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Performance Evaluation of Liquid Nitrogen as coolant in Turning of Al/SiC Metal Matrix Composites(AMMC)

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Abstract. This paper presents the results of an experimental investigation on the turning of Al/SiC (LM-13) composite using Cryogenic Liquid Nitrogen (LN_2) as coolant. The influence of machining performance parameters such as cutting force, cutting temperature and surface finish were investigated under wet and cryogenic machining. The results proved that the application of cryogenic LN_2 coolant reduced the cutting temperature and the cutting force for about 19 to 30% and 24 to 35% respectively. The surface finish of the machined part is about 10 to 23% better than in the conventional coolant. Thus it was proved that the application of cryogenic coolants reduced the cutting force and temperature which resulted in an appreciable improvement in surface finish in machining of Al/SiC MMC.

Introduction

Selection of any casting alloy depends on the service requirement and the economy of processing (welding, casting and machining). The required dimensions and surface finish is obtained through machining. The majority of manufactured parts are machined before they are used to manufacture engineering components [1]. Hence, machining of materials plays an important role in determining the economy of various applications.

The aluminum alloy reinforced with ceramic reinforcements is rapidly replacing conventional materials in various automotive, aerospace and automobile industries [2]. But the problems associated with the machining of Al/SiC-Metal Matrix Composites (AMMCs) restricts its wide spread engineering application [3]. The use of carbide tipped tools in machining of Al/SiC MMCs caused the excessive tool wear and a very poor surface finish [4,5] . During the process of turning, friction, high temperature and pressure produced by the sliding of Al/SiC-MMC work piece over a hard cutting tool edge. It leads the particles of the Al/SiC-MMC to adhere with the cutting tool edge referred to as Built-Up Edge (BUE). When the turning process is proceeded further, more particles will be accumulated with the already adhering edge leads to a very poor surface finish during machining.

The issues of turning AMMC have been addressed from various aspects. Several researchers have done experiments on machining of Aluminum metal matrix composites. It is observed that machining of AMMC at high cutting speed with low feed rate, increases the cutting temperature and decreases the cutting force resulting a good surface finish [6]. The flank rate is high at low cutting speed due to high cutting force and formation of BUE during machining of AMMC. When machining LM13 and LM28 alloys, BUE is formed at low speeds and also chip fracture producing the rough surface [7]. When turning AMMC,though the use of conventional cutting fluid form a lubricating film at the rake surface, the surface is slightly deteriorated due to flushing away of debonded particulates from the AMMC [8].

When machining AMMC the usage of coolant prevents the formation of BUE. This results in an excellent surface finish comparable to ground surface. But the techno-environmental problems caused by conventional coolants are more though these coolants are effective to some extent. Hence, an environmental safe alternate method known as cryogenic machining is carried out to eliminate these problems.Various experiments were carried out earlier by the researchers for turning other materials by using cryogenic LN_2 as the prime cryogenic coolant and succeeded to a greater extent in obtaining the reduced cutting temperature, cutting force, surface roughness and tool wear [9,10,11]. It is observed that surface roughness,tool wear,cutting force and cutting temperature get reduced when cryogenic LN_2 was used as coolant in turning of Ti-6Al-4V alloy and AISI 4045 Steel respectively [12,13]. Researchers have also used gases as cutting coolants in the past for this purpose and contributed well to the metal cutting industry[14,15].

This experimental work focuses on studying the effect of cryogenic LN_2 as the cutting fluid and to compare the results in terms of cutting temperature, cutting force and surface roughness with that of conventional wet machining in turning Al/SiC(LM-13) Metal Matrix composite.

Experimental procedure

In this work, Al.12%wt Si alloy (LM13) with SiC is used as reinforcement material. The dimensions of 60mm diameter and 300 mm length bar is used for experimentation. The silicon size 15 microns and volume fraction of 20% is considerd for Al/SiC Metal Matrix. The experimental conditions considered for the machining conditions is mentioned in Table 1.

Table 1 Experimental conditions

Work piece	LM13 composite bar (Ø 60 mm x 300 mm)
Cutting tool insert	Un coated carbide insert (SCLCR2525M12) Rake angle: 0º
Process parameters	Cutting velocity 226 m/min, Feed rate 0.159,0.2,0.24 mm/rev Constant depth of cut 1 mm
Machining conditions	Wet and LN_2

The objective of this experiment is to compare the performance of LN_2 as a cutting fluid with the conventional wet machining of LM13 composite material. The experimental set up used for cryogenic LN_2 machining is shown in Fig. 1. The different sets of experiments were performed by turning operation on a High speed automatic lathe(NAGMATI175).The cutting force was measured using a calibrated Kistler type 9257B Piezoelectric Dynamometer. A non-contact type IR thermometer was used for measuring the cutting temperature on the rake face (cutting zone) of the insert during the machining process.

