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RESEARCH ARTICLE

A COMPREHENSIVE REVIEW ON EVALUATION OF ENVIRONMENTAL FRIENDLY MACHINABILITY, CUTTING FLUIDS AND TECHNIQUES IN METAL CUTTING OPERATION

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Abstract

Todays, due to the environmental concerns, growing contamination and pollution regulations, the demand for renewable and biodegradable cutting fluids is increasing day by day. Environmental friendly machining is one of the latest approach which is economical and also eco-friendly that improve the machinability. Different types of environmental friendly machining techniques are available e.g. MQL machining, cryogenic machining, dry machining and high pressure cooling approach. In this article, an attempt is made regarding environmental friendly machining processing, including different types of cutting fluids and machining techniques. The Knowledge 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. In any manufacturing industries or company two factors play important role in machinability and productivity e.g. surface quality and tool wear. The main objective of this review article that analysis the different environmental friendly machining techniques and encourages the cooling approach in metal cutting operation. So finally, after the literature survey found that environmental friendly machining approach is cost effective machining process and also eco-friendly machining process.

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 was developed [1]. In past, the conventional cooling technique is used in metal cutting process which is neither economical nor environmentally friendly [2], 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 [3], Minimum quantity lubricant (MQL) [4], [5] and cryogenic cooling method have been introduced as an alternative method to improve machinability as compared to other machining.

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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 improve tool life. In cryogenic machining liquid nitrogen, CO2, helium gas uses as a cutting fluid which has been defined as an environmentally friendly technique [6-7]. 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 area. Figure 1 showing function of environmental friendly machining.

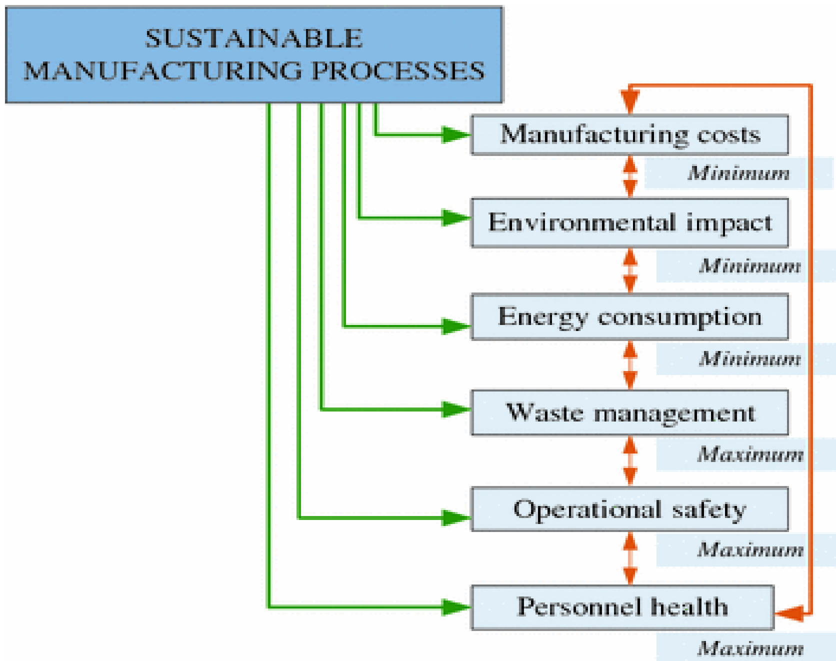

Fig. 1:- Function of Environmental friendly machining [8].

Nomenclature

TiAlN	Titanium aluminum nitride	TiN	Titanium nitride
Al2O3	Aluminum oxide	AlCrN	Aluminum chromium nitride
CO2	Carbon dioxide	LN2	Liquid nitrogen
PVD	Physical vapor deposition	CVD	Chemical vapor decomposition
MQL approch	Minimum quantity lubrication	Cryogenic -MQL	Cryogenic cooling + MQL
nMQL	Nano fluid MQL	Ra	Surface Roughness
hBN	Hexagonal boron nitride	MRR	Metal removal rate
TW	Tool wear	ScCO2	Super critical carbon dioxide

