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Recycling possibilities for reducing waste from cutters on combined cutter-loaders and road builders

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Abstract

The objective of this study was to find opportunities for metal waste recycling in the process of rock breaking in mines A built-up cutter design for a combined cutter-loader and a recycling technique for a considerable portion of the deteriorated tool are suggested Industrial tests have proven the possibility of a ten-fold increase in the use of cutters on mining machines for coal rock mass destruction The proposed technique allows a four times reduction in metal consumption in the production and use of cutters and a reduction of the ultimate resulting waste by 80% This advanced technique could be transferred extensively into such industries as open-cast mining, repair of motor-roads, construction and agriculture

Keywords

Mine, mining machine, technique, cutter, recycling, waste, resource efficiency

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Introduction

Recycling techniques are becoming more and more widespread around the world owing to their obvious economic attractiveness, lower levels of waste production and improvement of the ecological situation in industrial areas Recycling includes the reuse of resources until complete exhaustion of their capacity before disposal The drive to reuse resources can be noted in the mining industry as well, particularly in mines. So, waste rock from mine workings is returned underground and used for stowing waste (Trubetskoy, 2011), water pumped from mine drainage shafts is purified and returned to the irrigation and dust suppression systems of mining machines (Marx et al , 2005), mine pipes are regularly turned around their longitudinal axis, which extends their service life by four times or more (Vaisberg et al., 2013)

One of the more resource-intensive mining techniques, until recently, has been the use of the cutting tools on mining machines. Modern cutter-loaders and heading machines in the slate, coal, gypsum, salt and ore, etc , mines of Russia, China, the United States and Australia, etc , are equipped with so-called tangential rotary cutters, capable of destroying rocks with a compressive strength of up to 80–100 MPa and an abrasivity of up to 15 mg

A mining machine with a swept operating member needs 28–42 cutters (models GPKS, KP-21 and KSP-35) and with two crowns it needs 90 (112) cutters (model P-110, depending on the version) Miners produced at Kopeysky Mashzavod Ural have several operating members of different designs with a total of about 150 cutters The design of a Sandvik MB600 mining machine provides for a bar cutting unit from 4 2 to 6 0 m wide with 160–210 cutters Cutter-loaders are, as a rule, equipped with two screw-type operating members with a total of 106–136 cutters

The special attention paid to machine cutters has evolved from their key role in the production process Mined rock-breaking with cutters is how the process line of underground coal output begins. The condition of the cutters determines the efficiency of the entire mine

The world's current leading manufacturers and suppliers of cutters for mines are companies such as Betek, Kennametal, Sandvik and Element Six. Russian coal mines use the cutters of both foreign and Russian producers JSC Kopeysky Mashzavod, Kuznetsky Mashinostroitelniy Zavod, Kirovograd Hard Alloys Plant, Gorniy Instrument and others The mining and technical conditions of coal output from deep formations become more complicated and the product quality of a number of vendors, which is not always consistent, creates a high demand by mines for rock cutting tools An average coal mine in Kuzbass consumes 10–20 thousand cutters annually When work is carried

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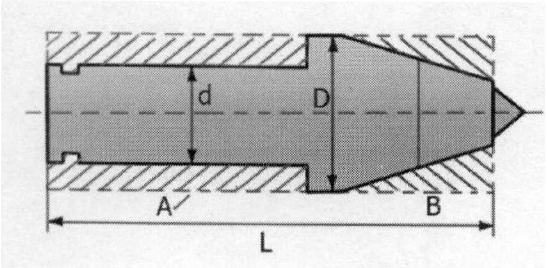

Figure 1. Metal waste calculation diagram for cutter manufacture

out in hard rock, cutter consumption increases steeply and can reach 250–300 pieces a day. The purchase of machine cutters is a significant cost item of mines, which tends to increase.

The main problem with the cutters used in mines is the single-cycle technique, which determines its high cost and waste production. The currently applied technique provides for cutter delivery to the mine face, where it is temporarily stored. Then the mining machine stops, and the required cutter is found and is mounted on the cutting body of the machine. Next, the cutter breaks the rock mass and gradually loses its weight and shape owing to abrasive wear. Finally, when the cutter reaches a critical condition, it is removed from the mining machine and discarded or (at best) taken to the surface as scrap metal. A study in Russian mines showed that the proportion of the remaining and almost unworn part of the cutter is 60–90% of the initial length and weight of the tool, which is very significant. This demonstrates the current high waste level and low resource efficiency of the cutter use process in mines.

