Impact of cryogenic cooling during machining: A Literature Review

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Abstract- Evolution in new engineering materials like difficult to cut materials, super alloys & composites materials and following of strict international norms during machining the use of conventional cutting fluids are unsatisfactory. Liquid nitrogen is better eco friendly and efficient coolant available. This is a step forward towards green machining. Direct supply of LN2 at the interface of tool and workpiece removes heat fast and make the temperature low. Co- efficient of friction, cutting force, cutting temperature, tool wear and surface roughness between tool and workpiece are reduced by 20-35%, 50-75%, 60-82%, 50-60% and 35-50% in comparison to dry machining respectively.
Keywords – Cryogenic cooling, Liquid nitrogen, cutting insert, dry machining, cutting fluid

I. INTRODUCTION

Dry machining is non polluting but it is restricted to low cutting parameters. This results in low manufacturing rate. Conventional cutting fluids can no longer be used during machining due to the development of new engineering materials to fulfill the ever rising demand of world and community [1-4]. Cryogenic cooling with LN2 is better available alternate. This is eco friendly and operator friendly. LN2 is colorless, odorless, tasteless and do not produce any toxic fumes. The boiling point of LN2 is -196°C. The high rate of heat transfer makes it efficient coolant for removing heat [5-7]. It is shown in Fig. 1 that during turning LN2 is directly supplied at the rake face of cutting tool and workpiece. LN2 is stored in Dewar container and passed through insulated pipes at the specified position. Compressor is used to supply compressed air in the container. Pressure regulator is used to keep the supply constant. Flow meter is used for measuring the flow rate.

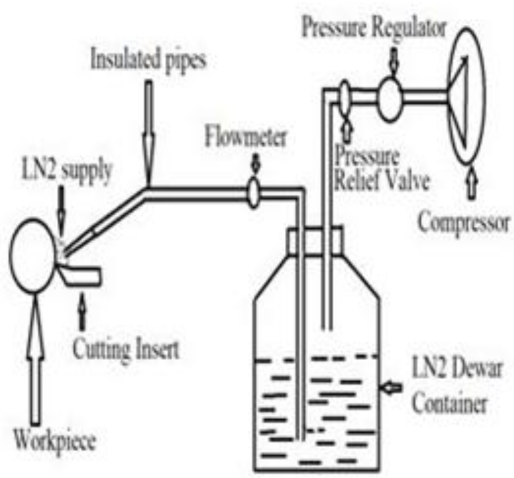

Fig.1. Schematic process of cryogenic machining

II. LITERATURE REVIEW:

2.1 Work done by researchers in Cryogenic Cooling

Cryogenic cooling means cooling the surface below 0°C to - 196°C. At low temperature the metallurgical properties of materials get changed e.g. porous materials become hard. This cooling is done by liquid nitrogen, solid carbon dioxide or other refrigerated non toxic gas and chilled air. The cutting temperature reduced by 60-70%.

Sno.	Author, Year, Reference No., Title of paper	Work Done	Results/ Findings

1	Mputz et al. 2016 [1]: Investigation of turning elastomers assisted cryogenic cooling.	Investigated approach to enhance machinability with cryogenic cooling during cutting elastomer components	Liquid Nitrogen used to cool down elastomers before machining. The surface quality was improved.
2	M.J. Bermingham et al. 2011 [2]:New observation on tool life, cutting forces and chip morphology in cryogenic machining Ti-6Al-4V	Investigated the effectiveness of cryogenic coolant during turning of Ti-6AI-4V at constant speed and material removal rate (125m/min, 48.5cm3/min) with different combinations of feed rate and depth of cut	Cryogenic coolant was effective in extending tool life compared to dry cutting for all machining parameters
3	Xinda Huang et al. 2014[3]: The influence of cryogenic cooling on milling stability.	Experimental studied the effect of cryogenic cooling on milling stability using a dedicated cryogenic cooling system for applying liquid nitrogen (LN2) jet to cutting zone.	Cryogenic cooling was enhanced the stability limits in end milling by 50-100%
4	N Yuvaraj et al. 2016 [4]: Cutting aluminium alloy with abrasive water jet and cryogenic assisted abrasive water jet: A comparative study of the surface integrity approach.	Cutting aluminium alloy with abrasive water jet and cryogenic assisted abrasive water jet: A comparative study of the surface integrity approach	CAAW Cutting process enhanced the functional performance of cut surface and uniform surface roughness pattern.
5	J.Schoop et al. 2013[5]:The effects of depth of cut pre cooling on surface porosity in cryogenic machining of porous tungsten.	Investigated the influence of cryogenic pre-cooling time and depth of cut on the attainable surface morphology of porous tungsten.	Result showed that increased pre-cooling significantly altered the deformation mechanism during machining.
6	Aman Aggarwal et al. 2008 [6]: Optimization of multiple quality characteristics for CNC turning under cryogenic cutting environment during desirability function	Optimized multiple characteristics (tool life, cutting force, surface roughness and power consumption) in CNC turning of AISP-20 tool steel using nitrogen as coolant.	Models developed were adequate in explaining the effect of independent parameters on responses.
7	Shane Y. Hong et al. 2001[7]: Cooling approaches and cutting temperature in cryogenic machining of Ti-6Al-4V	Introduced an innovative and economical dispensing method that directed LN2 through microjets to the flank, rake or both near the cutting edge in the turning of Ti6A1-4V alloy	Results showed that small amount of liquid nitrogen applied locally to the cutting edge was superior to emulsion cutting in lowering the temperature.
8	K.Aslantas et al. 2016[8]: Performance evaluation of a hybrid cooling lubrication system in micro - milling of Ti6Al4Valloy	Presented a hybrid system for cooling and lubrication in micro-milling of Ti6A14V alloy. Hybrid system was based on mixing oil with chilled air	Result showed that hybrid system gave minimum tool wear and burr size.
9	Nabil Ben Fredj et al. 2006[9]: Ground surface improvement of the austenitic stainless steel AISI 304 using cryogenic cooling	Presented evaluation of ground surface quality improvements of the austenitic stainless steel AISI 304 resulting from the application of cryogenic cooling.	Due to cryogenic cooling surface roughness reduced by 40%.
10	Le De Chiffre et al.	Investigated efficiency of cryogenic	Results showed that cryogenic

