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ЗАГАЛЬНИЙ ОГЛЯД СПОСОБІВ ФРИКЦІЙНОГО ОБРОБЛЯННЯ РІЗАЛЬНИХ ІНСТРУМЕНТІВ РУБАЛЬНИХ МАШИН

Стаття презентує класифікацію обладнання для подрібнення деревини, зокрема рубальні машини, описуючи їхні особливості разом з перевагами та недоліками. Поставлено проблему та визначено мету майбутнього дослідження, яке стосується тривкості різальних інструментів у рубальних машинах.

Розглянуто методи фрикційної обробки, які ґрунтуються на терті поверхонь, і виокремлено способи поверхневого зміцнення металів, визначаючи найбільш оптимальний серед них. У кінцевому аналізі представлено висновки проведеного дослідження.

Ключові слова: *рубальна машина, тривкість, механічне зношування, фрикційна обробка, ніж, контрніж, поверхневе зміцнення, конструкційна сталь, мікроструктура сталі.*

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GENERAL OVERVIEW OF FRICTIONAL PROCESSING METHODS FOR CUTTING TOOLS OF CHOPPING MACHINES

The article presents a classification of equipment for wood shredding, particularly chopping machines, describing their features along with advantages and disadvantages. The problem is identified and the aim of future research related to the durability of cutting tools in chopping machines is determined.

Methods of friction processing based on surface rubbing are considered, and ways of surface strengthening of metals are distinguished, determining the most optimal among them. The conclusions of the conducted research are presented in the final analysis.

Keywords: *chopping machine, durability, mechanical wear, friction processing, blade, counterblade, surface strengthening, structural steel, steel microstructure.*

Problem statement. In the modern world, where humanity constantly seeks new ways to optimize and facilitate work, the utilization of various resources becomes a key task. One of the most accessible and widely used resources is wood. By focusing on improving the energy characteristics of wood, significant benefits can be obtained, especially if energy is extracted from it after certain processing. To ensure a more efficient use of wood, its small particles can be compacted into briquettes, which is a fairly economical method. It is important to note that shredded wood, known as wood chips, is also used in the production of various wood-based materials, such as particleboard, fiberboard, and others.

The main problem addressed in the study was to increase the durability of cutting blades and counter blades of chopping machines to prevent their mechanical wear.

Task formulation. The aim is to identify an effective method for enhancing the durability of tools to prevent mechanical wear of their materials.

Presentation of the main material. Chopping machines are used for the shredding of wood into technological or energy chips as needed. Currently, there are three main types of such machines: disc, drum, and screw [1]. Table 1 presents some technical characteristics of each of them.

Analyzing Table 1, we can determine the structural features and advantages of each of the presented types of chopping machines. Disk-type machines are characterized by the lowest motor power, up to a maximum of 105 kW, have the fewest number of blades (from 1 to 4 pieces), and relatively low productivity (from 2 to 60 m3/h). Screw-type machines, due to the characteristics of the working element - the screw, ensure the wood cutting process without impacts, which contributes to the increased service life of parts [2], however, their productivity is significantly lower (from 5 to 40 m3/h). Drum-type machines have a simple design and use blades of a simple shape, which facilitates their preparation for work. The use of high-power motors in drum-type machines is compensated by their high productivity compared to other types. A detailed classification of drum-type harvesting machines is presented in Figure 1.

Considering the provided classification, it is evident that the range of drum-type harvesting machines is very diverse. In our case, we have chosen a stationary chopping machines with a cylindrical drum for conducting research. In this machine, the blades are located inside the drum, and the feed of the raw material is carried out by a feeding mechanism.

One of the major problems of chopping machines of all types today is the insufficient durability of the tools [3]. The preparation of the blades and counterblades of chopping machines for operation involves taking into account large dynamic loads [2] acting on the tools, as well as possible foreign inclusions directly in the wood. Therefore, low tool durability of carbon steel, even after hardening, is a significant issue. Hence, we decided to analyze known methods of steel strengthening today and compare some of them to determine the most effective. Considering previous research [15] on the strengthening of structural steels, the simplest and most accessible method is friction processing.

Table 1.

