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LASER GLASS-DEFACETING TECHNOLOGY

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A new laser-blunting technology using thermal stresses to remove the sharp edges of articles made of glass and other brittle nonmetallic materials is described. A physical model is proposed for laser heating of the edges of a metallic material that is opaque to laser radiation. A relation is established between the main parameters of the process: facet size, defaceting speed, laser radiation intensity, and glass edge strength. The technological regimes are optimized; the technological process and laser equipment for cutting and defaceting glass are elaborated. The advantages of the new technology of laser blunting of glass edges over the conventional defaceting technology using a diamond-abrasive tool are shown.

Key words: glass, edge blunting, defaceting, laser-controlled thermal splitting (LCT), thermal stresses.

Sizing of glass articles, as a rule, presupposes together with the cutting operation a subsequent operation of blunting the sharp edges of articles or defaceting. The main purpose of faceting is to ensure safe handling of glass articles and to increase operational reliability of the glass by increasing its edge strength. The problem is that a sharp cutting edge of glass is itself a stress concentrator and a zone where the risk of damage and destruction of the entire article during use is high.

The conventional glass defaceting technology is based on the use of a diamond abrasive tool to blunt the edges, grinding, and often polishing the facet and the entire edge of the glass in order to obtain a smooth ground or polished surface. This operation is very laborious and expensive. Moreover, the defaceting operation is accompanied by contamination of the entire glass article by the products generated by the processing, which requires an additional cleaning operation.

The present work is devoted to the development of a new technology of laser blunting of the sharp edges of glass and other brittle nonmetallic materials by using the thermal stresses due to the removal of the sharp edge of the material to form a facet. The modern technology of producing different types of display panels, smart phones, and other articles presupposes that all final technological assembly operations are performed in vacuum-clean rooms. Numerous tests and industrial adoption have shown that the method of laser controlled thermal splitting meets these requirements, since the cutting process is waste-free and is not accompanied by the formation of any extraneous particles [1, 2].

However, in the defaceting process the display panels and smart phones are subjected to the additional operation of edge blunting which is performed with a conventional diamond-abrasive tool. A drawback of this method, aside from low efficiency, is low manufacturing culture and contamination of the articles by the products of grinding as well as finish low quality of the final products after diamond-abrasive machining of the edges, associated with the presence of large numbers of microcracks and a damaged layer in the processing zone. For this reason, in a number of cases subsequent mechanical or fire polishing of edges is used in the manufacture of domestically produced articles with strict strength requirements.

In summary, in a number of cases the incontrovertible advantages of the new technology of laser waste-free precision cutting are lost because of the added operation of defaceting with the aid of a diamond-abrasive tool, which requires a subsequent operation of cleaning the articles to remove the contaminants.

The works [3, 4], where the new method of laser defaceting of glass was first proposed, are devoted to solving this problem.

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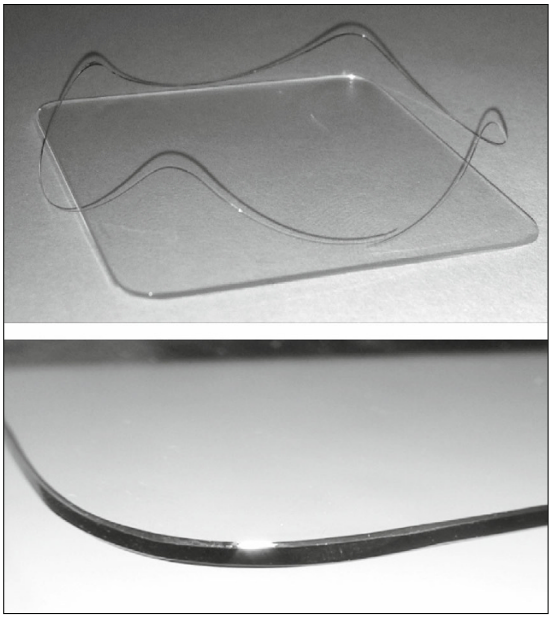

Fig. 1. Photographs of articles after laser defaceting.

The present work is devoted to optimizing the technological regimes, developing an industrial technology and laser equipment for cutting and blunting the sharp edges of glass articles and other nonmetallic materials, specifically, articles made of sapphire.

PHYSICAL MODEL OF THE PROCESS OF LASER GLASS DEFACETING BY MEANS OF THERMAL STRESSES

In local heating of a glass surface by 10.6 μm laser radiation (CO_2 gas laser), to which the glass is opaque, the radiation energy is absorbed and released in the form of heat in a thin surface layer. Subsequently, heat propagates into the glass by heat conduction. When the glass is heated up to a temperature below plastic deformations, compressive stresses arise in the glass in the heating zone, but because of the high ultimate strength of glass in compression they cannot cause fracturing.

