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Application Of Nano Fluid And Impact Of Cutting Forces In The Milling Of Aluminium And Aluminium Based Metal Matrix Composites

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Abstract

Milling of aluminium (Al) and aluminium based MMC is well-known key-process for modern machining in the various engineering applications. The analysis of the cutting forces in themilling of Al and its MMC plays an important role in characterizing the cutting operations, surface integrity and tool life depending upon the cutting forces. In this paper, study the milling of Al under different influence factors like milling with new class of lubricant and also cover the part of the effect of the Nanofluid apply through minimum quantity lubrication system (MQL). Furthermore, the physical properties of the Nano fluids show a non-linear relation with the concentration of the percentage of the Nano particle and also impact on the cutting parameters[1]. For additional improvement, application of Nanofluids canreduce the cutting forces in the milling of aluminium [2].Nano fluid MQL effectively eliminates the chips and reduced the build-up edge (BUE) [3].

Keywords: milling of aluminium and aluminium MMC, cutting forces, Nano Fluids (NF)and MQL.

1. Introduction

In the era of machining of aluminium alloy and aluminium based metal matrix composites (AlMMC): cutting forces, surface roughness, cutting temperature, chip evacuation, material removal rate,tool life and machine tool power prediction plays a crucial role having in the application of Automobile, Defence, Medical, electronics and Satellite industry[4],[5]. Use of low specific weight of the material is an effective way to reduce the weight of the work part, aluminium and Al-based MMC amongst one of the classes used under it. The cutting forces during machining of Al and AlMMC are low as compared to another different alloy under the same machining conditions. It nevertheless provides a good indicator [6].

Conventionally there are three theories for the functioning of predicting cutting forces: empirical, analytical and mechanistic[7].The analytical approach is just the way of numerical algorithms for the modelling of the cutting forces. The empirical approach is quite expensive and time-consuming too. For the precision in the machining, the various response components like cutting force components, tool life, tool wear and surface roughness try to build in the empirical approach and the mechanistic model derived the cutting forces in the real sense[6][8].

In mechanical cutting processes, cutting forces are essential for consideration proper cutting of the materials. There are three cutting forces components during milling of the components that are axial, radial and tangential direction and each isperpendicular to oneanother[9]. The magnitude of the cutting forces depends upon the material property and chip section area[10]. The magnitude of the cutting force equals to[11]

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Tangential Cutting force (Ft) = C.T.B

Whereas C = cutting resistance of the material, T=thickness of the chip and B=width of the chip.

The cutting resistance depends upon the thickness and width of the chip, the cutting resistance increases while decreases value of the chip thickness and width merely gives less impact on cutting resistance[12]. The other force components depend upon the tangential component. Radial components (Fr) depends upon the tangential cutting components and having magnitude is = KrFt

For higher yields and income in the manufacturing industry can be obtained by minimize the production cost, efficient uses of resources like cost and energy along with improvising in the functionality[13]. In the path of enhancing the per capitals of the industry, the metal cutting fluids/ Lubricants play a crucial role. The lubricant can reduce the temperature between the surfaces, can wash and remove thegenerated chip, reduce the friction resistance and finally reduces the cutting force which directly increases the life of the tool[14].

Although the importance of cutting fluid in cutting operation is accepted universally, to apply conventional cooling system in cutting operation has become a huge liability. The disposal of such pollutant mixtures, have become hazardous for the country and effect the life of the workers how directly involved in it. In economics term, it has been reported that the cost related to the cutting fluid is 17 percent of the total cost of the production which is very higher than the comparisons with the total cost for tooling is 7.5 percentof the total production cost. According to the Europe automotive industry, the various type of cost for the production of camshafts is illustrates in the figure 1.[15]