Comparison of characteristics of disc, drum, and screw chopping machines

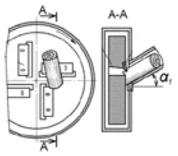
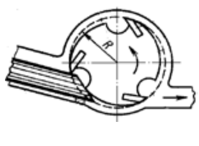
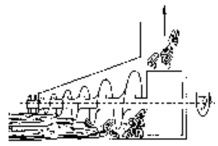
Indicators	Machine Type		
	Disk	Drum	Augers
			
Cutting Tool, pcs.	1…4	3…20	Spiral knife
Feed Type	Gravity, Mechanical	Gravity, Mechanical	Mechanical (self-feeding)
Maximum Log Diameter, mm	100…300	80…450	160…270
Thickness of the Cut Layer, mm	4…80 Adjustable	5…80 Adjustable	20…80 Dependent on the screw pitch
Power, kW	8…105	45…325	30…130
Productivity, m^3/h	2…60	5…100	5…40

Fig.1. **Classification of chopping machines**

For better understanding, let's briefly discuss all methods related to frictional friction. According to source [4], there are four main methods based on friction (Fig. 2).

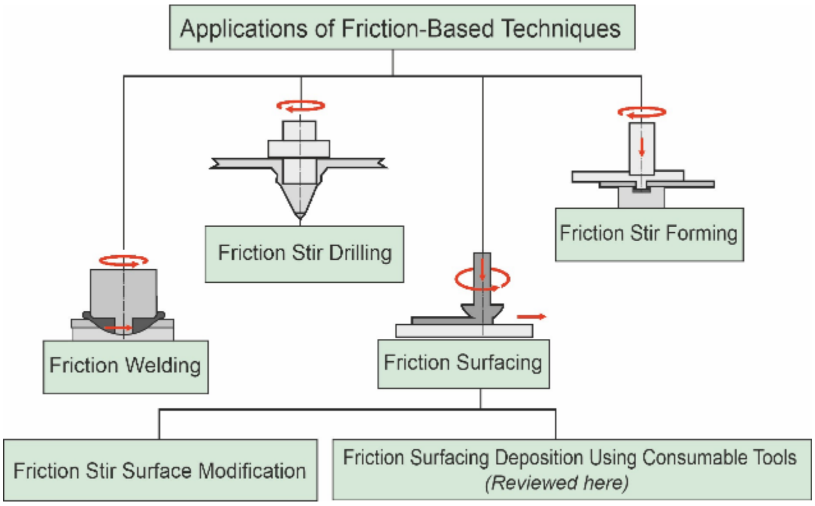


Fig. 2. **Methods of strengthening based on friction**

Friction welding is often used for joining parts made of different metals or with metals of different chemical structures. For example, this method is applied in the production of spiral drills or end mills, where the working part is made of high-speed steel and the shank is made of structural steel. Friction drilling is a suitable method for many products, especially those made of thin-sheet metal. During this process, the metal is not cut into chips but heated and deformed into a shell shape. This shell, often in the form of a hollow cylinder, can be used as a base for threading. There is also a method of friction stirring, similar to friction welding, where different metals are used. In the article "Rapid surface hardening and enhanced tribological performance of 4140 steel by friction stir processing," the author [5] indicates that friction stirring is a kind of offshoot of friction welding, which can also be used to join metals in the solid state. This process occurs due to significant plastic deformation with subsequent physical mixing of metals. It is important to note that this method does not involve the non-detachable connection of two materials but changes the microstructure of their surface layer. Moreover, this method is widely used to improve plasticity, increase material fatigue resistance, or correct defects in its microstructure.

After conducting classical heat treatment, studies have been carried out on the latest, fourth method - friction surfacing. Nowadays, a large volume of work is dedicated to the analysis, optimization, and implementation of friction surfacing methods with various tools on various materials. It is essential to understand that the analyzed friction surfacing method is divided into two separate sub-methods (see Figure 2): modified surfaces formed by friction mixing (frictional strengthening) and surfaces frictionally surfaced using consumable materials. Let's consider these two methods separately in more detail.

Describing the friction surfacing method using consumable materials, it is important to mention patent "GB572789A" [9] as the primary source. In this patent, the method is presented as an alternative to welding: "In joining steel or hard alloys, iron, aluminum, brass, or other metals, the heat necessary is produced by friction ..." [9, p. 1]. Recently [10], this method has been developed as a practical industrial process. It has been applied to obtain various types of coatings distinguished by wear resistance and resistance to aggressive environments.

Friction surfacing (see Fig. 3) is the process of applying metal from one surface to another by friction, with both metals being in a solid state. During such processing, a thick layer of fine-grained structure can be created in the coating. During this procedure, significant thermal energy is generated due to frictional contact and shear of the rod material inside its structure.

There are successful examples of research on applying metal coatings to a substrate of steel and aluminum, as well as applying high-speed steels to a substrate of ordinary carbon steel.