In the case of laser-controlled glass [1, 2] a cooling agent is delivered immediately following the laser beam into the heating zone, where rapid cooling of the glass results in the formation of a separating microcrack under the action of tensile stresses. When a sharp glass edge is heated by a CO_2 laser beam compressive stresses are also formed in the narrow heating zone. At a certain depth these compressive stresses are compensated by tensile stresses, which can result in the formation of cracks in the bulk of the glass at a certain depth from the surface, as a result of which a narrow strip of glass along the edge is separated, i.e., an edge is formed (Fig. 1).

In addition, a blunted edge has no mechanical defects in the form of microcracks and a damaged layer, so that the edge has high mechanical strength.

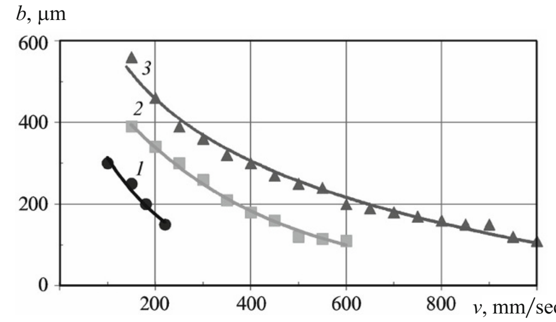

Fig. 2. Facet size b versus the relative speed the of the laser beam for different laser power: *1*) 30 W; *2*) 60 W; *3*) 100 W.

DEVELOPMENT OF A LASER GLASS DEFACETING TECHNOLOGY

To optimize the technological regimes of the process of laser edging of glass a relation must be established between the main parameters of the process: facet size, defaceting speed, laser radiation intensity, glass edge strength. Special attention was devoted to studying the repeatability and stability of the laser defaceting process or determining the "technological corridor", i.e. the range of obligatory governing parameters and constraints imposed on the technological parameters of the process.

The investigations were conducted using a commercial CO_2 laser with power up to 100 W. First, control of the parameters was investigated, first and foremost, the facet size in the process of blunting sharp edges. The dependence of the facet size on the relative speed of the laser beam is displayed in Fig. 2. The investigations were conducted for three values of the laser power: 30, 60, and 100 W. The 1000 mm/sec limit for the defaceting speed is associated with the technical capabilities of the equipment used.

It follows from the plot presented that the control of the facet size and edge blunting speed covers a wide range. It should be noted that laser defaceting does not require high laser power. For example, 100 W is adequate for defaceting at 1 m/sec. Thus, in terms of energy consumption the laser defaceting technology is the most cost-effective of all currently existing technologies. This makes the new technology very attractive for wide use in industry and competitive with respect to the conventional methods of blunting sharp edges.

The linear dependence of the defaceting speed on the laser power was investigated in the experimental investigations (Fig. 3).

It can be concluded from the experimental results presented above that by varying the relative speed of the laser beam and the material, the laser power, and the beam size it is possible to obtain faceting with prescribed size in a very wide range. Facet sizes ranging from 50 μm up to several millimeters were obtained in the course of these investigations.

Special attention was devoted to investigating the strength of a glass edge after laser defaceting and determin-

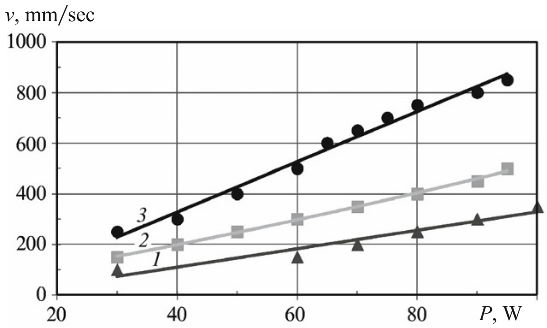

Fig. 3. Effect of laser power *P* on the defaceting speed and facet size: *1*) 0.35 mm; *2*) 0.25 mm; *3*) 0.15 mm.

ing the optimal technological regimes for maximizing the strength of the article. The transverse bending tests were conducted by the standard procedure on a Zwick 1445 universal testing machine.

Comparative tests of the mechanical strength of glass plates of thickness 2 mm in transverse bending were conducted after two different edging methods: after mechanical cutting and blunting of an edge by a diamond tool (Fig. 4, *1*) and after laser cutting and laser defaceting (Fig. 4, *2*).

The distribution of the strength of glass samples in transverse bending tests after mechanical and laser blunting of the edge is presented in Fig. 4. It was found that the average strength after laser blunting of the glass edge is 2.5 times higher than after the conventional machining of the edge.

Aside from higher average edge strength, appreciable increases in the minimum and maximum values of the edge strength were observed after laser blunting. As follows from the data presented, the maximum strength after mechanical machining corresponds to the minimum values of the edge strength after laser defaceting.