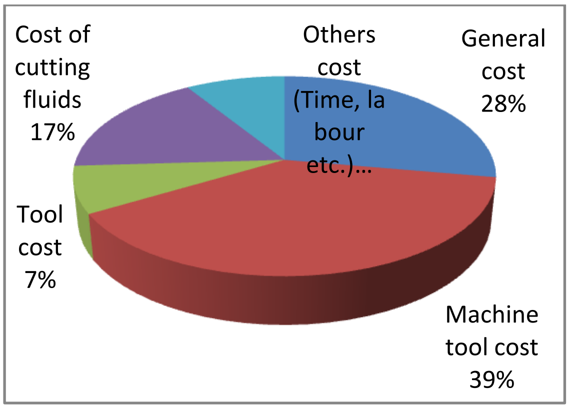

Figure.1 Manufacturing Cost for camshaft Europe by automotive industry

Several technologies were worked on this path for increasing the performance in the manufacturing industry like minimum quantity lubrication (MQL), flooded coolant system, Cryogenics and solid Lubricants etc.[16][17]. In MQL system, a mist of oil and air through thenozzle by keeping control on pressure and air control valve known as MQL, complete system is employed through a compressor as shown inthe figure.1[18][19].

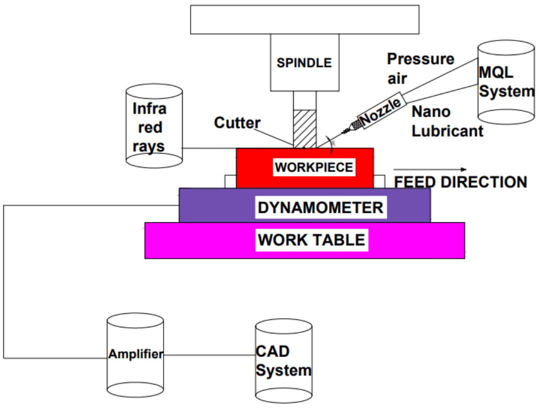

Fig.2. MQL Supply System[14]

2. Metalworking Fluids/Cutting Fluids

Reducing friction occurrences due to theworkpiece and the tool, a cutting fluid was employed[20]. Cutting fluid can be classified according to metal cutting operations (i) for cutting, (ii) for Abrading (iii) for metal forming. For cutting, removal of chips nears the workpiece and the tool in various operations (turning, milling, boring, drilling etc.).Better surface finish, longer tool life, lower energy consumption, cleaning cutting zone and better corrosion protection was the few advantages of the cutting fluids. Another class of the cutting fluid is (i) Straight metalworking (ii) Emulsified (iii) Synthetic cutting fluids(IV) Semisynthetic. Straight and Emulsified and mineral based oil while synthetic are water-based oil and semisynthetic are mixed based oil having different concentration.

Mineral and natural ester-based fluids were best recommended for cutting of the aluminium (Al) and Al-based MMC having physical properties are Density at 15.60C,905Kg/m3,kinematic viscosity 22.3,Flash and pour point- 1820C &-200C.

Another renewed metal cutting oils running nowadays are Nanofluid (NF).Most common nanoparticles are used for prepared NF are alumina oxide, copper oxide, Molybdenum disulphide, silicon dioxide and graphite. NF is prepared by mixing the nanoparticle through ultrasonic vibrator for approximate 24-48 hours to distribute in the base oil[21]. Due to small size, high surface area to volume ratio generates the potential to reduce the friction and increases the heat dissipation capacity[21][14].

A lot of researchers demonstrate that dispersed nanoparticles can easily penetrate into the rubbing surface, withstand high-temperature resistance, non-toxic, cost-effective and coefficient of friction is almost two times higher than the pure oil while at extreme pressure. It facilitates the hydrodynamics interaction because of thermal conductivity is increased linearly with the concentration[1], [22]–[24].

