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Experimental Investigations on Grindiability of Nickel Based Alloy Nimonic-90

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Abstract

There has been an increasing demand for Nickel based alloys especially Nimonic-90 in various fields viz. aerospace, power generators, heat exchangers, etc. Nickel based alloys have excellent mechanical properties like high specific strength, high resistance to corrosion, high resistance to oxidation, and ability to withstand high temperature which has facilitated their extensive use in various applications. However, this type of alloy is a very difficult to machine material due to its several inherent properties like low thermal conductivity, high chemical reactivity, and high hardness. In the present study, an attempt has been made to investigate the effect of grinding parameters (grinding speed, table feed and depth of cut) on the response parameters (grinding force and surface roughness) in grinding of Nickel based alloy Nimonic-90 under different grinding environments. To fulfill the sustainability criteria the experiments have been conducted under dry and minimum quantity lubrication (MQL) environments. Surface integrity of the ground surface has been studied using characterization facilities such as surface profilometer, Stereo Zoom Microscope (SZM) and Scanning Electron Microscopy (SEM). Minimum Quantity Lubrication (MQL) has been found to be the most effective in terms of reduction in grinding forces and enhancement of surface finish of the ground surface.

Keywords: Nimonic-90, Grinding Force, Surface Roughness, MQL.

1. INTRODUCTION

Nickel (Ni) based alloys are regarded as the most influential materials in the aerospace industry. Ni-based alloys account for almost 50 weight percent of materials in gas turbine compartment of aeroplanes [1]. Due to this reason, Ni-based alloys are also known as aerospace alloys. Additionally, these alloys are extensively used in other sectors such as nuclear power plants, petrochemical industry, paper and pulp industry and food processing plants. The high strength to weight ratio is one of the reasons for the popularity of these alloys amongst the various sectors. Also, the Ni-based alloys possess high corrosion resistance, high hot hardness and high wear resistance [2,3]. Despite many favorable properties, Nickel alloys are classified as difficult-to-machine materials due to the following reasons [4]: Ability to retain high strength at elevated temperature, High strain rate sensitivity which leads to work hardening during machining, High cutting temperature due to the lower thermal conductivity (Ni alloys ∼11W/m °C).

Grinding, being a super-finishing operation play a key role in producing high quality finished surfaces of even advanced engineering materials. Grinding is an abrasive machining process in which abrasives are responsible for material removal in the form of tiny chips. These hard abrasives are bonded together with the help of bonding materials and random in shape, size, orientation, and distribution. Hence, these abrasives result in rubbing and ploughing of the work material along with shearing during grinding. Altogether effect of rubbing, ploughing and shearing results into high specific energy requirement in grinding. Additionally, most of the abrasives in action seem to possess a high negative rake angle (around -45° to -60°) which again leads to the high energy consumption during grinding [5]. Subsequently, the high energy consumed while grinding reaches into high heat generation over the contacting surfaces. High heat generation is one of the prime suspects of deteriorating the ground surface quality and fast grinding wheel wear as well. Moreover, in grinding process, heat partition ratio that is the fraction of total heat taken by the workpiece is around 0.7 to 0.8 [6]. The ill effects due to high temperature can be controlled by increasing the heat transfer rate in the grinding zone using a suitable grinding fluid.

Nowadays, mostly grinding operations employ liquids such as coolants to control the surface quality, temperature and to improve the grinding wheel life. Additionally, cutting fluids should carry few other important properties like lubricity property, anti-corrosion property as well as debris flushing property. Apart from the appropriate cutting fluid selection, method of introduction of the cutting fluid in machining area is of prime importance. The most common and simplest cutting fluid delivery technique is Flood Cooling Technique (FCT), in which considerably high quantity pressurized fluid is introduced into the grinding zone. It has been adopted by manufacturing industries for many years. However, nowadays due to consideration of social, economic, environmental factors and adaption towards benign manufacturing, the research moved towards near-dry machining. There are many alternative ways of reducing coolant usage by considering economic and ecological factors. Though dry machining, techniques using compressed cold air, and Minimum Quantity Lubrication (MQL) methods have mainly been studied, all the three techniques can be categorized as environment-friendly machining [7]. According to Nascimento et al. [8], the cooling cost accounts almost 20% of the total manufacturing cost. MQL secured a good position in machining domain as the cleanest technique and green technology. Hence, many manufacturing industries have adopted it for cooling and lubrication purpose. Although the application of MQL in grinding operation has already been proven for other materials, such as steel, Inconel 718, Ti alloys, reports on MQL grinding of Ni-based alloys Nimonic-90 is almost absent. The purpose of this study has been to assess the grindability of Ni-based alloys Nimonic-90 during surface grinding using vitrified bonded White Alumina (Al_2O_3) grinding wheel under dry, FCT and MQL conditions. Several response parameters, such as normal force, tangential force, surface roughness, and surface morphology, which control product life considerably, were studied.

