A REVIEW ON MACHINABILITY STUDY OF CERAMIC REINFORCED AL ALLOY BASED MMCS

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ABSTRACT

Machinability is the relative susceptibility of a material to the machining process. The ease with which a metal can be machined is one of the basic and major factors affecting a product's utility, quality cost. The usefulness of a means to predict machinability is obvious. It is important to view machining, as well as all manufacturing operations, as a system consisting of the the tool, workpiece and the machine depending on the application, machinability may be seen in terms of surface roughness, tool wear rate, hardness, chip shape and several other benchmarks. Metal matrix composite has already proved to be a better material for marine, automobile etc application. Traditional machining of AMMCs however is difficult due to hard reinforcement in the AMMC material which tends to wrap around the cutting tool-bit leading to tool breakage. In this paper an attempt has been made to consolidate machinability study of ceramic reinforced Al alloy based MMC.

Keywords: Machinability, MMC, Tool Wear, Surface Roughness, Ceramic, Chip Shape.

I. INTRODUCTION

Aluminium metal matrix composites (AMMCs) are making inroads in various engineering applications (aviation, marine, automotive parts as diesel engine pistons, cylinder, and brake components) requiring higher strength and stiffness than those offered by conventional aluminium alloys. Traditional machining of AMMCs however is difficult due to hard reinforcement in the Aluminium metal matrix composite material which tends to wrap around the cutting tool-bit leading to tool breakage. The main advantage of the composites is its high strength, stiffness and low weight. The fibres present in composites share the applied load which prevents the rapid propagation of cracks as in case of metals. This high strength to weight ratio enables the greater usage of composites in space application where being light and strong are given prime importance. MMCs consist of at least two components; one is metal matrix and second is reinforcements. Using aluminium as matrix is advantageous due to their capability to be strengthened by choice, their low density, good corrosion resistance, high thermal and electrical conductivity makes aluminium a sustainable matrix. Using ceramics as matrix phase or reinforcement improves the fracture toughness and hence can be used in extreme environments of high temperature and stress state. Stir Casting is the simplest and most cost effective method of liquid state fabrication. Stir Casting is a liquid state method of composite materials fabrication, in which ceramic particles are mixed with a molten matrix (aluminium) metal by means of mechanical stirring. After the production of Metal Matrix Composites some parameters need to be improved regarding machining termed as machinability such that we can get an improved and MMc having better surface roughness. Machining of the composite produced after stir casting is necessary in order to remove the extra metal and provide it the shape in which it is required.

Matrix materials in Metal Matrix Composites (MMC) are magnesium, aluminium and titanium alloys. Reinforcing materials in MMC are silicon carbide, boron carbide, alumina and graphite in the form of short fibers (whiskers) ,long fibers or particles. In Aluminium Metal Matrix Composites (AMMC), matrix material is aluminium and reinforcement materials are aluminum oxide, boron carbide, silicon carbide, graphite etc. in the form of whiskers ,fibers & particles.This paper discusses the important aspects of machining of ceramic reinforced Al or Al alloy based metal matrix composite.

II. AN EXTENSIVE LITERATURE REVIEW

In year 1927 MMC Materials began as "Mississippi Concrete and Material Company" in Jackson, Mississippi, formed by the company now known as "Dunn Investment Company" located in Birmingham. In 1932 and in 1961 name changed to "Mississippi Materials Company" under President Ellis Hoffpauir. The field of Ai/SiC whisker composites began in the mid-1960s with the realization that whiskers or discontinuous fiber reinforcements can be competitive with continuous fiber reinforced material from the stand point of mechanical properties. Hibbered (1964), in a review presented in the introductory paper at the American Society for Metal Meeting on Fiber composite materials concluded: T h e r e should be little or no solubility or other reaction between the matrix and the fiber, which should wet each other . This condition is satisfied most readily by one special group of composites based on directionally solidified eutectics. The principal advances since 1964 meeting have been largely in control of inter face between reinforcements and matrices that do not meet restriction. In their keynote address at American institute of Mining and Metallurgical Engineers symposium on metal matrix composites, Burte and Lynch (1969) identified filament matrix compatibility as the pacing area for development of the technology of these composites. Although these authors include both physiological as well as mechanical compatibility within this subject, the basic problem was identified as degradation resulting from chemical interaction. Thereafter, the high cost SiC whisker precluded the potential application of these composites to engineering application. Lastly, with the availability of relatively inexpensive SiC produced mainly from rice hull, interest in Al-SiC composite since chemical, physical and mechanical properties were discussed by Divecha A.D.; Fishman S.G; and Karmarker S.D.; in 1981. Thereafter, began study on the machinability of Al/SiC/Grp composites for their potential industrial application. Since then a good number of researches are being made to machine Aluminum metal matrix composite using various machining process in the practical material machining field. Few of the research works are reviewed and reported in the area are described here in after.

