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Verification of the modification possibility of the circular saw blades for the machining of wood materials using ion implantation

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Abstract: *Verification of the modification possibility of the circular saw blades for the machining of wood materials using ion implantation*. The paper presents a verification of the possibility of modification of the circular saw blades for machining wood materials using the ion implantation method. These tools are used in the industrial production of wood construction joints (e.g., for formatting door frames). The tungsten carbide teeth soldered to the saw blade were modified in the process of nitrogen ion implantation. The modification process is presented, and the technical conditions of the proposed method and the possibility of their change in terms of industrial application are discussed.

Keywords: circular saw blades, wood materials machining, ion implantation, modification possibility

INTRODUCTION

WC-Co tools for wood machining – despite many attractive features such as strength, hardness, fracture toughness, refractoriness, stiffness, resistance to compressive deformation and wear resistance at room and higher temperatures up to 400°C (Milman et al., 1997; Sheikh-Ahmad and Bailey 1999; Pirso et al., 2004; Bonny et al., 2004; Choi et al., 2010; Olovsjö et al., 2013) – still show an insufficient tool life. This feature can be improved by appropriate modification. Ion implantation is a non-equilibrium (Barlak et al., 2009; Nowakowska-Langier et al., 2013; Werner et al., 2016; Chodun et al., 2020), relatively simple and cheap method of improving tool life (Barlak et al., 2016; Barlak et al., 2017; Barlak et al., 2019a). Previous papers were focused on the ion implantation of nitrogen and on selected metals such as zirconium, molybdenum, tin, lead and rhenium (Wilkowski et al., 2021; Barlak et al., 2019b; Barlak et al., 2021). However, they concerned relatively small, indexable knives with dimensions of 29.5×12×1.5 mm^3. The modified surfaces of these tools can be easily positioned perpendicular to the ion beam (i.e., when the effectiveness of the implantation process is the highest (Wilkowski and Barlak 2021)). This operation is more difficult in the case of the bigger tools and, additionally, with more complicated tool geometry because the vacuum process chamber must be larger and, therefore, more expensive. The positioning of the modified tools is also more expensive due to the cost of the additional equipment (e.g., the various types of manipulators). Without them, the diameter of the modifying ion beam can be insufficient to assure homogenous modification. The presented paper discusses an attempt to modify the circular saw blades for machining wood materials using nitrogen ion implantation. It shows the accepted solutions and selected possibilities of the process development.

MATERIALS AND METHODS

The commercially available circular saw blades FINISH CUT VH series, symbol 250×3,2/2,2 d-30 z-80 (Fig. 1 left), with special teeth geometry GSML (group toothing, flat top teeth, alternate top bevel teeth and top bevel teeth – Fig. 1 right) dedicated to hard, dry wood cutting along with exotic and fruitwood and for wood-derived materials – especially for ripping of high-density boards covered with natural veneers (produced by *Fabryka Pił i Narzędzi "WAPIENICA", Spółka z o. o.* Bielsko-Biała, Poland) – were used for the investigations.

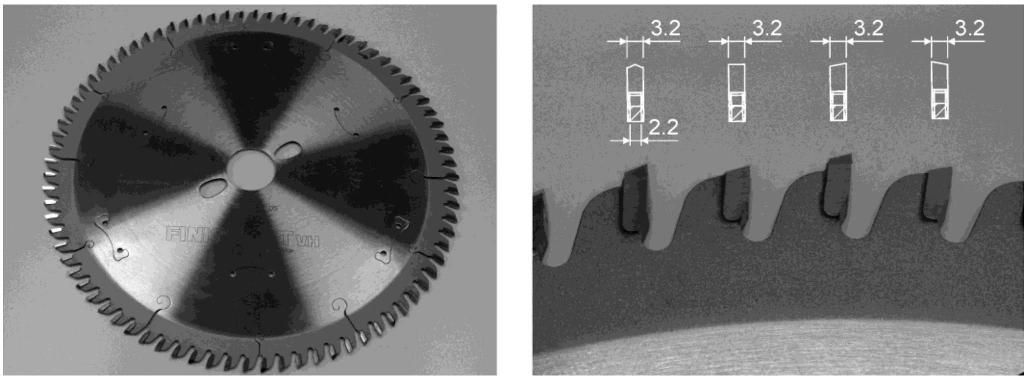

Figure 1. The saw blade used for the investigations (left) and its GSML teeth geometry (right)

