DOI: https://doi.org/10.32347/2707-501x.2025.56(1).54-63

UDK 621.7

Kostiantyn POCHKA,
Doctor of Technical Sciences, Professor
ORCID: 0000-0002-0355-002X
Vadym SHALENKO,
Candidate of Technical Sciences, Associate Professor
ORCID: 0000-0002-6984-0302
Borys KORNIICHUK,
Candidate of Technical Sciences, Associate Professor
ORCID: 0000-0003-3881-1581
Dmytro PALAMARCHUK,
Candidate of Technical Sciences, Associate Professor
ORCID: 0000-0002-8019-9659
Andrii MASLIUK,
assistant
ORCID: 0000-0002-6349-084X
Kyiv National University of Construction and Architecture, Kyiv

MODERN MATERIALS FOR CUTTING TOOLS AND THE MANUFACTURE OF THESE TOOLS BY MEANS OF WELDING

Industry uses a wide variety of tools that differ significantly in design and operating conditions, depending on their purpose.

For machining tools, the most important requirement is high strength and hardness, which ensure high wear resistance. In order to prevent plastic deformation of the working surfaces under the influence of high temperatures, the tool material, along with a high hardness 2…3 times greater than that of the workpiece, must have high heat resistance.

Welding plays a key role in the production of combination tools, where the cutting part is welded to a base made of cheaper material, which significantly reduces the cost and improves the performance of the tool.

Modern band saws are made from bimetallic compositions. Spring steel is used as the base, to which a narrow strip of high-speed steel is welded. After that, the teeth are cut on a milling machine. This combination solves several problems at once: it increases the fatigue resistance of the saw body; the cutting edge has optimal wear resistance; cutting resistance is minimized.

Spring steel grades are selected for the saw body: 45ХН2МФА, 50ХГФА. The cutting edge of the saw is made of high-speed steels of grades 7Р1М5К5, 11Р2М10К8 (M42 or HSS Co8 (High Speed Steel)) and 12Р10М4К10 (M51 or HSS Co10).

Band saws and knives can be welded using professional equipment from Ideal Werk, Germany.

We have reviewed equipment for manufacturing the latest models of band saws and knives from the BAS 320 and BAS 330 series, equipped with special clamping mechanisms for each type of product, automatic multi-stage weld annealing control, a hydraulic knife for removing weld ridges, and positioning systems.

The analysis conducted in this work allows reducing the cost of tool production by using expensive cutting materials only where necessary. Improve the mechanical properties of the tool by combining the hardness of the cutting part with the strength of *the base. Expand the range of tool applications by creating combined products for different types of processing.*

Keywords: tool, material, steel, welding, hardness, equipment, annealing, high-speed steel.

Problem statement. Industry uses a wide variety of tools that differ significantly in design and operating conditions, depending on their purpose.

Tool steels, hard alloys, oxide-carbide and oxide-nitride ceramics, superhard materials based on natural and synthetic diamonds, boron nitrides, and others are used to manufacture tools for various purposes [1].

For mechanical processing tools, the most important requirement is high strength and hardness, which ensure high wear resistance. In order to prevent plastic deformation of working surfaces under the influence of high temperatures, the tool material, along with high hardness 2…3 times greater than that of the workpiece, must have high heat resistance.

The heat resistance of tool material is understood as the ability to maintain high hardness at elevated temperatures.

In addition to performance characteristics, hardenability, minimal volume changes during hardening, machinability, and grindability have a significant impact on tool quality.

Welding plays a key role in the production of combination tools, where the cutting part (e.g., made of high-speed steel or hard alloy) is welded to a base made of a cheaper material, which significantly reduces the cost and improves the characteristics of the tool [2, 3].

An objective of this research is to reduce the cost of tool production by using expensive cutting materials only where necessary. To improve the mechanical properties of the tool by combining the hardness of the cutting part with the strength of the base. To expand the range of applications for tools by creating combined products for different types of processing.

