M.Tech (Production Engineering) Varsha Pathak 2018

OPTIMIZING THE MACHINING PARAMETERS FOR SURFACE ROUGHNESS IN CNC TURNING OF HYBRID METAL MATRIX (Al-RHA-GSA) COMPOSITES

A DISSERTATION
SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE
OF

MASTER OF TECHNOLOGY
In
PRODUCTION ENGINEERING

Submitted by:

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2K16/PIE/02

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DECLARATION

I, **Varsha Pathak** , Roll No(2K16/PIE/02) of M.Tech (Production Engineering), hereby declare that the project Dissertation titled "**Optimizing the Machining Parameters for Surface Roughness in CNC Turning of Hybrid Metal Matrix (Al-RHA-GSA) Composites**'' which is submitted by me to the Department of Mechanical, Production & Industrial and Automobile Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi — Varsha Pathak

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CERTIFICATE

I hereby certify that the Project Dissertation titled **"Optimizing the Machining Parameters For Surface Roughness in CNC Turning Of Hybrid Metal Matrix (Al-RHA-GSA) Composites"** which is submitted by **Varsha Pathak, Roll No (2K16/PIE/02)** Department of Mechanical, Production & Industrial and Automobile Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirements for the award of the degree of **Master of Technology,** is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this university or elsewhere.

PROF. RANGANATH. M. SINGARI
SUPERVISOR

Mr. RAVI BUTOLA
CO SUPERVISOR

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ACKNOWLEDGEMENT

It is a matter of great pleasure for me to present my dissertation report on " **"Optimizing the Machining Parameters for Surface Roughness in CNC Turning Of Hybrid Metal Matrix (Al-RHA-GSA) Composites".** First and foremost, I am profoundly grateful to my guide **Dr. Ranganath M. Singari, Professor, Mechanical Engineering Department** for his expert guidance and continuous encouragement during all stages of thesis. I feel lucky to get an opportunity to work with him. Not only understanding the subject, but also interpreting the results drawn there on from the graphs was very thought provoking. I am thankful to the kindness and generosity shown by him towards me, as it helped me morally complete the project before actually starting it. I would also like to thank **Mr. Ravi Butola** for his expert guidance and continuous support.

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Last, but not the least, I would like to thank **my family members** for their help, encouragement and prayers through all these months. I dedicate my work to them.

Date: VARSHA PATHAK

Place: 2K16/PIE/02

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LIST OF SYMBOLS, ABBREVIATIONS AND NOMENCLATURE

Description	**Parameter**
Metal Matrix composite	MMC
Rice Husk Ash	RHA
Groundnut Shell Ash	GSA
Parameter of roughness	Ra
Surface Roughness	SR
Analysis of Variance	ANOVA
Computer Numerical Controlled	CNC
Design of Experiment	DOE
Mean depth of roughness motifs	R
Maximum depth of roughness motifs	Rx
Mean spacing of roughness motifs	AR
Mean width of profile	Rsm
Maximum peak to valley height	Pt

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ABSTRACT

In manufacturing industries, for determining the quality, surface finish of a product is very important. This study focuses on analyzing cutting parameters based on Taguchi method, a powerful tool to design optimization for quality, is used to minimize surface roughness. Taguchi method of design of experiments, the signal-to-noise (S:N) ratio, analysis of variance (ANOVA) and regression analysis are employed to investigate the cutting characteristics of three different metal matrix composites in varying proportion of reinforcements i.e. MMC (Al 7075-2%RHA-2%GSA), MMC (Al7075-3.5%RHA-3.5%GSA) and MMC (Al7075-5%RHA-5%GSA) using carbide cutting tools. Different cutting parameters have different influence on the surface finish. The cutting speed, feed and depth of cut are considered using the suitable range recommended; which were 50.57m/min, 72.25m/min and 93.93m/min for cutting speed, 0.10mm/rev, 0.14mm/rev and 0.18mm/rev for feed and lastly 0.20mm, 0.35mm and 0.5mm for depth of cut. The specimen was turned under different level of parameters and was measured the surface roughness using a Taylor Hobson's Surtronic 3+. According to the ANOVA analysis, feed is the dominant factor by 55.073% for MMC (Al7075-2%RHA-2%GSA) and depth of cut is the dominant factor by 28.056% for MMC (Al7075-3.5%RHA-3.5%GSA) and feed is the dominant factor by 55.073 for MMC (Al7075-5%RHA-5%GSA). The optimum cutting parameters which produce minimum surface roughness for MMC (Al7075-2%RHA-2%GSA) are 50.57m/min, 0.10mm/rev and 0.20mm. The optimum cutting parameters which produce minimum surface roughness for MMC (Al7075-3.5%RHA-3.5%GSA) are 93.93m/min, 0.10mm/rev and 0.50mm. The optimum cutting parameters which produce minimum surface roughness for MMC (Al7075-5%RHA-5%GSA) are 50.57m/min, 0.18mm/rev and 0.50mm. From tensile test it is concluded that in MMC (Al7075-RHA-GSA), as the percentage of reinforcement increases up to certain value tensile strength decreases after this increase in reinforcement will improve tensile strength. From hardness test it is concluded that metal matrix composites (Al-RHA-GSA) have higher hardness value than pure Al 7075 alloy and as the percentage of reinforcement increases, hardness value also increases.

Keywords: MMC, RHA, GSA, Surface roughness, Taguchi, ANOVA, Regression analysis, Taylor Hobson's Surtronic3+.

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CHAPTER 1:
INTRODUCTION

1.1 TURNING OPERATION

In turning method material is discarded in the shape of chip via lowering the diameter of the rotating work to the required dimension on the CNC lathe machine by way of controlling the miscellaneous parameters.

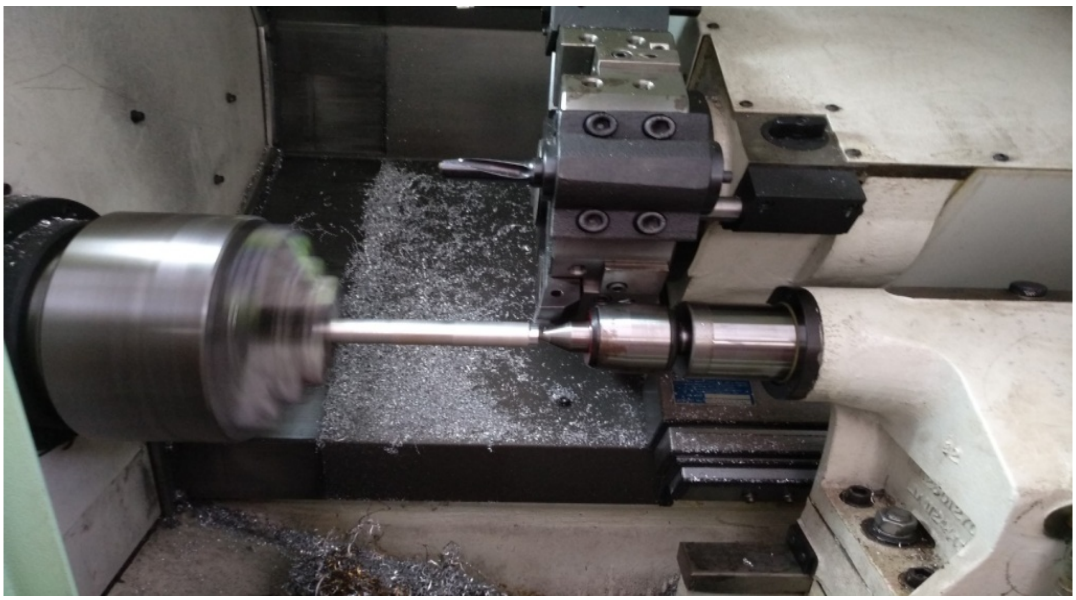

Fig.1.1: Turning operation

1.2 TURNING MACHINE:

Lathe machine is that the commonest used turning machine within the production industry to manufacture cylindrical components. Lathe machine is wide utilized in varied manufacturing industries where quality of surface is that the most important demand. Nowadays, CNC machines are wide used in varied affordable production processes. During manufacturing process in CNC machine, numerous functions like program editing, tool offset, program storage, tool compensation and reference point etc are controlled by computer.

Fig.1.2: CNC lathe

1.3 SURFACE PROPERTIES:

Surface integrity consist each surface metallurgy and surface topography. Surface integrity depict not solely geometric (topological) characteristics of surfaces, however additionally their mechanical and metallurgical properties. Surface topography evoke the texture of work piece's utmost layer. Surface topography depends on interface with the surroundings whereas surface metallurgy depends on base of material. Surface metallurgy narrates characteristics of the assorted layers below the surface with regard to the bottom of the matrix material.

1.4 Surface Roughness Measuring Instrument

Miscellaneous Parameters accessible for surface texture analysis are: Ra, Rq, Rz (DIN), Ry and Sm. If most popular, a Ni-Cad rechargeable battery will be used.

Fig.1.3: Surface roughness measurement apparatus

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1.5MISCELLANEOUS CUTTING FACTORS AFFECTING THE SR:

For attainment of higher cutting performance choice of cutting factors is most significant facet. For a selected machine and surroundings demand of miscellaneous cutting parameters is totally different. That's why optimization of cutting parameters is completed by using totally different ways for example Taguchi methodology, ANOVA, RSM etc. Feed depth of cut and cutting speed are the foremost overriding determinants affecting SR.

1.5.1 Cutting Speed

For different materials different value of cutting speed is required and to diagnose the optimal cutting speed (V_c) required,

$$V_c = \pi DN/1000$$

Where: V_c = Cutting Speed of Metal (m/min), D = Diameter of Work piece (mm), N = Spindle Speed (RPM)

1.5.2 Feed

The term 'feed' is used to define distance moved by tool in one revolution of work piece and varies largely on the basis of requirement of surface finish. For good finishing finer feed is recommended. For rough turning of soft material a feed of up to 0.25 mm/rev can be used and for rough turning of tough materials feed should be decreased up to a maximum of 0.11 mm/rev.

1.5.3 Depth of cut

It is the advancement of cutting tool in the job in a specific direction perpendicular (at an angle of 90°) to the machining surface. Depth of cut (doc) naturally varies between 0.5 to 5 mm for rough turning operation and 0.09 to 1 mm for finish turning operation.

1.5.4 Effect of cutting parameters

Since these cutting parameters will choose about the type of chips which we assume at the time of machining of a single constant material thus we have to examine them to abstain from built-up edge formation. At the optimal cutting speed at which the ramification of built up edge is insignificant, (high speed, ductile material) the profile of cutting tool is imitated

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on the work surface and this ideal SR is largely reliant on cutting feed. That means for a larger feed the mean roughness value is more as associated to the lesser feed. It would be noted that the size of chips cross-sectional area has a great influence on surface finish. Surface finish is poor for large cuts which is required from consequential of extraordinary tool life and power consumption. Larger feed is more detrimental to surface finish than a larger depth of cut. For very high cutting speeds the probabilities of built up edge decreases thus SR also expected to decrease, while when cutting speed is small built-up formation of chips would increase the SR.

1.6 Taguchi Method

Taguchi strategies seek advice from approaches developed by Taguchi to develop prime quality product. In experimental robust design, the effects of manageable and uncontrollable variables on the product are calculated. This approach minimizes variations in product dimensions and properties and ultimately brings the mean to desired level. The strategies used for experimental robust design are complicated and involve the utilization of factorial design and orthogonal arrays that reduce the amount of experiments needed. These strategies are capable of distinguishing the consequences of variables which will not be controlled (referred to as noise), like changes in environmental conditions and traditional property variations of incoming materials. As a result of we would like minimum surface roughness thus smaller is better formula is utilized for calculating S/N ratio.

Smaller-is-the better(minimize): $S/N_S = -10\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right)$

1.7 ANOVA

Some computational models are desideratum to ameliorate manufacturing method as a result of presence of an extensive varies of variables surveilling production methods. However, these models are to be established using exclusively the imperative facets governing manufacturing method rather than along with all the parameters. The guesstimate of the comparative assistances of each of the miscellaneous dominant facets to the final evaluated response would be enabled by a computational method avowed as ANOVA.

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1.8 METAL MATRIX COMPOSITE:

The metal matrix composite embodies two or additional separate fragments that are combination of miscellaneous variegated reinforcement with matrix material. Strengthened metal matrix composites (AL7075-RHA-GSA) in comparison to single alloy or particle of composite have auxiliary fringe as they entail meliorated Mechanical properties. Metal matrix composite (Al7075-RHA-GSA) composites embody excellent miscellaneous mechanical characteristics high hardness, high stiffness etc. As the proportion of reinforcement will be extended hardness of composite will also be Ameliorated, that consecutive will upgrade the quality in turning and make the surface rough. So as to countervail this concern reinforcement is balanced indistinguishable proportions with Al 7075, rice Husk Ash (RHA) and ground nut shell ash (GSA) etc.

1.8.1Aluminum Alloy 7075:

Table1.1: Composition of Aluminum 7075 in percentage

S.NO.	**Element**	**Value in Percentage**
1.	Zn	5.10 – 6.10
2.	Mg	2.10-2.90
3.	Cu	1.20-2.00
4.	Cr	o.18 - 0.28
5.	Fe	0.50 (Max.)
6.	Si	0.40 (Max.)
7.	Mn	0.30 (Max.)
8.	Ti	0.20 (Max.)
9.	Other	0.05 (Max.) each 0.15 (Max) total
10.	Balance	Aluminum

Table1.2: Mechanical Properties of AL7075.

PROPERTY	**VALUE**
Density	2.810 g/cc

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Vickers Hardness	175
Ultimate Tensile Strength	572 MPa
Yield Strength	503 MPa
Modulus of Elasticity	71.70GPa
Poisson's Ratio	0.330
Thermal Conductivity	130 W/m-K
Melting Point	477-635°C
Heat Capacity	0.960 J/g-°C

1.8.2 Rice Husk Ash (RHA):

Now a day's rice husk ash (RHA) has multitudinous miscellaneous practice the surface of rice husk consists of rough components, which embodies largely silicon dioxide. The center portion embodies no silicon dioxide. The chemical conformation of rice husk ash (RHA) is analogous there to numerous agro based fibers which embodies silicon dioxide, aluminum oxide, iron oxide, iron oxide, calcium oxide etc. RHA possesses multitudinous miscellaneous applications in mostly silicon based industries.

Table1.3: Chemical composition of RHA:

S.NO.	Elements	Proportion (%)
1.	Silicon dioxide	86.94
2.	Aluminum oxide	0.2
3.	Iron oxide	0.1
4.	Calcium oxide	2-2.2
5.	Magnesium oxide	0.2 – 0.6
6.	Sodium oxide	0.1 – 0.8
7.	Potassium oxide	2.15-2.30

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1.8.3 Groundnut Shell Ash (GSA):

Lignocelluloses fibers embodies three main dominating constituents that is hemicelluloses, polysaccharide and polymer, that are notable to gift terribly advanced structure. an oversized quantity of hydroxyl radical teams in polysaccharide provides hydrophilic properties to the natural fibers. Hemi cellulose is powerfully certain to the polysaccharide fibrils, presumptively by bonds.

Table1.4: Chemical composition of ground nut shell ash:

S.NO.	Elements	Amount (%)
1.	Cellulose	35.7
2.	Hemi cellulose	18.7
3.	Lignin	30.2

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CHAPTER 2

LITERATURE REVIEW:

- **P. Shanmughasundaram et al. [1]** studied influence of graphite and machining parameters on the surface roughness of Al-fly ash/graphite hybrid composite using multicoated carbide tool with a 0.8 mm nose radius on CNC lathe machine. Taguchi and ANOVA techniques in turning of Al, Al-15 wt% fly ash and Al-15 wt% fly ash /1.5 wt% composites for optimizing cutting speed, feed and depth of cut .They concluded that the presence of the ash particles reduces the surface roughness of composites compared with pure Al. The feed rate (46.96%) has the very best influence on surface roughness within the machining of an Al fly ash/Gr composite followed by cutting speed (43.35%) and depth of cut (5.58%).

- **E. Baburaj et al. [2]** used Taguchi method and ANOVA to optimize cutting parameters to achieve low surface roughness and high metal removal rate on hybrid metal matrix (Al-5%wt SiCp - 5% wt Fly ash) composite. They considered Cutting Speed (rpm), Feed Rate (mm/rev), Depth of Cut (mm) and nose radius as cutting parameters. They concluded that optimum setting for feed rate (0.2 mm/rev) and depth of cut (0.2 mm) was noted to be same in the Taguchi method and Genetic algorithm. From ANOVA, it is evident that the effect of nose radius (0.2 - 0.8 mm) on surface roughness is negligible compared to the other parameters.

- **Devinder Priya et al. [3]** studied effect of type and percentage of reinforcement for optimization of the cutting force in turning of Aluminum matrix composites using response surface methodologies on Al-SiC-Gr composites. They considered Type of composite, quantity in percentage weight and feed (mm/rev) as cutting parameters and concluded that the cutting force was maximum for SiC nano particles. There was only a marginal difference between the cutting forces for Graphite and hybrid composites.

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- **M. Nataraj et al. [4] used** RSM and ANOVA analysis for optimization of cutting parameters on Hybrid metal matrix composite (LM6 aluminum alloy –fly ash-silicon carbide) and for this analysis they considered Cutting Speed, Feed Rate and Depth of Cut as machining parameters. They concluded that cutting speed of 175 m/min, depth of cut of 0.25 mm and feed rate of 0.1 mm/rev during machining HMMCs are optimal machining parameters.

- **S. Rajesh et al. [5]** considered Cutting Speed (rpm), Feed Rate (mm/rev), Depth of Cut (mm) and nose radius as cutting parameters. In this investigation, grey-based Taguchi method coupled with principal component analysis is used for optimizing the machining parameters of aluminum-based red mud MMC during turning operation. The principal component analysis, used to determine the corresponding weighting values of each performance characteristics while applying grey relational analysis to a problem with multiple performance characteristics, is proven to be capable of objectively reflecting the relative importance for each performance characteristic.

- **Chintada Shoba et al. [6]** used Taguchi and ANOVA method to optimize cutting parameters to achieve low surface roughness on Al/6%SiC/6%RHA Hybrid Composites .Cutting Speed (rpm), Feed Rate (mm/rev), Depth of Cut (mm) and nose radius were considered as cutting parameters. They concluded that Optimal parameters for minimal surface roughness obtained for turning the hybrid composite are Spindle speed (N) =900rpm; Feed (f) =0.25mm/rev; Depth of cut (d) = 0.5mm.In ANOVA, it is revealed that feed has a major contribution on the surface roughness (82.6%) followed by depth of cut (6.8%) and the cutting speed (6.43%).

- **Prakash Rao C.R. et al. [7]** did optimization of surface roughness values of K10 grade carbide and Poly Crystalline Diamond (PCD) inserts while turning Al6061- fly ash composites containing 0% to15% fly ash in step of 5%. Chemical Composition (Wt %)Mg=0.84, Si=0.62, Fe=0.23, Cu=0.22 , Zn=0.1, Ti=0.1, Mn= 0.03, Cr=0.22, Al=Balance .Cutting Speed (rpm) ,Feed Rate (mm/rev) and Depth of Cut (mm) were considered as cutting parameters. They concluded that the hardness of the composite

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is greater than that of its cast matrix alloy and the hardness of composite increases with increased fly ash content and While machining Aluminum fly ash composites, as the cutting speed increases the surface roughness decreases and also while machining Aluminum fly ash composites as the feed increases surface roughness increases.

- **Basheer et al. [8]** studied the modeling of surface roughness in fine machining of MMC with Artificial Neural Network (ANN). They investigated roughness of machined surfaces on Al- SiC composites associated developed of an ANN-based model to predict surface roughness on CNC turning with PCD tool. They found that the most effective surface quality was obtained at lowest feed-rate, the smaller particle size and therefore the largest tool-nose radius.

- **S. P. Dwivedi et al. [9]** Studied the result of turning parameters like cutting speed, depth of cut and feed rate on surface roughness of A356-SiC 5% composite created by electromagnetic stir casting. Turning of A356 alloy 5 wt% SiC composites was carried out by tungsten carbide inserts on CNC lathe machine. They found that cutting speed increases surface roughness decreases, whereas depth of cut and feed increase surface roughness increase.

- **Boopathi et al. [10]** have reported an increasing trend in the hardness of composite with increase in weight fraction of reinforcements. They observed maximum hardness for Al /10wt.%SiC/10wt.%fly ash hybrid composites. This shows that incorporation of fly ash particles significantly improves hardness of the Al matrix. Boopathi et al. [13] have evaluated the strength of the HAMCs reinforced with SiC, aluminum oxide, fly ash and their mixtures. The results show that the tensile strength of composites is higher than the unreinforced Al-alloy. Tensile strength of unreinforced Al-alloy is 236 MPa and this value increases up to 263 MPa for Al/10%fly ash composite, 265 MPa for Al/10%SiC composite and 293 MPa for Al/10%SiC/10% fly ash hybrid composite.

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- **Davim.J et al. [11]** worked on surface roughness prediction models using artificial neural network (ANN) are developed to investigate the effects of cutting conditions during turning of free machining steel, 9SMnPb28k(DIN). The ANN model of surface roughness parameters (Ra and Rt) is developed with the cutting conditions such as feed rate, cutting speed and depth of cut as the affecting process parameters. The experiments are planned as per L27 orthogonal array with three levels defined for each of the factors in order to develop the knowledge base for ANN training using error back-propagation training algorithm (EBPTA). 3D surface plots are generated using ANN model to study the interaction effects of cutting conditions on surface roughness parameters. The analysis reveals that cutting speed and feed rate have significant effects in reducing the surface roughness, while the depth of cut has the least effect. When the depth of cut is low, the surface roughness is highly sensitive to cutting speed; an increase in cutting speed sharply reduces the surface roughness. However, this reduction becomes smaller and smaller with the higher values of depth of cut. It is also observed that, surface roughness variation is minimal with the variations of depth of cut at higher values of cutting speed. The surface roughness has a tendency to reduce with the increase in cutting speed and also with the reduction in feed rate.

- **P. Suresh et al. [12]** used grey-fuzzy algorithm to optimize the machining parameters in turning of Al-SiC-Gr hybrid composite. This logic provided optimum input machining parameters with multi performance characteristics They used Al-SiC-Gr Aluminum alloy LM25 as matrix Material and SiC and Gr particles with equal mass fraction of 5%, 7.5% and10% as reinforcement. They concluded that Al-10 %(SiC-Gr) provides better machinability with minimum Surface Roughness and a maximum Material Removal Rate. And Recommended that Optimal Turning Parameters are Cutting Speed=200 m/min Feed rate=0.07 mm/rev Mass fraction=10 %.

- **W.H. Yang et al. [13]** states that the Taguchi method, a powerful tool to design optimization for quality, is used to find the optimal cutting parameters for turning operations. An orthogonal array, the signal-to-noise (S: N) ratio, and the analysis of

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variance (ANOVA) are employed to investigate the cutting characteristics of S45C steel bars using tungsten carbide cutting tools. The Taguchi method provides a systematic and efficient methodology for the design optimization of the cutting parameters with far less effect than would be required for most optimization techniques. The confirmation experiments were conducted to verify the optimal cutting parameters. The improvement of tool life and surface roughness from the initial cutting parameters to the optimal cutting parameters is about 250%.

- **M. Nalbant et al. [14]** used Taguchi method to find the optimal cutting parameters for surface roughness in turning. The orthogonal array, the signal-to-noise ratio, and analysis of variance are employed to study the performance characteristics in turning operations of AISI 1030 steel bars using TiN coated tools. Three cutting parameters namely, insert radius, feed rate, and depth of cut, are optimized with considerations of surface roughness. The experimental results demonstrate that the insert radius and feed rate are the main parameters among the three controllable factors (insert radius, feed rate and depth of cut) that influence the surface roughness in turning AISI 1030 carbon steel. In turning, use of greater insert radius (1.2 mm), low feed rate (0.15 mm/rev) and low depth of cut (0.5 mm) are recommended to obtain better surface roughness for the specific test range. The improvement of surface roughness form initial cutting parameters to the optimal cutting parameters is about 335%.

- **N.R. Abburi et al. [15]** develops a knowledge-based system for the prediction of surface roughness in turning process. Neural networks and fuzzy set theory are used for this purpose. Knowledge acquired from the shop floor is used to train the neural network. The trained network provides a number of data sets, which are fed to a fuzzy-set-based rule generation module. A large number of IF–THEN rules are generated, which can be reduced to a smaller set of rules by using Boolean operations. The developed rule base may be used for predicting surface roughness for given process variables as well as for the prediction of process variables for a given surface roughness. Results shows that reducing the ranges and increasing the number of training data is expected to improve the accuracy of the surface roughness to the optimal cutting parameters is about 250%.

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- **JanezKopac et al. [16]** focuses on optimizing the turning of raw work pieces of low-carbon steel with low cold pre-deformation to achieve acceptable surface roughness. An attempt was made to minimize the number of experimental runs and increase the reliability of experimental results. According to the presence in the additive model and according to the analysis results, the cutting speed is the most powerful control factor of the process. A higher cutting speed results in a smoother surface.

- **P.V.S. Suresh et al. [17]**, deals with the study and development of a surface roughness prediction model for machining mild steel, using Response Surface Methodology (RSM). The experimentation was carried out with TiN-coated tungsten carbide (CNMG) cutting tools, for machining mild steel work-pieces covering a wide range of machining conditions. A second order mathematical model, in terms of machining parameters, was developed for surface roughness prediction using RSM. This model gives the factor effects of the individual process parameters. An attempt has also been made to optimize the surface roughness prediction model using Genetic Algorithms (GA) to optimize the objective function. Surface quality can be greatly controlled using Genetic Algorithms.

- **W.S. Lin et al. [18]**, a network is adopted to construct a prediction model for surface roughness and cutting force. This network is composed of a number of functional nodes, which are self-configured to form an optimal network hierarchy by using a predicted square error (PSE) criterion. Once the process parameters (cutting speed, feed rate and depth of cut) are given, the surface roughness and cutting force can be predicted by this network. To verify the accuracy of the network, regression analysis has been adopted to develop a second prediction model for surface roughness and cutting force. Comparison of the two models indicates that the prediction model developed by the network is more accurate than that by regression analysis. Critical elements that affect surface roughness are the feed rate, where increasing feed rate will increase the surface roughness value, while a regression multiplier for the surface roughness demonstrates that the cutting speed does not have a significant impact on surface roughness.

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- **Mazaheri et al. [19]** described friction stir processing as a novel technique for developing surface metal matrix composites (SMMCs)because metal matrix composites developed via stir casting and powder metallurgy are often reported to have increased strength and stiffness at the expense of ductility and toughness. Friction stir processing offers the opportunity of developing SMMCs with higher surface hardness and improved creep resistance while maintaining the ductility and toughness of the metal same

- **M.Y. Noordin et al. [20]** described the performance of a multilayer tungsten carbide tool using response surface methodology (RSM) when turning AISI 1045 steel. Cutting tests were performed with constant depth of cut and under dry cutting conditions. The factors investigated were cutting speed, feed and the side cutting edge angle (SCEA) of the cutting edge. The main cutting force, i.e. the tangential force and surface roughness were the response variables investigated. The experimental plan was based on the face centered, central composite design (CCD). The experimental results indicate that the proposed mathematical models suggested could adequately describe the performance indicators within the limits of the factors that are being investigated. The ANOVA revealed that feed is the most significant factor influencing the response variables investigated.

- **D.I. Lalwani et al. [21]**, In the present study, an attempt has been made to investigate the effect of cutting parameters (cutting speed, feed rate and depth of cut) on cutting forces (feed force, thrust force and cutting force) and surface roughness in finish hard turning of MDN250 steel [equivalent to 18Ni(250) steel] using coated ceramic tool. The machining experiments were conducted based on response surface methodology (RSM) and sequential approach using face centered central composite design. The results show that cutting forces and surface roughness do not vary much with experimental cutting speed in the range of 55– 93 m/min. A non-linear quadratic model best describes the variation of surface roughness with major contribution of feed rate and secondary contributions of interaction effect between feed rate and depth of cut, second order (quadratic) effect of feed rate and interaction effect

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between speed and depth of cut. Good surface roughness can be achieved when cutting speed and depth of cut are set nearer to their high level of the experimental range (93m/min and 0.2mm) and feed rate is at low level of the experimental range (0.04mm/rev).

- **Alaneme et al. [22]** studied the fabrication characteristics and mechanical behavior of rice husk ash–alumina reinforced Al-Mg-Si alloy matrix hybrid composite produced via stir casting. The 10 wt% reinforcing phases consisted of 2, 3, 4, and 6 wt% RHA as a complementing reinforcement to alumina. The authors reported that there was a slight decrease in hardness, ultimate tensile strength of the hybrid composites as compared with the single reinforced Al-Mg-Si/Alumina composites.

- **Davim. J et al. [23]**, presents a study of the influence of cutting parameters on surface roughness in turning of glass-fiber-reinforced plastics (GFRPs). A plan of experiments was performed on controlled machining with cutting parameters prefixed in work piece. A statistical technique, using orthogonal arrays and analysis of variance, has been employed to investigate the influence of cutting parameters on surface roughness in turning GFRPs tubes using polycrystalline diamond cutting tools. The objective was to obtain the contribution percentages of the cutting parameters (cutting velocity and feed rate) on the surface roughness in GFRPs work piece. Results shows that with this cutting parameters (speed and feed) it was possible to obtain surfaces with 0.80-1.75mm of arithmetic average roughness (Ra) and 4.9-9.3mm of maximum peak-to-valley height (Rt/Rmax). The surface roughness (Ra and Rmax) increases with the feed rate and decreases with the cutting velocity and feed rate is the cutting parameter that has the highest physical as well statistical influence on surface roughness (Ra and Rt/Rmax) in work piece.

- **J.Paulo et al.[24]** studied on optimization of machining parameters of Al-SiC-MMC with ANOVA and ANN technique for analysis. A medium duty lathe machine with 2Kw spindle power was used to perform the experiments with PCD coarse grade tool, surface roughness under different cutting conditions data was collected for varied mixtures of cutting speed, feed rate, and depth of cut. The PCD tool with

CNMA 120408 inserts and PCLNR 25X 25 M12 tool holders were used for turning of 150mm diameter work piece. ANN methodology takes lesser time for giving higher accuracy. Therefore, optimization with ANN is that the simplest technique compared with ANOVA. They found that in ANOVA, the feed rate has highest physical as well as statistical influence on the surface roughness (51%) right when the depth of cut (30%) and therefore the cutting speed (12%).

- **Dilbag Singh et al. [25],** An experimental investigation was conducted to determine the effects of cutting conditions and tool geometry on the surface roughness in the finish hard turning of the bearing steel (AISI 52100). Mixed ceramic inserts, having different nose radius and different effective rake angles, were used as the cutting tools. Mathematical models for the surface roughness were developed by using the response surface methodology. The results also indicate that feed is the dominant factor affecting the surface roughness, followed by the nose radius, cutting velocity and effective rake angle.

- **Ahmet Hasçalhk et al. [26],** In this study, the effect and optimization of machining parameters on surface roughness and tool life in a turning operation was investigated by using the Taguchi method. The experimental studies were conducted under varying cutting speeds, feed rates, and depths of cut. An orthogonal array, the signal-to-noise (S/N) ratio, and the analysis of variance (ANOVA) were employed to the study the performance characteristics in the turning of commercial Ti-6Al-4V alloy using CNMG 120408-883 insert cutting tools. Results show that the feed rate parameter is the main factor that has the highest importance on the surface roughness and this factor is about 1.72 times more important than the second ranking factor (depth of cut) whereas the cutting speed does not seem to have much of an influence on the surface roughness.