Many research works of scientists from different countries are concerned with cutter improvement. There are many studies on the effect of cutter inclination on their ability to penetrate into the rock mass (Fu et al., 2015, Jonker et al., 2014). Dewangad and Chattopadhyaya (2016) presented the dependency of the amount of broken-down coal and cutter temperature on the cutting depth. The influence of the elemental composition of the tip material on its wear resistance properties when breaking rock and coal, as well as the degradation mechanism of tungsten-cobalt alloy at the contact point with the rock, are described in studies by Hall (2014) and Dewangad et al. (2015).

Chinakhov (2011) and Prokopenko et al. (2015a) suggest cutter head strengthening with additional armouring and steel body hardening by welding to prolong the tool life. The developed technical solutions for changing the geometry and shape of the head to increase the destructive capacity of the tool are presented in proceedings (Fader and Lammer, 2011; Greenspan et al., 2014; Sarwary and Hagan, 2015). Tompson and Tank (1990) and Liu et al. (2015) studied the impact of water supply in the breaking area on the efficiency of rock breaking.

Other researches (Bolobov et al. 2012, Khoreshok et al. 2012; Mamet'ev et al. 2015, Kolesnichenko et al. 2012) present test results of tangential rotary cutters operating on mining machines in mines in Kuzbass (Russia) and recommendations to improve their design. Advanced design of cutters with replaceable reinforcing cells, removable head, secured shank, etc., are offered in various scholarly proceedings (Bell, 2013, Bookhamer and Swope, 2014, Monyak et al., 2014, Parrott, 2014, Prokopenko et al., 2015b, 2016). Using ellipsoid cutter tips instead of conical ones is discussed by Khoreshok et al. (2013).

However, no effective solutions for reusing the spent tools and substantially reducing the amount of consumed cutters in mines have been found so far. The objective of this article is to examine the parameters of deteriorated tools and develop a new built-up cutter design for combined cutter-loaders with the aim of exploiting their reusability and improving resource-efficient mining technology.

Materials and methods

The study materials were the cutters of the continuous heading machines and cutter-loaders in the Kuzbass mines. The studies were conducted from 2008 to 2014. The working faces and stocks of 15 coal mines were surveyed in total. Products of both Russian and foreign machine-building plants were subjected to measurement and analysis. New and worn cutters were examined at the mine faces, as well as the used products stored in warehouses as scrap metal.

During cutting operations, metal wastes were accounted for using a diagram that indicates the areas where metal is removed from the incoming billet (Figure 1).

To solve the problem of the high waste level of rock-breaking tools, the authors suggested a cutter recycling technique for mining machines. This became possible thanks to the idea of reusing the main body of the cutter and replacing the worn part. The idea was implemented based on the solution of scientific optimisation problems for the parameters of replaceable and main parts of the cutter and the development of a reliable fastening method for tool components. As a result, a special cutter design with a built-up head was developed, so that the part of the head most subjected to wear became replaceable (Figure 2).

The efficiency of the technique was demonstrated in industrial tests arranged in the Kuzbass mine from 2012 to 2014 by making a conveyor belt entry of a 16.5-m^2 section through a layer with an average thickness of 1.03 m. The lithological hardnesses were as follows.

- Coal–f = 1–1.1 on the scale of Professor MM Protodyakonov
- Draw slate solids (sandstone up to 0.5 m thick) f = 4–6
- Main roof solids (light grey medium-grained sandstone 0.5–0.8 m thick)- f = 5.9–11.7.
- Soil solids (siltstone up to 0.3 m thick) f = 4.5–6 and sandstone layer up to 1 m thick, very hard f = 8–9

The suggested cutters with built-up heads were mounted on the operating member of the KSP-35 heading machine together with conventional cutters produced by Kennametal and Gorniy Instrument. The operating duration of the various cutting tools, their daily consumption, entry length and volume of broken rock mass were monitored. When the built-up cutters were worn, the