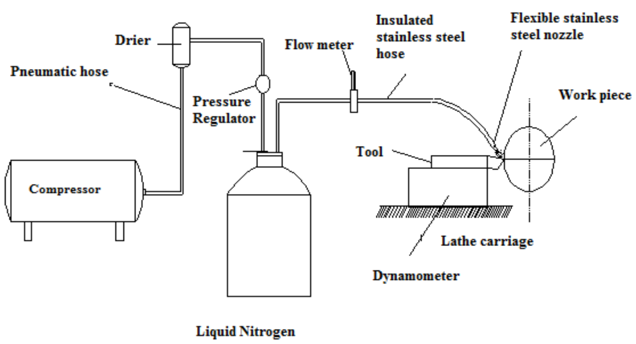


Fig.1 Schematic views of Experimental set up for cryogenic LN_2 machining

Surface roughness was measured after completion of turning work pieces using a Talysurf surface roughness tester.

Results and Discussions

Cutting temperature and cutting force

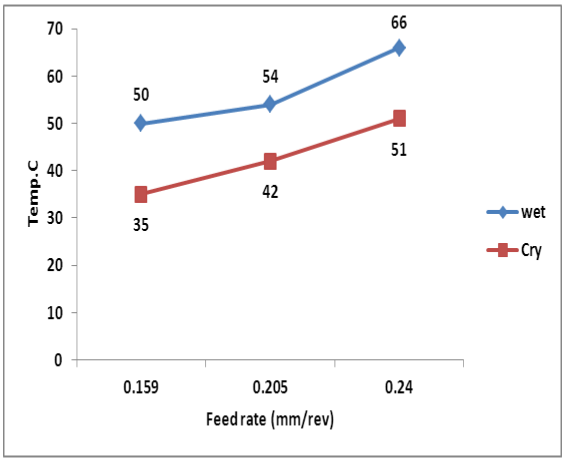


Fig 2a. Cutting temperature at cutting velocity of 226m/min with different feed rate when machining Al/SiC(LM-13) composite under wet and cryogenic coolant condions

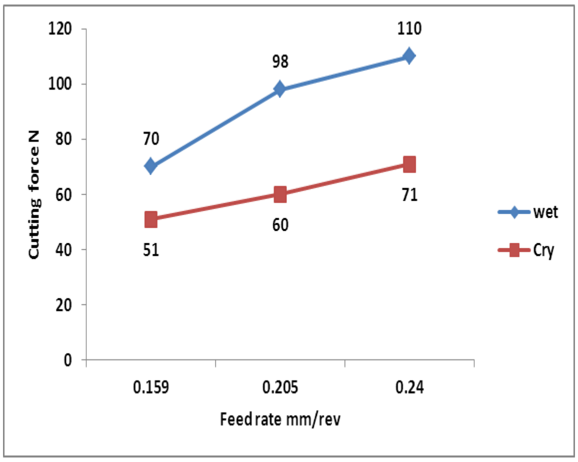


Fig 2b. Cutting force at cutting velocity of 226 m/min with different feed rates when machining Al/SiC(LM-13) composite under wet and cryogenic coolant condions

Cutting temperature. The cutting tool temperature was measured for different cutting velocity and federate selected. The Fig 2a shows variation of cutting temperature with different feed rate at cutting velocity of 226m/min. It is observed that cutting tool temperature was increased with the increase of feed rate and cutting velocity. This due to increase in workdone per unit time with the increase of velocity and feed rate.The Si and SiC particles separates from metal matrix due to plastic deformation during machining. Due to this increase in plastic deformation and friction during high feed rate and velocity, high heat energy developed at cutting zone area resulting high cutting tool temperature. The LN_2 applied between cutting tool and work piece is absorbing high heat generated in cutting zone area.The LN_2 gets evaporated by abosrbing high heat due to its low boiling point (-196ºC).The friction between and tool and work piece also reduced extensively due more penetration of LN_2 in liquid and gaseous form into tool and work piece.This reduces cutting tool temperature compared to wet machining conditions. The experimental results shows that application of LN_2 reduced the cutting temperature by about 19-30% when compared to wet machining conditions.

Cutting force. It is observed that with the increase in feed rate, cutting force was increasing. This is due to increase in Matrix material and SiC particle removal rate.It is also observed that change in magnitude of cutting force is obtained due to contact of tool with SiC particles.The application of LN_2 reduces cutting force compare to wet machining. This is due to better cooling effect and less friction between tool and work piece.

Fig. 2b shows the variation of cutting force with respect to feed rate at cutting velocity of 226 m/min.The results show that the main cutting force is reduced by about 24–35% with application of LN_2 than wet machining conditions. The reduction of cutting force in increasing cutting velocity is considerable because of the reduction of built up edges and reduction of cutting tool temperature on application of low temperature cryogenic LN_2.

