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CURRENT SCENARIO OF MACHINING PROCESS IN ADVANCED Al_2O_3 AND Al_2O_3 CERAMICS COMPOSITE MATERIALS: A STUDY REVIEW

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ABSTRACT: The recent developments in Al_2O_3 and Al_2O_3 based ceramics focused not only on the improvements of strength and toughness, but also on very difficult to machine complex shapes. The present paper reports that, in the study of contemporary literature resources available to focus on different types of machining processes used to machine Al_2O_3 and Al_2O_3 based ceramics. Furthermore an analysis of all literature review of different types of machining process, input parameters and output parameters used by various researchers.
KEYWORDS: Al_2O_3, AWJ, EDM, LAM, Laser

1. INTRODUCTION

Al_2O_3 and Al_2O_3 based ceramics are universally used in airlines, electronic substrates, space shuttle, bicycles, automobiles, golf clubs [1], cylinder liner, bushing, bearing [2], cylinder block, liners, automotive pistons, bicycle frames [3], electronics, aerospace, material processing [4, 5], cutting tool inserts, electrical and electronic elements, heat exchangers, refractory linings, heavy duty electric contacts, turbine blades, automotive brakes, next-generation, computer memory products piezoceramic sensors [6], biomedical and Engineering [7]. The Al_2O_3 and Al_2O_3 based ceramics have wide range of application, due to its exceptional Physical, Mechanical, Thermal, chemical, electrical properties which resulted into high hardness, high bending stiffness, high strength, wear resistance, resistance to chemical degradation , high refractoriness and low density [2, 7, 8], excellent dielectric strength, thermal stability, conductivity corrosion resistance, chemical stability, good damping , high strength to low mass ratio, controlled thermal expansion, high oxidation [5, 8, 9], high scratch resistance, low friction rate [10], excellent biocompatibility [29]. Al_2O_3 and Al_2O_3 based ceramics having characteristics such as very hard, brittle, lack of ductility, low fracture toughness due to this it is very difficult to use in conventional machining techniques [5, 6, 8, 9, 10, 11]. Thus, for such kind of alumina ceramics it is essential to use special purpose machine as well as non traditional machining processes.

2. CLASSIFICATION IN MACHINING PROCESS OF Al_2O_3 AND Al_2O_3 BASED CERAMICS FLOW CHART

The figure 1 shows the classification flow chart of machining process used to machine Al_2O_3 and Al_2O_3 based ceramics.

