 \log_{10} \left[\sum_{i=0}^{n} \frac{{y_i}^2}{n}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Table 2: Table of Surface Roughness and S/N Ratio Values for 5% AlSiC MMC.

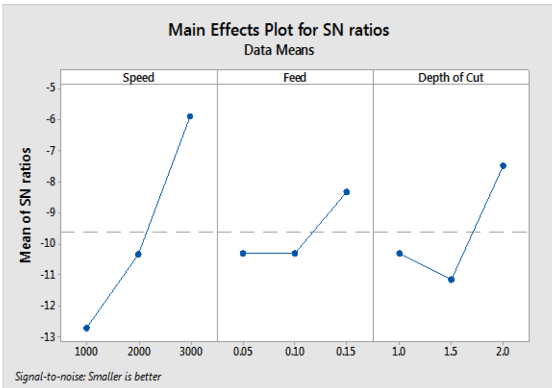
Exp No.	Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)	Surface Roughness (R_a) (µm)	S/N Ratio
1	1000	0.05	1.0	3.865	-11.7430
2	1000	0.10	1.5	4.65	-13.3491
3	1000	0.15	2.0	0.885	1.06113
4	2000	0.05	1.5	3.075	-9.75690
5	2000	0.10	2.0	1.185	-1.47437
6	2000	0.15	1.0	2.685	-8.57889
7	3000	0.05	2.0	1.125	-1.02305
8	3000	0.10	1.0	1.785	-5.03276
9	3000	0.15	1.5	1.29	-2.21179

Table 3: Table of Surface Roughness and S/N Ratio Values for 10% AlSiC MMC.

Exp No.	Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)	Surface Roughness (R_a) (µm)	S/N Ratio
1	1000	0.05	1.0	7.05	-16.9638
2	1000	0.10	1.5	3.915	-11.8546
3	1000	0.15	2.0	2.93	-9.3374
4	2000	0.05	1.5	4.27	-12.6086
5	2000	0.10	2.0	3.87	-11.7542
6	2000	0.15	1.0	2.145	-6.6285
7	3000	0.05	2.0	1.17	-1.3637
8	3000	0.10	1.0	2.315	-7.2910
9	3000	0.15	1.5	2.8	-8.9432



(a)



(b)

Fig. 7: Main Effect Plot for S/N Ratio for (a) 5% AlSiC MMC and (b) 10% AlSiC MMC.

Main effect plot for S/N Ratio for surface roughness obtained for drilled 5% AlSiC MMC is shown in the figure above (Fig. a). Main effect plot show the effect of machining parameters and their levels on to the response variable. It is shown that S/N ratio value increases with increasing spindle speed, feed rate and depth of cut. Hence minimum surface roughness obtained at 1000RPM spindle speed, 0.05mm/rev feed rate and at 1mm depth of cut. Corresponding surface roughness value ((R_a) is 3.865µm.

Main effect plot for S/N Ratio for surface roughness obtained for 10% AlSiC MMC is shown in the figure above (Fig. b). It is shown that S/N ratio increases with increasing spindle speed and feed rate but S/N ratio decreases from 1.0 to 1.5 mm depth of cut and increases from 1.5 to 2.0 mm depth of cut. Hence minimum surface roughness obtained at 1000RPM spindle speed, 0.10mm/rev feed rate and 1.5mm depth of cut. Corresponding surface roughness value ((R_a) is 3.915µm.

4.2 Response Table for S/N Ratio:

After calculating S/N Ratio for surface roughness, response table for S/N Ratio was carried out using minitab software in order to find out most effective machining parameter on surface roughness. Average response characteristic for each level of each parameter for both 5% and 10% AlSiC MMC is shown below. Rank has been given based on the delta value in the response table from the highest effect to least effect depending upon characteristics of response. More delta value ranked first and least delta value ranked last.

Table 4: Response Table for S/N Ratio for 5% AlSiC MMC.