Analysis of recent researches and publications. Welding different types of steel has its own characteristics. Many factors affect the weldability of steel, the main ones being the carbon and alloying element content, as well as the structure. Based on these characteristics, steels are divided into groups: low-carbon and low-carbon low-alloy, medium-carbon, high-carbon, medium-alloy, and high-alloy. For each group of steels, the approximate weldability must be determined based on various characteristics: for carbon steels, based on the amount of carbon; for low- and medium-alloyed steels with low and medium carbon content – by the carbon equivalent value, for high-alloyed steels – mainly by the structure and properties obtained after welding. In addition, the carbon content must always be taken into account, as an increase in its amount worsens weldability.

Most high-alloy steels are widely used as corrosion-resistant materials. Due to the fact that they vary in composition and structural characteristics, as well as have different physical properties, their specific features should be taken into account during welding.

For welding stainless steels, fusion welding methods (automatic, mechanized, manual arc, plasma, laser, and others) are used, as well as compression welding methods (electrical contact welding, friction, etc.) [2-5].

Various types of welding are used to create cutting tools, including gas, arc, and modern methods such as laser or electron beam welding, which ensure high precision and weld quality.

The narrowest cut and minimal material loss in chips when cutting workpieces is achieved by using band saws. This type of tool allows you to successfully cut carbon and alloy steels, cast iron, non-ferrous metals, and alloys, maintaining high productivity without compromising the quality of the cut. The main disadvantages of band saws are significant wear of the cutting edge (teeth) and the risk of blade breakage along the weld seam. Sharpening requires complex special equipment, so most companies prefer to simply replace blunt tools with new ones.

Bimetal cutting tools are tools that consist of two (or more) metals that provide an optimal combination of properties for cutting, such as hard steel for the cutting edge and ductile steel for the base. Such tools include metal band saws, high-performance table saws, and high-speed cutters, which have a cutting part made of super-hard alloy [1] or high-speed steel connected to a strong base made of low-carbon steel.

Modern band saws are made from bimetallic compositions. Spring steel is used as a base, to which a narrow strip of high-speed steel is welded. After that, the teeth are cut on a milling machine. This combination solves several problems at once: it increases the fatigue resistance of the saw body; the cutting edge has optimal wear resistance; cutting resistance is minimized.

Spring steel grades are selected for the saw body. Steels and alloys intended for the manufacture of elastic elements in mechanical engineering (springs, torsion bars, shock absorbers) and instrument making (membranes, suspension springs, relay plates, bellows, etc.)) must have, in addition to strength, toughness, and endurance, a high elastic limit, fatigue resistance (σ_{-1}) under multi-cycle loads, and high resistance to small plastic deformations ($\sigma_{0,005}$ and $\sigma_{0,2}$) [6-8]. Such materials will not deteriorate over time under the influence of variable cyclic working loads.

The cutting edge of the saw is made of high-speed steel. The group of high-speed steels with heat resistance of 600…650 °C consists of high-carbon (C = 0.7…0.95%) and high-alloy steels containing carbide-forming elements (W, Mo, V, Cr), which chemically bind almost all carbon.

Due to their high hardness, strength, and heat resistance, the cutting speed during machining with such steels increases by 2 to 4 times compared to carbon and low-alloy steels. For this reason, such steels are called high-speed steels and are marked with a separate designation – the letter “P” (cutting) and a number after it, which shows the tungsten content in percent. The chromium content in these steels is ≈ 4% and the vanadium content is from 1 to 5%. For example, P6M5 steel contains ≈ 6% W, ≈ 5% Mo, and ≈ 4% Cr. The C and Cr content in high-speed steel grades is not specified.

High-speed steels are heat treated to achieve maximum hardness and heat resistance by minimizing the amount of residual austenite. This is achieved after quenching and repeated tempering.

A distinctive feature of hardening high-speed steels is slow heating and holding for additional heating at temperatures of 450 °C and 850 °C in salt environments to prevent oxidation and decarburization. Hardening heating of high-speed steels is carried out at T = 1270...1290 °C, which ensures complete dissolution of secondary carbides and, after hardening, the formation of high-alloy martensite with high hardness (HRC 63...65), strength, and heat resistance [6-9].

For band saws with high wear resistance requirements, the cutting edge is formed by soldering and sharpening teeth made of hard alloys. Segmented blades are manufactured with a cutting surface coated with finely dispersed abrasive grit. In this case, the principle of cutting with an abrasive wheel is replicated.

