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Variations in Surface Roughness and Material Removal by using Chemical/Chemically Assisted/ Hybrid Machining Processes - A Review

Gursharan Singh, Harish Kumar and Arun Kumar

Department of Mechanical Engineering, Chandigarh University, Mohali - 140413, Punjab, India; gursharan.lucky@gmail.com, harishprashar@gmail.com, arunlatawa@gmail.com

Abstract

Background/Objectives: Non-traditional machining is nowadays widely used in industrial as well as research areas to increase both machining accuracy as well as machining efficiency. Non-traditional methods of machining are well known for machining hard fragile materials having complex shapes and complex mechanical properties. **Methods/ Statistical Analysis:** With regard to the machining of such materials the review paper has been presented including chemical machining techniques used by the researchers to achieve the higher machining efficiency and better removal rate. **Findings**: To bring such materials under industrial use number of machining techniques falling under the category of non-traditional machining is implemented. One of the oldest such technique is chemical machining or chemically assisted machining which include a chemical reaction for oxidizing the material surface which makes material removal easier. **Improvements/Applications:** This paper presents the effects of chemical machining on surface roughness and material removal which may be further used by the researchers and industrial applications too.

Keywords: Chemical-Mechanical Polishing, ECM, EMM, EMAF, EPP, MEAPS, MFGA, UAMAF

1. Introduction

Chemical machining is one of the aged non-conventional forms employed in the machining of hard fragile materials. Chemical machining gives numerous advantages over other methods as it provides burr-free machining, high surface finishing, no cold working stresses induced, can be employed to any metal, no heat or residual stress is formed, large and complex components could be used, easy material removal, low tooling costs, low scrap rates. Chemical can be involved in machining process in number of ways like in the form of etchant electro-chemical processes, tool coat, surface coat and solution in which workpiece can be immersed.

2. Effects on Surface Roughness

Surface roughness is being reduced to its minimum value to obtain mirror like finishing for great industrial importance, ergonomics and finishing influence. Developments in chemical machining and their effect on surface roughness have been discussed in[1]. Magnetic abrasive finishing (MAF) on stainless steel rollers to replicate non-magnetic Si_3N_4 which are extremely difficult to get machined with traditional machining techniques and the factors effecting i.e Wt. % of Zinc stearate ($C_{36}H_{70}O_4Zn$), processing time on the surface finish and material removal rate are discussed in the Figure 1 & 2.

**Author for correspondence*

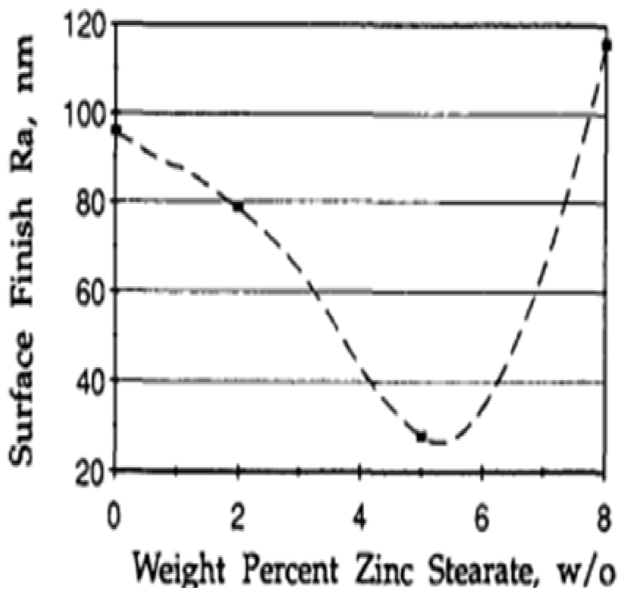

Figure 1. Wt.% of abrasives vs. Surface Finish[1].

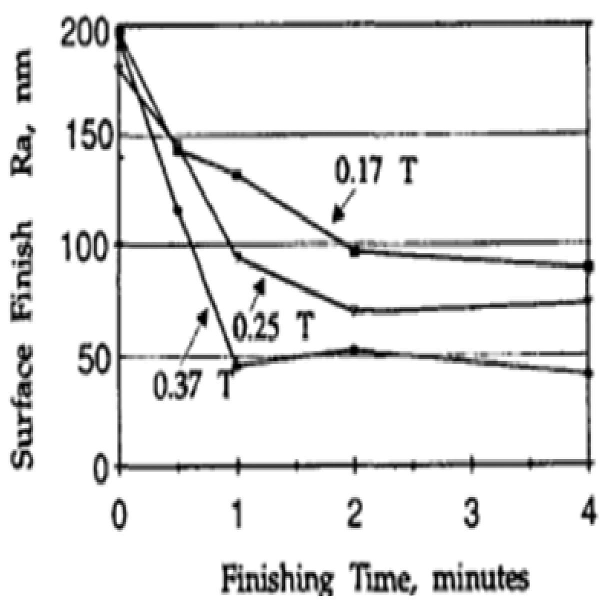

Figure 2. Finishing Time vs. Surface Finish[1].

