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Impact of environmental friendly machining on machinability: A review

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A B S T R A C T

Today's, due to the environmental concerns, growing contamination and pollution regulations, the demand for renewable and biodegradable cutting fluids is increasing day by day. In this review article, an attempt is made regarding ecological processing, including different types of cutting fluids. The Knowledge of different types of cutting fluid and its processing conditions is of critically importance to maximize the efficiency of cutting fluids in any machining process. In general, the generation of heat in the cutting zone due to friction at the tool-chip interface and the friction between the safety surface of the tool and the work piece is always the deciding factor on the quality of the work piece surface. The two factors such as surface roughness and tool wear are always used as quality indicators of a finished or semi-finished product. The main motive of this review article that studies the different environmental friendly machining and encourages the cooling approach in machining operation. So finally, it is observed that the environmental friendly machining is cost effective machining and environmental friendly.

1. Introduction

Due to the environmental and health problems which are caused by using conventional cutting fluids in metal cutting operations, a new economical and practical approach cryogenic machining wasdeveloped. In the past, the conventional cooling technique is used in metal cutting process which is neither economical nor environmentally friendly [1], also conventional cutting fluids and dry machining failed to satisfy manufacturers requirement because some issue such as poor surface finish, low productivity and less tool life. Due to these problems are occur so unconventional cooling method such as chilled air [2], Minimum quantity lubricant (MQL) [3,4] and cryogenic cooling method have been introduced as an alternative method to improve machinability as compared to other machining process.

After the literature survey it is visually examined that cryogenic cooling approach provide better results compared to other unconventional techniques, because in cryogenic machining micro nozzle jetting to the cutting point locally is used so this approach minimizes the tool wear and enhancement of machinability. In addition, these techniques improve surface quality, remove built up edge, reduced friction force and also improve tool life. In cryogenic machining liquid nitrogen, CO2, helium gas uses as a coolant which has been defined as an environmentally friendly technique [5]. The cryogenic machining is environmental friendly machining and also cost-effective route to improve its environmental, economic, and social footprint when it comes to cutting with different grade intractable materials. Environmental friendly machining having different advantage in different areas such as minimum manufacturing cost, minimum environmental impact.

1.1. Background report of cooling approach

It was accounted for that the measure of lubrication utilized in machining around 38 Mt with an expected ascent of 1.2% over one decade from now. And furthermore 80–85% mineral based cutting fluids are utilized. This is neither affordable nor earths cordial. Mineral-based cutting liquids that are perilous for capacity and removal require the uncommon physical or substance treatment by an environmental protected agency to eliminate poisonous segments inside the cutting fluids preceding removal [6]. The expense of cutting fluids including buy, readiness, support and removal, is assessed to be around 16% of an item's absolute assembling costs. The expense of discarding cutting fluids can be dependent upon

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two to multiple times higher than the buy costs on the grounds that the cutting fluids are not biodegradable and require costly treatment before removal [7]. The persistently expanding the expenses of utilizing and discarding cutting fluids with the blend of the new follow up on the insurance of the climate and health problems, which is required to turn out to be significantly all the more requesting later on, have prompted a total logical exploration towards ecological well disposed machining [8]. In this manner, the attention on cutting fluids has moved throughout the years from biodegradability to inexhaustibility so as to ensure our venerated climate. The various parts of a naturally adjusted cutting fluid are recorded regarding biodegradability, harmfulness, sustainability, and biocompatibility and so forth [9].

