Archives of Materials Science and Engineering
Volume 94
Issue 2
December 2018
Pages 49-54
International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Substantiation of the choice of the cutter material and method of its hardening, working under the action of friction and cyclic loading

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ABSTRACT

Purpose: The main problem with the use of rescue instruments during emergency response is the low strength of the tool's cutting edge. The consequence of this is the low efficiency of rescue operations. The purpose of this study is to substantiate experimentally the choice of material for the tool's cutting edge and the method of surfacing it on the cutter of a hydraulic tool, operating under the simultaneous influence of friction and cyclic loading.

Design/methodology/approach: The choice of material was carried out by the way of analytical analysis with subsequent experimental verification. For this purpose, specially made samples of cutters from various grades of alloyed steel were used. With these cutters the steel rod Ø 12 mm made of St3 steel was cut; the number of cutting cycles preceding blunting or destruction of the cutting edge of the tool was counted. Analytical study of the possibility of cutter's surface hardening by fusing the cutting edge onto it was carried out by the way of analyzing scientific research in the area of improving the technical characteristics of a mechanized hydraulic tool.

Findings: It has been experimentally established that Steel 30HGT gives the greatest number of working cycles before blunting, while steels of the manufacturer (Steel 65G and Steel 12M) are destroyed in 180 and 200 working cycles, respectively. Other steels are not destroyed, but can stand fewer number of cutting cycles. To reduce the cost and increase the efficiency of rescue operations, it is proposed to perform surface hardening of the tool cutter by fusing the cutting edge made of Steel 30 HGT steel (analogs: in Germany – 30MnCrTi; in the Czech Republic – 14231). Analytical research has shown that manual arc welding as a method of welding metals is widely tested, reliably reproducible, allows for surfacing in any conditions outside the fabrication facility and is carried out with non-bulky equipment. This will increase the life of the hydraulic rescue tool.

Research limitations/implications: The study was conducted for steels that meet the requirements of national standards.

Practical implications: Equipping rescue workers with a mechanized tool that has been upgraded by the proposed method improves the efficiency of rescue operations in emergency situations.

Originality/value: It is proposed to increase the strength and reliability of a mechanized tool for rescue operations. For the first time, an attempt to substantiate the choice of method for hardening the cutting edge of an instrument by applying reliably reproducible technologies was made.

Keywords: Steel cutter, Hardening, Impact of friction and cyclic loads

Reference to this paper should be given in the following way:

D. Sokolov, V. Sobyna, S. Vambol, V. Vambol, Substantiation of the choice of the cutter material and method of its hardening, working under the action of friction and cyclic loading, Archives of Materials Science and Engineering 94/2 (2018) 49-54.

METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

Technogenic activity leads to an increase in the risk of emergency situations of man-made [1-5] and natural character. Therefore, there is a need to study the ways of assessing the readiness of civil protection units to act in emergency situations [6-8]. When applying a rescue instrument during emergency response, it is important to follow the established rules and follow the operation manual for the tool.

The rescue instrument is designed for rescue and other urgent work, especially when performing tasks assigned to the rescue service. The rescue instrument includes mechanisms and devices that are used in accordance with their technical capabilities to improve the efficiency of the work. Mechanized rescue instrument is a means of small mechanization. In these tools, the movement of the working body is performed by engine, or the primary drive, while the auxiliary movements and control over the working body are carried out manually. These devices and mechanisms make it possible to perform various types of work using the strength of a human's muscles. The rescue instrument increases the productivity of manual labor by 5-10 times (compared to labor without mechanization), significantly improves the quality of technological operations and reduces the time of their completion, which is very important during urgent rescue operations.

Most often, 65G steel hydraulic cutters are used for rescue operations. Their advantages are: high power with low mass, mobility in work and the possibility of their using in an explosive environment. Carbon tool steels are known to be the cheapest. As a rule, they are used for the manufacture of cutting low-responsible instruments operating at low cutting speeds. Parts made of 65G steel are used in conditions of high wear resistance, but without impact loads. As a result, rapid blunting or destruction of the cutting edge of the tool occurs. This not only leads to the accumulation of waste [9,10], but also significantly reduces the effectiveness of rescue work. Alloying tool steels for cutting tools reduces the disadvantages of carbon steels, but increases their cost significantly. Therefore, there is a need to search for ways to increase the cutter's service life for improving the efficiency of rescue operations.