- **Vishal S. Sharma et al. [27],** In this study, machining variables such as cutting forces and surface roughness are measured during turning at different cutting parameters such as approaching angle, speed, feed and depth of cut. The data obtained by experimentation is analyzed and used to construct model using neural

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networks. The model obtained is then tested with the experimental data and results are indicated. Surface roughness (Ra) is positively influenced with feed and it shows negative trend with approaching angle, speed and depth of cut. The neural network model for cutting force Ra could predict with moderate accuracy.

- **Thomas M. et al. [28]** conducted a full factorial experimental design (288 experiments) that allows considering the three-level interactions between the independent variables has been conducted. The results show that second order interactions between cutting speed and tool nose radius, along with third-order interaction between feed rate, cutting speed and depth of cut are the factors with the greatest influence on surface roughness and tool dynamic forces in this type of operation and parameter levels studied. The analysis of variance revealed that the best surface roughness condition is achieved at a low feed rate (less than 0.35 mm/rev), a large tool nose radius (1.59 mm) and a high cutting speed (265 m/min and above). The results also show that the depth of cut has not a significant effect on surface roughness, except when operating within the built-up edge range. The effect of built-up edge formation on surface roughness can be minimized by increasing depth of cut and increasing tool vibration.

- **Ranganath M.S. et al. [29]**, investigates the parameters affecting the roughness of surfaces produced during the turning process for the material Aluminum 6061. The surface roughness is considered as quality characteristic while the process parameters considered are speed, feed and depth of cut .Design of experiments were conducted for the analysis of the influence of the turning parameters on the surface roughness by using Taguchi design. The results of the machining experiments for Aluminum 6061 were used to characterize the main factors affecting surface roughness by the Analysis of Variance (ANOVA) method. The ANOVA and F-test revealed that the feed is dominant parameter followed by depth of cut and speed for surface roughness. The optimal combination process parameter for minimum surface roughness is obtained at 2100 rpm, 0.1 mm/rev and 0.2mm. A regression model is developed for surface roughness which is reasonably accurate and can be used of prediction within limits. Taguchi gives systematic simple approach and efficient method for the optimum operating conditions.

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- **A.K. Sahoo et al. [30]** studied development of Al/SiC 10% metal matrix employing a typical casting method and studied its machining parameters on lathe machine using multilayer TiN coated carbide tool under dry condition. From the experimental study using Taguchi's L9 orthogonal array they found that cutting speed was the foremost affecting parameter on the flank wear. Feed was found to the next important parameter for surface roughness. Surface roughness increases with increase of feed up to 0.1 mm/rev. At above 0.15 mm/rev feed, the surface quality decreases continuously.

- **K.Ramadevi et al.[31]** used Taguchi method to study of machining behavior of Aluminum- 7075- with (0, 2.5, 5 wt%) of TiB2 and TiC and concluded that A significant improvement is observed in the tensile strength and hardness of the composite with increasing percentage reinforcement of material, and a decrease in the ductility of the composite is observed with increasing percentage reinforcement of material and on material removal rate the strongest influence was exerted by Feed rate (44 mm/rev), followed by Depth of cut (31.2 mm), spindle speed (12.8 rpm), and lastly percentage reinforcement (1.69), and for cutting force the strongest influence was exerted by spindle speed (68.9 rpm), followed by Depth of cut (8.31 mm), percentage reinforcement (7.7 wt%) and lastly Feed rate (4.10 mm/rev).

- **Puneet Bansal et al. [32]** did Experimental studies on Effect of Turning Parameters on Tool Wear, Surface Roughness and Metal Removal Rate of Alumina Reinforced Aluminum Composite by considering Concentrations of Alumina, Cutting Speed, Feed Rate and Depth of Cut as effective cutting parameters Experimental studies were done for the tool wear, MRR and surface roughness with two types of tool coated and concluded that Microstructure of MMCs indicates the homogeneous mixture of the alumina in the composite and Hardness and tensile strength increases with the reinforcement ratio and Tool wear increases with the process variables whether it is coated or uncoated tool, however tool wear is less in coated tool as compared to uncoated due to the coating and Surface Roughness increase with the process variables except the speed, speed made adverse effect on surface roughness

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and MRR increases with the process parameters except the concentration of reinforced particles due the presence of hard ceramic particles.

CHAPTER 3
EXPERIMENTAL SET UP

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3.1 BALL MILLING MACHINE:

Rice Husk Ash and ground nut shell ash were grinded in ball milling machine in metrology lab for 90 minutes. In this operation 12 ceramic ball were used. A ball milling machine could be a sort of grinder accustomed grind and blend materials. It works on the principle of impact and attrition.

Fig.3.1: Ball milling machine

Fig.3.2: Rice husk ash before ball milling operation

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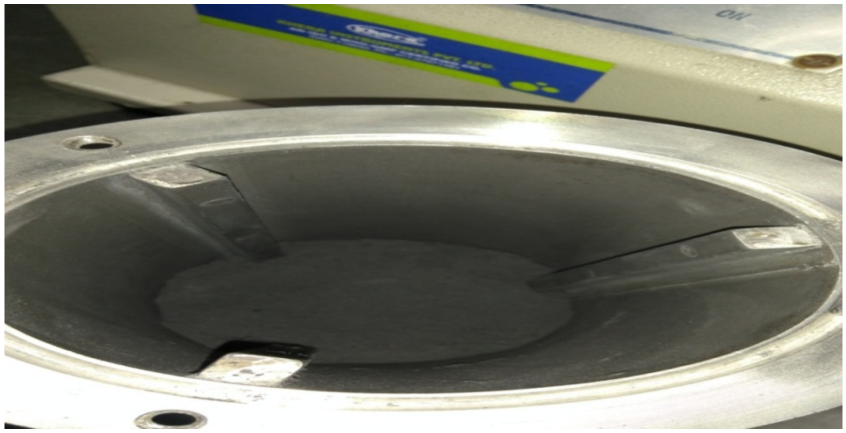

Fig.3.3: Rice husk ash after ball milling

Fig.3.4: Ground nut shell ash before ball milling

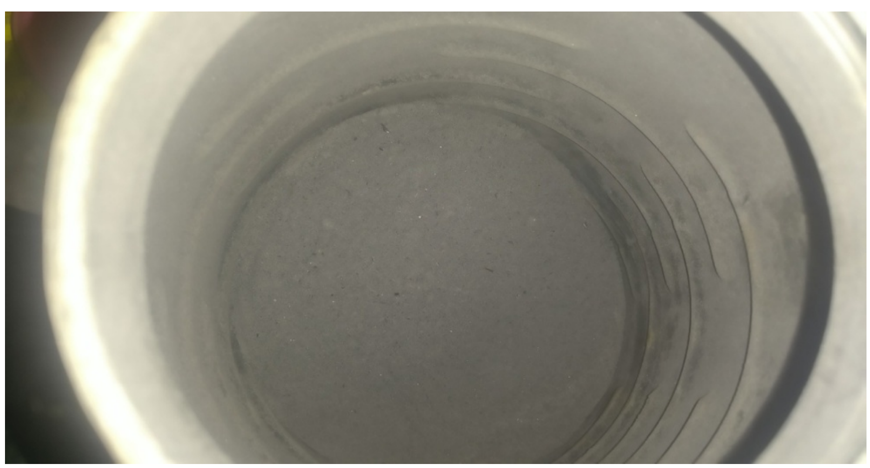

Fig.3.4: Ground nut shell ash after ball milling

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3.2 SIEVE SHAKER

Generally, for granular materials such as different types of ash (RHA, GSA, CSA, BLA etc) sieve analysis is done to find their size. Innumerable ASTM standard sieves were utilized to ascertain the size of rice husk ash (RHA) and ground nut shell ash (GSA).

Fig.3.6: Sieves

Table3.1: Sieve Size

S.NO.	TYPE OF ASH	SIZE (ASTM)
1.	Rice Husk Ash(RHA)	140
2.	Groundnut Shell Ash (GSA)	70

Fig.3.7: Sieve shaker

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3.3 TENSILE TEST ON UTM:

Because of its relative lucidity, the tension test is that the most typical test for determiner of the strength-deformation characteristics of miscellaneous materials. It involves the preparation of a test specimen as per ASTM E8 standards, and testing it in tension on any of a reach of accessible testing equipment. The utmost stress is understood as the material's ultimate tensile strength UTS). When applied load is exceeded on ASTM E8 standard tensile specimen such that stress exceeds the ultimate tensile strength, the engineering stresses dwindle additionally and also the ASTM E8specimen finally fractures within the high-necked region. The ultimate stress level at fracture is understood as fracture stress.

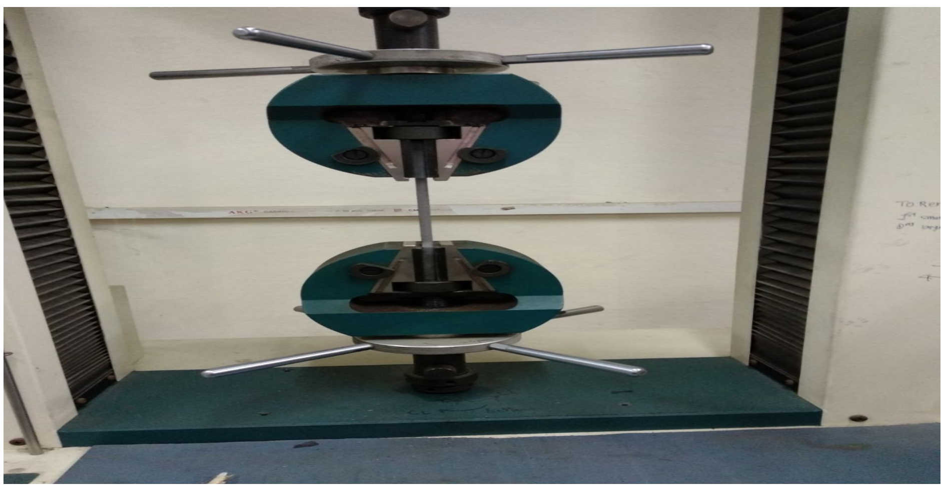

Fig.3.8: Universal testing machine

Tensile test was done on 3 metal matrix composites (AL-RHA-GSA) as shown in figure:

Table3.2: Weight percentage of RHA and GSA used.

S.NO.	% of ash by weight	**Al 7075 weight (gm)**	RHA weight (gm)	GSA weight (gm)
1.	4	**1032.6**	20.652	20.652
2.	7	**1021.1**	35.73	35.73
3.	10	**1013.5**	50.675	50.675

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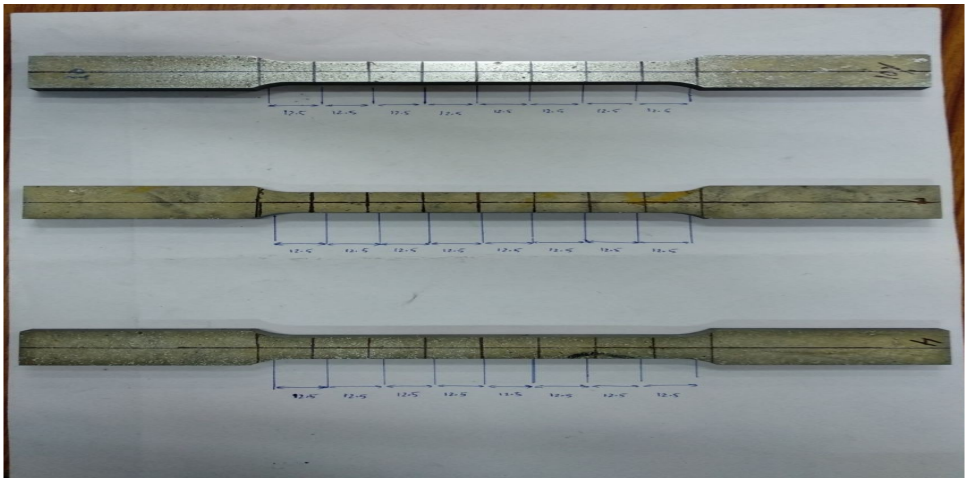

Fig.3.9 Preparation of parent material for tensile testing

Method Name: Generic Metals Tensile from Position

Output Name: Generic Metals Tensile from Position

Thickness mm	Width mm	Gage Length (Initial) mm	Gage Length (Final) mm	Area mm²	Ultimate Force N	Ultimate Stress MPa	Offset @ 0.2% N	Offset @ 0.2% MPa	TE (Auto) %	Diameter mm
6.96	12.5	85.0	87.0	87.0	10400	119	703	8.09	2.27	N/F

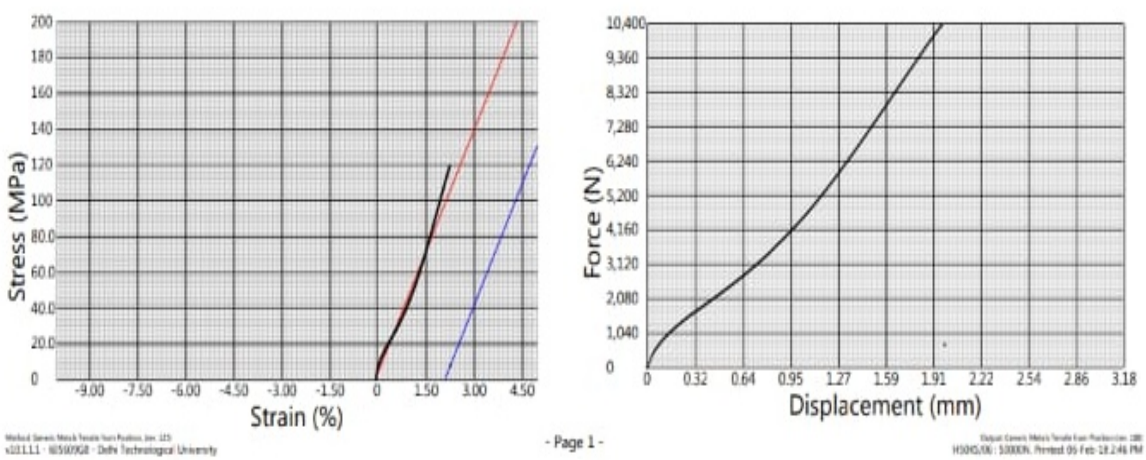

Fig.3.10 Tensile Test Graph of MMC (Al 7075-2%RHA-2%GSA)

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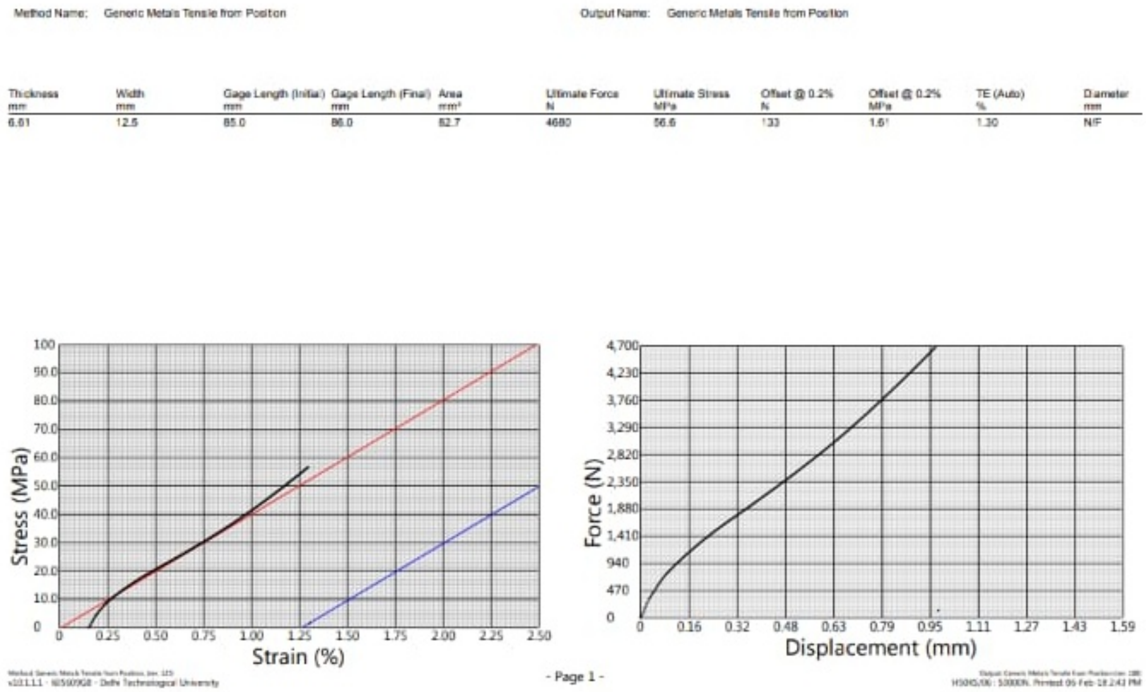

Fig.3.11 Tensile Test Graph of MMC (Al 7075-3.5%RHA-3.5%GSA)

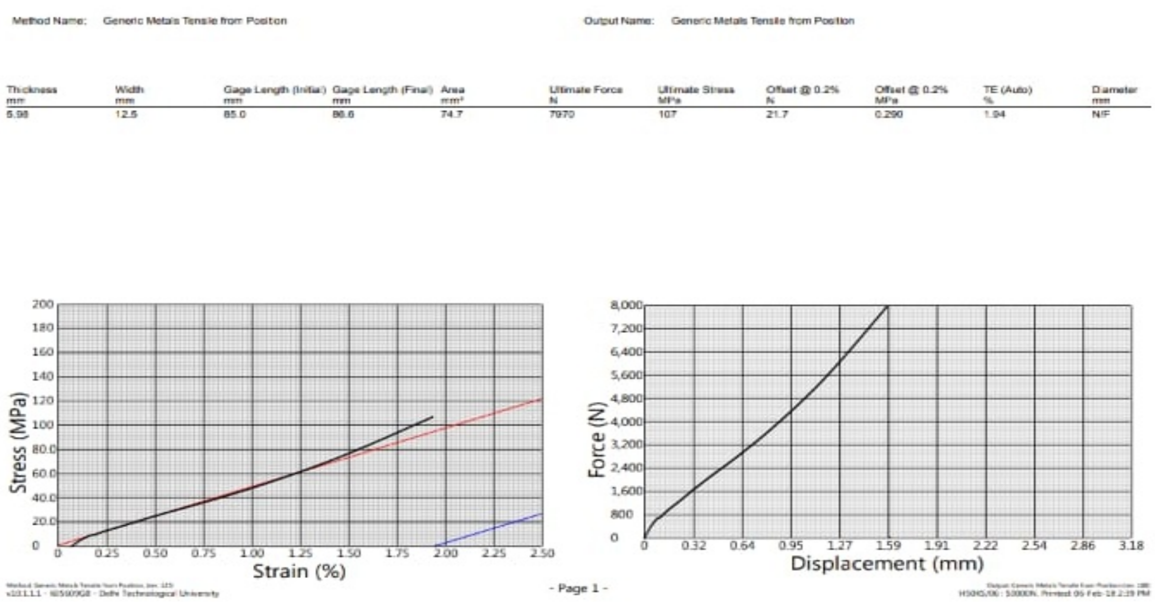

Fig.3.12 Tensile Test Graph of MMC (Al 7075-5%RHA-5%GSA)

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Table3.3: Result of Tensile Test.

S.NO	Material	Ultimate tensile strength (MPa)
1.	100 % Al 7075	572
2.	MMC (Al 7075-2%RHA-2%GSA)	119
3.	MMC (Al 7075-3.5%RHA-3.5%GSA)	56.6
4.	MMC (Al 7075-5%RHA-5%GSA)	107

Three ASTM E8 standard specimens were formed by wire EDM process i.e. MMC (Al 7075-2%RHA-2%GSA), MMC (Al 7075-3.5%RHA-3.5%GSA) and MMC (Al 7075-5%RHA-5%GSA) as shown in fig3.9. Tensile test was conducted on UTM machine. It can be seen from table that MMC (Al 7075-2%RHA-2%GSA) has 119 MPa ultimate tensile strength which is lower than pure Al 7075 alloy but as the percentage of reinforcement increases, up to certain value tensile strength decrease after this tensile strength increases because MMC (Al 7075-3.5%RHA-3.5%GSA) has 56.6 MPa tensile strength while MMC (Al 7075-5%RHA-5%GSA) has 107 MPa tensile strength.

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3.4 MICRO HARDNESS TESTING MACHINE:

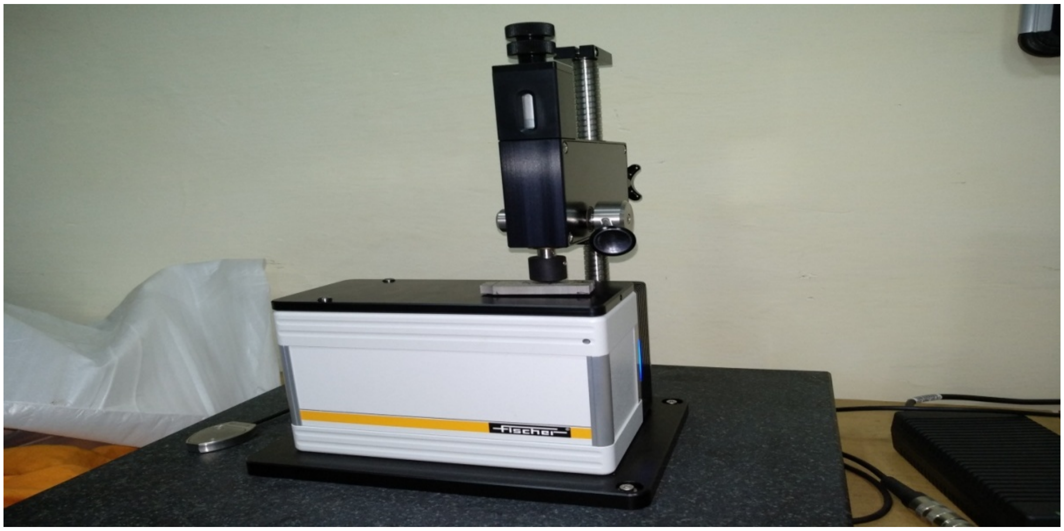

Fig 3.13: Hardness testing machine

Table3.4: Micro-hardness value of composite

S.NO.	Material	Hardness (hv)
1.	100% Al 7075	**175**
2.	MMC (Al 7075-2%RHA-2%GSA)	**195.4**
3.	MMC (Al 7075-3.5%RHA-3.5%GSA)	**218.7**
4.	MMC (Al 7075-5%RHA-5%GSA)	**234.1**

Hardness test was conducted on same 3 specimens. It can be seen from table that metal matrix composites (Al-RHA-GSA) have higher hardness value than pure Al 7075 alloy and as the percentage of reinforcement increases, hardness value also increases.

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3.5 CNC LATHE:

Lathe machine is that the commonest used turning machine within the production industry to manufacture cylindrical components. Lathe machine is wide utilized in varied manufacturing industries where quality of surface is that the most important demand. Nowadays, CNC machines are wide used in varied affordable production processes. During manufacturing process in CNC machine, numerous functions like program editing, tool offset, program storage, tool compensation and reference point etc are controlled by computer.

They're appropriate for low to medium volumes of production. They're designed to use trendy carbide tooling and absolutely use trendy processes. Thus, once deciding the machining zero at an exact purpose the command is given within the sort of a part program.

Fig 3.14: Experimental setup (lathe)

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Table3.5: CNC specifications

Model	**Turn master-3S**
Capacity	
Swing over bed	510mm
Swing over carriage	340mm
Admit between centers	420mm
Maximum Turning Length	310mm
Interference free Turning diameter	265mm
Maximum Turning Diameter	320mm
Chuck size	210 (8”) mm
Spindle	
Spindle Nose	A2-6
Spindle Inside Taper	MT-7
Hole through Spindle	61mm
Maximum Bar Capacity	51mm
Spindle speed range	3500rpm
Maximum Torque in Spindle	140Nm
Turret	
Number of stations	8
Tool shank size	25x25mm

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Maximum Boring bar diameter	40mm
Indexing	Bi-directional
Indexing time (per station)	0.9sec
General	
Machine size (Length x Breadth x Height)	2065x1925x1680
Weight (Approx.)	3500kg
Floor Space required	4.0m2
Power Supply	
Voltage	AC, 415 ±10% V, 300
Frequency	50 ± 1 Hz
Power	22.2kVA
Accuracy	
Positioning of slides - X Axis	0.005mm
Positioning of slides - Z Axis	0.010mm
Repeatability: X-Axis / A Axis	± 0.002 / ±0.003mm
CNC System	Fanuc 0i- mate TD

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3.6 Surface Roughness Measuring Instrument

Fig.3.15Surface roughness measurement apparatus

Table3.6: Surtronic 3+ Specifications

Battery	Alkaline: Minimum 600 Measurements of 4mm Measurements Lengths. Ni-Cad: Minimum 200 Measurement of 4mm Length Size: 6 LR 61 (USA/Japan), Fixed Battery External Charger (Ni-Cad Only) 110/240V, 50/60 Hz
Traverse Unit	Traverse Speed: 1mm/Sec
Measurement	Metric/Inch Preset by DIP-Switch
Cut-Off Values	0.25mm, 0.8mm, and 2.50mm
Traverse Length	1, 3, 5, 10, Or 25.4 + 0.2mm At 0.8mm Cut-Off.
Display	LCD-MATRIX. 2 lines*16 characters
Keyboard	Membrane Switch Panel Tactile
Filters	Digital Gauss Filters or 2CR Filter (ISO) Selectable By DIP-Switch.
Parameters	Ra, Rq, Rz (DIN), Ry and Sm.
Calculations Time	Less Than Reversal Time Or 2 Sec Which Ever Is the Longer.

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3.7 Experimental Procedure

Three cylindrical metal matrix composite(Al7075-RHA-GSA) , with ash composition by weight 4%, 7% and 10 % , work piece of diameter 23 mm and length 100 mm is formed by stir casting method. Experiment is conducted on a CNC lathe on these work pieces of 23 mm diameter and 100 mm long mounted between 3-jaw chuck and tailstock. Initially rough turning is done on CNC to remove scaling that is present on the surface of hybrid metal matrix (Al-RHA-GSA) composite at 1000 RPM 0.15 feed and0.2 depth of cut. Experiments are conducted on MMC (Al 7075-2%RHA-2%GSA), MMC (Al 7075-3.5%RHA-3.5%GSA) and MMC (Al 7075-5%RHA-5%GSA) according to the Taguchi DOE. Surface roughness is measured by using instrument Surtronic 3+. With the help of Minitab software, Taguchi, ANOVA and Regression analysis are applied and results are obtained.

3.7.1 Work piece material

Table3.7: Composition of Work Piece

	% of ash by weight	**AL 7075 Wt(gm)**	**RHA wt(gm)**	**GSA wt (gm)**
1	**4%**	**1032.6**	**20.652**	**20.652**
2	**7%**	**1021.1**	**35.73**	**35.73**
3	**10%**	**1013.5**	**50.675**	**50.675**

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Fig: 3.16 Metal Matrix Composite work piece before turning

The chuck holding the work piece was self-centering type. Material was selected to ensure consistency of the alloy, which is a hybrid metal matrix (Al-RHA-GSA) composite made in the form of cylindrical bars with the size of diameter 23 mm and 100 mm length which was easily fit in the chuck.

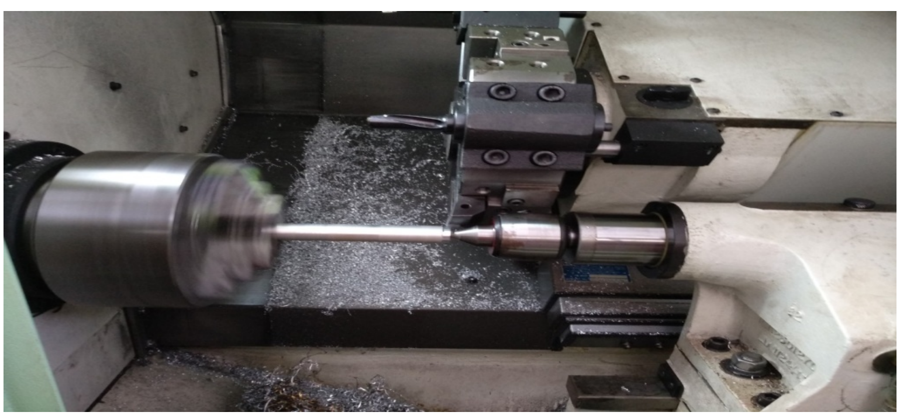

Fig: 3.17 Metal Matrix Composite work piece undergoing rough-turning

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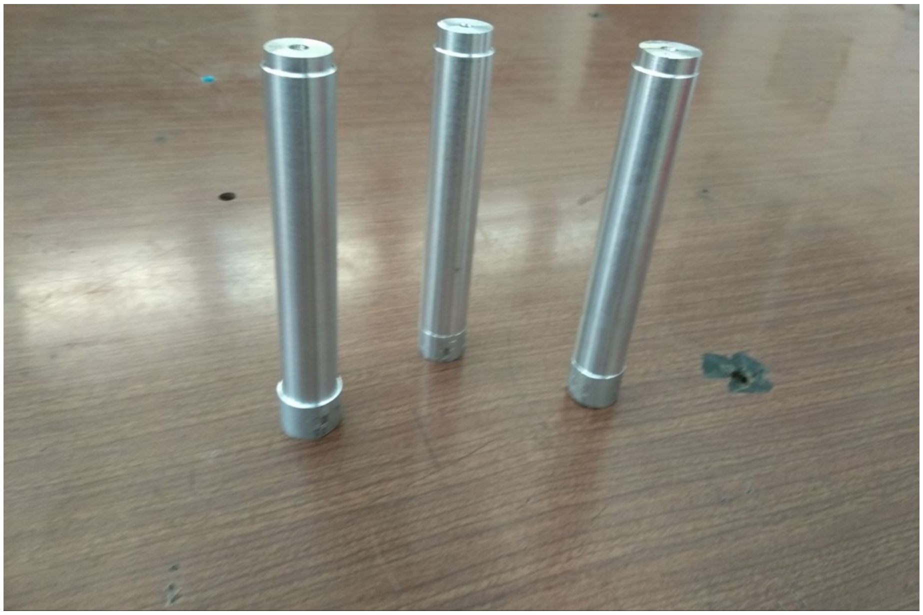

Fig: 3.18 Metal Matrix Composite work piece after turning

Taylor Hobson Surtronic 3+ instrument available has a pickup with a skid which is used to travel automatically through a drive motor. Thus, such travel would at least require a distance of at least 10 mm. Thus, we require appropriate surface travel distance on turned work piece. These dimensions were engaged so as to keep travel the stylus on the best surface as the cutting could improper at the starting or at the end. In this way, the error in measurement could also be reduced and there is less chance of measuring the wrong side values.