1.2. Limitations of conventional fluids

In the previous years, the impact of ordinary cutting fluids on natural or monetary variables with preparing it has become a rising dangerous perspective. It was seen that around 70–80% skin issues of machine administrator were because of contact with cutting fluids [10]. The hurtful impacts of cutting fluid reason bunches of techno-ecological issues and furthermore genuine medical conditions, for example, cellular breakdown in the lungs, respiratory illnesses, dermatological and hereditary ailment [11]. For improving compound solidness, fire obstruction, low toxicity; chlorinated paraffin is utilized as added substances in cutting liquids [12]. By the by, cutting liquids containing Chloroparaffin as outrageous weight added substances are not, at this point legitimate to be utilized in future. This is on the grounds that chlorinated paraffin in outrageous weight cutting fluids changes to dioxin by warmth and pressure and could prompt chlorine skin inflammation. Plus, removal of cutting fluids containing chlorinate is just permitted to be scorched in unique cremation locales since the poisonous dioxins can prompt uncontrolled consuming. Accordingly, it is named perilous waste to human life just as to the climate [13]. And furthermore cutting liquids have chlorine added substances which are not appropriate in machining of titanium composites as it can cause consumption on the machined surface. Also, cutting liquids that have disintegrated and atomized because of high weight and temperature in machining tasks, bringing about the arrangement of cutting fluid mist. Mist, exhaust, smoke and scents created by cutting liquids, particularly with synthetic added substances, for example, sulfur, chlorine, phosphorus, hydrocarbons and biocides, can cause skin responses and breathing issues [14].

2. Techniques of environmental friendly machining

In environmental friendly machining following types of techniques are considered. These are followings,

2.1. Dry machining

Dry machining, meaning no cutting fluids applied in the machining process. This method is applied to avoid the problems

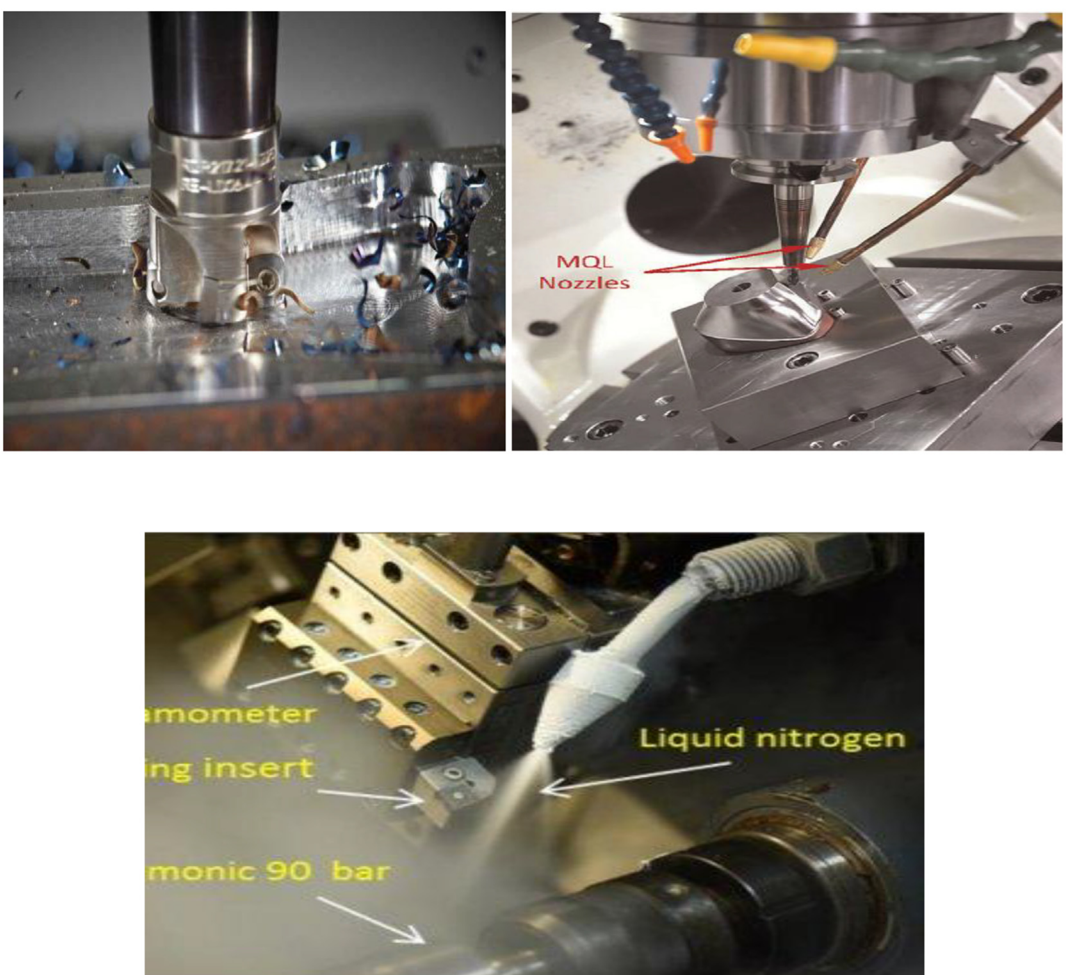

Fig. 1. (a, b & c) Dry machining [16], MQL machining [18] & Cryogenic Machining System [19]

Table 1
Showing literature of machining on Ti and its alloy under different cooling environment.