Limitations of Conventional Fluids

In the past years, the effect of conventional cutting fluid on environmental or economic factors with processing it has become an emerging problematic aspect. It was observed that approximately 70-80% skin problems of machine operator were due to contact with cutting fluid [9]. The harmful effects of cutting fluid cause lots of technoenvironmental problems and also serious health problems such as lung cancer, respiratory diseases, dermatological and genetic disease [10]. For improve chemical stability, flame resistance, low toxicity; chlorinated paraffin is used as a additives in cutting fluids [11]. Nevertheless, cutting fluids containing Chloroparaffin as extreme pressure additives are no longer legal to be used in future. This is because chlorinated paraffin in extreme pressure cutting fluid changes to dioxin by heat and pressure and could lead to chlorine acne. Besides, disposal of cutting fluids containing chlorinate is only allowed to be burned in special incineration sites since the toxic dioxins can lead to uncontrolled burning. Therefore, it is classified as hazardous waste to human life as well as to the environment [12]. And also cutting fluids have chlorine additives which are not suitable in machining of titanium alloys as it can cause corrosion on the machined surface. Additionally, cutting fluids that have vaporized and atomized due to high pressure and temperature in machining operations, resulting in the formation of cutting fluid mist. Fog, fumes, smoke and odors generated by cutting fluids, especially with chemical additives such as sulfur, chlorine, phosphorus, hydrocarbons and biocides, can cause skin reactions and breathing problems [13].

Environmentally friendly cutting fluids

In the early 90's, research on biodegradable cutting fluids appeared as one of the top precedence in lubrication and led to growing of ecological friendly cutting fluids in the market. The demand for bio-based lubricants was 0.50 Mt in 2011, which is expected to be increased to 0.79 Mt in 2018. The demand of synthetic lubricants was 35 Mt in 2011 and is predicted to reach 42 Mt in 2018. This shows that biodegradable lubricants are slowly replacing the synthetic lubricants. Biodegradable cutting fluids that accomplish the lowest amount of environmental contamination provide high reliability and satisfactory economic conditions. Besides, the output of bio-based cutting fluid is cleaner and contributes less mist in the air, subsequently minimizes occupational health risks [14].

Biodegradability is the main aspect with respect to environmentally friendly. Biodegradable substance is susceptible to biochemical breakdown by the action of micro-organism. The original molecule of a recyclable substance will disappear in the primary degradation. Then, carbon dioxide, hydrogen, and biomass will form in the ultimate degradation. Ultimate biodegradability is important as it ensures the safe reintegration of the organic material in the natural carbon cycle. Furthermore, sustainability of the use of cutting fluids can be divided into two aspects. The first aspect is the resources of the cutting fluids, whether fossil or renewable raw materials. The second aspect is the environmental pollution associated with the use and disposal of the cutting fluids. The carbon cycle of renewable product is closed, where the amount of carbon dioxide liberated to the atmosphere during the disintegration of organic chemicals is equivalent to the amount of carbon dioxide absorbed by the plants. In contrary, the carbon cycle of a mineral oil based product is open which lead to an increase of carbon dioxide emissions to the atmosphere and consequently results in global warming [15]. Following types of cutting fluids,

Vegetable-based Cutting Fluids

Vegetable oil is formed by triglycerides, which are glycerol molecules with three long chain fatty acids attached to the hydroxyl groups through ester linkages as shown in Figure 3. Natural vegetable oils consist of fatty acids, which differ in chain length and number of double bonds. Thus, the fatty acid composition is determined by the ratio and the location of carbon-carbon double bonds. Long carbon chains that form with one, two, or three double bonds are having oleic, linoleic and linolenic fatty acid components respectively as shown in Figure 2. Most of the vegetable oil consist of four up to twelve different fatty acids [16].

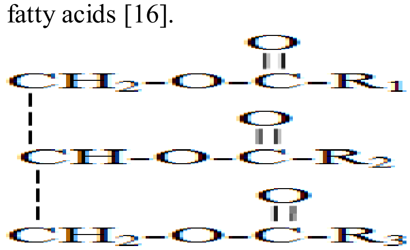

Fig. 2:- Chemical structure of triglyceride of a typical vegetable oil where R1, R2 and R3 are fatty acid chains [17]

Scrutinized the performance of coconut oil (vegetable based) on machining of AISI 304 material with a carbide tool. They figured out that coconut oil had not only improved the surface finish but also reduced the tool wear compared to mineral oils [18].

