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Water-Jet Cutting of Glass Sheet

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Abstract—Water-jet cutting of glass is considered. Data are presented regarding its applicability, advantages, disadvantages, and potential. In water-jet cutting, the following parameters are most significant: the jet velocity, abrasive grain size, jet inclination, and the distance from the nozzle to the machined surface. Computer simulation shows that, in water-jet cutting, the stress in the glass is lower than in mechanical cutting by a roller. That corresponds to minimal heat liberation and a precise cut with surface roughness R_a = 1.6 μm at the edges.

Keywords: water-jet cutting, abrasive machining, cutting jets, computer simulation

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In any technological process, the shape, dimensions, and properties of a material are modified so as to obtain a product that conforms to the design drawing. Each process is expediently used within a specific range of parameters (workpiece properties, technological characteristics) [1–5]. In water-jet cutting, practically any materials may be cut; it is an alternative not only to mechanical cutting but also to laser, plasma, and ultrasonic cutting. In some cases, it is the only possible option.

In machine design, stringent requirements are often imposed on the quality of the cut in metals. That rules out traditional equipment: guillotines or plasma cutting. Water-jet cutting has been used since the 1960s at aviation plants in the United States and is regarded as optimal for the cutting metals and other strong materials [6, 7]. Considerable experience has been gained in machining complex profiles by mechanical methods, ultrasonic energy, plasma, lasers, and water jets [2, 4, 8]. The global market for water-jet cutting systems is expected to increase rapidly over the medium term [9].

Water-jet cutting is used in mass production to cut stacks of sheets. Cutting stacked sheets permits the cutting of thick sheets to any contour without buckling or melting of the edges; less abrasive is consumed than in cutting individual sheets; productivity is high; and the workpieces cut from a single stack are of identical and precise shape [10].

Despite its high productivity, water-jet cutting has not been adequately studied. That has slowed its practical adoption. This method was analyzed in [11–14]. Parameters investigated include the jet velocity, abrasive grain size, jet inclination, and the distance from the nozzle to the machined surface.

The most common technology for laying out float glass is the use of cutting rollers (Fig. 1). The rollers used in cutting glass have a broad tapering cross section and are made from hard alloys. Their sharpening is specified in accordance with the thickness of the glass. Two steps are used here. First, the outline is traced; that is, a scratch is created, with a chain of cracks radiating below. Then a flexural force is applied transverse to the cut. This cut corresponds to the creation of microcracks in the glass under the action of the cutting roller. That is followed by cleavage along the outline.

The quality of the cut depends on factors such as the type of cutting tool, its position, the type of glass, the pressure applied, the speed, the surface quality of the glass, and the temperature. To obtain a good cut, the cutting speed of the roller (up to 160 m/min) and its pressure on the glass must be sufficiently high and constant. These factors are interrelated: with increase

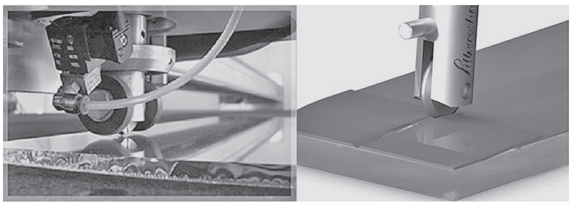

Fig. 1. Automatic machining of glass by a cutting roller.

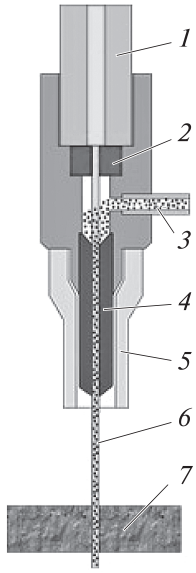

Fig. 2. Water-jet cutting: (*1*) high-pressure water supply; (*2*) nozzle; (*3*) abrasive supply; (*4*) mixer; (*5*) housing; (*6*) cutting jet; (*7*) workpiece.

in the pressure, the velocity declines, and vice versa. However, the quality of the cut depends not so much on the splinters formed in scratch application and the surface defects already present as on the stress created in the glass by those defects. The decisive factor is the deepest crack arising under the action of tensile stress created by the tool's pressure.

FUNDAMENTALS OF WATER-JET CUTTING

In manufacturing today, the finishing operations have the greatest influence on the quality and performance of the product [13–17]. Improving product quality entails improving the finishing procedures, notable among which are abrasive methods. By abrasive machining, the required product precision and quality may be obtained with high productivity; in addition, the operational reliability and life of the equipment are excellent. Accordingly, the use of abrasive machining in manufacturing is steadily growing.