3.3.2 Cutting Tool Material

Fig: 3.19 Carbide tool materials (CNMG 120408-THM-F)

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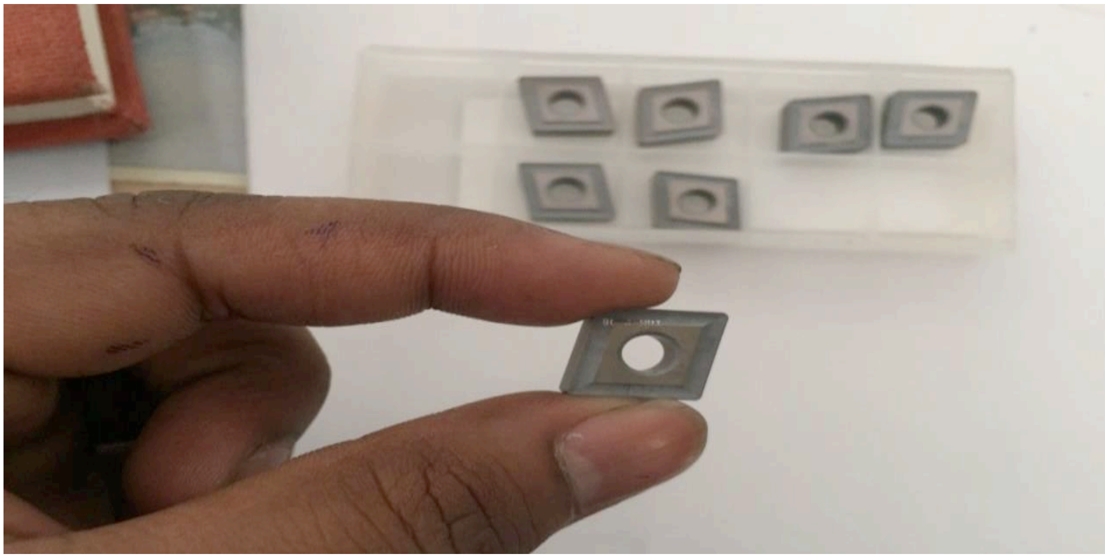

Fig: 3.20 Carbide tool materials (CNMG 120408-THM-F)

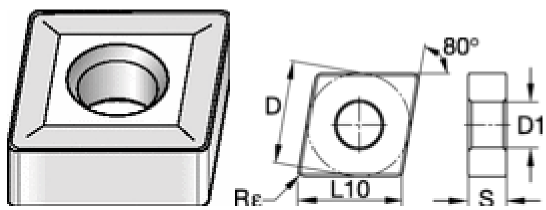

Fig: 3.21 Carbide tool specifications

Table3.8: Carbide Tool Specifications

ISO catalog number	**ANSI catalog number**	**Grade**	**D (mm)**	**L10 (mm)**	**S (mm)**	**Rε (mm)**	**D1 (mm)**
CNMG 120408	CNMG432	THM-F	12,70	12,90	4,76	0,8	5,16

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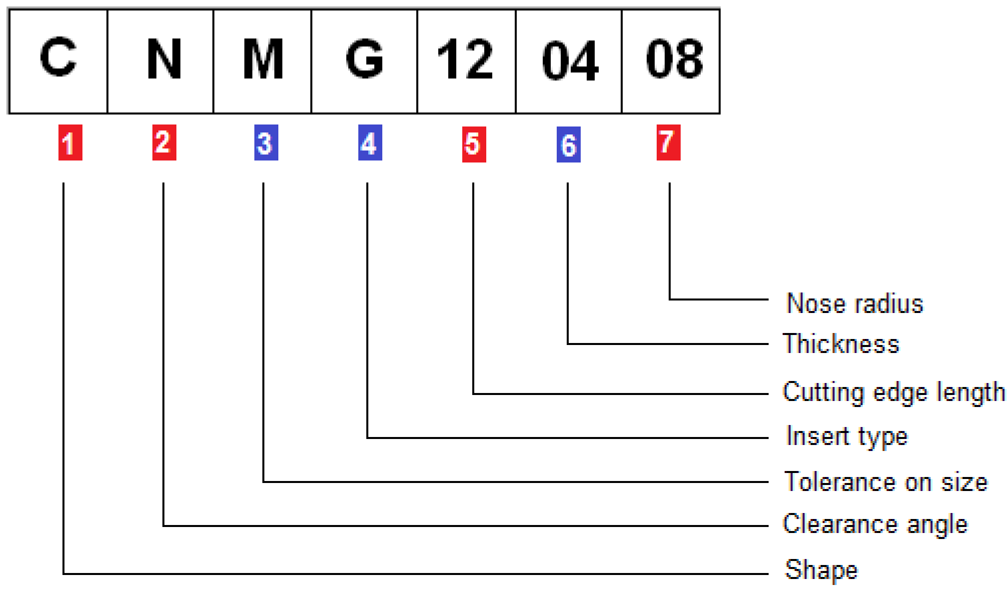

Fig: 3.22 Carbide tool insert-ISO nomenclature

3.5Miscellaneous Factors and their Levels

The facets and their values have been selected on the basis of tool and work piece material, machine parameters and by studying a lot of research papers and data hand books. Various cutting parameters and their level are shown in table:

Table3.9: miscellaneous Cutting facets and their levels

Symbol	**Cutting Parameters**	**Units**	**Level 1**	**Level 2**	**Level 3**
A	**Speed**	m min-1	**50.57**	**72.25**	**93.93**
B	**Feed**	mm rev-1	**0.10**	**0.14**	**0.18**
C	**Depth of cut**	mm	**0.20**	**0.35**	**0.50**

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CHAPTER 4

ANALYSIS OF DATA

As per the experiments done on CNC the following is the Design of Experiment used.

Table 4.1: Experiment conducted as per DOE:

S.No.	Diameter 'D' mm	Speed 'S'		Feed 'f' mm/rev	Depth of Cut 'd' Mm
		Rpm	m/min		
1	23	700	50.57	0.10	0.20
2	23	700	50.57	0.14	0.35
3	23	700	50.57	0.18	0.50
4	23	1000	72.25	0.10	0.35
5	23	1000	72.25	0.14	0.50
6	23	1000	72.25	0.18	0.20
7	23	1300	93.93	0.10	0.50
8	23	1300	93.93	0.14	0.20
9	23	1300	93.93	0.18	0.35

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4.1 GRAPHICAL ANALYSIS FOR MMC (Al-2 % RHA-2%GSA)

4.1.1 S 700 rpm, f=0.10 mm/rev, d=0.20 mm

1. Profile Curve

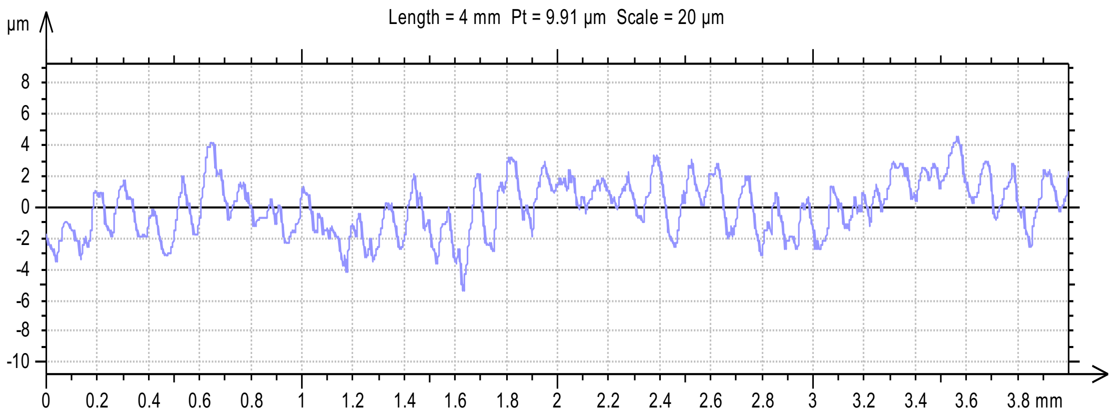

Fig.4.1: Profile curve for MMC (Al-2 % RHA-2% GSA) at S =700 rpm, f=0.10 mm/rev, d=0.20 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=9.91µm
Scale of profile=20µm

2. Roughness and Waviness Motifs (ISO 12085)

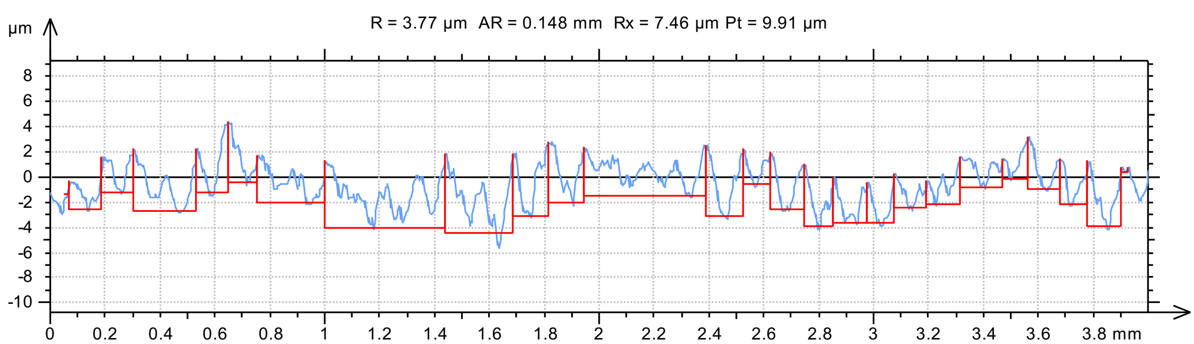

Fig.4.2: Roughness and Waviness Motifs for MMC (Al-2 % RHA-2% GSA) at S =700 rpm, f=0.10 mm/rev, d=0.20 mm

Arithmetical average depth of roughness motifs R= 3.77µm
Arithmetical average spacing of roughness motifs AR=148µm
Max depth of roughness motifs Rx= 7.46µm

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4.1.2 S=700 rpm, f=0.14 mm/rev, d=0.35 mm

1. Profile Curve

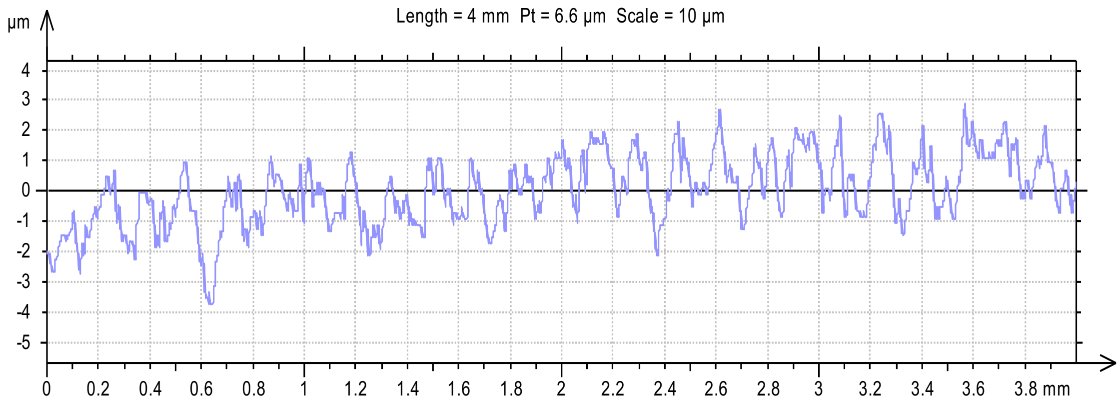

Fig.4.3: Profile curve for MMC (Al-2 % RHA-2% GSA) at S =700 rpm, f=0.14 mm/rev, d=0.35 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=6.6 µm
Scale of profile=10 µm

2. Roughness and Waviness Motifs (ISO 12085)

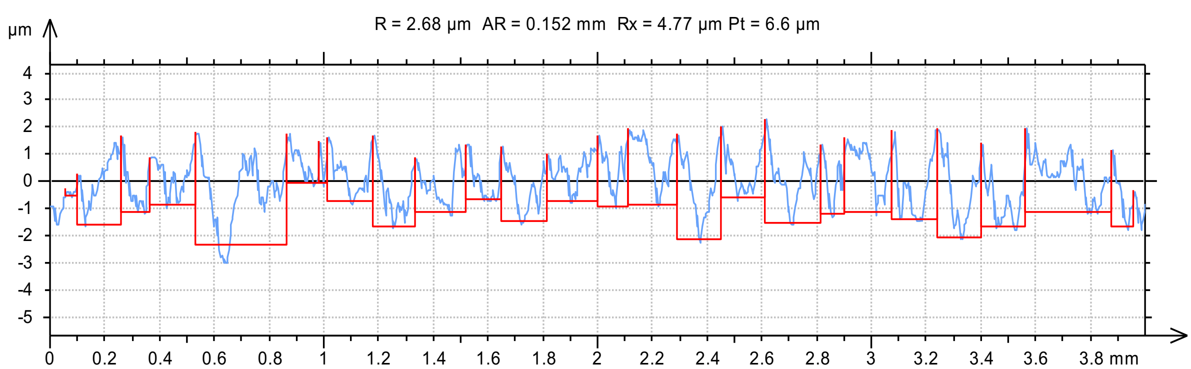

Fig.4.4: Roughness and Waviness Motifs for MMC (Al-2 % RHA-2% GSA) at S =700 rpm, f=0.14 mm/rev, d=0.35 mm

Arithmetical average depth of roughness motifs R= 2.68 µm

Arithmetical average spacing of roughness motifs AR=152 µm

Max depth of roughness motifs Rx= 4.77 µm

`

4.1.3 S=700 rpm, f=0.18 mm/rev, d=0.5 mm

1. Profile Curve

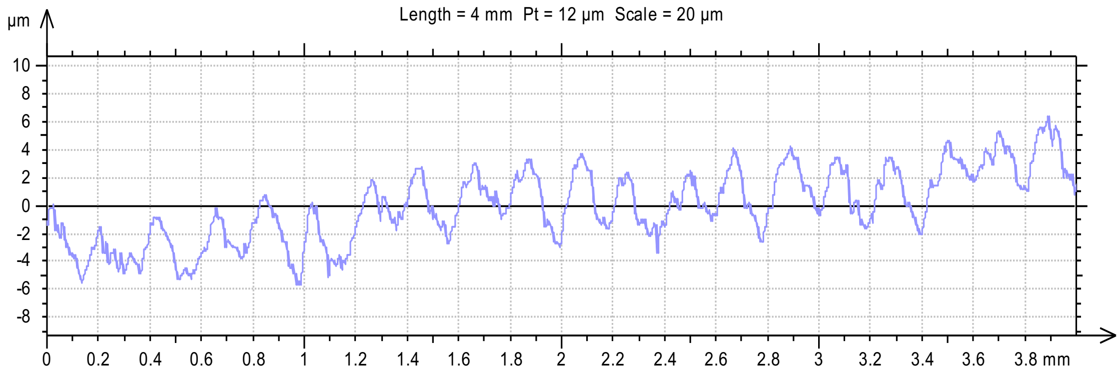

Fig.4.5: Profile curve for MMC (Al-2 % RHA-2% GSA) at S =700 rpm, f=0.18 mm/rev, d=0.5 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=12 µm
Scale of profile=20 µm

2. Roughness and Waviness Motifs (ISO 12085)

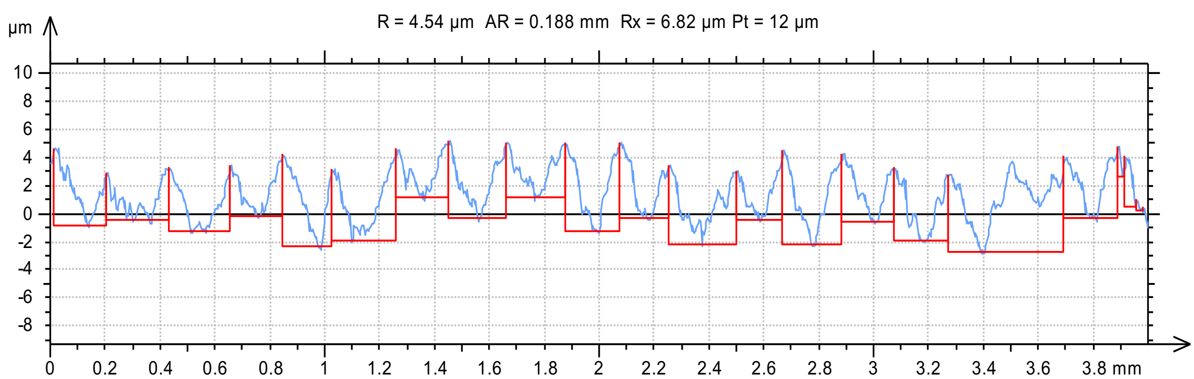

Fig.4.6: Roughness and Waviness Motifs for MMC (Al-2 % RHA-2% GSA) at S =700 rpm, f=0.18 mm/rev, d=0.5 mm

Arithmetical average depth of roughness motifs R= 4.54 µm
Arithmetical average spacing of roughness motifs AR=188 µm
Max depth of roughness motifs Rx= 6.82 µm

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4.1.4 S=1000 rpm, f=0.10 mm/rev, d=0.35 mm

1. Profile Curve

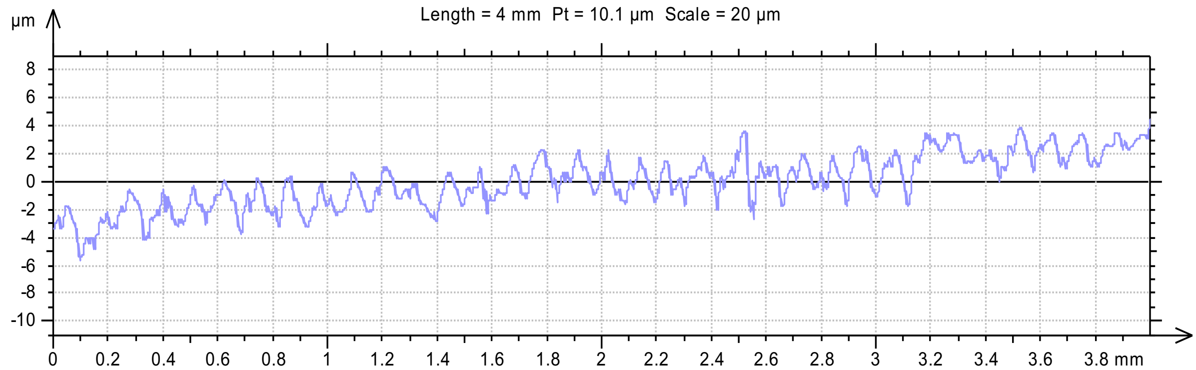

Fig.4.7: Profile curve for MMC (Al-2 % RHA-2% GSA) at S =1000 rpm, f=0.10 mm/rev, d=0.35 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=10.1 µm
Scale of profile=20 µm

2. Roughness and Waviness Motifs (ISO 12085)

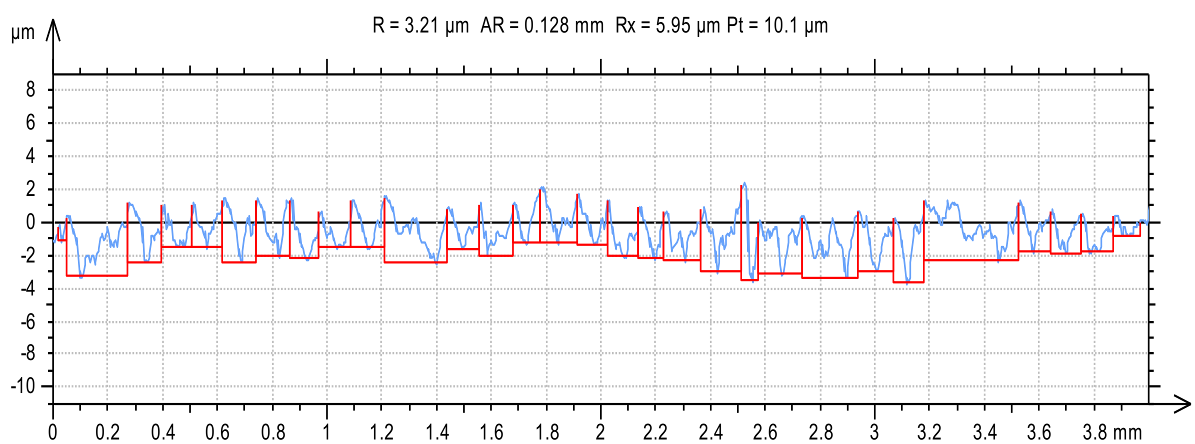

Fig.4.8: Roughness and Waviness Motifs for MMC (Al-2 % RHA-2% GSA) at S =1000 rpm, f=0.10 mm/rev, d=0.35 mm

Arithmetical average depth of roughness motifs R= 3.21 µm
Arithmetical average spacing of roughness motifs AR=128 µm
Max depth of roughness motifs Rx= 5.95µm

`

4.1.5 S=1000 rpm, f=0.14 mm/rev, d=0.50mm

1. Profile Curve

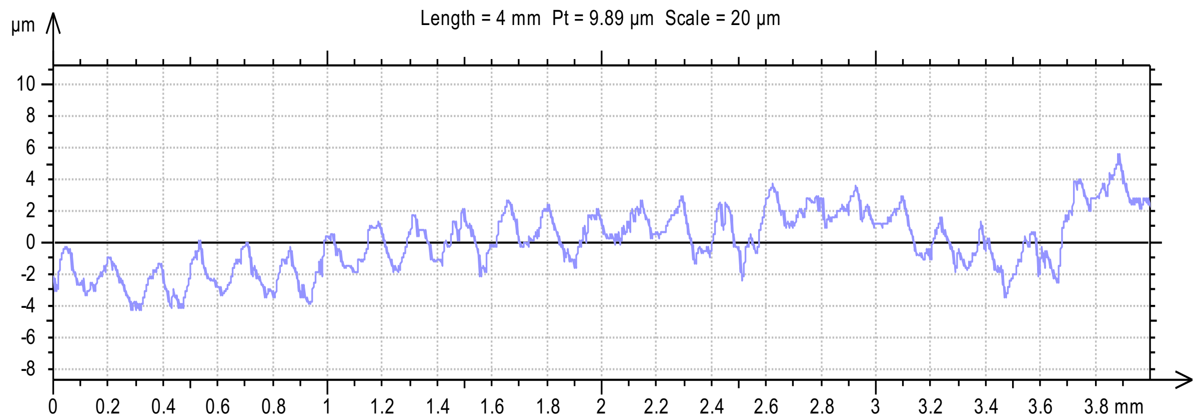

Fig.4.9: Profile curve for MMC (Al-2 % RHA-2% GSA) at S =1000 rpm, f=0.14 mm/rev, d=0.50 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=9.89 µm
Scale of profile=20 µm

2. Roughness and Waviness Motifs (ISO 12085)

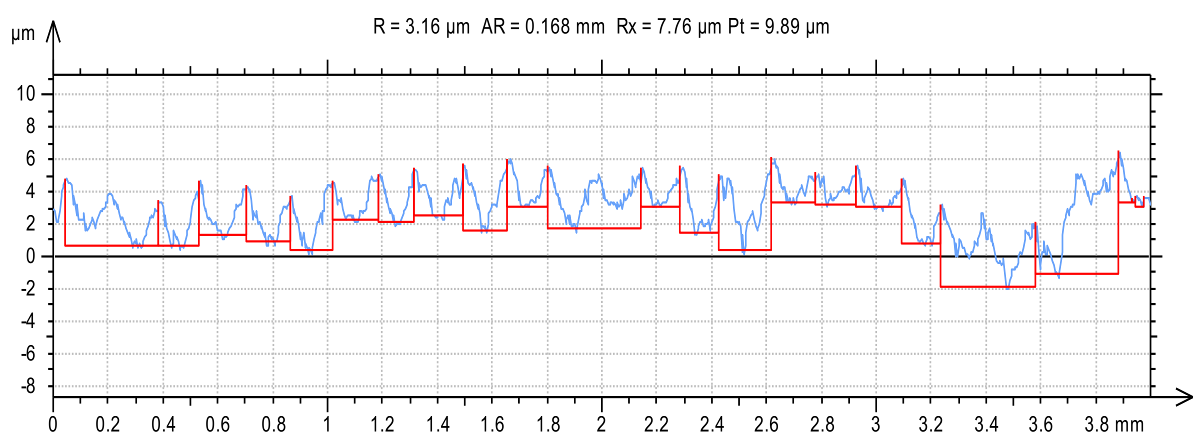

Fig.4.10: Roughness and Waviness Motifs for MMC (Al-2 % RHA-2% GSA) at S =1000 rpm, f=0.14 mm/rev, d=0.50 mm

Arithmetical average depth of roughness motifs R= 3.16µm
Arithmetical average spacing of roughness motifs AR=168 µm
Max depth of roughness motifs Rx= 7.76 µm
`

4.1.6 S=1000 rpm, f=0.18 mm/rev, d=0.20 mm

1. Profile Curve

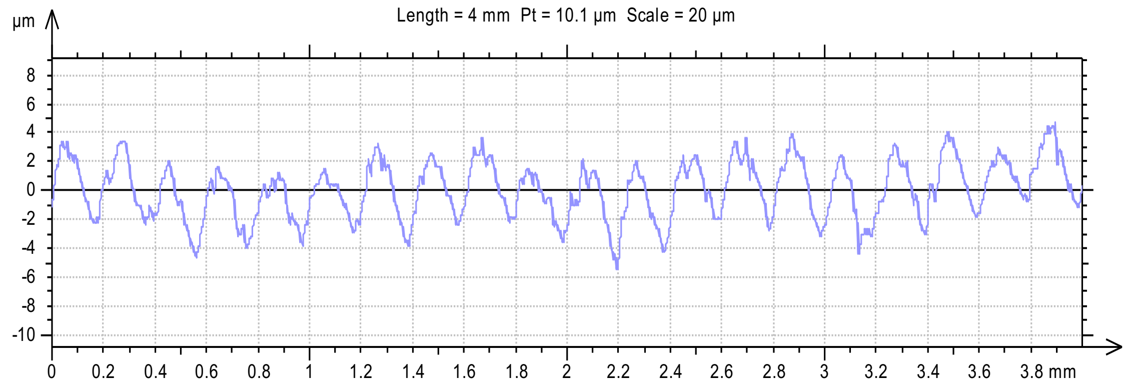

Fig.4.11: Profile curve for MMC (Al-2 % RHA-2% GSA) at S =1000 rpm, f=0.18 mm/rev, d=0.20 mm

Length of profile= 4 mm
Max. peak to valley height P_t=10.1 µm
Scale of profile=20 µm

2. Roughness and Waviness Motifs (ISO 12085)

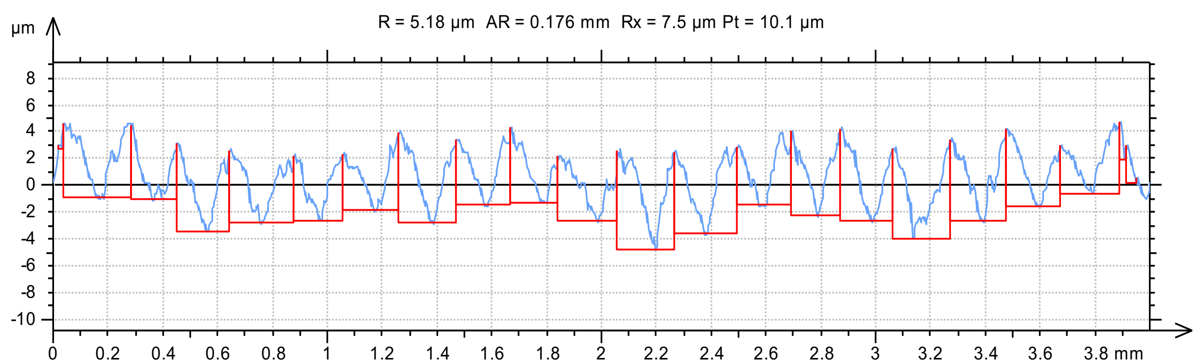

Fig.4.12: Roughness and Waviness Motifs for MMC (Al-2 % RHA-2% GSA) at S =1000 rpm, f=0.18 mm/rev, d=0.20 mm

Arithmetical average depth of roughness motifs R= 5.18 µm
Arithmetical average spacing of roughness motifs AR=176µm
Max depth of roughness motifs Rx= 7.5µm

`

4.1.7 S=1300 rpm, f=0.10 mm/rev, d=0.50mm

1. Profile Curve

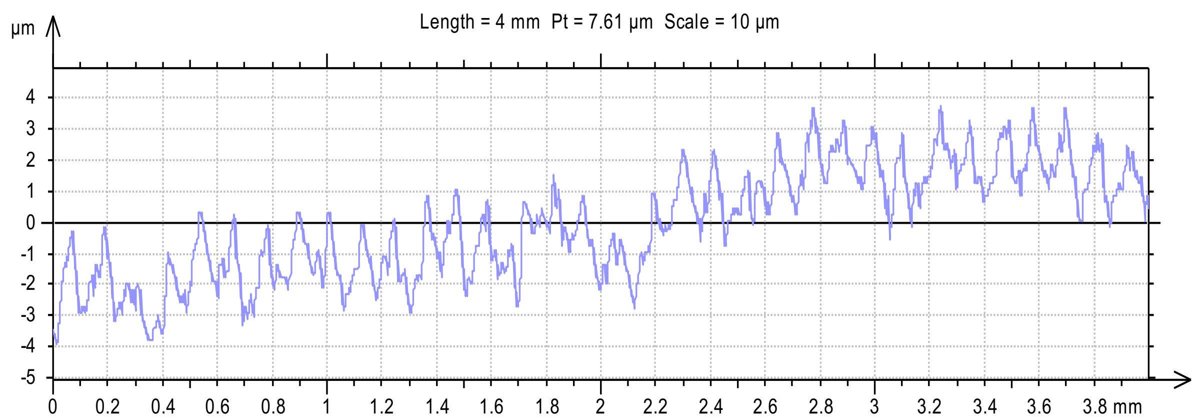

Fig.4.13: Profile curve for MMC (Al-2 % RHA-2% GSA) at S =1300 rpm, f=0.10 mm/rev, d=0.50 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=7.61µm
Scale of profile=10 µm

2. Roughness and Waviness Motifs (ISO 12085)

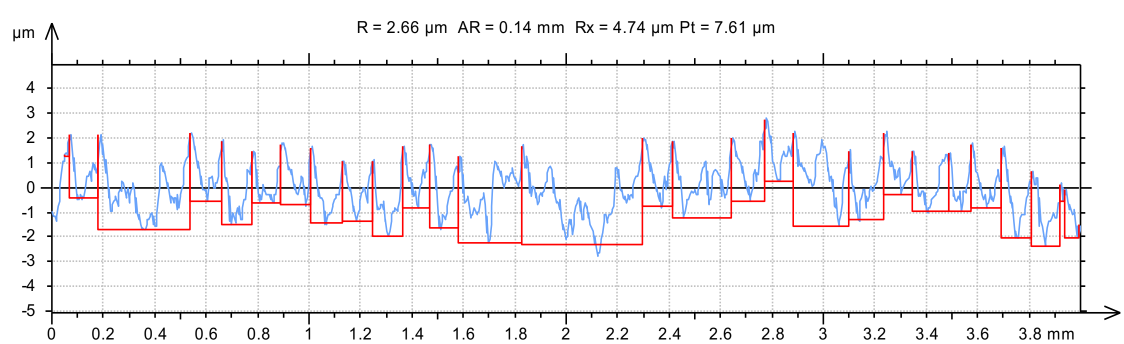

Fig.4.14: Roughness and Waviness Motifs for MMC (Al-2 % RHA-2% GSA) at S =1300 rpm, f=0.10 mm/rev, d=0.50 mm

Arithmetical average depth of roughness motifs R= 2.66 µm
Arithmetical average spacing of roughness motifs AR=140µm
Max depth of roughness motifs Rx= 4.74µm
`