Numbers of studies have been done to visualize the effect of cutting force using nanofluid coolant. In the CNC milling of Al6061-T6 alloy, cutting force is minimized by applying 1 wt% nanoparticle, when it is suspended in mineral oil and applied at high pressure (4 bars) having a 30-degree nozzle orientation angle[16]. Solid lubricants like graphite also play a vital role in reducing cutting forces. In micro-milling of H13 tool steel by graphite nano platelet-based cutting fluid; the tangential force gets reduced [17]. In micro-drilling of Al 6061 workpiece with nanodiamond (30nm diameter) particles and paraffin and vegetable oil base fluids, both torque and thrust force has been reduced. Overall, the reduction was more in case of paraffin oil compared to vegetable-based oil. In volumetric concentration based comparison 1 volume% of nanodiamond was more effective in reducing torque and thrust force when paraffin was used. In case of vegetable-based oil 2 volume% was more effective [23].

3. Tools used in Milling of aluminium and AlMMC

Milling of Aluminium (AL) is not possible if material, coating and tool geometry don't work together. The first and prime motive about the tooling when machining of aluminium are: minimizing the tendency of the Al to stick the cutting tool, chip evacuation from the cutting zone, withstand the cutting forces and cutting temperature without damaging the core strength of the tool[25]. The various tools used in the milling of aluminium and aluminium based MMC are high-speed steel (HSS), monocrystalline diamonds (MCD), diamond (PCD), ploy crystalline boron nitride (PcBN), coated and uncoated tungsten carbide[5]. The percentages of the milling tools areshown in the fig.2. Carbide tools are quite cheaper as compared to the HSS and Diamond cutting tools.

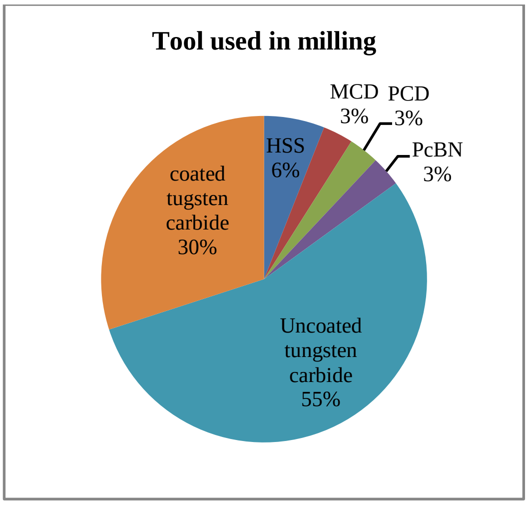

Figure.2 different tools used in Milling

4. Literature review

Several methodologies are adopted for cooling and flushing of chips away from the risk cutting zone. Some of these are elaborated in the coming session.

4.1Kinematics of the chip in milling

The chip section is not constant in the milling operation which causes the main failure of the milling. It varies constantlydepending upon the diameter, anumberof inserts, theangle of the cutter, speed, feed, depth and feed of the cut. The constant variation in the chip section areacaused pulsation of the cutting forces[26]. The chip thickness of the un-deformed cross-section area of the chip is one of the basic elements in the milling operation [27]. The thickness of deformed chip can be measured with callipers gauge and the chip cutting ratio is defined as theratio of un-deformed chip thickness to the deformed chip thickness[28].

As increased the percentage of SiC particle in aluminium based MMC, the chip thickness ratio, chip disposability ratio and shear angle were also increased. Chip thickness ratio, chip disposability ratio and shear angle decreased with the passage of the machining timing [10]. The specific cutting pressure was the function of the chip thickness for slab and face milling and the cutting forces are equal to the multiplied the area of the chip section and a specific cutting pressure [26]. Up-milling is better than the down milling because of lesser cutting pressure during operation and thecutting pressure was determined by dividing the tangential force to the corresponding chip cross-section[26].

4.2 Milling of Aluminium under Nano Fluid (NF)

Sarhan et al. investigated the milling of aluminium (AA6061-T6) by using SiO_2nanoparticle based NF and concluded that reduction in cutting forces, power and specific energy requirement by using NF instead of ordinary mineral oil [14].

