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The Problems of Mechanical Treatment of Leucosapphire Blanks

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Abstract. The problems of the technology of mechanical treatment of hard crystal materials, particularly leucosapphires and their possible solutions, are discovered. General questions of the project works, solutions of accurate basic tasks and secure fixation of the blanks or tooling backup of the work technology are considered. The results of experimental studies of the diamond tool dressing and their efficiency evolution results are provided. Some recommendations on the technological process development are worked out.

1. Introduction

Recently the application of leucosapphire as a construction material has become more popular. It is also more often treated mechanically. For some of the products, base plates of semi-conductive devices for example, the technologies are practiced comparatively well, including manufactured equipment, tools, accessories. But the experience of direct transfer of electrical equipment gross production technology to the general machine and instruments building is not always available due to the variety of the parts and series production. The existing experience of metal blanks treatment does not consider the specific features of leucosapphire mentioned below.

Leucosapphire has high hardness and its mechanical treatment can be performed only by a diamond tool. Leucosapphire is characterized by clear properties anisotropy, which is used for the elements design and should be considered, controlled, and maintained during the manufacture. A leucosapphire's friction steel ratio (cast iron) is low, which together with fragility creates problems during blanks fixation. Leucosapphire is very sensitive to thermal shock, which leads to high risk of micro and macro defects.

The methods of the leucosapphire mechanical treatment technology development have not been studied enough, which prevents its distribution despite its unique properties and interesting operational characteristics.

2. Task description

The literature analysis and preliminary studies showed that the leucosapphire cutting process is not very difficult to organize. The problems are to ensure this process stability, productivity, accuracy of the treated form, its position towards its crystal axe and surface quality.

Basic method of monocrystals formation is Kyropoulos method. By means of this method, it is possible to obtain the blanks of an irregular pear-shaped form with the diameter of up to 300 mm and

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the height of up to 500 mm. Grown crystals are primary blanks. Then, depending on the sort, the blanks for the details are cut outfrom the primary blank. As a rule cutting is realised by diamond circle drilling. The requirements to the form correctness, surfaces arrangements relatively crystallographic axes, dimensions accuracy, gritness are very high. For example, the orientation accuracy of the cylinder blanks for optoelectronics in the C/A/M/R plane is usually taken as $\pm(0.1\div0.2)^{\circ}$; and in a set of cases – as $\pm0.05^{\circ}$ [1].

The arrangement of crystalographic axes in a boule depends on the arrangement of the corresponding inoculating crystals axes and its orientation accuracy and fixation during the growing process. As a rule the orientation of crystalographic axes of the parts does not coincide with the orientation of the optimal direction of the crystal (boule) growth. Thus, the formation of secondary blanks is complicated.

The task of the research was to determine the peculiarities of mechanical treatment of leucosapphire blanks, problems concerning technical preparation and the practical implementation process of the particular operations and their components. A special attention should be paid to the problems concerning the required parameters of the surface layer, which determine operational characteristics of the future product [2]. It is especially important for the production of blanks in optics or electronics industries, as it is associated with the form errors measured in microns, or grits – in nanometres.

Such task description is complex and it demands a larger amount of experiments. Consequently, the tasks of theoretical and experimental research of the basic operations of mechanical treatment and their particular components were set.

The disc cutting, flat and circular sanding and circular drilling by the diamond drill of the crystals were discussed.

During the study of mechanical treatment processes, the questions associated with accurate basing and secure fixation of the blanks, treatment modes designation, diamond tool cutting properties restoration, ensuring the treated surfaces quality arose.

Some questions arise while arranging experimental installations, tools and other technological equipment, necessary for the research.

3. The results

The grown crystal has no accurate surfaces suitable for the restoration of the crystallographic surfaces position. A first approximation provides a very rough direction of plane C; there are specific ‘folds’ along this axle on the crystal known as cleavage planes, Figure 1.

These planes are clear and in practice their appliance as a preliminary blank installation ensures the orientation with the accuracy of up to 3…5 °. Then, the position of C plane is clarified using different methods, primarily X-Ray and glass plates cut out from the boule. The corresponding metrological supervision is required for the implementation of the mechanical treatment technology with the required accuracy.

The required accuracy and the crystallographic direction of the blanks are mainly ensured by the installation devices, which enable the provision of correct, accurate basing and secure fixation.

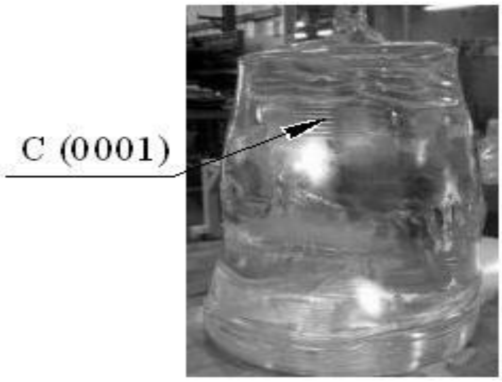

Figure 1.A Leucosapphire Crystal.

