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Study the effect of cryogenic cooling on orthogonal machining Process

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Abstract : *In present scenario , all the manufacturing organization aims to maximize the productivity of organization in respect of all the aspect of manufacturing process, in case of machining process, it associated with various factors which affect the productivity directly in sense of tool life . Temperature, cutting forces, shear angle, work-piece surface finishing & accuracy, amount of power consumed in machining process and other thing also. All the factors might be optimized by applying effective and efficient amount of coolant throughout the process, to get desired efficiency of process. A coolant play a vital role in machining operation but which must have specific properties which have been reviewed in previous article of various student , research scholars , scientist and industrial candidates .in this research paper , we were focusing on the effect of cryogenic cooling on cutting temperature , cutting forces , chip behavior , shear angle , when alloy steel EN-8 and aluminum alloy 6061-T89 was machined by carbide cutting tool (coated & uncoated) & applying liquid nitrogen as a coolant and observed that temperature was decreased during the machining process about 16% to 27% and cutting forces improved to 13%when the machining was performed , the same without cooling of EN-8 alloy, similarly on the other hand in case of aluminum alloy 6061-T89 , temperature was decreased to 25% to 37% and cutting force improved to 9% .*

Key word: *cryogenic cooling, productivity, cutting temperature, liquid nitrogen coolant, cutting forces*

I. Introduction

Cryogenics in the context of scientific sense is usually referring to events occurring at temperature -153°C or lower [1]. In the usual meaning of cryogenic liquids, chemicals such as liquid nitrogen, oxygen, helium, methane, carbon dioxide, ethane and argon are the area of interest. The proposed work , mainly concentrated upon liquid nitrogen (LN2) . The modern manufacturing world of producing and processing metals, offers a great variety of alternatives to produce a product demanded by the market. Turning, milling and drilling are among the most common methods exercised in order to shape and form metals to meet the requirements of the market. Myriads of factors affect the final outcome and productivity in manufacturing processes and higher demands are constantly forcing the industry to improve and optimize working methods [2]. Cutting fluids which are provided to the cutting zone in metal cutting are one of the most important elements in machining metal parts. The main purpose of cutting fluids is to provide cooling and lubrication in the cutting zone, work piece, tool or the chip [3]. They are either classified as coolants, lubricants or a chemical formulation of cutting fluids which are designed to provide both cooling and lubrication. Coolants are usually water-based solutions or water emulsions and lubricants are usually oil-based fluids. Cooling-lubrication cutting fluids are most commonly oil-based and contain dozens of chemicals which can be hazardous for the environment [4, 5]. Environmental issues and sustainability demands are growing and have become an inseparable part of modern manufacturing. The industry is being forced to come up with innovative and sustainable solutions to sustain its level of competitiveness. Using cryogenic cooling liquids is an environmentally friendly method of providing cooling and lubrication to the cutting zone. Under certain parameters, cryogenic cooling has shown clear superiority over conventional oil-based coolants with pressure additives. E.g. the cooling efficiency is normally much higher and in some cases the conventional cutting fluids fail to provide desirable control of cutting temperature due to their lack of ability to penetrate sufficiently to the chip-tool interface [6]. Research and experiments with cryogenic gases as cooling and lubrication can be dated back to the 1950's and is still being developed by scientists today [7]. The technique has not been fully adapted by the industry but has shown some great potential within certain combination of materials, cutting tools and machining methods [5]. Among the most common materials showing promising results associated with cryogenic cooling are difficult-to-machine materials such as nickel-based alloys, titanium-based alloys and hardened steels [8, 9]. In the criteria for machinability there are usually few factors involved in the judgment. The factors are:

- Chip form
- Magnitude of cutting forces
- Vibration of machining system
- Tool wear
- Surface finish
- Dimensional deviation

These are all issues that have been proven to be influenced positively by cryogenic cooling.

1.1 Cryogenic technology

Several cryogenic liquids are available but for machining operations, CO2 and LN2 are almost exclusively used. How the liquid nitrogen (LN2) control the temperature rise , the complete mechanism regarding the context is given below in deep .