4.1.8 S=1300 rpm, f=0.14 mm/rev, d=0.2 mm

1. Profile Curve

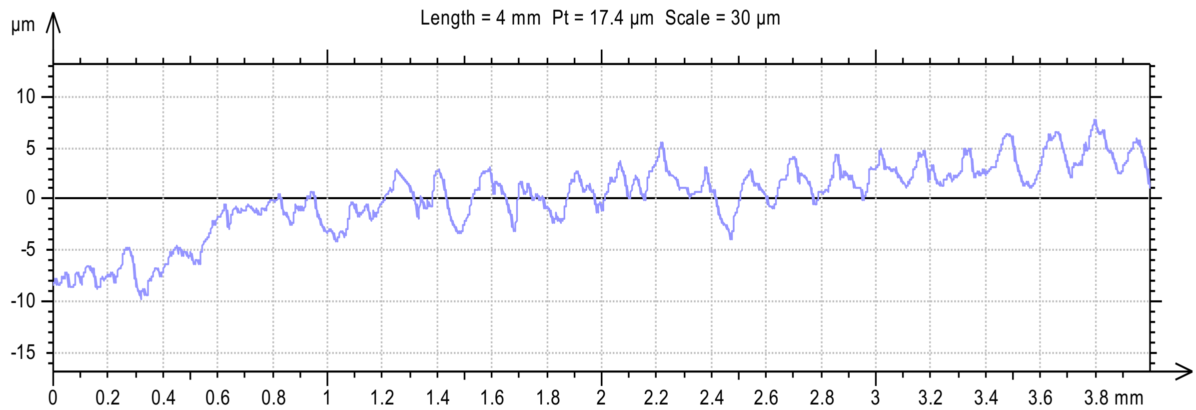

Fig.4.15: Profile curve for MMC (Al-2 % RHA-2% GSA) at S =1300 rpm, f=0.14 mm/rev, d=0.20 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=17.4µm
Scale of profile=30 µm

2. Roughness and Waviness Motifs (ISO 12085)

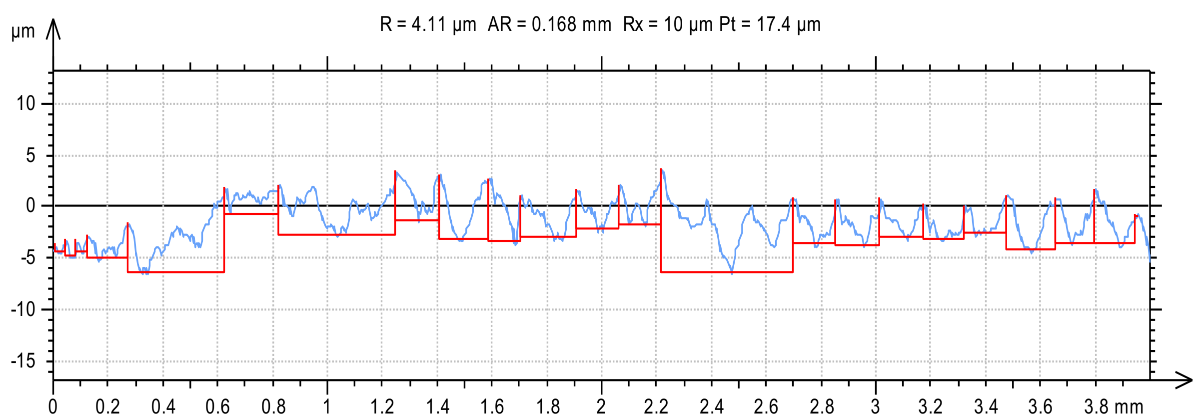

Fig.4.16: Roughness and Waviness Motifs for MMC (Al-2 % RHA-2% GSA) at S =1300 rpm, f=0.14 mm/rev, d=0.20 mm

Arithmetical average depth of roughness motifs R= 4.11 µm
Arithmetical average spacing of roughness motifs AR=168 µm
Max depth of roughness motifs Rx= 10µm

`

4.1.9 S=1300 rpm, f=0.18 mm/rev, d=0.35 mm

1. Profile Curve

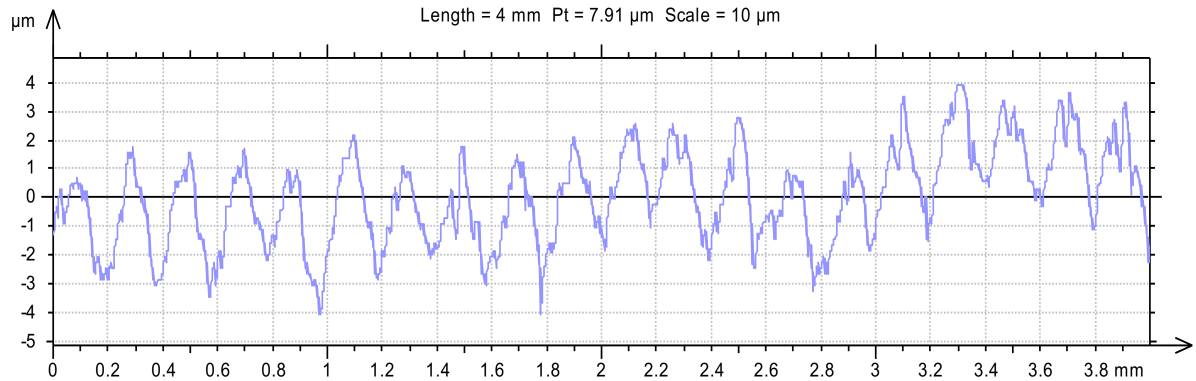

Fig.4.17: Profile curve for MMC (Al-2% RHA-2% GSA) at S =1300 rpm, f=0.18 mm/rev, d=0.35 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=7.91 µm
Scale of profile=10 µm

2. Roughness and Waviness Motifs (ISO 12085)

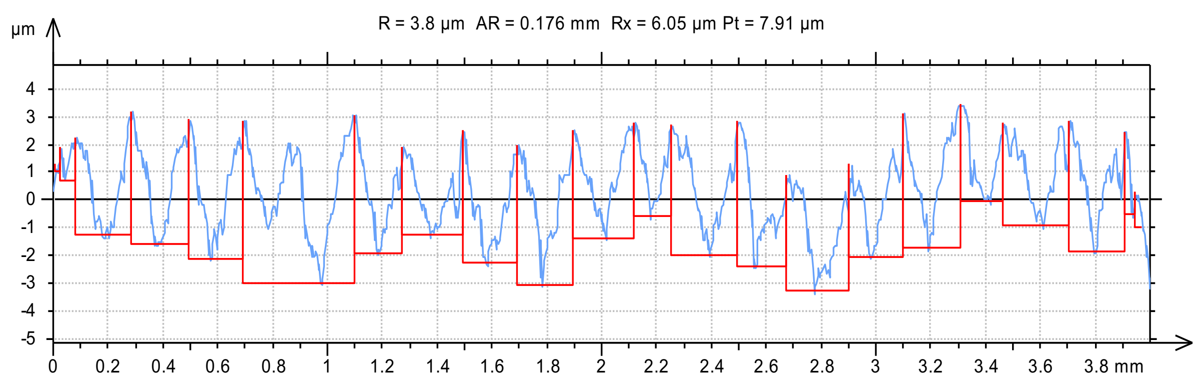

Fig.4.18: Roughness and Waviness Motifs for MMC (Al-2 % RHA-2% GSA) at S =1300 rpm, f=0.18 mm/rev, d=0.35 mm

Arithmetical average depth of roughness motifs R= 3.8 µm
Arithmetical average spacing of roughness motifs AR=176µm
Max depth of roughness motifs Rx= 6.05µm

`

4.2 Graphs from Taguchi

4.2.1 Signal-to-Noise:

Mean of SN ratio for miscellaneous cutting facets is depicted in figure.

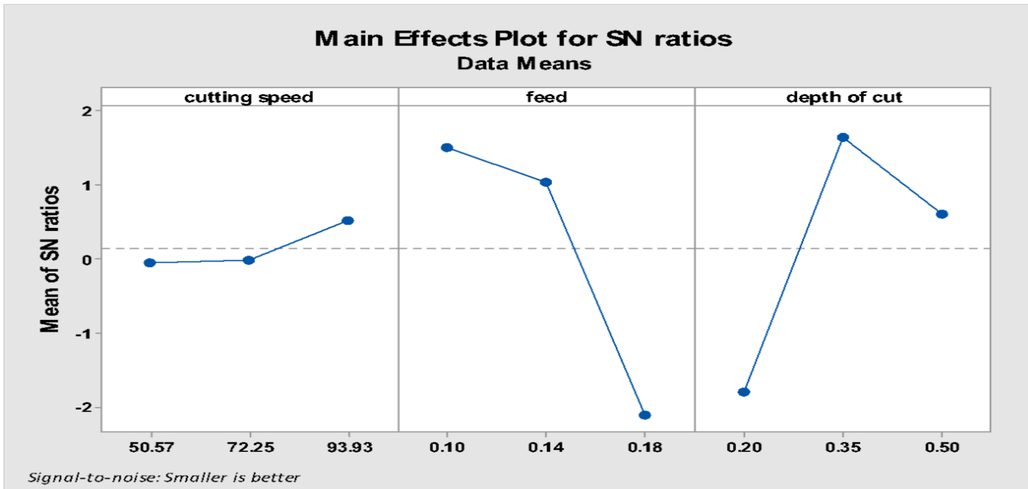

Fig.4.19: Main Effects Plot for SN ratios for MMC (Al-2 % RHA-2%GSA)

4.2.2 Mean:

As specified by the main effect plot, the optimal conditions for minimum surface roughness is A3B1C2 which is speed at level 3(93.93 m min-1), feed rate at level 1 (0.10 mm rev-1) and depth of cut at level 2 (0.35mm).

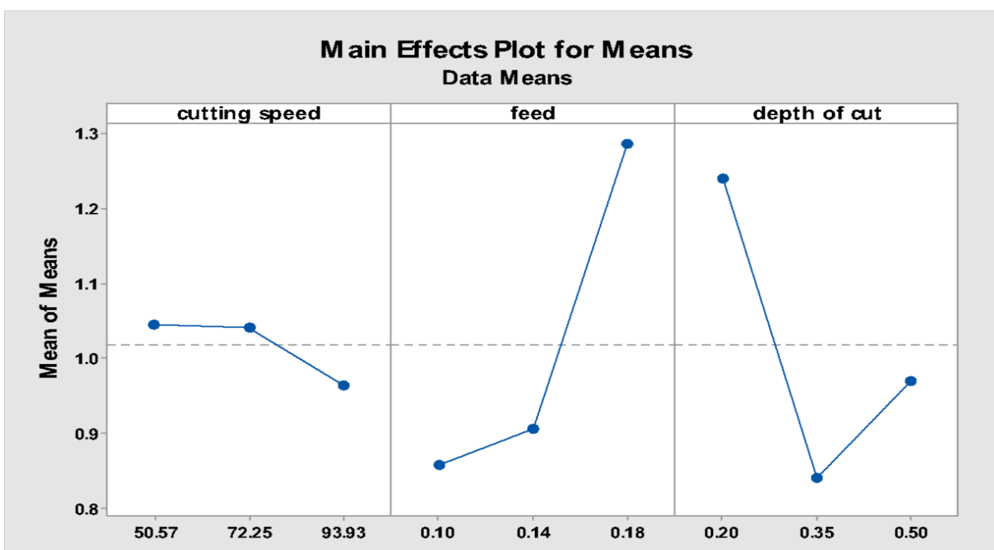

Fig.4.20: Main Effects Plot for Means for MMC (Al-2 % RHA-2%GSA)

`

Table4.2: Experimental results for S/N ratio by Taguchi method for MMC (Al-2 % RHA-2%GSA)

S.No.	Diameter (mm)	RPM	Speed (m/min)	Feed 'f' (mm/rev)	d (mm)	Ra (µm)	S/N Ratio (dB)	Mean (µm)
1.	23	700	50.57	0.10	0.20	1.11	-0.90646	1.110
2.	23	700	50.57	0.14	0.35	0.686	3.27352	0.686
3.	23	700	50.57	0.18	0.50	1.34	-2.54210	1.340
4.	23	1000	72.25	0.10	0.35	0.78	2.15811	0.780
5.	23	1000	72.25	0.14	0.50	0.884	1.07095	0.884
6.	23	1000	72.25	0.18	0.20	1.46	-3.28706	1.460
7.	23	1300	93.93	0.10	0.50	0.686	3.27352	0.686
8.	23	1300	93.93	0.14	0.20	1.15	-1.21396	1.150
9.	23	1300	93.93	0.18	0.35	1.06	-0.50612	1.060

Table4.3: S/N response table for surface roughness for MMC (Al-2 % RHA-2%GSA)

Smaller is better

Symbol	Cutting Parameters	Mean S/N Ratio (dB)				
		Level 1	Level 2	Level 3	Max-min	Rank
A	Speed	-0.05835	-0.01933	0.51781	0.57616	3
B	Feed	1.50839	1.04351	-2.11176	3.62015	1
C	Depth of Cut	-1.80249	1.64184	0.60079	3.44433	2

Total mean S/N ratio = 0.1467

Table4.4: Mean response table for surface roughness for MMC (Al-2 % RHA-2%GSA)

Symbol	Cutting parameters	Mean (µm)				
		Level 1	Level 2	Level 3	Max-min	Rank
A	Speed	1.0453	1.0413	0.9653	0.08	3
B	Feed	0.8587	0.9067	1.2867	0.428	1
C	Depth of Cut	1.2400	0.8420	0.9700	0.398	2

`

Table4.5: Analysis of variance (ANOVA) for surface roughness for MMC (Al-2 % RHA-2%GSA)

Symbol	Cutting parameters	DF	SS	MS	F	P	Contribution (%)
A	**Speed**	2	0.02605	0.00489	0.33	0.752	1.55
B	**Feed**	2	0.32562	0.17375	11.73	0.079	55.073
C	**Depth of Cut**	2	0.24408	0.12204	8.24	0.108	38.682
Error		2	0.02962	0.01481			4.694
Total		8	0.62536	0.31549			100

It can be seen from ANOVA table 4.5 that feed is the highest contributing factor with 55.073 % and other details of DOF - Degrees of freedom, S.S - Sum of Squares, M.S - Mean of Squares, F-value, P-value and Error are mentioned.

Table4.6: Regression Analysis for Surface roughness for MMC (Al-2 % RHA-2%GSA)

S.NO.	Log S	Log d	Log f	Log Ra	Residual	Fits
1	1.7038	-0.698	-1	0.045	0.0586179	-0.0136179
2	1.7038	-0.456	-0.85	-0.163	-0.174876	0.0118761
3	1.7038	-0.301	-0.744	0.127	0.103882	0.0231183
4	1.858	-0.456	-1	-0.107	-0.0008462	-0.106154
5	1.858	-0.301	-0.85	-0.0535	0.0046108	-0.0581108
6	1.858	-0.698	-0.744	0.164	0.0253525	0.138647
7	1.972	-0.301	-1	-0.163	0.0090569	-0.172057
8	1.972	-0.698	-0.85	0.0606	-0.0009022	0.0615022
9	1.972	-0.456	-0.744	0.0253	-0.0248954	0.0501954

4.3 Graphs from Regression Analysis

4.3.1 Normal probability plot of Residuals for Log Ra

`

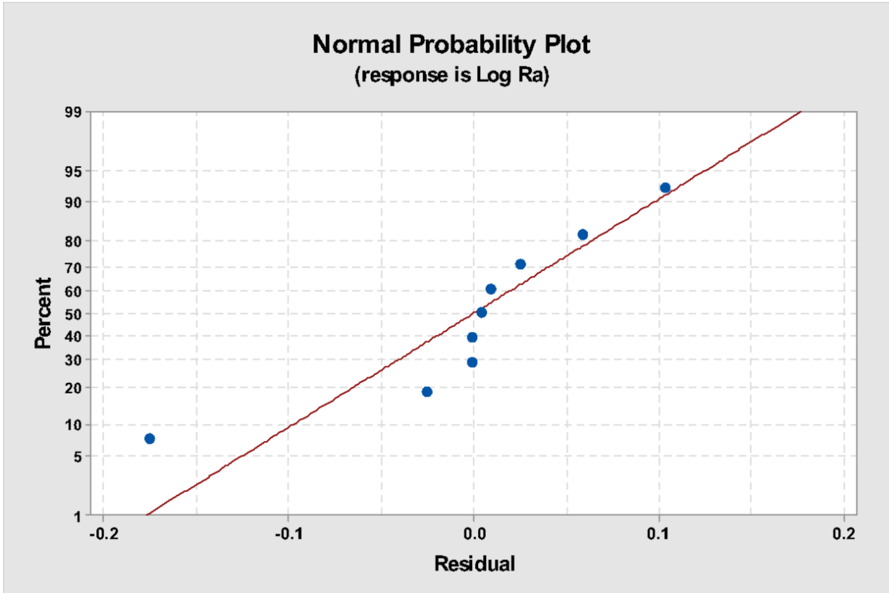

Fig.4.21: Normal Probability Plot for MMC (Al-2 % RHA-2%GSA)

As in this project work data have less than 50 inspections, the plot might show bend in the tails even if the residuals are normally distributed.

4.3.2 Residuals vs Fits for Log Ra

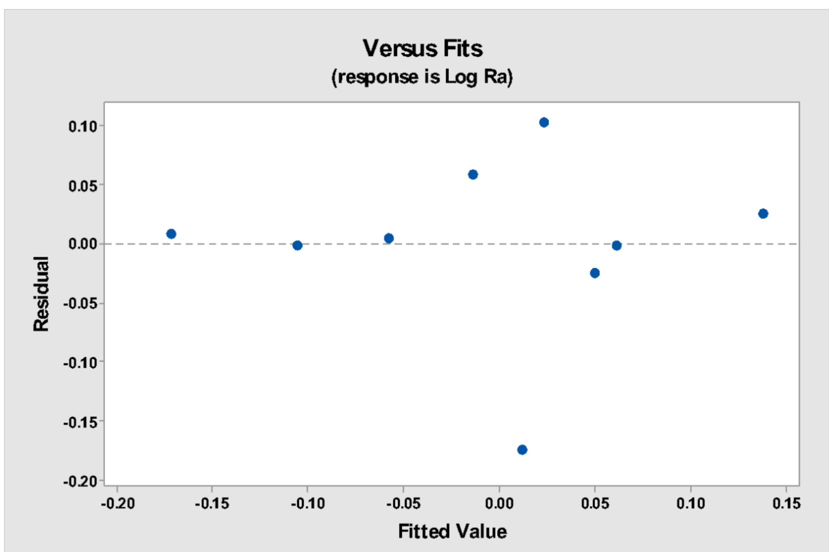

Fig.4.22: Versus Fits for MMC (Al-2 % RHA-2%GSA)

It can be concluded that all the values are within the control range, indicating that there is no obvious pattern and unusual structure.

4.3.3 Residual Histogram for Log Ra

`

The aspect of the histogram changes Influenced by the number of intervals used to group the data.

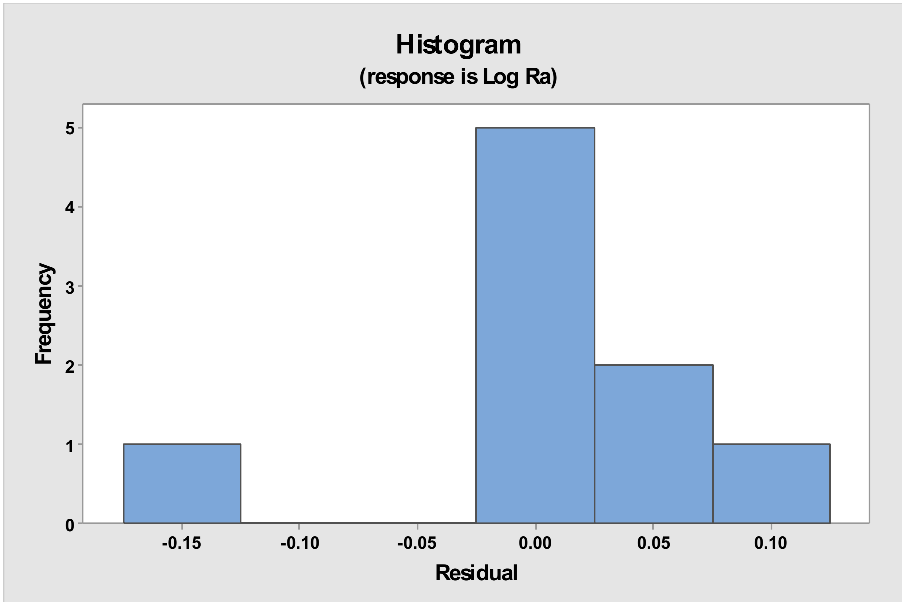

Fig.4.23: Histogram Plot for MMC (Al-2 % RHA-2%GSA)

4.3.4 Residuals vs Order for Log Ra

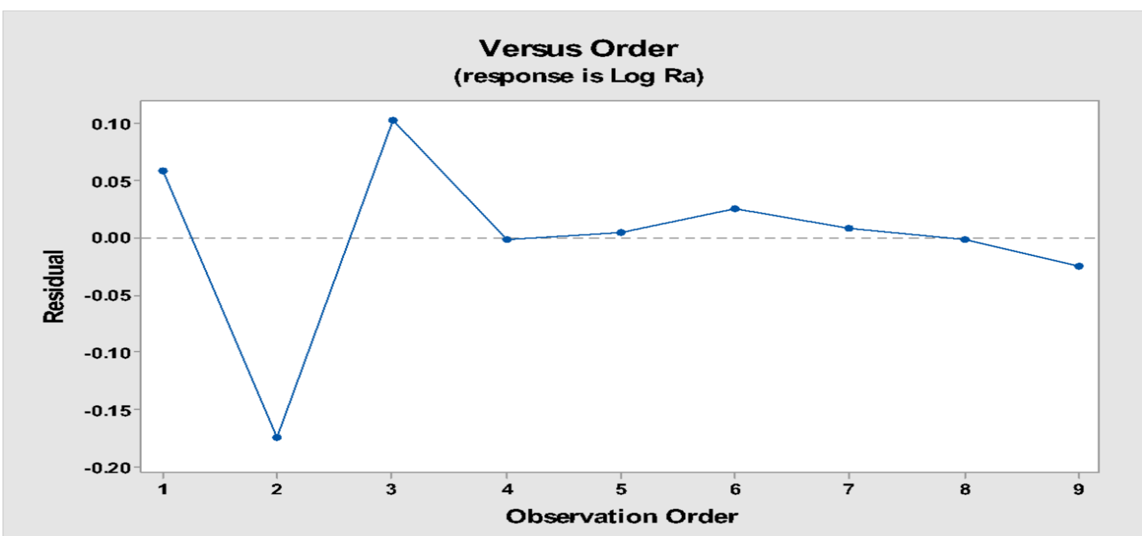

Fig.4.24: Versus order plot for MMC (Al-2 % RHA-2%GSA)

From graphs 4.20, 4.21, 4.23, 4.24 it can be conjectured that all the values are within the control range, indicating that there is no obvious pattern and unusual structure and also the residual analysis does not indicate any model inadequacy.

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Table4.7: Analysis of Variance

Symbol	Cutting parameters	DF	Adj SS	Adj MS	F	P	Contribution (%)
	Regression	3	0.070172	0.023391	2.53	0.171	
A	Log S	1	0.001122	0.001122	0.12	0.742	1.4129
B	Log d	1	0.042978	0.042978	4.65	0.083	54.123
C	Log f	1	0.026072	0.026072	2.82	0.154	32.833
Error		5	0.046176	0.009235			11.629
Total			0.116348	0.079407			100

4.3.5 Regression Equation

$$\text{Log Ra} = -0.058 - 0.102 \text{ Log S} + 0.423 \text{ Log d} - 0.512 \text{ Log f}$$

$$Ra = -0.058\ S^{-0.102}\ d^{0.423}\ f^{-0.512}$$

Table4.8: Calculated Surface Roughness's from Regression Equation for MMC (Al-2 % RHA-2%GSA)

S.No.	S (m/min)	F (mm/rev)	D (mm)	Ra (µm)	Calculated Ra (µm)	Error (%)
1.	50.57	0.10	0.20	1.11	0.96	-13.51
2.	50.57	0.14	0.35	0.686	1.029	50
3.	50.57	0.18	0.50	1.34	1.052	-21.49
4.	72.25	0.10	0.35	0.78	1.18	51.28
5.	72.25	0.14	0.50	0.884	1.154	30.54
6.	72.25	0.18	0.20	1.46	0.688	-52.87
7.	93.93	0.10	0.50	0.686	1.33	93.87
8.	93.93	0.14	0.20	1.15	0.76	-33.91
9.	93.93	0.18	0.35	1.06	0.85	-19.81

From Table 4.8, it might be concluded that the optimum miscellaneous process parameters for minimum SR is obtained at speed 50.57 m/min (700rpm), feed 0.10 mm/rev and depth of cut 0.20 mm which gives 1.11 µm surface roughness.

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4.4 GRAPHICAL ANALYSIS FOR MMC (Al-3.5% RHA-3.5% GSA)

4.4.1 S=700 rpm, f=0.10 mm/rev, d=0.20 mm

1. **Profile Curve**

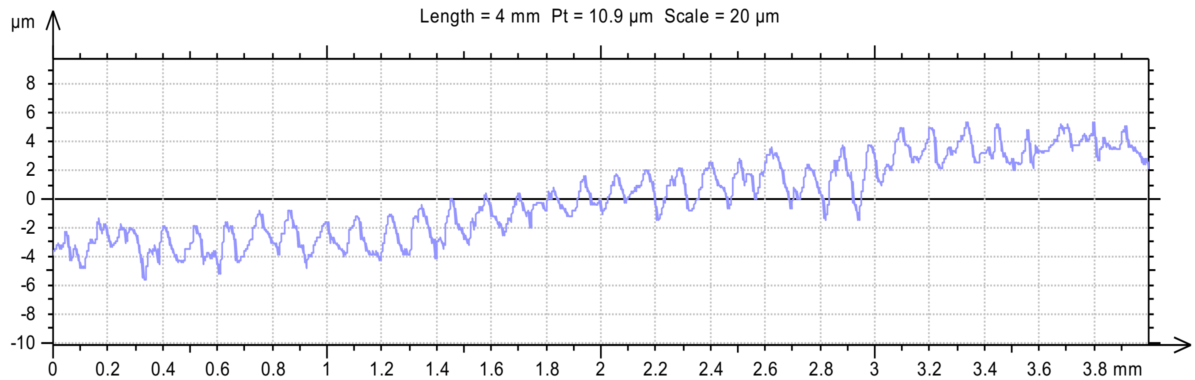

Fig.4.25: Profile curve for MMC (Al-3.5% RHA-3.5% GSA) at S =700 rpm, f=0.10 mm/rev, d=0.20 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=10.9 µm
Scale of profile=20 µm

2. **Roughness and Waviness Motifs (ISO 12085)**

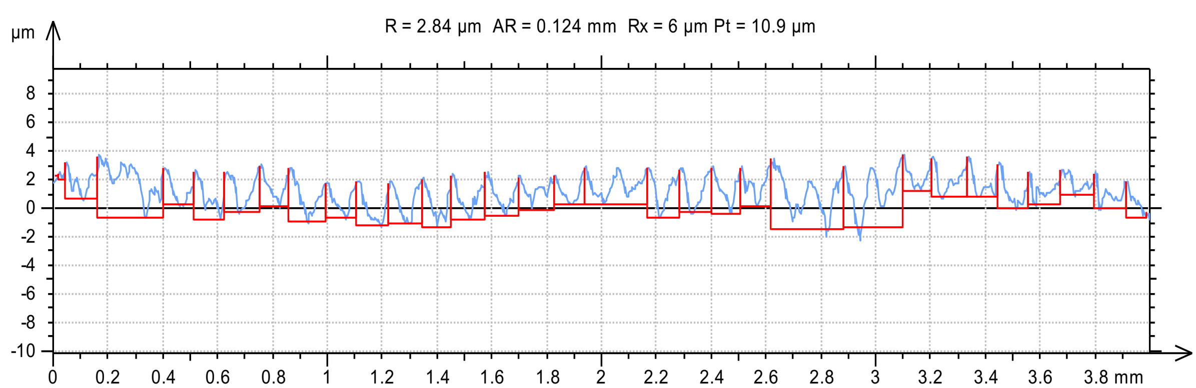

Fig.4.26: Roughness and Waviness Motifs for MMC (Al-3.5% RHA-3.5% GSA) at S =700 rpm, f=0.10 mm/rev, d=0.20 mm

Arithmetical average depth of roughness motifs R= 2.84µm
Arithmetical average spacing of roughness motifs AR=124µm
Max depth of roughness motifs Rx= 6µm
`

4.4.2 S=700 rpm, f=0.14 mm/rev, d=0.35 mm

1. **Profile Curve**

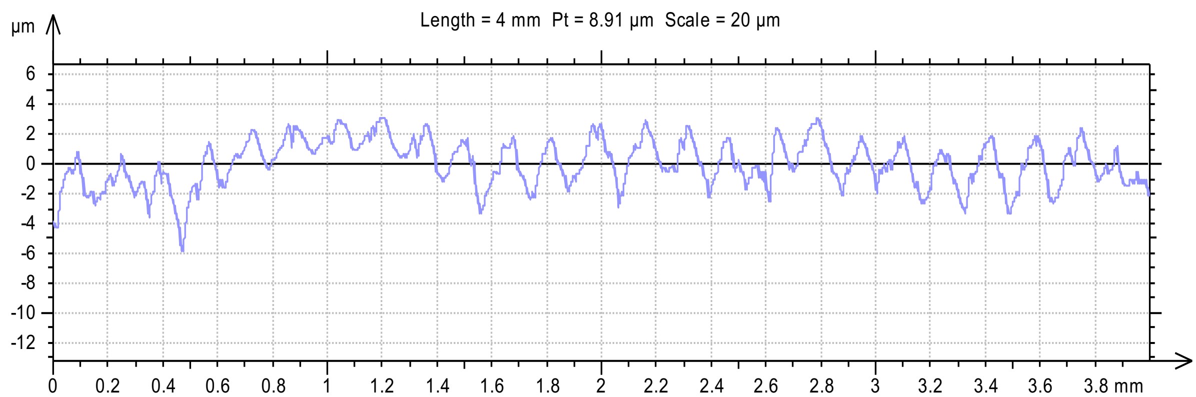

Fig.4.27: Profile curve for MMC (Al-3.5% RHA-3.5% GSA) at S =700 rpm, f=0.14 mm/rev, d=0.35 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=8.91µm
Scale of profile=20 µm

