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Review on Material Removal Technology of Soda-Lime Glass Material

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Abstract

Objective: To provide comprehensive literature survey of machining process in soda lime glass with reference to the conventional and non-conventional material removal process. **Methods/Statistical Analysis:** For more convenient understanding, the various processes, research and advanced progress in this field is presenting in table format. The ascending pyramid diagram shows progress of advanced researches on soda lime glass machining. The percent contribution of machining processes has been calculated and explained in a pie chart. **Findings:** There are totally eight machining processes used by various researchers to treat the soda lime glass. From which, Laser Machining Process and Electrochemical Discharge Machining Process showing highest contribution i.e. 22% are because of its advanced and wide range of applications in various fields. Whereas 6% contribution is observed for Abrasive Jet Machining process and micro grinding process, which is used at very low scale, it may be due to an extensive range of limitations. **Application/Improvement:** The present study is a first attempt towards the literature review on soda lime glass material. This review may be helpful to classify and select the most significant machining method to work with soda lime glass material.

Keywords: Abrasive Jet Machining, ECDM, Laser, Micro Grinding, Microwave Drilling, Soda Lime Glass

1. Introduction

The requirement of high-performance micro devices is increased day by day. It may be due to the advanced technology of equipment is which is used in various fields such as medical, electrical and optical. The glass is used as engineering material from the very long period, but due to rapid progress in the glass industry, it is known as most versatile engineering material for the present days. It is used as work piece in many systems due to its significant properties such as high chemical corrosion resistance, optical transparency, biocompatibility, attractive appearance, high electrical resistivity, temperature stability, non-porosity, various reflective indices, homogeneity, high hardness, durability, isotropy[1-6]. With these all-considerable properties, glass also has one drawback i.e. poor machinability due to its amorphous structure, which gives brittleness and hardness to the glass[1-3]. Depending upon chemical composition glass is classified into various types. Soda lime is also one of the types of glass. It is prepared by melting and mixing of silica with soda, dolomite, lime and alumina at a temperature of up to 1,675°C. The soda lime glass material is mostly used for the production of mirrors, photo masks, glass masters, data storage disks, microscopic slides, touch screens, filters, printed circuit substrates, photographic plates, wafers, optical windows, chemical apparatus, camera lens, micro gas turbines, micro electromechanical systems (MEMS), microfluidic devices, mass spectrometry, microcapillary electrophoresis and optomechatronic systems[2,7-9].

The glass has the wide range of advantages. It is very difficult to handle and processing due to which the research activities in this field have been increasing in the current decade. The review study on glass and borosilicate glass micromachining have been already reported[10,11], but the analysis of soda lime glass is not reviewed yet. Thus, to fulfill this lacuna present investigation has been undertaken. The aim of this article is to focus on machining technology, which is used to treat soda lime glass, with reference to the conventional and non-conventional material removal process. The mechanical and tribological performance of nickel matrix composites

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have analyzed by[12]. In[13] authors have reviewed impact behavior of PMC Reinforced with fibers under subzero temperature.

2. Various Machining Process of Soda-Lime Glass

From the studied literature review it is found that, there are totally 8 machining processes used by various researchers as shown in Figure. 1. [Figure 1]

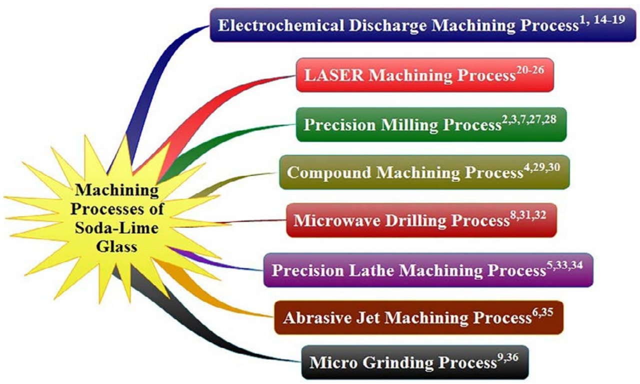

Figure 1. Various material removal processes of soda lime glass material.