Level	Speed	Feed	Depth of Cut
1	-8.0103	-7.5076	-8.4515
2	-6.6034	-6.6187	-8.4393
3	-2.7559	-3.2432	-0.4788
Delta	5.2544	4.2645	7.9728
Rank	**2**	**3**	**1**

It can be seen from the response table that Depth of cut is influencing more on minimizing the surface roughness for drilled 5% AlSiC MMC followed by Speed and lastly feed parameter.

Table 5: Response Table for S/N Ratio for 10% AlSiC MMC.

Level	Speed	Feed	Depth of Cut
1	-12.719	-10.312	-10.294
2	-10.330	-10.300	-11.135
3	-5.866	-8.303	-7.485
Delta	6.853	2.009	3.650
Rank	**1**	**3**	**2**

It can be seen from the response table that Speed is the most influencing factor on minimizing surface roughness for drilled 10% AlSiC MMC followed by Depth of Cut and lastly feed parameter.

4.3 Analysis of Variance (ANOVA):

ANOVA carried out for finding out percentage contribution of each parameter on surface roughness of drilled composites. Result is shown below.

Table 6: ANOVA for 5% AlSiC MMC.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	P_c
Speed	2	44.39	22.196	2.76	0.266	20.38
Feed	2	30.37	15.185	1.89	0.346	13.94
Depth of Cut	2	126.93	63.467	7.90	0.112	58.28
Error	2	16.06	8.029			7.40
Total	8	217.76				100

DF: Degrees of Freedom, Adj SS: Adjusted Sum of Squares, Adj MS: Adjusted Mean of Squares, P_c: Percentage Contribution.

As per Analysis of Variance more percentage contribution means more effect of that parameter on output parameter. It is seen from the ANOVA table for 5% AlSiC MMC that percentage contribution of spindle speed on surface roughness is 20.38%, feed having percentage contribution of 13.94% and depth of cut has percentage contribution of 58.28%. Depth of cut has more percentage contribution compared to other two parameters. Hence Depth of cut is the most influencing parameter on surface roughness followed by Spindle Speed and Feed.

Table 7: ANOVA for 10% AlSiC MMC.

Source	DF	Adj SS	Adj MS	F-Value	P-Value	P_c
Speed	2	9.660	4.830	1.34	0.428	37.62
Feed	2	3.551	1.776	0.49	0.670	13.83
Depth of Cut	2	5.236	1.217	0.34	0.748	20.39
Error	2	7.225	3.612			28.16
Total	8	25.672				100

It is seen from the ANOVA table for 10% AlSiC MMC that percentage contribution of spindle speed on surface roughness is 37.62%, feed having percentage contribution of 13.83% and depth of cut has percentage contribution of 20.39%. Spindle Speed has more percentage contribution compared to other two parameters. Hence Spindle Speed is the most influencing parameter on surface roughness followed by Depth of Cut and Feed.

V. Conclusion

AlSiC MMCs have been fabricated successfully using stir casting method. Drilling of prepared composites carried out using HSS as drill tool material with the help of CNC Vertical Machining Center according to L9 orthogonal array with varying drilling parameters. Surface Roughness found out at circumference of drilled holes using surface roughness tester. Following are the conclusion made from experimental results and discussions.

- By using Taguchi method, for 5% SiC AMMC optimal values of machining parameters on minimizing surface roughness found to be 1000 RPM spindle speed, 0.05 mm/rev feed rate and 1 mm depth of cut. Corresponding surface roughness value is 3.865 µm. Depth of cut found to be more effective parameter followed by spindle speed and feed rate.

- For 10% SiC AMMC optimal values of machining parameters on minimizing surface roughness found to be 1000 RPM spindle speed, 0.10 mm/rev feed rate and 1.5 mm depth of cut. Corresponding Surface Roughness Value is 3.915 µm. Spindle speed found to be more effective parameter followed by depth of cut and feed rate.

- Using ANOVA. for 5% AlSiC MMC it was found that percentage contribution of spindle speed on surface roughness is 20.38%, feed having percentage contribution of 13.94% and depth of cut has percentage contribution of 58.28%. Depth of cut has more percentage contribution compared to other two parameters. Hence Depth of cut is the most influencing parameter on surface roughness followed by Spindle Speed and Feed.

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