In[2] explored finishing properties of Cr-coated roller using Magneto-electrolytic-abrasive polishing system (MEAPS) using $NaNO_3$ as an electrolyte which gave the enhanced surface finishing and finishing efficiency. They considered current density, Pressure and Work speed as the effective parameters and Surface roughness as the output response and their effect has been described. In [3] investigated the characteristics of non-woven abrasives pads Al_2O_3 and SiC in Magneto-Electric-Abrasive polishing. These pads have been proved as higher efficiency and more economic polishing material and economic benefits of Magneto-Electric-Abrasives polishing systems have been explained. In this experiment the non-woven abrasive pads were used to observe the effects on surface roughness. The polishing efficiency of the newly developed abrasive pads depends on the percentage of abrasive ratio they contain; the 30% abrasive pads have better precision and efficiency than those of 20 % abrasive pads and 10 % abrasive pads. The surface roughness after polishing

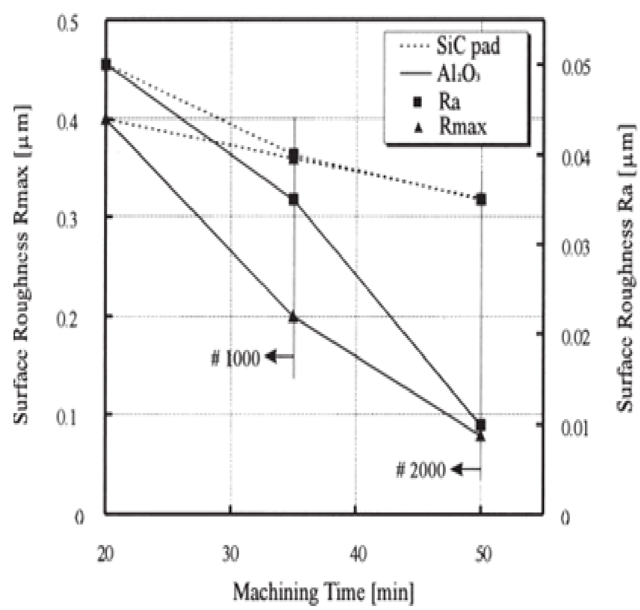

Figure 3. Machining time vs. Surface Roughness[3].

by 30% pads, Ra, was reduced to 0.01 mm and R_{max} was reduced to 0.08 mm. This produces a very nice mirror-like surface which is obtained through the variation in the parameters and hybrid machining used for conducting the experiment and the results are shown in Figure 3.

In[4] carried cylindrical MAF with comparison of steel grit and iron grit along with SiC abrasives mixed with SAE30 oil and declared the more adaptability of steel grit over iron grit due to their polyhedron structure. They also

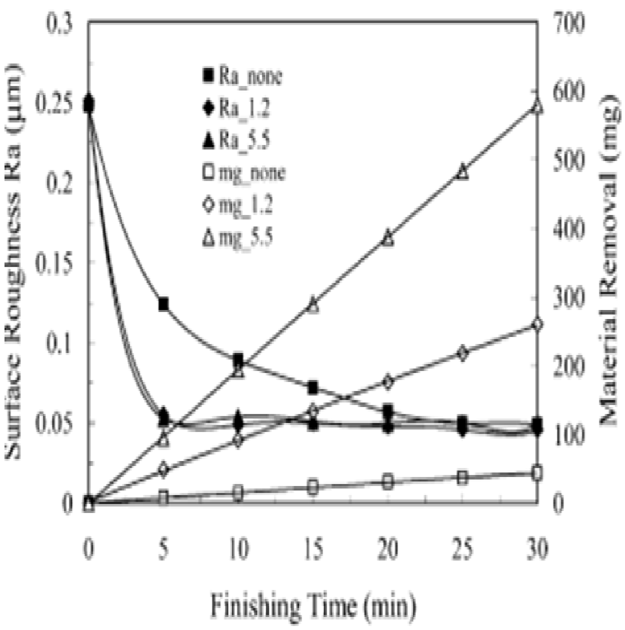

Figure 4. Finishing Time vs. Surface Roughness and MR[4].