N. Muthukrishnan1* and J. Paulo Davim studied on “Cutting force and Surface Roughness in machining of Al alloy Hybrid Composite and Optimized using Response Surface Methodology” and concluded that surface roughness and cutting force are majorly effected by depth of cut and feed rate. Higher percentages of reinforcement leads to consuming higher cutting energy and poor surface finish. The increase in weight of Sic particles and depth of cut increases the both cutting force and surface roughness.

D. Sai Chaitanya Kishorea, K. Prahlada Raob and A. Mahamanic investigated on "Investigation of cutting force, surface roughness and flank wear in turning of In-situ AlTiC metal matrix composite" and concluded the presence of TiC particles after SEM and EDX test were performed. Vickers's micro hardness test concluded that the hardness value was increased by increasing in wt percentage of TiC reinforcement. Cutting force was decreased with the increase in the cutting speed was found out after conducting machinability tests. Surface roughness inversely proportional to cutting force. Flank wear directly proportional to cutting speed because higher cutting speed results to increase in cutting temperature and this softens the tool cutting edge. Cutting force is directly proportional to feed rate and depth of cut. Surface roughness value was increasing by the increase in feed rate and depth of cut.

K. Venkatesan1*, R. Ramanujam1, J.Joel1, P.Jeyapandiarajan1, M.Vignesh studied on "Cutting force and Surface Roughness for machining of Al alloy Hybrid Composite and Optimized" and concluded that the feed rate and depth of cut are the major factors to affect the performance measures such as surface roughness and cutting force. Higher percentages of reinforcement leads to consumption of higher cutting energy and poor surface finish.

Chintada Shobaa, Nallu Ramanaiahb Damera, Nageswara Rao studied on "Optimizing The Machining Parameters for Minimum Surface Roughness In Turning Al/SiC" and concluded that microstructural characterization suggested uniform distribution. The Taguchi technique suggested the effect of machining parameters on the surface quality (Ra) has been evaluated and optimal machining conditions are derived. Optimal parameters for minimal surface roughness obtained for turning the hybrid composite are Spindle speed (N) = 900rpm; Feed (f) =0.22mm/rev; Depth of cut (d) = 0.05mm.

Ahmed A.D. Sarhan, Mohsen Marani Barzani, Saeed Farahany, Singh Ramesh, Ibrahem Maher studied on "Machinability study of Al–Si–Cu cast alloy containing bismuth and antimony using coated carbide insert" and concluded from Sb are more reliable compared to other workpiece. It can be related to massive amount of built of edge on the rake face of tools which leads to an increase in value of surface roughness and cutting force and Bismuth addition improves machinability of Al-Si-Cu cast alloy. This addition is suitable alloying element to add into the aluminum alloys in order to fabricate casting components with good mechanical properties and machinability which are usually used in automotive industry.

Abbas Razavykia , Saeed Farahany , Noordin Mohd Yusof has done Evaluation on "Cutting force and surface roughness in the dry turning of Al–Mg--Si in-situ metal matrix composite inoculated with bismuth" and concluded that all main effects of machining parameters have an effect on surface roughness and cutting force . Predictive models for cutting force and surface roughness are statistically significant as p-value is less than 0.05 at 95% confidence level.

