International Journal of Advance Research in Science and Engineering
Vol. No.4, Issue 09, September 2015
www.ijarse.com
IJARSE
ISSN 2319 - 8354

REVIEW ON EXPERIMENTAL ANALYSIS OF CRYOGENIC COOLING ON VARIOUS MACHINING PROCESSES

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ABSTRACT

The word Cryogenics is originated from two Greek words, which are "Kayos" and "Genes" respectively. The word "Kayos" means "Cold or freezing" and "Genes" is nothing but "born or produced". Generally Cryogenic concept is known for attaining or obtaining very low temperatures and in this generally Liquid Nitrogen and Liquid Oxygen are commonly used. Sometimes Liquid Helium is also used for Cryogenic purposes. The temperature required to hold hydrogen and oxygen at liquid state are 20K and 90K respectively. Cryogenic technology mainly refers to systematic study of producing very low temperatures of below 120K and studying material's behavior and properties at particular temperatures. In Era of Modern Engineering and Technology the "Sustainable Manufacturing" is of prime importance. In the manufacturing processes, machining of components results in tool wear due to increase in cutting tool temperature and heat zone thereby deformation and destruction of work piece and cutting tool, finally work piece and cutting tool both get damaged. To avoid above adverse effects ofmachining, adoption of proper cooling technique is required. But conventional cooling processes are unable to control all such adverse effects because of this cooling of machined components by Cryogenic technique is growing demand in sector of manufacturing and production. The cryogenic fluids used in cooling of machined components are environmentally safe, clean, nontoxic and cheap unlike conventional emulsion cutting fluids. Generally Liquid Nitrogen is the most commonly used cryogenic fluid for cooling, as it is cheap and has greater capacity to dissipate heat from heat zone. The manufacturing of components employing cryogenic cooling technique results in technical benefits such as reduction in cutting tool temperature, increased tool life , minimizing cost of production, increased speed without fracture and overheating of tool, reduction width of heat and temperature affected zone, etc. but this technique also has some drawbacks itself like for cryogenic cooling, separate setup is required for monitoring and controlling the process makes it uneconomical at some conditions also cryogenic fluids are not reusable so sometimes this cooling technique is not feasible. Cryogenic technique is also widely utilized in Space and Aircraft, Atomic Energy, Refrigeration sectors. This paper critically reviews and analyses cryogenic technique as remedy in the field of manufacturing. This study reviews different cryogenic cooling techniques and its effect in properties of

material during different stages of machining. The current paper describes details of effects of cryogenic tool life, surface quality of finished product, etc. Thus Cryogenic cooling can be the optimum alternative for conventional cooling in field of manufacturing.

Keywords: Cryogenic Cooling, Sustainable Manufacturing, Cutting Temperature, Sinter Hardened Materials, Joule Thomson Coefficient, Oxidizer, Tool Wear, Orthogonal Cutting, Etc.

I. INTRODUCTION

The cryogenic technology can be defined as "it is branch of Applied Science which deals with the study of producing and obtaining very low temperatures and its effects on system as well as surroundings". This study mainly includes attaining those temperatures which are not naturally occurring on Earth. In more realistic way, cryogenics is nothing but branch of Physics associated with obtaining temperatures below 120K. Generally temperature range for cryogenic cooling is between 120K to77K.Liquid Nitrogen, liquid Oxygen, liquid helium are some cryogenic fluids commonly used in this technique.

During World War II, Rocket Engines were developed by Germans, Americans and Russians. In such engines high mass flow rate of Oxidizer and Fuel is required to provide sufficient thrust to rocket engines, ultimately the efficiency of Rocket Engines get decreased due to high weight of fuel tank. To avoid this problem it was necessary to store and cool the fuel at low temperatures in liquid form, this could be only possible by cryogenic technology, thus from the days of world war II cryogenic technology is being used for various industrial applications. Nowdays, Cryogenic technology is being widely used in many industrial as well as commercial applications such as Cryogenic Refrigeration, Cryogenic cooling and machining, Nuclear and Atomic energy, Space and Research, etc. cryogenic technology is mostly used in typical rocket engines which are specially designed to release satellite into Earth's Orbit as well as to escape from Earth's gravity to deliver probes into space. In such rocket engines the propellants are in liquid form which are stored and cooled at very low temperatures which would be in gaseous state if exposed to normal atmospheric pressure and temperatures. Such propellants are nothing but Oxygen as Oxidizer and Hydrogen as fuel. To produce required propellant force or thrust either hydrogen as fuel ignited with oxygen as oxidizer or they are mixed to generate super-hot stream at engine nozzle which produces sufficient thrust.