Main part. Spring steel grades are selected for the saw body: 45ХН2МФА, 50ХГФА. The cutting edge of the saw is made of high-speed steels of grades 7Р1М5К5, 11Р2М10К8 (M42 or HSS Co8 (High Speed Steel)) and 12Р10М4К10 (M51 or HSS Co10). For band saws with high wear resistance requirements, the cutting edge is formed by brazing and sharpening teeth made of hard alloys Т5К10, ВК4, ВК8 [6-9].

The technology for manufacturing band saws is as follows. The complex profile of the band saw teeth is obtained by contour milling. After cutting, the blade undergoes complex heat treatment, as a result of which the cutting part acquires a hardness of 62...64 HRC, while the main part remains significantly softer – within the range of 42...45 HRC. To increase durability, some saws are coated with a protective layer of aluminum and titanium nitride [10]. This increases the service life of the product by 2 to 4 times, and the surface hardness of the teeth increases from 720 HV to 2300 HV. The saw ring acquires its final appearance through pressure contact welding. This technology does not require filler material, so the weld seam fully matches the mechanical characteristics of the saw metal. To remove residual stresses, it is subjected to stabilization annealing.

Band saws are highly productive tools that allow you to cut workpieces of any cross-section with minimal chip waste. The cutting part of the saw has a complex toothed contour with a specific pitch. The technological capabilities of the band blade directly depend on the geometry of the working part, and a wide range of options allows you to choose the right tool for any technical task.

The thicknesses of the blades are standardized and defined by a series of established numbers. The actual cutting thickness in metal will be slightly greater, taking into account the spacing of the teeth on both sides, bending loads, and some distortion of the profile during cutting. The working part of the saw can be made with a constant or variable tooth pitch. The tolerance for this value ranges from 0.2 mm to 1 mm. Precise positioning reduces the overall load on the teeth and the intensity of wear, but increases the cost of production. The teeth of the band blade are spaced on both sides to ensure a stable cut and even load distribution. Products are available with four tooth arrangement options: variable pattern – a repeating sequence of "straight tooth, right, left"; combined pattern – a sequence of "straight tooth, right, left, right, left"; group pattern – composition based on the variable pattern, but the teeth with a slope are doubled; wave pattern – a straight tooth is followed by a triple doubling of teeth with a slope in one direction, then a straight tooth and the same block with a slope in the other direction.

The front angle of the teeth has the greatest influence on the distribution of cutting forces. Previously, blades were only produced with a zero value, but technological advances have made it possible to profile the cutting part with a clear focus on the area of application:

- 0˚ front angle – for cutting cast iron, stainless and high-alloy steels, thin-walled pipes, and shaped rolled products;
- 6˚ front angle – for cutting under conditions of possible impact loads and vibrations;
- 10˚ front angle – for cutting thick-walled pipes, structural steels, and non-ferrous alloys;
- 16˚ front angle – for cutting high-alloy and tool steels.

For cutting hard-to-machine materials – titanium and cobalt alloys, nickel-based heat-resistant alloys – band saw blades with increased tooth height are used. The special geometry reduces the risk of jamming in the metal workpiece.

The tooth pitch of the saw blade can be: constant – from 1 to 32 (pieces per inch, TPI); variable – from 10/14 to 0.75/1.25.

M42 and M51 are the names of the type of high-speed steel used for high-precision, wear-resistant cold stamping equipment. M42 high-speed steel can also be used for the production of cutting tools, as well as saw blades, scrapers, gear knives, and other tools for manufacturing tooth tips. The main characteristics are high red heat hardness, high wear resistance and cutting ability, high impact toughness, fine and uniform grain, and high viscosity.

The hardness of the M42 tooth tip ranges from HRC 67 to 69, while the hardness of the M51 tooth tip ranges from 69 to 71. Its back is made of spring steel to ensure the flexibility of the saw blade.

The M42 bimetal band saw is widely used and, in general, is capable of cutting almost all materials. Due to its cost, the M51 bimetal band saw is only used when cutting metal materials with higher hardness, such as bearing steel, stainless steel, tool steel, and other special steels. For irregular cutting of thin-walled pipes, hollow pipes, and other profiles, we usually use the tip of the tensile teeth or flat teeth – this is the M42 material.