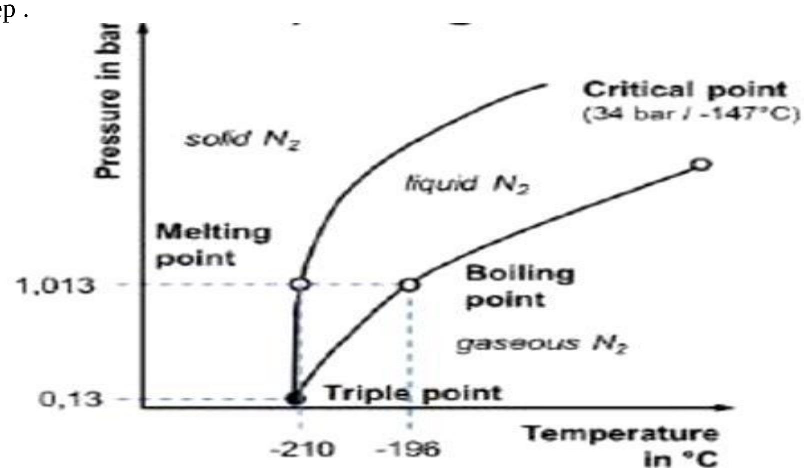

Figure -1 phase diagram for liquid nitrogen gas

1.2 (Liquid Nitrogen Gas) LN2

Figure -1 shows the phase diagram for LN2. The triple point, occurring at pressure 0, 13 bar and -210°C, is the state where nitrogen can be found at all forms. LN2 is nitrogen in a liquid state at a very low temperature and usually stored in isolated tanks at very high pressure. When the media enters the ambient temperature and the pressure drops (1, 01325 bar), the nitrogen starts boiling at -196°C [15]. In cutting processes it absorbs the heat dissipated from the cutting process and evaporates into nitrogen gas and becomes a part of the air. It is safe non-combustible chemical and leaves no harmful residue to the environment since in becomes a part of the other 79% of nitrogen in the atmosphere [3, 16, 17]. However, in some cases when LN2 comes in contact with hot surfaces it starts boiling and vaporizing, an insulating film of gas forms and surrounds the part, reducing the cooling effect [15].