During the application of tool steel to a substrate of soft steel, the formation of a strong, uniform, and efficient coating was observed, which differs from the process of applying aluminum. The latter process occurred only under significant contact pressure between the surfaces. Regarding the application of coatings on an aluminum substrate, aluminum melting under the influence of heat generated by friction was noticed. This surfacing occurred at a spindle rotation speed of 3000 rpm and a constant pressure on the substrate surface of 21.8 MPa. This led to the formation of brittle intermetallic compounds at the interface of the coatings with the substrate.

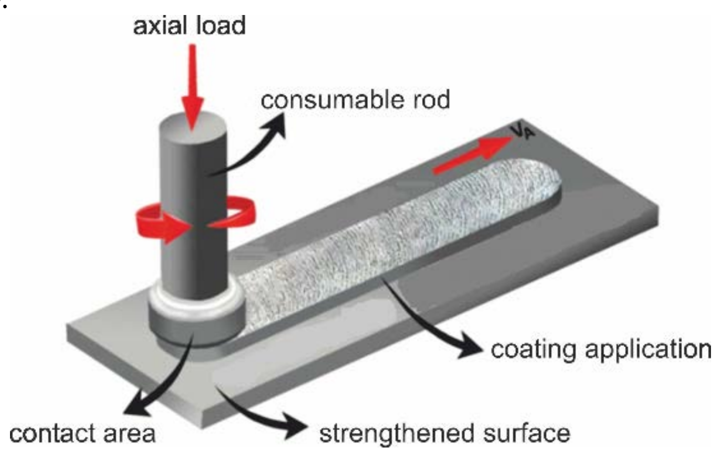


Fig. 3. **Scheme of Frictional Strengthening with Consumable Tools**

Further research [10], conducted using X-ray microscopy, confirmed the presence of discrete layers in the coating structure, which inclined towards the substrate phase at a certain angle. Moreover, the formation of cracks between these layers was observed, especially near the outer edge of the coating. The authors [10] note that to obtain a higher quality surface, it is necessary to remove the upper layers of the coating through mechanical processing. The aforementioned studies were conducted on a milling machine with a vertical spindle. Before the experiment, the substrate was cleaned, degreased, and placed in a closed box made of organic glass, with an opening for feeding the consumable rod [10].

Friction strengthening, also known as "high-speed strengthening," has gained popularity in Eastern Europe for increasing the surface strength of rollers [13].

The process of friction strengthening is relatively simple (see Fig. 4). It is carried out on a milling machine with a vertically arranged spindle. A workpiece is placed on the table and fixed with clamps or clamps on the working surface of the table. An indenter, which is a metal rod with a hardness of 62-63 HRC, is fixed on the spindle through a collet. Strengthening occurs at an indenter rotation speed of Vc = 50-80 m/s, with a constant pressure on the workpiece of Fn = 40-60 kg, while the table of the machine performs the feed movement.

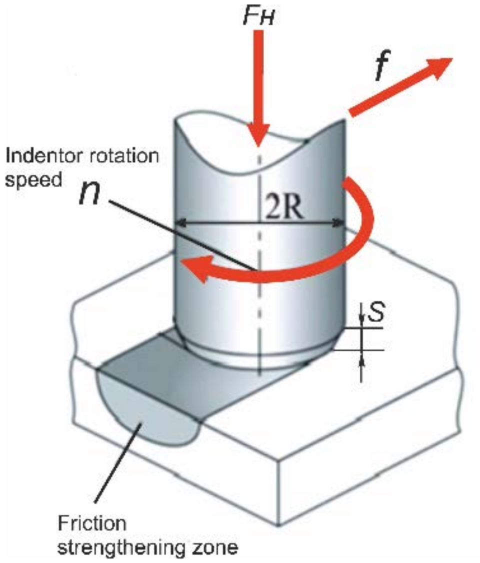


Fig. 4. **Schematic diagram of friction strengthening**

Yes, cementation and classical heat treatment processes are key for enhancing the tribological properties of steels with different carbon contents. For steels with low carbon content, cementation, where steel is artificially enriched with carbon, is often used. In the case of high carbon content, classical heat treatment is applied to increase strength. This process involves heating the steel with open flame and rapidly quenching it in a specific medium, resulting in a finer structure and increased strength. Following this, a normalization process is conducted, which includes reheating the material to relieve stress and eliminate brittleness. This technological process is quite complex and requires significant energy resources due to its multi-step approach.

Comparing classical thermal treatment of steel with frictional strengthening, it can be noted that frictional strengthening usually takes place over a shorter period and involves fewer technological operations. Classical thermal treatment requires a sequence of operations such as heating, cooling, normalization, and others, which can be time-consuming and energy-intensive. In contrast, frictional strengthening occurs by processing the material surface using friction from the tool, resulting in strengthening without significant heating and cooling. Therefore, frictional strengthening can be a faster and more efficient option for certain applications.