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2. MATERIAL AND METHODS

Experiments were conducted on a Chevalier Smart H1224 CNC Surface grinder with the conventional Al_2O_3 abrasive wheel on Nimonic-90 material. The wheel used was Al_2O_3 grinding wheel (WA60K5V; Carborundum Universal Ltd, India). The size of the workpiece and wheel was 40 x 40 x 10 mm and 350 x 40 x 127 mm, respectively. The specimen has length 40 mm in the direction of grinding and width 10 mm. To customize the experimental runs, a number of experiments have been decided using RSM (Response Surface Methodology). It has been used to reduce the number of experiments and time. In the present work, total 17 experiments have been decided and subsequently conducted under each grinding condition. All the experiments have been repeated thrice, and then the mean values of the responses have been calculated and reported. The study uses the Box-Behnken Design (BBD) technique because it has fewer design points and is less expensive to run than other design techniques with the same number of factors. Three levels of grinding parameters were selected to investigate the grindability of this alloy. Table 1 shows the grinding parameters and their levels.

Table 1. Grinding parameters and their levels

Process Parameters	Level		
	-1	0	+1
Table feed, Vw (m/min)	6	9	12
Depth of cut, ap (µm)	5	10	15
Grinding Speed, Vc(m/sec)	12	16	20

To maintain the uniform wheel topography, dressing operation was performed before every experiment with a single-point diamond dresser with the following parameters: dressing depth (50 µm), dressing lead (200 mm/min), wheel speed at 1000 rpm and a number of passes (5). All the tests were carried out in a down grinding mode. During the grinding operation, the wheel cutting speeds were varied from 12 to 20 m/s, work table speeds from 6 to 12 m/min, and depth of cut from 5 to 15 µm. The experiments were conducted under three different cooling environments: dry, FCT (soluble oil, 1:20 ratio), and MQL (MQL flow rate: 150 ml/h, MQL air pressure: 8 bar [9]). Grinding forces were measured online using a piezoelectric dynamometer (9257B; Kistler, Switzerland), coupled to a charge amplifier (5070 multichannel; Kistler) and computer data acquisition Dynoware software. After the grinding operation, the machined surface characteristics were observed using a SEM (Zeiss make), surface roughness values were measured with a surface profilometer (Taylor Hobson Limited, UK; Form Talysurf Intra).

3. RESULTS AND DISCUSSION

The grinding forces generated during the grinding process and the average surface roughness (*Ra*) have been studied to understand the grindability aspects of Nimonic-90. In surface grinding process, the forces can be resolved into two components- tangential force and normal force. These forces are dependent on the various grinding parameters and application of coolants used during grinding. Average surface roughness indicates a surface quality of the ground product. At the end of each test, the surface roughness (Ra) across the grinding direction was measured and analyzed over the ground surface at three different points. The grinding forces and surface roughness observations have been discussed in subsequent sections. To have a better understanding of the inherent variations in experimental data, the mean value of grinding forces and surface roughness has been obtained from ANOVA analysis and main effects plot using MINITAB17.