According to the manufacturer, this circular saw blades series is dedicated to processing veneered board (cutting along the veneer) and is perfect for cutting worktops and other glued elements. There is a possibility of using one saw blade for solid wood and wood-derived materials with excellent cutting quality and with a wide range of the height of materials cut: from 20 to 120 mm (i.e., in universal applications) with less power consumption. The cut surface is perfect, regardless of the thickness of the cut material or the veneered materials. The steel used ensures repeatability and high parameters of the disc, which contribute to the stability of the blade during operation, very small cutting resistance, comfort and assurance during the cutting process. Additionally, the sintered carbide and NANOGRAIN type – with a hardness of more than 2,250 HV – guarantees even longer effect of the saw blade operation (Saw blades FINISH CUT VH series).

The saw blades used characterised the following main technical parameters:
- diameter: 250 mm;
- number of teeth: 80;
- blade thickness: 2.2 mm;
- teeth width: 3.2 mm;
- maximum rotational speed: 7,500 rpm;
- bore diameter: 30 mm.

The above-described circular saw blades were implanted using a semi-industrial gaseous ion implanter operated by the National Centre for Nuclear Research Świerk (Otwock, Poland). This device is equipped with a large vacuum chamber with the following dimensions: a length of about 120 cm and a diameter of about 80 cm (i.e., a volume of about 600 litres). Additionally, two sleeves with a length of about 130 cm and a diameter of about 25 cm increase the functionality of the implanter. For example, the series of the drill-type tools can be moved under the ion beam using a computer-controlled, cart-type special holder placed in the sleeves. Other manipulators, such as table, rotary and planetary holders, increase the possibilities of manipulating the implanted tools.

The base pressure in the vacuum chamber at a level of about 8e-4 Pa (8e-6 mbar) is obtained in several dozen minutes using a computer-controlled set of vacuum pumps consisting of a rotary pump, a Roots pump and a diffusion pump.

5N purity gases, like nitrogen, helium or argon, can be used as the source of the implanted ions. The presented implanter is a device with a non-mass-separated ion beam, which means that the ion beam may be mass inhomogeneous. It is irrelevant in the case of inert gases ionised homogeneously throughout the volume, like the mentioned helium or argon. It is different in the case of gases, where the beam consists of two or more types of ions. For example, the implanted nitrogen is delivered as two kinds of ions (i.e., N_2^+ and N^+ in the ratio of ~1:1). This effect should be taken into account, for example, when determining the depth profiles of the implanted element.