II. Literature review

Literature review provide a correct path & background for futuristic approach in the research work, following are very important review of researcher, scholars and scientist in the field of metal machining process, whose thought & ideas give us a constant guidance as well as motivation .The purpose of the application of the cutting fluids in metal cutting was stated as reducing cutting temperature by cooling and friction between the tool, chip and work piece by lubrication [6]. Chip formation and curl, which affects the size of the crater wear and the strength of the cutting tool edge, is also affected when coolant is carried out during machining. Generally, a reduction in temperature results in a decrease in wear rate and an increase in tool life. Seah et al. examined water-soluble lubricating on tool wear in turning of AISI 4340 and AISI 1045 steel with an uncoated tungsten carbide insert. They found that there was no significant difference between the cases where coolant was used and that of dry cutting. In fact, they showed that it aggravated flank and crater wear in some of the cutting conditions [8]. It was also proved that the conventional cooling action worsened the surface roughness when compared with dry cutting [9].The main functions of cryogenic cooling in metal cutting were defined by Hong and Zhao [28] as removing heat effectively from the cutting zone, hence lowering cutting temperatures, modifying the frictional characteristics at the tool/chip interfaces, changing the properties of the work piece and the tool material. In cryogenic pre-cooling, the work piece and chip cooling method, the aim is to cool work piece or chip to Change properties of material from ductile to brittle because, the ductile chip material can become brittle when the chip temperature is lowered [46]. Chip formation and its effect on productivity in metal cutting have been proved by Jawahir [47] and control and breaking of chips during cutting will increase performance of machining. Hong et al. [46, 50] developed a cryogen delivery system. In this system, LN2 was supplied to chip faces to improve the chip breakability. In this design, the size, shape and position of the nozzle were selected so that the LN2 jet covered the chip arc, and liquid flow was oriented parallel to the axial line of the curved chip faces. Wang and Rajurkar [54–56] designed a liquid nitrogen circulation system on the tool for conductive cooling of the cutting edge. Ahmed et al. [51] modified a tool holder with two designs for cryogenic machining. In one of their design, the discharging gas was directed away from the work piece for maintaining ductility of materials. Piling up of nitrogen below the insert and thus keeping the tool insert at low temperatures were targeted without evaporating. So, the design is suitable for conductive remote cooling of the cutting edge. Hong and Broomer, LN2 was injected with three nozzles to the cutting zone; in a _Z direction, parallel to the spindle axis, or in _X direction, perpendicular to the spindle axis, on the tool rake face and flank face, similarly [60]. In design of Dhar et al. [61–63], LN2 jets were targeted along the rake and flank surfaces, parallel to the main and auxiliary cutting edges too. In another design, Venugopal et al. [64] used LN2 jets through a nozzle on the face and flank of the cutting tool. Zurecki et al. [57] made a tool life comparison between cryogenic nitrogen cooled Al2O3-based cutting tools and conventionally cooled CBN tools in machining of hardened steel. They applied cryogenic coolant by spraying with a nozzle to the rake surface of the tool. They found that cryogenic cooled Al2O3-based cutting tools endured longer than the conventionally cooled CBN tools. Hong et al. [95] presented an experimental sliding contact test setup on CNC turning centre composed of a carbide tool and Ti–6Al–4V titanium alloy and AISI 1018 low carbon steel disks. Their findings showed that the LN2 lubricated contact produced lower friction coefficient than the dry sliding contact and the emulsion-lubricated contact for both disk materials. Wang et al [1] have carried out turning of ceramics [Si3N4] with Polycrystalline Cubic Boron Nitride [PCBN]under cryogenic cutting conditions and reported that liquid nitrogen cooling system reduced the cutting tool temperature and tool wear over dry machining Hong and Ding [2] conducted an experiment with various cooling approaches in cryogenic machining of Ti-6Al-4V. Temperatures in cryogenic machining were compared with conventional dry cutting and emulsion cooling. It was showed that a small amount of liquid nitrogen applied locally to the cutting edge is superior to emulsion cutting in lowering the cutting temperature. Dhar and Kamruzzaman [5] conducted an experiment on cryogenic cooling and stated that benefits of cryogenic cooling are mainly by substantially reducing the cutting temperature, which improves the chip-tool interaction and maintains sharpness of the cutting edge and accuracy as compared to dry and wet machining . **Prudvi Reddy et al [1] indicate that** Cryogenic cooling result in increased in grinding ratio as well as effective cooling of grinding zone indicated by Scanning Electron Microscope (SEM) , shows cryogenic cooling enhances life of grinding wheel and reduction in grinding temperatures. In an investigation of **Ranajit Ghosh et al [2]** For sinter hardened material machining, only specific type of cutting tool materials can be used like Poly Cubic Boron Nitric (PCBN). Due to conventional cooling techniques, negative effects of tool wear, deformation of tool wear, slow cutting speed, etc. were caused higher abrasive resistance and lower flank wear due to elimination of hardness of cutting tool. Improvement in life of tool was found to be 135%. In an another investigation of **D. Umbrello et al [3] he perform,** of cryogenic cooling on surface integrity on AISI 52100 steel of hard machining. Reduction in white layer formation and residual stresses due to cryogenic coolants was noticed. Cryogenic cooling helps to improve surface integrity during machining of hard components'**. Pradeep Kumar et al [4]** investigate the effect on orthogonal machining processes by liquid nitrogen (LN2) cooling. The main objective of researcher behind presenting this paper is to study the effects of cryogenic coolants on various aspects of machining on work piece such as cutting temperatures, shear angle, cutting force and chip thickness also in orthogonal manufacturing of AISI 1045 and Al 6061- T6 alloy. & concluded that Reduction in cutting temperature was found to be 19-40%. Cutting forces were increased by 10%. Chip thickness is increased by 25%. Shear angle was increased to 30%.