Gas-based Coolant Lubricants

Gas-based coolant lubricants are generally referred to the substances that are in gaseous form at room temperature and considered as environmentally friendly cutting fluids. However, they can be either gas or cooled-pressured fluids in machining applications. Gas-based coolant-lubricants are air, nitrogen, argon helium, or carbon dioxide. Since the gas-based coolant lubricants are considered as inert gas, they have high corrosion resistance that prevents the cutting tool and machined surface from oxidation at high cutting temperatures. Besides, they can be applied in conjunction with conventional cutting fluids in the form of mist or droplets to improve their lubrication capability. Studied spraying micro-drops of bio-biodegradable oil in the air when milling low carbon steel in high speed [19]. The application of oil spray into the machining zone significantly reduced the tool flank wear up to 44 %. Application of oil spray into the machining zone also reduces the cutting temperature and forces.

Techniques of Cutting Fluids in Conventional and Environmental Friendly Machining

Techniques of Cutting Fluids in Conventional Machining

The friction and heat generation in machining plays a negative role in the deterioration of cutting tools and the superficial layer of the work piece. A small reduction in temperature between tool and work piece, considerably improves the tool life and surface finish. A good understanding of the method to apply cutting fluids (cooling techniques) at the cutting zone, which effectively reduce the heat generation in machining, may lead to an efficient and economic machining of most of the modern materials. In recent years, several technologies have been developed for controlling the temperature in the cutting zone in order to improve productivity and increase the overall effectiveness of the process [20].

Wet Cooling Techniques

Wet cooling and flood cooling is comparable thing. In this cooling methods flood is utilized as a coolant. Stream rates commonly range from 10 L/min for single direct devices toward 225 L/min per shaper for numerous tooth cutters, for example, processing [21]. Flood cooling gives a constant flow of liquid to the apparatus work or device chip interface for machining activity [22]. Contemplated the surface uprightness and wear systems related with mechanical miniature boring of nickel-based super amalgam (Inconel 718) under dry and wet cutting conditions. Mechanical and metallurgical portrayal was embraced utilizing Scanning Electron Microscopy (SEM) and other microstructure study methods [23]. The surface honesty results uncovered a huge scope close to surface disfigurements with high separation thickness alongside nano glasslike grain structures under wet cutting conditions. The creators presumed that the cutting temperature and utilization of coolant assumed a critical part in the development of the changed surfaces. Scraped spot, dispersion and miniature chipping were discovered to be the fundamental wear instruments for wet slicing contrasted with scraped area, high grip, large scale chipping and cataclysmic disappointment for dry cutting.

High Pressure Cooling Techniques

The high-pressure framework application is utilized to expand the pace of warmth expulsion from the cutting zone where heat age turns into a huge factor with the speed up and power. Cutting liquid is conveyed through extraordinarily planned spouts that point an amazing plane of liquid to the zone especially into the leeway or help face of the device. The pressing factor applied is in the reach from 5.5 to 35 MPa and hitting at a speed of 350 - 500 km/h. This high liquid pressing factor permits better infiltration of the coolant into the instrument work piece and apparatus chip contact region, accordingly builds creation proficiency. This application not just improves the tool wear and gives better cooling impact yet in addition brings about decreasing the contact lengths as the coolant conveyance pressure powers the chip away from the apparatus rake face [20]. Assessed the impact of utilization of cutting liquid at high tension on tool wear during turning activity of AISI 316 austenitic hardened steel. The cutting liquid was applied at various pressing factors (10, 15, and 20 MPa) between the chip and apparatus on the rake face in the turning activity. The outcomes uncovered that high pressing factor coolant strategy was more effective contrasted with dry cutting and wet cutting as far as apparatus wear [24].

Explored the utilization of the HPJA in unpleasant turning of Inconel 718 with covered carbide insert [25]. Machined Inconel 718 with a triple PVD covered (TiCN/Al2O3/TiN) carbide tool at speeds up to 50 m/min utilizing regular and different high coolant pressures, up to 20.3 MPa. Apparatus life, surface harshness (Ra), device wear and part powers were recorded [26]. The test outcomes showed that worthy surface completion and improved tool life can be accomplished while machining Inconel 718 with high coolant pressures.