	2007[10]:Performance testing of cryogenic CO2 as cutting fluid in parting/ grooving and threading austenitic stainless steel.	CO2 and compared a commercial water based cutting fluid in terms of tool life, surface finish, chips disposal etc.	CO2 was an alternative as compared to water based cutting fluid
11	Weiwei Wu et al. 2017 [11]: The reinforcing effect of graphene nano platelets on the cryogenic mechanical properties of GNPs/Al2O3 composites	Presented the GNPs/Al2O3 (Graphene nano platelets reinforced alumina) fabricated by colloidal process. The optimum content of GNPs in GNPs/Al2O3 composite was 1.0 vol%.	Presented the GNPs/Al2O3 (Graphene nano platelets reinforced alumina) fabricated by colloidal process. The optimum content of GNPs in GNPs/Al2O3 composite was 1.0 vol%.
12	Y. Kayank et al. 2013 [12]: Tool-wear analysis in cryogenic machining of NiTi shape memory alloys: A comparison of tool-wear performance with dry and MQL machining	Examined the effets of cryogenic cooling on tool-wear rate and progressive tool-wear by comparing new findings from cryogenic machining with MQL and dry machining.	Cryogenic cooling was effective on reducing tool-wear rate at high cutting speeds and reducing flank wear and notch wear.
13	Satish et al. 2015 [13]: Machining of hardened steel - experimental investigations, performance modeling and cooling techniques: A review	Presented a comprehensive literature review on marching of hardened steels using coated tools, studies related to hard turning, different cooling method and attempt so far to machining performance	Optimal combination of low feed and low depth of cut with higher cutting speed was beneficial for reducing machining force and surface roughness.
14	E.M. Rubio et al. 2015[14]: Cooling systems based on cold compressed air a review of the applications in machining process.	Collected the review and analysised the cooling systems based on cold compressed	Results showed that cold compressed air is a real environmental friendly alternative to other conventional lubrication / cooling systems
15	Vishal S.Sharma et al. 2009[15]:Cooling techniques for improved productivity in turning.	Presented an overview of major advances in techniques as minimum quantity lubrication (MQL) / near dry machining (NDM), high pressure coolant (HPC) cryogenic cooling, compressed air cooling and used of solid lubricants coolants.	Result showed that coconut oil as coolant was encouraging at lower speeds. All types of cooling techniques gave good response with almost all tool material, particular with carbide (coated/uncoated) and PCBN.
16	C.Courbon et al. 2013[16]:Tribological behaviour of Ti6 Al4V and Inconel 718 under dry and cryogenic conditions application to the context of marching with carbide tools	Investigated the cooling and lubrication capabilities of nitrogen jet under extreme contact conditions using a dedicated tribometer..	Neither liquid nor gas nitrogen was able to decrease the co-efficient of friction and material transfer when Ti6Al4V and uncoated carbide pins were used, but a significant improvement was noted for Inconel 718 and TiN coated pins
17	Yang Gao et al. 2016[17]:Effects of keep cryogenic treatment on the microstructure and properties of WC-Fe-Ni cemented carbides.	Investigated the effects of deep cryogenic treatment on microstructure and properties of WC-Fe-Ni cemented carbides. The specimens were treated about -196° C for 2,12 and 24 hours.	The mastensite transformation temperature for WC-Fe-Ni cemented carbide was approximately - 23.28°C. The hardness and TRS of WC-FE-Ni cemented carbides after deep cryogenic treatment was higher