Cryogenic Cooling Process

Cryogenic cooling techniques involve various methods:

- Pre cooling of work piece by cryogenic fluids
- Direct cryogenic cooling
- Indirect cryogenic cooling
- Jet cryogenic cooling

Experimental setup

Machining is the operation of removal of unwanted material from the block of metal to get desired shape & size as per the design specification, the overall operation is known as metal cutting throughout the machining process high heat is generated which affects the productivity directly, due to the decrease tool life, surface finishing of work piece, increase in cutting forces, friction between tool & rake face of the tool and so many other factor also. In present work alloy steel EN-8 & aluminum alloy 6061-T89, is used as test specimen whose dimension and related machining parameters are given below in table -1 when machining is going cryogenic cooling is applied through nozzle of liquid nitrogen between tool chip interface, the cryogenic cooling set up is given in figure- 2 similarly the orthogonal machining process is given in figure-3

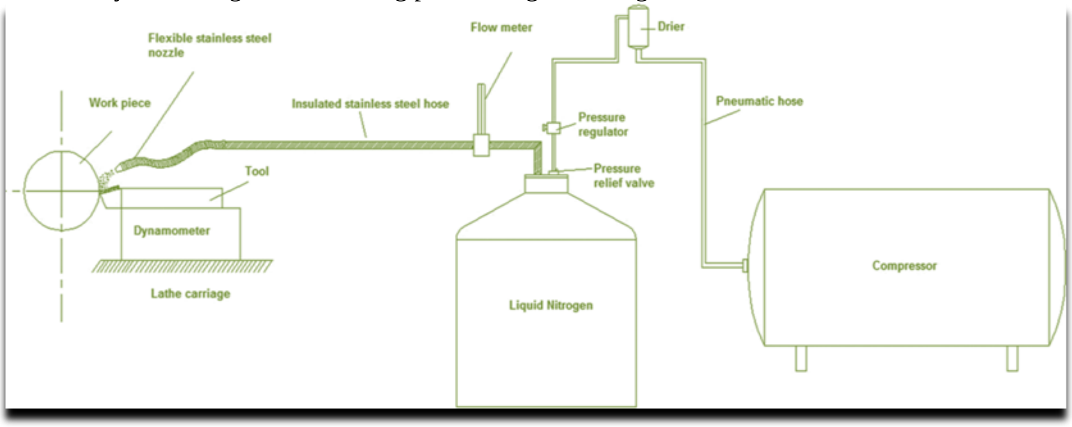

Figure -2 cryogenic cooling setup of liquid nitrogen

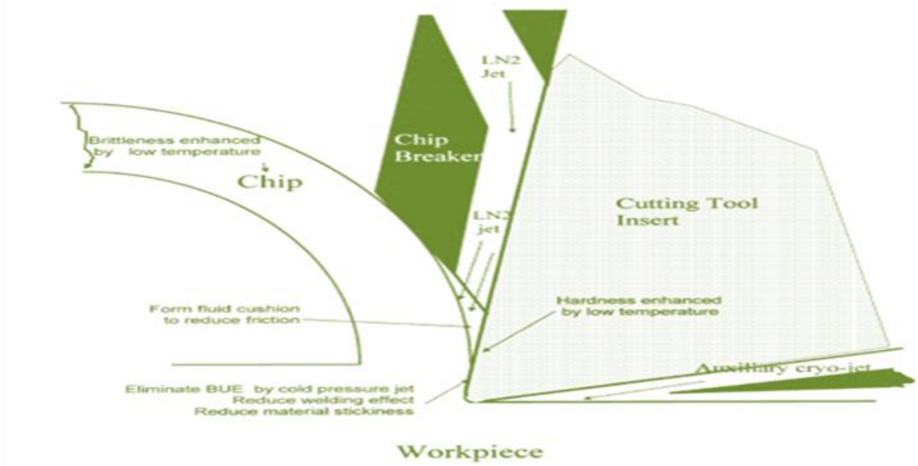

Figure- 3 A schematic diagram of the orthogonal cryogenic machining process

Work – piece dimension

work-piece dimension	**Test specimen- I**	**Test specimen- II**
Work-piece metal	EN-8 (ALLOY STEEL)	Aluminum alloy --6061-T89
Length of work-piece in MM	225 mm	230 mm
Diameter of work-piece in MM.	50 mm	50 mm

Cutting tool & cutting tool parameter:-

Tool name & cutting parameter	**For test specimen-I**	**For test specimen-II**
Cutting tool name	Carbide cutting tool	Plain carbide cutting tool
Cutting velocity (m/min)	50 and 180	50 and 180
Feed rate (mm/rev)	0.079 , 0.110 , 0.148	0.079 , 0.110 , 0.148
Coolant used	Dry cooling on tool chip interface	Dry cooling on tool chip interface
Coolant used (Liquid Nitrogen)	Between tool chip interface	Between tool chip interface