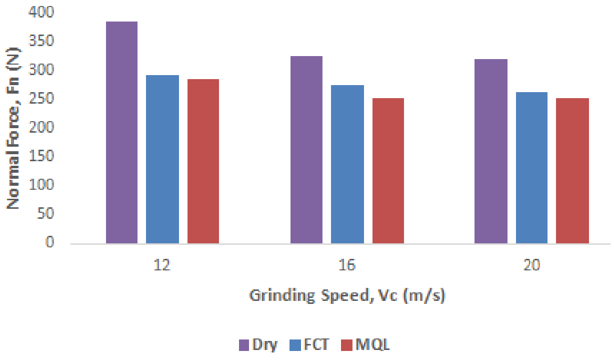

Fig. 1. Variation of normal force with grinding speed

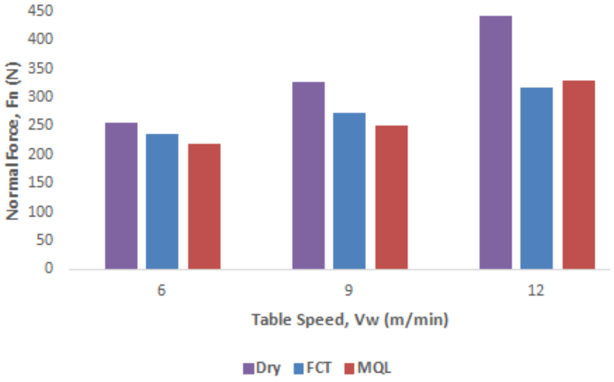

Fig. 2. Variation of normal force with table Speed

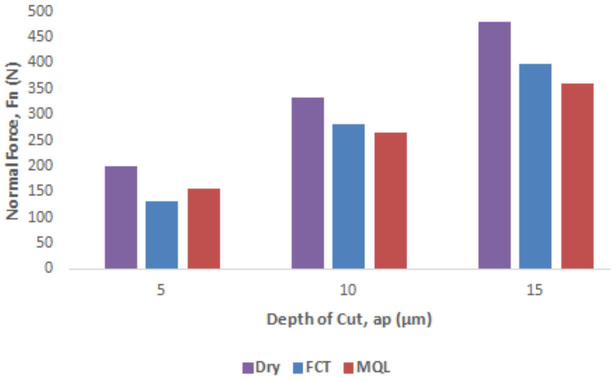

Fig. 3. Variation of normal force with depth of cut

3.1 Normal force (Fn) variation

Normal force variations in dry, FCT and MQL with grinding speed, table speed and depth of cut have been shown in Fig. 1, 2, and 3 respectively. Figure 1 shows the normal force decreasing with an increase in cutting speed which is due to more active grits coming in contact with the workpiece surface. Moreover, in case of MQL, the grit sharpness of the grinding wheel has been retained for longer duration which supports the ease in indentation by abrasive grits over the workpiece surface resulting in lowest normal grinding forces. Figure 2 & 3 shows the variations in the normal forces with respect to table speed and depth of cut, which also points towards the relatively lower forces obtained during MQL as compared to dry and FCT grinding environments.