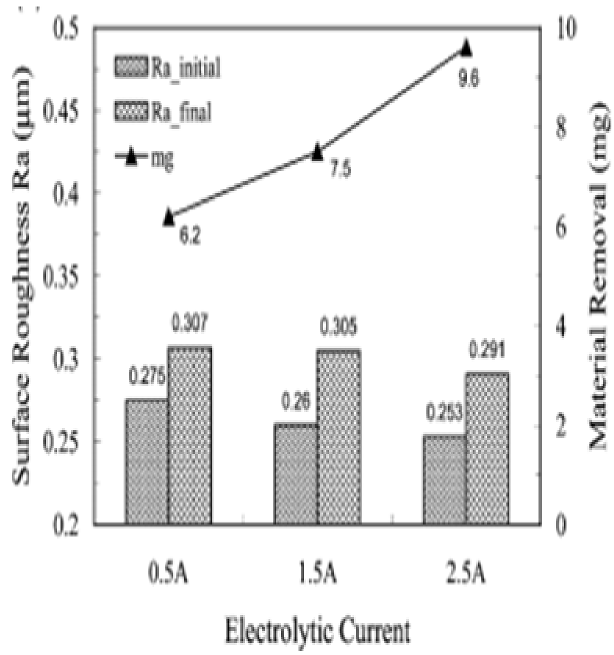

Figure 5. Electrolytic Current vs. surface roughness and MR[6].

investigated the influence of finishing characteristics on surface roughness and material removed and yielded the results on surface finish as per the graph provided below at the conditions of SiC abrasive mixed with 180 µm steel grit on surface roughness and material removal with finishing time. With smaller size of 1.2 µm SiC abrasive, the most appropriate surface roughness of 0.042 µm Ra can be obtained if 180 µm steel grit is mixed in SAE30 lubricant. The resultant effects are shown by the Figure 4.

In[5] experimentally investigated the effects of magnetic induction intensity, inter-electrode voltage and inter-electrode gap in Magnetic electrochemical finishing. The experimental results show that magnetic polishing yields better effect on rough surface than that of smoother surface[6] used the EMAF (electrolytic magnetic abrasive finishing) technique to machine SKD11(HRC61) material with $NaNO_3$ as etchant, Mn-Zn ferrite as abrasives used and concluded the better performance of EMAF over MAF as the oxide layer (loose bonded molecular structure) of material is much easier to remove than parent metal itself. They concluded that the factors of RPM, electrolytic current must be proper fitted to produce a passive film quickly and clearly, and the speed of workpiece revolution must be matched to the formation rate of the passive film to remove it rapidly with better surface finish and explained the effects at 500 RPM using following

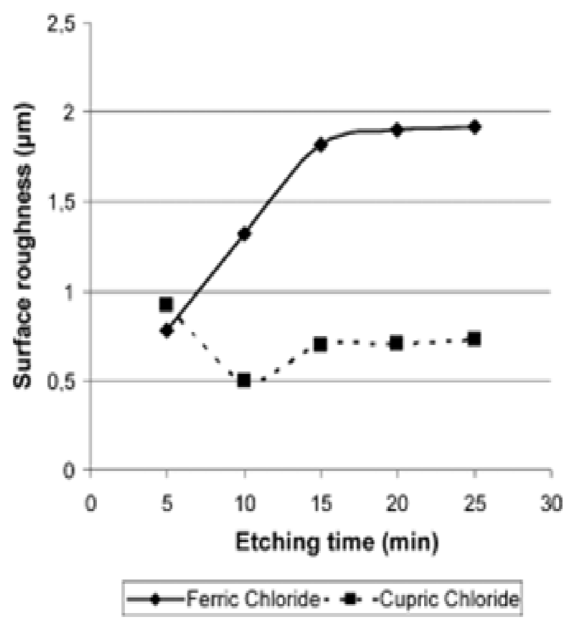

Figure 6. Etching time vs. Surface Roughness[8].