2. **Roughness and Waviness Motifs (ISO 12085)**

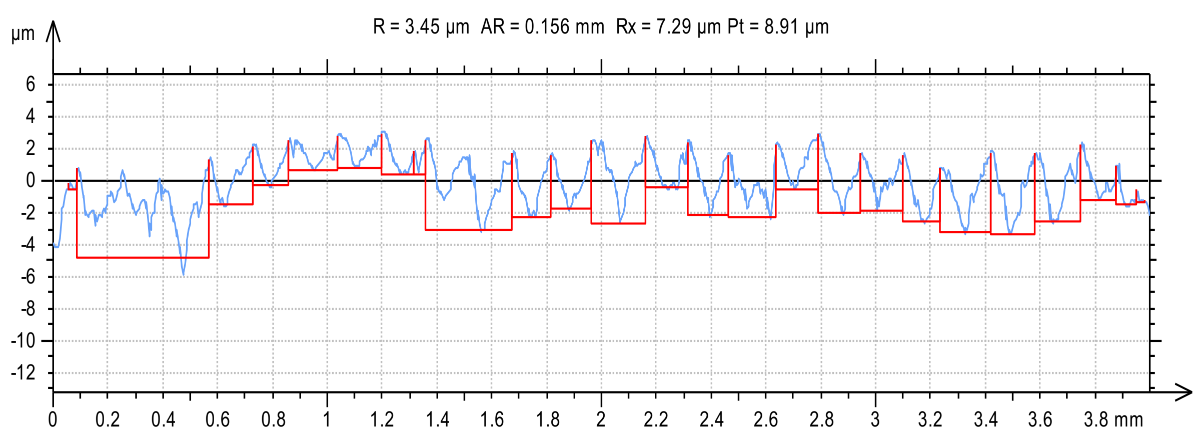

Fig.4.28: Roughness and Waviness Motifs for MMC (Al-3.5% RHA-3.5% GSA) at S =700 rpm, f=0.14 mm/rev, d=0.35 mm

Arithmetical average depth of roughness motifs R= 3.45 µm
Arithmetical average spacing of roughness motifs AR=156µm
Max depth of roughness motifs Rx= 7.29µm

`

4.4.3 S=700 rpm, f=0.18 mm/rev, d=0.50 mm

1. **Profile Curve**

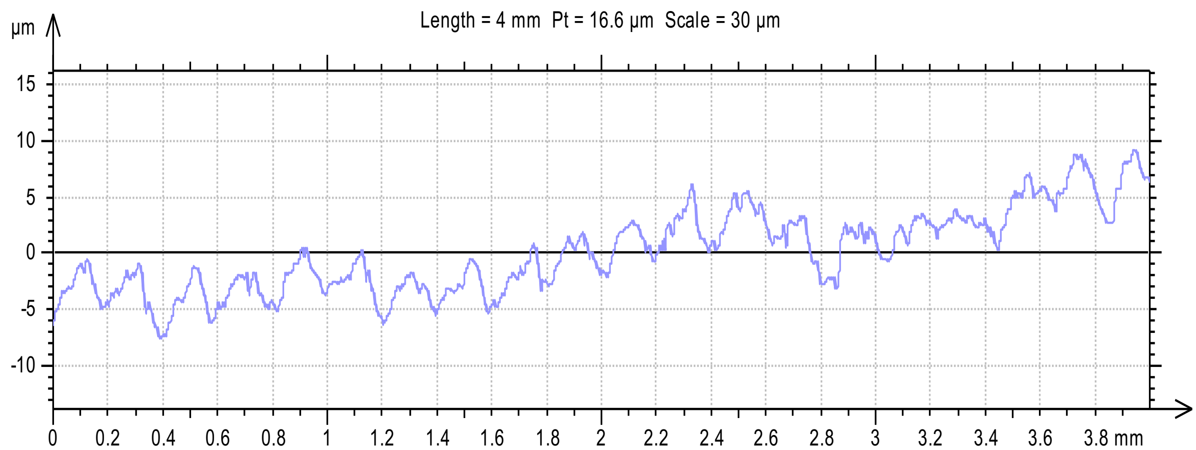

Fig.4.29: Profile curve for MMC (Al-3.5% RHA-3.5% GSA) at S =700 rpm, f=0.18 mm/rev, d=0.50 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=16.6µm
Scale of profile=30µm

2. **Roughness and Waviness Motifs (ISO 12085)**

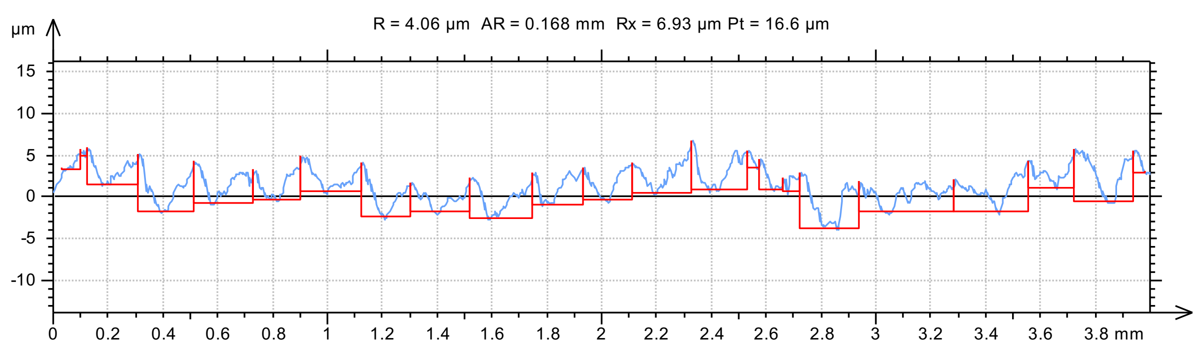

Fig.4.30: Roughness and Waviness Motifs for MMC (Al-3.5% RHA-3.5% GSA) at S =700 rpm, f=0.18 mm/rev, d=0.5 mm

Arithmetical average depth of roughness motifs R= 4.06 µm
Arithmetical average spacing of roughness motifs AR=168 µm
Max depth of roughness motifs Rx= 6.93µm

`

4.4.4 S=1000 rpm, f=0.10 mm/rev, d=0.35 mm

1. **Profile Curve**

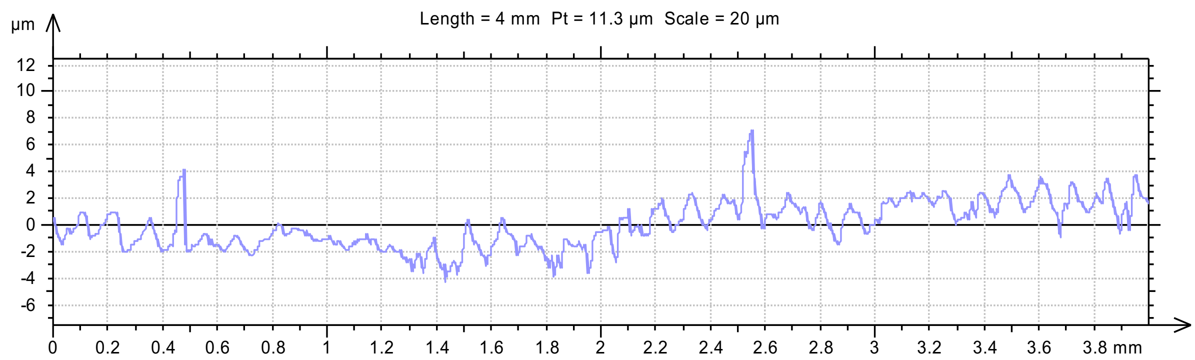

Fig.4.31: Profile curve for MMC (Al-3.5% RHA-3.5% GSA) at S =1000 rpm, f=0.10 mm/rev, d=0.35 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=11.3µm
Scale of profile=20 µm

2. Roughness and Waviness Motifs (ISO 12085)

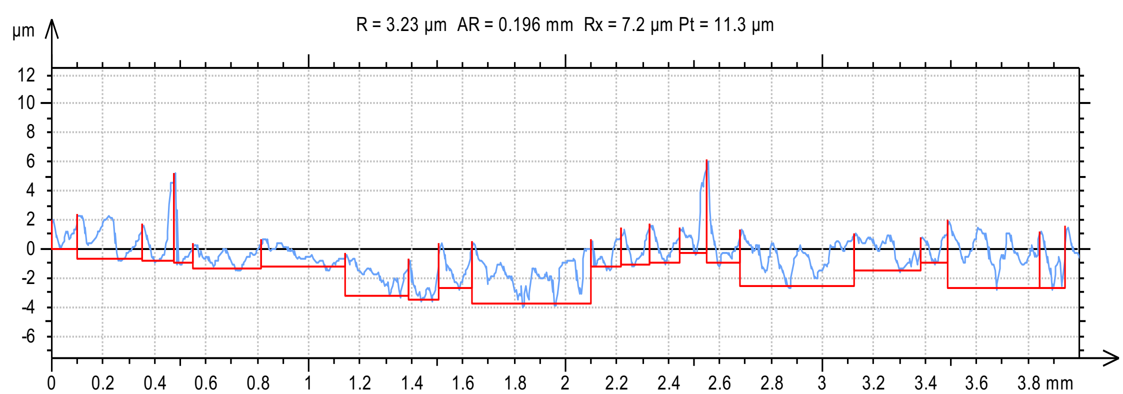

Fig.4.32: Roughness and Waviness Motifs for MMC (Al-3.5% RHA-3.5% GSA) at S =1000 rpm, f=0.10 mm/rev, d=0.35 mm

Arithmetical average depth of roughness motifs R= 3.23 µm
Arithmetical average spacing of roughness motifs AR=196µm
Max depth of roughness motifs Rx= 7.2µm

`

4.4.5 S=1000 rpm, f=0.14 mm/rev, d=0.50 mm

1. Profile Curve

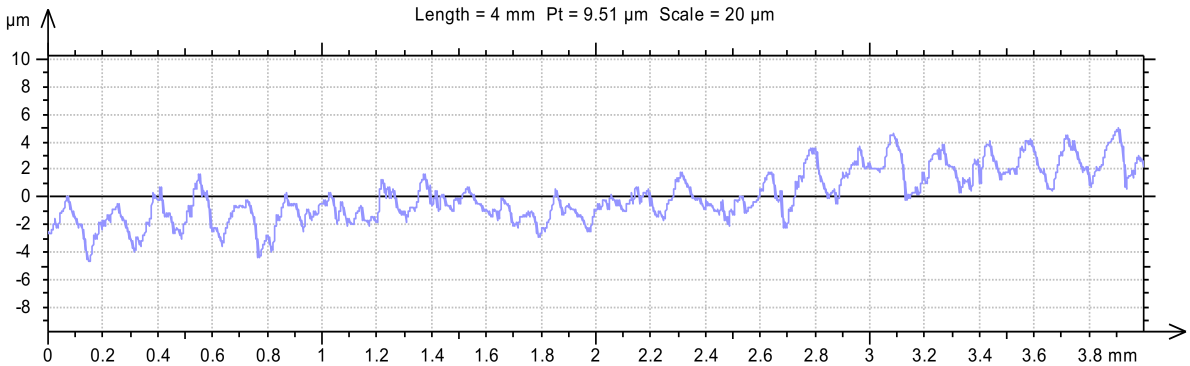

Fig.4.33: Profile curve for MMC (Al-3.5% RHA-3.5% GSA) at S =1000 rpm, f=0.14 mm/rev, d=0.50 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=9.51µm
Scale of profile=20 µm

2. Roughness and Waviness Motifs (ISO 12085)

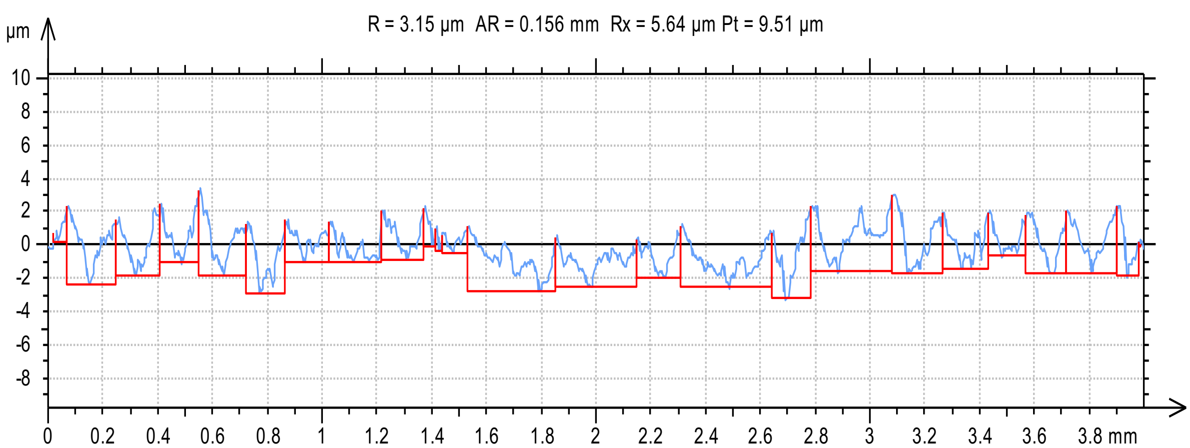

Fig.4.34: Roughness and Waviness Motifs for MMC (Al-3.5% RHA-3.5% GSA) at S =1000 rpm, f=0.14 mm/rev, d=0.50 mm

Arithmetical average depth of roughness motifs R= 3.15µm
Arithmetical average spacing of roughness motifs AR=156µm
Max depth of roughness motifs Rx= 5.64µm

`

4.4.6 S=1000 rpm, f=0.18 mm/rev, d=0.20 mm

1. Profile Curve

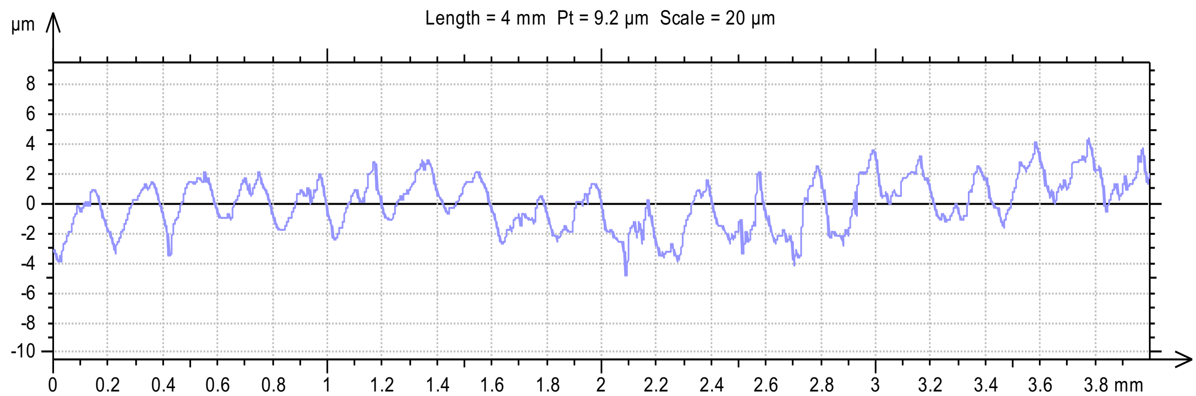

Fig.4.35: Profile curve for MMC (Al-3.5% RHA-3.5% GSA) at S =1000 rpm, f=0.18 mm/rev, d=0.20 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=9.2µm
Scale of profile=20 µm

2. Roughness and Waviness Motifs (ISO 12085)

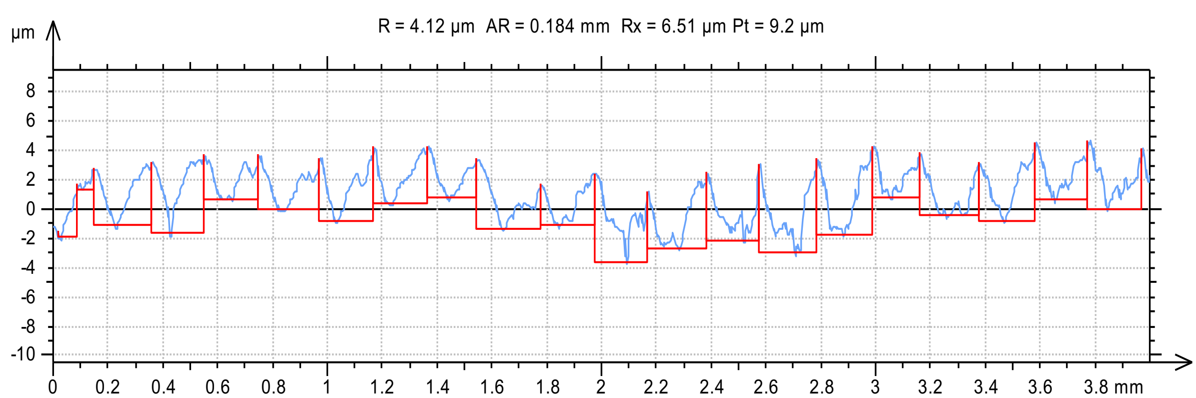

Fig.4.36: Roughness and Waviness Motifs for MMC (Al-3.5% RHA-3.5% GSA) at S =1000 rpm, f=0.18 mm/rev, d=0.20 mm

Arithmetical average depth of roughness motifs R= 4.12 µm
Arithmetical average spacing of roughness motifs AR=184µm
Max depth of roughness motifs Rx= 6.51µm

`

4.4.7 S=1300 rpm, f=0.10 mm/rev, d=0.50mm

1. Profile Curve

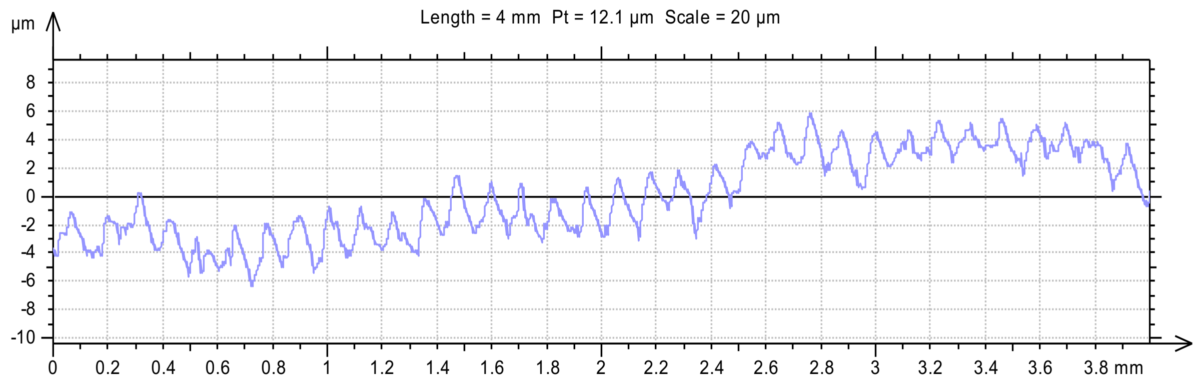

Fig.4.37: Profile curve for MMC (Al-3.5% RHA-3.5% GSA) at S =1300 rpm, f=0.10 mm/rev, d=0.50 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=12.1µm
Scale of profile=20 µm

2. Roughness and Waviness Motifs (ISO 12085)

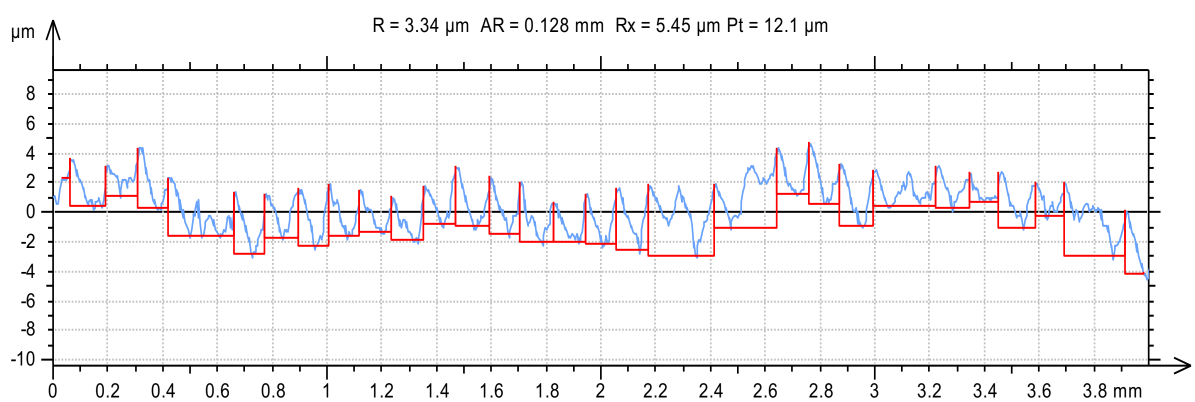

Fig.4.38: Roughness and Waviness Motifs for MMC (Al-3.5% RHA-3.5% GSA) at S =1300 rpm, f=0.10 mm/rev, d=0.50 mm

Arithmetical average depth of roughness motifs R= 3.34 µm
Arithmetical average spacing of roughness motifs AR=128 µm
Max depth of roughness motifs Rx= 5.45µm

`

4.4.8 S=1300 rpm, f=0.14 mm/rev, d=0.20 mm

1. Profile Curve

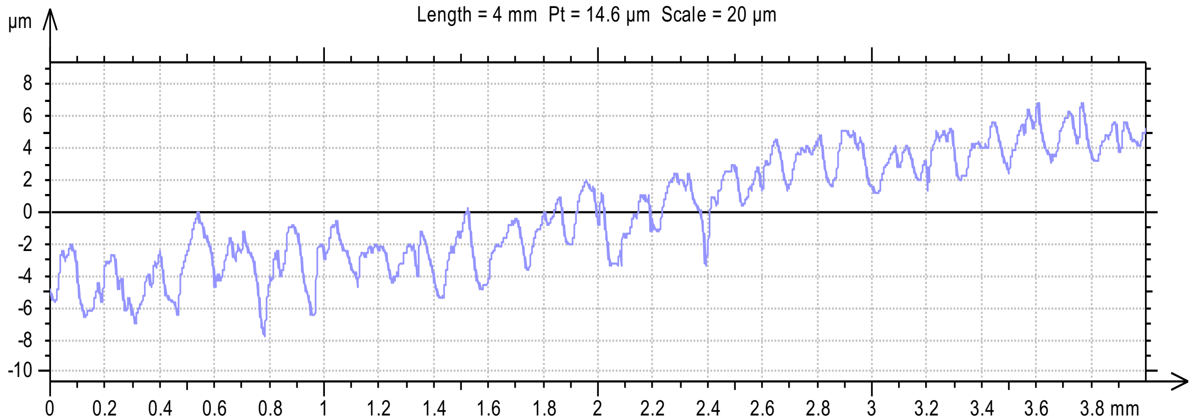

Fig.4.39: Profile curve for MMC (Al-3.5% RHA-3.5% GSA) at S =1300 rpm, f=0.14 mm/rev, d=0.20 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=14.6µm
Scale of profile=20 µm

2. Roughness and Waviness Motifs (ISO 12085)

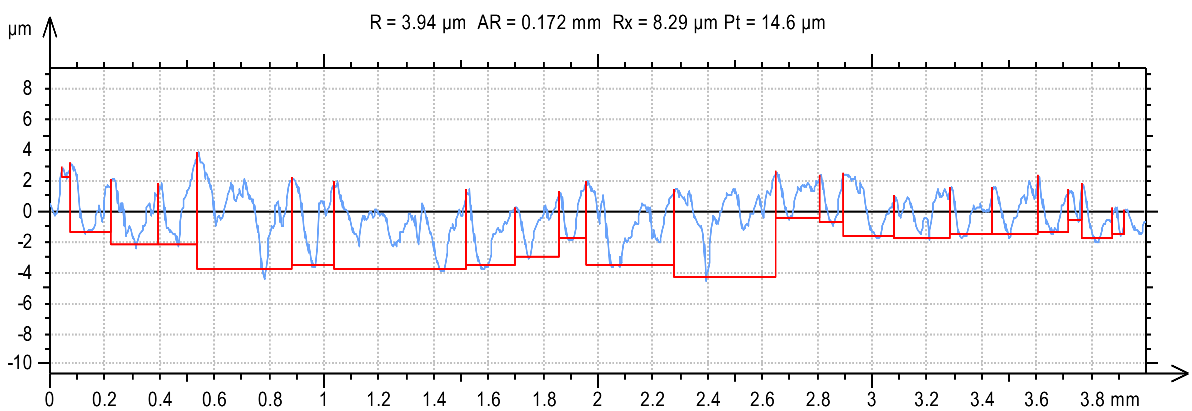

Fig.4.40: Roughness and Waviness Motifs for MMC (Al-3.5% RHA-3.5% GSA) at S =1300 rpm, f=0.14 mm/rev, d=0.20 mm

Arithmetical average depth of roughness motifs R= 3.94 µm
Arithmetical average spacing of roughness motifs AR=172µm
Max depth of roughness motifs Rx= 8.29µm

`

4.4.9 S=1300 rpm, f=0.18 mm/rev, d=0.35mm

1. Profile Curve

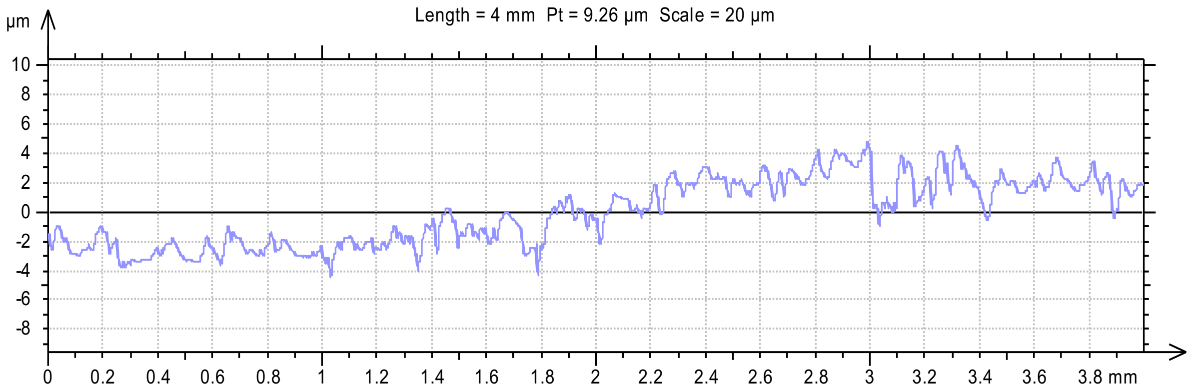

Fig.4.41: Profile curve for MMC (Al-3.5% RHA-3.5% GSA) at S =1300 rpm, f=0.18 mm/rev, d=0.35 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=9.26µm
Scale of profile=20 µm

2. Roughness and Waviness Motifs (ISO 12085)

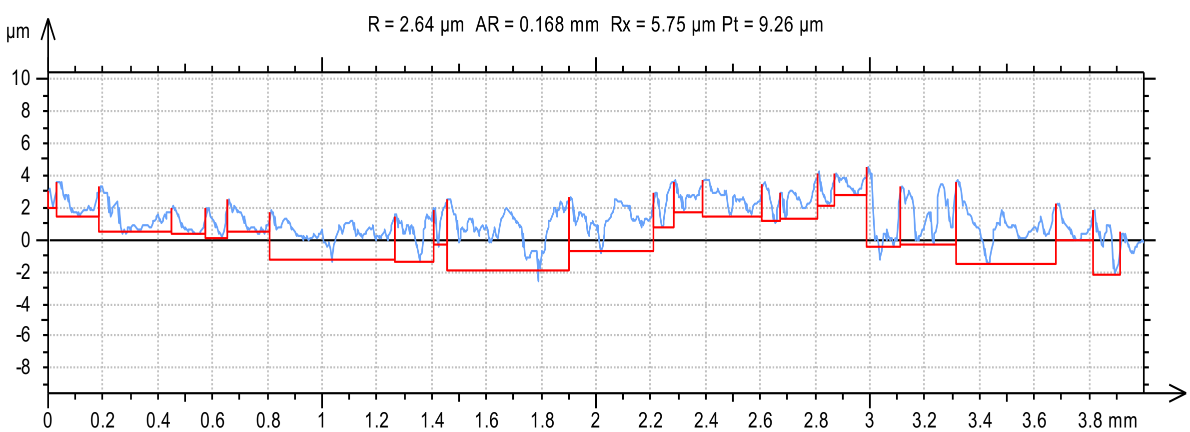

Fig.4.42: Roughness and Waviness Motifs for MMC (Al-3.5% RHA-3.5% GSA) at S =1300 rpm, f=0.18 mm/rev, d=0.35 mm

Arithmetical average depth of roughness motifs R= 2.64 µm
Arithmetical average spacing of roughness motifs AR=168 µm
Max depth of roughness motifs Rx= 5.75µm

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4.5 Graphs from Taguchi

4.5.1 Signal-to-Noise:

Mean of SN ratio for miscellaneous cutting facets is depicted in figure.

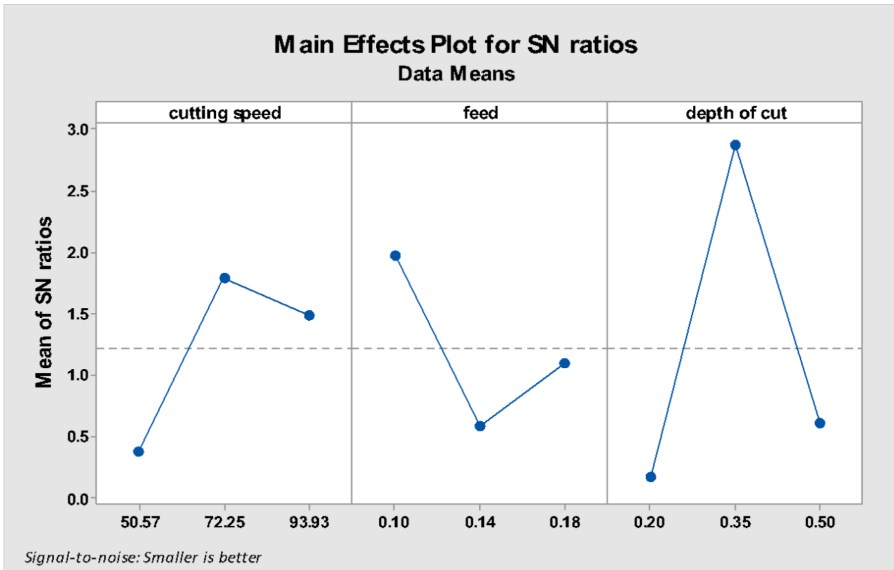

Fig.4.43: Main Effects Plot for SN ratios for MMC (Al-3.5% RHA-3.5% GSA)

4.5.2 Mean:

As specified by the main effect plot, the optimal conditions for minimum surface roughness isA2B1C2 which is speed at level 2(72.25 m min-1), feed rate at level 1 (0.10 mm rev-1) and depth of cut at level 2 (0.35mm).