R. Behera,G. Majumdar, Sujit Das,B. Oraon,G. Sutradhar investigated on "The machinability of powder formed silicon carbide particle reinforced aluminium metal matrix composites" and concluded that during dry turning at constant (feed rate, cutting speed, depth of cut) and turning operation, the cutting forces (Ft &Fr) increased with the increase in weight percentage of abrasive reinforcement particles SiC. During machining SiC reinforced Aluminum MMC at constant feed rate and different cutting speed, the cutting forces are increases on increasing the depth of cut. That indicates the power consumption during machining of aluminium alloy MMCs is directly proportional to the depth of cut at the same condition. Surface roughness of SiC material got increased by increasing the weight percentage of SiC. During turning of MMC samples, the surface roughness increases on increasing the depth of cut at constant feed rate and cutting speed. Surface roughness is also affected by cutting speed during dry turning of aluminium MMCs that is on increasing the cutting speed at constant feed rate the surface roughness decreases.

Yusuf Ozcatalbas studied on "Investigation of the machinability behaviour of Al4C3 reinforced Al-based composite produced by mechanical alloying technique" and concluded that machinability of Al- based MMCs Al3C4 brought out some results such as high MA duration resulted in a high volume fraction of Al_2C_4 alloy after sintering. Increase volume fraction of those particles results in increaseing the hardness of MMC but decrease in the transverse rupture strength. This may be probably due to growth and nucleation of micro cracks at the particle/matrix interface during fracturing. During the formation of chip, deformation occurs along the shear plane and stress con- centration occurs around the Al4C3 particles which facilitates the formation of the micro cracks. These micro cracks propagate at particle/matrix interface facilitates the fracturing through the chip cross-section. This effect reduces the chip sticking period, segment thickness, tool/chip contact length and also cutting forces. Micro- structure and the hardness were found to be important factors for surface quality of MMC during machining. High MA duration causes the MMC with homogeneous microstructure and high hardness which reduces the formation of BUE especially at high cutting speeds that improves the quality of surface roughness.

A. Pramanik, L.C. Zhang , J.A. Arsecularatne investigated on "Machining of metal matrix composites and Effect of ceramic particles on residual stress, surface roughness and chip formation" studied the machinability of MMCs and the effect of reinforcement particles on chip formation, machining forces, surface integrity and shear and friction angles. For turning of the MMC and non-reinforced alloy, cutting forces of similar magnitude were noted and they increased with the increase of feed. However, speed did not influence forces significantly for the MMC. On the other hand, forces for the non-reinforced alloy were initially lower than those for the MMC and increased with speed.

Johny James.Sa, Venkatesan.Kb, Kuppan.Pc*, Ramanujam.Rd studied on "Hybrid Aluminium Metal Matrix Composite Reinforced With SiC and TiB2" and concluded that Micro structural analysis shows the presence of SiC and TiB2 and its distribution in the metal matrix. x Increase in weight percentage of reinforcement (SiC10%&TiB25%) leads to cluster formation. Hence the maximum % of TiB2 into the matrix is limited to 2.5% for 10% SiC .It has been concluded from hardness measurement that, addition of reinforcements has effect on hardness value, but addition of TiB2 up to 5% leads to porosity which affects hardness value. From tensile test results it has been observed that addition of reinforcement Sic to base metal added 20% strength to the composite but addition of TiB2 reduction in 50 -60% strength is recorded. It has been analyzed from micro structure study and from tensile specimen after experiment that cluster formation leads to porosity and porosity leads to reduction in strength than base aluminium alloy .It has been proved from wear analysis that TiB2 particles increase the wear resistance behavior of hybrid aluminum metal matrix. Using Taguchi analysis the below optimal machining parameters are tabulated for best surface roughness and its values are cutting speed 120m/min, feed rate 0.3mm/rev, depth of cut 0.5mm and 0% of reinforcement of TiB2. It has been concluded from tool wear analysis that, The high tool wear is caused due to both abrasive and adhesive actions.