Table – 1 work-piece dimension & cutting tool parameter

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Measuring equipment method

Cutting force measurement

Measurement of cutting force in machining process is very complex in nature; dynamometer is used to fulfill the requirement purpose –which is piezo electric three component dynamometer

Temperature measurement

temperature measurement in metal machining also a very complicated & complex task , there are generally two method which is direct method and indirect method , in this case non-contact pyrometer is used which is indirect one

Cryogenic cooling effect on temperature

Whenever machining operation is going on , metal is being operated thus high heat is generated which affect the surface finishing as well as performance of machining operation , in order to reduce the effect of temperature we are applying liquid nitrogen as a coolant on chip tool interface whose effect is noticed and temperature is

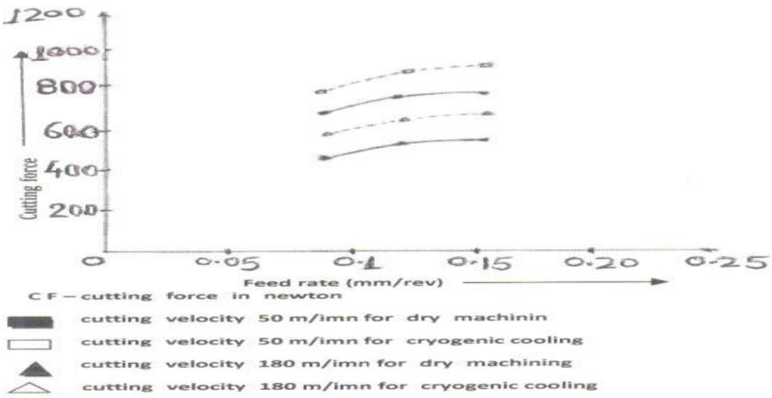
Cutting velocity	*50*	*50*	*50*	*180*	*180*	*180*
Feed rate	0.079	0.110	0.148	0.079	0.11	0.148
Temperature reduced For EN-8(%)	26.37	25.21	24.92	20.56	18.2	16.89
Temperature reduced For 6061-T89 (%)	37.12	35.65	33.13	30.52	28.4	26.98
Temperature in dry machining (EN-8)	130.16	120.81	129.0	104.86	105	105.92
Temperature in dry machining (6061-T89)	102.62	102.8	104.0	103.86	104	103.77

reduced . Summary of result is tabulated below in table-2

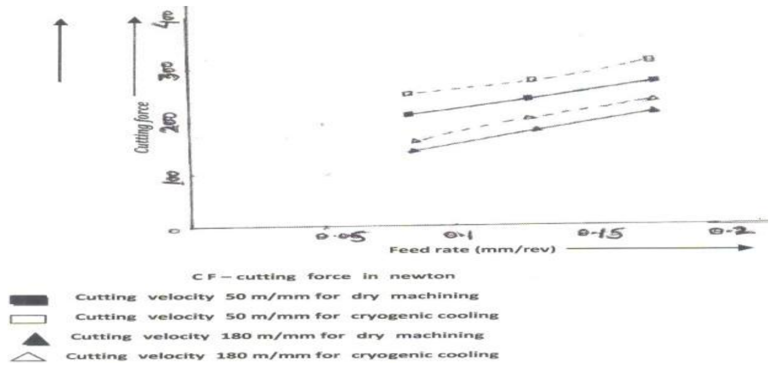
Cutting force analyses

During the machining operation high heat generated to overcome the high heat we applied here a liquid nitrogen as a cutting fluid whose effect is to control temperature as well as the work-piece foreign material that is removed from block of metal represent less sticky behavior and also work-piece become harder and hence increased cutting force and less sticky between tool chip interface table shows the resulting data,

Specimen material	Cutting force improved
EN-8	13%
6061-T89	9%



Graph -3 showing the relative position of effected forces under dry and cryogenic cooling On alloy steel EN-8