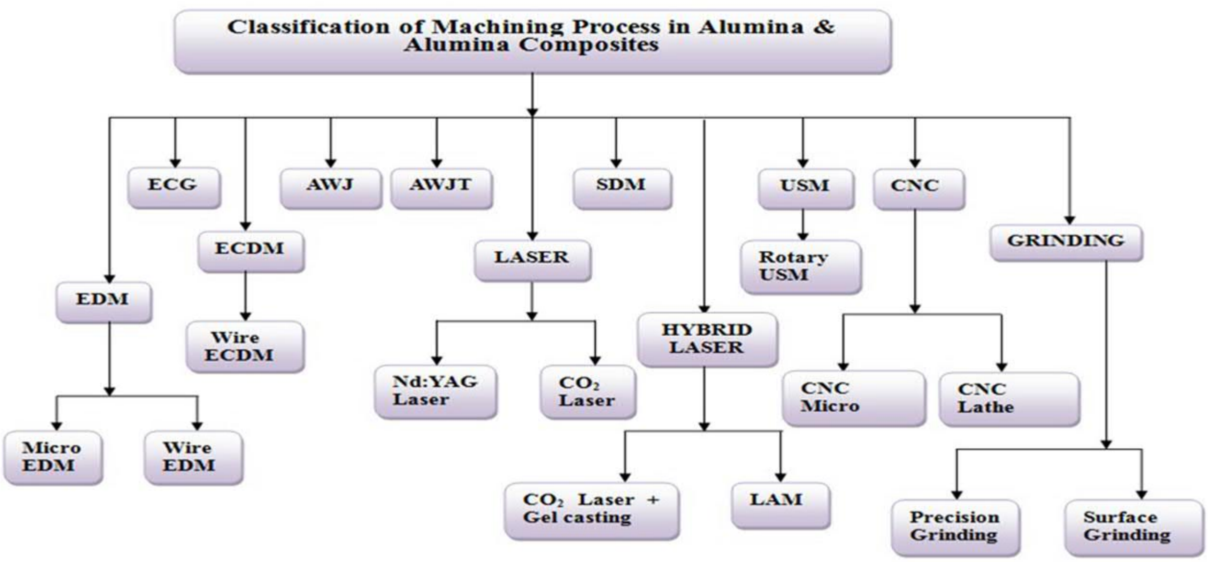

Figure 1 classification of machining process of Al_2O_3 and Al_2O_3 based ceramic materials

3. CATEGORIZATION OF VARIOUS MACHINING PROCESS OF Al_2O_3 AND Al_2O_3 BASED CERAMICS

3.1 Abrasive Water-jet Machining (AWJ)

Guo et al. [12] has experimented with alumina materials using an AWJ machining process. Drilling produced in workpiece materials is calculated by using moire interferometer. The authors have developed a finite element model for analyzing surface distribution and machining forces occurring during the process. Xu et al. [13] has stated that comparative study of AWJ cutting of alumina material (Mtl.) with large and small nozzle oscillation angles. The comparative output responses found out by the authors are surface roughness, the depth of the cut, and kerf taper.

3.2 Electro Discharge Machining (EDM)

Ahn et al. [14] has been modeled an electrical discharge machining process, as an unsteady state mathematical model and to solve it Galerkin's implicit finite element method is used. The result of this experiment shows that, the current and duty factor would increase the material removal rate (MRR) as well as it also increases the rough and defective surfaces. Chiang [15] has elaborated a mathematical model for the analysis of machining parameters and discusses the output results which shows that, for MRR discharge, current and the duty factor were the most powerful factors. For tool wear rate (TWR), duty factor and open discharge voltage were most significant factors and for roughness discharge current and open discharge voltage was the most powerful factors. Patel et al. [16] has experimented on alumina composite material using EDM, to study the feasibility of EDM to advanced alumina composite materials. The results were showing that, the current, pulse on time, duty cycle and gap voltage are the most important factors for both MRR and surface roughness. Patil et al. [1] found the effect of electrical and non electrical machining parameters achievement in wire electro discharge machining of metal matrix composite. Finally observed surface finish and dimensional precision, kerf width, cutting rate, material removal rate and wire breakage. Muttamara et al. [17] has used various types of EDM electrodes and machined alumina materials. The comparative study of numerous electrodes results gives out material removal rate and surface roughness. The author reported that the material removal rate of ceramics can be improved by operating positive polarity of electrodes. Fukuzawa et al. [19] has machined alumina composite material using wire EDM. The author obtained three-dimensional complex shape on alumina composite ceramic material using WEDM. Ferraris et al. [20] has achieved micro scale machined in alumina composite material utilizing micro EDM. The author observed various output parameters such as material removal rate, tool wear, surface quality and identification of material removal mechanism. Tak et al. [2] has checked conductivity of alumina composite material during machining conditions. The authors concluded that dimensional accuracy and the circularity of micro holes is different for separate alumina composite materials. Singh [11] has used grey relational analysis to find out optimal parameters of maximum MRR and minimum tool wear rate and surface roughness. Calignano et al. [9] has determined the feasibility of copper electrodes during machining over alumina composite material. The researcher made a full factorial design with input was taken as current, pulse on time, pulse off time, voltage, power and output responses are material removal rate, tool wear rate, surface roughness and overcut. Also author observed surface morphology of drilling holes.

3.3 Laser Assisted Machining (LAM)

Rebro et al. [21] has indicated that laser assisted matching process was applied into an alumina composite material mullite had used for experimentation. The output results were struck out sufficient depth of cut produced without any fracture or crack free surfaces. Yang et al. [4] have made novel myth of complex-shaped Al_2O_3 ceramic element by linking laser machining and gel casting technique. The author analyzes complex-shaped Al_2O_3 ceramic material and discovered the effects of input and output parameters. Kibria et al. [22] has made a combination of two processes of micro turning and pulsed Nd: YAG laser to machining advanced alumina ceramic materials. The author studied experimentally to measure surface roughness and deviation in turn depth. Using this author determined desired surface quality and dimensional accuracy.

