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OPTICAL GLASS TREATMENT THROUGH CUTTING AND HOT PRESSING: A COMPREHENSIVE ANALYSIS

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ABSTRACT *The secondary processing in the technological cycle of optical glass production is studied. The manufacturing of optical glass is a complex multi-stage process that includes melting, forming the glass mass, and subsequent technological operations necessary to achieve the final material characteristics. In addition to primary production, glass undergoes additional stages of mechanical processing, which allow it to obtain the required geometry and, in some cases, adjust its optical parameters. It provides a detailed analysis of the mechanical processing of colored and colorless optical glass, including cutting, grinding, and polishing methods. Special attention is given to the comparison of mechanical processing and hot pressing as an alternative method for forming optical components. The influence of temperature regimes and pressure during hot pressing on the spectral characteristics and mechanical strength of products is analyzed. Mechanical processing of optical glass requires high precision to meet surface smoothness requirements and avoid internal defects. The grinding and polishing process significantly affects light transmission and the level of light scattering, which is critical for high-precision optical systems. The characteristics of abrasive materials used in processing, as well as the speed and cutting parameters, play an important role in determining residual stresses in the material. The main advantages and disadvantages of both methods are determined depending on the type of raw material, the required dimensional accuracy, and surface parameters. The techno-economic analysis of the application of mechanical processing and hot pressing in industrial conditions is conducted. Hypothetical costs for the use of each method, including equipment costs, energy consumption, and material losses, are calculated. The obtained results allow for the formulation of recommendations on the optimal choice of optical glass processing technology, considering the requirements for the final product and economic feasibility.*

Keywords*: optical glass; manufacturing processes; cutting and grinding; hot pressing; transmittance; industrial economy.*

ОБРОБКА ОПТИЧНОГО СКЛА ШЛЯХОМ РІЗКИ ТА ГАРЯЧОГО ПРЕСУВАННЯ: КОМПЛЕКСНИЙ АНАЛІЗ

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АНОТАЦІЯ *Досліджено вторинні процеси обробки у технологічному циклі виробництва оптичного скла. Виробництво оптичного скла є складним багатоетапним процесом, що включає плавлення, формування скломаси та подальші технологічні операції, необхідні для досягнення кінцевих характеристик матеріалу. Окрім первинного виготовлення, скло проходить додаткові етапи механічної обробки, що дозволяють надати йому необхідну геометрію та, в окремих випадках, коригувати оптичні параметри. Розглянуто особливості механічної обробки кольорового та безкольорового оптичного скла, включаючи методи різання, шліфування та полірування. Механічна обробка оптичного скла потребує високої точності та відповідності вимогам до гладкості поверхні та відсутності внутрішніх дефектів. Процес шліфування і полірування суттєво впливає на світлопропускання скла та рівень розсіювання світла, що є критичним для оптичних систем високої точності. Важливу роль відіграють також характеристики абразивних матеріалів, що використовуються при обробці, а також швидкість та параметри різання, які визначають рівень залишкових напружень у матеріалі. Проведено порівняльний аналіз механічної обробки та гарячого пресування, як альтернативного методу формування оптичних компонентів. Проаналізовано вплив температурних режимів та тиску при гарячому пресуванні на спектральні характеристики та механічну міцність виробів. Визначено основні переваги та недоліки обох методів залежно від типу вихідного матеріалу, необхідної точності розмірів та параметрів поверхні. Проведено техніко-економічний аналіз застосування механічної обробки та гарячого пресування у промислових умовах. Розраховано гіпотетичні витрати на використання кожного з методів, включаючи витрати на обладнання, енергоспоживання та втрати матеріалу. Отримані результати дозволяють сформулювати рекомендації щодо оптимального вибору технології обробки оптичного скла з урахуванням вимог до кінцевого продукту та економічної доцільності.*

Ключові слова: *оптичне скло; виробничі процеси; механічна обробка; гаряче пресування; спектральні характеристики; техніко-економічний аналіз.*

Introduction

The process of glass manufacturing is highly complex due to the simultaneous influence of chemical, physical, and technological factors [1]. In real production conditions, individual stages of this process are interconnected, meaning that any deviation in technological parameters at one stage can cause disruptions across the entire process.

