Proceedings of the International Conference on Applied Mechanical Engineering Research(IC-AMER2019)
NIT Warangal, India – May 02-05, 2019
Paper No. XXX (The number assigned when the paper is accepted)

Effect of Graphene Nanofluid on machining Inconel 718

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Abstract: Cutting fluids have superior convective and conductive heat transfer coefficient, good lubrication and better chip removal rate from cutting zone. But when applied in large quantities, as flood machining, its treatment and disposal increases economic burden on industries. Application of just sufficient quantity of cutting fluid exactly at the cutting zone as Minimum Quantity Lubrication (MQL) is found to be an alternative approach to flood machining. But it requires use of cutting fluids with enhanced properties. Researchers suggested that nanofluid is the latest concept to achieve high performance of cooling and lubrication effect in machining. This project mainly focuses on performance evaluationof Minimum Quantity Lubrication (MQL) application of graphene nano cutting fluid while turning Inconel 718 alloy. Different weight proportions (0.1wt%,0.3wt%,0.5wt%) of graphene is mixed with soluble oil using TX 100as surfactant. Machining performance is evaluated by measuring cutting forces, cutting temperature, surface roughness and tool wear. Performance is compared with dry machining and MQL application of cutting fluid without graphene.

Keywords: Minimum Quantity Lubrication, Tool wear, Graphene, Inconel 718.

1. Introduction

Nickel based super alloys (Inconel 718) are widely used in the aerospace industry due to its unique oxidation resistance, corrosion resistance and retention of mechanical strength even at very high temperatures. But their lower thermal conductivity, work hardenability, hardness, and affinity for tool material, causes the cutting tools to wear very rapidly. Cutting fluid is widely used for cooling and lubrication, disposal of chip, improvement of machining accuracy and surface finish and extension of tool life. But their treatment and disposal are of economic concern to industries. Also, cutting fluids impose serious respiratory related problems in employees. In order to have sustainable environment, application of cutting fluid as Minimum quantity lubrication is an alternative approach, where a small amount of cutting fluid is sprayed to the tool tip with compressed air. Many researchers worked on machining of Inconel 718 using different conditions: Dry machining, flood machining, MQL application, cryogenic machining, use of coated and self-lubricating tools. Umbrello [1] addressed the effects of cutting speed and feed on surface integrity of Inconel 718 alloy using coated tool and found that cutting conditions have significant effect on surface integrity of the product. At high speed and feed, surface hardness as well as depth of hardness was found to be more. As per Thakur et al. [2] machinability problems of Inconel 718 could be economically tackled by machining with tungsten carbide tool at medium cutting speed and feed and low d.o.c instead of costly PCD and CBN tools. Devillez et al. [3] performed dry and wet machining using coated carbide tool to determine the effect on surface integrity. Cutting forces and surface roughness was found to be low while residual tensile stress was found to be high with dry machining compared to wet machining. Obikawa et al. [4] used a specially designed nozzle for concentrating small amounts of oil mist onto the cutting interface. Performance of concentrated spray of oil mist in micro-liter lubrication machining of Inconel 718 was investigated and compared with that of ordinary spraying. Concentrated spraying of oil mist was found to be effective in increasing tool life in the micro-liter lubrication range.Kaynak [5] performed machining on Inconel 718 work piece using dry, MQL, and cryogenic cooling conditions. Cutting forces, flank, notch and crater wear, temperatures, surface roughness and chip morphology were studied. MQL application showed least cutting forces at low speed while cryogenic machining at high speeds. Numbers of nozzles were found to be significant in cryogenic machining. Paturi [6] studied the effect of solid lubricant assisted minimum quantity lubrication (MQL) turning on finish quality of machined surface. Tungsten disulphide(WS_2) solid lubricant powder was dispersed (0.5% wt.) in emulsifier oil based cutting fluid. Compared to the MQL machining, WS_2 solid lubricant assisted MQL machining gave good improvement on finish quality of work material by 35%. Kamata [7] performed dry machining on Inconel 718 using three coated carbide tools: TiCN/Al_2O_3/TiN (CVD), TiN/AlN (PVD) and TiAlN (PVD) at cutting speeds 1m/s and 1.5 m/s. Biodegradable synthetic ester was used for MQL machining. With increase in cutting speed to 1.5 m/s the tool life was found to drastically decrease. The longest life was attained in MQL machining by using TiCN/Al_2O_3/TiN as cutting tool. Shokrani et al. [8] investigated the performance of cryogenic cooling, Minimum quantity lubricant (MQL) machining and CryoMQL, to improve machinability and surface integrity of difficult to machine materials. Rapeseed oil was used at 60ml/hr. Cryogenic cooling resulted in increased hardness of material and hence rapid tool wear while CryoMQL doubled tool life by reducing tool wear and improved surface roughness by 18%. Sidik et al. [9] reviewed applications of nanofluids in MQL machining. Several aspects like preparation methods of nano fluids and enhancement in their thermal conductivity were discussed. Application of Al2O3,CNT,MoS2 and diamond nanoparticles in MQL machining was discussed in detail and they were found to reduce the coefficient of friction and wear effect. Stability and cost of production were identified as challenges in application of nanofluid to machining. Saravanakumar et al. **[10]**used silver particles as nano particles which are synthesized, characterized, dispersed in cutting fluid and experimented in a turning operation. Addition of silver nanoparticles in cutting fluid showed significant reduction in tool tip temperature, cutting force and surface roughness of the work piece**.** Najiha et al. [11]used water-based TiO_2 nano fluids in MQL machining (milling) on aluminium alloy, AA6061-T6 at three different speeds : 5200, 5400 and 5600 rpm. 0.65 ml/min and 1.0 ml/min are used as flow rates for MQL machining. TiO_2 nanoparticles were used in 0.5, 2.5 and 4.5%. Lesser adhesion and edge integrity was found to take place a higher MQL flow rate. 2.5% was found to be best with respect to tool damage. Behera[12**]** prepared nano fluids by mixing different concentrations of alumina (Al_2O_3) and colloidal solution of silver (Ag) nanoparticles with water. Performed MQL machining and dry machining on nickel based alloy. Cutting forces, tool wear, chip thickness, surface tension & contact angle cutting fluid are measured. Al_2O_3 nanofluid at 125ml/hr showed least cutting force due to formation of tribo film which reduced the sliding friction. Chip thicknesses, coefficient of friction are found to be less in MQL machining. Revuru et al. [13] presented a detailed review on different lubricating conditions such as dry machining, cryogenic machining, flood machining and MQL machining with nanofluids in machining titanium alloys. MQL was found to perform better than dry and flood machining, as it has capability to enter the tool chip interface via capillary action providing lubrication. Cryogenic cooling could provide lesser tool wear, forces and better finish initially but extreme cooling led to increased hardness of machined surface leading to further increase in cutting forces and surface roughness.