Low cutting speed, high depth of cut and increased wt % of TiB2 reinforcement causes as high tool wear. Built-up edge formation affects surface quality.

H. Joardar , N.S. Das , G. Sutradhar , S Singh investigated on "Application of response surface methodology for determining cutting force model in turning of SiC metal matrix composite" and concluded that This paper presents the findings of an experimental investigation of the effect of cutting speed, depth of cut and weight percentage of SiC in the metal matrix on cutting forces (Ft, Fr, Fa) in straight turning of LM6 Al/SiC metal matrix composites and following conclusions are drawn. Sequential approach in face central composite design is beneficial as it saves number of experimentations required. This was observed in force analysis. A functional relationship between the cutting forces and the cutting parameters is established using the principles of response surface methodology. Quadratic model is fitted for tangential force, radial force and axial force.The results of ANOVA and the conducting confirmation experiments have proved that the mathematical models of the cutting forces fit and predict values of the responses which are close to those readings recorded experimentally with a 95% confident interval. The sensitivity analysis revealed that cutting speed is most significant factor influencing the response variables investigated.

Anand Kumar, M.M. Mahapatra, P.K. Jha studied on "Effect of machining parameters on cutting force and surface roughness of in situ Al–4.5%Cu/TiC metal matrix composites" and concluded that Al–4.5%Cu metal matrix alloy reinforced with 5, 7 and 10 wt.% of TiC using in situ method for synthesization of MMCs. The present experimental study was carried out for analyzing the influence of different machining parameters on the machinability characteristics such as cutting forces, surface roughness, BUE and chip formation of in situ Al–4.5%Cu/TiC MMCs during dry turning using uncoated carbide inserts. The following conclusion can be drawn from the investigations:1. With the increase in wt.% of TiC reinforcement, the tensile strength and hardness of Al–4.5%Cu/TiC MMCs increased with reduced ductility. 2. Cutting force increased upto medium cutting speed (80 m/min) then decreased when cutting speed increased from medium to higher (120 m/min). The good quality of surface finish was observed at 120 m/ min cutting speed. 3. The high value of cutting force and surface roughness was observed during dry condition machining at higher feed rate (0.36 mm/rev) and depth of cut (1.0 mm). 4. The formation of BUE was more prominent at lower cutting speed (40 m/min) and continued to decrease with increasing cutting speed. 5. With less than 10% of TiC reinforcements, mostly helical and C-types chips were produced at relatively higher cutting speed. Discontinuous and short length chips were produced with 10% of TiC reinforcements during the machining.

J. Paulo Davim , C.A. Conceicao Antonio, investigated on "Optimization of cutting conditions in machining of aluminum matrix composites using a numerical and experimental model" and concluded that the optimization based on genetic algorithms has proved to be very useful dealing with discrete variables defined on a population of cutting condition values obtained results show that machining (turning and drilling) of composite materials made of metal matrices with PCD tools is perfectly compatible with the cutting conditions the optimal machining parameters (cutting forces, work piece surface finish and tool wear). Finally, it should be referred that the optimization of machining parameters using numerical and experimental models based on genetic algorithms is a matter of scientific interests and large industrial application.

Y. Sahina,*, M. Kokb, H. Celikc studied on "Tool wear and surface roughness of Al2O3 particle-reinforced aluminum alloy composites", and concluded that The results of turning studies on Al2O3 particle-reinforced aluminium alloy composites using TiN (K10) coated tools and TP30 coated tools were presented. The effect of cutting speeds on tool wear and surface roughness was measured, and physical appearance of the chips produced using both cutting tools are observed. The following conclusions have been drawn:. The tool life of the TiN (K10) tool was significantly longer that of the TP30 tool. The tool life decreased with an increase in the cutting speed for both tools. Also the dependency of the tool wear on the cutting speed was smaller when the particle size was smaller. It is found that the major wear form of the tools were the combination of flank wear and rounding of the nose. For these tools, a removal of coated layer from the substrate material and BUE formation were appeared when cutting the compo- sites at lower speed. For the TP30 tools, however, edge chipping and nose rounding was evident due to high temperature and stresses at the cutting edge. 2. The surface roughness increased with increasing volume fraction of particles. The optimum surface roughness in the machining of MMCs was obtained at the cutting speed of 160 m min1 for both types of cutting tools while the maximum surface roughness values appeared in the machining of the 10% Al2O3 particles reinforced composite with particle size of 16 mm. In the machining of the particle-reinforced composites, the surface rough- ness of the TP30 tool was lower than that of the TiN (K10) tool due to not having a chip breakness geometry. 3. Physical appearance of chips produced by the TiN (K10) cutting tools on particle-reinforced composites were discontinuous and smaller sizes because of tool geometry while the chip appearance of the same composites but produced by TP30 cutting tools were continuous type and larger size. The length of the chips were shortened when the volume fraction of particles increased and the cutting speed was only effective for the alloy matrix or lower volume fraction of the composites.