In their study, the authors [5] conducted an analysis of strengthening medium carbon steel AISI 4140 (Ukrainian equivalent - steel 40ХФА) using frictional surface strengthening. They investigated the impact of this process on the characteristics of mechanical wear during reciprocating sliding under dry and liquid friction conditions. According to the results obtained, frictional strengthening provided a similar level of hardness compared to classical thermal treatment, but a decrease in contact interaction of bodies, friction processes, and wear was observed. It was noted that to carry out this process, the energy required for processing was reduced by only 10%, without the need for subsequent steel normalization.

The study used flat test samples of AISI 4140 steel with a thickness of 6.5 mm, which were pre-annealed before testing. Other test samples with the same parameters and material were hardened using the traditional method followed by water quenching. The surface hardness of the material strengthened by frictional processing was 7.8 GPa (62 HRC), whereas during classical thermal treatment (with water quenching), the ultimate strength was 7.5 GPa (61 HRC).

Further microstructural analysis conducted by the authors [5] confirmed that both in classical thermal treatment and frictional strengthening, a martensitic structure is formed. Despite the fact that the signs of wear for surfaces processed by both frictional and conventional methods were approximately the same, the wear of the surfaces processed by the frictional method decreased by almost half. These improved tribological properties can be explained by the finer grain in the metal structure combined with the formation of martensite. Thus, an intermediate conclusion can be drawn that frictional strengthening of medium carbon steel is an effective, energy-saving, and environmentally friendly alternative to traditional hardening methods.

The studies conducted by the authors [14] aimed to apply frictional strengthening to high carbon steel AISI 1080 (Ukrainian equivalents - steel 75, steel 80, steel 85) to improve its surface properties. In this research, a tool made of a refractory tungsten alloy was used, with a rotation frequency of $n = 1000$ rpm, compression force $F = 5$ kN, and feed rate $v = 15$ mm/s. Additionally, to prevent oxidation of the processed layer, an argon shield was applied.

Similarly to the previous example of medium carbon steel strengthening, during frictional strengthening of high carbon steel, transformation of the initial pearlite microstructure into martensite was observed, resulting in increased surface hardness. This increase in hardness affected the friction and wear efficiency of the material, evaluated through dry and liquid sliding. The tests were conducted on a commercial pin-on-disc tribometer using a "ball-flat" contact configuration. The objects of the study were flat samples of AISI 1080 steel with dimensions (L×W×H) - 25×25×10 mm, previously untreated [14].

During dry sliding friction, observations [14] showed that the friction coefficient decreased by approximately 25%, and the wear rate compared to the analogous material hardened by conventional means decreased by an order of magnitude. Regarding liquid friction (lubricated sliding), frictional strengthening had a minor effect on friction, but the wear rate decreased by a factor of 4. The improvement in characteristics during the contact interaction of materials is explained by the lower plasticity of the material during sliding contact.

For our future research object, which is the cutting pair, the frictional strengthening method appears to be the most suitable. This method demonstrates high effectiveness in increasing the metal's resistance to wear, which is a critical aspect for the efficient operation of the cutting pair in a chopping machine.

Conclusions:

1. Literature analysis regarding the classification of chopping machines, the toughness of their cutting tools, and various frictional processing methods is crucial for understanding the fundamental principles and potential applications of these methods. Identifying frictional processing methods used for surface strengthening indicates the need to search for optimal methods to enhance the properties of cutting tools.
2. An important distinction between frictional strengthening and friction surfacing has been identified - the absence of material adhesion of the tool to the substrate in frictional strengthening. This may be considered a drawback, as adhesion can result in better bonding and more uniform deposition of material onto the substrate in friction surfacing. Based on this, we can conclude the advantages and disadvantages of each of these processes and determine which suits our specific situation better.
3. The possibility of using friction surfacing to improve wear resistance has been established. This means that utilizing friction surfacing can increase the material's resistance to wear, which is a crucial factor for many applications where materials undergo mechanical or thermal wear.
4. Frictional strengthening involves instantaneous heating of the workpiece metal through friction, as well as similarly instantaneous cooling due to heat dissipation. This process allows for strengthening the material by rapid heating and cooling, promoting the formation of stronger structures within the material and improving its mechanical properties.
5. The choice of frictional strengthening method for strengthening the working surfaces of blades can be justified by its ability to increase the strength, hardness, and wear resistance of the material. This method allows for locally heating the blade surface through friction and rapidly cooling it, resulting in the formation of a martensitic structure, which ensures enhanced strength. Additionally, frictional strengthening can reduce abrasive wear and increase the blade's service life, making it an effective and durable tool for cutting applications.

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