Reff.	Cutting tools	Work piece	Machining environment	Input parameters	Response	Outcomes
[20]	Uncoated carbide inserts,ISO CNMG120408	Ti-6Al-4 V	UT, CT (12H, 24H, 36H)	V_c- 50,75,100 m/min.,f- 0.1,0.15,0.2 mm/rev.,D- 0.2, 0.4, 0.6 mm	TW, Ra, Cutting force	Deep CT up to 36H is most effective parameter.
[21]	TiAlN coating insertsCNMG431RP	Ti-6Al-7Nb	Dry, flood and cryogenic environment	V_c- 30 m/min., d- 0.75 mm, f- 0.05 mm/rev.	Ra, Microstructure	Ra was improved by 35%, 6.6% compared to both.
[22]	SANDVIK 432MM insert with TiCN coating	Ti-5553	Flood, MQL, Cryogenic cooling	V_c- 50 m/min., f- 0.05, 0.125, 0.2 mm/rev.	TW, force analysis	Cutting force and thrust force reduced by 30% compared to flood, MQL.
[23]	Carbide inserts CNMX120408A2S	Ti-6Al-4 V	Dry, Cryogenic compressed air	V_c- 150, 220 m/min.,	Tool life	Reductions in tool wear with compressed air.
[24]	Cemented carbide CNMG120,404	Ti-10 V-2Fe-3Al	Emulsion, Co2	V_c- 50,100,150 m/min.,f- 0.1, d- 0.3 mm	Tool wear	Compared to flood emulsion cooling the tool wear reduce with Co2 method.
[25]	Coated carbide tool CNMG120,412	Ti-6Al-4 V	Oil based coolant, cryogenic cooling	V_c- 70, 100 m/min.,f- 0.25 mm/rev., d- 0.5 mm	Tool wear,Chip formation	After experimental work it was observed that cryogenic cooling system improve machinability and reduce tool wear.
[26]	Uncoated cemented carbide inserts	Ti-6Al-4 V	Dry, wet with MQL, MQL with 0, −15, −30, −45 degree	V_c- 62.8 m/min., T- 8–22 min., d- 1.00 mm, f- 0.075 mm/rev., width- 8.00 mm	Ra, TW, force, Chip morphology	MQL with −15 cooling strategy was effective input parameter.
[27]	Uncoated microcrystalline ISO grade k20 insert	Ti-6Al-4 V	Conventional cooling, High pressure cooling	V_c- 90, 100, 111 m/min.,f- 0.16, 0.20, 0.24 mm/rev.,d- 0.6, 0.8, 1.0 mm	Ra, tool life, Chip morphology	It was observed that significant improvement in tool life and other evolution parameters could be achieved utilizing moderate range of coolant pressure.
[28]	PVD coated tungsten carbide insert	Ti-6Al-4 V	UT, CT (24H, 48H)	V_c- 40, 60, 80 m/min.,f- 0.05, 0.1 mm/rev., d- 1 mm	Ra, force, vibration	48H gives most favorable results compared to UT.
[29]	Coated with AlCrN	Ti-6Al-4 V	Flood, MQL + Nano particles,Internal cryogenic cooling, External cryogenic cooling.	V_c- 72 (f), 86(O),SS-143 (f), 1026(O)TS- 860 (f), 1026 (O)	Tool wear, Cutting force	After experimental work it was found that MQL + internal cryogenic cooling system helpful for improve tool life up to 32%.
[30]	SANDVIK 419 R-1405E-MMS407	Ti-6Al-4 V	Flood, ScCO2 and MQL + ScCO2	V_c- 50, 60, 80 m/min.,f- 0.50, 1.0 mm/tooth,ADOC- 1 mm	Ra, cuttingforce	It was observed that the machinability improve with ScCO2 + MQL at V_c- 60 m/min., f- 0.5 mm/tooth.
[31]	Uncoated/TiAlN coated tungsten carbide insert	Ti-6Al-4 V	Dry, MQL, flood	f- 0.1, 0.3, 0.5 mm/rev.,d- 0.2, 0.3, 0.4, 0.5 mm ,V_c- 50	TW	After the experimental work, it was observed that flood; MQL is most effective parameters compared to dry machining.
[32]	Cemented carbide with diamond coating	Ti-6Al-4 V	Dry, SCO2, SCO2 + WMQL, SCO2 + O_oWMQL	Flow rate- 50 m/h.,Pressure- 7.5	TW,Surface integrity	SCO2 + O_oMQL provide better results compared to other.
[33]	Uncoated carbide insert	Ti-6Al-4 V, Inconel 718	MQL, Cryogenic cooling (CO2)	Ti-6Al-4 VV_c-150 m/min., f- 0.2 mm/rev., d- 1 mmInconel 718V_c- 100 m/min., f- 0.2 mm/rev., d- 1 mm	TW, SurfaceFinish, chipformation	After systematical experiment results, CMQL were identified as the most favorable cooling method considering environmental impact, tool wear, surface finish, chip formation.