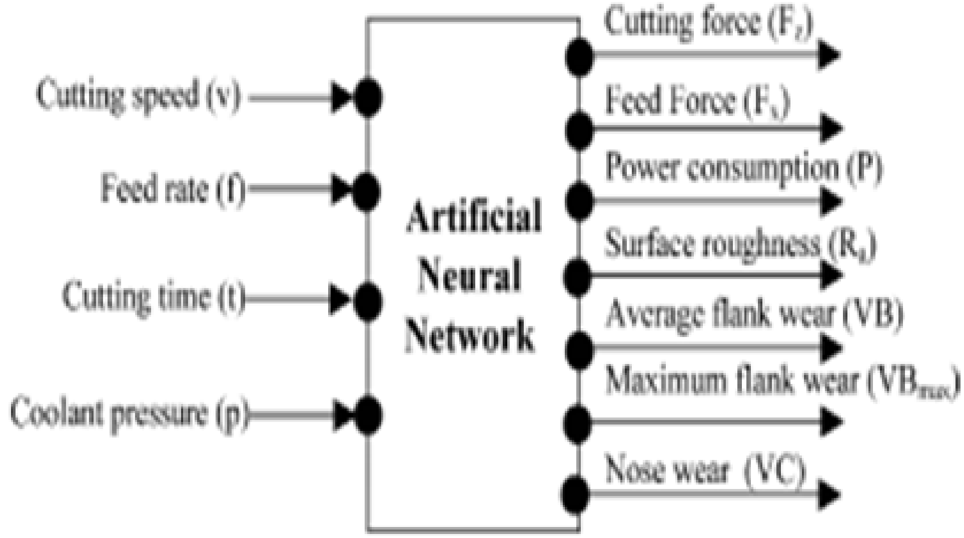

Figure 7. Neural network[9].

graph. Increasing the electrolytic current and the speed of workpiece revolution increases finishing efficiency, and the surface roughness improves rapidly (Figure 5).

In[7] performed and signified the process of machining of mild steel with chemically (TiN) coated carbide tool which resulted into longer tool life, better surface finish. They concluded that feed rate and cutting speed came out to be significant parameters affecting surface roughness whereas depth of cut came out to be insignificant or insensitive factor. In[8] compared $FeCl_3$ and $CuCl_2$ for etching Copper surface and concluded that $CuCl_2$ produced smoother surface finish than $FeCl_3$. Each observation was taken after 5 min. interval and Etching period was 25 min. in total and Machining temperature was kept at 50 ± 2^{0}C. The Figure 6 shows the experimental analysis of the study.

In[9] performed the machining of INCONEL 718 with triple (TiCN/Al2O3/TiN) PVD-coated carbide tool using neural network consisting of cutting speed, feed rate, cutting time, coolant pressure as input factors and cutting force, feed force, power consumption, surface roughness, average flank wear, maximum flank wear, and nose wear as output factors. Machining for longer time period gave steady increase in component forces, power consumption, average and maximum flank wear, and nose wear. Cutting speed of 25-35 m/min. was a most optimum cutting speed for minimum surface roughness and increased feed rate led to decrease in surface roughness. The neural network included in the study is shown in Figure 7.

In[10] explained the process of chemical machining, its advantages disadvantages, choice of the etchant accord-

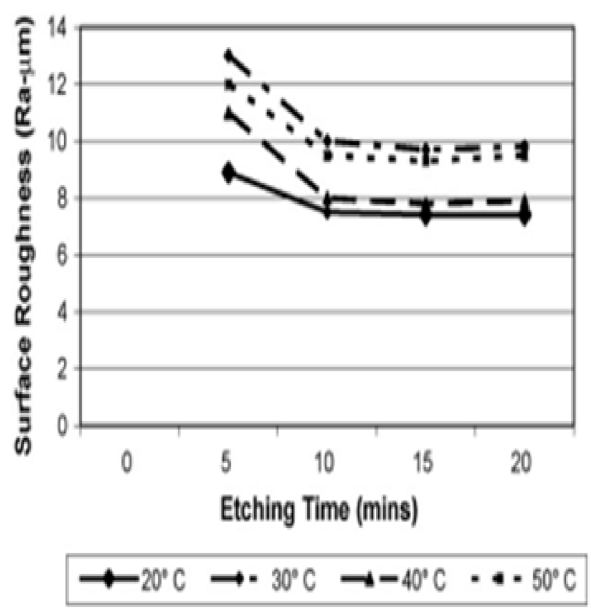

Figure 8. Etching Time vs. Surface roughness[12].

ing to the workpiece material, usage of maskant for proper etching of complex shapes, properties of etchants responsible in chemical machining i.e High etch rate, Good surface finish, Minimum undercut, Compatibility with commonly used maskants, High dissolved-material capacity, Economic regeneration, Etched material recovery, Easy control of process, Personal safety maintenance which effect the machinability and surface finishing of workpiece. In[11] performed analysis of hybrid Electrochemical turning and magnetic abrasive finishing on 6061 Al/Al_2O_3 surface which resulted into better surface finishing and yielded higher material removal rate over traditional ECT. Effects of Input parameters like Magnetic flux density, applied voltage, feed rate, and rotation were observed upon MRR and surface finish. Increase in both tool feed rate and voltage applied provides the increase in surface finish significantly. In[12] used $FeCl_3$ for etching Aluminium and studied the effects of etching temperature and etching time on surface roughness. The author also described the adaptability of $FeCl_3$ as etchant for Aluminium. Etching temperature and etching time period were considered as major factors effecting the surface finish of Aluminium (Figure 8).