In the Era of Precision Engineering, Sustainable manufacturing becoming a growing and demanding trend for restricting difficulties regarding economical as well as health related problems mainly caused due to conventional cooling techniques. Every commercial industry is primarily looking for workforce and environmental safety so proper manufacturing cooling techniques are being adopted by them. In manufacturing, due to machining wear of cutting tool, thermal deformation of component, increase in cutting temperature at interface of tool and job, etc. takes place. But these effects cannot be easily controlled by conventional cooling results in poor surface finish and quality of final product, increase in production cost, etc. conventional cooling has more adverse effects on economic and ecological basis. Conventional coolants are not degradable and also bacteria get produced in it after time period, it causes lung disease, cancer, etc. health related problems and reduction in lubricity. Besides this the cryogenic

fluids are normally used in dry machining enjoys some benefits over conventional cooling like they are nontoxic, environmental friendly, safe, clean, etc. They absorb heat quickly and dissipate it to environment without releasing harmful residues

Fig 1.1 Sustainable Manufacturing

1.1 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

In Cryogenic cooling process cryogenic fluid is stored in pressurized cylinders or vessels outside plant building from cylinder it is circulated in plant through vacuum jacketed flexible lines. A control box is permanently attaches to machine setup to regulate flow of cryogenic fluid. Nozzles are clamp to turret of machine for discharging cutting fluid near insert. Thus cryogenic fluid is sprayed on tool chip interface and proper care is taken so that work piece should not freeze due to low temperature of cryogenic fluids .The process setup is shown in fig no.1.2