Graphene has high thermal conductivity, lubricating property, high specific surface area and reduced particle clogging [14] compared to other nanoparticles. In the present work, graphene based cutting fluids of different concentrations are applied as MQL in machining Inconel718 and their performance is compared with dry machining and MQL application of conventional cutting fluid.

2. Experimentation

Graphene based nanofluids are prepared in different concentrations: 0.1wt%, 0.3wt% and 0.5wt% by dispersing graphene in conventional soluble oil (1:20). Surfactant used is Triton X 100 in same concentration as graphene to maintain stable dispersion. Graphene along with Triton X100 is first added to water and ultra-sonicated for an hour to get stable dispersion. Concentrated cutting oil is added to it in ratio 1:20 to form graphene dispersed cutting fluid. Cutting experiments are conducted using CDL6236 lathe machine with coated carbide tool CNMG120408MS KC5010 on

Inconel 718 rod of 150 mm length and 30 mm diameter at constant cutting conditions: cutting velocity 74m/min, depth of cut 0.5 mm and feed of 0.14mm/rev. Machining is performed at different machining conditions such as dry machining, MQL machining using soluble oil, MQL machining using 0.1wt%, 0.3wt% and 0.5wt% graphene dispersed cutting fluid. Cutting forces are measured using Kistler dynamometer, cutting temperatures using Infra-Red (IR) thermometer Extech42570 and IR Camera Optris PI160. Tool wear is measured using Metzer Toolmaker's Microscope with image acquisition. Surface roughness is measured using Surftest 301J. Emissivity value of Inconel 718 is taken as 0.33. Experimental setup is shown in Fig1.