2.1 Electrochemical Discharge Machining Process

The applied voltage is the most influencing factor to increase radial overcut, materials removal rate, heat affected zone and roundness error stated by[1]. According to them, when electrolyte concentration increases, it also increases chemical etching of glass and improves the MRR. They also achieved geometrical accuracy and machining rate of ECDM process. The applied voltage was the most influencing factor in material removal and tool wear concluded by[14]. Similarly[15] observed that the applied voltage is most significant parameters for material removal; However, NaOH experimental results were more efficient as compared to $NaNO_3$. In[16] authors accomplished that vibration tooling in ECDM process has to be enhanced material removal rate as compared to conventional ECDM process. The main advantage of vibration tool is to improve the continuity in feeding during electrochemical discharge machining process. In[17] authors have applied longitudinal oscillation to cathode electrode in ECDM machining process and observed the result for vibration parameters such as waveform of vibration, the amplitude of vibration, depth cut, and frequency of vibration. He also observed that cylindrical rod tool electrode shows geometrical shape, as soon as a square waveform voltage were applied to the actuator, which enhanced the material removal rate and cut machining time. In[18] authors have used mechanical contact detector for electrode controlled position in the electrolyte solution, which will help to reduce required voltage. This process has obtained high aspect ratio structures in a glass workpiece, which can have resulted into superior surface quality. In[19] calculated drilling depth evolution in discharge regime using a finite element based model for ECDM drilling in less than 300μm depth. The authors found that the analytical model predicted values valid with experimental results.

2.2 LASER Machining Process

In[20] author drilled micro-holes on soda lime glass material by using femtosecond machining technology with ambient air as a medium, which has resulted into a superior characteristic of soda lime glass. According to him to achieve a superior quality of micro hole, the drilling should be carried out in the distilled water medium. In[21] authors fabricated superhydrophobic soda-lime glass surface by manufacturing periodic micro-gratings with self-formed periodic micro-ripples inside the micro-gratings by a single-beam femtosecond laser. He observed that microstructured glass surface illustrate excellent transparency, which is higher than 77% in the visible spectrum. The new laser machining technique is invented by[22] i.e. laser processing strategies and adequate optical systems and devices. In this process, use of diode-pumped solid-state laser generating nanosecond pulsed green laser light in combination with both scanners and special trepanning systems, which can give consistent glass machining at excellent efficiency. The surface roughness of processed area is near about 10μm. In[23] authors applied a hybrid method to manufacture microfluidic microchannels on the soda-lime glass. The hybrid method consists of pulsed nanosecond laser process and thermal treatment for reshaping and improving the morphological qualities of the created microchannels. He successfully produced microchannels have a minimum diameter of 8 mm and depth of 1.5 mm. 24, which contain15-ps ultrafast laser with a UV wavelength, successfully manufacture the functional microfluidic pillar array channels. The optimal energy fluence of 15.28 J/cm^2 was used to diminish the debris and dross on the surface of ablated pillar array structures. In[25] authors have found out thermal properties of the material and thermal conductivity, which is highly influenced by etching results. They concluded that, etch rate is relative to laser fluence and opposite to laser pulses number. According to them, the aspect ratio is dependent on laser pulses number and laser fluence. In[26] developed the mathematical model for line time shape laser, triangle time shape laser, and parabola time shape laser. He concluded that with the same output laser energy, the thermal stress created in glass heated by line time shape laser is higher than that of the triangle time shape laser and parabola time shape laser.

2.3 Precision Machining Process

In[2],authors has used ductile mode milling process to obtain the fracture-free surface of soda lime glass. They also suggested that feed per edge is the main influencing factor in the milling process technology. In[3], author has made slots at submicron scale without any fracture by using micro end milling technology. According to them, the feed per edge and axial depth of cut are most affecting parameters. In[7] authors observed that feed rate and cutting speed are the most affecting parameters on surface roughness, critical axial depth, and material removal rate. In[27] authors studied the cutting forces and surface characteristic of soda lime glass material during the conical scratch tests using torus end milling process. He found that the feed rate significantly affected by the forces and surface finishes, as well as higher critical chip thickness at higher cutting speeds is also observed. In[28] have developed ductile regime model and evaluated critical chip thickness and cutting forces in a conical scratch test on a soda lime glass. The scratch tests performed on a precision vertical CNC milling machine. They also investigated machining performance by using coated ball end mill cutters to analyze feed rate effects, up and down milling, depth of cuts on the surface finish and tool wear. In up milling process they achieved less cutting forces as compared to the down milling process, it is due to the brittle crack and less impact. However, the material removal rate is dependent on feed rate process parameter.