Mohsen Marani Barzani a, Ahmed A.D. Sarhan a,c,⇑, Saeed Farahany b, Singh Ramesh a, Ibrahem Maher a,d investigated on “Investigating the Machinability of Al–Si–Cu cast alloy containing bismuth and antimony using coated carbide insert”And concluded from this study on dry turning of Al–11.3Si–2Cu, Bi- and Sb-containing alloys at three different cutting speeds and feed rates.The change of flake-like eutectic silicon into the refinedlamellar structure increased surface roughness and decreased machinability of Al–12Si–2Cu cast alloy. However, formation of Bi compound which acts as lubricant during turning can be more likely a reason to obtain the best surface roughness and lowest main cutting force value compared to the base and Sb-containing workpieces. Chip formed for Sb-containing workpieces were longerthan other workpieces, it was less breakable and free from the formation of cracks. It can be related to massive amount of BUE on the rake face of tools, lead to an increase in value of cutting force and surface roughness. Bismuth addition improves machinability of Al–12Si–2Cu cast alloy. This addition is suitable alloying element to add into the aluminum alloys in order to fabricate casting components with good mechanical properties and machinability which are usually used in automotive industry.

A. Mannaa,⁎, B. Bhattacharayyab investigated on “A study on machinability of Al/SiC-MMC” and concluded that Based on the performance and test results of the various set of experiments performed for analysing the influence of different machining parameters on the machinability char- acteristics, e.g. cutting forces, tool wears, BUE, surface fin- ish and chip formation during turning of Al/SiC-MMC uti- lizing fixed rhombic tooling, i.e. CCGX-09-T3-04-Al-H10 type insert without use of coolant, the following points can be observed as listed below:(i) The flank wear rate is high at low cutting speed due to the generation of high cutting forces and formation of BUE during machining of Al/SiC-MMC. (ii) Cutting speed zone between 60 and 150m/min is recommended for machining of Al/SiC-MMC, where cut- ting forces are more or less independent of cutting speed. (iii) The generation of BUE increase the actual rake angle when machining of Al/SiC-MMC at low cutting speed and it is found to correlate with the increment of cut- ting forces which may in turn increase the cutting tool wear. (iv) Feed is less sensitive to the flank wear as compared to the cutting speed. High speed, low feed and low depth of cut are recommended for better surface finish.Effective machining of Al/SiC-MMC is a challenge to the manufacturing industries which mainly restrict the wide spread application of this advance metal matrix composite in practice. The fixed rhombic tooling of CCGX-09-T3-04-Al- H10 type insert can be effectively used for proper machining of Al/SiC-MMC.

Prakash Rao C.R.a*, Bhagyashekar M.Sb, Narendraviswanathc studied on "Effect of Machining Parameters on the Surface Roughness while Turning Particulate Composites" and concluded that the hardness of the composite is greater than that of its cast matrix alloy and the hardness of composite increases with increased fly-ash content. The density of the composites found lower than that of the Al6061 matrix material. The increase in percent fly-ash in the matrix Al6061further decreases the density of its composites.While machining Aluminum fly ash composites, as the cutting speed increases the surface roughness decreases. While machining Aluminum fly ash composites as the feed increases surface roughness increases. While machining Aluminum fly ash composites the surface roughness values measured low when aluminum fly ash metal matrix composite containing 10% filler was machined at all machining conditions. The surface roughness values measured on the aluminum fly ash composites containing 15% filler found high, this may be due to the presence of micro pores. The surface roughness values measured on the aluminum fly ash composites when machined using PCD inserts measured low when compared to K10 grade carbide insert under identical conditions.