3.4 Electrochemical Discharge Machining (ECDM)

Liu et al. [18] has obtained the effect of voltage, current, pulse duration and the concentration of the electrolyte on the machining of Al_2O_3 composite material in WECDM. The experimental results show that, for elevated MRR most important factors were current, pulse duration and electrolyte concentration. Peng et al. [23] has conducted experiments to observe the material removal rate and surface roughness using Traveling wire electrochemical discharge machining applied into alumina workpiece materials. Manna et al. [24] has experimentally proved that, the input parameters of electrolyte concentration and DC voltage are the most important factors for the material removal rate.

3.5 Grinding machining

Zhong [25] has used to ductile or partial ductile mode grinding machining process on the alumina ceramic material, it results in reduced time and cost as well as it increases the surface quality. Emami et al. [26] used and analyze four lubrications cutting fluids during grinding operation such as mineral, hydrocracked, synthetic, and vegetable oils to obtain the performance of these oils during the machining process. The results show that hydrocracked oil shows satisfactory results with respect to surface roughness and cutting force.

3.6 LASER Machining

Tsai et al. [27] has investigated recent fracture laser machining techniques. The author found that, due to this technique it requires less power and the material removal rate is elevated as compared to conventional laser machining process. The process is shown that the formation of crack defects is negligible and also surface quality and surface roughness is also significant. The author employed to that experimentation was CO_2 and Nd: YAG laser. Samant et al. [28] has checked the feasibility of laser machining to alumina ceramic material. The author developed a hydrodynamic machining model to predict different machining parameters employed in laser process. The experimental results were proved that the depth of cut to machine cavity is dependent on thermo-physical properties of the ceramic materials. Yan et al. [29] has made a crack-free milling for producing deep cavities in alumina materials using CO_2 laser underwater machining process. The final results showed that the process aspect in underwater machining is much superior as compared to air. Vora et al. [5] has detected a computational model for finding out laser machining on the surface finish of alumina under different laser energy densities. The results show low material removal with an excellent surface finish.

3.7 Electro Chemical Grinding (ECG)

Goswami et al. [30] has experimentally discovered the results such as the material removal rate (MRR), surface finish, and cutting forces during electrochemical grinding of Alumina composite. It shows that for MRR most significant factors were the electrolyte concentration and voltage used. For SR electrolyte concentration, applied voltage and depth of cut and for cutting force most significant factor was the concentration, voltage, depth of the cut, and flow rate of the electrolyte.

3.8 CNC Lathe Machining

Kök [3] has experimented on alumina composite ceramic material using a CNC lathe machine. The author studied the effects of cutting speed, size and volume fraction of particles in the surface roughness of the alumina composite material with respect to different types CNC tool inserts. Roy et al. [7] has successfully fabricated micro-dimple pattern on an Al_2O_3 surface by using a CNC micro machine. The author measured dimple pattern mechanical properties as well as tribological performance of materials after fabricating micro dimple pattern such as hardness, toughness and residual strength. The author also found that, there is no foreign wear debris occurs.

3.9Ultrasonic Machining (USM)

Wu et al. [31] have conducted experiments on Alumina using rotary ultrasonic machine. The experimental results determine that the feed rate was a dominant factor in the rotary ultrasonic machining process. Spindle speed affects the cutting force and ultrasonic vibration plays a major role in surface profiles of holes. The author also observed the surface roughness and surface integrity. Liu et al. [10] has experimentally shown the reduction of micro chipping or cracking at the exit of the hole of alumina ceramic material utilizing USM. The author used response surface methodology for analyzing input parameters of depth directional feed rate, ultrasonic power, and spindle speed with respect to output responses of exit chipping and tool wear. Bhosale et al. [8] has determined the effect of amplitude, slurry concentration and slurry type during the machining of alumina composite material.