Sayuti et. al. performed vertical milling of theaerospace duralumin workpiece and used adifferent concentration of weight %age of carbon onion mixed with alumicut oil. They noticed that minimum cutting forces (CF) and surface roughness when the carbon onion concentration not more than 1.5% by weight and obtained 21.99 and 46.32 by percentage reduction in CF and surface roughness respectively, as compared normal lubrication oil[21].

Rahmati et al. demonstrated the morphology produced by end milling of Al-6061 by using molybdenum disulfide based NF under different concentration 0.2, 0.5 and 1 % by weight through FESEM and XRD, the lowest surface roughness and CF at 0.5% by wt. of the particle in NF [2].

Sayuti et.al. performed the milling of aerospace Al-6061 by using SiO_2 NF, the researcher used the same experiment in the previous case but here change is in new nanofluidand showed that by using 0.2 wt. %age of SiO_2in NF, a marvellous reduction in the cutting temperature and cutting forces [21], [29]. In the present study, three different parameters are taken into consideration nozzle angle, air pressure and nanoparticle concentration in NF and optimize these parameters,intention to reduce the cutting temperature, cutting forces and surface roughness. At 60^0 nozzle angle, 2 bar pressure with 0.2% by wt. of concentration of nanoparticle in NF reduced the cutting forces while at 15^0 nozzle orientation angle, lower particle concentration and high air stream pressure minimize the cutting temperature and at 30^0 nozzle angle, higher particle concentration and at 2 bar pressure lowest surface roughness was attained [2], [21], [30].

5. Difficulties of Applying Nanofluids (NF) in Machining

Nanofluids are anew class of the fluids by dispersed Nanometer size structure (nanoparticle, nanofiber, nanowires, nanotubes, nanosheet, droplets and platelets etc.) in the base fluids[31]. There are two methods for prepared itis (i) one phase (solid phase) and (ii) two-phase method (liquid phase)[31], [32].NF founds the enhanced the thermophysical properties like viscosity, convective heat transfer coefficient, thermal conductivity and diffusivity[33], [34].Difficulty in NF is for preparing and applying NF like stable and uniform suspensionin NF, low clustering of the particles and having asmall life as compared to the convention oils. Moreover preventing from cluster and expensiveness are two other difficulties of apply NF, so that should be taken into consideration [35].

6. Conclusion

From the study the following points of conclusions are:

i. To apply Nanofluid during machining of aluminium, nevertheless to reducing the cutting forces.
ii. With keeping the lower depth of cut, chips are easy to remove from the cutting zone and hence reducing the tool wear and cutting forces as well.
iii. To apply Nanofluids, no doubt it increases the thermophysical properties but compromises with the cost and short lifespan of the nano lubricant.
iv. Better to recommend an appropriatepercentage of reinforcement in MMC, with increases the percentage also increases the chip thickness ratio, chip disposability ratio and shear angle.

Nano Fluid was applied to the machining of the aluminium alloys and observed the positive effects in terms of reducing cutting forces, cutting temperature, surface roughness, evacuating the chip etc. But Nanofluid applies on machining of the aluminium based MMC was still the part of under study.

References

[1] P. Keblinski, R. Phillpot, S. Choi, and A. Eastman, “Mechanisms of heat ¯ow in suspensions of nano-sized particles (nano¯uids),” vol. 45, pp. 855–863, 2002.

[2] B. Rahmati, A. A. D. Sarhan, and M. Sayuti, “Investigating the optimum molybdenum disulfide (MoS2) nanolubrication parameters in CNC milling of AL6061-T6 alloy,” *Int. J. Adv. Manuf. Technol.*, vol. 70, no. 5–8, pp. 1143–1155, 2014.

[3] J. S. Nam, P. H. Lee, and S. W. Lee, “Experimental characterization of micro-drilling process using nanofluid minimum quantity lubrication,” *Int. J. Mach. Tools Manuf.*, vol. 51, no. 7–8, pp. 649–652, 2011.