The errors may be caused by either basing errors or blank shift during the treatment. The installation and secure fixation of the crystal having an incorrect form with the weight of up to 85 kg and more is a complicated task. Additional difficulties are connected with the fragility and a low fraction ratio. The boule basing and fixation are especially complicated. The secondary blanks are already of the correct form, they are more accurate, but they may still be difficult to install.

The existing design methods of the installation of machine accessories were analysed, and their correctness was assessed when developing the equipment for leucosapphire treatment. The fixation of the metallic blanks in the devices is performed mainly by friction forces [3]. Let us determine the possibility of leucosapphire blanks fixation in such a case.

Due to anisotropy the leucosapphire properties are fluctuating, thus the most suitable basic and treated surfaces location values are used for the calculation. The leucosapphire-steel fraction ratio is 0.15, leucosapphire strength is 300 MPa [4].

Having the compression strength of leucosapphire, the maximal force, applicable to the carefully sanded and polished blank during the fixation, should be determined at first approximation. Let us suggest, that the blank and the device are in contact along the whole surface, and fixation force is distributed equally along the whole blank surface (clamp fixation on the top through a completely rigid and perfectly flat plate).

This evaluation is applied for the diamond disc cutting of the prism-shaped seed blank with the cross section area of 10×10 mm and the length of 100 mm. The blank contact surface for the accepted contact scheme is 10^{-3} m^2. The breaking compression force of the blank for the accepted loading scheme is 300 kN. Consequently, the elicited friction force on the blank-device joint, even considering the friction ratio reduction due to the applied lubricating-cooling liquid, will be at least 30 kN. A shifting component of the friction force, measured during the experiment, amounted to 120 N in average with peak values of up to 250 N.

Clearly, that in such conditions the blank is securely fixed due to the friction forces. However, in real conditions, the preliminary cut blankh as spacious defects and high gritness. The studies showed, that due to the disk extraction, cut width spacing of such defects can be 0.1…0.4 mm. The calculations are provided with the consideration of these defects. The following calculation scheme is agreed. The blank is presented as a beam on supports impacted by the equally distributed load. The calculation is executed for the above-mentioned leucosapphire seed blank on the parallelepiped shape with the length of 0.1m and a square cross section of the profile of 0.01m. For such beam let us calculate the breaking force and the deflection during the breaking. For such loading scheme, which is closer to real conditions, the secure fixation due to the cut force is possible only with reservations. Seed blank is broken only if the deflection exceeds 0.16 mm, and the load is around 3 kN. The elicited fraction force is close to the cutting force shift component value. The correctness of the performed calculation estimate was verified experimentally. A blank shift was observed when cutting the blanks with spatial defects exceeding the designed ones and fixed on the device by the scheme close to the designed one by means of the torque wrench (Figure 2). Thus, the design methods of machine accessories associated

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with treatment of hard large crystals should be corrected.

Figure 2. A leucosapphire blank cut by a diamond disc.

The calculation of fixing forces should be supplemented with the calculation of the blank breaking force considering the existing form errors. If the breaking forces exceed the forces necessary for secure fixation, the device's construction should be changed. For the case of impossibility of secure fixation only by the friction forces the changes to standard design solutions were provided. Particularly, the constructions with additional underwater supporting elements and clamping units, equipped with rigid rubber and polymer shims for preventing the risk of contact breaking at the blanks fixation point were successfully tested.

The blanks fixation security can be sufficiently increased by the use of glue. This method provides secure fixation, but increases material and labour costs. At the same time production standards also increase. Provided studies showed that in case of seed blanks gluing, if no special measures are applied, the difference of the glue layer and other reasons can lead to the planes non-parallelism during flat sanding in the amount of up to 0.05 mm.

To merge a spindle axle with the specified crystallographic direction of the blank, the device should provide a high-accuracy turn of the installed leucosapphire blank in two planes. Some principal engineering solutions of this task were analysed. Few schemes were considered: 1) the device is based on the central spherical joint – the plane turn is provided by the central joint, equipped with the plate with the installed blank: 2) the device, where inclination of the plane with the fixed boule is adjusted by few screws, which support ends, forms a plane inclined to the spindle axle by two axles; 3) the device with two cylindrical joints, where each joint enables the independent turn of each plane. All solutions have benefits and drawbacks. Based on the analysis the recommendations concerning their rational use were provided.

Practically all sapphire treatment operations are diamond-abrasive treatment. It is known that for such operations normal cut is possible either in self-sharpening conditions or during involuntary correction. The study results showed that binder metal tools self-sharpening, recommended for sapphire treatment, is difficult to implement. During the study of cutting, front and peripheral sanding, circular drilling, a self-sharpening mode was available only for the cutting disk for the cut of rotating boule. This can be explained by the fact that with such cutting system the tool and the blank contact along the line. Due to this contact the worn products are removed freely from the cutting zone, and even with the low cutting forces the specific loads are high, which leads to intensive wear of the binder and new seeds discovery. Normally the disc loses its cutting properties when being worn. If such disk is operated the cutting forces and temperature increase. Thermal shocks cause a large number of micro- and then macro-defects or a complete destruction of the blank.