3.10 Single Discharge Machining (SDM)

Ji et al. [6] have developed a novel technique of machined Al_2O_3 ceramic using high spontaneous pulse energy. The author determined the cause of polarity, capacitance, voltage, and current on the final output responses such as crater volume, crater depth and tool wear ratio.

3.11 Abrasive Water-jet Turning (AWJT)

Yue et al. [32] have carried out an experiment using response surface methodology for machine alumina ceramic material. The final results show that MRR is dependent on water pressure and abrasive mass flow rate. It also resulted in surface roughness with optimum parameters.

4. LITERATURE REVIEW

The table 1 shows, a review segregated on the basis of authors, publication year, mechanism, workpiece material, tool material specification, input and output parameters.

Table 1. Literature Review

Sr. No.	Authors (Year)	Mechanism	Workpiece Mtl.	Tool Mtl. Specification	Input Parameters	Output Parameters
1.	Guo Z. et al. (2001) [12]	Abrasive Water-jet Machining	Al_2O_3	Sapphire orifice	Supply pressure, Standoff distance, Abrasive flow rate	Surface displacement distributions, Machining Forces, Strains
2.	Ahn Y.C et al. (2002) [14]	Electro Discharge Machining	Al_2O_3 (66%) +TiC (33%)	Conductive Mtl.	Current, Voltage, Pulse on Time, pulse off Time, Duty Factor	MRR
3.	Rebro P.A. et al.(2002) [21]	Laser Assisted Machining	$3Al_2O_3$-$2SiO_2$	1.5 kW CO_2Laser+ SPG-422 K313 Uncoated Carbide Inserts	Feed Rotational speed, Depth of cut, Laser power, Beam diameter	Material Removal Temperature, Tool wear at flank, Surface roughness
4.	Peng W.Y. et al. (2003) [23]	Traveling Wire Electrochemical Discharge Machining	Al_2O_3	stainless wire	Voltage, Frequency , Duty factor, Electrolyte	MRR, Surface Roughness
5.	Zhong Z. W. (2003) [25]	Surface Grinding Machine	Al_2O_3	Diamond grinding wheels.	Depth of cut, Grinding speed	Surface Roughness
6.	Tsai C.H. et al. (2004) [27]	Laser Machining (CO_2 and Nd:YAG)	Al_2O_3	CO_2 laser, Nd:YAG laser	CO2 laser Power , Nd:YAG laser Power, Laser moving speed, Crack depth	Surface roughness, Crack defects
7.	Xu S. et al. (2006) [13]	Abrasive Water-jet Machining	87% Al_2O_3	Abrasive -80 Mesh garnet sand	Abrasive mass flow rate, Standoff Distance, Water pressure, Nozzle traverse speed , Oscillation frequency	Surface Roughness , Depth of cut, kerf taper
8.	Samant A. N. et al. (2008) [28]	Laser Machining (Nd:YAG)	Al_2O_3	Nd:YAG laser	Pulse energy, Pulse duration, Repetitions rate	MRR feasibility check with respect to different ceramics, Depth of cut
9.	Chiang K.T. (2008) [15]	Electro Discharge Machining	70%Al_2O_3+ 30%TiC	Electrolytic Copper	Discharge current , Pulse on time ,Duty factor, open discharge voltage	MRR ,TWR ,Surface Roughness
10.	Goswami R. N. et al. (2009) [30]	Electro Chemical Grinding	Al_2O_3- 68.9% + Al- 31.1%	Diamond impregnated metal bonded grinding wheel	NaCl concentration , Supply voltage, Depth of cut , Electrolyte flow rate	MRR, Surface finish , Cutting force
11.	Patel K. M. et al. (2009) [16]	Electro Discharge Machining	Al_2O_3–SiCw–TiC	Electrolytic Copper	Discharge Current, Pulse-on time, Duty cycle, Gap voltage	MRR , Surface Roughness