Mist Cooling Method
Mist cooling is used mostly for water based cutting fluids. The cutting fluids are applied by the pressurized air stream at a high-speed mist. Evaporation of the fluid droplets suspended in the air provides effective cooling [27]. It supplies fluid to unreachable areas and provide better visibility of the work piece being machined compared to flooding [21]. The effective air pressure ranges to apply water-based fluid is from 70 to 600 kPa. Since the mist or vapor is toxic, venting is necessary to avoid the operator directly inhale of airborne fluid particles. If care is not taken, contact of mist may cause irritation and serious respiratory problems [28]. According to [29], attention should be focused on high speed machining rather than lower speed machining process like drilling, because lower speed machining process creates less cutting fluids mist and thus pose a less health risk. Figure 3 showing cutting temperature with cooling environment.

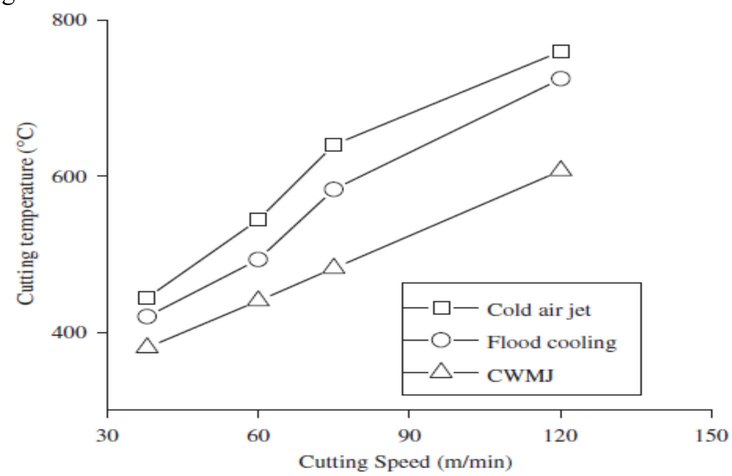

Fig. 3:- Cutting temperature with cooling environment [30].

Techniques of Environmental Friendly Machining
In environmental friendly machining three types of techniques considered. These are followings,

Dry Machining
Dry machining, which means no cutting liquids applied in the machining cycle. This strategy is applied to maintain a strategic distance from the issues of cutting liquid like defilement, removal, and unsafe parts. Dry machining doesn't incite the contamination of air or water assets. Accordingly, removal cost of cutting liquids is diminished. Certain evaluations of carbides and covered carbide cutting apparatuses are created for the utilization in dry machining. Dry machining is desirable over work at lower cutting paces and produce a low creation rate to delay tool life [22].

MQL (Minimum Quantity Lubrication)
Minimum quantity lubrication (MQL) is alternative environmental friendly machining process to dry machining and machining with flood [31].

Cryogenic Machining
Cryogenic machining is environmental friendly machining process in which gases is utilizes as a coolant e.g. nitrogen gas, helium gas and carbon dioxide gases [32]

Table 1:- Classification of Lubrication Types [33].

Lubrication type	Content	Used volume
Wet machining (using coolant)	Flooding supply, full jet lubrication	10 to 100 l/min
Reduced lubrication	MQL,	50 ml/h up to

	MMKS	1-2 l/h
Without lubrication	Dry machining	without

Literature Survey on Machining With Different Cooling Environment

In this paper, literature survey carried out on different types of material such titanium alloy, mg alloy, aluminum alloy etc under different machining environment. In this paper, all the literature survey present in tabular form. Table 2. Showing literature on machining on different materials under different cooling environment.

Table 2 Showing literature review on machining of different materials under different cooling environment

Reference	Machining Environment	Response	Research Outcome
[34]	UT, CT (12H, 24H, 36H)	TW, Ra, Cutting force	Deep CT up to 36H is most effective parameter.
[35]	Dry, flood and cryogenic environment	Ra, Microstructure	Ra was improved by 35%, 6.6% compared to both.
[36]	Flood, MQL, Cryogenic cooling	TW, force analysis	Cutting force and thrust force reduced by 30% compared to flood, MQL.
[37]	Dry, Cryogenic compressed air	Tool life	Reductions in tool wear with compressed air.
[38]	Emulsion, Co2	Tool wear	Compared to flood emulsion cooling the tool wear reduce with Co2 method.
[39]	Oil based coolant, cryogenic cooling	Tool wear, Chip formation	After experimental work it was observed that cryogenic cooling system improve machinability and reduce tool wear.
[40]	Dry, wet with MQL, MQL with 0, -15, -30, -45 degree	Ra, TW, force, Chip morphology	MQL with -15 cooling strategy was effective input parameter.
[41]	Conventional cooling, High pressure cooling	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.
[42]	UT, CT (24H, 48H)	Ra, force, vibration	48H gives most favorable results compared to UT.
[43]	Flood, MQL+ Nano particles, Internal cryogenic cooling, External cryogenic	Tool wear, Cutting force	After experimental work it was found that MQL + internal cryogenic cooling system helpful for improve tool life up to 32%.