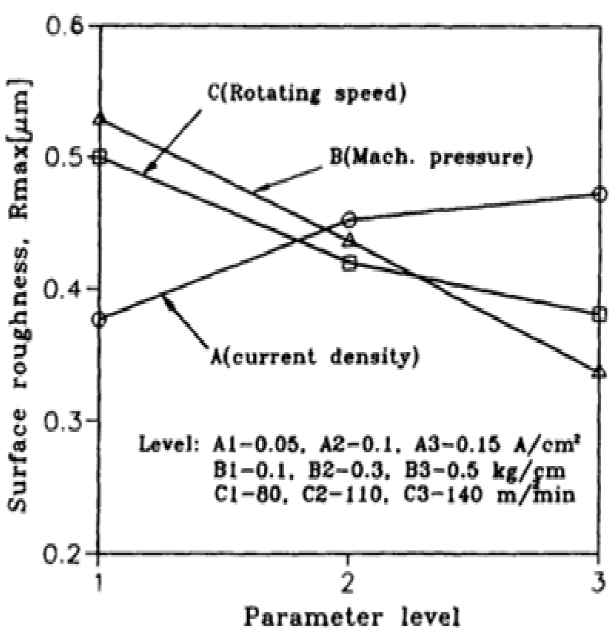

Figure 9. Parameter level vs. Surface Roughness[15].

In[13] compared Ultrasonic assisted magnetic abrasive finishing on the surface of High carbon antifriction bearing steel workpiece (AISI 52100) with unbounded SiC abrasives to that of MAF process and yielded better surface finish and lesser shear tracks on the workpiece surface. Ultrasonic-assisted magnetic abrasive finishing process reveals that the microchipping and nano-scratching by abrasives due to ultrasonic vibrations are the mechanisms responsible for finishing. The process parameters, their levels included in the process were namely voltage, mesh number, RPM, Abrasive weight and the results with their corresponding effects have represented in Figure 9. Where parameter levels of current density was 0.05-0.10-0.15, Pressure was 0.1-0.3-0.5, Work speed was 80-110-140.

In[14] presented the performance of cylindrical electrochemical magnetic abrasive finishing on cylindrical AISI304 stainless steel work piece and concluded the effects of speed, electromagnet current, electrolytic current and vibration frequency on the surface roughness. They concluded and simultaneous reduction in Ra due to the synergistic effect of abrasion-assisted passivation and passivation assisted abrasion. Increase in current to electromagnet leads to more machining pressure and has significant effect for increasing MR and decreasing R_a. Frequency of vibration has also significant effect on $R_{a.}$ In[15] investigated the % age improved surface finish by finishing workpiece with integrated use of UAMAF and yielded the following results that best surface finish was observed at the condition- 800 mesh no. and 280 rpm (Ra = 0.0219 micronmetre); T_{off} = 2 s kept constant for all experiments. In[16] used silicon gel as interaction medium of abrasives to finish cylindrical rods which tends to raise the working temperature rapidly and introduced the self-sharpening effect of abrasives over the work-piece which made the MFGA process shorter, easier and efficient than MAF. Best mirror like finish was obtained at the condition of mesh no.=6000 SiC (10 g), #70 SG (15 g), silicone gel with plasticity 80 (10 g), current (2 A), rotation rate (1300 rpm), and vibration frequency (6 Hz). In[17] investigated the effects of various parameters on Tungsten by chemically assisted magnetic abrasive finishing and more effective results were observed as compared to other

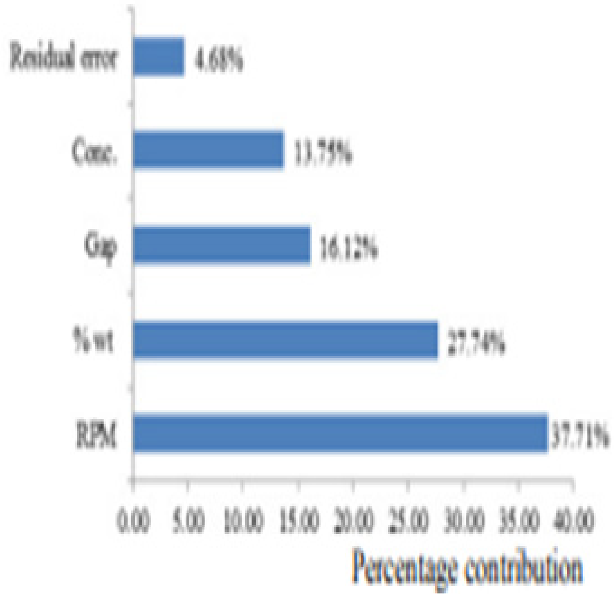

Figure 10. Percentage contribution of various parameters[17].

machining techniques for machining such hard materials. The effects of factors like pole rotational speed, wt.% abrasives and concentration of H_2O_2 as oxidizing agent was investigated on surface roughness of Tungsten surface. The results of this investigation has been provided in the Figure 10.