Table 1. Literature Review

Sr. No	Authors (Year)	Mechanism	Workpiece Mtl.	Tool Mtl. Specification	Input Parameters	Output Parameters
12.	Patil N. G. et al. (2009) [1]	Wire Electro Discharge Machining	Al/Al_2O_3p 10%, Al/Al_2O_3p 22%	Coated brass wire (CuZn50)	Servo reference mean voltage, Pulse on-time, Pulse off-time, Ignition pulse current, Max. feed speed, Wire speed, Wire tension	Cutting speed , Kerf width , Surface Roughness
13.	Muttamara A. et al. (2009) [17]	Electro Discharge Machining	Al_2O_3	Copper electrodes and Powder EDM Electrodes	Types of electrode, Electrode polarity, Discharge current, Discharge duration, Pulse interval time, Rotating speed	Feasibility of electrode, MRR, Surface finish
14.	Liu J. W. et al. (2009) [18]	Wire Electrochemical Discharge Machining	10%and20% Al_2O_3+ aluminum alloy 6061	Molybdenum wire	Pulse duration, Current, electrolyte concentration, Voltage	MRR
15.	Fukuzawa Y. et al. (2009) [19]	Wire electrical discharge machining	ZrO_2-20%Al_2O_3	Zinc coated brass wire	open circuit voltage	Bending Strength, MRR, Surface roughness
16.	Ferraris E. et al. (2011) [20]	Micro EDM	Al_3O_2–TiC0.7N0.3 grade	WC	Voltage, current, frequency, width energy.	MRR, TWR 4 times lower than that of steel
17.	Yan Y. et al (2011) [29]	CO_2 Laser Machining	Al_2O_3	CO_2 Laser	Laser power, optimal water layer thickness, scanning cycles	Optimal MRR, kerf width, kerf depth, surface roughness
18.	Tak H.S. et al. (2011) [2]	Micro-electrical discharge machining	Al_2O_3 99.9%0.1% MgO	Tungsten rod.	Voltage, Condenser, Purified CNTs	Electrical conductivity, MRR, Dimensional Accuracy
19.	Kok M. (2011) [3]	CNC lathe Machine	23.3% Al_2O_3/2024 Al alloy	TiN coated on K10 carbide grade, triplayer coated on P30 carbide grade cutting tool	Cutting speed, Particle size, Volume fraction of particle	Surface roughness for k10, Surface roughness for TP30, Check feasibility of Tools
20.	Wu J. et al. (2011) [31]	Rotary Ultrasonic Machining	92% Al_2O_3	diamond drills	spindle speed, Feed rate, Ultrasonic vibration power, Grit size	Surface roughness, cutting force
21.	Yang J. et al. (2012) [4]	Laser Machining (CO_2)+ gelcasting technique	Al_2O_3	CO_2 Laser	Laser power	Complex shaped Machined
22.	Vora H. D. et al. (2012) [5]	Laser Machining (Nd:YAG)	99.6% purity Al_2O_3	Nd:YAG Laser	Pulse energy, Average energy density	Surface roughness
23.	Ji R. et al. (2012) [6]	Single Discharge Machining	Al_2O_3	Red copper	Tool polarity, peak voltage, capacitance	Crater volume, Crater depth, TWR and assisting electrode wear ratio
24.	Singh S. (2012) [11]	Electro Discharge Machining	6061Al/Al_2O_3p/20P	Electrolytic copper electrodes (99.9%)	Aspect ratio, Pulse current, Pulse ON time , Duty cycle, Gap voltage, Tool electrode lift time	MRR,TWR, Surface roughness