Surface roughness

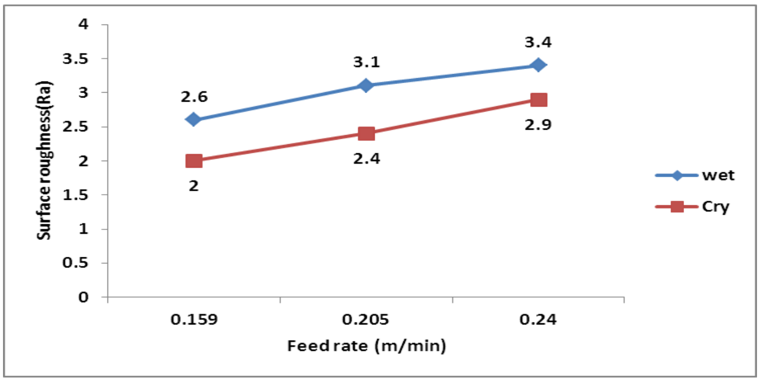
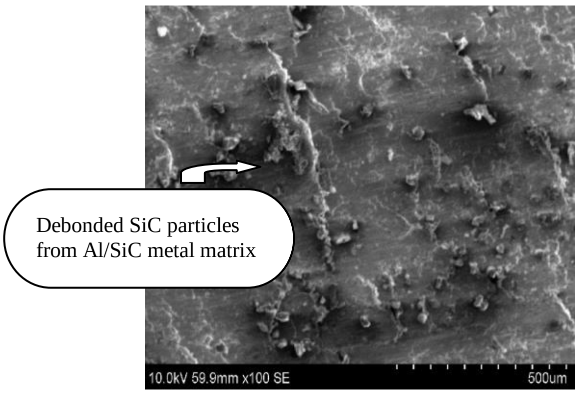


Fig 3.Surface roughness at 226 m/min cutting velocity and different feed rate

The surface roughness value was measured using Talysurf surface roughness tester by varying cutting velocity at constant federate of 0.24mm/min and different values of feed rate at constant cutting velocity of 226 m/min.The mean roughness value (Ra) for conventional and cryogenic cooling machining conditions were taken for evaluation. The surface roughness values at constant cutting velocity of 226 m/min and different feed rate is shown in Fig 3. It is clearly seen that the surface roughness increased with the increase in feed rate.This is due to increase in material removal rate and increase in separation of Si and SiC particles from metal matrix.

It can be observed that application of LN_2 reduces surface roughness values in both the conditions. This is because of reduction of cutting temperature and cutting force compare to wet machining conditions, reduces separation of Si and SiC particles from Al/SiC metal matrix due to less plastic deformation. It is also noted that the low Built up edge formation and better cushioning effect reduced friction, and higher tool hardness improved surface finish values better. Application of cryogenic LN_2 as the cutting fluid produced better surface finish values by about 10– 23% when compared with wet machining conditions. It was observed that better surface finish value is obtained at lower feed rate of 0.159 mm/rev and higher cutting velocity of 226 m/min.



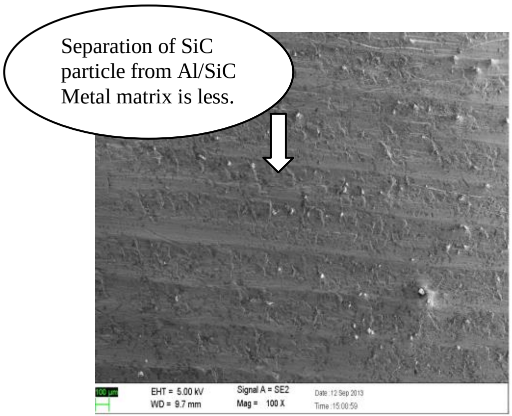


Fig. 4a SEM view of machined surface for wet machining (velocity at 226m/min and feed rate at 0.159 mm/rev)

Fig. 4b SEM view of machined surface for cryogenic LN_2 machining(velocity at226 m/min and feed rate at 0.159 mm/rev)

The samples of machined surface at the feed rate of 0.159 mm/rev and cutting velocity of 226m/min for both wet and cryogenic LN_2 were taken for SEM view. The Fig. 4a and Fig. 4b shows SEM view at wet and cryogenic LN_2 coolant conditions respectively. It is observed from both the SEM view that SiC particles debonded from the matrix resulting poor surface finish. However in cryogenic LN_2 machining the uniform texture is observed compare to wet machining. This is due to better tool chip interface and reduced friction between work piece and tool insert.

Conclusion

Based on turning of Al/SiC MMC by using Cryogenic liquid nitrogen as coolant following conclusions can be drawn:

1. Application of cryogenic LN_2 coolant reduced cutting temperature in compare to conventional wet machining. This is about 19–30% compared to wet machining conditions.
2. The cutting forces reduced about 24–35% when using cryogenic LN_2 coolant compare to wet machining.
3. Surface roughness of the machined work piece reduced on application of the cryogenic coolants. Application of LN_2 coolant reduced surface roughness value to about 10-23 % compare to wet machining conditions.

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