This is especially important for the boules cutting and circular drilling. In such case the tool almost constantly remains in contact with the blank and sanding products; removing from cutting zone is complicated. Even in case of segment tools use the slug remains in the cutting zone and impacts the normal cutting process [6]. Such treatment reminds of the process of cutting by a fine pitch cutter with a large stroke or the case of deep cutting. The chip groove volume in such case should be enough for the placing of the obtained chip. Otherwise, different accidents are possible, including tool destruction or blank rupture. This phenomena is quite specific in case of sanding operations. During the diamond cutting by the leucosapphire disks the tool diameter increases. The investigation of the sanding disk under the microscope showed that the worn products had not only blocked all the pores, but also intruded in the binder. The use of this cutting process was monotonously deteriorating or terminating at some stage. The attempt to continue cutting applying larger forces caused the crystal destruction; thermal shock induced the microcracks net on the surface.

Thus, the trueing of diamond disks on the binder metal is mandatory. Within this work the studies of the basic trueing processes were conducted in order to identify optimal solutions.

Manufacturing plants prefer the diamond disk trueing method. However, for the plants applying these disks in practice the method complicates the efficient use of equipment – for quite a long time the machines are involved in trueing operations. Special staff for trueing and maintenance is required. Commercial equipment is often equipped with the devices of electrical chemical treatment (anode etching). Trueing is merged with the cutting process, which provides high efficiency of the process. However, such equipment is comparatively expensive, the process demands the application of quite aggressive lubricant-cooling agents, which leads to fast machines corrosion, deteriorates labour conditions and ecology.

Electro-erosive trueing is harmless for the machine and relatively green. Loose abrasive trueing is very efficient. The experimental studies of the electro-erosive, electrical chemical and loose abrasive trueing were conducted. All methods enable solution of the described tasks of the cutting properties and the disk shape recovery.

The most efficient and qualitative was the loose abrasive method. Binder removing in such case is performed without causing any harm to diamond seeds. But this method failed its application for diamond disks. The disk breaking corner value and consumption of working trueing medium were exceeded. This process was not completely implemented for the circular diamond drill due to the insufficient cutting rate.

Electro-erosive trueing provides practically the same efficiency. The process is well controlled and relatively easily implemented on the existing and new developed equipment. It was also implemented directly on the processing equipment and using a special device. The important advantage of such trueing type is the developed relief of the operating part of the disk. However, the experiments showed that disks firmness after such trueing was significantly lower (up to 30 %), than in the delivery condition or after chemical trueing. Due to high temperature of the process, the seed tops were found to be graphitized, which was also proved by microscope observations.

An electrical chemical impact was not severe. During anodic dissolution the binder was removed, the seeds were discovered and relief was formed. The seeds are of the light colour, without a defect layer on them. Although disks' relief is not much developed in this case, they operate well. Thus, considering cutting properties, this method can be regarded as the most attractive, although its efficiency is much worse. The reagents selection enables minimization of the corrosive impact on the machine. Owing to this fact the process efficiency is reduced. This quite efficient process demands serious organizational-engineering solutions and costs.

During the experiments one more problem, associated with the cutting process control was also found. Typical for most machines, a constant delivery operational mode is available only with the constant cutting properties of the tool. Comparatively fast glazing and the change of cutting properties complicate a constant delivery operation. Thus, the work with the stable force should be organized, which is typical for the optical industry machines, or proceed to the application of adaptive systems, including self-teaching ones [2].

4. Conclusion

The basic method of leucosapphire treatment is diamond-abrasive treatment. The methods of development of the leucosapphire mechanical treatment technology in general and for particular operations are favourable only for separate product groups and should be studied concerning the improvement of labour efficiency and products quality.

The existing design methods of the metal treatment machines demand a set of changes. The content and sequence of calculation procedures should be corrected, they should include the estimation of acceptable forces, limited by blank strength. Additionally, the auxiliary design solutions are required for accuracy and reliability increasing of the leucosapphire blank installation.

Leucosapphire, which is hard for fragile material treatment has its specific features. The provision and recovery of high-quality cutting properties of the diamond-abrasive instrument is an important issue.

Diamond-abrasive tool trueing is usually a mandatory procedure, a self-sharpening mode for binder metal tools can be implemented only occasionally. In case of operation with worn disks, the slug was identified in the tool binder, which even caused the diameter increase with the drop in cutting properties.

Loose abrasive trueing demonstrated very high results concerning both the efficiency and the quality. But the existing problem of edge effects limits the use of this method for cut off disks and circular diamond drills.

An electro-erosive trueing method of diamond disks negatively affects the cutting properties of diamond seeds in case of the high-efficiency process. Consequently, the tool firmness reduces by 20…30 %.

Electrical chemical trueing of the disks is relatively low-efficient, but provides a high quality. The technology is high-efficient if trueing is merged with treating. Due to this fact the risks of the negative ecological impact of reagents and labour safety risks should be considered.

During the treatment the cutting properties of the tool within its firmness period were significantly changed. This factor requires correction of the treatment process in the performance mode. Ignorance of the specified dynamics may lead to quality deterioration, including irreparable spoilage. This problem can be solved by the adaptive process control or proceeding to the actual cutting force treatment instead of delivery of the actual value.

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