Table 1. Literature Review

Sr. No	Authors (Year)	Mechanism	Workpiece Mtl.	Tool Mtl. Specification	Input Parameters	Output Parameters
25.	Calignano F. et al. (2013) [9]	Electro Discharge Drilling	72 wt% Al_2O_3–28 wt% TiC.	Copper Electrodes	Peak current, Pulse on time, Pulse off time, Drilling depth	MRR, TWR mean, Surface Roughness mean, Overcut
26.	Manna A. (2013) [24]	Traveling Wire Electrochemical Spark Machining	Al_2O_3	IS-3748/T35Cr5Mo 1V30/	DC supply voltage , Electrolyte concentration, Gap between tool & anode, Wire speed	MRR, spark gap width over micro slice
27.	Kibria G. (2013) [22]	Nd:YAG laser micro-turning	Al_2O_3	Nd:YAG laser	Average power, Pulse frequency, Rotational speed, Air pressure, feed rate	Surface roughness, Depth Deviation
28.	Emami M. et al. (2014) [26]	Precision Grinding Machine	96% purity Al_2O_3	Diamond Grinding Wheels	Minimum Quantity Lubrication-Mineral oil, Hydrocracked oil, Synthetic oil, Vegetable oil, Depth of cut, Feed rate, Grain size	Grinding force, Specific Grinding Energy, Surface Roughness
29.	Roy T. et al. (2014) [7]	CNC Micro Machine	99.6% Al_2O_3	solid carbide drill	Dimple distance/pitch, Dimple depth, Dimple area density , Dimple diameter , Load	wear rate and load carrying capacity
30.	Liu J. W. et al. (2014) [10]	Rotary Ultrasonic Machining	96%Al_2O_3	CVD Diamond-coated drill	Feed rate, Ultrasonic power , tool amplitude, Spindle speed	Tool wear, Exit crack
31.	Yue Z. et al. (2014) [32]	Abrasive Water-jet Turning	96%Al_2O_3	Mesh size #80 cermet abrasive	Water pressure, Jet feed speed, Abrasive mass flow rate , Surface speed, Nozzle tilted Angle	MRR, Surface Roughness
32.	Bhosale S.B. et al. (2014) [8]	Ultrasonic Machining	Al_2O_3+ ZrO_2	EN 8 alloy	Slurry of Nature, Slurry Concentration, Amplitude	MRR, TWR, Surface Roughness

5. STUDY OF VERIOUS PROCESSES USED IN MACHINING OF Al_2O_3 AND Al_2O_3 BASED CERAMIC MATERIALS

The figure 2 shows, causes and effects diagram (Fishbone) of various machining parameters to be utilized in machining of Al_2O_3 and Al_2O_3 based ceramic materials. The figure 3 shows that number of research papers recently published on the machining process of Al_2O_3 and Al_2O_3 based ceramic materials. The figure 4 shows the percentage distribution of different machining process used to machine Al_2O_3 and Al_2O_3 based ceramic materials.

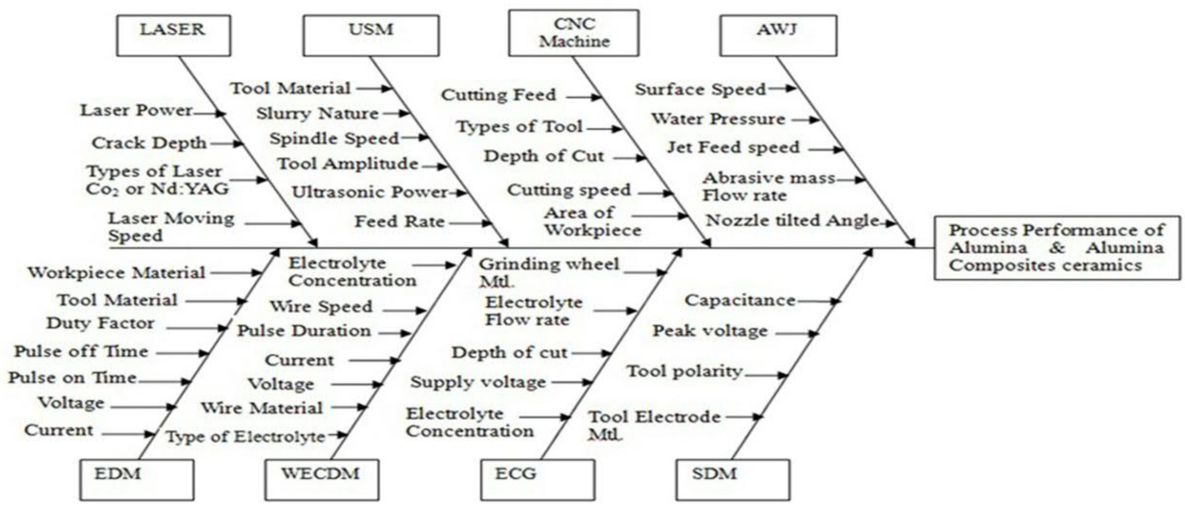

Figure. 2 Cause and Effect Diagram for machining process of $Al_2O_3$and Al_2O_3 based ceramics (Fishbone)