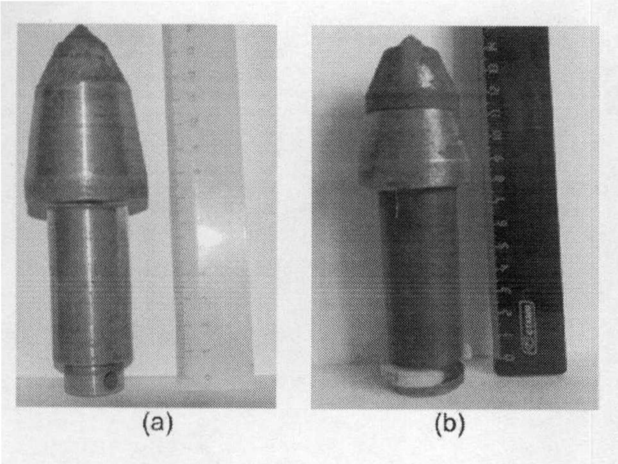

Figure 2. Cutter designs with (a) a single part and (b) built-up head

changeable heads were replaced, and operation of the holders was continued. A specially created commission of mine engineers and scientists visited the drill hole, examined the cutting body and assessed the wear rate of the cutters. The data was recorded in the observation log. The commission sent the worn cutters to scientists at the laboratory for study, where the cutters were weighed and measured, and the characteristics of the wear were assessed, along with the causes.

Results and discussion

One of the objectives of the study was to evaluate the level of metal losses in the manufacture of cutters and use of tools in mines. The following diagram (Figure 1) was used to evaluate metal losses when manufacturing a cutter of length L and diameter D.

Losses in zone A are generated when turning the cylindrical shank of diameter d and amount to about 20% of the blank bar weight. The results of the calculations show that, with the grinding on a lathe of a cylindrical shank with diameter d, the losses in area A are of the order of 20% of the mass of the incoming billet. The manufacture of the conical cutter head causes metal waste in zone B, which represents an additional 10%. Evaluation of the total waste level is shown in the example of cutter model RGP 32-70-85/16 for mining machine KSP-35 (Table 1).

The making of cutter model RGP 32-70-85/16 is accompanied by metal waste of 30% of the original blank. With an initial product mass of 1067 g, the mass of the material worn and removed from the cutter is 880–920 g. Because they go to waste, the total waste level rises to about 88%–90%, which makes cutter use one of the most wasteful processes in the mine. This is quality tool steel with a high processing level and high value that goes to waste.

The developed and proven cutter-recycling technique initially provided for the mounting of a replaceable head on the main one was by means of a threaded connection. Tests of such cutters in the mine were accompanied by the loss of replaceable head parts during one or two machine operating periods. It was then decided

Table 1. Level of metal waste in the cutter manufacture and use.

No.	Indicator	Mass (g)	Resulting waste (g)	Waste level (%)
1	Blank cutter	1524	457	30
2	Manufactured cutter	1067	–	–
3	Used cutter	880–920	880–920	58–60
	Total	1524	1337–1377	88–90

to attach the replaceable head using a spring half-ring placed in the shank groove.

Tests in the mines showed good results, the replaceable heads were used for several days. However, some of them were still lost. The solution was to mount the replaceable head by increasing the width and depth of the groove on the shank and by screwing the locking screw into it from the main head. This connection ensured reliable attachment of the replaceable head to the main head, free rotation of the replaceable head around the longitudinal axis, uniform wear and self-sharpening. Removable head losses were eliminated, they were then used up to the point of complete wear (Figure 3).

The head wear rate is influenced by the hardness and humidity of the broken rocks, strength of the cutter holder, armouring element design, armour sealing reliability, etc. Studies in the mine demonstrated that when coal cutting in the presence of 70% of the coal working in the form of sandstone with a hardness f = 7–8 using MM Protodyakonov's scale, the head wear rate may be characterised by the curves shown in Figure 3(c). Analysis of the graphs shows that under these conditions, the head can be operated for three shifts (or 18 hours), at which time it must be renewed.

The reliable cutter design made its continued operation possible. Two test pieces were installed in the second row on the cutting body of road header and were operated together with conventional cutters. When the replaceable heads were worn, they were replaced by new ones, and the cycle was repeated. The first cutting heads lasted 10 days. The production rate was 4–5 m per day. The daily output of conventional cutters produced by Kennametal and Gorniy Instrument was 10–20 pieces. The worn cutters were taken from the mine to the laboratory for study. Subsequently, new replacement heads were manufactured and mounted on the test cutters. The replacement heads were secured with locking screws on the side of the main heads. Thanks to the high degree of their heat treatment, the lifespan of the replacement heads averaged 50–60 production metres. The test results, published by Prokopenko and Ludzish (2014) and Prokopenko et al. (2015b) demonstrated that the cutters could stand nine operating cycles (Figure 4).