[4] S. Gopalakannan and T. Senthilvelan,

"Application of response surface method on machining of Al-SiC nano-composites," *Meas. J. Int. Meas. Confed.*, vol. 46, no. 8, pp. 2705–2715, 2013.

[5] S. Durante, G. Rutelli, and F. Rabezzana, "Aluminum-based MMC machining with diamond-coated cutting tools," *Surf. Coatings Technol.*, vol. 94–95, pp. 632–640, 1997.

[6] I. Zaghbani and V. Songmene, "A force-temperature model including a constitutive law for Dry High Speed Milling of aluminium alloys," *J. Mater. Process. Technol.*, vol. 209, no. 5, pp. 2532–2544, 2009.

[7] N. Banerjee and A. Sharma, "Identification of a friction model for minimum quantity lubrication machining," *J. Clean. Prod.*, vol. 83, pp. 437–443, 2014.

[8] X. Li and W. K. H. Seah, "Tool wear acceleration in relation to workpiece reinforcement percentage in cutting of metal matrix composites," *Wear*, vol. 247, no. 2, pp. 161–171, 2001.

[9] V. Gyliene and V. Eidukynas, "The Numerical Analysis of Cutting Forces in High Feed Face Milling, Assuming the Milling Tool Geometry," *Procedia CIRP*, vol. 46, pp. 436–439, 2016.

[10] R. Karthikeyan, G. Ganesan, R. S. Nagarazan, and B. C. Pai, "A CRITICAL STUDY ON MACHINING OF Al/SiC COMPOSITES," *Mater. Manuf. Process.*, vol. 16, no. 1, pp. 47–60, 2001.

[11] A. C. Okafor and A. A. Sultan, "Development of a mechanistic cutting force model for wavy-edge bull-nose helical end-milling of inconel 718 under emulsion cooling strategy," *Appl. Math. Model.*, vol. 40, no. 4, pp. 2637–2660, 2016.

[12] C. Adolfsson and J. E. Ståhl, "Cutting force model for multi-toothed cutting processes and force measuring equipment for face milling," *Int. J. Mach. Tools Manuf.*, vol. 35, no. 12, pp. 1715–1728, 1995.

[13] S. Kannan and H. A. Kishawy, "Surface characteristics of machined aluminium metal matrix composites," *Int. J. Mach. Tools Manuf.*, vol. 46, no. 15, pp. 2017–2025, 2006.

[14] A. A. D. Sarhan, M. Sayuti, and M. Hamdi, "Reduction of power and lubricant oil consumption in milling process using a new SiO2 nanolubrication system," *Int. J. Adv. Manuf. Technol.*, vol. 63, no. 5–8, pp. 505–512, 2012.

[15] E. Brinksmeier, A. Walter, R. Jansscn, and P. Diersen, "Aspects of cooling lubrication reduction in machining advanced materials," *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.*, vol. 213, no. 8, pp. 769–778, 1999.

[16] S. W. Kim, D. W. Lee, M. C. Kang, and J. S. Kim, "Evaluation of machinability by cutting environments in high-speed milling of difficult-to-cut materials," *J. Mater. Process. Technol.*, vol. 111, no. 1–3, pp. 256–260, 2001.

[17] O. S. Joshua, M. O. David, and I. O. Sikiru, "Experimental Investigation of Cutting Parameters on Surface Roughness Prediction during End Milling of Aluminium 6061 under MQL (Minimum Quantity Lubrication)," *J. Mech. Eng. Autom.*, vol. 5, no. 1, pp. 1–13, 2015.

[18] N. Boubekri and V. Shaikh, "Minimum Quantity Lubrication (MQL) in Machining : Benefits and Drawbacks," *J. Ind. Intell. Inf.*, vol. 3, no. 3, pp. 205–209, 2015.

[19] A. Duchosal, R. Serra, R. Leroy, and C. Louste, "Numerical steady state prediction of spitting effect for different internal canalization geometries used in MQL machining strategy," *J. Manuf. Process.*, vol. 20, pp. 149–161, 2015.