The continuous improvement of optical glass properties often necessitates the application of secondary treatments beyond the initial fabrication process [2]. These treatments are essential for achieving specific optical, mechanical, and structural characteristics that enhance the performance and durability of optical components. Among the various post-production techniques, cutting and hot pressing stand out as fundamental methods for treatment optical glass [3]. This study provides a detailed examination of these processes, focusing on their influence on optical performance, mechanical integrity, and overall material quality.

Cutting serves as a critical step in shaping optical glass to precise dimensions while minimizing potential adverse effects on optical quality [4]. It is a precision-driven process that involves mechanical or laser-based techniques to achieve highly accurate geometry. The accuracy of cutting not only ensures the optimal fitting of components in optical systems but also affects surface smoothness, stress distribution, and the preservation of intrinsic material properties. The choice of cutting methodology, whether diamond sawing, laser cutting, or waterjet machining, directly impacts the structural integrity and subsequent processing capabilities of the glass [5].

On the other hand, hot pressing is a thermomechanical process that involves subjecting optical glass to controlled heating and compressive forces. This method enables the manipulation of the glass microstructure, allowing for the adjustment of physical and optical properties such as transmittance, refractive index homogeneity, and mechanical strength. Hot pressing can be utilized for shaping complex optical elements, reducing residual stresses, and enhancing the material’s resistance to environmental factors [6]. Furthermore, the ability to modify surface morphology and internal structures through thermal control makes hot pressing a valuable tool in precision optics manufacturing.

This investigation employs a systematic approach to assess the effects of cutting and hot pressing on optical glass. Through experimental trials and analytical evaluations, key performance metrics – including transmittance, surface roughness, mechanical resilience, and stress distribution – are quantitatively measured. The findings provide insights into the interplay between processing parameters and material behavior, offering a deeper understanding of the trade-offs and optimization strategies involved in secondary treatments [7].

Cutting and hot pressing play pivotal roles in enhancing the properties of optical glass for diverse applications, ranging from high-precision optical instruments to industrial-scale production. By refining these techniques, manufacturers can achieve superior product quality, improved durability, and tailored optical performance. The implications of this research extend to both academic and industrial domains, contributing to the advancement of optical material processing and the broader field of photonics [8].

The goal of the work

The aim of this study is to analyze and compare secondary processing methods in optical glass manufacturing, specifically mechanical processing and hot pressing. The research focuses on evaluating their impact on the optical and mechanical properties of glass, identifying advantages and limitations based on material type and required precision. Additionally, a techno-economic analysis is conducted to determine the feasibility and efficiency of each method in industrial applications. The results provide recommendations for optimizing optical glass processing technologies to enhance product quality and cost-effectiveness.

The main results and their discussion

In the large-scale production of optical glass in a pot furnace, after completing all physicochemical processes of glass melting, the initial forming stage begins (Fig. 1), followed by gradual cooling and subsequent annealing.

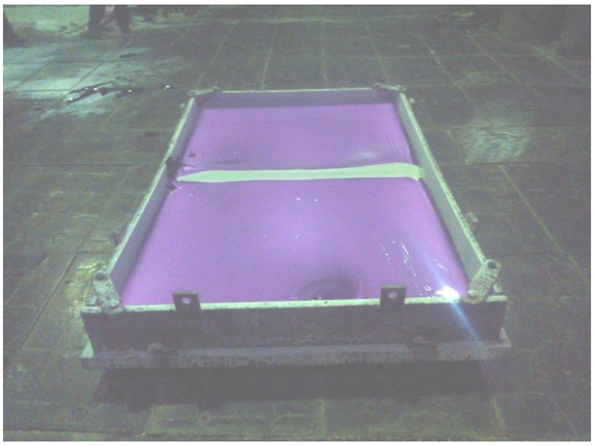

Fig. 1 – Glass forming stage before annealing

The annealing process plays a crucial role in removing internal mechanical stresses that arise during the cooling phase [9]. Incomplete or uneven annealing can lead to residual stress, reducing the material's mechanical strength and making it susceptible to fractures and thermal failure. Once stress relief is complete, glass blocks require further mechanical processing and segmentation into smaller workpieces. This is essential for facilitating subsequent manufacturing operations such as precision grinding or thermal forming.