	cooling.		
[44]	Flood, ScCO2 and MQL+ ScCO2	Ra, cutting force	It was observed that the machinability improve with ScCO2 + MQL at V_c- 60 m/min., f- 0.5 mm/tooth.
[45]	Dry, LN2	Ra, cutting force, Temperature	Result found that the temperature reduced 61-68%, force 8-33% with LN2.
[46]	Dry, MQL, LN2	TW	LN2 provide significance results compared to dry, MQL.
[47]	Liquid nitrogen and dry condition	TW, force, Surface integrity	LN2 cooling techniques reduced tool wear and improve surface finish.
[48]	Dry machining, LN2 machining	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.
[49]	Dry, LN2	Surface integrity	Liquid nitrogen enhance the surface finish compared to dry machining.
[50]	Dry, LN2	Surface integrity	LN2 assisted machining of hardened AISI52100 has a significant effect.
[51]	Dry, MQL, LN2, MQL + LN2	Surface integrity	Cryogenic cooling system helpful for improve machinability compared to other.
[52]	UT, CT	Ra, error	It was observed that CT insert improve surface finish and minimization of error.
[53]	Dry environment, machining with LN2	Ra, TW, force	Liquid nitrogen cooling system reduced force up to 27% over machining with dry environment.
[54]	LN2, MQL + Nano particles	Ra, TW, force	LN2 provide significant result and reduced flank wear. Also improve machinability.
[55]	LN2	Ra	It was observed that the error in this with Ra only 5.32%.
[56]	UT, CT	MRR	As a results, the machining performance was better with CT.
[57]	Dry, wet, MQL and liquid nitrogen machining	Chip analysis, Ra, COF	Studied that minimum Ra found machining with liquid nitrogen cooling system.

[58]	Dry, wet, LN2	Force, Cutting temp.	Cutting temp. and force 13%, 18% reduced with LN2.
[59]	Dry, LN2	Cutting temperature, thrust force	It was observed that LN2 cooling helpful for improve machinability compared to dry machining.
[60]	Dry, LN2, MQL, MQL+LN2, MQL+CO2	TW, force, Surface integrity	Most effective results found with MQL+CO2 cooling environment.
[61]	Dry, pure MQL, LN2, MQL+LN2, NMQL+LN2	Ra, TW, cutting temp.	0.5 vol % hbn cooling method with LN2 gave best results.
[62]	Dry, LN2 cooling UT	Ra, flank wear, hardness	As a result, DCT24 provide effective results compared to SCT6, DCT6.
[63]	Dry and LN2 cooling environment	Tool wear, Ra, force	LN2 provide to be more effective result compared to dry.
[64]	Dry and Cryogenic machining (CO2)	Tool wear, Chip morphology	CO2 is effective machining compared to dry machining and Novel machining.
[65]	Dry machining and LN2	Hole quality	LN2 drilling of CFRP composite improve drilling performance in term of Ra compared to dry machining.
[66]	Dry, wet, MQL, LN2	Tool wear, Chip morphology, Surface integrity	LN2 cooling system satisfies the response compared to dry, wet, MQL cooling conditions.
[67]	Dry, flood, LN2, LCO2	TW, Ra, Power consumption	LN2 and LCO2 as sustainable cooling approach and improve machinability compared to other.
[68]	CHT, DCH (36), DCTT(36)	TW, Ra	After experimental studied it was observed that DCTT (36) provide better result compared to other input parameters.
[69]	Dry, flood, LN2	Tool life	As a result, 15-17 % reduced tool wear with liquid nitrogen cooling compared to other.
[70]	Dry, MQL, flood	TW	After the experimental work, it was observed that flood, MQL is most effective parameters compared to dry machining.