[20] R. D. Joel, K. L. Dev, A. Raj, and B. A. Beatrice, "Optimization of Cutting Parameters and Fluid Application Parameters during Turning of OHNS Steel," *Procedia Eng.*, vol. 97, pp. 172–177, 2014.

[21] M. Sayuti, A. A. D. Sarhan, T. Tanaka, M. Hamdi, and Y. Saito, "Cutting force reduction and surface quality improvement in machining of aerospace duralumin AL-2017-T4 using carbon onion nanolubrication system," *Int. J. Adv. Manuf. Technol.*, vol. 65, no. 9–12, pp. 1493–1500, 2013.

[22] W. Wang, K. Liu, and M. Jiao, "Thermal and non-Newtonian analysis on mixed liquid-solid lubrication," *Tribol. Int.*, vol. 40, no. 7, pp. 1067–1074, 2007.

[23] J. H. Lee *et al.*, "Effective viscosities and thermal conductivities of aqueous nanofluids containing low volume concentrations of Al2O3nanoparticles," *Int. J. Heat Mass Transf.*, vol. 51, no. 11–12, pp. 2651–2656, 2008.

[24] S. M. S. Murshed, K. C. Leong, and C. Yang, "A combined model for the effective thermal conductivity of nanofluids," *Appl. Therm. Eng.*, vol. 29, no. 11–12, pp. 2477–2483, 2009.

[25] V. P. Astakhov and X. Xiao, "A methodology for practical cutting force evaluation based on the energy spent in the cutting system," *Mach. Sci. Technol.*, vol. 12, no. 3, pp. 325–347, 2008.

[26] F. Koenigsberger, "An i n v e s t i g a t i o n into t h e c u t t i n g f o r c e pulsations d u r i n g m i l l i n g operations," vol. I, no. 3, pp. 15–33, 1961.

[27] M. E. Martellotti, "An analysis of the milling process," *Trans. ASME*, vol. 82, no. 63, pp. 677–700, 1941.

[28] Y. Ozcatalbas, "Chip and built-up edge formation in the machining of in situ Al4C3-Al composite," *Mater. Des.*, vol. 24, no. 3, pp. 215–221, 2003.

[29] M. Sayuti, O. M. Erh, A. A. D. Sarhan, and M. Hamdi, "Investigation on the morphology of the machined surface in end milling of aerospace AL6061-T6 for novel uses of SiO2 nanolubrication system," *J. Clean. Prod.*, vol. 66, pp. 655–663, 2014.

[30] M. Sayuti, A. A. D. Sarhan, and M. Hamdi, "An investigation of optimum SiO2 nanolubrication parameters in end milling of aerospace Al6061-T6 alloy," *Int. J. Adv. Manuf. Technol.*, vol. 67, no. 1–4, pp. 833–849, 2013.

[31] A. K. Sharma, A. K. Tiwari, and A. R. Dixit, "Progress of Nanofluid Application in Machining: A Review," *Mater. Manuf. Process.*, vol. 30, no. 7, pp. 813–828, 2015.

[32] S. J. Doshi, P. K. Jain, and N. K. Mehta, "Prospective applications of nano fluid during machining process," *Int. J. Mach. Mach. Mater.*, vol. 14, no. 3, p. 257, 2013.

[33] Y. Zhang *et al.*, *Experimental evaluation of cooling performance by friction coefficient and specific friction energy in nanofluid minimum quantity lubrication grinding with different types of vegetable oil*, vol. 139. Elsevier Ltd, 2016.

[34] M. Rifat, H. Rahman, and D. Das, "A Review on Application of Nanofluid MQL in Machining," *AIP Conf. Proc. 1919,* vol. 6, no. 9, pp. 139–144, 2017.

[35] S. Khandekar, M. R. Sankar, V. Agnihotri, and J. Ramkumar, "Nano-cutting fluid for enhancement of metal cutting performance," *Mater. Manuf. Process.*, vol. 27, no. 9, pp. 963–967, 2012.