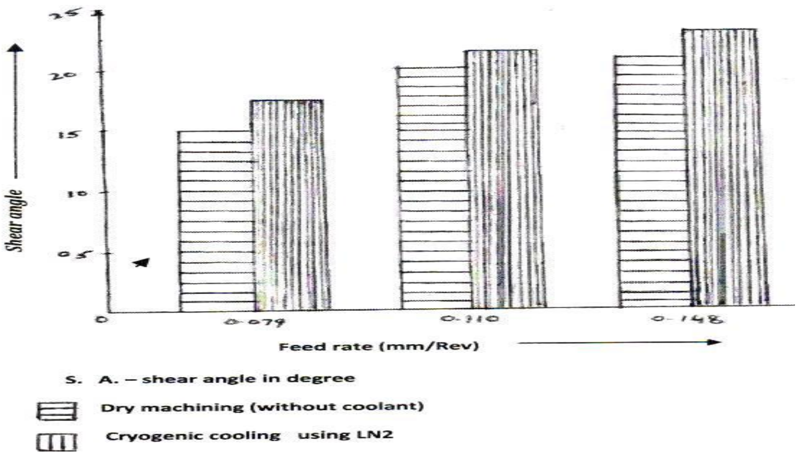


Graph -4 showing the relative position of effected forces under dry and cryogenic cooling

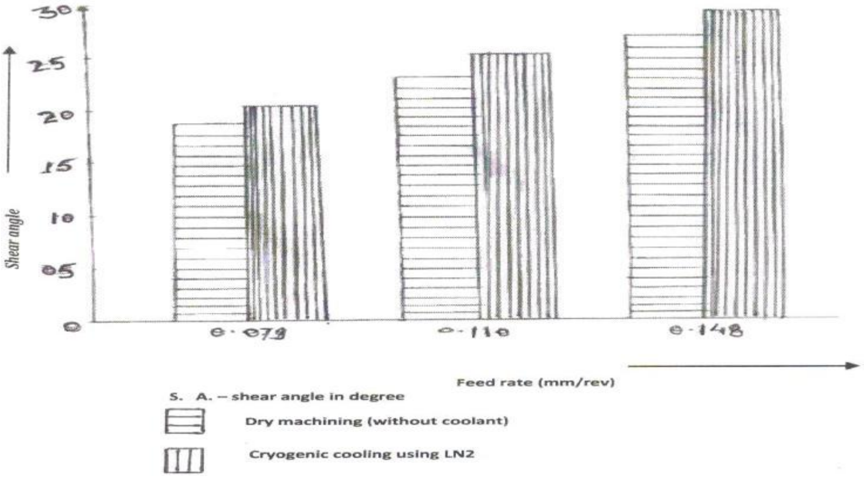
On alloy steel 6061-T89

Analyses of shear angle variation due to the effect of cryogenic cooling

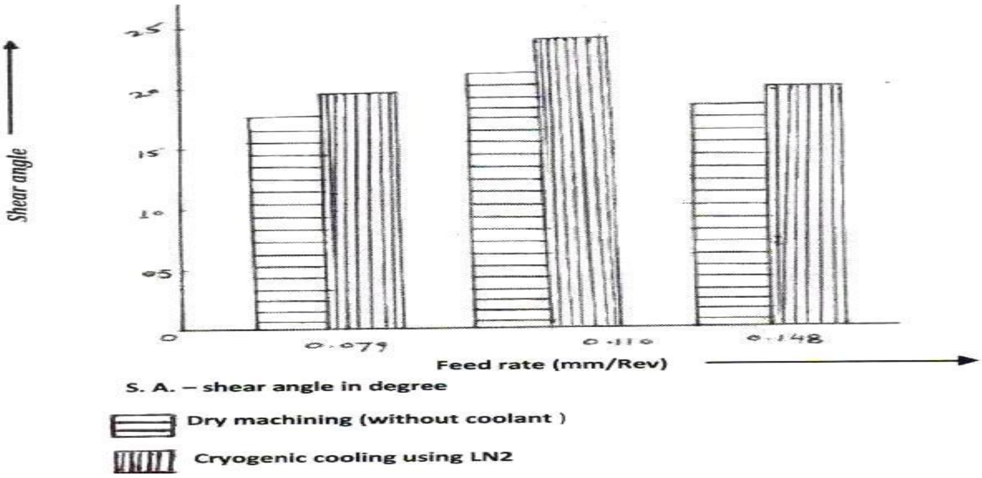
When test specimen 1& 2 are machined, at different feed rate and cutting velocities with consideration of dry and cryogenic cooling. it is observed that shear angle is increased due to the reduction of cutting temperature in cutting zone of metal as well as dimension of chip also changed i.e. thickness is reduced , the variation of shear angle is achieved between range of 13% to 27% for test specimen- 1 & test specimen-2 respectively. And hence shear angle alteration directly affect the dimension of chip & its behavior. Graph -5 & 6 shows the relative position of shear angle variation at different feed rate & cutting speed for EN-8 alloy steel similarly graph – 7 & 8 for aluminum alloy 6061 –T89 respectively.