There are two traditional methods for processing glass blocks. *Mechanical processing*, which includes cutting, grinding, and polishing. This method ensures high precision but involves significant time and energy consumption. *Thermal processing*, specifically hot pressing, where the glass is softened and molded into the desired shapes. This technique minimizes mechanical damage but requires strict control of temperature profiles and equipment pressure conditions.

Both methods involve multiple preparatory steps. Together, they form a complex technological chain where precision at each stage is critical for achieving the desired product quality.

Since the technology of hot glass pressing is limited by the size of the final product compared to the mechanical processing method, the techno-economic analysis is conducted on small standard products. These products are typical of hot pressing but, in some cases, can also be manufactured using mechanical processing. This study examines a plane-parallel optical filter with a diameter of 32 mm and a thickness of 4 mm. Such products are used in optical systems that require high surface processing precision and material homogeneity.

Mechanical processing

Mechanical processing of glass is widely used for manufacturing large optical elements, such as viewing plates, lenses, and prisms. This is due to the difficulty of uniformly heating large blanks during hot pressing, which significantly increases the risk of defects such as internal stresses, microcracks, and optical distortions. As a result, mechanical processing remains the primary method for producing such components, ensuring high precision and material uniformity. The mechanical processing cycle includes several stages: cutting, grinding, and polishing. The number of these sub-steps depends on the required size and quality of the final product.

Initially, the glass block, formed and annealed, is cut into blanks of optimal shape and size. This process considers the presence of defects in the glass mass, such as gas bubbles, inclusions, or stress concentrations. For this study, it is necessary to manufacture parts with a diameter of 32 mm and a thickness of 6 mm. The division of the main glass block is performed on a horizontal milling machine (Fig. 2), equipped with diamond tools, which provides high precision and minimal material waste.

Fig. 2 – A horizontal milling machine for glass balk grinding

After cutting every next samples treatment by grinding. This is a process aimed at eliminating micro-defects on the surface, leveling the product’s geometry, and preparing it for polishing. It is performed using abrasive powders of varying grain sizes, such as corundum, silicon carbide, and cerium oxide. During grinding, it is essential to control parameters such as pressure on the glass surface, uniform cooling fluid supply, and grinding disk rotation speed.

Glass Block Processing and Material Loss Analysis

In our case, the first step of production involves cutting a large glass block with dimensions 2100 × 1360 × 100 mm into four equal blocks, each measuring 1050 × 680 × 100 mm. **Stage 1** is the cutting into strips. Each 1050 × 680 × 100 mm block is then cut into 25 strips of size 680 × 35 × 100 mm. During this process, approximately 17% of the material is lost due to defects and material waste. **Stage 2** is Edge Grinding to eliminate microcracks on the edges, each strip undergoes grinding along one side. This process results in an additional *3% material loss* due to irreversible waste. **Stage 3** is the cutting into Plates. Each 680 × 35 × 100 mm strip is then further divided parallel to the 100 mm side into 34 plates of dimensions 100 × 35 × 34 mm. At this stage, *approximately 26%* of the material is lost. **Stage 4** is Cylindrical Shaping. The rectangular plates are then rounded to form a cylinder with a diameter of 32 mm and a height of 100 mm. This shaping process leads to *12% material loss*. **Stage 5** is Slicing into Discs. Each D32 × 100 mm cylinder is sliced into 7 discs with dimensions D32 × 10 mm. The cutting and defect rejection process at this stage results in *30% material loss*.

The total number of final blanks produced is 12,600 pieces. However, due to a 5% defect rejection rate, the final usable quantity of blanks is ***11,970 pieces***. The total yield of usable products is approximately ***40.6%***. This means that to produce one defect-free part, it is necessary to manufacture 2.46 parts to account for material losses and defects.