It was concluded from the experiments that surface roughness was majorly influenced by the RPM and was least effected by conc. of H_2O_2. In[18] carried out number of experiments to checkout the feasibility of EMAF for finishing nickel based alloy GH4169 and have proved the combined effect of EPP (Electrolytic polishing process) and MAF provides better and significant machining as EPP reduces the hardness of the surface layer of alloy and MAF carries out the finishing process over that layer by abrasive action thus increasing the machining efficiency by 50%. The effect of the processing time on surface finish yielded from this experiment is given as in Figure 11.

3. Effects on Material Removal

To keep a check on material removal, it is essential to calculate machining efficiency of process used for machining. It also provides parametric influence considered in the process on the Material Removed after finishing. It is important to consider MR for keeping it in the controlled amount. In [1]performed MAF on stainless steel rollers to simulate non-magnetic silicon nitride which are difficult

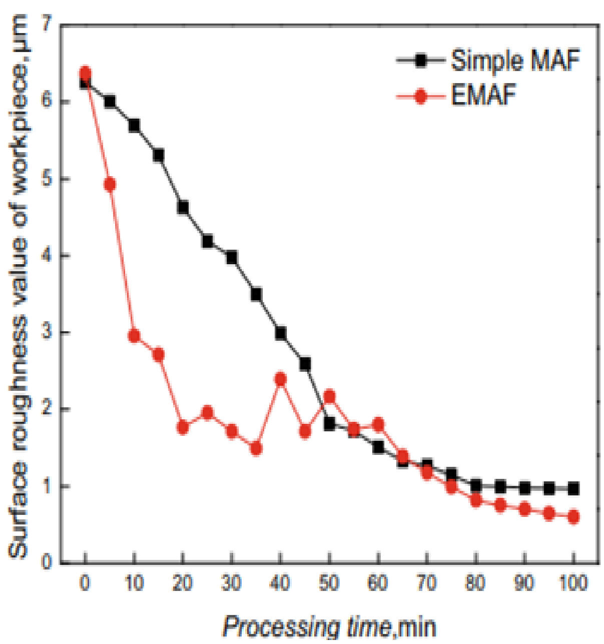

Figure 11. Processing Time vs. Surface Roughness[18].

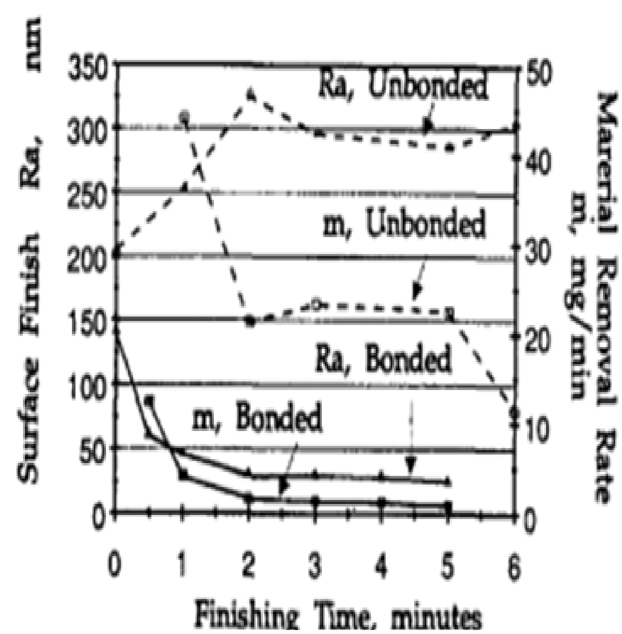

Figure 12. Finishing time-Surface Finish-MRR[1].

to machine with traditional machining techniques and the effects of finishing time and bonded and unbounded abrasives on MRR has been provided in Figure 12.

Increase in current to electromagnet leads to more machining pressure and has significant effect for increasing MR and decreasing. In[19] reviewed and highlighted the applicability of Chemical-Mechanical polishing in industrial use and their inadaptability for general use. He

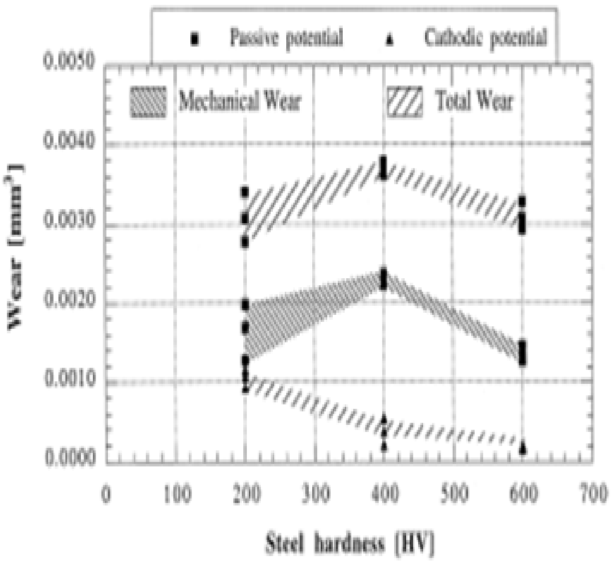

Figure 13. Steel Hardness-Wear[20].