With timely replacement of the ninth head and prevention of holder deformation, the operation could be continued for 2–3 more cycles (according to the opinion of the testing commission).

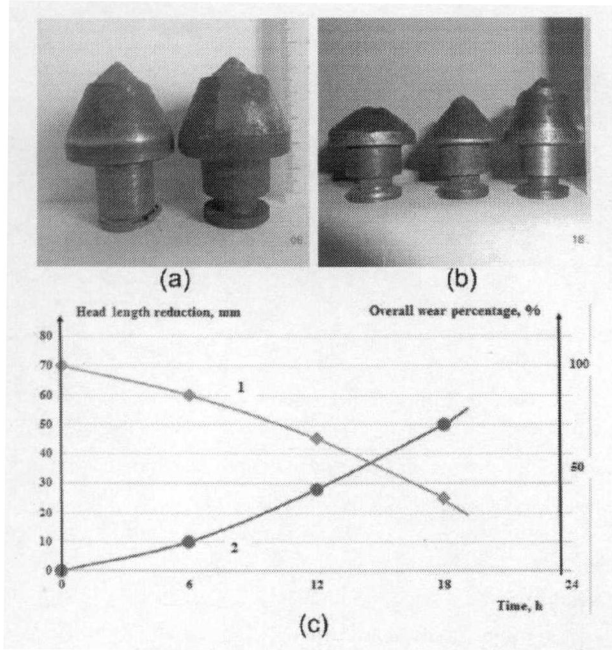

Figure 3. Replaceable head attachment design (a) design using a spring half-ring (left) and locking screw (right), (b) change in shape and size of replaceable cutter head in the course of its wear, (c) cutter head wear rate 1 = head length reduction, 2 = overall wear percentage

The results of industrial tests of the current and recycling techniques of cutter use in a KSP-35 mining machine are shown in Figure 5. The testing experience revealed that the use of a recyclable cutter weighing 1067 g and nine heads weighing 1935 g (215 g × 9 pcs) allowed for the replacement of 10 products of conventional design with a total weight of 10,670 g in a working mine. Calculations show that each set of the innovative cutting tool (cutter + 9 heads) reduces metal consumption in the rock-breaking process by 3.6 times and saves 7.6 kg of metal.

The overall efficiency (production + use) of the cutter recycling technique compared with the conventional single-cycle technique is presented in Table 2.

The recycling technique allows a three-fold reduction of metal consumption in the manufacture and operation of cutters for five cycles, and a four-fold reduction for 10 cycles with the use of the built-up tool. The metal saving in these cases is 5 and 11.5 kg, respectively. The metal waste weight after a ten-fold use of the suggested cutter is 2877–2977 g, which is 4.6 times less than the waste of ten conventional cutters.

With an account of the cost of metal and products at the end of 2015, a set of recyclable cutters with ten heads saves about 2500 roubles in comparison with the currently used cutting tool. The return on costs is 40% per set.

The mines of the Russian Federation, which output 100 million tonnes of coal annually, consume about 250–300 thousand pieces of tangential rotary cutters during the same period. These go to waste after a single use. Worn cutters need to be removed