Water-jet cutting is a form of machining with free abrasive. It permits the creation of complex surfaces that are difficult to obtain in traditional machining. More study of this process is required. It depends mainly on the following parameters: the jet pressure, the nozzle supply, the grain size of the abrasive, its hardness, its flow rate, the distance from the nozzle to the machined surface, and the physicomechanical properties of the workpiece.

Along with these advantages, disadvantages of the process include nonuniform distribution of the surface roughness of the cut over the depth; and loss of quality with increase in the nozzle supply [13–18]. In Fig. 2, we show a system for water-jet cutting of glass.

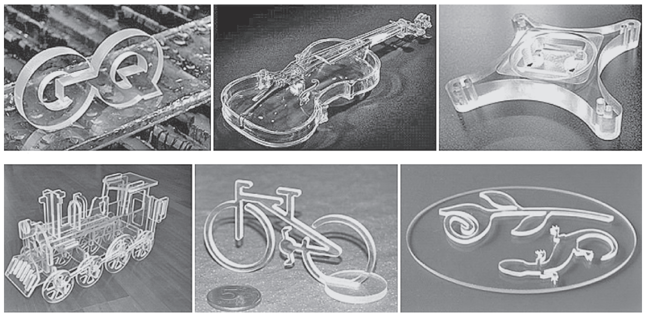

Fig. 3. Product samples.

Water compressed by a hybrid pump to more than 4000 atm passes through the nozzle, forming a jet (diameter ~0.5 mm), which enters the mixing chamber. The water jet takes on abrasive (for example, garnet sand of particle size ~0.4 mm) and then passes through a hard-alloy nozzle (internal diameter 1 mm). The jet of abrasive-bearing water leaves this nozzle at a speed of around 3 M (~1200 m/s) and is incident at the glass surface. After cutting, the residual energy of the jet is quenched by a special water trap. As a rule, the workpiece sits on a coordinate table.

In water-jet cutting, electric power, air, abrasive, and water are consumed. The abrasive flow rate is ~300–350 g/min. Only natural abrasive is recommended: garnet, which has satisfactory strength. The grain size of the abrasive must be 200–600 μm. The nozzle life is around 50 h; that of the tubes is ~100 h. The cut width may be easily compensated by numerical control. Thus, it will not affect the precision and quality of the cut [17].

The main difference between water-jet cutting and other methods of sheet cutting is that there is no mechanical action on the metal. The absence of friction and tool heating will unavoidably affect the quality of the cut and the applicability of the method. Water-jet cutting of metal by pure water or an abrasive mixture has been successfully used to cut the following materials: marble, granite, and other rock; glass, ceramic; steel and metals (including titanium and stainless steel); ferroconcrete; plastic, fiberglass, ebonite, and paronite (asbestos rubber) plates; and rubber [7].

PRIMUS 202 JET-CUTTING MACHINE

The supersonic water jet used for cutting is produced by concentrating a water flux through a calibrated hole. The velocity of the resulting jet is three times the speed of sound (810 m/s). Abrasive need not be added to the water. Depending on the type of workpiece, the Primus 202 may be set up with one, two, three, or five axial heads so as to ensure maximum productivity and continuous cutting without loss of flexibility.

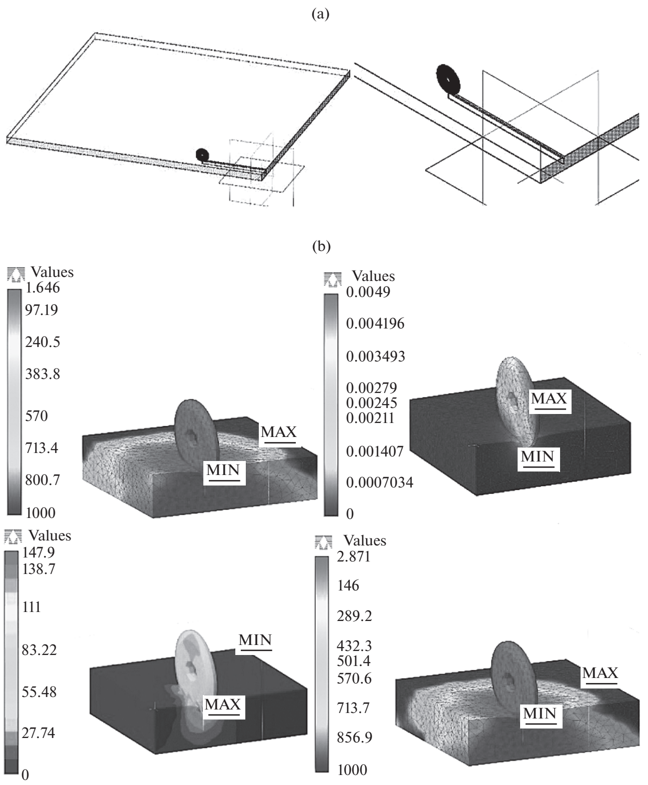

Fig. 4. 3D model (a) and results of statistical calculation (b) for the machining of glass by a cutting roller.