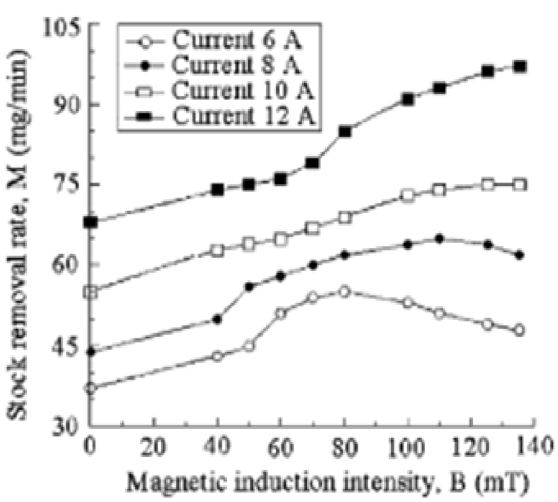

Figure 14. Magnetic Induction Intensity vs. Stock Removal Rate[5].

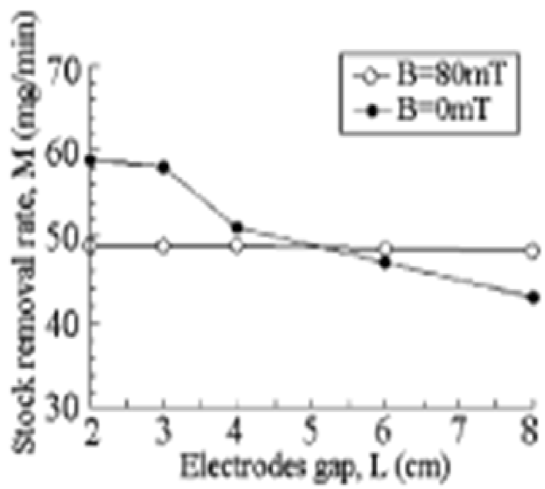

Figure 15. Electrode Gap vs. Stock removal Rate[5].

concluded that removal rate is the most important topic for modeling of CMP which consists of chemical and mechanical contribution. He also stated and elaborated other problems associated with it like stresses induced, transport and flow of slurry which make the applicability of CMP difficult in industrial use. In[20] investigated the contribution of mechanical and chemical mechanisms individually in overall metal degradation of carbon steel rubbing against alumina and oxidized using 8.4 pH borate solution. They found that the presence of passive film influenced the degradation mechanism and increased wear rate was observed and compared to that of oxide free metal. Corresponding results obtained from experiments were presented in the Figure 13.

In[4] carried cylindrical MAF with comparison of steel grit and iron grit. With the deeper cutting depth for each 5.5 μm SiC particle, although more material is removed, but the surface roughness is worse[5] experimentally investigated the effects of magnetic induction intensity and inter-electrode gap in Magnetic electrochemical finishing on stock removal rate which has been explained by graph as provided in Figure 14-15.

In[6] used the EMAF (electrolytic magnetic abrasive finishing) technique to machine SKD11(HRC61) material with $NaNO_3$ as etchant, Mn-Zn ferrite as abrasives used.

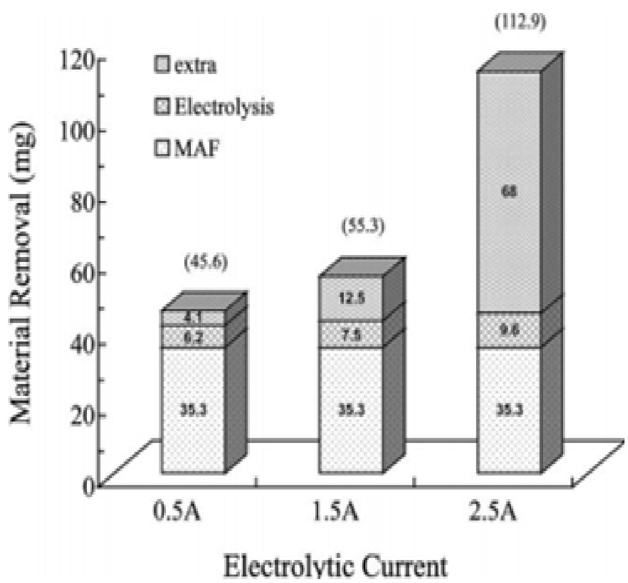

Figure 16. Electrolytic current vs. MR[6].