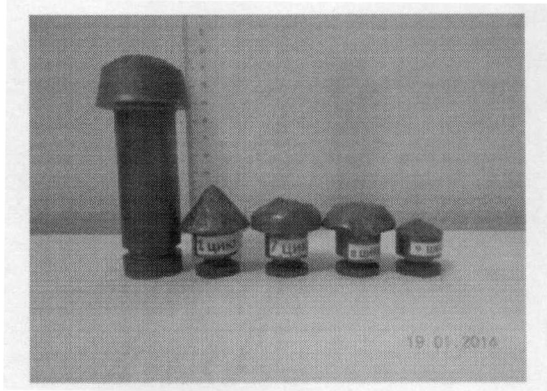

Figure 4. Built-up cutter after nine operating cycles

from the mine and taken to the store room, but workers, who do not want to bother with the dead weight, often neglect this. Miners often throw out worn cutters in the mine shaft, and they end up in commercial coal, contaminating it. Switching to the cutter recycling technique for coal and rock breaking can reduce the annual demand for metal from the current 250,000–300,000 kg to 70,000–75,000 kg. This means that annual metal waste and area for storing waste can be reduced by three times. Thus, metallurgical plants do not need to produce as much metal, polluting the environment in the process. Despite ongoing improvements in technologies, currently, metal smelting is a dirty process, as it is accompanied by significant emissions of pollutants into the atmosphere and water bodies and the use of land for storage. In addition, less ore has to be extracted for metal smelting. Metal waste in machine-building plants that manufacture cutters is reduced. Costs are cut, and benefits to the environment are observed throughout the full cycle of mining-machine-building and metallurgical production. The same significant reduction in metal consumption can be expected with the conversion of road maintenance machines to the cutter recycling technique. The cutting body of asphalt road recirculation machines are equipped with cutters of a similar design, which break the road surface during reconditioning work. In Russian roads, both domestic and foreign machines are used, mostly from the Wirtgen.

Active consumers of cutters similar to the mining variety are the open-pits using excavation machines of the class 'continuous surface miner'. They are produced by such well-known companies as Krupp, MAN Takraf, Sandvik, the Wirtgen Group and Voest-Alpine. Machines from these firms have cutting rotors or milling cutters equipped with carbide-tipped tools in numbers of 200 pieces and more, which are able to break rock up to 100–120 MPa hard, both in layers and in benches 5–10 m high. Such machines are used all over the world for mining coal layers, limestone, gypsum, phosphates, iron ore, bauxites, kimberlites and other minerals. The cutters of milling machines are large in size and weight, which is reflected in their high cost for a single-cycle use. The traditional cutter use technique results in a large waste mass of cutters, often used for the large volumes of rock crushing in quarries.