H. A. Kishawy' , S. Kannan' , M. Balazinski investigated on "Analytical Modeling of Tool Wear Progression During Turning Particulate Reinforced Metal Matrix Composites" and concluded that This paper presents a model for prediction of tool wear progression during turning aluminium based particulate reinforced metal matrix composites. A novel approach is presented for modeling the tool wear that takes into consideration the effect of particle size and volume fraction. The flank wear rate is quantified by considering the tool geometry in 3D turning. In addition, the model was also used to study the effect of tool nose radius on the progress of tool wear. The main wear mechanisms during cutting MMCs are identified as two body and three body abrasion over most investigated cutting conditions, which agrees with the documented observations. The proposed methodology is based on formulating the wear volume models due to two body and three body abrasion in quadrature incorporating the tooVworkpiece material properties, tool geometry and cutting conditions. The comparisons show that the proposed model generally agrees with the measured tool wear data.

T. Sornakumar , A. Senthil Kumar studied on "Machinability of bronze–alumina composite with tungsten carbide cutting tool insert" and concluded that Bronze–alumina composite was developed using stir-casting method. The machining experiments were performed on bronze and bronze–alumina composite using a tungsten carbide tool insert. The flank wear of carbide tool is higher on machining of bronze–alumina composite than on machining bronze. The surface roughness produced on the bronze and the bronze–alumina composite after machining with the carbide tool was compared. Surface roughness produced on the bronze–alumina composite is higher than that on the bronze. The cutting force encountered during machining of bronze and bronze–alumina composite decreases with increasing cutting speed. The bronze–alumina composite underwent higher cutting force than the bronze. In summary, the bronze–alumina composite was developed and its machinability evaluated and it compares well with bronze.

A. Pramanik, L.C. Zhang, J.A. Arsecularatne studied on "Prediction of cutting forces in machining of metal matrix composites" and concluded that In this work, a mechanics model was developed for predicting the forces when machining aluminum alloy based MMCs reinforced with ceramic particles. The resultant cutting force was considered to consist of components due to chip formation, ploughing and, particle fracture and displacement, and the calculations of these force components were based on Merchant's shear plane analysis, slip line field theory and Griffith theory, respectively. The predictions revealed that, the force due to chip formation is much higher than those due to ploughing and particle fracture. A comparison between predicted and experimental force results showed excellent agreement.

III. CONCLUSION

The paper has given an extensive literature survey on machining of ceramic reinforced Aluminum metal matrix composites. Enormous endeavors have been made in the machining of AMMCs. The course of action stays as yet difficult because of the dispersion and orientation of reinforcement in the matrix and non-homogeneous and anisotropic nature of composite in general. By suitably selecting the machining parameters, machining of AMMC can be made efficient.

REFERENCES

[1]. Muthukrishnan, N., & Davim, J. P. (2011). An investigation of the effect of work piece reinforcing percentage on the machinability of Al-SiC metal matrix composites. Journal of Mechanical Engineering Research, 3(1), 15-24.

[2]. Kishore, D. S. C., Rao, K. P., & Mahamani, A. (2014). Investigation of Cutting Force, Surface Roughness and Flank Wear in Turning of In-situ Al6061-TiC Metal Matrix Composite. Procedia Materials Science, 6, 1040-1050.

[3]. Venkatesan, K., Ramanujam, R., Joel, J., Jeyapandiarajan, P., Vignesh, M., Tolia, D. J., & Krishna, R. V. (2014). Study of Cutting force and Surface Roughness in machining of Al alloy Hybrid Composite and Optimized using Response Surface Methodology. Procedia Engineering, 97, 677-686.