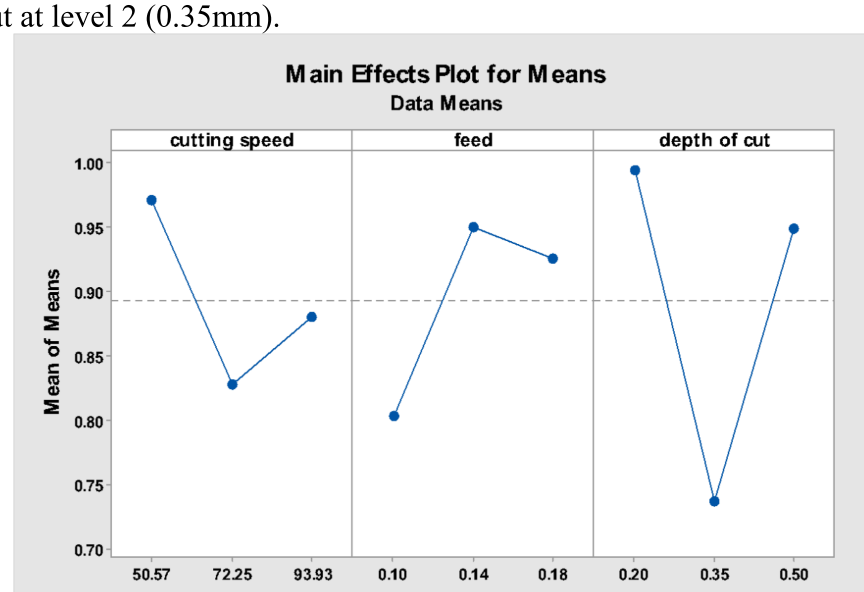

Fig.4.44: Main Effects Plot for SN ratios for MMC (Al-3.5% RHA-3.5% GSA)

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Table4.9: Experimental results for S/N ratio by Taguchi method for MMC (Al-3.5% RHA-3.5% GSA)

S.No.	Diameter (mm)	RPM	Speed (m/min)	Feed 'f' (mm/rev)	d (mm)	Ra (µm)	S/N Ratio (dB)	Mean (µm)
1.	23	700	50.57	0.10	0.20	0.783	2.12476	0.783
2.	23	700	50.57	0.14	0.35	0.961	0.345532	0.961
3.	23	700	50.57	0.18	0.50	1.170	-1.36372	1.170
4.	23	1000	72.25	0.10	0.35	0.693	3.18534	0.693
5.	23	1000	72.25	0.14	0.50	0.742	2.59192	0.742
6.	23	1000	72.25	0.18	0.20	1.050	-0.423786	1.050
7.	23	1300	93.93	0.10	0.50	0.935	0.583768	0.935
8.	23	1300	93.93	0.14	0.20	1.150	-1.21396	1.150
9.	23	1300	93.93	0.18	0.35	0.558	5.06732	0.558

Table4.10: S/N response table for surface roughness for MMC (Al-3.5% RHA-3.5% GSA)
Smaller is better

Symbol	Cutting Parameters	Mean S/N Ratio (dB)				
		Level 1	Level 2	Level 3	Max-min	Rank
A	**Speed**	0.3689	1.7845	1.4790	1.4156	2
B	**Feed**	1.9646	0.5745	1.0933	1.3901	3
C	**Depth of Cut**	0.1623	2.8661	0.6040	2.7038	1

Total mean S/N ratio = 1.2108

Table4.11: Mean response table for surface roughness for MMC (Al-3.5% RHA-3.5% GSA)

Symbol	Cutting parameters	Mean (µm)				
		Level 1	Level 2	Level 3	Max-min	Rank
A	**Speed**	0.9713	0.8283	0.8810	0.143	3
B	**Feed**	0.8037	0.9510	0.9260	0.1473	2
C	**Depth of Cut**	0.9943	0.7373	0.9490	0.257	1

`

Table4.12: Analysis of variance (ANOVA) for surface roughness for MMC (Al-3.5% RHA-3.5% GSA)

Symbol	Cutting parameters	DF	SS	MS	F	P	Contribution (%)
A	Speed	2	0.02620	0.01566	0.23	0.812	10.57
B	Feed	2	0.05342	0.02337	0.35	0.743	15.77
C	Depth of Cut	2	0.08312	0.04156	0.62	0.619	28.056
Error		2	0.13509	0.06754			45.6
Total		8		0.14813			

It can be seen from ANOVA table 4.12 that depth of cut is the highest contributing factor with 28.056 % and other details of DOF - Degrees of freedom, S.S - Sum of Squares, M.S - Mean of Squares, F-value, P-value and Error are mentioned.

Table4.13: Regression Analysis for Surface roughness for MMC (Al-3.5% RHA-3.5% GSA)

S.NO.	Log S	Log d	Log f	Log Ra	Residual	Fits
1	1.7038	-0.698	-1	-0.106	-0.191537	0.974537
2	1.7038	-0.456	-0.85	-0.172	0.0681512	0.892849
3	1.7038	-0.301	-0.744	0.068	0.0722055	1.09779
4	1.858	-0.456	-1	-0.159	0.121905	0.571095
5	1.858	-0.301	-0.85	-0.129	-0.202121	0.944121
6	1.858	-0.698	-0.744	0.021	0.0623745	0.987625
7	1.972	-0.301	-1	-0.029	0.0700463	0.864954
8	1.972	-0.698	-0.85	0.0607	0.0734612	1.07654
9	1.972	-0.456	-0.744	-0.253	-0.268770	0.826770

4.6 Graphs from Regression Analysis

4.6.1 Normal probability plot of Residuals for Log Ra

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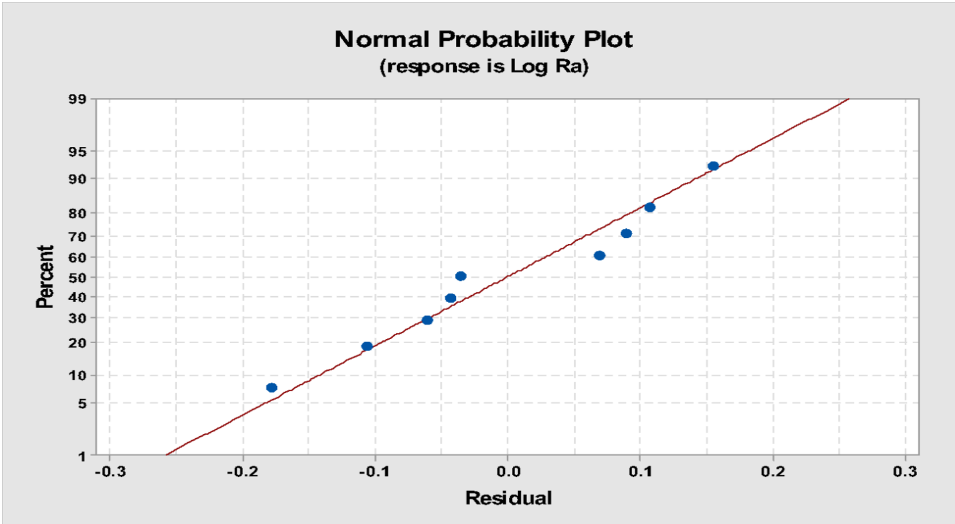

Fig.4.45: Normal Probability Plot for MMC (Al-3.5% RHA-3.5% GSA)

As in this project work data have less than 50 inspections, the plot might show bend in the tails even if the residuals are normally distributed.

4.6.2 Residuals vs Fits for Log Ra

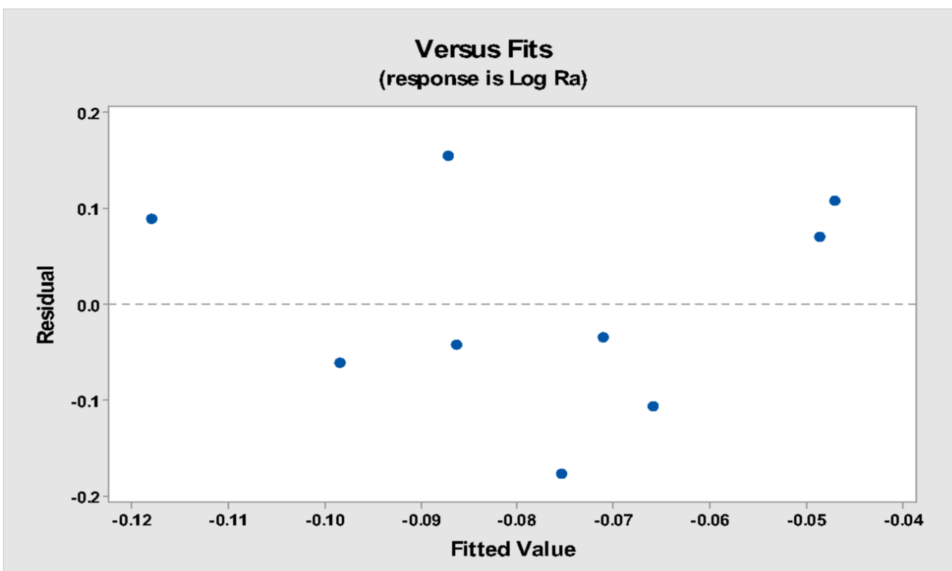

Fig.4.46: Versus Fits for MMC (Al-3.5% RHA-3.5% GSA)

It can be concluded that all the values are within the control range, indicating that there is no obvious pattern and unusual structure.

4.6.3 Residual Histogram for Log Ra

The aspect of the histogram changes Influenced by the number of intervals used to group the data.

`

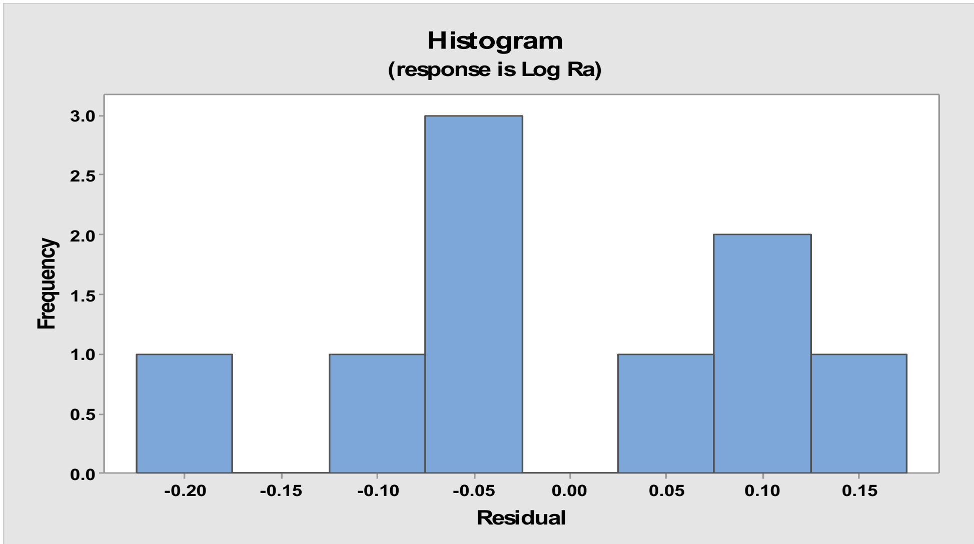

Fig.4.47: Histogram Plot for MMC (Al-3.5% RHA-3.5% GSA)

4.6.4 Residuals vs Order for Log Ra

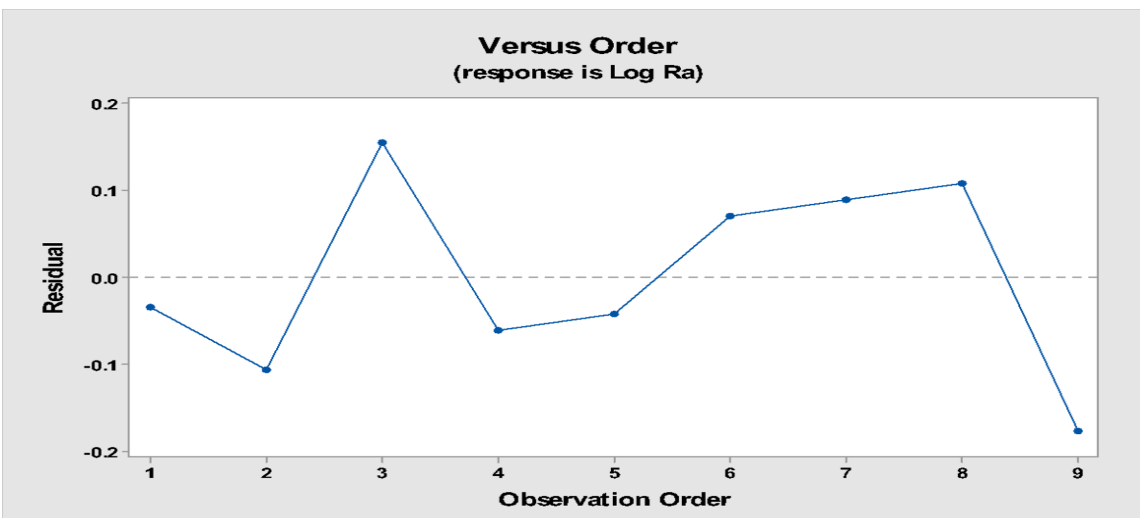

Fig.4.48: Versus order plot for MMC (Al-3.5% RHA-3.5% GSA)

From graphs 4.45, 4.46, 4.47, 4.48, it can be conjectured that all the values are within the control range, indicating that there is no obvious pattern and unusual structure and also the residual analysis does not indicate any model inadequacy.

`

Table4.14: Analysis of Variance for MMC (Al-3.5% RHA-3.5% GSA)

Symbol	**Cutting parameters**	**DF**	**Adj SS**	**Adj MS**	**F**	**P**	**Contribution (%)**
	Regression	3	0.004197	0.001399	0.07	0.973	
A	**Log S**	1	0.000045	0.000045	0.00	0.964	0.189
B	**Log d**	1	0.001530	0.001530	0.08	0.791	6.431
C	**Log f**	1	0.002623	0.002623	0.13	0.729	11.025
Error		5	0.097964	0.019593			82.35
Total			0.102161	0.023791			100

4.7 Regression Equation

Log Ra = -0.181 - 0.020 Log S - 0.0255 Log d - 0.163 Log f

$Ra = -0.181\ S^{-0.020}\ d^{-0.0255} f^{-0.163}$

Table4.15: Calculated Surface Roughness from Regression Equation for MMC (Al-3.5% RHA-3.5% GSA)

S.No.	**S (m/min)**	**F (mm/rev)**	**D (mm)**	**Ra (µm)**	**Calculated Ra (µm)**	**Error (%)**
1.	50.57	0.10	0.20	0.783	0.456	-41.75
2.	50.57	0.14	0.35	0.961	0.86	-10.51
3.	50.57	0.18	0.50	1.17	0.82	29.9
4.	72.25	0.10	0.35	0.693	0.904	30.44
5.	72.25	0.14	0.50	0.742	0.848	14.28
6.	72.25	0.18	0.20	1.05	0.833	20.59
7.	93.93	0.10	0.50	0.935	0.89	-4.63
8.	93.93	0.14	0.20	1.15	0.86	-24.86
9.	93.93	0.18	0.35	0.558	0.817	46.53

`

From Table 4.15, it can be concluded that the optimum combination process parameters for Minimum SR is obtained at speed 93.93 m/min (1300 rpm), feed 0.10 mm/rev and depth of cut 0.50 mm which gives 0.935 µm surface roughness.

4.8 GRAPHICAL ANALYSIS FOR MMC (Al-5%RHA-5%GSA)

4.8.1 S=700 rpm, f=0.10 mm/rev, d=0.20 mm

1. **Profile Curve**

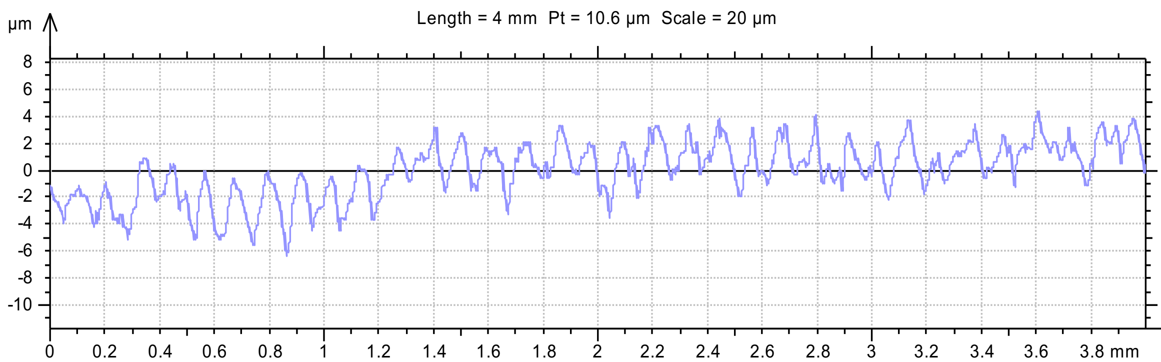

Fig.4.49: Profile curve for MMC (Al-5%RHA-5%GSA) at S =700 rpm, f=0.10 mm/rev, d=0.20 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=10.6µm
Scale of profile=20 µm

2 **Roughness and Waviness Motifs (ISO 12085)**

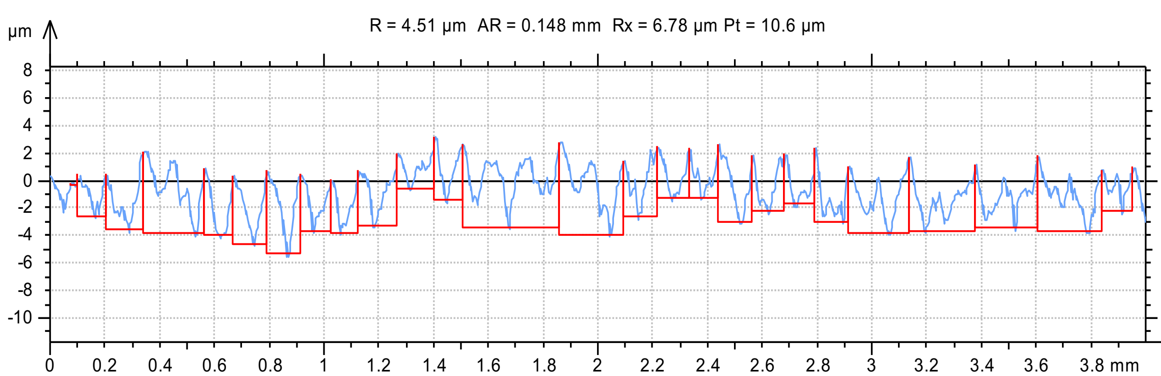

Fig.4.50: Roughness and Waviness Motifs for MMC (Al-5%RHA-5%GSA) at S =700 rpm, f=0.10 mm/rev, d=0.20 mm

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Arithmetical average depth of roughness motifs R= 4.51µm
Arithmetical average spacing of roughness motifs AR=148 µm
Max depth of roughness motifs Rx= 6.78µm

4.8.2 S=700 rpm, f=0.14 mm/rev, d=0.35mm

1. Profile Curve

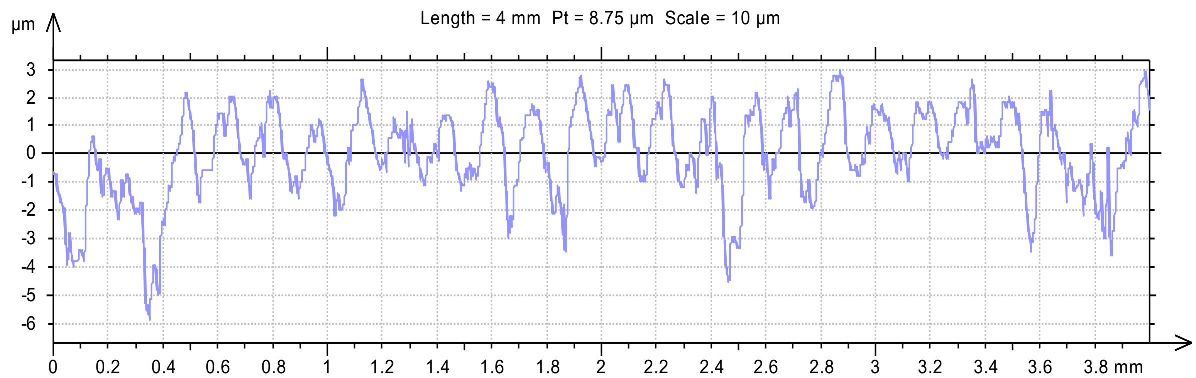

Fig.4.51: Profile curve for MMC (Al-5%RHA-5%GSA) at S =700 rpm, f=0.14 mm/rev, d=0.35 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=8.75µm
Scale of profile=10 µm

2. Roughness and Waviness Motifs (ISO 12085)

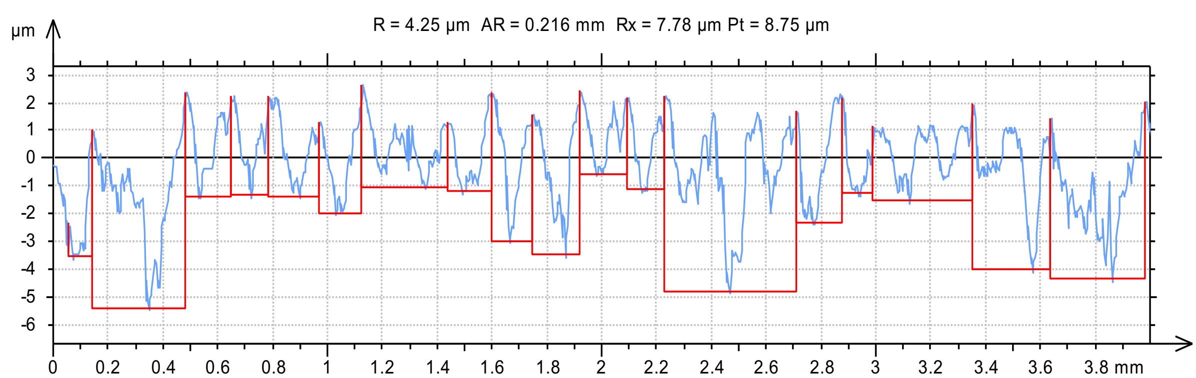

Fig.4.52: Roughness and Waviness Motifs for MMC (Al-5%RHA-5%GSA) at S =700 rpm, f=0.14 mm/rev, d=0.35 mm

Arithmetical average depth of roughness motifs R= 4.25 µm
Arithmetical average spacing of roughness motifs AR=216µm
Max depth of roughness motifs Rx= 7.78µm

`

4.8.3 S=700 rpm, f=0.18 mm/rev, d=0.50 mm

1. Profile Curve

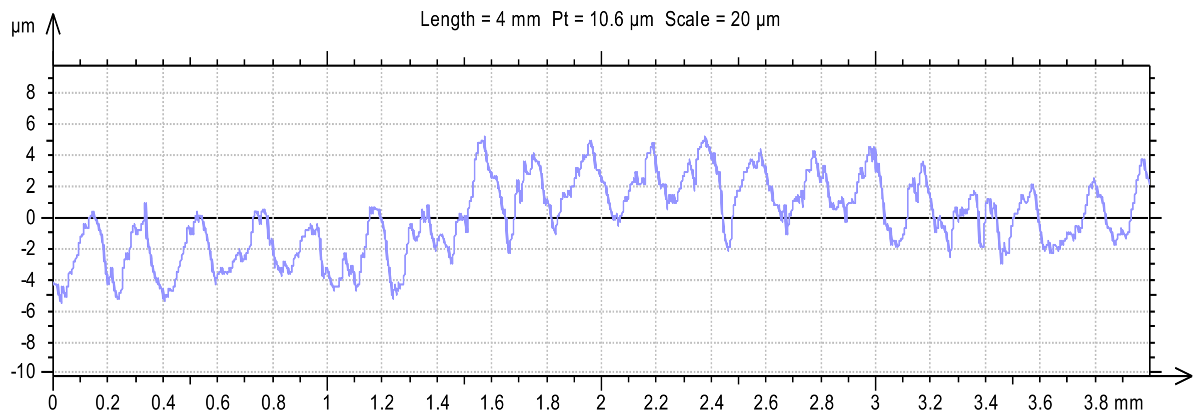

Fig.4.53: Profile curve for MMC (Al-5%RHA-5%GSA) at S =700 rpm, f=0.18 mm/rev, d=0.50 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=10.6µm
Scale of profile=20 µm

2. Roughness and Waviness Motifs (ISO 12085)

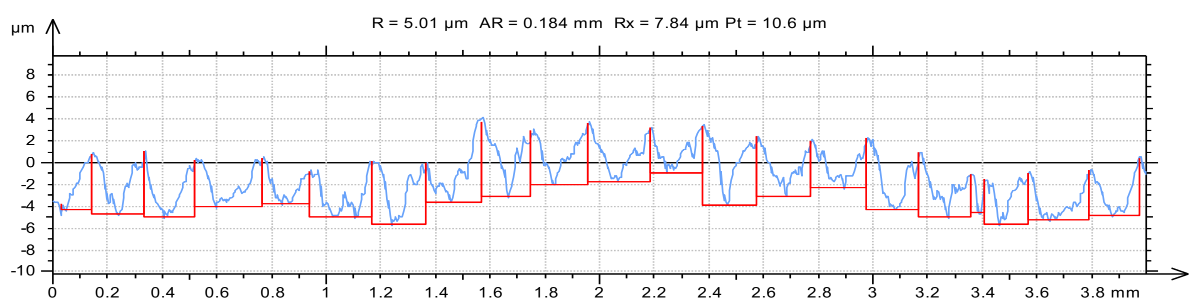

Fig.4.54: Roughness and Waviness Motifs for MMC (Al-5%RHA-5%GSA) at S =700 rpm, f=0.18 mm/rev, d=0.50 mm

Arithmetical average depth of roughness motifs R= 5.01 µm
Arithmetical average spacing of roughness motifs AR=184µm
Max depth of roughness motifs Rx= 7.84µm

`

4.8.4 S=1000 rpm, f=0.10 mm/rev, d=0.35 mm

1. **Profile Curve**

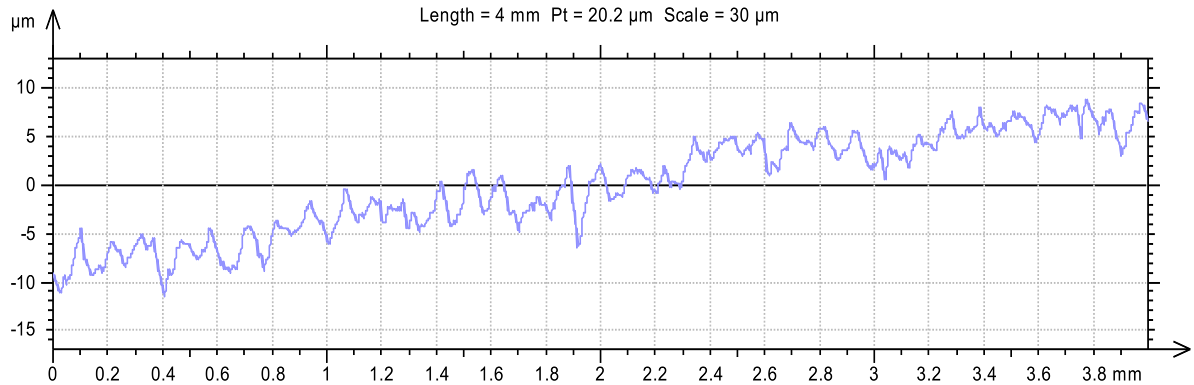

Fig.4.55: Profile curve for MMC (Al-5%RHA-5%GSA) at S =1000 rpm, f=0.10 mm/rev, d=0.35 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=20.2 µm
Scale of profile=30 µm

2. Roughness and Waviness Motifs (ISO 12085)

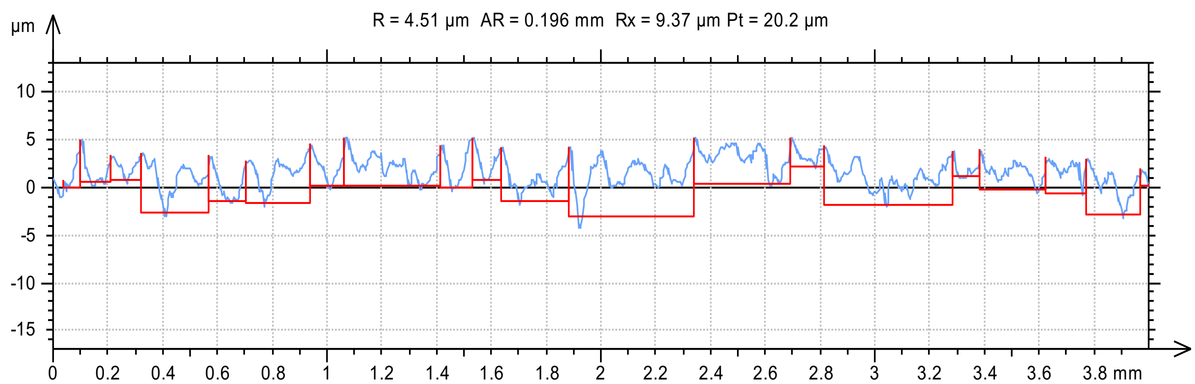

Fig.4.56: Roughness and Waviness Motifs for MMC (Al-5%RHA-5%GSA) at S =1000 rpm, f=0.10 mm/rev, d=0.35 mm

Arithmetical average depth of roughness motifs R= 4.51 µm
Arithmetical average spacing of roughness motifs AR=196µm
Max depth of roughness motifs Rx= 9.37µm

`

4.8.5 S=1000 rpm, f=0.14 mm/rev, d=0.50 mm

1. **Profile Curve**

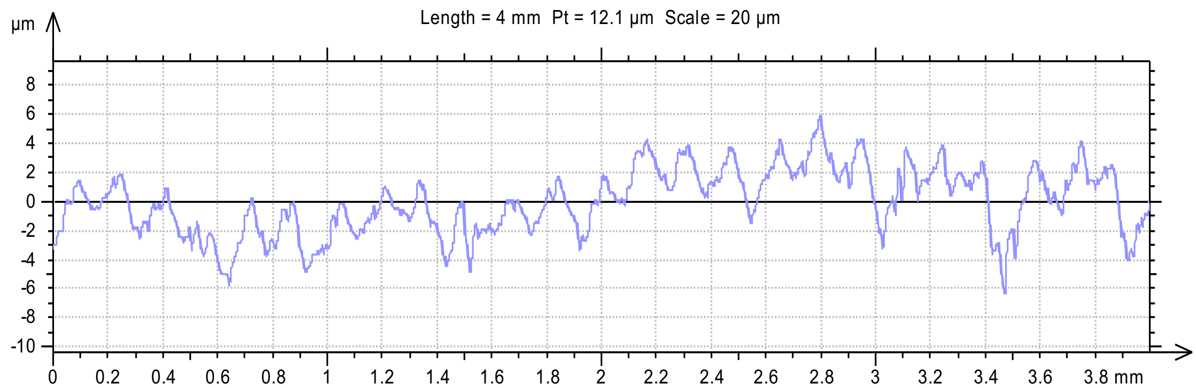

Fig.4.57: Profile curve for MMC (Al-5%RHA-5%GSA) at S =1000 rpm, f=0.14 mm/rev, d=0.50 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=12.1µm
Scale of profile=20 µm

2. **Roughness and Waviness Motifs (ISO 12085)**

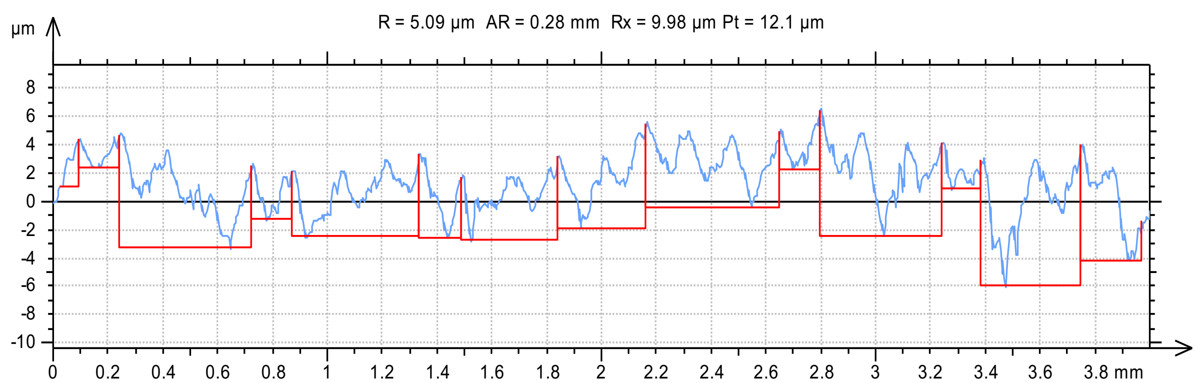

Fig.4.58: Roughness and Waviness Motifs for MMC (Al-5%RHA-5%GSA) at S =1000 rpm, f=0.14 mm/rev, d=0.50 mm