M42 steel is a high-speed tool steel containing the following elements: 1.05–1.15% carbon (C), 3.50…4.25% chromium (Cr), 9.00…10. 00% molybdenum (Mo), 0.95...1.35% vanadium (V), 1.15...1.85% tungsten (W), and 7.75...8.75% cobalt (Co), which ensure high hardness and resistance during hot working.

The exceptional quality of this material is the wear resistance of the cutting edges of the saw blade teeth. The decisive factor here is the size of the carbide particles and their uniform distribution (Fig. 1). In the presented structure, white tungsten carbides are evenly distributed in a martensitic heat-resistant base. The hardness of the cutting edges of the teeth is 675...685 HRC. This material is suitable for sawing all basic grades of steel with a hardness of up to 40...45 HRC.

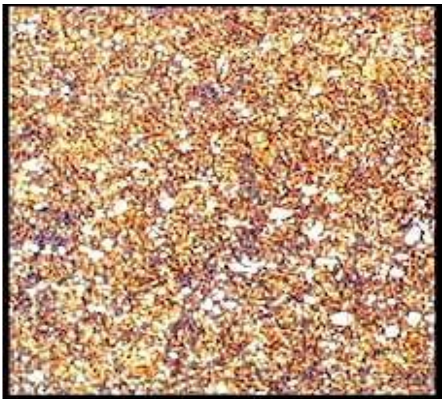

Fig. 1. Microstructure of M42 steel (11P2M10K8)

A higher tungsten content increases the number of carbides, thereby increasing resistance to abrasive wear. The high cobalt content increases the red hardness of the cutting edge. This allows the tool to be used for cutting high-strength, stainless, and heat-resistant steels, including workpieces with a large cross-section and a hardness of up to 45 HRC. The hardness of the cutting edge is 69 HRC. The stability of such a band blade is usually 10…20% higher than that of saws with an M42 cutting edge material (Fig. 2).

Fig. 2. Microstructure of M51 steel (12P10M4K10)

The characteristics of M51 are very similar to those of M42. The difference is that M51 is harder than M42, which means that M51 is more brittle. In order to make the best results in normal use, most brands in the country and abroad now use M42 high-speed steel.

M42 high-speed steel bimetal band saw blades for metal are shown in Fig. 3.

Fig. 3. Band saw blades for metal made of high-speed steel M42

Band saw blades for metal made of high-speed steel M51 are shown in Fig. 4.

Fig. 4. Band bimetal saws for metal made of high-speed steel M51

Butt welding technology is used in machines for welding band saws. Butt welding is a type of contact welding in which the workpieces are welded across the entire contact surface. They are secured in the movable clamps of the butt-welding machine. Electric current is supplied through a welding transformer. The contact surfaces are heated, the workpieces are compressed by a settling mechanism, and welding takes place. As a result of plastic deformation and rapid recrystallization, recrystallized grains from the material of both parts are formed in the zone.

Butt welding by melting does not require processing the ends of the workpieces. In this case, workpieces with uneven ends are brought into contact and an electric current is passed through them. This causes the ends to melt and, after compression, a weld is formed. At the same time, part of the metal from the weld is squeezed out in the form of slag. During the melting process, the unevenness of the joint is leveled, and oxides and contaminants are removed, so no preparation of the joint area is required.

Butt welding can be used to weld workpieces with different cross-sections, as well as dissimilar metals (high-speed and carbon steels, copper and aluminum, etc.). It is widely used for welding reinforcing bars, pipes, and other products.

With this welding method, there is only point contact between the band saw parts during the heating stage.

To maintain contact, the machine operates with electrode feed movement, including the band saw part. Once the desired temperature is reached, it presses the parts together.

A burr forms at the point of contact, which is removed in the next stage (hydraulic tool for burr removal). The manufacturing process also uses: a pneumatic device for laying blanks; a centering device for the ends of the strip; a special clamping device for fastening and aligning band saw blades.

Band saws and knives can be welded using professional equipment from Ideal Werk, Germany [11, 12].