[4]. Shoba, C., Ramanaiah, N., & Rao, D. N. (2015). Optimizing The Machining Parameters For Minimum Surface Roughness In Turning Al/6% SiC/6% RHA Hybrid Composites. Procedia Materials Science, 10, 220-229.

[5]. Barzani, M. M., Sarhan, A. A., Farahany, S., Ramesh, S., & Maher, I. (2015). Investigating the Machinability of Al–Si–Cu cast alloy containing bismuth and antimony using coated carbide insert. Measurement, 62, 170-178.

[6]. Razavykia, A., Farahany, S., & Yusof, N. M. (2015). Evaluation of cutting force and surface roughness in the dry turning of Al–Mg 2 Si in-situ metal matrix composite inoculated with bismuth using DOE approach. Measurement, 76, 170-182.

[7]. Das, S., Behera, R., Majumdar, G., Oraon, B., & Sutradhar, G. (2011). An experimental investigation on the machinability of powder formed silicon carbide particle reinforced aluminium metal matrix composites. International Journal of Scientific & Engineering Research, 2(7), 1.

[8]. Ozcatalbas, Y. (2003). Investigation of the machinability behaviour of Al 4 C 3 reinforced Al-based composite produced by mechanical alloying technique. Composites Science and Technology, 63(1), 53-61.

[9]. Pramanik, A., Zhang, L. C., & Arsecularatne, J. A. (2008). Machining of metal matrix composites: effect of ceramic particles on residual stress, surface roughness and chip formation. International Journal of Machine Tools and Manufacture, 48(15), 1613-1625.

[10]. James, S. J., Venkatesan, K., Kuppan, P., & Ramanujam, R. (2014). Hybrid Aluminium Metal Matrix Composite Reinforced with SiC and TiB 2. Procedia Engineering, 97, 1018-1026.

[11]. Joardar, H., Das, N. S., Sutradhar, G., & Singh, S. (2014). Application of response surface methodology for determining cutting force model in turning of LM6/SiC P metal matrix composite. Measurement, 47, 452-464.

[12]. Kumar, A., Mahapatra, M. M., & Jha, P. K. (2014). Effect of machining parameters on cutting force and surface roughness of in situ Al–4.5% Cu/TiC metal matrix composites. Measurement, 48, 325-332.

[13]. Davim, J. P., & Antonio, C. C. (2001). Optimisation of cutting conditions in machining of aluminium matrix composites using a numerical and experimental model. Journal of Materials Processing Technology, 112(1), 78-82.

[14]. Sahin, Y., Kok, M., & Celik, H. (2002). Tool wear and surface roughness of Al 2 O 3 particle-reinforced aluminium alloy composites. Journal of Materials Processing Technology, 128(1), 280-291.

[15]. Barzani, M. M., Sarhan, A. A., Farahany, S., Ramesh, S., & Maher, I. (2015). Investigating the Machinability of Al–Si–Cu cast alloy containing bismuth and antimony using coated carbide insert. Measurement, 62, 170-178.

[16]. Manna, A., & Bhattacharayya, B. (2003). A study on machinability of Al/SiC-MMC. Journal of Materials Processing Technology, 140(1), 711-716.

[17]. Rao, C. P., & Bhagyashekar, M. S. (2014). Effect of machining parameters on the surface roughness while turning particulate composites. Procedia Engineering, 97, 421-431.

[18]. Kishawy, H. A., Kannan, S., & Balazinski, M. (2005). Analytical modeling of tool wear progression during turning particulate reinforced metal matrix composites. CIRP Annals-Manufacturing Technology, 54(1), 55-58.

[19]. Sornakumar, T., & Kumar, A. S. (2008). Machinability of bronze–alumina composite with tungsten carbide cutting tool insert. journal of materials processing technology, 202(1), 402-405.

[20]. Pramanik, A., Zhang, L. C., & Arsecularatne, J. A. (2006). Prediction of cutting forces in machining of metal matrix composites. International Journal of Machine Tools and Manufacture, 46(14), 1795-1803.