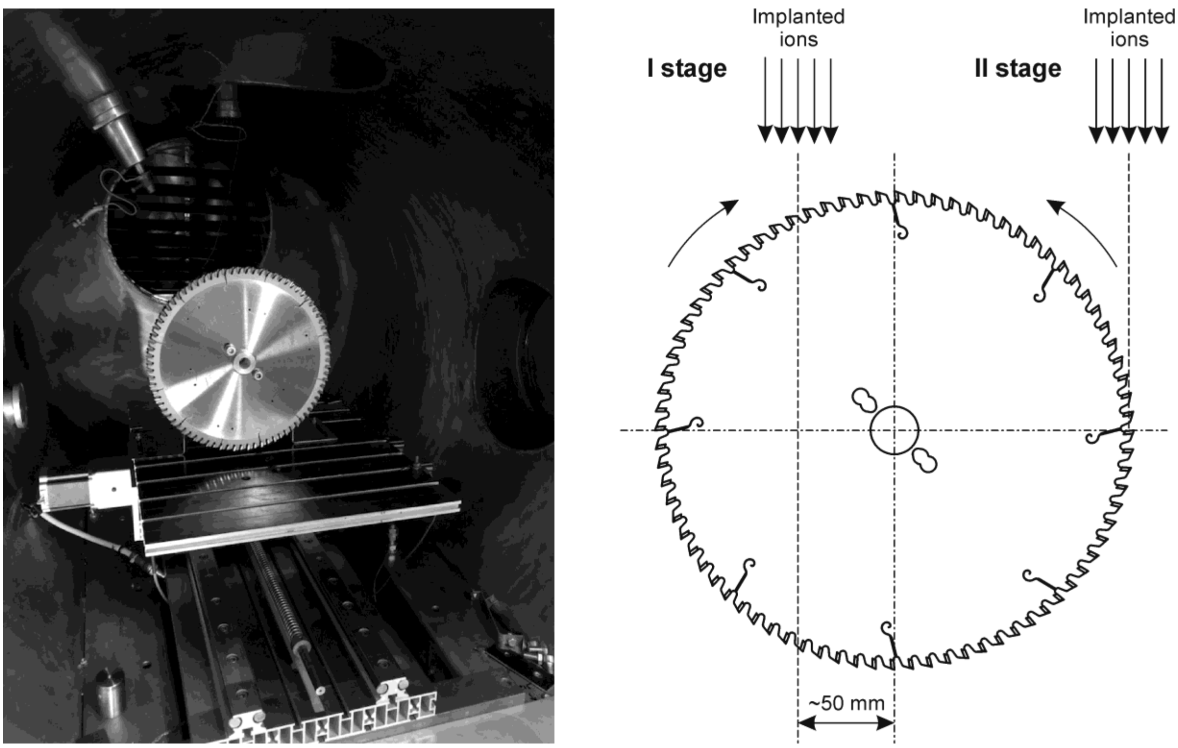

Figure 2. The circular saw blades in the implanter chamber (left) and the scheme of the ion implantation (right)

The value of the potential difference at a distance of about 100 cm between the ion source and the implanted surface (acceleration voltage of the implanted ions) can be set in a range of 20-70 kV. The ion beam is continuous. Its diameter (without a significant decrease in current density) is about 50 mm, which gives an implanted surface of about 20 cm^2 for the diameter 3.5 mm circular diaphragm. The change of this diameter influences the cross-section of the ion beam. The change of the circular shape beam affects the beam shape.

The current of the ion beam can be set in a range from 100 to 500 μA, which gives the ion current densities from about 5 to 25 μA/cm^2 for the assumed value of an implantation area of 20 cm^2.

Prior to the processing, the saw blades were washed in high-purity acetone. Next, the three above-mentioned saw blades were put together in a package and placed in the implanter chamber (Fig. 2 left). The total implanted dose of nitrogen ions was 5e17 cm^{-2} (2×2.5e17 cm^{-2}), and the ions were implanted at 50 kV acceleration voltage. Such values of the main parameters of implantation correlate with previous investigations (e.g., Wilkowski et al., 2019; Wilkowski et al., 2021). The ion implantation was performed in two stages. The details of the procedure are presented in the right-hand side of Fig. 2. In the first stage, the ion beam axis was moved about 50 mm with respect to the axis of the saw blades. In the second stage, the ion beam axis was moved near the saw blades' tangent. In both cases, the saw blades rotated at a speed of 0.3 s^{-1} (i.e., 18 rpm).

The current of the ion beam was about 300 μA, and the time of the ion implantation was 11 h 40 mins (700 mins) per stage. The maximum estimated temperature value of the implanted tools did not exceed 200°C.

The implanted saw blades were tested in industrial conditions in the Porta KMI Poland factory (Ełk, Poland) for formatting door frames. The door frames were made of wood-based materials such as particleboards, plywood, MDF and HDF. The new innovative materials intended for use in the recently designed PortaFRAME technological line were also tested. During the tests, the wear of the tools was measured, and their durability was estimated on this basis. The details and the results of the performed tests will be the subject of our next publication.

RESULTS AND DISCUSSION

As mentioned above, all test details of the modified saw blades will be presented in the next paper; however, it should be mentioned that the estimated tool life of the implanted circular saw blades increased about three times compared to the durability of the non-modified tools.

The information obtained from the machine tool operator shows that the typical tool life of the discussed tool ranges from 3 to 5 eight-hour shifts.

The modification time is relatively long for the proposed case since it amounts to 1,400 mins for three pieces of the saw blades. The average arithmetic time for one piece is, thus, about 470 mins. There is a possibility of increasing the number of simultaneously implanted tools due to "an unused" part of the ion beam. The blade thickness is 2.2 mm, and the teeth width is 3.2 mm. Using the appropriate spacers, with a thickness of about 1.5 mm, will allow us to assemble a package of 10 saw blades for the diameter 3.5 mm diaphragm hole. In this case, the average arithmetic average implantation time will be 140 mins per one piece. An additional increase in the diameter of the ion beam (e.g., to 10 cm) will increase the number of the modified parts to 15 pieces. It is possible with the use of, for example, the running track shape diaphragm with a similar surface area like for the diameter 3.5 mm diaphragm. The obtained time value is at a level of 90 mins per one piece, and it is an acceptable value from a technical point of view.