Arithmetical average depth of roughness motifs R= 5.09 µm
Arithmetical average spacing of roughness motifs AR=280µm
Max depth of roughness motifs Rx= 9.98µm

`

4.8.6 S=1000 rpm, f=0.18 mm/rev, d=0.20 mm

1. **Profile Curve**

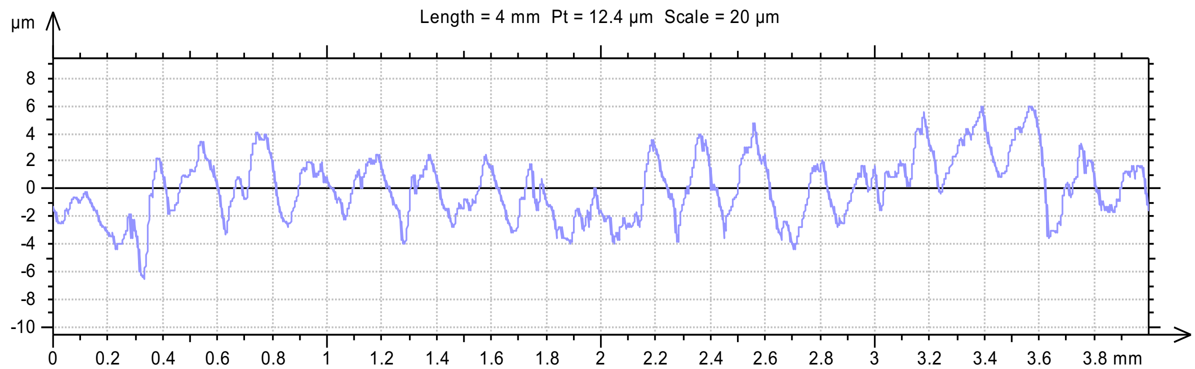

Fig.4.59: Profile curve for MMC (Al-5%RHA-5%GSA) at S =1000 rpm, f=0.18 mm/rev, d=0.20 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=12.4µm
Scale of profile=20 µm

2. **Roughness and Waviness Motifs (ISO 12085)**

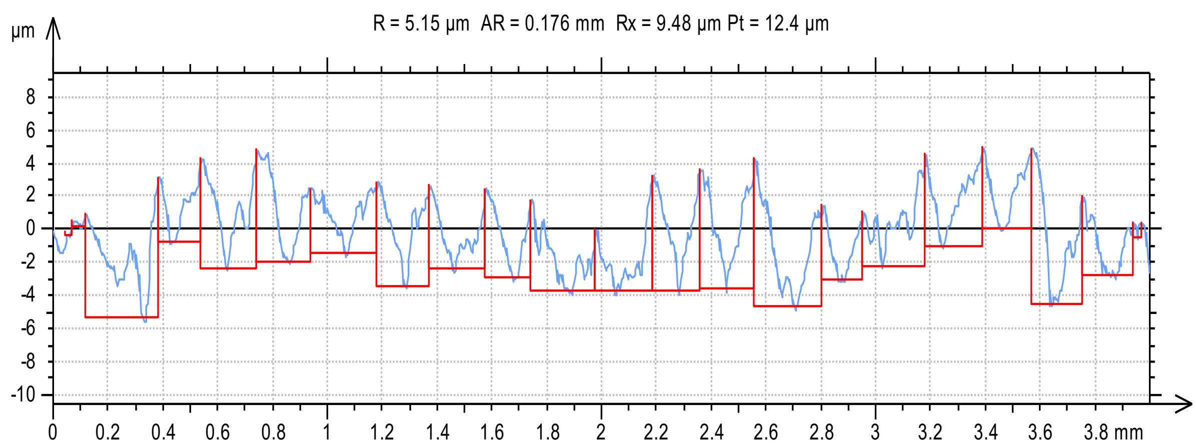

Fig.4.60: Roughness and Waviness Motifs for MMC (Al-5%RHA-5%GSA) at S =1000 rpm, f=0.18 mm/rev, d=0.20 mm

Arithmetical average depth of roughness motifs R= 5.15 µm
Arithmetical average spacing of roughness motifs AR=176µm
Max depth of roughness motifs Rx= 9.48µm

`

4.8.7 S=1300 rpm, f=0.10 mm/rev, d=0.50 mm

1. Profile Curve

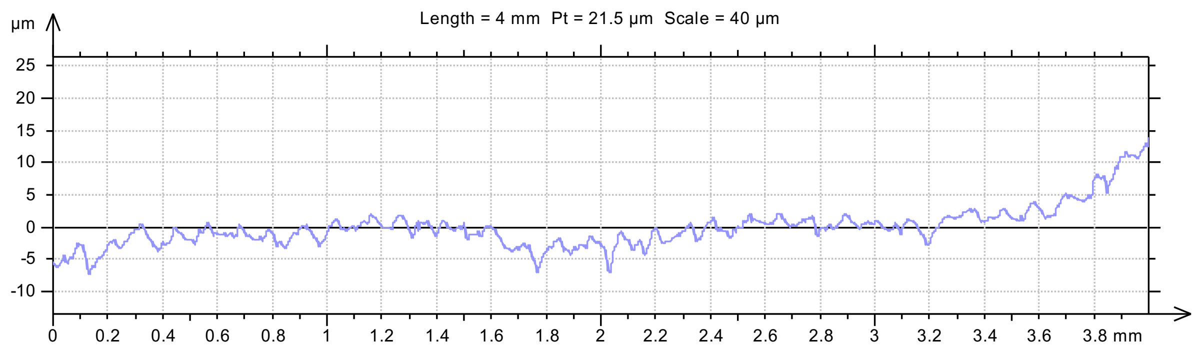

Fig.4.61: Profile curve for MMC (Al-5%RHA-5%GSA) at S =1300 rpm, f=0.10 mm/rev, d=0.50 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=21.5µm
Scale of profile=40µm

2. Roughness and Waviness Motifs (ISO 12085)

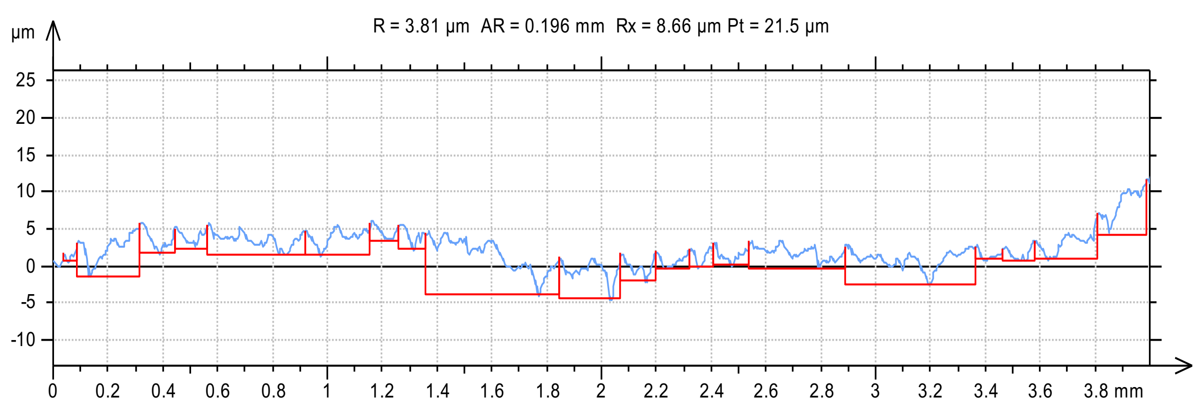

Fig.4.62: Roughness and Waviness Motifs for MMC (Al-5%RHA-5%GSA) at S =1300 rpm, f=0.10 mm/rev, d=0.50 mm

Arithmetical average depth of roughness motifs R= 3.81 µm
Arithmetical average spacing of roughness motifs AR=196µm
Max depth of roughness motifs Rx= 8.66µm

`

4.8.8 S=1300 rpm, f=0.14 mm/rev, d=0.20 mm

1. Profile Curve

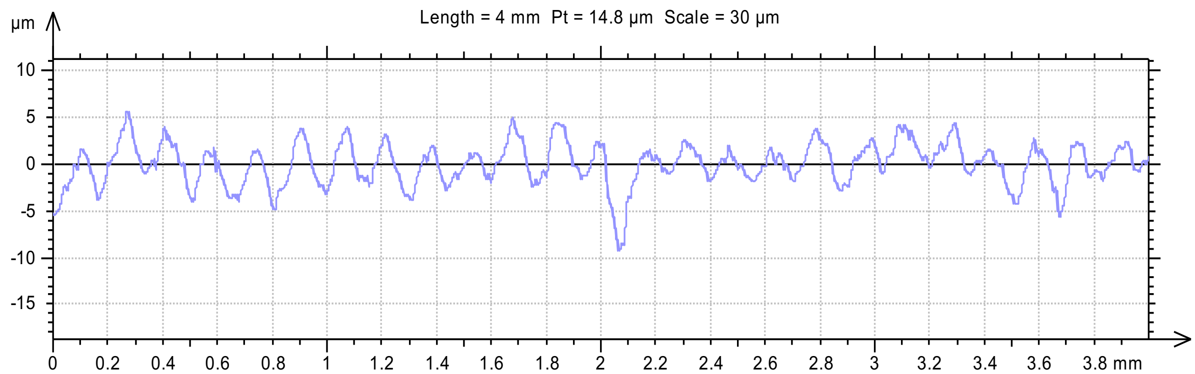

Fig.4.63: Profile curve for MMC (Al-5%RHA-5%GSA) at S =1300 rpm, f=0.14 mm/rev, d=0.20 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=14.8µm
Scale of profile=30 µm

2. Roughness and Waviness Motifs (ISO 12085)

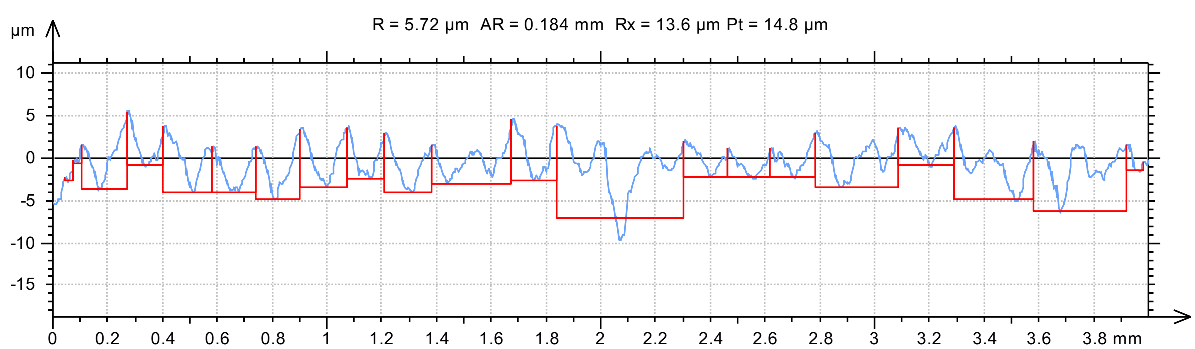

Fig.4.64: Roughness and Waviness Motifs for MMC (Al-5%RHA-5%GSA) at S =1300 rpm, f=0.14 mm/rev, d=0.20 mm

Arithmetical average depth of roughness motifs R= 5.72 µm
Arithmetical average spacing of roughness motifs AR=184µm
Max depth of roughness motifs Rx= 13.6µm

`

4.8.9 S=1300 rpm, f=0.18 mm/rev, d=0.35 mm

1. **Profile Curve**

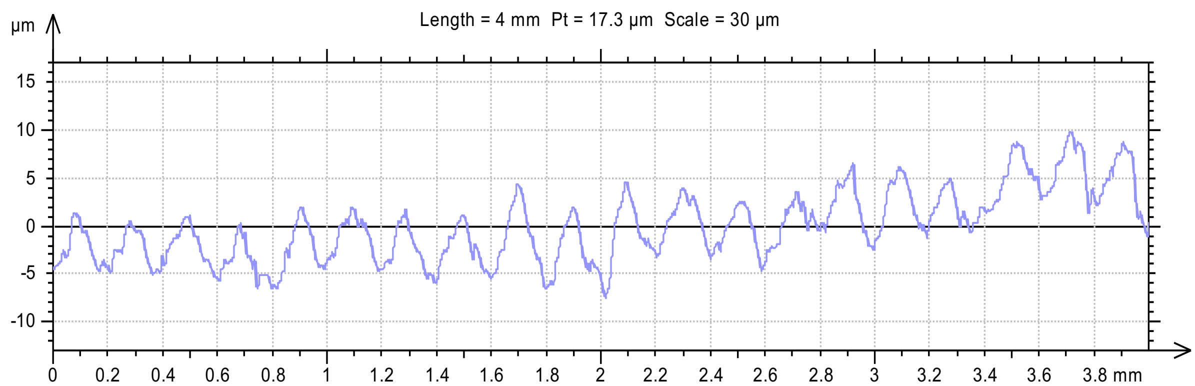

Fig.4.65: Profile curve for MMC (Al-5%RHA-5%GSA) at S =1300 rpm, f=0.18 mm/rev, d=0.35 mm

Length of profile= 4 mm
Max. Peak to valley height P_t=17.3µm
Scale of profile=30 µm

2. **Roughness and Waviness Motifs (ISO 12085)**

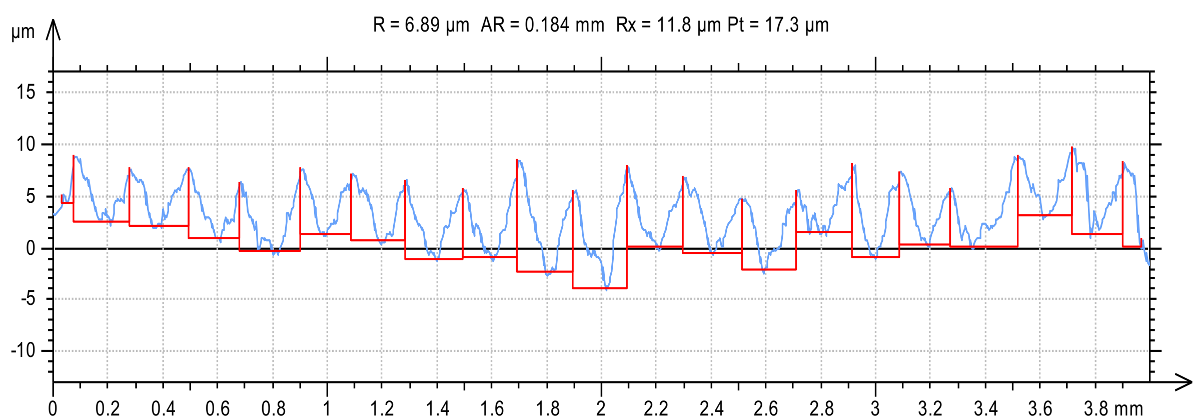

Fig.4.66: Roughness and Waviness Motifs for MMC (Al-5%RHA-5%GSA) at S =1300 rpm, f=0.18 mm/rev, d=0.35 mm

Arithmetical average depth of roughness motifs R= 6.89 µm
Arithmetical average spacing of roughness motifs AR=184µm
Max depth of roughness motifs Rx= 11.8µm

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4.9 Graphs from Taguchi

4.9.1 Signal-to-Noise:

Mean of SN ratio for miscellaneous cutting facets is depicted in figure.

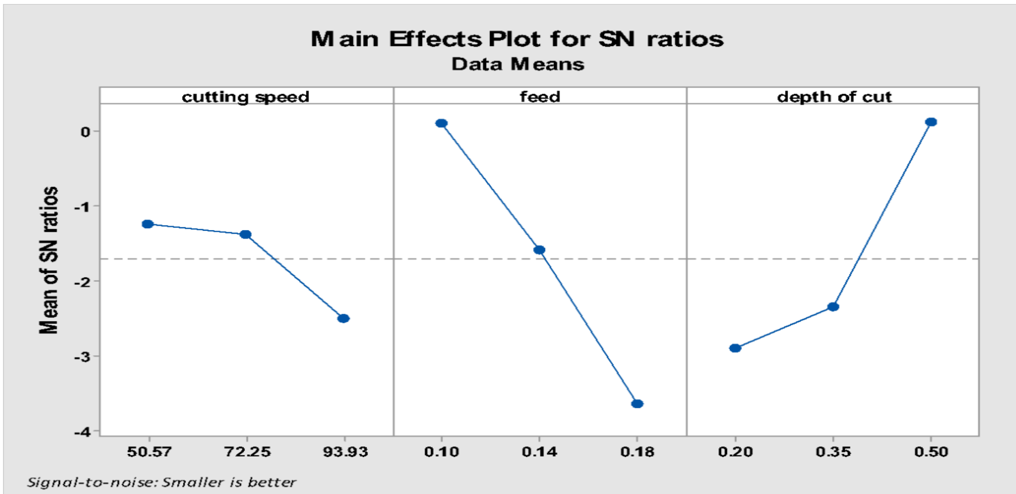

Fig.4.67: Main Effects Plot for SN ratios for MMC (Al-5%RHA-5%GSA)

4.9.2 Mean:

As specified by the main effect plot, the optimal conditions for minimum surface roughness isA1B1C3 which is speed at level 1(50.57 m min-1), feed rate at level 1 (0.10 mm rev-1) and depth of cut at level 3 (0.50mm).

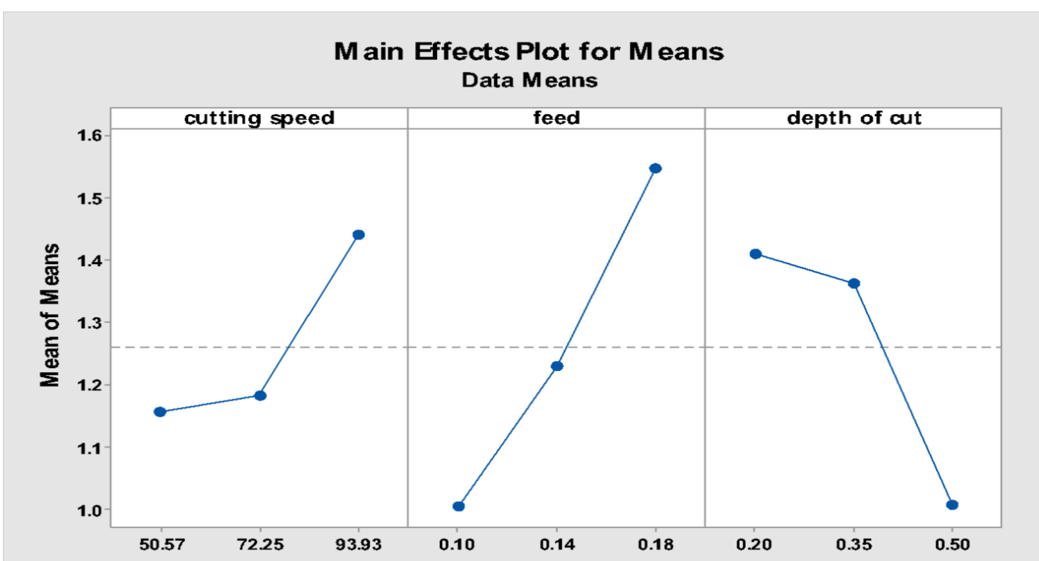

Fig.4.68: Main Effects Plot for SN ratios for MMC (Al-5%RHA-5%GSA)

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Table4.16: Experimental results for S/N ratio by Taguchi method for MMC (Al-5%RHA-5%GSA

S.No.	Diameter (mm)	RPM	Speed (m/min)	Feed 'f' (mm/rev)	d (mm)	Ra (μm)	S/N Ratio (dB)	Mean (μm)
1.	23	700	50.57	0.10	0.20	1.160	-1.28916	1.160
2.	23	700	50.57	0.14	0.35	1.040	-0.340667	1.040
3.	23	700	50.57	0.18	0.50	1.270	-2.07607	1.270
4.	23	1000	72.25	0.10	0.35	1.110	-0.906460	1.110
5.	23	1000	72.25	0.14	0.50	1.010	0.0864275	1.010
6.	23	1000	72.25	0.18	0.20	1.430	-3.10672	1.430
7.	23	1300	93.93	0.10	0.50	0.744	2.56854	0.744
8.	23	1300	93.93	0.14	0.20	1.640	-4.29688	1.640
9.	23	1300	93.93	0.18	0.35	1.940	-5.75603	1.940

Table4.17: S/N response table for surface roughness for MMC (Al-5%RHA-5%GSA
Smaller is better

Symbol	Cutting Parameters	Mean S/N Ratio (dB)				
		Level 1	**Level 2**	**Level 3**	**Max-min**	**Rank**
A	**Speed**	-1.2353	-1.3665	-2.4948	1.2595	3
B	**Feed**	0.1243	-1.5747	-3.6463	3.7706	1
C	**Depth of Cut**	-2.8976	-2.3344	0.1353	3.0329	2

Total mean S/N ratio = -1.698

Table4.18: Mean response table for surface roughness for MMC (Al-5%RHA-5%GSA

Symbol	Cutting parameters	Mean (μm)				
		Level 1	**Level 2**	**Level 3**	**Max-min**	**Rank**
A	**Speed**	1.157	1.183	1.441	0.284	3

`

B	**Feed**	1.005	1.230	1.547	0.542	1
C	**Depth of Cut**	1.410	1.363	1.008	0.402	2

Table4 .19: Analysis of variance (ANOVA) for surface roughness for MMC (Al-5%RHA-5%GSA

Symbol	**Cutting parameters**	**DF**	**SS**	**MS**	**F**	**P**	**Contribution (%)**
A	**Speed**	**2**	0.50495	0.13567	1.55	0.392	22.174
B	**Feed**	**2**	0.47251	0.25181	2.88	0.258	41.156
C	**Depth of Cut**	**2**	0.27364	0.13682	1.56	0.390	22.36
Error		**2**	0.17509	0.08754			14.307
Total		**8**	1.42618	0.61184			

It can be seen from ANOVA table 4.19 that feed is the highest contributing factor with 41.156 % and other details of DOF - Degrees of freedom, S.S - Sum of Squares, M.S - Mean of Squares, F-value, P-value and Error are mentioned.

Table4.20: Regression Analysis for Surface roughness for MMC (Al-5%RHA-5%GSA

S.NO.	**Log S**	**Log d**	**Log f**	**Log Ra**	**Residual**	**Fits**
1	1.7038	-0.698	-1	0.064	0.0332544	0.0311456
2	1.7038	-0.456	-0.85	0.017	-0.0412431	0.0582431
3	1.7038	-0.301	-0.744	0.103	0.0330140	0.0699860
4	1.858	-0.456	-1	0.045	0.0640727	-0.0190727
5	1.858	-0.301	-0.85	.00432	-0.0285868	0.0329068
6	1.858	-0.698	-0.744	0.155	-0.0943612	0.249361
7	1.972	-0.301	-1	-0.128	-0.0745690	-0.0534310
8	1.972	-0.698	-0.85	0.2148	0.0115399	0.203260
9	1.972	-0.456	-0.744	0.287	0.0968791	0.190121

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4.10 Graphs from Regression Analysis

4.10.1 Normal probability plot of Residuals for Log Ra

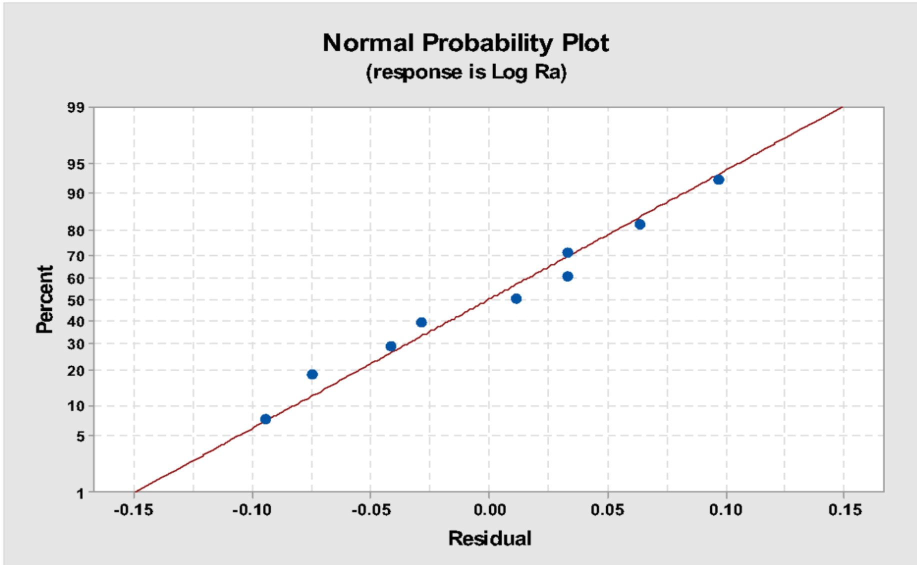

Fig.4.69: Normal Probability Plot for MMC (Al-5%RHA-5%GSA)

As in this project work data have less than 50 inspections, the plot might show bend in the tails even if the residuals are normally distributed.

4.10.2 Residuals vs Fits for Log Ra

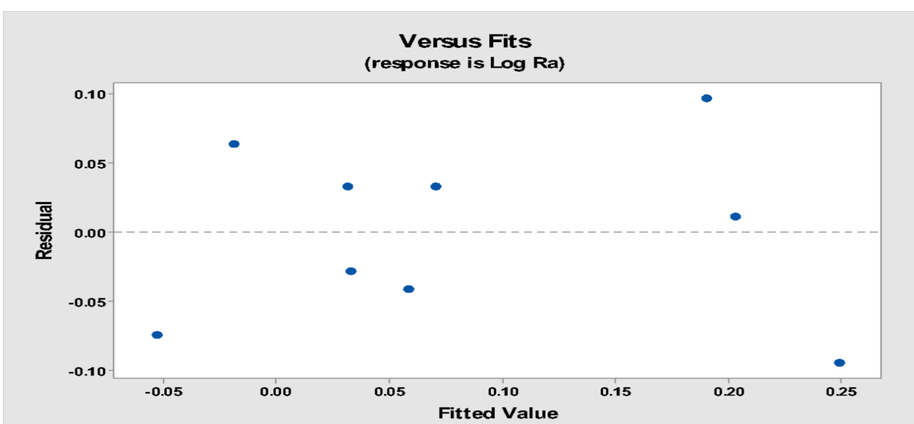

Fig.4.70: Versus Fits for MMC (Al-5%RHA-5%GSA)

It can be concluded that all the values are within the control range, indicating that there is no obvious pattern and unusual structure.

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4.10.3 Residual Histogram for Log Ra

The aspect of the histogram changes Influenced by the number of intervals used to group the data.

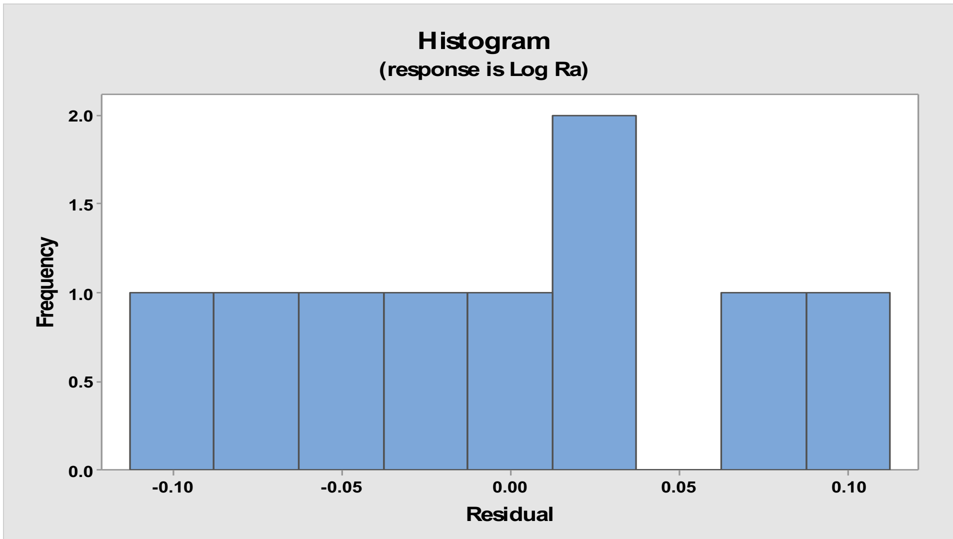

Fig.4.71: Histogram Plot for MMC (Al-5%RHA-5%GSA)

4.10.4 Residuals vs Order for Log Ra

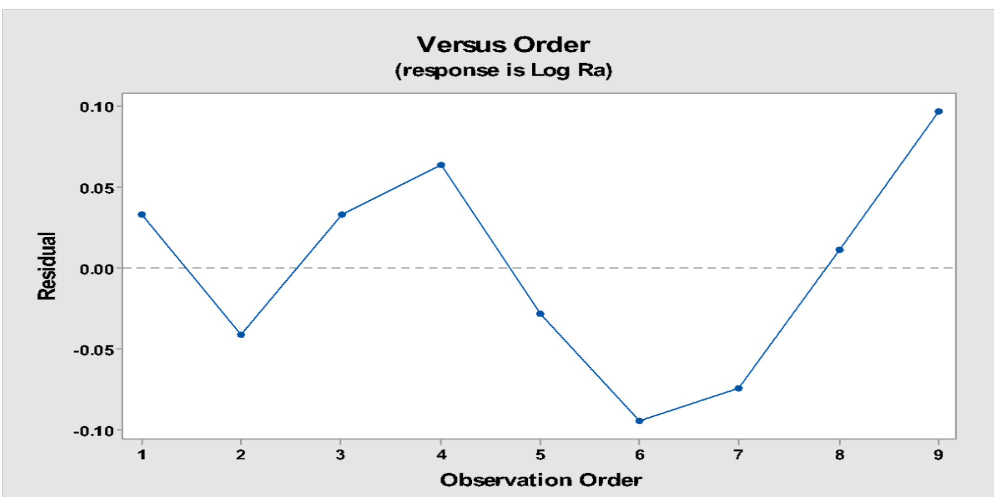

Fig.4.72: Versus order plot for MMC (Al-5%RHA-5%GSA)

From graphs 4.69, 4.70, 4.71, 4.72 it can be conjectured that all the values are within the control range, indicating that there is no obvious pattern and unusual structure and also the residual analysis does not indicate any model inadequacy.

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Table4.21: Analysis of Variance for MMC (Al-5%RHA-5%GSA)

Symbol	Cutting parameters	DF	Adj SS	Adj MS	F	P	Contribution (%)
	Regression	3	0.088599	0.029533	4.50	0.069	
A	Log S	1	0.005475	0.005475	0.83	0.403	5.753
B	Log d	1	0.051378	0.051378	7.83	0.038	53.99
C	Log f	1	0.031746	0.031746	4.84	0.079	33.36
Error		5		0.006561			6.894
Total		8		0.09516			

4.11 Regression Equation

$$\text{Log Ra} = -0.594 + 0.224 \text{ Log S} + 0.462 \text{ Log d} - 0.566 \text{ Log f}$$
$$Ra = -0.594\ S^{0.224}\ d^{0.462} f^{-0.566}$$

Table4.22: Calculated Surface Roughness from Regression Equation for MMC (Al-5%RHA-5%GSA

S.No.	S (m/min)	F (mm/rev)	d (mm)	Ra (µm)	Calculated Ra (µm)	Error (%)
1.	50.57	0.10	0.20	1.16	1.073	-7.5
2.	50.57	0.14	0.35	1.04	1.15	10.57
3.	50.57	0.18	0.50	1.27	1.175	7.48
4.	72.25	0.10	0.35	1.11	1.505	35.58
5.	72.25	0.14	0.50	1.01	1.467	45.24
6.	72.25	0.18	0.20	1.43	0.833	-41.74
7.	93.93	0.10	0.50	0.744	1.88	153.08
8.	93.93	0.14	0.20	1.64	1.019	-37.86
9.	93.93	0.18	0.35	1.94	1.14	-41.23

From Table 4.22, it can be concluded that the optimum combination process parameters for Minimum SR is obtained at speed 50.57 m/min (700 rpm), feed 0.18 mm/rev and depth of cut 0.50 mm which gives 1.27µm surface roughness.