The manufacture of cutters made entirely of alloyed steels is not economically viable because of the relatively high cost of such steels. In this regard, the creation of parts from low-carbon low-alloy steels that have coatings from steels with enhanced performance characteristics is a promising task of modern production [11]. Such coatings can be used both to increase the resource of new parts, and for the renovation of units with a simultaneous increase in their resource to initial or higher level [12]. One of the ways to restore and strengthen the cutting edge of a hydraulic tool is surfacing. To reduce the cost of a hydraulic tool, it is advisable to make a cutter from inexpensive carbon steel, and weld the cutting edge from alloyed or high-alloyed steel to it, since such steels have higher strength characteristics. Thus, in order to improve the technical characteristics of the cutting tool and increase its efficiency for rescue operations in emergency situations, this study proposes:

- experimental substantiation of the choice of alloyed steel for the manufacture of the cutter's cutting edge, since the manufacture of the entire cutter from alloyed steel will significantly increase the cost of the tool;
- an analytical study of the possibility of surface hardening of the instrument's cutter by fusing the cutting edge on it.

In Figure 1 a sample hydraulic tool's cutter is shown.

In this regard, the purpose of this study is to experimentally substantiate the choice of material for the cutting edge of the cutter and the method of its surfacing on the cutter of a hydraulic tool, whose operation is carried out under the simultaneous influence of friction and cyclic loading.

Fig. 1. Sample hydraulic tool's cutter

2. Materials and methods of investigations

Experimental substantiation of the choice of alloyed steel for the manufacture of the cutting edge of the instrument's cutter's was carried out as follows. Samples of cutters from various grades of alloyed steel were specially made. With these experimental cutters the steel rod Ø 12 mm made of St3 steel was cut and the number of cutting cycles preceding blunting or destruction of the cutting edge of the tool was counted. For the study a set of mechanized hydraulic rescue tools was used (see Figs. 2-5).

Fig. 2. Hand pumping station HC-35.8

Fig. 3. Hydraulic cutting pliers

Fig. 4. Cable chopping knife

Fig. 5. Nut splitter

The hand pumping station is designed to deliver a lubricant under pressure to a hydraulic hand tool that does not have its own input. For specification of the pump station HC-35.8 see Table 1.

Hydraulic cutting pliers are designed for cutting metal rods, profiles and thin-walled pipes. For specification of hydraulic cutting pliers see Table 2.

The cable chopping knife is designed for cutting cable with aluminum or copper cores including armored and multiple core wires at voltage up to 10 kV, by puncturing it in diameter with the closing cores of all the phases between them and to the ground. For specification of the cable chopping knife see Table 3.

Table 1.
Pumping station HC-35.8 specification

Operating pressure, kg/cm^2	350
Force on the handle, kg/cm^2	20
Volume of power fluid, l	2.5
Overall dimensions, mm	222 × 153 × 501
Weight, kg	8.9

Table 2.
Hydraulic cutting pliers specification

Applied force, kg/cm^2	6
Diameter of the rod being cut, mm	12
Knife opening, mm	120
Overall dimensions, mm	190 × 172 × 440
Weight, kg	13

Table 3.
Cable chopping knife specification

Cutting force, kg/cm^2	4
Diameter of the rod being cut, mm	60
Overall dimensions, mm	179 × 80 × 137
Rated voltage, kV	10
Weight, kg	7.1

Analytical study of the possibility of cutter's surface hardening by fusing the cutting edge onto it was carried out by the way of analyzing scientific research in the area of improving the technical characteristics of a mechanized hydraulic tool.

3. Results of investigation and discussion of them

The numerical values of the results of an experimental study of the instrument's cutting edge are shown in Table 4. For a comparative analysis of performance potentials of the cutter made of manufacturer's steel and experimental cutters of other steel grades see Figures 6 and 7.

Thus, it may be concluded that the use of alloyed steels for the manufacture of the cutter's cutting edge increases the service life of the instrument. For example, Steel 30HGT provides the greatest number of working cycles preceding bluntness, while manufacturer's Steel 65G and Steel 12M become destroyed in 180 and 200 working cycles, respectively. Other steels are not destroyed, but are suitable for fewer cutting cycles.

