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Possibilities and non-standard applications of abrasive wires coated with diamonds

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Nowadays diamond abrasive wire cutting has become a technology associated mainly with electronics and photovoltaics. This method allows obtaining silicon substrate plates (wafers) on a mass and global scale. However, isn't the potential of the diamond wires much greater? The article presents the possibilities of using permanently coated wires in areas where such tools have not been attempted to be implemented or investigated.

KEYWORDS: *wire cutting, fixed abrasive diamond wires, diamond tools, hard-machinable materials*

Introduction

Over the past 20 years, wire cutting has become the leading method for obtaining the silicon substrates [1]. It is worth mentioning the bi-directionality of this method, which is related to the mechanism of wire reinforcement. A distinction is made between wire cutting in abrasive slurry and using permanently reinforced wires. The latter solution has recently gained interest due to its high efficiency (and thus shorter cutting time) and the possibility of reducing non-organic abrasive slurry [2].

The wire, permanently coated with diamond grain, embedded in a nickel matrix, is a tool that allows to increase productivity by two or even three times in relation to cutting in abrasive slurry. It is characterized by abrasion resistance and can be used for a wide range of materials and in the presence of a water-based coolant. Therefore, it is a tool with huge potential.

Possibilities of using diamond wires

In the literature and information provided by companies from the wire cutting industry, only a few applications of diamond wires (other than those related to the production of ground tiles) can be found. The wide possibilities of using permanently reinforced wire tools (fig. 1) can be seen on the example of the Ensoll company offer, specializing in adapting the cutting technology to the needs of individual clients [3]. In the movies, the company presents the use of diamond wires, including for: cutting KDP crystals, cutting glass and wood, cutting foam cement and mineral wool, separating precious stones and block corrugated paper. The company uses wires permanently coated with diamond grain - most often they are wires in the form of loops. Surface roughness after cutting, obtained for a single crystal KDP, is less than 1.6 µm [3].

Fig. 1. Examples of cutting with using fixed abrasive diamond wire: *a–b*) natural stones, *c*) glass, *d*) mineral wool

Among the advantages of cutting with permanently coated wires, Ensoll mentions: cutting speed (up to 60 m/s), good surface and edge quality of the cut element, possibility of cutting very thin details and flat parallelism of the surface [3].

On the European market, Dramet [4], which shapes structural materials and cuts complicated contours (which is a niche application), boasts interesting applications for wire cutting. Wires are the only abrasive tools that can cut in shape, but this property is nowhere to be found. Materials cut by a German company include foam and structural materials (fig. 2*a*), composites, ceramics and carbides. The company uses shape cutting for the production of graphite electrodes (fig. 2*b*) and cutting out contours in felt and GFRP composites (figs. 2*c–d*) [4]. The choice of a wire tool is dictated by the cost, high edge quality, no delamination, dimensional accuracy and the possibility of obtaining very complex shapes.

Fig. 2. Examples of elements cut with fixed abrasive diamond wires: *a*) foam composites, *b*) graphite electrodes, *c*) felt, *d*) glass fiber composites [4]

Research on potential applications of permanently coated diamond wires

Diamond wires permanently reinforced with abrasive grain (fig. 3) work very well in laboratories that deal with a wide spectrum of materials with various properties and therefore need universal tools. Such wires are useful especially at the stage of sample preparation for testing (e.g. microscopic, fatigue).

Fig. 3. Topography of an example abrasive wire tool permanently coated with diamond grain in the field of view of a stereoscopic microscope

Companies decide to test cutting with reinforced wire materials to avoid problems (such as too high temperature in the cutting zone, no possibility of cooling, material fragility or heterogeneity, rapid wear of conventional tools, too wide cutting gap, introduction of too high stress) typical of other methods. An example of a non-standard application of a reinforced wire may be cutting the AM60 magnesium alloy sample, in which the threads were made. For the purposes of microscopic examination, it had to be cut in such a way as to reveal the thread made without destroying the sample itself (fig. 4). Due to the small size of the sample, no other tested method succeeded. A surface roughness of less than $0.8\text{ }\mu\text{m}$ was obtained.