of cutting fluid such as contamination, disposal, and hazardous components. Dry machining does not provoke the pollution of air or water resources. As a result, disposal cost of cutting fluids is reduced. Certain grades of carbides and coated carbide cutting tools are developed for the use in dry machining. Dry machining is preferable to operate at lower cutting speeds and produce a low production rate in order to prolong tool life [15]. Fig. 1(a) showing dry machining setup and process [16].

2.2. MQL (Minimum quantity lubrication)

An alternative to flooding or dry cutting fluid application, minimum quantity lubrication (MQL) applications is introduced as an environmentally friendly and economically beneficial method [17]. Similarly dry machining, Fig. 1(b) has shown MQL machining [18].

2.3. Cryogenic machining

Cryogenic machining is the recent development that uses cryogenic gas such as nitrogen and helium as the coolant. Fig. 1 © showing cryogenic machining setup [19] and flow system. Nitrogen is an inert gas, which forms 78% of the atmosphere and is lighter than air. It is an environmentally safe alternative to the conventional emulsion cooling because the nitrogen evaporates harmlessly into the air without producing any waste of cutting fluids.

3. Literature survey on different Machining environment with Ti alloy, mg alloy, Stainless steel and Inconel as a Work-piece materials

3.1. Literature review on Ti and its alloy

In this paper, literature survey carried out on different types of material such titanium alloy, mg alloy, stainless steel, aluminum alloy etc under different machining environment. In this review paper, all the literature survey present in tabular form Table 1. Showing literature on machining on Ti and its alloy under different cooling environment.

3.2. Literature review on Stainless steel

Stainless steel[34-36] is a portion of iron-based alloys that contain at least roughly 11% chromium [37-39] an arrangement that keeps the iron from rusting [40] just as giving heat safe properties.[37,38,41-44] Different kinds of stainless steel incorporate the components carbon (from 0.03% to more prominent than 1.00%), nitrogen, aluminum, silicon, sulfur, titanium, nickel, copper,

Table 2
Literature of machining on stainless steel.