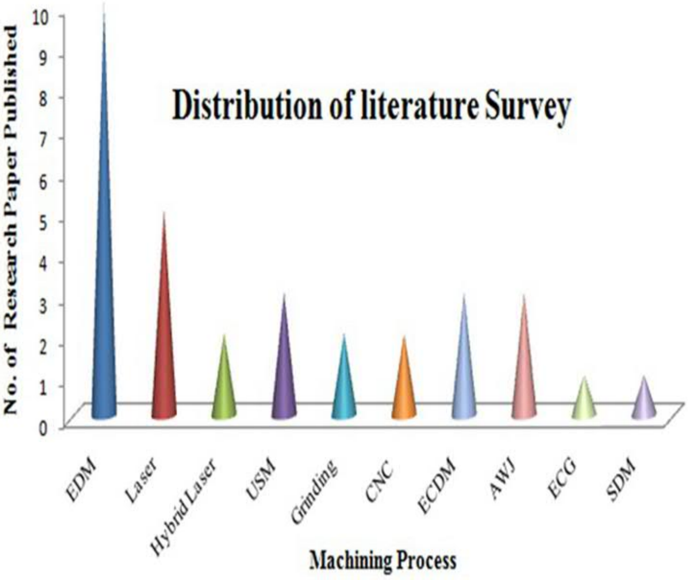

Figure. 3 Distribution of collected research papers for machining on Al_2O_3 and Al_2O_3 based ceramics

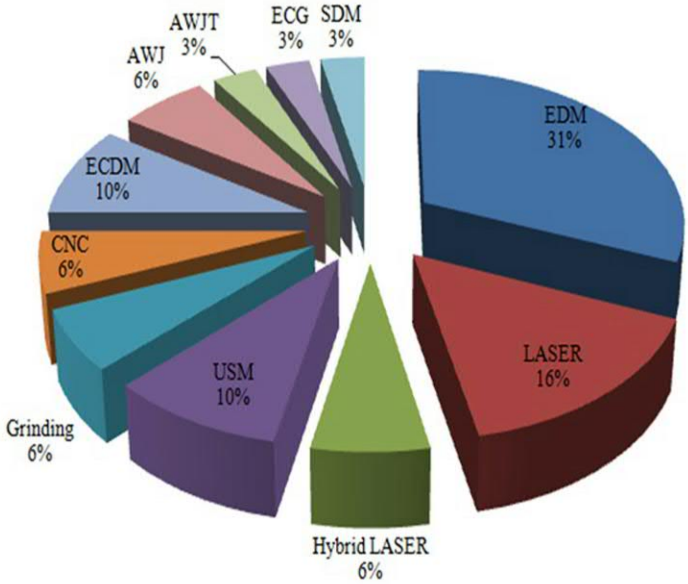

Figure. 4 Percentage of research conducted in different machining process on $Al_2O_3$and Al_2O_3 based ceramics

6. CONCLUSIONS

1. From the present investigation it can be concluded that, the machining process of Al_2O_3 and Al_2O_3 based ceramic, composite by different machining process mechanism, that uses 31% of Electro Discharge Machining process, 16% of Laser Machining, 10% of Ultrasonic Machining process, 10% of Electro Chemical Discharge Machining Process, 6% of Abrasive Water jet Machining process, 6% of Hybrid Laser Machining, 6% Grinding process, 6% CNC Machining, 3% of Abrasive Water-jet Turning, 3% of ECG and 3% of SDM.
2. The most of authors found that, the responses such as MRR, TWR, Ra, Cutting force, Dimensional accuracy etc.
3. The researchers applied various machining processes to obtain various advanced machines of Al_2O_3 and Al_2O_3 based ceramic composite.

7. ACKNOWLEDGEMENTS

The author would like to express their sincere thanks to Department of Manufacturing Engineering, National Institute of Technology, Jamshedpur for their encouragement, motivation, and continuous support for performing this research work

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