Fig. 4. Laboratory use of fixed abrasive diamond wires for sample preparation for microscopic examination

A new and non-standard area of application is the incision procedure of paddle samples, intended for testing the effect of applied coatings on the fatigue strength of a material. The samples shown in fig. 5 have a layered structure. Various composite coatings were applied to the base in the form of AISI 304 steel. The samples were then cut to obtain a suitable stress concentrator. The notch length and geometry may be different and often depend on the sample geometry. The optimal notch length was 3 mm in the tested paddle samples with 15 mm narrowing width.

Fig. 5. Oar-shaped samples with notch cut with diamond wire

The notch cutting task proved difficult to accomplish, because delamination of the coating from the metallic base had to be avoided. At the same time, the cut had to be as thin as possible and finished oval (e.g. sawing makes the notch rectangular, which generates problems). The research was aimed at checking the impact of the applied coatings on the fatigue strength of the material. AISI 304 steel is often used for extrusion and other plastic working. Based on preliminary studies, it was found that after applying the coating, one can achieve up to a six-fold increase in fatigue strength.

For notching, a reinforced wire was used in the form of a loop with a thickness of 600 μm and a grain size of about 64 μm - this tool perfectly fulfilled its role. During the cutting of the wire, the sample was not delaminated, cracked or the coating damaged, which was the case when other tools were used. It is possible that if a thinner wire was chosen, the effects would be even better.

Permanently reinforced wire has also enormous potential for cutting ceramic plates, from which whetstone is made (fig. 6). The most common form of cutting board is a cuboid with dimensions of 250×50×200 mm or 250×40×200 mm. The stones are cut at $L = 250$ mm and $L = 200$ mm.

Fig. 6. The process of cutting ceramic blocks into whetstones using a fixed abrasive diamond wire

Material, from which the cut block is made, is corundum grain or silicon carbide with granulation of 46÷400 μm , bonded with a ceramic binder. Cut-out whetstone has different thicknesses, but flatness of parallelism is important. A 900 mm thick wire and diamond grain size of approximately 120-140 μm was used to test the possibility of cutting ceramic blocks. At a relatively low cutting speed (10 m/s), the process went very smoothly. The material showed very good machinability. After modifying the method in terms of the number of wires (for so-called multi-wire cutting) and increasing the cutting parameters (cutting speed and pressing material to the wire), it would be possible to create an extremely efficient whetstone technology.

Another example of the potential of the wire cutting method is cutting of composites and materials that are easily damaged during machining. There are many materials used in industry that are difficult to machine due to their properties. When the coolant cannot be used - e.g. in the machining of hygroscopic, water-upset, low-melting or easily delaminated and damaged materials - the choice of cutting method is very narrow. Interleaving

composites, built e.g. from foam (rohacel 71sl) bonded (from above and below) by a carbon fiber fabric (the fabric has a surface density of 200 g/m^2 and is filtered with epoxy resin), are a classic example of problems with delamination and plucking and damage to the fibers during the cutting process (fig. 7). However, the use of such a delicate cutting technique as the wire method allows to obtain very smooth edges without damaged fibers and without penetration of the filler [5].

Fig. 7. General view of the carbon fiber composite

Good results can also be obtained when using the wire method to cut wood or fireproof insulation boards (e.g. Ceraboard 100). Of course, a lot depends on the hardness and construction of the wood, but generally the surfaces after cutting have good quality (e.g. R_a parameters for the speed range $5 \div 15 \text{ m/s}$ were: approximately $1.5 \text{ }\mu\text{m}$ for spruce, below $1.3 \text{ }\mu\text{m}$ for birch, below $1 \text{ }\mu\text{m}$ for beech) [6]. The temperature generated in the cutting zone causes burns and discoloration of the surface, which can be considered either as a defect or as an aesthetic effect, allowing to emphasize the wood structure (fig. 8).

Ceraboard 100 material is a widely used insulation product, resistant to high temperatures [7], which is also easily damaged when cutting too aggressively. When using high cutting forces and tools with a wide cutting edge, the material easily breaks and crumbles. However, when the wire method is used, these problems do not occur - the material is subjected to straight and shaped cutting.

Fig. 8. Examples of wood surfaces after wire cutting [6]

Summary

Although cutting with reinforced wire has found its place in the industry, new directions of application of this method are constantly emerging. This is due to the high strength of the tool and its resistance to abrasive wear - these qualities are provided by diamond grain. When adding to this small cutting edge thicknesses, low cutting temperature and low cutting forces, it turns out to be a tool with great potential. They are increasingly used in industrial conditions, where they replace other cutting tools in the area of separation of difficult-to-cut materials.

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