2.4 Compound Machining Process

The cause of laser heating on the material elimination of soda lime glass material have studied by in[4], with the help of a single point diamond tool in a micro laser assisted machining process. This process is useful to improve the cutting performance and produces high-quality optical shapes on the soda-lime glass. In[29] authors have successfully fabricated microfluidic chips for capillary electrophoresis and solo-chamber chips on the glass surface by using ultrasonic micro-machining and wet etching process. The experimental observation shows the improvement in surface morphology of the microstructures by a ultrasonic-assisted chemical etching process by using the hydrofluoric acid solutions. In[30] authors produced the arithmetical model by applying Hertzian theory to verify the probability of vibration-assisted nano impact machining with loose abrasives. The authors have successfully machined the soda lime glass material at nano scale with diameters starting from 78 to 276nm and depths starting from 6 to 64nm.

2.5 Microwave Drilling Process

In has evaluated the local heat flow characteristics on target drilling zone is evaluated by[8], with the help of various surface precursors. According to them, the cracking defects can be eliminated by using solid and liquid fluxes as precursors. They found that glycerin and perspex are the best precursors to control the crack defects. In[31] investigated internal thermal ablations system on a hole in microwave drilling process. However, the plasma creation for heating and ablation was considerable at lower power. In this study, they performed drilling the hole in glass by nailing of a tool and cracking around heat affected zone was substituted by melting and ablation, due to which the sharp edges at the hole boundary might be eliminated. They achieved the machining time for drilling hole was less than 4 seconds in soda lime glass for 1.2 mm plate thickness. However[32], in this process high heat is generated it may be due to microwave energy, which is caused by producing cracking and deformation defects in the drilling zone. They have successfully drilled 90μm diameter hole on soda lime glass material.

2.6 Precision Lathe Machining Process

The grooving and cutting tests on a soda-lime glass were did in[5], byusing an ultra-precision lathe with a single-crystal diamond tool. He found that the depth of cut increasing there is a ductile-brittle transition in cutting materials and cutting modes, which have a considerable effect on the machined workpiece, surface roughness. The tool wear occurs on the flank face. In[33] authors have anticipated collective breakage and plastic flow properties of a glass material which is used in machining with brittle-ductile mode cutting process. According to him, the cracking defects can be greatly reduced with the help of edge-indention experiments by using a single straight tool having big inclination angle. The experimental results obtained are the crack free surface with a good finish. The wear mechanism on the tool wear and its effect on surface roughness in a diamond cutting of glass is analyzed in[34]. He concluded that wear occurred on the diamond tool while cutting of glass is due to the reason of diffusion, mechanical friction, thermo-chemical action and abrasive wear.

2.7 Abrasive Jet Machining Process

In[6] authors have used a thick SU-8 layer as a mask to fabricate micro-channels on soda lime glass micro by the abrasive jet machining process. He successfully achieved a microchannel with an aspect ratio of 0.33 with good pattern resolution on glass surface. In[35] has examined the material erosion rate is 1.4 to 1.7 times larger at the higher temperature than that of at room temperature during abrasive hot air jet machining process. However, the surface roughness was decreased by 4-10% when hot air is utilized as carrier media.

2.8 Micro Grinding Process

The novel analytical model is developed in[9] to evaluate material removal mode in soda lime glass by applying the micro grinding process. The developed model consists of three phases, which includes brittle type, ductile-brittle type and ductile type by the quantization of undeformed chip thickness. The experimental results show that, the critical depths achieved to 2 and 5nm.The novel theoretical model is invented by[36] for predicting surface roughness in micro-grinding of hard brittle materials. It is seeing to micro grinding tool grains protrusion topography. The theory explains that characterizing grains distribution densities of the micro-grinding tool. He found that, the low feed rate and high grinding speed could accomplish a precision surface roughness value. The author achieved 78 nm to 0.98 μm surface roughness by micro-grinding process on soda lime glass material.