			than untreated ones.
18	A.I. Tyshchenko et al. 2010 [18]: Low-temperature martensitic transformation and deep cryogenic treatment of a tool steel.	The tool steel X220 CrV Mo 13-14 (DIN 1.2380) containing (mass%) 2.2C, 13 Cr, 4V,1Mo and the binary alloy Fe2 O3 mass%C were studied using transmission electron microscopy. It was cryogenically cooled to - 50°C	he results showed that , there was an increase in the density of dislocations, captured of immobile carbon atoms by moving dislocations and strain induced partial dissolution of carbide phase.
19	Alborz Shokrani et al. 2016[19]: Investigation of the effects of cryogenic machining on surface integrity in CNC end milling of Ti-6Al- 4Vi titanium alloy	Presented first comprehensive investigation on the effects of cryogenic cooling using liquid nitrogen on surface integrity of Ti-6Al-4V titanium alloy workpiece in milling operations	Results showed that 39% and 31% lower surface roughness when compared to dry and flood cooling methods respectively.
20	J. Schoop et al. 2016[20]: Cryogenic machining of porous tungsten for enchanced surface integrity.	Investigated cryogenic machining of porous tungsten was developed as alternative sustainable process to current industry practice of machining plastic infiltrated workpieces.	Results showed that by using modified polycrystalline diamond cutting tool, high speed cryogenic machining of porous tunsten by ductile shear was achieved. Cutting speed of 400m/min and low surface roughness Ra ~ 0.4 μm
21	B. Podgernik et al. 2012[21]: Improving tribological properties of tool steels through combination of deep - cryogenic treatment and plasma nitriding	Investigated the effect of deep cryogenic treatment parameters (time and temperature) in combination with plasma nitriding on the tribological performance of powder - metallurgy (P/M) high speed steel.	Results showed that deep cryogenic treatment contributed to improved abrasive wear resistance plasma nitriding improved tribological properties of P/M high speed steel and reduced the effect of austenzing temperature
22	Shaohong Li et al. [2013], [22]. Experimental verification of segregation of carbon and precipitation of carbides due to steel by internal friction method.	Presented an internal frictional behaviour of cold work tool steel subjected to different heat treatment schedules to get insight to segregation of carbon and refinement of carbide particles due to deep cryogenic treatment.	Results showed that interstitial carbon atoms migrated and segregated near by dislocations of shrinking strain energy during deep cryogenic treatment.
23	Shane Y. Hong et al. 2001[23]: Micro temperature manipulation in cryogenic machining of low carbon steel	Presented an environmentally safe approach of micro manipulation of cutting temperature in machining AISI /SAE 1008 low carbon steel.	Results showed that chip breaking was improved by cryogenic cooling the chip to below the embrittlemnt temperature -55°C the tool wear decreased and increased tool life..
24	F. Pusavec 2012 [24]: Porous tungsten machining under cryogenic conditions.	Experimentally studied on high performance machining of porous tungsten under cryogenic conditions	Cryogenic method was compared with traditional carbide tools PCD, CBN, ceramic etc. Results showed cryogenic was capable of producing unsemeared surfaces. The surface finish was improved.
25	Vojteh Leshovsek et al. 2012[25]: Vaccum heat treatment deep cryogenic treatment and simultaneous pulse plasma nitriding and tempering of	Presented vaccum heat treatment deep cryogenic treatment and pulse plasma nitriding were efficient techniques to improve properties of tool and high speed steels.	Results showed that deep cryogenic treatment improved the micro structure of investigated P/M high speed steel.

	P/M 5390 MC Steel.		
26	V.G. Dhokia et al. 2011[26]: A process control system for cryogenic CNC elastomer.	Presented the novel concept of cryogenic CNC maching of elastomers and development of a process control system for cryogenic CNC machining.	Results showed that the surface finish was very good as compared to other conventional methods.
27	Shaohong Li et al. 2010[27]: Influence of deep cryogenic treatment of microstructure and evaluation by internal friction of a tool steel.	Studied deep cryogenic treatment (DCT) on microstructure of tool steel.	Results showed that retained austenite was present in a thin film between laths of martensite and stably existed even during prolonged soaking time in liquid nitrogen. Hardness and wear resistance on tool steel increased.

III.CONCLUSION

1. The liquid nitrogen is an efficient and eco friendly coolant during machining.
2. It leaves no residue after applying at the interface of tool and workpiece.
3. The metal scrap after machining do not require any treatment for removing any oil deposits or toxic elements and can be readily available as a source of recycling material for further industrial use.
4. The tool life during cryogenic cooling is increased by 70-80% as compared to dry machining and 30-50% in wet machining using conventional cutting fluids.
5. Co- efficient of friction, cutting force, cutting temperature, tool wear and surface roughness between tool and workpiece are reduced by 20-35%, 50-75%, 60-82%, 50-60% and 35-50% in comparison to dry machining respectively.

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