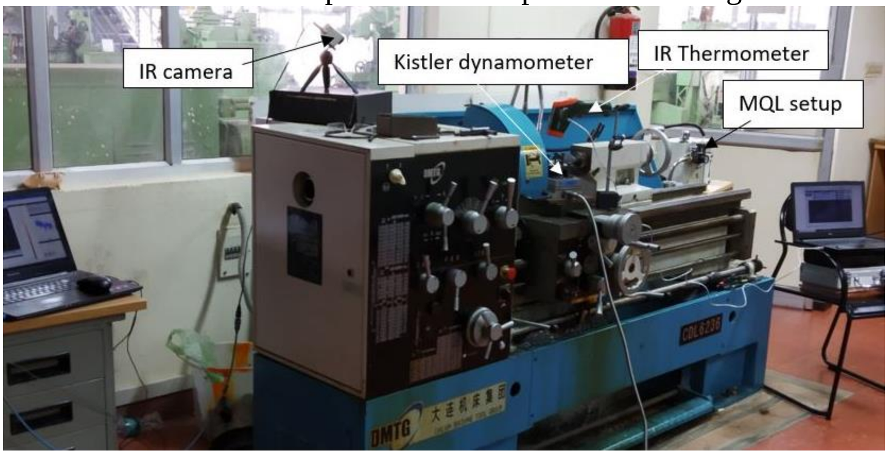

Fig 1: Experimental setup

3. Results and Discussions

3.1Cutting forces

Mean values of the feed force (F_y), radial force (F_x) and tangential cutting force (F_z) obtained from Kistler dynamometer are presented in Fig 2 and are used for further analysis. Resultant forces and frictional forces in machining are calculated and are presented in Fig 3.

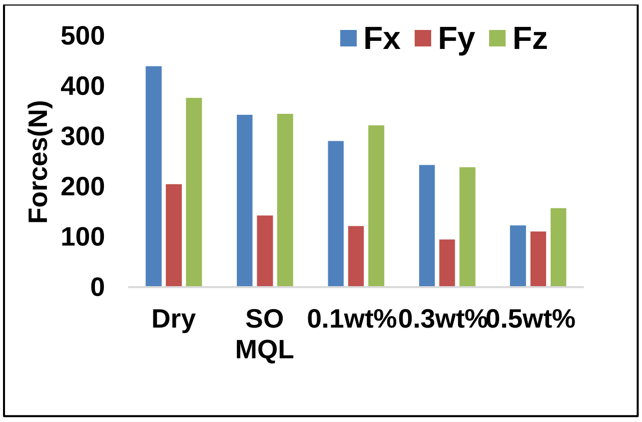

Fig 2: Variation in radial force(F_x), feed force(F_y) and tangential cutting force (F_z)

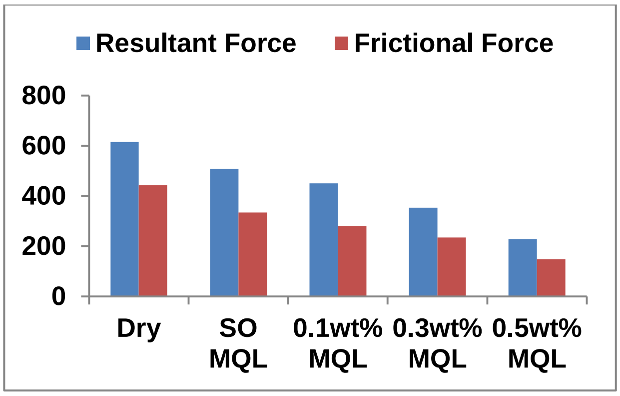

Fig 3: Variation of resultant force and frictional force

Among all the components of forces, feed force is found to be minimum.MQL machining showed less force when compared to dry machining. Almost all components of forces are found to decrease with increase in concentration of graphene. Resultant and frictional forces are also found to decrease with increase in concentration of graphene. Cutting fluid with 0.5wt % showed least cutting forces. The protective layer of suspended nanoparticles formed, helped in reducing the cutting forces. Due to increase in the volume of graphene in nano cutting fluid of 0.5wt% graphene nanofluid, the lubrication property became more which led the cutting forces to decrease.

3.2. Cutting Temperature

Fig. 4 shows the variation of maximum and average cutting temperatures measured using both IR Thermometer and IR Camera. Variation in temperature was found in range 10^0-50^0 with both devices. As IR Camera could measure temperature over an area, compared to IR thermometer which measures at a single point, IR camera showed higher temperatures. Fig 5 shows the variation of average cutting temperature measured using IR Camera for all cases. Dry machining showed maximum temperature.MQL machining could reduce the temperature by providing cooling. Temperature was found to further decrease with addition of graphene in cutting fluid. There may be enhanced thermal conductivity of the cutting fluid due to addition of graphene. 0.3wt% as well as 0.5wt% graphene showed almost similar cutting temperature.