The latest modifications of the BAS 320 and BAS 330 series machines (Fig. 5) are equipped with special clamping mechanisms for each type of product, automatic multi-stage weld annealing control, a hydraulic knife for removing weld ridges, and positioning systems.

The equipment is designed for continuous cycle operation with a stable process.

Additionally, welds are tested on a semi-automatic specialized stand for dynamic and cyclic loading, which simulates the working conditions of the tool.

The advantages of this machine are as follows:

- annealing device with automatic annealing temperature control using an infrared spectral pyrometer and built-in lighting;
- repeatable welds using software-controlled welding and annealing processes;
- storage of up to 100 programs with all welding parameters and settings for the corresponding annealing process; integrated spark protection;
- distance measurement system and welding parameter control; pneumatic or hydraulic clamping devices (depending on the size of the machine);
- LED illumination of the welding point; individual adjustment of the start and end speeds, as well as adjustment of the length of the melted section using maintenance-free drives;
- low emissions and resource-saving use of workpieces thanks to high-precision reproduction of welding processes.

Fig. 5. BAS 330 resistance welding machine from Ideal Werk, Germany

Conclusions. To reduce the cost of tool production, it is necessary not only to use expensive cutting materials only where necessary, but also to have high-performance equipment. This guarantees high quality and accuracy in reproducing all heat treatment parameters (in our case, annealing), as well as welding and weld quality. The ability to work with any type of band saw, regardless of cross-section or width. This will improve the mechanical properties of the tool by combining the hardness of the cutting part with the strength of the base and expand the range of applications for the tools by creating combined products for different types of processing.

References:

1. Dobrovol′s′kyy O., Shalenko V., Polishchuk Y. (2019). Fuleryt – nanomaterial tverdosti yakoho, vyshcha za tverdist′ almazu. [Fullerite is a nanomaterial with a hardness greater than that of diamond.] *Proceedings of International scientific-practical conference of young scientists «BUILD-MASTER-CLASS-2019»*. pp. 302, 303 *(in Ukrainian)*.
2. Dobrovol′s′kyy O.H., Kosenko V.A., Shalenko V.O., Maslyuk A.A. (2018). Osoblyvosti zvaryuvannya staley. [Features of welding steels]. *Hirnychi, budivelni, dorozhni ta melioratyvni mashyny*. Issue 92, pp. 49-55 (in Ukrainian).
3. Makovets′ka O.K., Pustovoyt S.V., Petruk V.S., Onyshchenko N.S., Polishko H.O. (2022). Osnovni napryamy doslidzhen′ i rozrobok u haluzi zvaryuvannya naukovykh tsentriv ta providnykh vyrobnykiv zvaryuval′noyi tekhniky. [Main areas of research and development in the field of welding by scientific centers and leading manufacturers of welding equipment]. *Avtomatychne zvaryuvannya*. Issue 12, pp. 50-54 (in Ukrainian).
4. Malysheva D.I., Vynohradov N.A., Sysoyev V.YU. (2022). Konstruktyvni osoblyvosti mobil′nykh reykozvaryuval′nykh mashyn dlya kontaktnoho stykovoho zvaryuvannya. [Design features of mobile rail welding machines for contact butt welding]. *Avtomatychne zvaryuvannya*. Issue 2, pp. 45-51 (in Ukrainian).
5. Shalenko V.O., Polishchuk A.H., Maslyuk A.A. (2025). Materialoznavstvo i tekhnolohiya konstruktsiynykh materialiv (modul′ 2). Zvaryuval′ne vyrobnytstvo. [Materials Science and Technology of Structural Materials (Module 2). Welding Production]. Metodychni vkazivky do vykonannya laboratornykh robit dlya zdobuvachiv pershoho (bakalavrs′koho) rivnya vyshchoyi osvity spetsial′nostey G9 «Prykladna mekhanika», G11 «Mashynobuduvannya (za spetsializatsiyamy)». – TSP «Komprynt», 72 s. (in Ukrainian).
6. Shalenko V.O., Maslyuk A.A. (2023). Materialoznavstvo i tekhnolohiya konstruktsiynykh materialiv (modul′ 1). [Materials Science and Technology of Structural Materials (Module 1)]. Metodychni vkazivky do vykonannya laboratornykh robit dlya zdobuvachiv pershoho (bakalavrs′koho) rivnya vyshchoyi osvity spetsial′nostey 131 «Prykladna mekhanika» ta 133 «Haluzeve mashynobuduvannya». – Kyyiv: KNUBA, 72 s. (in Ukrainian).
7. Harnets′ V.M. (2009). Materialoznavstvo [Materials science]. Pidruchnyk. – Kondor. – 386 s. (in Ukrainian).
8. Harnets′ V.M., Smirnov V.M. (2009). Metalichni konstruktsiyni materialy [Metal structural materials]. Dovidnyk. – «MP Lesya». – 140 s. (in Ukrainian).
9. https://insel.kiev.ua/index.php?route=information/uni_news_story&news_id=23
10. Peremit′ko V.V., Kolomoyets′ I.V., Sukhomlyn V.I. (2022). Osoblyvosti struktury ta vlastyvosti shariv metalu, naplavlenykh iz poperednim nanesennyam karbidiv tytana ta bora. [Features of the structure and properties of metal layers deposited with