Reff.	Cutting tools	Work piece	Machining environment	Input parameters	Response	Outcomes
[45]	PVD coated Nano – Multilayer TiAlN insert	Duplex stainless steel 2205	Liquid nitrogen and dry condition	V_C- 72, 119, 197 m/min.,f- 0.111 mm/rev., d- 1 mm	TW, force, Surface integrity	LN2 cooling techniques reduced tool wear and improve surface finish.
[46]	CBN TCGW16T304S105MT	AISI 52,100	Dry, LN2	V_C- 150, 240, 300 m/min., f- 0.1 mm/rev.	Surface integrity	LN2 assisted machining of hardened AISI52100 has a significant effect.
[47]	HSS twist drill	SS310	UT, CT	SS- 600, 700, 800 rpm, f- 0.02, 0.04, 0.06 mm/rev.,	Ra, error	It was observed that CT insert improve surface finish and minimization of error.
[48]	HSS T-42 S-400 Insert	AISI4340 steel	LN2	N- 300 rpm, f- 0.0045, 0.090, 0.135 mm/rev., d- 0.2, 0.4, 0.6 mm	Ra	It was observed that the error in this with Ra only 5.32%.
[49]	TiN and TiAlN coated inserts	AISI D2	Dry, wet, LN2	V_C- 125 m/min., f- 0.02 mm/tooth	Force, Cutting temp.	Cutting temp. And force 13%, 18% reduced with LN2.
[50]	TiN coated carbide DNMG150608 MM	AISI304	Dry, LN2, MQL, MQL + LN2, MQL + CO2	V_C- 225 m/min., d- 1.5 mm, f- 0.25 mm/rev.	TW, force, Surface integrity	Most effective results found with MQL + CO2 cooling environment.
[51]	TiCN/Al_2O_3/TiN coated tungsten carbide insert	AISI *H*11	Dry, LN2 cooling UT	V_C-200, 240, 280 m/min., f- 0.15, 0.18, 0.21 mm/rev., d- 0.6 mm	Ra, flank wear, hardness	As a result, DCT24 provide effective results compared to SCT6, DCT6.
[52]	AlTiN PVD coated KC 5010 tungsten carbide insert	17–4 HSS	Dry, wet, MQL, LN2	V_C- 78.5 M/MIN., F- 0.143 MM/REV., D- 0.2, 0.4, 0.6, 0.8, 1 mm	Tool wear,Chip morphology, Surface integrity	LN2 cooling system satisfies the response compared to dry, wet, MQL cooling conditions.
[53]	Uncoated SNGA 120,408 T01020AB30	AISI D2	CHT, DCH (36), DCTT (36)	V- 50, 100, 150 m/min, d- 0.25, 0.50, 0.75 mm	TW, Ra	After experimental studied it was observed that DCTT (36) provide better result compared to other input parameters.
[31]	TiN coatedISO-P30TN450XPDT	AISI p20	Dry, flood, LN2	V- 75, 100, 125 m/min.,f- 0.2 mm/rev., d-0.5 mm	Tool life	As a result, 15–17% reduced tool wear with liquid nitrogen cooling compared to other.
[54]	CVD coated (TiCN/Al_2O_3) carbide insert	AISI4340	Dry machining and LN2	V_C- 160, 200, 240 m/min.,f- 0.3 mm/rev.d-1.0 mm	Surface integrity	After experimental work observed in all cryogenically machined surfaces, which contributed to the higher hardness compared to those machined under dry conditions.

Table 3
Literature of machining on Mg alloy, Aluminum alloy, Nickel alloy and Inconel.