Because the table is divided into two cutting zones, continuous operation in an alternating cycle is possible: unloading (loading) of the workpiece in one part of the table, while the system operates in the other part of the table [13, 18]. In Fig. 3, we show samples from the machine for water-jet cutting.

RESULTS AND DISCUSSION

Because precise water-jet cutting of metal over a complex contour is possible, this method may be used to produce ornaments and decorative elements. The quality and precision attained largely depend on the operator's experience, as well as the quality of the equipment and the software.

Applications of water-jet cutting have been found in many spheres. A great benefit of this method is the lack of chipping. Another is that there is no surface heating, which is typical of traditional methods. As the technology and equipment are improved, applications are expanding.

Nonstandard cutting is also possible. Adjusting the cut inclination has no effect on the final quality. The precision of inclined cutting permits the production of steel workpieces, without the need for additional machining [18].

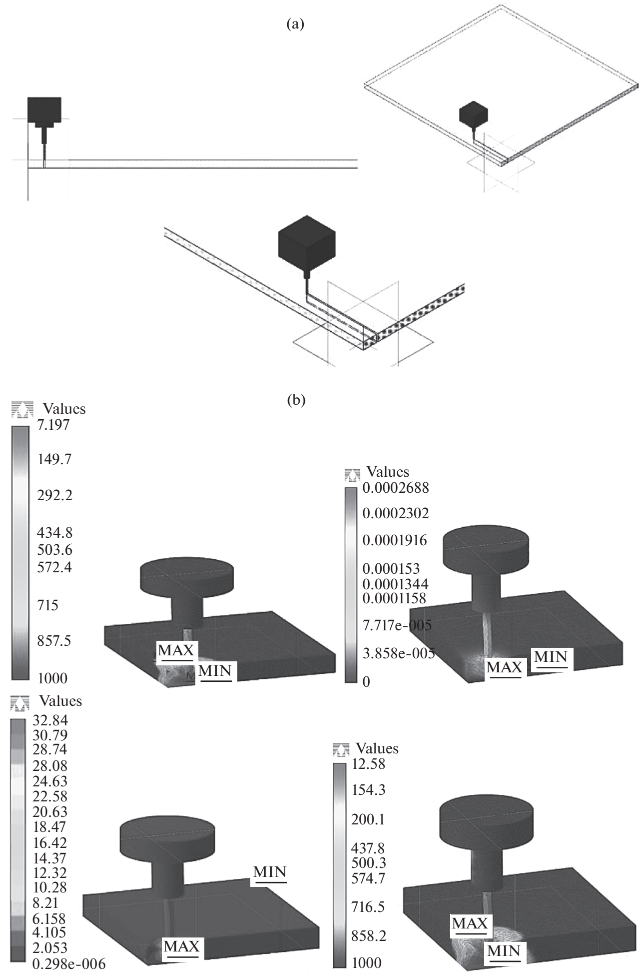

Fig. 5. 3D model (a) and results of statistical calculation (b) for water-jet cutting of glass.

COMPARISON WITH MECHANICAL CUTTING

Transparent glass (1 × 1 mm, thickness 10 mm) is machined by means of a cutting roller and by water-jet cutting. In Fig. 4a, we show a 3D model of mechanical cutting by a roller.

Using this 3D model, a finite-element grid is created and used for static calculation. In Fig. 4b, we show the results: the Mises equivalent stress, the total linear displacement, the margin of fluidity, and the strength margin.

In Fig. 5, we show the results of analogous statistical calculation for water-jet cutting: the Mises equivalent stress, the total linear displacement, the margin of fluidity, and the strength margin.

Analysis of the results of computer modeling shows that less stress is formed in the glass by water-jet cutting. The cut is of higher quality, and the method is more efficient and produces less waste.

CONCLUSIONS

1. Water-jet cutting significantly increases the cutting speed and cut quality. In economic terms, the consumption of materials and energy is considerably (20–30%) less thanks to the use of the water's energy as the cutting agent. The only materials consumed are water and abrasive.

2. Experience shows that this method is economical, environmentally sound, and has the following benefits: precise cutting thanks to minimal heat liberation; cutting speeds as high as 30000 mm/min; precision of the final product, in complete agreement with the design drawing; no heating of the workpiece (temperature in the cutting zone 60–90°C); applicability to a broad range of materials, with sheet thickness up to 200–300 mm (or more); no melting or scorching of the edges of the workpiece and in the adjacent layer; no environmental impact and no harmful gas emissions; and high quality of the cut (surface roughness at the edge R_a = 1.6 μm).

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