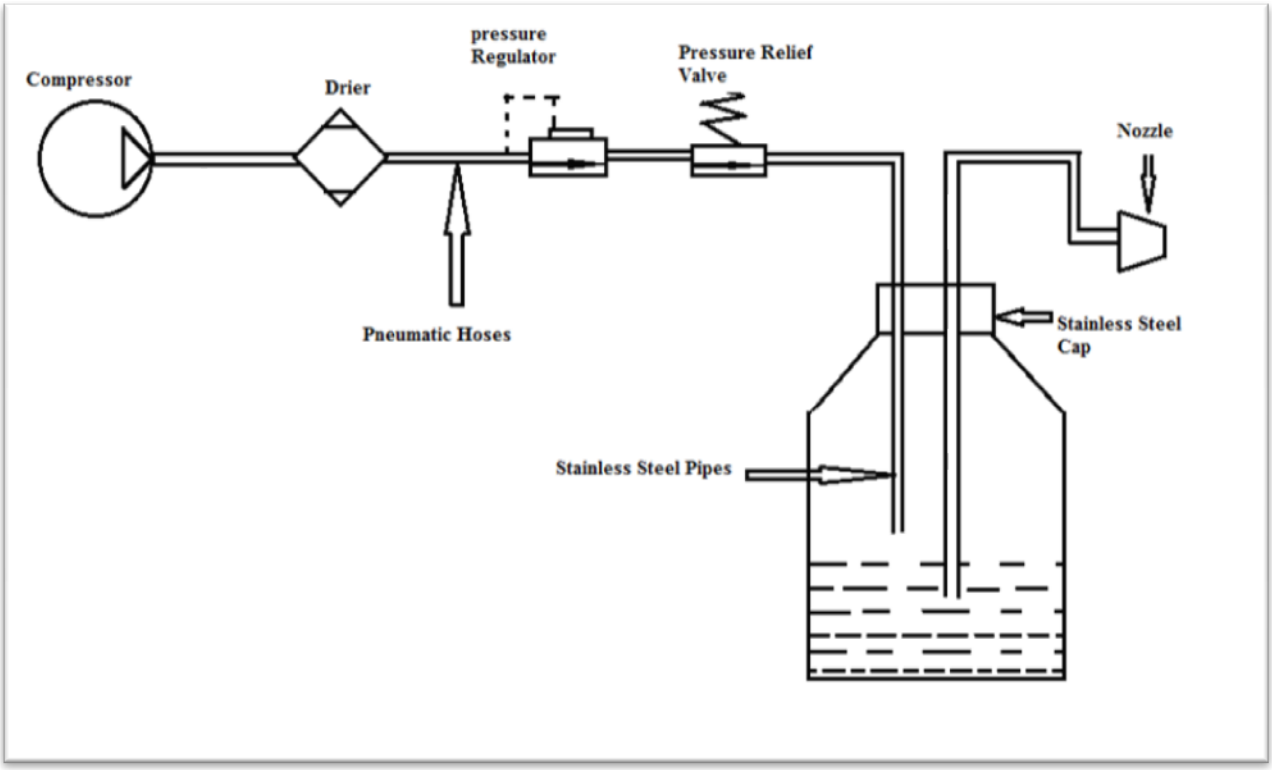

Fig 1.2 Setup for Cryogenic Process

Generally cooling of equipment by cryogenic fluids is by utilizing latent heat of vaporization. Latent heat of vaporization of cryogenic fluids generally lies between temperature range of critical point and triple point. For cryogenic fluids, sensible heat of vaporization between range of saturation temperature is much large than latent heat of vaporization, thus the process provide adequate cooling potential of intermediate temperature for thermal cooling at normal room temperature.

1.2 Joule Thomson Coefficient Effect

The rate of change of temperature **T** with respect to **P**in Joule Thomson process (that is at constant Enthalpy H) is the Joule Thomson coefficientμ_{JT}. The coefficient can be expressed in terms of gas volume V, its heat capacity at constant pressureC_P and its coefficient of thermal expansionα. The equation can be given as:-

$$\mu_{JT} = \left(\frac{\partial T}{\partial P}\right)_H = \frac{V}{C_P}(\alpha T - 1)$$

1.3 Advantages of Cryogenic Cooling

Cryogenic cooling technology enjoys some great advantages over conventional cooling processes. Such advantages are as follows:

- Reduced energy consumption in machining processes

- Clean fluids
- Economical
- Safe and Environmental friendly
- High metal removal rate(MRR)
- Better Quality/surface of product
- Increased speed without fracture and overheating of tool
- Reduction in overall production cost
- Reduction in width of heat and temperature affected zone
- Chemically stable
- Colorless(Liquid Nitrogen)
- Readily vaporizes to gas
- Non toxic

1.4 Disadvantages of Cryogenic Cooling

In spite of some great advantages cryogenic cooling has some limitations which are as follows:

- Extra or additional controlling setup is required to monitor and regulate the cooling process.
- High initial as well as maintenance cost.
- Some cryogenic fluids such as Liquid Nitrogen are not reusable, so sometimes may not be feasible, hence uneconomical.
- Chances of damage of work piece when cryogenic fluid held at very low temperatures comes in direct contact with it during machining process.
- Cryogenic cooling technique is not suited for Heat Treatment Process

1.5 Applications of Cryogenics

Although Cryogenic technology is being used in almost all fields of Engineering, but some specific and important applications are listed below:

- Nuclear magneto Resonance Spectroscopy.
- Magnetic Resonance imaging.
- Blood Banking and Frozen Food.

II. REVIEW OF SOME RESEARCHERS

2.1 Prudvi Reddy et al [1]:- This paper mainly underlines the performance of cryogenic cooling technique on various aspects of grinding operation such as Grinding Ratio and Spindle power of Hardened bearing steels using Alumina grinding wheel. Cryogenic cooling result in increased in grinding ratio as well as effective cooling of grinding zone indicated by Scanning Electron Microscope (SEM). But at the same time it cause dimensional

inaccuracy and increased power consumption than dry cooling. Researchers had performed the experiment, shows cryogenic cooling enhances life of grinding wheel and reduction in grinding temperatures. Cryogenic fluids are more advantageous for grinding of ceramic materials. And spindle power, chip morphology, grinding ratio was critically studied.

2.1.1 Material Specification

- Reciprocating surface grinding machine (Alex Machine Tools Pvt Ltd)
- Solenoid valve (UK Model TVP 60)
- AISI steel plates of (100 X 80 X 10)
- Initial Hardness of 190HVP
- Table speed- 6m/min
- Grinding wheel- Alumina abrasive wheel of mesh size 60
- Pressure of LN_2 in vessel- 1.5 bar

2.1.2 Experimental Setup:

Experimental Setup for Grinding of Hardened Bearing Steel using Alumina Grinding Wheel is shown in fig 1.3.