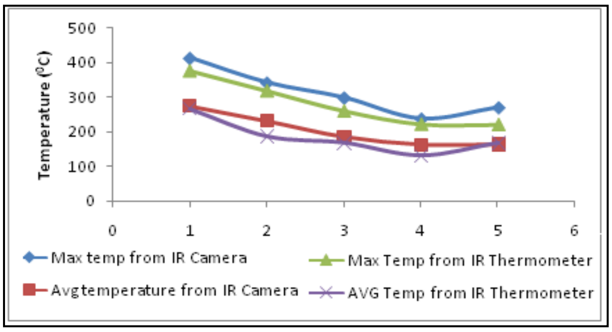

Fig 4: Variation in temperature for different machining operations

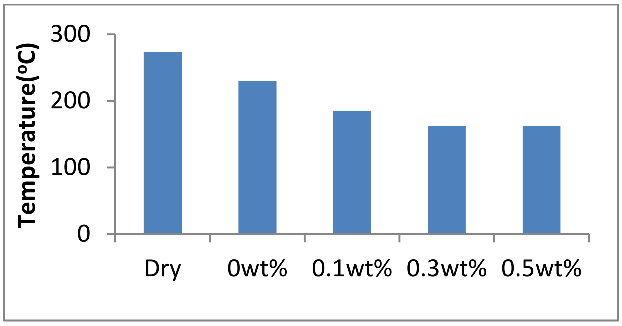

Fig 5: Variation in cutting temperature for different cases

3.3. Surface roughness

Variation in all the measured values of surface roughness $(R_a, R_q, R_z)$for all machining operations are shown in Fig 6. Surface roughness values are less for MQL machining process when compared with dry machining. Among the different weight proportions of graphene nano fluids, 0.5wt% gave less surface roughness values. Increase in volume of graphene in nano fluid may have enhanced the lubrication property resulting in smooth machined surface.

3.4. Tool wear

One of the most important parameter which has direct effect on the final quality of the product is tool wear. The performance of the tool and tool life is influenced by tool wear. Variation in the tool flank wear is shown in Fig 7. Tool wear was minimum with MQL machining when compared with dry machining process. MQL machining with 0.3 wt% of graphene showed least tool wear.

4. Conclusions

1. The cutting forces decreased when the concentration of graphene increased. MQL machining with 0.5wt% of graphene showed least force with 74% reduction when compared to dry machining.
2. Cutting fluid with 0.3wt% as well as 0.5wt% showed almost same cutting temperature.

3. 0.5wt% graphene nanofluid gave least surface roughness.
4. Tool wear was found to be minimum with 0.3wt% graphene nanofluid.

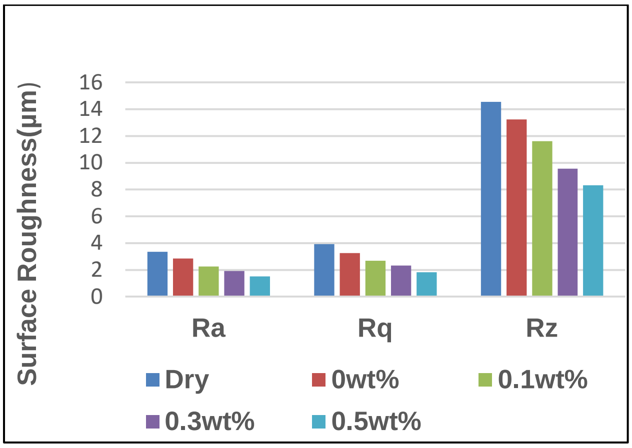

Fig 6: Variation in surface roughness

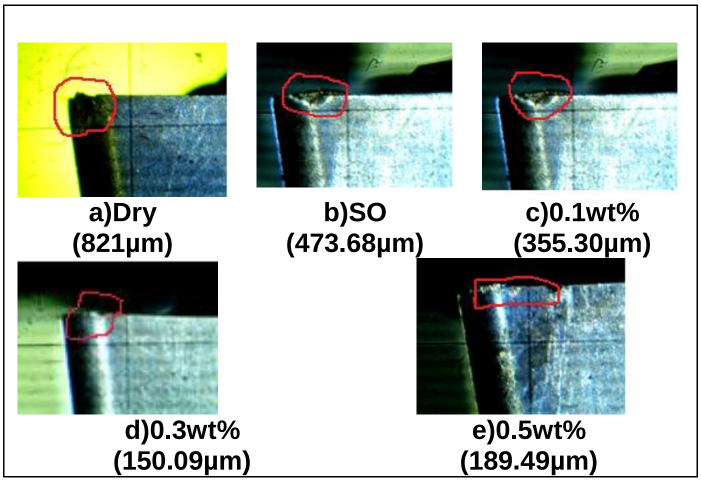

Fig 7: Variation of tool wear

5. Acknowlegment:

This work was supported by Science & Engineering Research Board F NO. ECR/2017/001172 as research project. The authors are grateful to Science & Engineering Research Board for providing financial support.

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