Thermal hot pressing

The hot-pressing method is primarily used for small-caliber optical elements, such as microoptics and micro-prisms. These components find wide applications in various fields, including laser technology, measuring instruments, sensors, technological cameras, modern mobile phones, and lighting systems [10]. Hot pressing allows for the efficient and cost-effective production of such elements with high precision and quality.

Pressed glass is produced by pressing glass that has been softened under the influence of temperature to a formable state, using either a manual or foot-operated press (Fig. 3). To ensure that the pressed billet has the required mass and weight according to the calculations, glass pieces are carefully weighed before pressing. To prevent the glass from sticking to the mold, a special powdered chamotte additive is first applied to the base of the furnace, where the heating occurs. The mold itself is

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treated with graphite to improve its sliding properties and to prevent surface damage to the glass.

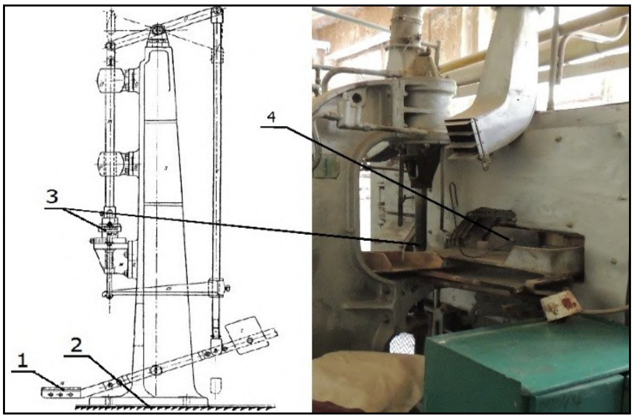

Fig. 3 – Foot press diagram: 1 – foot lever; 2 – base; 3 – press mold; 4 – furnace chamber

In hot-pressing, several critical parameters must be considered, such as the viscosity of the glass melt at different temperatures, the uniformity of pressure distribution, and the quality of the mold used for pressing. The viscosity of the glass melt varies with temperature, significantly affecting the material's flowability and its ability to fill the mold. High viscosity may hinder the even distribution of the mass within the mold, leading to defects in the finished product. Pressure control and its uniform distribution are also critical in preventing defects like cracks or improper shapes.

Adhering to the correct temperature-viscosity parameters is crucial in the hot-pressing process, as the viscosity of the glass melt changes depending on the glass composition and temperature. Different types of glass have varying temperature-viscosity characteristics, which affect their flowability and ability to fill the mold. Insufficient or uneven heating of the glass can lead to differences in viscosity across the volume, resulting in the formation of edge bubbles and other defects in the final product. To ensure uniform heating of the glass, it is essential to maintain a stable temperature throughout the material (Fig. 4).

Fig. 4 – Glass samples in a heating camera

Direct heating from heaters can cause inertial heating, leading to localized overheating and stress in certain areas of the glass mass. One of the best solutions to prevent this is the use of indirect heating through ceramic plates, which provide more even temperature distribution and contribute to a more stable pressing process, reducing the risk of defects.

During the pressing of colored glass containing metal oxides with variable valency, special attention must be paid to the temperature regime. Thermal exposure can shift the balance of ion valence may lead to changes in the spectral characteristics of the glass [11]. For example, the presence of Fe^{3+} ions give the glass a brown tint, whereas Fe^{2+} imparts a greenish hue. Changes in the ratio of these ions under the influence of temperature can significantly affect the final color and optical properties of the product.

Glasses containing colloidal colorants are of particular interest. These colorants form colloidal-dispersed metal particles or their compounds within the glass mass, affecting its coloration. For instance, colloidal particles of antimony sulfide (Sb_2S_3) crystals give the glass an intense red color, known as "ruby" glass [12]. Initially, such glass may appear brownish or yellowish, but after a specialized heat treatment process called "striking," it develops a rich red color.