Reff.	Cutting tools	Work piece	Machining environment	Input parameters	Response	Outcomes
[55]	Carbide insert	AA6063 alloy	Dry machining, LN2 machining	SS- 800, 1000, 1200, 1400 rpm, f- 100, 120, 140, 160 mm/min., d- 0.2, 0.3, 0.4, 0.5 mm	Ra, MRR	After the experimental work it was found that the best machining condition obtained with 120 mm/min., 1400 rpm, 0.4 mm with liquid nitrogen cooling system.
[56]	Uncoated carbide insert	AZ31B Mg	Dry, LN2	V_C- 100 m/min., f- 0.1 mm/rev., R- 30, 70 mm	Surface integrity	Liquid nitrogen enhances the surface finish compared to dry machining.
[57]	Carbide insert CNMG120404	Inconel 718	Dry, MQL, LN2, MQL + LN2	V_C- 60 m/min., f- 0.05 mm/rev., d- 0.63 mm,	Surface integrity	Cryogenic cooling system helpful for improve machinability compared to other.
[58]	AlTiN coated tungsten carbide insert	Nickel alloy	LN2, MQL + Nano particles	V_C- 20, 40, 60, 80, 100 m/min., f- 0.04, 0.08, 0.12, 0.16, 0.2 mm/rev.	Ra, TW, force	LN2 provide significant result and reduced flank wear. Also improve machinability.
[59]	Two flute helical PVD	AZ31mg	Dry, LN2	V_C- 40, 120 m/min.,d- 0.1, 0.15, 0.2, 0.25 mm/rev.	Cutting temperature, thrust force	It was observed that LN2 cooling helpful for improve machinability compared to dry machining.
[60]	Coated carbide insert	Inconel 625	Dry, pure MQL, LN2, MQL + LN2, NMQL + LN2	V_C- 70 m/min., f- 0.1 mm/rev., d- 0.8 mm	Ra, TW, cutting temp.	0.5 vol% hbn cooling method with LN2 gave best results.
[61]	PVD TiAlN/AlCrNGrade ACK300	Inconel 718	Dry and LN2 cooling environment	V_C- 140, 160 m/min.,f- 0.15, 0.20 mm/tooth,ADOC- 0.3 mm, RDOC- 0.2, 0.4 mm	Tool wear,Ra, force	LN2 provide to be more effective result compared to dry.
[62]	PVD coated insert	Inconel718	Dry and Cryogenic machining (CO2)	V_C- 120, 130, 140 m/min.,f-0.15, 0.2, 0.25 mm/tooth,ADOC-0.3, 0.5, 0.7 mm,RDOC- 0.4 mm	Tool wear, Chip morphology	CO2 is effective machining compared to dry machining and Novel machining.
[63]	PVD TiAlN/TiN coated carbideinsert	Ni-based Alloy625	MQL, Cryo, Cryo + MQL	V_C- 50, 75, 100 m/min.,d-0.5 mm	TW, Ra,Chip morphology	After experiment investigation it was found that Cryo + MQL improved Ra (1.4 μm) by 24.82% compared to cryogenic cooling system.Also, tool wear reduced with cryo + MQL compared to both. Finally say, MQL is more effective input Parameter compared to other.

selenium, niobium, and molybdenum. Explicit kinds of tempered steel are frequently assigned by a three-digit number, e.g., 304 impeccable.

Stainless steels protection from ferric oxide arrangement results from the presence of chromium in the compound, which shapes a passive film that shields the fundamental material from erosion assault, and can self-recuperate within the sight of oxygen. In this way, Stainless steel is generally utilized in machining measure. Table 2. Shown literature of machining on Stainless steel.

3.3. Literature review on mg alloy, aluminum alloy, nickel alloy and Inconel

Similarly, Table 3. Showing literature review of machining on different types of materials such mg alloy, aluminum alloy, nickel alloy and Inconel etc.

4. Conclusion

This review paper based on environmental friendly machining, which increase the machinability in metal cutting process. The conclusions are following;

- The environmental problems and health issue caused by conventional cutting fluid at the beginning. After the literature survey, it observed that the green and environment machining such as dry machining, minimum quantity lubrication (MQL) machining and cryogenic cooling approach are solution of these problems. These all approach related to sustainable machining.
- After literature review, it is observed that dry cutting is best method and also environmental friendly approach. The applications of dry machining in turning, milling and gear cutting on different materials. But dry machining has limitations in drilling process, because in drilling process more heat generated at metal cutting zone so machinability is reducing.
- After literature survey, it is observed that another effective cooling approach such MQL, cryogenic cooling minimize environmental issue, health issue and also improve machinability.
- In cryogenic machining micro nozzle jetting to the cutting point locally is used, this approach minimizes the tool wear and enhancement of machinability. In addition, these techniques improve surface quality, remove built up edge, reduced friction force and improve tool life. Cryogenic cooling has been successfully used for the machining of difficult to machine materials such as: Titanium, Inconel 718 and several other heat resistant alloys. The direct penetration of cryogenic coolant into the cutting zone not only reduced the cutting temperature, but also enhanced the surface finish up to several folds. Overall as compared to conventional methods, cryogenic cooling is able to enhance the productivity by providing satisfactory results under high speed and feed conditions.

CRediT authorship contribution statement

Rajeev Sharma: Writing - review & editing. **Binit kumar Jha:** Supervision. **Vipin Pahuja:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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