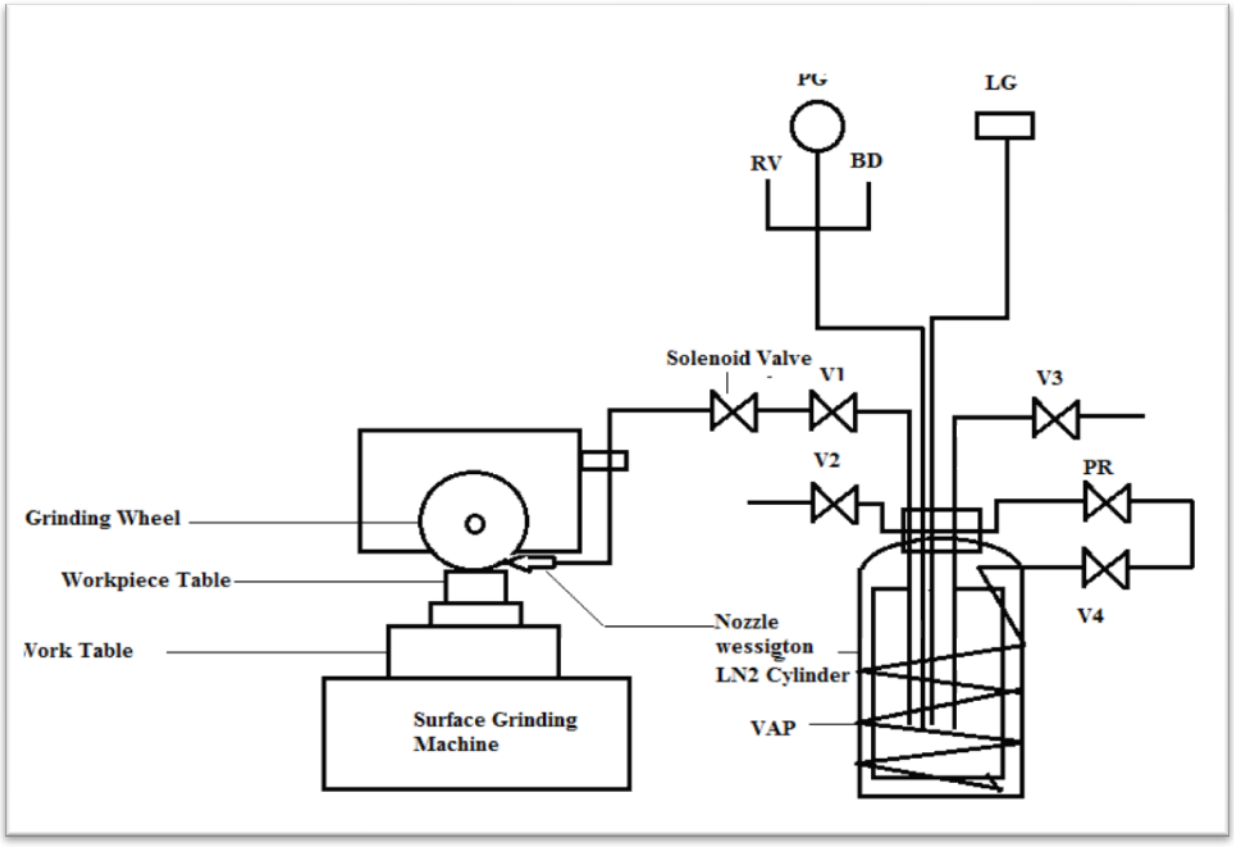

Fig 1.3 Experimental Setup

2.1.3 Experimentation

The experimental setup was dedicated to deliver the Liquid Nitrogen for cryogenic cooling. The machine used was reciprocating grinding machine. Liquid nitrogen is delivered through copper nozzles and liquid nitrogen was stored in dewar. The sample is prepared first by heat treatments by austenite temperature 870C for nearly 2 hours. Then Hardness test is performed on sample. And finally sample was grinded and machined. Generally Alumina Grinding wheel is used for grinding. Experiment was performed and results are discussed.

21.1.4 Spindle Power Measurement

To evaluate how much improvement in grinding using cryogenic coolants, spindle power was measured using power cell which was integrated by hall's effect. In this experiment the voltage and current drawn by spindle was fed to data acquisition system, peak voltages are measured and finally spindle power was calculated by subtracting idle power from total power.

2.1.5) Grinding ratio Evaluation

Grinding ratio is nothing but index of wear rate of grinding wheel. In this, work piece is allowed to ground around 1000 passes under alumina grinding wheel. Finally Grinding ratio calculated by ratio of volume of material removed per unit volume of grinding wheel wear.

2.1.6)Results and Discussions

Power consumption was reduced by 25 folds as that of conventional cooling process. Dimensional accuracy was found to be increased. Optimum grinding ratio was defined and the same was found to be better than before. Improved cooling was observed in chips under SEM grinding of work piece.