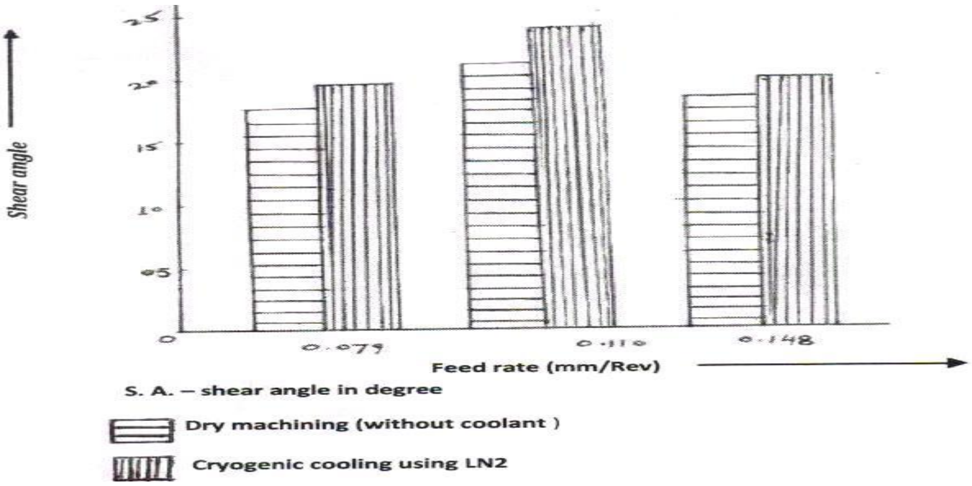
Graph – 5 shows plot between shear angle & feed rate for cutting speed 50 (m/min) when machined EN-8



Graph – 6 shows plot between shear angle & feed rate for cutting speed 180 (m/min) when Machined EN-8



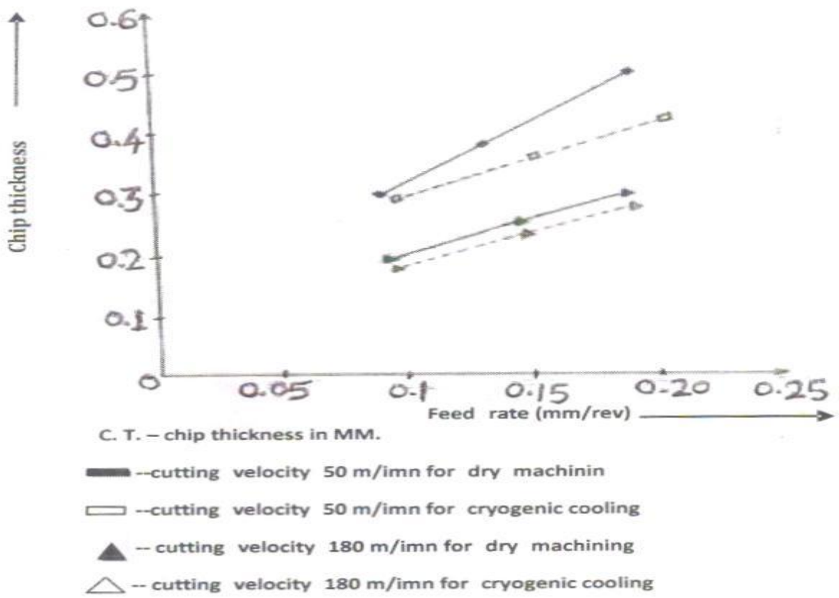
Graph – 7 shows plot between shear angle & feed rate for cutting speed 50 (m/min) when Machined Aluminum 6061-T 89