Fig. 3 presents the two kinds of ion beam trace (i.e., for the diaphragm with a circular hole diameter of 3.5 mm and for the diaphragm with a hole with a semi-major axis of 7.5 mm and a semi-minor axis of 3 mm). Additionally, the view of both diaphragms is shown. The non-regular shapes on the beam traces are caused by pieces of quartz used during the diagnosis of the ion beam size (quartz glows under the influence of the ion beam). Additionally, the circular traces on the right-hand photo show the reference to the circle trace obtained using the circular hole diaphragm.

There are at least two other possibilities for increasing the ion beam diameter and hence the number of implanted saw blades with maintaining the correct and stable operation of the ion source – namely an increase of the distance between the ion source and the implanted surface – using 30 cm extra sleeve in the vacuum chamber construction and/or the application of the stretching of the ion beam using the additional electrical field. Unfortunately, in both cases, the ion current density will be smaller due to an increased implanted surface area.

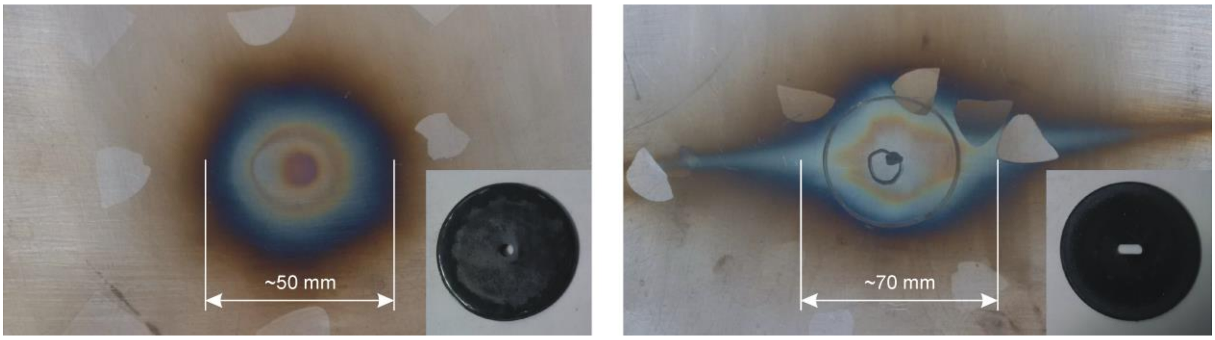

Figure 3. The ion beam traces and view of the diaphragms with the circular hole (left) and the running track shape hole (right)

The above considerations apply to a relatively large dose of the implanted ions (i.e., 5e17 cm^{-2}). The subsequent investigations should determine whether such a large dose is actually necessary. Perhaps the implanted ion dose may be lower and the associated implantation time shorter.

CONCLUSIONS

It seems that the estimated (near threefold) increase in the lifetime of circular saw blades may be attractive for industrial recipients. Such an increase in tool life is possible with the use of relatively simple and cheap gas ion implanters equipped with the appropriate equipment that increases their possibilities. The feasibility of using ion implantation to increase tool life on an industrial scale has been demonstrated. The process optimisation can have an additional effect on cost reduction.

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Streszczenie: *Weryfikacja możliwości modyfikacji ostrzy pił tarczowych do obróbki materiałów drzewnych metodą implantacji jonów*. W artykule zweryfikowano możliwość modyfikacji ostrzy pił tarczowych do obróbki materiałów drzewnych. Tego typu narzędzia są wykorzystywane w przemysłowej produkcji stolarki budowlanej, np. do formatowania ościeżnic drzwiowych. Zęby z węglika spiekanego wlutowane w brzeszczot piły tarczowej były modyfikowane w procesie implantacji jonów azotu. Przedstawiono przebieg modyfikacji i przeprowadzono rozważania nt. technicznych uwarunkowań zaproponowanego procesu i możliwości ich zmiany pod kątem przemysłowego zastosowania.

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