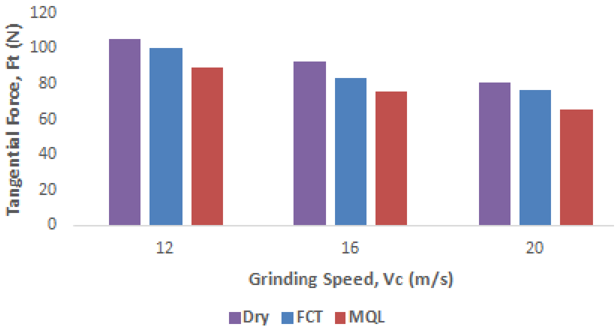

Fig. 4. Variation of tangential force with grinding speed

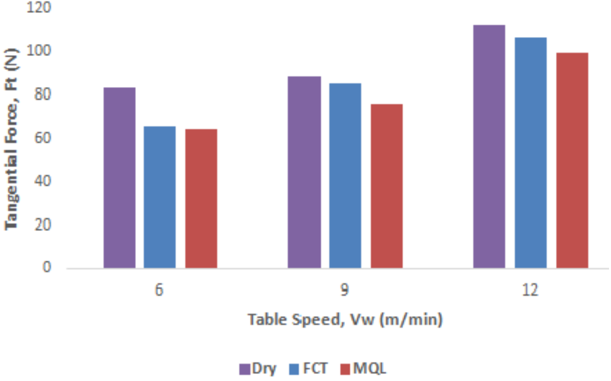

Fig. 5. Variation of tangential force with table speed

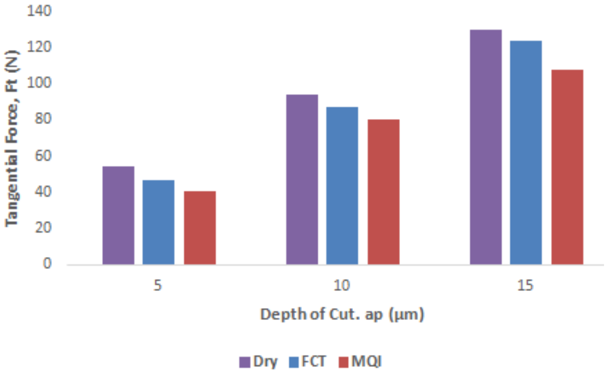

Fig. 6. Variation of tangential force with Depth of cut

3.2 Tangential force (Ft) variation

The magnitude of the tangential force acting in grinding direction is an important indicator of grindability of the material. It plays a vital role in the power and specific energy consumption during grinding. From Fig. 4, 5 and 6, it can be seen that the tangential force decreases with increase in cutting speed whereas increases with increase in table speed as well as the depth of cut. In addition, it can be seen that tangential forces in MQL grinding are smaller than those obtained in dry and FCT grinding. Small force signifies that there is possibly better lubrication at the contact zone due to effective mist formation. From this, it can be concluded that lesser power consumption and hence lower specific energy requirement under MQL environment. Subsequently, it may result in lower heat generation which is one of the most favorable conditions for grinding of Nimonic-90 as it has poor thermal conductivity.

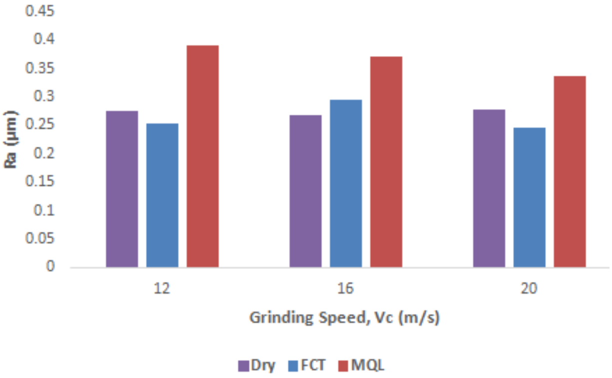

Fig. 7. Variation of surface roughness with grinding speed

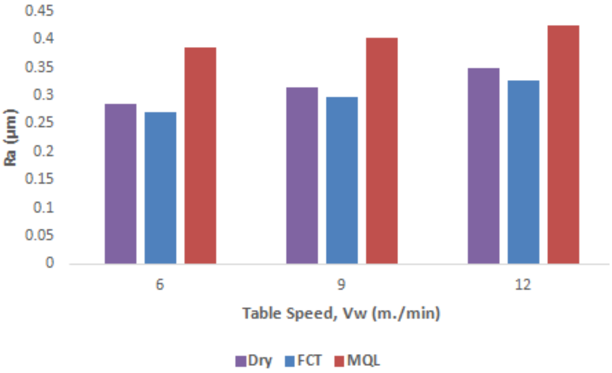

Fig. 8. Variation of surface roughness with table speed

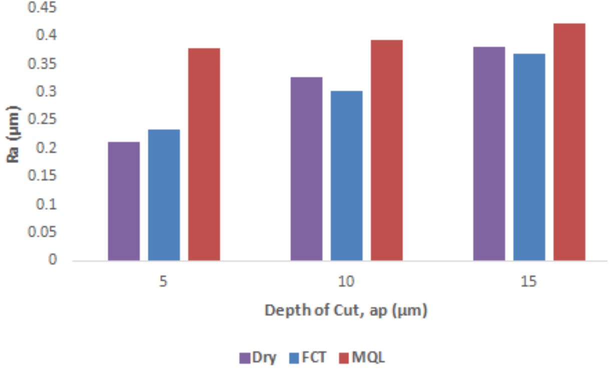

Fig. 9. Variation of surface roughness with Depth of cut

3.3 Surface roughness (Ra) variation

The variation in surface roughness (Ra) with grinding speed, table speed and depth of cut are shown in Fig. 7, 8 & 9 respectively. It can be observed that the surface roughness decreases with increase in grinding speed whereas reverse trends are observed with increase in table speed and depth of cut. Moreover, in MQL grinding the surface roughness are observed towards higher side compare to dry and FCT grinding environment. This is possibly due to the retained sharper grits during MQL grinding which produces grinding marks over the ground surface resulting in higher values of surface roughness.