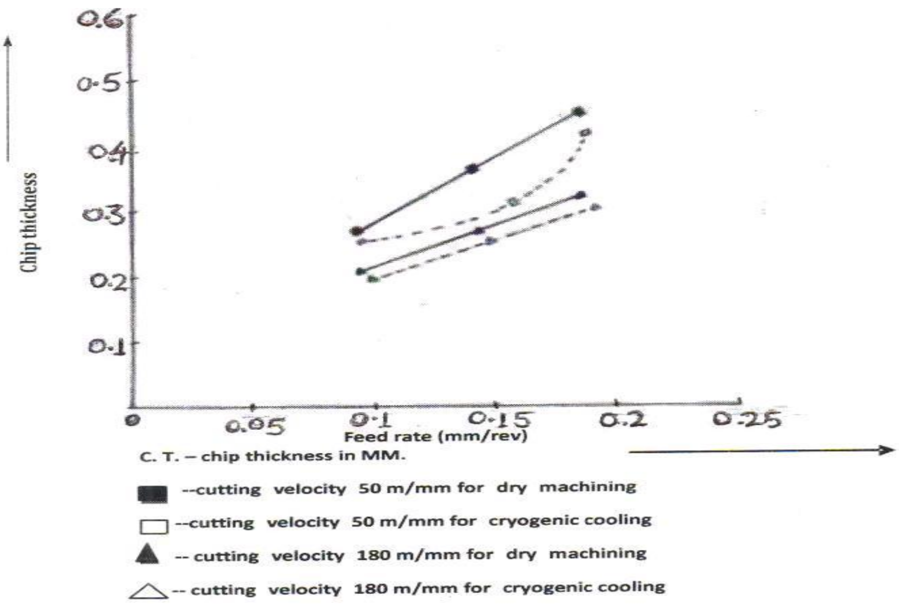
Graph – 8 shows plot between shear angle & feed rate for cutting speed 180 (m/min) when Machined Aluminum 6061-T 8

Analyses the effect of cryogenic cooling on chip behavior

During the machining process, high heat generation takes place when liquid nitrogen is applied it is reducing temperature, minimizing the friction at tool chip interface, thus it also work as lubricant during machining operation. The generation of high heat associated the process is responsible for chip dimension if temperature is high thickness of chip will be larger on the other hand temperature is in decreasing order then thickness will be lesser ,in other word we can say that during dry machining process thickness of chip will be larger & minimum when cryogenic cooling is provided when both test specimen machined at different feed and cutting velocity it is observed that reduction achieved between 15 % to 23 % respectively. The behavior of the chip with respect to different feed rate can be clearly understand by following graph , the graph – 9 represent the chip thickness behavior of EN- 8 alloy steel when machined at dry state and under cryogenic cooling similarly graph- 10 associated with the aluminum alloy 6064-T89.



Graph –9 represent chip thickness V/s feed rate under dry and cryogenic cooling for EN -8



Graph – 10 represent chip thickness V/s feed rate under dry and cryogenic cooling for aluminum Alloy 6061–T 89

V. Conclusion

The above orthogonal metal machining experiment of EN – 8 & Aluminum alloy 6061 – T 89 is performed under the dry state and the cryogenic cooling state , with respect to the study following conclusion is comes on the front line .

- Machinability of any metal is depends upon the various factor like cutting velocity , feed , depth of cut & characteristic's of work piece material , throughout the machining process high heat generated when we put the coolant it can be limited , if cryogenic cooling is perform by LN_2 temperature is reduced about 16 % to 27% . the temperature of variation depends upon the value of cutting parameter.
- The value of associated cutting cutting forces is increased by 13% and 9% if cryogenic cooling is done for alloy steel EN-8 & aluminum alloy 6061 –T 89 respectively.
- The chip thickness is reduced about 15 % to 23% in respect of dry machining state of EN – 8 & AL-6061 T89.
- The shear angle variation by cryogenic cooling is achieved about range of 13% to 27% for respective test specimens

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