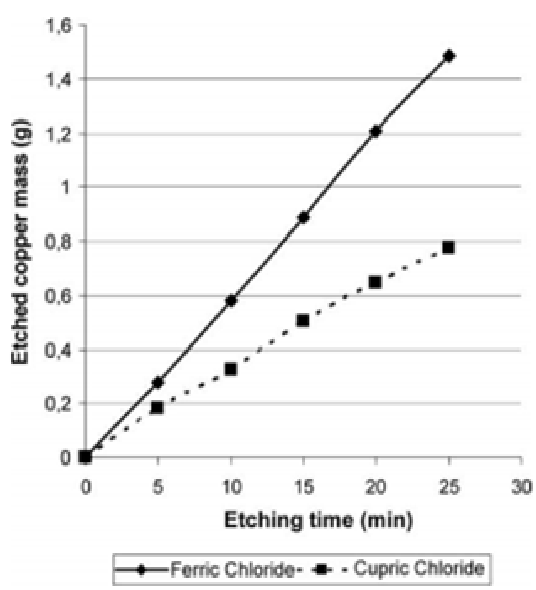

Figure 17. Etching time vs. amount of Cu etched[8].

They studied the effects on electrolytic current on material removal rate and explained in Figure 16 respectively.

In[21] highlighted the recent developments in ECM, EMM and Chemical machining as well and concluded the advantages, future challenges, and research efforts related to these machining techniques. They explained Anodic reaction and current efficiency, Mass transport effects, Current distribution and shape evolution as major forms of factors affecting Material Removal in EMM process and also highlighted the role of inter-electrodal gap and electrolyte used in the process[8] experimentally concluded that $FeCl_3$ etched more mass than $CuCl_2$ when both were used on Copper with same etchant volume and for same etching period. The experimental results have been described in Figure 17.

In[22] examined the effects of various parameters like applied pressure, plate speed, slurry concentration on material removal rate of Si (100) by the process of Chemical-Mechanical Polishing. Researcher concluded that removal rate increases sublinearly with applied pressure, plate speed, and slurry silica content. In[11] performed analysis of hybrid Electro-chemical turning and magnetic abrasive finishing on 6061 Al/Al_2O_3 surface and obtained the maximum MRR with maximum applied voltage and maximum tool feed rate. In[23] highlighted difficult to machine materials and the influence of varying nature of cutting fluids used in machining them. Environmental effects and cost factors related to cutting fluids were also brought to the consideration and alternative methods of machining difficult to machine materials were also compared to the cutting fluid assisted machining. This paper reviewed the difficult to machine materials and different kinds of cutting fluids involved to enhance their material removal and increase the tool life as compared to those obtained by the use of traditional cutting fluids. In[14] presented the performance of cylindrical electrochemical magnetic abrasive finishing on cylindrical AISI304 stainless steel workpiece and concluded the effects of speed, electromagnet current, electrolytic current and vibration frequency on the material removal. Increase in current to electromagnet leads to more machining pressure and has significant effect for increasing MR. The multiple response optimization for maximum MR and minimum Ra has been carried out, and the optimal input variable settings are workpiece rotational speed 1,200 RPM, current to electromagnet 2.4 A, electrolytic current 2.5 A, and frequency of vibration 6 Hz[18] carried out number of experiments to check out the ability of EMAF for finishing nickel based alloy GH4169 and have proved the combined effect of EPP (Electrolytic polishing process) and MAF (Magnetic abrasive finishing) provides better and significant machining. Electrolytic-magnetic abrasive finishing can soften the workpiece surface by electrolytic polishing before the magnetic grinding, so it is relatively easier to remove the material and effectively improve the efficiency of magnetic abrasive finishing.

4. Conclusion

This review paper highlights the effects of Chemical machining on different types of materials using different machining processes and varying other parameters which resulted into following conclusions:

- Chemical assisted machining allows the chemical to be used along with mechanical methods in numerous ways as per the requirement and compatibility i.e as an etchant, maskant, oxidizing agent, as a coating and as a cutting fluid.
- Difficult to machine materials are easier to machine with chemical machining.
- Complex shaped machining can easily be done with chemical etching.
- Chemical machining results in better surface finish and better removal rate.
- Hybrid machining process could be used to prevent machining defects raised in single machining technique.
- Oxide layer of hard material could be easily removed as compared to its parent material.

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