prior application of titanium and boron carbides]. *Avtomatychne zvaryuvannya*. Issue 4, pp. 8-13 (in Ukrainian).

11. https://www.ideal-werk.com/en/
12. https://geomotors.com.ua/CodeCatalog/main/StrickoviPili.html

Костянтин ПОЧКА, Вадим ШАЛЕНКО, Борис КОРНІЙЧУК, Дмитро ПАЛАМАРЧУК, Андрій МАСЛЮК

Сучасні матеріали для ріжучих інструментів і виробництво цих інструментів за допомогою зварювання

В промисловості використовується велике різноманіття інструментів, які суттєво відрізняються конструкцією та умовами експлуатації, відповідними до їх призначення.

Для інструментів механічної обробки найважливішою вимогою є високі міцність і твердість, які забезпечують високу зносостійкість. Для того, щоб під дією високих температур не виникала пластична деформація робочих поверхонь інструментальний матеріал, поряд з високою твердістю в 2…3 рази більшою, ніж у заготовки, повинен мати високу теплостійкість.

Зварювання відіграє ключову роль у виробництві комбінованих інструментів, де різальна частина приварюється до основи з більш дешевого матеріалу, що значно знижує вартість та покращує характеристики інструменту.

Сучасні стрічкові пилки виготовляють на базі біметалевих композицій. За основу беруть пружинну сталь, до якої за допомогою зварювання приєднують вузьку смугу швидкорізальної сталі. Після цього на фрезерному верстаті нарізають зуби. Таке поєднання вирішує відразу кілька завдань: підвищує опір втоми корпусу пилки; ріжуча кромка має оптимальну зносостійкість; зводиться до мінімуму опір різанню.

Для корпусу пилки підбирають ресорно-пружинні марки сталей: 45ХН2МФА, 50ХГФА. Ріжучу кромку пилки виготовляють зі швидкорізальних сталей марок 7Р1М5К5, 11Р2М10К8 (М42 або HSS Co8 (High Speed Steel)) і 12Р10М4К10 (М51 або HSS Co10).

Зварювання стрічкових пилок і ножів можливо проводити на професійному обладнанні компанії Ideal Werk, Німеччина.

Розглянуто обладнання для виготовлення таких стрічкових пилок і ножів останніх модифікацій серій BAS 320, і BAS 330, оснащених спеціальними притискними механізмами для кожного типу продукції, автоматичним багатоступеневим контролем відпалу зварного шва, гідравлічним ножем для видалення гребеня шва і системами позиціонування.

Аналіз проведений в роботі дозволяє знизити вартість виробництва інструменту, використовуючи дорогі ріжучі матеріали тільки там, де це необхідно. Покращити механічні властивості інструменту, поєднуючи твердість різальної частини з міцністю основи. Розширити спектр застосування інструментів, створюючи комбіновані вироби для різних типів обробки.

Ключові слова: інструмент, матеріал, сталь, зварювання, твердість, обладнання, відпал, швидкорізальна.