3.4 Surface morphology

Figure 10 illustrates the SEM images of ground surfaces observed under different grinding environments. Thermal cracks and debris sticking are observed in dry grinding as shown in Figure 10a. The clear thermal cracks over the ground surface also support the possibility of much higher grinding zone temperature eventually leading to attritious wear of the grits in dry grinding [10]. Minimal surface damage in MQL also points towards least heat accumulation during grinding. Less wear and non-uniform surface are seen in FCT grinding due to improper lubrication. Whereas, negligible wear and uniform surface are observed in MQL due to proper lubrication.

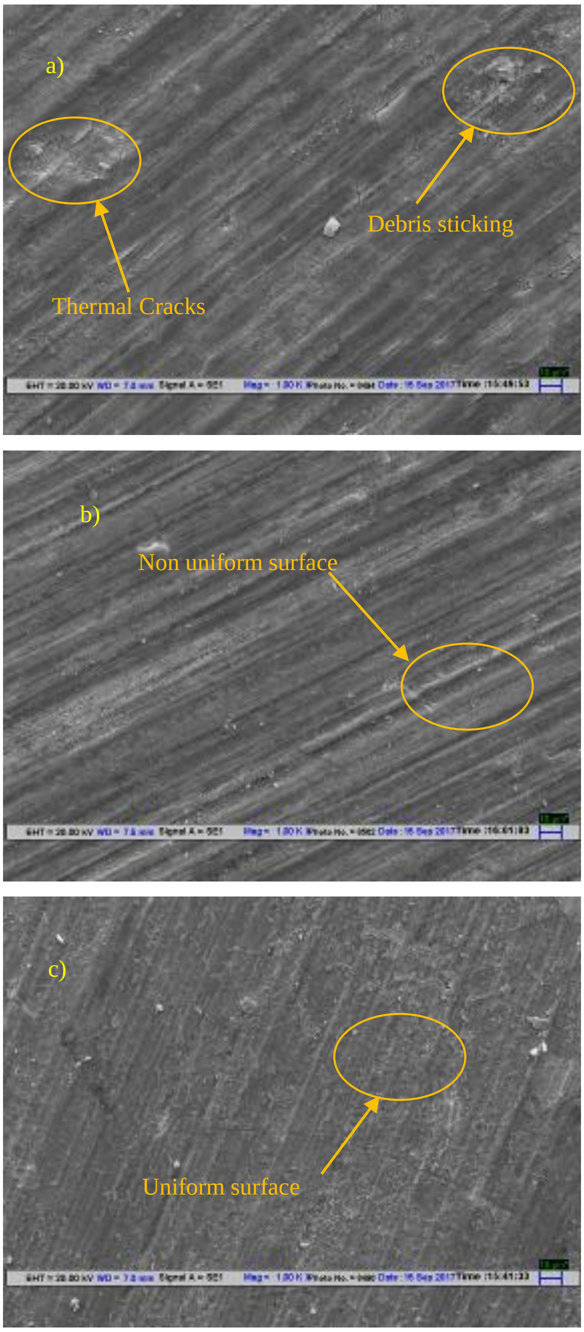

Fig. 10 SEM micrographs of ground surfaces at 1000x magnification (a) Dry grinding, (b) FCT grinding and (c) MQL grinding

4 CONCLUSION

From the present work the following major conclusions can be drawn:

1. In MQL grinding, the normal and tangential forces are found to be less as compared to dry and FCT grinding which clearly indicates the proper cooling and lubrication in MQL.
2. Higher surface roughness is observed in MQL grinding due to retention of sharp grit for a longer time by proper cooling and lubrication.
3. MQL technique is found to be the most effective in terms of enhanced surface quality of the ground surface.
4. Dry grinding does not remain a preferred choice in grinding of high strength temperature resistant material like Nimonic-90 mainly because of thermal cracks developed at the ground surface.

MQL grinding is most promising and effective environment than dry and FCT for grinding of Nimonic-90 which can be adopted as a benign manufacturing.

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