[71]	Dry and Cryogenic machining	Hole quality, Surface integrity, Thrust force, MCI damage, Torque	After the experimental work it was observed that the torque decrease up to 7-25% with cryogenic machining. MCI damage factor also reduced with cryogenic machining and finally say machinability improve with cryogenic machining compared to other.
[72]	MQL, Cryo, Cryo+MQL	TW, Ra, Chip morphology	After experiment investigation it was found that Cryo + MQL improved Ra(1.4 micrometer) 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.
[73]	Dry, SCO2, SCO2+WMQL, SCO2+O_oWMQL	TW, Surface integrity	
[74]	MQL, Cryogenic cooling (CO2)	TW, Surface Finish, chip formation	After systematical experiment results, CMQL was identified as the most favorable cooling method considering environmental impact, tool wear, surface finish, chip formation.

Graphical Represent of Literature Survey

The graphical represent of all the literature review. These are following;

Graphical Represent with No. of Papers

In this section graph showing literature survey on basis of number of papers with machining material. Figure 4 shown graph between number of paper with materials.

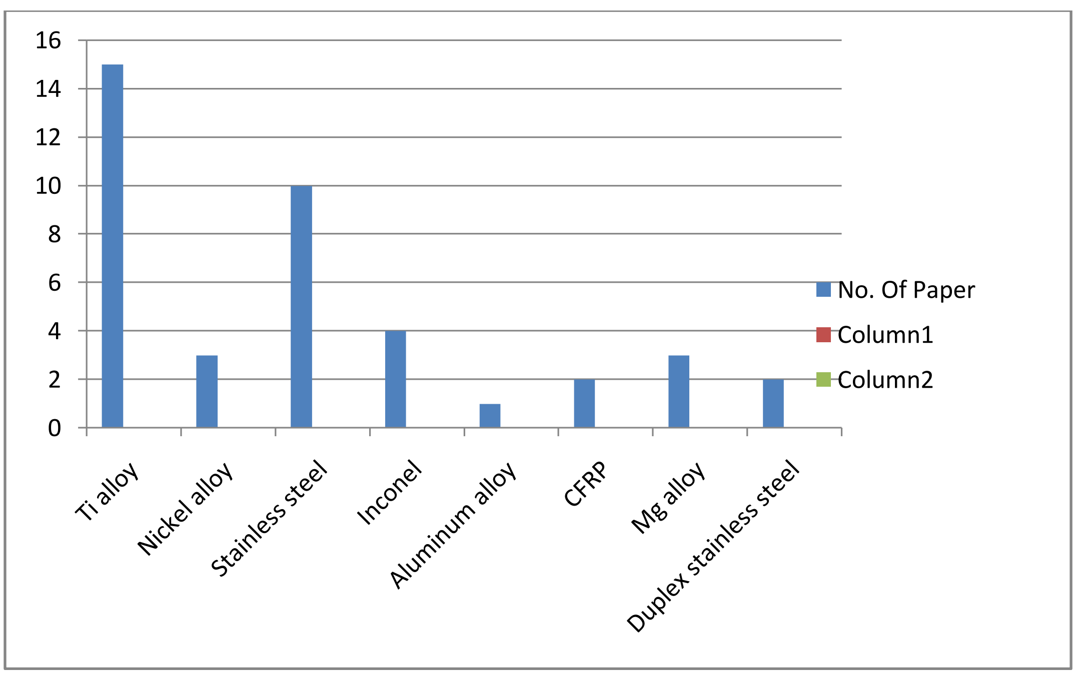

Fig. 4:- Showing No. of paper with materials.

Conclusion:-

This review article based on environmental friendly machining approach and different types of cutting fluids, which improve machinability in metal cutting operation. After literature survey some conclusions are obtained. These are following;

1. In the past conventional cutting fluids are used in machining process. In conventional cutting fluids are some issue are present related to environmental issue and health issue.
2. After literature survey it was observed that for resolve health issue and environmental issue, environmental friendly machining approach is utilize for improve machinability which is eco-friendly machining process.
3. Different types of environmental friendly machining approach are available such as dry machining, MQL machining, high pressure cooling approach and cryogenic machining. After literature survey, it was observed that dry machining is attractive machining but limitation on drilling machining process. Because in drilling process more heat generated in cutting zone so surface quality of product reduce and more tool wear.
4. After literature survey, it was observed that another environmental friendly method such as MQL machining, high pressure cooling approach and cryogenic machining are available which are eco-friendly method and cost effective method which easily improve machininability in metal cutting operation [rajee]

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