The progress in research of soda lime glass material with special reference to machining technology is shown in Figure 2. Which is presented in the form of ascending pyramid diagram? As the figure, consist research work from 2004 to present year the research activities in this area increased rapidly. Thus, it is a need to take an overview of advancement in machining process of soda lime glass to enhance the overall performance of experiments in this field. [Figure 2]

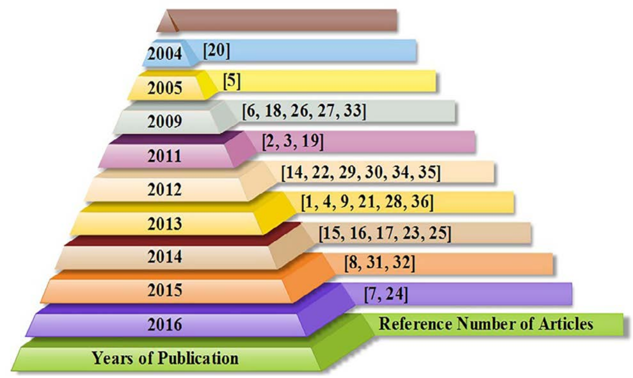

Figure 2. Progress in machining process of Soda Lime glass material.

3. A Brief Evaluation in Material Removal Processes of Soda Lime Glass Material

In present article, different types of material removal processes of soda lime glass material were scrutinized and depending on that a brief literature study has been put into a table format. The various material removal processes of soda lime glass material with its input parameters and achieved results, which are obtained by various researchers, have been presented in Table 1. [Table 1]

On the bases of this literature survey, the percent contribution of machining processes has been calculated which is used to treat soda lime glass and presented in Figure 3. [Figure 3]

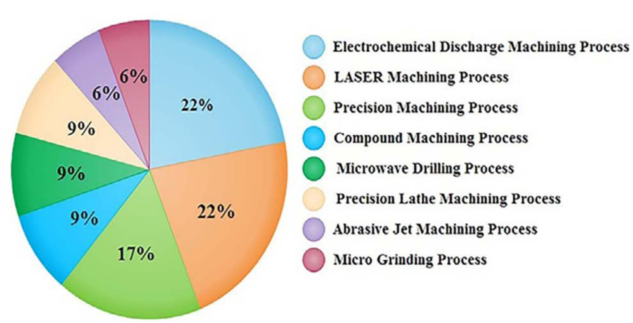

Figure 3. Percent contribution of soda lime glass material machining processes.