As shown above, laser blunting of glass edges can be accomplished in a wide range of speeds. The effect of the defaceting speed on the edge strength was investigated. It was found that the reason for the reduction in edge strength is the appearance of residual thermal stresses accompanying excessive reduction of the edging speed without simultaneous reduction of the laser power, which results in overheating of the glass up to the appearance of plastic deformations.

The results for the dependence of the glass edge strength on the defaceting speed at constant laser power 100 W are presented in Fig. 5.

Increasing the defaceting speed from 300 to 1000 mm/sec doubles the edge strength: from 80 to 160 MPa. On the basis of the data it is logical to pick the optimal defaceting speed in the range 800 – 900 mm/sec according to the following considerations. This value gives practically the maximum edge strength at high production efficiency and 100% repeatability and reliability of the laser defaceting process.

When the facet size must be increased one must resort to decreasing the speed and at the same time the laser power in order to decrease the laser power density in the heating zone

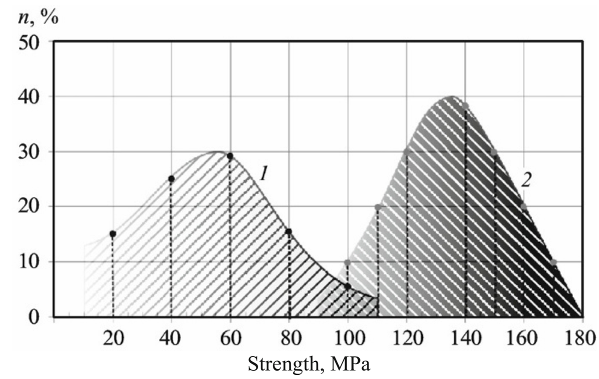

Fig. 4. Distribution of the strength of glass samples in transverse bending tests after mechanical blunting of the edge *1* and laser defaceting *2*.

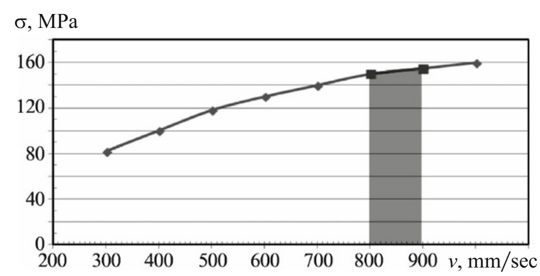

Fig. 5. Strength σ of a glass plate versus the defaceting speed at constant laser power 100 W.

of the edge. The productivity of the laser defaceting process for large edges can be increased by increasing the length of an elliptic beam and at the same time increasing the laser power.

The laser defaceting technology should be regarded as a method of laser controlled thermal splitting (LCT) of brittle nonmetallic materials [1] with all characteristics and possibilities inherent in this method. This means that defaceting can be done not only on glass but also materials such as sapphire, quartz, ceramic, and semiconductor materials.

In the course of these investigations a specialized technological equipment was developed jointly with the Taiwanese company Foxconn Technology Group Ltd for cutting and blunting sharp edges of glass and sapphire articles in the production of panel and smart phone displays. This equipment will make possible automatic high-precision cutting of an article from a blank, trimming, and defaceting on both sides.

It should be emphasized, separately, that the laser defaceting technology can be effectively used not only in combination with high-precision cutting by laser controlled thermal splitting but also defeating of glass after the conventional machining was diamond or carbide cutters. In addition, owing to the removal of the defective glass, damaged during cutting of the glass edge, the technology will make it possible to obtain articles with very high mechanical strength, close to the edge strength after laser cutting and defaceting.

CONCLUSIONS

It can be concluded on the basis of these investigations that the technology developed for laser defaceting of glass and other brittle nonmetallic materials has indisputable advantages and it holds promise for use in different industries.

The primary advantages of the technology of laser defaceting of glass and other brittle nonmetallic materials over the conventional technologies are:

– multi-fold increase of the productivity of the defaceting process with speeds up to 1 m/sec;

– at least doubling of the article strength owing to defect-free edges and absence of residual stresses;

– absence of contamination of the article by the products generating by processing, so that the technology can be used under the heightened requirements of purity in so-called “clean” rooms;

– low energy consumption;

– high quality of faceting, not requiring additional polishing;

– absence of products of surface contamination of articles in the process of defecting, so that the defaceting process can be conducted with purity and vacuum hygiene;

– absence of products for recycling; complete environmental cleanliness of the defaceting process;

– no additional expendable materials;

– complete automation of the cutting and defaceting process in the fabrication of free-form articles; and,

– sharp reduction of expenses, increase of productivity, and reduction of the manufacturing expenses associated with defaceting after conventional machining.

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