The "striking" process involves controlled heating of the glass, which facilitates the formation and growth of colloidal particles of a specific size responsible for the desired color. Precise control of temperature and heating duration enables the achievement of exact optical characteristics, which is particularly crucial in the production of photochromic glass [13]. Photochromic glasses can change their transparency and color under light exposure due to the presence of colloidal particles that react to changes in illumination. Thus, proper management of the pressing and heat treatment process allows for the creation of glass with unique and predictable optical properties.

Production Process and Yield Analysis

The first step in production involves cutting a large glass block with dimensions of 2100 × 1360 × 100 mm into four equal blocks, each measuring 1050 × 680 × 100 mm. Next, these blocks are further cut into plates of 337 × 347 × 100 mm, with average material losses of approximately 3%.

Subsequently, the plates are cut into thinner slabs measuring 337 × 100 × 17 mm, with an average material loss of around 13%. To eliminate surface irregularities and defects, a grinding process is applied to both sides of the slabs, removing 0.5 mm from each plane. As a result, the final slab dimensions are reduced to 337 × 100 × 16 mm, with an additional material loss of about 7%.

The next step involves cutting these slabs into smaller blanks with dimensions of 25 × 25 × 16 mm. This size is selected to match the required weight of the final pressed part, which will have dimensions of Ø32 × 6 mm. This cutting stage results in an additional material loss of approximately 9%.

Before pressing, each blank is inspected for cracks, as these defects could cause the sample to break during heating. The rejection rate at this stage is around 2%. After quality control, the samples proceed to the hot-pressing process, followed by annealing.

After pressing, the total number of produced blanks is approximately 21,216 pieces. Considering a defect rate of around 5% during processing, the final yield of acceptable parts is 20,155 pieces.

This method allows for an overall yield of up to 70%, meaning that to produce one acceptable final part, approximately 1.45 raw pieces must be processed.

Results

A comparative analysis of mechanical processing and hot pressing of optical glass was conducted to evaluate their effectiveness in terms of material efficiency, surface quality, and overall feasibility.

Table 1 – Comparison of Processing Methods for Optical Glass

Parameter	Mechanical Processing	Hot Pressing
Total Labor Intensity, man-hours	210	205
Total Energy Consumption, kWh	706	3710
Yield of Quality Products, %	~40%	~70%
Production Start Ratio	2.46	1.45
Material Loss, %	~40%	~20%
Irrecoverable Material Loss. %	~20%	~10%
Number of Good Products, unit	11 970	20 155

Mechanical processing results in significant material loss due to cutting, grinding, and defect rejection. Hot pressing demonstrates better efficiency but is constrained by mold size limitations. Mechanical processing is preferred for large optical elements where high dimensional accuracy is required. Hot pressing is more efficient for small-scale optical components such as micro-optics and prisms due to lower defect rates and faster processing times.

Conclusions

Both mechanical processing and hot-pressing offer unique advantages. Mechanical processing excels in precision and large-scale component manufacturing, whereas hot pressing is more suitable for mass production of smaller optical elements.

Despite the fact that the thermal pressing process consumes nearly five times more electricity, it is more cost-effective for the production of small-scale optical components due to the significantly higher yield of quality products. This higher efficiency in production outweighs the increased energy consumption, making thermal pressing a more advantageous method for mass production of high-quality micro-optics.

However, the primary drawback of thermal pressing lies in the need for an additional technological line dedicated to the hot-pressing process. This necessitates the involvement of specialized personnel. In contrast, during mechanical processing, a single specialist can independently carry out all necessary operations, leading to lower operational complexity.

Particular attention must be given when pressing colored glass due to the potential for valence balance shifts, especially in glass compositions containing metal oxides with variable valency. Such shifts can lead to unintended spectral changes, affecting the final product's color and optical properties. Additionally, for colorless glass, it is essential to check for crystallization zones before pressing. If these zones coincide with the pressing temperatures, it could result in defects or material degradation. In such cases, either the glass composition needs to be adjusted, or the glass should be directed to mechanical processing to ensure the desired quality and performance.

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