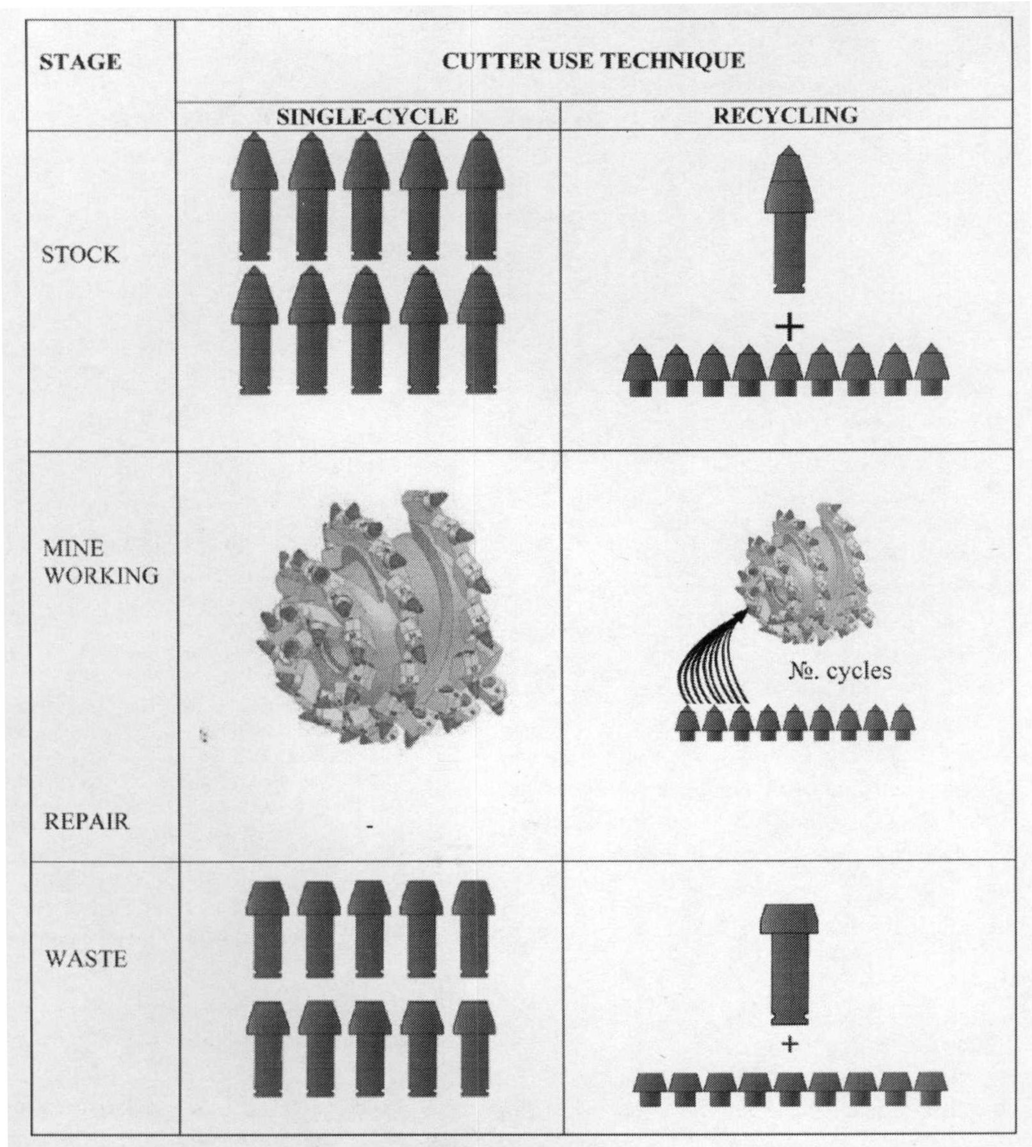

Figure 5. The test results for single-cycle and cutter recycling techniques in a mining machine

Table 2. Traditional vs. cutter recycling techniques.

No.	Type of product and indicator	Metal consumption (g) for technique:		
		Single-cycle	Recycling:	
			after 5 cycles	after 10 cycles
1	Blank traditional cutter	1524	7620	15,240
	–waste	1337–1377	6685–6885	13,370–13,770
2	Blank built-up cutter	1274	—	—
	Replaceable head	250	1000	2250
	Cutter + head	1524	2524	3774
	Cutter waste	617–627	2077–2127	2877–2977
	–including head waste	160–170	800–850	1600–1700
4	Metal saving	—	5096	11,466
5	Decrease in metal consumption, times	—	3.0	4.0

In addition to the mining and road industries, the proposed built-up reusable cutters can be applied on chain-and-disc trench diggers used for laying cables and pipes, as well as on agricultural machinery The proposed recycling technique can become widespread owing to the active use of tangential rotary cutters on machines used for military applications, main pipe work, site landscaping and farms. Furthermore, it should be possible to return the cutter waste gathered from mine warehouses, open pits, construction companies, etc., back into the production process. Only the moderately worn waste would need to be selected, modified and equipped with replaceable heads. This leads to a reduction in the need for metal to produce cutters and a drop in the environmental load in the areas where they are produced and used.

Conclusion

The cutter use technique applied to mining, quarry, road and excavating machines in Russia, China, Germany, the United States, Australia and other countries is characterised by low resource efficiency owing to the single use of the cutting tool. As a result, up to 90% of the metal consumed in manufacturing the cutters goes to waste within a very short time.

There are 28–42 cutters on the cutting body of a small mining combine, and on large and powerful combines there are as many as 160–210 pieces, depending on the modifications. Each year, the average Russian coal mine uses 10–20 thousand cutters. When carrying out excavations in strong rocks, the consumption of cutters sharply increases and can reach 250–300 pieces per day. Since they are designed for one-time use, worn cutters end up in mining waste. Over the year, 10–20 tonnes of metal waste that is unsuitable for use accumulates in the mine. Because of high transportation costs, this waste is shipped out for melting once or twice a year. Discarded cutters end up in storage for an extended period, occupying space, growing rustier and losing commercial value.

The performed studies found an opportunity and developed a reliable cutter design that allows multiple uses of its main part by replacing worn heads. The optimum parameters and options for attaching the replaceable head to the cutting tool were determined. Industrial tests in the Kuzbass mine showed the possibility of cutter operation on a heading machine of up to 9–12 cycles.

The recycling technique allows a three-fold reduction in metal consumption during the manufacture and operation of cutters in five cycles, and a four-fold reduction in 10 cycles using the built-up tool. The production and use of a recyclable cutter that replaces the ten traditional cutters saves up to 11 kg of high-quality metal. A five-fold reduction in the mass of generated waste can be achieved.

The recycling of cutters on mining machines in Russia can reduce the annual demand for metal used in coal and rock breaking from the current 250,000–300,000 kg to 70,000–75,000 kg. The amount of metal cutters wasted in the mines of Russia can be reduced annually from 250 to 70 tonnes. This entails a decrease in the production of rod metal in hazardous metallurgical plants, and a reduction in the negative impact on the environment.

The same significant reduction in metal consumption can be expected with application of the cutter recycling technique on milling machines in quarries, road repairs, trench-digging, laying of various communications networks, site landscaping, etc.

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