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RESULTS AND CONCLUSION

This thesis has conferred an application of the parameter design of the Taguchi methodology in the optimization of turning operations and analysis by ANOVA on 3 different work piece i.e. MMC (Al-2%RHA-2%GSA), MMC (Al-3.5%RHA-3.5%GSA) and MMC (Al-5%RHA-5%GSA). These optimum turning conditions can also be used when the metal matrix composites are turned for the typical applications like bearings, automobile pistons, cylinder liners, piston rings, connecting rods, sliding electrical contacts, turbo charger impellers, space structures, etc. The subsequent conclusions may be drawn:

- **For MMC (Al-2%RHA-2%GSA):** Feed rate is the major parameter among the 3 governable factors (speed, feed rate and depth of cut) that influence the surface roughness in turning of MMC (Al7075-RHA-GSA).As per analysis of variance the percentage contributions of speed, feed rate and depth of cut are 1.55%, 55.073% and 38.682 %, severally for the vary of parameters. In turning, use of lower speed (50.57 m/min), low feed rate (0.10 mm/rev) and low depth of cut (0.2 mm) are counseled to get lesser Surface Roughness for the specific test range.
- **For MMC (Al-3.5%RHA-3.5%GSA):** Depth of cut is the major parameter among the 3 governable factors (speed, feed rate and depth of cut) that influence the surface roughness in turning of MMC (Al7075-RHA-GSA).As per analysis of variance the percentage contributions of speed, feed rate and depth of cut are 10.57%, 15.77% and 28.056 %, severally for the vary of parameters In turning, use of higher speed (93.93m/min), low feed rate (0.10 mm/rev) and high depth of cut (0.5 mm) are counseled to get lesser Surface Roughness for the specific test range.
- **For MMC (Al-5%RHA-5%GSA):** Feed rate is that the major parameter among the 3 governable factors (speed, feed rate and depth of cut) that influence the surface roughness in turning of metal matrix composite (Al7075-RHA-GSA).As per analysis of variance the percentage contributions of speed, feed rate and depth of cut are 22.174 %, 41.156% and 22.36%, severally for the vary of parameters. In turning, use of lower speed (50.57 m/min), higher feed rate (0.18 mm/rev) and higher depth of cut (0.50 mm) are counseled to get lesser Surface Roughness for the specific test range.
- Tensile test was conducted on UTM machine. From Tensile Test it is concluded that in MMC as the percentage of reinforcement increases, up to certain value tensile strength decrease

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after this tensile strength increases because MMC (Al 7075-3.5%RHA-3.5%GSA) has 56.6 MPa tensile strength while MMC (Al 7075-2%RHA-2%GSA) has 107 MPa tensile strength. MMC (Al 7075-2%RHA-2%GSA) has ultimate tensile strength(119MPa) which is lower than the tensile strength of pure Al 7075 alloy.

- From Micro Hardness Test it can be concluded that metal matrix composites (Al-RHA-GSA) have higher hardness value than pure Al 7075 alloy and as the percentage of reinforcement increases, hardness value also increases.

SCOPE OF FUTURE WORK

In the present work only two types of ash are used as reinforcement. In place of rice husk ash and ground nut shell ash, jute ash, bamboo leaf ash, coconut shell ash can also be used as reinforcement in various types of alloy not just Al7075 and mechanical properties can be determined for such a new metal matrix composites and also optimization of cutting facets for surface roughness on CNC turning can also be done on such new composites. In the present work only set-up variables are considered. Tool variables and work piece variables can also be studied. There is also scope for considering more factors levels, Interactions to optimize a selected set of parameters.

APPENDIX A

Tensile Test of MMC (Al-2%RHA-2%GSA):

Stress (MPa)	Strain (%)	Force (N)	Position (mm)

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0.0383	-0.047	3.33	0
0.54	-0.0403	47	0.00574
1.85	-0.0305	160	0.0141
2.94	-0.0212	256	0.022
3.91	-0.0118	340	0.03
4.84	-0.00146	421	0.0388
5.64	0.00769	490	0.0465
6.33	0.0165	550	0.054
6.89	0.0259	599	0.062
7.46	0.0349	649	0.0697
8.01	0.045	697	0.0783
8.53	0.0542	742	0.086
9.09	0.0635	790	0.094
9.6	0.073	835	0.102
10.1	0.0824	876	0.11
10.5	0.0918	915	0.118
11	0.101	953	0.126
11.4	0.11	988	0.134
11.8	0.119	1020	0.141
12.2	0.129	1060	0.149
12.6	0.138	1090	0.157
13	0.148	1130	0.166
13.3	0.156	1160	0.173
13.7	0.166	1190	0.181
14.1	0.176	1220	0.189
14.4	0.185	1260	0.197
14.8	0.194	1290	0.205
15.2	0.204	1320	0.213
15.5	0.213	1350	0.221
15.8	0.222	1380	0.229
16.2	0.231	1410	0.237
16.5	0.241	1440	0.245
16.9	0.251	1470	0.253
17.2	0.259	1490	0.26
17.5	0.269	1520	0.268
17.8	0.278	1550	0.277
18.1	0.288	1580	0.284
18.5	0.296	1600	0.292
18.8	0.306	1630	0.3
19.1	0.316	1660	0.308
19.3	0.325	1680	0.316
19.6	0.334	1710	0.324

19.9	0.343	1730	0.332
20.2	0.353	1760	0.34
20.5	0.362	1780	0.347
20.8	0.372	1810	0.356
21.1	0.381	1830	0.364
21.4	0.39	1860	0.372
21.7	0.4	1890	0.38
22	0.408	1910	0.387
22.3	0.418	1930	0.395
22.6	0.427	1960	0.403
22.9	0.436	1990	0.411
23.2	0.445	2010	0.419
23.5	0.455	2040	0.427
23.8	0.465	2070	0.435
24.1	0.474	2100	0.443
24.4	0.483	2120	0.45
24.7	0.492	2150	0.459
25	0.502	2180	0.467
25.3	0.512	2200	0.475
25.6	0.521	2230	0.483
26	0.531	2260	0.491
26.3	0.539	2280	0.498
26.6	0.549	2310	0.506
26.9	0.558	2340	0.515
27.2	0.567	2360	0.522
27.5	0.576	2390	0.53
27.8	0.586	2420	0.538
28.1	0.595	2440	0.546
28.4	0.605	2470	0.554
28.7	0.614	2500	0.562
29	0.623	2530	0.57
29.4	0.633	2560	0.578
29.7	0.642	2580	0.585
30.1	0.652	2610	0.594
30.4	0.661	2640	0.602
30.7	0.669	2670	0.609
31	0.68	2700	0.618
31.4	0.688	2730	0.625
31.7	0.698	2760	0.633
32	0.707	2780	0.641
32.4	0.717	2810	0.65
32.7	0.726	2840	0.657
33.1	0.735	2870	0.665

33.4	0.745	2900	0.673	50.7	1.15	4410	1.01
33.8	0.754	2940	0.681	51.1	1.16	4450	1.02
34.1	0.764	2960	0.689	51.6	1.16	4490	1.03
34.5	0.773	3000	0.697	52.1	1.17	4530	1.04
34.8	0.782	3030	0.705	52.5	1.18	4570	1.05
35.1	0.792	3060	0.713	53	1.19	4610	1.05
35.5	0.8	3090	0.72	53.5	1.2	4650	1.06
35.8	0.81	3120	0.728	53.9	1.21	4690	1.07
36.2	0.819	3150	0.736	54.4	1.22	4730	1.08
36.6	0.828	3180	0.744	54.9	1.23	4780	1.09
37	0.838	3210	0.752	55.4	1.24	4820	1.09
37.3	0.847	3240	0.76	55.9	1.25	4860	1.1
37.7	0.857	3280	0.769	56.4	1.26	4910	1.11
38.1	0.866	3310	0.776	56.9	1.27	4950	1.12
38.4	0.875	3340	0.784	57.4	1.28	4990	1.13
38.8	0.885	3380	0.792	57.9	1.29	5040	1.13
39.2	0.894	3410	0.8	58.5	1.3	5080	1.14
39.6	0.904	3440	0.808	59	1.3	5130	1.15
40	0.913	3480	0.816	59.5	1.31	5170	1.16
40.4	0.921	3510	0.823	60	1.32	5220	1.17
40.8	0.932	3550	0.832	60.5	1.33	5260	1.17
41.2	0.94	3590	0.839	61	1.34	5310	1.18
41.7	0.95	3620	0.848	61.6	1.35	5360	1.19
42.1	0.959	3660	0.855	62.1	1.36	5400	1.2
42.5	0.968	3700	0.863	62.7	1.37	5450	1.2
42.9	0.978	3730	0.871	63.2	1.38	5500	1.21
43.3	0.987	3770	0.879	63.7	1.39	5540	1.22
43.7	0.996	3800	0.887	64.3	1.4	5590	1.23
44.2	1.01	3840	0.896	64.8	1.41	5640	1.24
44.6	1.02	3880	0.904	65.4	1.42	5680	1.24
45	1.02	3910	0.911	65.9	1.43	5730	1.25
45.4	1.03	3950	0.919	66.5	1.44	5780	1.26
45.8	1.04	3990	0.927	67	1.44	5830	1.27
46.3	1.05	4020	0.935	67.6	1.45	5880	1.28
46.7	1.06	4060	0.942	68.1	1.46	5930	1.28
47.1	1.07	4100	0.951	68.7	1.47	5980	1.29
47.5	1.08	4130	0.959	69.3	1.48	6020	1.3
48	1.09	4170	0.967	69.9	1.49	6080	1.31
48.4	1.1	4210	0.974	70.4	1.5	6120	1.32
48.9	1.11	4250	0.983	71	1.51	6170	1.32
49.3	1.12	4290	0.99	71.5	1.52	6220	1.33
49.8	1.13	4330	0.999	72.1	1.53	6270	1.34
50.2	1.14	4370	1.01	72.7	1.54	6320	1.35

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73.3	1.55	6370	1.36
73.8	1.56	6420	1.36
74.4	1.57	6470	1.37
75	1.58	6520	1.38
75.6	1.58	6570	1.39
76.2	1.59	6630	1.4
76.8	1.6	6680	1.4
77.3	1.61	6730	1.41
77.9	1.62	6780	1.42
78.5	1.63	6830	1.43
79.1	1.64	6880	1.43
79.7	1.65	6930	1.44
80.3	1.66	6990	1.45
80.9	1.67	7040	1.46
81.5	1.68	7090	1.47
82.1	1.69	7140	1.47
82.7	1.7	7190	1.48
83.3	1.71	7250	1.49
83.9	1.72	7300	1.5
84.5	1.72	7350	1.51
85.1	1.73	7400	1.51
85.7	1.74	7450	1.52
86.3	1.75	7510	1.53
86.9	1.76	7560	1.54
87.6	1.77	7610	1.55
88.2	1.78	7670	1.55
88.8	1.79	7720	1.56
89.3	1.8	7770	1.57
89.9	1.81	7820	1.58
90.6	1.82	7880	1.59
91.2	1.83	7930	1.59
91.8	1.84	7980	1.6
92.4	1.85	8040	1.61
93	1.86	8090	1.62
93.6	1.86	8140	1.63
94.2	1.87	8190	1.63
94.8	1.88	8250	1.64
95.5	1.89	8300	1.65
96.1	1.9	8350	1.66
96.7	1.91	8410	1.66
97.3	1.92	8460	1.67
97.9	1.93	8510	1.68
98.5	1.94	8570	1.69
99.1	1.95	8620	1.7
99.7	1.96	8670	1.7
100	1.97	8730	1.71
101	1.98	8780	1.72
102	1.99	8830	1.73
102	2	8890	1.74
103	2	8940	1.74
103	2.01	8990	1.75
104	2.02	9050	1.76
105	2.03	9100	1.77
105	2.04	9150	1.78
106	2.05	9200	1.78
106	2.06	9260	1.79
107	2.07	9310	1.8
108	2.08	9360	1.81
108	2.09	9420	1.82
109	2.1	9470	1.82
109	2.11	9520	1.83
110	2.12	9570	1.84
111	2.13	9630	1.85
111	2.14	9680	1.86
112	2.14	9730	1.86
112	2.15	9780	1.87
113	2.16	9840	1.88
114	2.17	9890	1.89
114	2.18	9930	1.89
115	2.19	9980	1.9
115	2.2	10000	1.91
116	2.21	10100	1.92
117	2.22	10100	1.93
117	2.23	10200	1.93
118	2.24	10200	1.94
118	2.25	10300	1.95
119	2.26	10300	1.96
119	2.27	10400	1.97
8.09	2.29	703	1.98

Tensile Test of MMC (Al-3.5%RHA-3.5%GSA)

Stress (MPa)	Strain (%)	Force (N)	Position (mm)
0.0403	0.154	3.33	0
0.104	0.157	8.63	0.002
0.497	0.161	41.1	0.006
1.13	0.166	93.8	0.01

1.81	0.171	150	0.014	15	0.37	1240	0.183
2.4	0.176	198	0.018	15.2	0.375	1260	0.187
2.98	0.18	247	0.022	15.4	0.379	1270	0.191
3.52	0.185	291	0.0258	15.6	0.384	1290	0.195
4.01	0.19	331	0.03	15.8	0.389	1310	0.2
4.44	0.194	367	0.0338	16	0.393	1330	0.203
4.85	0.199	401	0.0376	16.2	0.398	1340	0.207
5.22	0.203	431	0.0414	16.4	0.403	1360	0.211
5.61	0.208	464	0.0453	16.6	0.407	1370	0.214
6.04	0.213	499	0.0494	16.8	0.412	1390	0.219
6.43	0.218	531	0.054	17	0.416	1410	0.223
6.82	0.222	564	0.0571	17.2	0.421	1420	0.227
7.17	0.227	593	0.0619	17.4	0.425	1440	0.23
7.52	0.232	621	0.0657	17.6	0.43	1450	0.234
7.87	0.236	650	0.0695	17.8	0.434	1470	0.238
8.2	0.24	677	0.073	18	0.439	1490	0.242
8.53	0.245	705	0.077	18.2	0.444	1500	0.246
8.84	0.25	731	0.081	18.4	0.448	1520	0.25
9.14	0.255	756	0.0852	18.6	0.453	1530	0.254
9.42	0.259	779	0.089	18.7	0.458	1550	0.258
9.65	0.264	798	0.093	18.9	0.463	1560	0.262
9.89	0.269	817	0.0971	19.1	0.467	1580	0.266
10.2	0.272	839	0.1	19.3	0.472	1600	0.27
10.4	0.278	861	0.105	19.5	0.477	1610	0.274
10.7	0.282	881	0.108	19.6	0.481	1620	0.277
10.9	0.287	901	0.112	19.8	0.485	1640	0.281
11.2	0.291	923	0.116	20	0.49	1650	0.285
11.4	0.296	943	0.12	20.2	0.494	1670	0.289
11.7	0.301	963	0.124	20.3	0.499	1680	0.293
11.9	0.306	981	0.129	20.5	0.504	1700	0.297
12.1	0.31	1000	0.133	20.7	0.508	1710	0.301
12.4	0.315	1020	0.137	20.9	0.513	1720	0.305
12.6	0.319	1040	0.14	21.1	0.518	1740	0.309
12.8	0.324	1060	0.144	21.2	0.523	1750	0.313
13.1	0.328	1080	0.148	21.4	0.527	1770	0.317
13.3	0.333	1100	0.152	21.6	0.531	1780	0.32
13.5	0.337	1110	0.155	21.7	0.536	1800	0.325
13.7	0.342	1130	0.16	21.9	0.54	1810	0.328
13.9	0.347	1150	0.164	22.1	0.545	1830	0.332
14.2	0.352	1170	0.168	22.3	0.55	1840	0.336
14.4	0.357	1190	0.172	22.4	0.554	1850	0.34
14.6	0.36	1200	0.175	22.6	0.56	1870	0.345
14.8	0.366	1220	0.18	22.8	0.564	1880	0.348

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23	0.569	1900	0.352	30.8	0.767	2550	0.521
23.1	0.574	1910	0.356	31	0.772	2560	0.525
23.3	0.577	1930	0.36	31.2	0.776	2580	0.529
23.5	0.582	1940	0.364	31.4	0.781	2600	0.533
23.7	0.587	1960	0.368	31.6	0.786	2610	0.537
23.8	0.592	1970	0.372	31.8	0.791	2630	0.541
24	0.596	1990	0.376	32	0.795	2640	0.544
24.2	0.601	2000	0.38	32.2	0.8	2660	0.549
24.4	0.605	2010	0.383	32.4	0.805	2680	0.553
24.6	0.61	2030	0.387	32.6	0.809	2690	0.556
24.7	0.615	2040	0.391	32.8	0.814	2710	0.56
24.9	0.62	2060	0.396	33	0.818	2720	0.564
25.1	0.624	2070	0.399	33.1	0.823	2740	0.568
25.3	0.628	2090	0.403	33.3	0.827	2760	0.572
25.5	0.633	2110	0.407	33.5	0.832	2770	0.576
25.7	0.638	2120	0.411	33.7	0.837	2790	0.58
25.8	0.642	2130	0.414	33.9	0.841	2800	0.583
26	0.647	2150	0.419	34.1	0.846	2820	0.588
26.2	0.652	2160	0.423	34.3	0.851	2840	0.592
26.4	0.657	2180	0.427	34.5	0.855	2850	0.595
26.6	0.661	2200	0.43	34.7	0.86	2870	0.599
26.7	0.665	2210	0.434	34.9	0.864	2890	0.604
26.9	0.671	2220	0.439	35.1	0.868	2900	0.607
27.1	0.674	2240	0.442	35.3	0.873	2920	0.611
27.3	0.679	2250	0.446	35.5	0.878	2940	0.615
27.5	0.684	2270	0.45	35.7	0.883	2950	0.62
27.6	0.688	2280	0.454	35.9	0.887	2970	0.623
27.9	0.694	2300	0.459	36.1	0.892	2990	0.627
28	0.698	2320	0.462	36.4	0.897	3000	0.631
28.2	0.703	2330	0.466	36.6	0.902	3020	0.636
28.4	0.708	2350	0.47	36.8	0.906	3040	0.639
28.6	0.712	2360	0.474	37	0.911	3060	0.643
28.8	0.716	2380	0.478	37.2	0.915	3070	0.647
28.9	0.721	2390	0.482	37.4	0.92	3090	0.651
29.1	0.725	2410	0.485	37.6	0.924	3110	0.654
29.3	0.73	2420	0.49	37.8	0.929	3120	0.659
29.5	0.735	2440	0.494	38	0.933	3140	0.662
29.7	0.74	2450	0.498	38.3	0.939	3160	0.667
29.9	0.745	2470	0.502	38.4	0.943	3180	0.67
30.1	0.748	2480	0.505	38.7	0.948	3190	0.674
30.3	0.754	2500	0.51	38.9	0.952	3210	0.678
30.4	0.758	2520	0.513	39.1	0.957	3230	0.682
30.6	0.762	2530	0.517	39.3	0.962	3250	0.686

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39.5	0.966	3270	0.69
39.7	0.97	3280	0.693
40	0.975	3300	0.698
40.2	0.98	3320	0.701
40.4	0.985	3340	0.706
40.6	0.989	3360	0.71
40.8	0.994	3380	0.714
41.1	0.998	3390	0.717
41.3	1	3410	0.721
41.5	1.01	3430	0.725
41.8	1.01	3450	0.73
42	1.02	3470	0.733
42.2	1.02	3490	0.737
42.4	1.03	3510	0.741
42.7	1.03	3530	0.745
42.9	1.04	3540	0.749
43.1	1.04	3560	0.753
43.3	1.04	3580	0.757
43.6	1.05	3600	0.761
43.8	1.05	3620	0.764
44	1.06	3640	0.769
44.3	1.06	3660	0.772
44.5	1.07	3680	0.776
44.7	1.07	3690	0.78
44.9	1.08	3710	0.784
45.2	1.08	3730	0.788
45.4	1.09	3750	0.792
45.6	1.09	3770	0.796
45.9	1.1	3790	0.8
46.1	1.1	3810	0.804
46.3	1.1	3830	0.808
46.6	1.11	3850	0.812
46.8	1.11	3870	0.815
47.1	1.12	3890	0.82
47.3	1.12	3910	0.824
47.5	1.13	3930	0.828
47.8	1.13	3950	0.832
48	1.14	3970	0.835
48.2	1.14	3990	0.839
48.5	1.15	4010	0.844
48.7	1.15	4030	0.847
48.9	1.16	4040	0.851
49.2	1.16	4070	0.856
49.4	1.16	4090	0.859
49.7	1.17	4110	0.863
49.9	1.17	4130	0.867
50.2	1.18	4150	0.871
50.4	1.18	4170	0.875
50.6	1.19	4190	0.879
50.9	1.19	4210	0.883
51.1	1.2	4230	0.886
51.4	1.2	4250	0.89
51.6	1.21	4260	0.894
51.9	1.21	4290	0.898
52.1	1.22	4310	0.902
52.4	1.22	4330	0.906
52.6	1.22	4350	0.91
52.8	1.23	4370	0.914
53.1	1.23	4390	0.918
53.3	1.24	4410	0.921
53.6	1.24	4430	0.926
53.9	1.25	4450	0.93
54.1	1.25	4470	0.933
54.3	1.26	4490	0.937
54.6	1.26	4510	0.941
54.9	1.27	4530	0.945
55.1	1.27	4550	0.949
55.4	1.28	4580	0.953
55.6	1.28	4590	0.957
55.8	1.29	4620	0.961
56.1	1.29	4640	0.965
56.4	1.29	4660	0.969
56.6	1.3	4680	0.973
1.61	1.31	133	0.982

Tensile Test of MMC (Al-5%RHA-5%GSA)

Stress (MPa)	Strain (%)	Force (N)	Position (mm)
0.0223	0.0714	1.67	0
0.043	0.0736	3.21	0.00193
0.836	0.081	62.5	0.00821
1.91	0.0885	143	0.0146
2.82	0.0961	211	0.021
3.65	0.104	272	0.0277
4.46	0.111	333	0.0335

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5.18	0.118	387	0.04	22.1	0.443	1650	0.316
5.85	0.127	437	0.047	22.4	0.45	1680	0.322
6.45	0.134	482	0.0533	22.8	0.458	1700	0.329
7.02	0.141	524	0.059	23.1	0.466	1730	0.335
7.59	0.149	567	0.066	23.5	0.473	1760	0.342
8.13	0.156	607	0.072	23.9	0.481	1780	0.348
8.63	0.164	644	0.0787	24.2	0.489	1810	0.355
9.09	0.171	679	0.085	24.6	0.496	1830	0.361
9.31	0.179	695	0.0917	25	0.504	1860	0.368
9.34	0.187	698	0.098	25.3	0.511	1890	0.374
9.63	0.194	719	0.104	25.7	0.518	1920	0.38
10.1	0.202	751	0.111	26	0.527	1940	0.387
10.5	0.209	785	0.117	26.3	0.533	1970	0.393
11	0.217	818	0.124	26.7	0.541	1990	0.399
11.4	0.224	851	0.13	27	0.549	2020	0.406
11.8	0.232	881	0.137	27.4	0.556	2050	0.412
12.2	0.239	912	0.143	27.7	0.564	2070	0.419
12.6	0.247	940	0.149	28.1	0.571	2100	0.425
13	0.254	969	0.155	28.4	0.578	2120	0.431
13.3	0.262	997	0.162	28.7	0.587	2150	0.438
13.7	0.269	1020	0.168	29.1	0.594	2170	0.444
14.1	0.277	1050	0.175	29.4	0.601	2190	0.45
14.4	0.285	1080	0.182	29.7	0.609	2220	0.457
14.8	0.292	1100	0.188	30.1	0.616	2250	0.463
15.1	0.3	1130	0.194	30.4	0.624	2270	0.47
15.5	0.308	1160	0.201	30.7	0.632	2300	0.477
15.8	0.315	1180	0.207	31.1	0.639	2320	0.483
16.2	0.323	1210	0.214	31.4	0.647	2340	0.489
16.6	0.33	1240	0.22	31.7	0.654	2370	0.495
16.9	0.338	1260	0.227	32	0.661	2390	0.502
17.3	0.345	1290	0.233	32.4	0.669	2420	0.508
17.6	0.353	1320	0.24	32.7	0.677	2440	0.515
18	0.36	1350	0.246	33	0.684	2470	0.521
18.4	0.368	1370	0.252	33.4	0.692	2490	0.528
18.7	0.375	1400	0.258	33.7	0.699	2520	0.533
19.1	0.383	1430	0.265	34	0.707	2540	0.54
19.5	0.39	1450	0.271	34.4	0.715	2570	0.547
19.8	0.398	1480	0.278	34.7	0.722	2590	0.553
20.2	0.405	1510	0.284	35	0.729	2620	0.559
20.6	0.413	1540	0.29	35.4	0.737	2640	0.566
21	0.421	1570	0.297	35.7	0.744	2670	0.572
21.4	0.428	1600	0.303	36	0.752	2690	0.579
21.7	0.435	1620	0.309	36.4	0.76	2720	0.585

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36.7	0.767	2740	0.592
37.1	0.776	2770	0.599
37.4	0.783	2800	0.605
37.8	0.789	2820	0.61
38.1	0.797	2850	0.617
38.5	0.805	2870	0.624
38.8	0.813	2900	0.63
39.2	0.819	2930	0.636
39.6	0.828	2960	0.643
39.9	0.835	2980	0.649
40.3	0.843	3010	0.656
40.7	0.85	3040	0.662
41	0.857	3060	0.668
41.4	0.865	3090	0.675
41.7	0.873	3120	0.681
42.1	0.881	3140	0.688
42.5	0.888	3170	0.694
42.8	0.896	3200	0.701
43.2	0.903	3220	0.707
43.5	0.91	3250	0.713
43.9	0.918	3280	0.72
44.2	0.925	3300	0.726
44.6	0.933	3330	0.732
45	0.941	3360	0.739
45.3	0.949	3390	0.746
45.7	0.956	3410	0.752
46.1	0.963	3440	0.758
46.4	0.971	3470	0.765
46.8	0.979	3500	0.772
47.2	0.987	3520	0.778
47.6	0.994	3550	0.784
47.9	1	3580	0.79
48.3	1.01	3610	0.797
48.7	1.02	3640	0.803
49.1	1.02	3670	0.81
49.5	1.03	3700	0.816
49.9	1.04	3730	0.823
50.3	1.05	3760	0.829
50.7	1.05	3790	0.836
51.1	1.06	3820	0.842
51.5	1.07	3850	0.848
51.9	1.08	3880	0.855
52.3	1.08	3910	0.861
52.7	1.09	3940	0.867
53.1	1.1	3970	0.874
53.5	1.11	4000	0.88
53.9	1.11	4030	0.887
54.3	1.12	4060	0.893
54.7	1.13	4090	0.9
55.1	1.14	4120	0.906
55.5	1.14	4150	0.912
55.9	1.15	4180	0.919
56.3	1.16	4210	0.925
56.8	1.17	4240	0.931
57.1	1.17	4270	0.937
57.6	1.18	4300	0.944
58	1.19	4330	0.951
58.4	1.2	4360	0.957
58.8	1.2	4390	0.963
59.2	1.21	4420	0.97
59.6	1.22	4450	0.977
60.1	1.23	4490	0.983
60.5	1.23	4520	0.989
60.9	1.24	4550	0.996
61.3	1.25	4580	1
61.8	1.26	4610	1.01
62.2	1.27	4640	1.01
62.6	1.27	4680	1.02
63.1	1.28	4710	1.03
63.5	1.29	4740	1.03
63.9	1.3	4770	1.04
64.4	1.3	4810	1.05
64.8	1.31	4840	1.05
65.2	1.32	4870	1.06
65.7	1.33	4910	1.07
66.1	1.33	4940	1.07
66.6	1.34	4970	1.08
67	1.35	5000	1.08
67.5	1.36	5040	1.09
67.9	1.36	5070	1.1
68.3	1.37	5100	1.1
68.8	1.38	5140	1.11
69.3	1.39	5170	1.12
69.7	1.39	5210	1.12
70.2	1.4	5240	1.13
70.7	1.41	5280	1.14

71.1	1.42	5310	1.14	89.2	1.69	6660	1.37
71.6	1.42	5350	1.15	89.7	1.7	6700	1.38
72	1.43	5380	1.16	90.2	1.7	6740	1.39
72.5	1.44	5420	1.16	90.8	1.71	6780	1.39
73	1.45	5450	1.17	91.3	1.72	6820	1.4
73.5	1.45	5490	1.18	91.8	1.73	6860	1.41
74	1.46	5520	1.18	92.4	1.73	6900	1.41
74.4	1.47	5560	1.19	92.9	1.74	6940	1.42
74.9	1.48	5600	1.19	93.4	1.75	6980	1.42
75.4	1.48	5630	1.2	94	1.76	7020	1.43
75.9	1.49	5670	1.21	94.5	1.76	7060	1.44
76.4	1.5	5710	1.21	95	1.77	7100	1.44
76.9	1.51	5740	1.22	95.5	1.78	7130	1.45
77.4	1.51	5780	1.23	96.1	1.79	7180	1.46
77.9	1.52	5820	1.23	96.6	1.79	7220	1.46
78.4	1.53	5850	1.24	97.2	1.8	7260	1.47
78.9	1.54	5890	1.25	97.7	1.81	7290	1.48
79.3	1.54	5930	1.25	98.2	1.82	7340	1.48
79.9	1.55	5970	1.26	98.8	1.82	7380	1.49
80.4	1.56	6000	1.27	99.3	1.83	7420	1.5
80.9	1.57	6040	1.27	99.9	1.84	7460	1.5
81.4	1.57	6080	1.28	100	1.85	7500	1.51
81.9	1.58	6120	1.28	101	1.85	7540	1.51
82.4	1.59	6160	1.29	101	1.86	7580	1.52
82.9	1.6	6190	1.3	102	1.87	7620	1.53
83.4	1.6	6230	1.3	103	1.88	7660	1.53
83.9	1.61	6270	1.31	103	1.88	7700	1.54
84.5	1.62	6310	1.32	104	1.89	7740	1.55
85	1.63	6350	1.32	104	1.9	7780	1.55
85.5	1.63	6390	1.33	105	1.91	7820	1.56
86	1.64	6430	1.34	105	1.91	7860	1.57
86.6	1.65	6470	1.34	106	1.92	7900	1.57
87.1	1.66	6500	1.35	106	1.93	7930	1.58
87.6	1.66	6540	1.35	107	1.94	7970	1.59
88.1	1.67	6580	1.36	0.29	1.95	21.7	1.6
88.6	1.68	6620	1.37				

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