Table 1. Assessment of Borosilicate Glass Machining Processes

No.	Machining Process	Main Significant Input Parameters	Achieved Results
1.	Electro Chemical Discharge Machining Process	Tool Material, Workpiece Material, Electrolyte Material, Applied Voltage, Electrolyte concentration[1,14-19], Tool immersion depth[1,15-17,19], Work feed rate[14,18], Time of current flow[15], Rotational speed[16,18], Vibration Frequency, Vibration Amplitude[16,17], Duty ratio[16], Voltage pulse waveforms[17], Pulse on/off-time ratio[18], Machining Time[19].	Material Removal Rate[1,14-19], Machining Depth[1,16-19], Tool Wear[14,15], Radial overcut, Heat Affected Zone, Average hole diameter, Thickness and roundness error of the holes[1], High aspect ratio Structures, Surface Roughness, 3D microstructure fabricated[18], Drilling depth evolution in discharge regime predicted[19].
2.	Laser Machining Process	Type of Laser, Work material[20-26], Pulse Energy[20,21,23-25], Repetition Rate[21,23-25], Pulse duration[20,24,25], Pulse Width[21-24], Laser Wavelength[21-25], power[23-26], Energy Fluence[22-25], Drilling/cutting diameter, Laser beam inclination angle, focal length, Rotation speed[22], Ablation threshold[23], Spatial mode, Scanning speed, Beam diameter[24], laser frequency, Etch (depth/pulse), Etch width/pulse[25], Shapes of laser sources[26].	Surface quality[20,24,25], Aspect ratio[20,21,25],Surface Roughness[22,23,24], Fabrication of superhydrophobic soda-lime glass surface[21], Drilling slanted through-holes[22], Microfluidic Micro-channels[23], Fabrication of functional microfluidic pillar array channels, Desirable feature size, Feature characteristics[24], Etch rates[25], Calculated Temperature distribution and Resulting thermal stress[26].
3	Precision Machining Process	Tool material, Work Material, Cutting speed, Feed Rate, Axial Depth of Cut[2,3,7,27,28], Radial depth of cut[2], Mode of machining[7], Coolant[28].	Tool Wear[2,3,27,28], Surface Roughness, Critical Chip Thickness[3,7,27,28], Critical axial depth of cut[3,7,27], Feed per edge[2,3], Fracture-free Surface[2,7],Fracture-free slots[3],Cutting Force[3,27],Tool wear, Material removal rate[7,28]
4.	Compound Machining Process	Tool Material, Work Material[4,29,30], Resonance Ultrasonic Frequency, Abrasive material[29,30], Type of Laser, Laser source, Applied Loads, Lasers Powers, cutting speed[4], Ultrasonic Horn, Wet-etching chemicals, Electric Current of the Transducer[29],Amplitude, Velocity[30].	Good quality surfaces[4,29], Depths of Cut, Material Removal Rate[4],Aspect Ratio, Fabricated Micro-channels, Microchambers and microholes, Microfluidic chips for capillary Electrophoresis and solo-chamber chips[29], Tool Wear, Controllability and Repeatability aspect, Nanocavity Pattern[30]
5.	Microwave Drilling Process	Drill tool concentrator material, Microwave Frequency, Microwave Power, Duty cycle, Microwave Wavelength, Precursors[8,31,32].	Simulation of microwave drilling, Hole accuracy, Heat affected Zone, Crack Identification[8,31,32], Observed glycerin and perspex as precursors to control cracking[8], Mechanism of Material Removal[31], Photoelasticity approach to Characterize defects[32].
6.	Precision Lathe Machining Process	Tool Material, Workpiece Material, Speed, Feed Rate, Depth of Cut[5,33,34], Undeformed Chip Thickness[5], Inclination angles[33].	Surface Roughness, Tool Wear[5,34], Surface Texture, Chip Formation[5], Cutting depth, Crack-free surface, Good Surface finish, High Efficiency, Low costs[33].
7.	Abrasive Jet Machining Process	Workpiece Material, Nozzle Size, Jet Air Pressure, Abrasive Material, flow rate, Stand-off distance, Air Temperature, Feed rate[6,35], Scanning speed, Number of scans[6].	Fabricated Micro-channels, Aspect ratio[6], Material Removal Rate, Surface Roughness[35].
8.	Micro Grinding Process	Workpiece Material, Grinding wheel Material, Wheel diameters, Grinding feed rate, Grinding Depth, Rotation speed[9,36].	Material Removal Mechanism, Surface Roughness, Undeformed Chip Thickness[9,36].

According to this pie chart, it is observed that the Electrochemical Discharge Machining Process and Laser Machining Process showing highest contribution i.e. 22%, because of its advanced and wide range of applications in various fields. The Precision Machining Process give 17% contribution. The Compound Machining Process, Microwave Drilling Process and Precision Lathe Machining Process showing 9% contribution. Whereas, 6% contributions were observed for Abrasive Jet Machining Process and Micro Grinding Process which is very less as compare to other processes.

4. Conclusion

This article is based on literature review of material removal processes, which is used for soda lime glass material. It included last 10 to 12 years' data with specific reference to the different machining processes. According to present survey, there are totally eight machining processes used to treat the soda lime glass by various researchers. From which Electrochemical Discharge Machining Process and Laser Machining Process are highly used because it has wide range of advancement and applications. The Precision Machining Process, Compound Machining Process, Microwave Drilling Process and Precision Lathe Machining Process are moderately used processes. Whereas, Abrasive Jet Machining Process and Micro Grinding Process is rarely used due to its number of limitations. Thus, this literature survey can be useful to recognize and selecting the most significant machining process when working with soda lime glass material.

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