2.2 Ranajit Ghosh et al [2]

In current paper, the researcher had proposed new cryogenic cooling approach for sinter hardened material. As we all know, sinter hardened materials having excellent mechanical properties but this also limits its ability to machine easily. 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. So researcher carried out experiment of cryogenic cooling on sinter hardened materials and results were discussed.

2.2.1 Specifications

- Cutting tool material- PCBN, Tin coated Al_2O_3
- Depth of cut- 0.25 mm
- Feed rate- 0.30mm
- Cryogenic cooling method- Nitrogen cooling (Bottom cooling)
- Cutting speeds- 290-412 m/min

2.2.2 Experimentation

To test the effects of cryogenic cooling on machining of sinter hardened materials, different machine test were performed on it under cryogenic cooling using liquid bottom cooling method. Before that sample of sinter hardened material was prepared by mixing various additives in it, and it was compacted to press at 140 tones, heating at temperatures at 1140C to get sufficient hardness up to 40-60HRc. The machining tests were carried out and results were discussed.

2.2.3Results and Discussions

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%.

2.3 D. Umbrello et al [3]:- This paper mainly describes effect of cryogenic cooling on surface integrity on AISI 52100 steel of hard machining. Generally what happens, during machining processes, deformation of cutting tool occurs in narrow region due to localized heat and temperatures, so alteration in microstructure arrangement of material takes place, is nothing but formation of white layer. The formation of white layer on the surface of job is undesirable because it causes poor surface finish and severe impact on wear of work piece. To avoid this, researcher took experiment of treating AISI hardened steel with cryogenic coolants. Experiment was performed and results were discussed. He mentioned, Zurecki proved that there is elimination of white layer when material is machined under cryogenic cooling.

2.3.1 Specification

- Tool insert- low CBN
- Chamfer- (20 X 0.2 mm)
- Tool holder- TFNR322P11(rake angle is between -8 to 8)
- Material-AISI 52100 steel
- Outer diameter- 150mm
- Thickness- 1.4 mm
- Cutting speed- 75m/min

2.3.2 Experimentation

First heat treatment is done on specimen, and then disks of AISI steels are machined at given cutting speed, feed rate and cutting time. Generally CBN tool inserts were used to detect flank wear and then job is polished in natal solution for 5 seconds and scanning electron microscope is used to observe formation of white layer on surface of machined component. The experiments were performed and results were discussed.

2.3.3 Results and Discussions

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.

2.4 M. Pradeep Kumar et al [4]

In current paper researcher introduces the idea of investigating the effect on orthogonal machining processes by liquid nitrogen (LN_2) 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.

2.4.1 Specifications

- Material- AISI 1045 and Al 6061- T6 alloy
- Outer diameter- 80 mm
- Thickness- 2 mm
- Temperature measuring device- non contact type of pyrometer (infrared)
- Dynamometer- Kistler type multi-channel amplifier

2.4.2 Experimentation

The orthogonal cutting of work piece or specimen was carried out. In cryogenic cooling setup, there was a specially designed nozzle. Through the nozzle, liquid nitrogen was injected at rake face of cutting tool as well as chip tool interface of specimen during orthogonal machining. Experiment was performed and results were discussed.

2.4.3 Results and Discussions

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%.

2.5 L. Liqing et al [5]

According to the point of view of researcher cryogenic cooling has great advantage for machining of dry EDM processes. In this paper dry EDM on cryogenically cooled jobs are experimented. As we all know that EDM means Electro Discharge machining is type of non-conventional machining and widely used in industries now days. But during machining of components by EDM on conventional cooling technique, resulting insufficient rate of Metal Removal Rate (MRR), more wear of electrode. So many researches were done by the scientist on improving efficiency of dry EDM; experiment was performed in which jobs on EDM machine were cooled by cryogenic coolants.

2.5.1 Experimentation

In this experiment, cryogenic cooling system devices are utilized to cool job or work piece. Here cryogenic coolant (Liquid nitrogen) kept in vessel shaped like kettle. LN_2 was injected on job through a nozzle or spout of kettle. Work piece was mounted on upper surface of kettle. And thermocouple is used to measure the temperature at interface of cutting tool and work piece. Experiment was performed and results were discussed.

2.5.2 Results and Discussions

Tool wear was decreased to by 20%.Also there is improvement in SR 27%

III. CONCLUSION

This paper critically reviews and focuses on effect of cryogenic cooling on various machining processes along with its advantages and disadvantages. From the paper it can be reviewed that cryogenic cooling technology is very beneficial for manufacturing sector from economical, health and environmental point of view.

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