Material hardness is connected with a number of its mechanical and physical properties, including dislocation density at low-angle boundaries [13,14]. In paper [15], the authors proposed using the indentation method on several scale levels for the strain hardening of heat-resistant steel. And this method is effective at the stage of creating a tool in an industrial environment, but not in the conditions of eliminating the consequences of an emergency.

Table 4.
Test results

No.	Steel grade	The average number of working cycles before blunting	The average number of working cycles before destruction
1	Steel 65G (GOST 2053-83) (manufacturer's cutter)	68	180
2	Steel 18HGT (GOST 4543-81)	127	no destruction
3	Steel 30 HGT	222	no destruction
4	Steel 12M	90	200
5	Steel 12HM	111	no destruction
6	Steel 15HM	123	no destruction

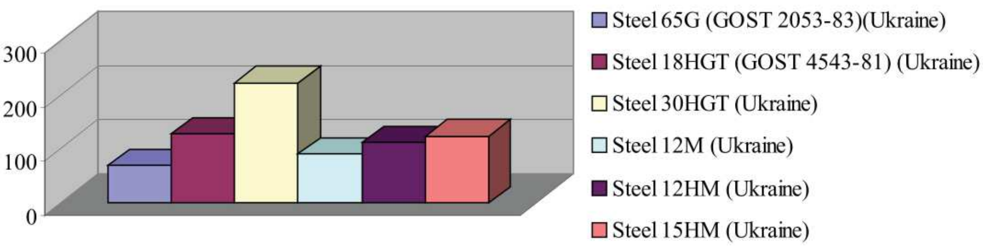

Fig. 6. Comparative analysis of the average number of operation cycles of the tested cutters preceding blunting of the cutting edge, where 65G Steel (GOST 2053-83) is the factory cutter; other types of steel – steel of experimental samples

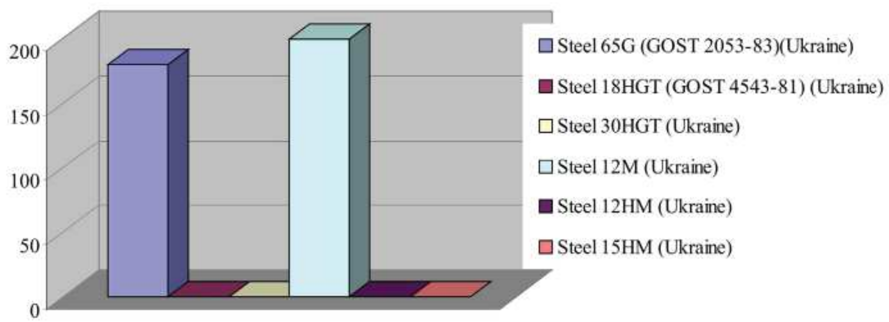

Fig. 7. Comparative analysis of the average number of operation cycles of the tested cutters preceding destruction of the cutting edge, where 65G Steel (GOST 2053-83) is the factory cutter; other types of steel – steel of experimental samples

Increasing the reliability of instrument steel (without alloying additives) is possible by single-frequency induction hardening [16]. The authors obtained consistent patterns of the influence of induction voltage on the microstructure of the processed elements in the process of hardening, however, such studies were carried out to harden machine parts, for example, gears. It is promising to increase the wear resistance of structural steel by creating hybrid surface layers created by controlled gas nitriding and laser modification [17]. The authors found that the forming of hybrid layers mainly influenced the tribological properties. Laser-thermally treated nitrided layers were characterized by increased wear resistance as compared to a single gas-nitrated layer. At the same time, the economic efficiency of such an improvement in the properties of steel has been proven on a number of successful examples. However, the properties of the materials obtained are studied not sufficiently [11] and do not allow predicting the results of the use of such material, especially in emergency situations. Improving the quality of the surface of a material by nanostructuring the surface in the process of electrochemical etching is acceptable only for parts used in electronics [18]. Comparison of mechanical, physical and microstructural properties of cutting tools obtained by various sintering methods was carried out in [19]. However, the analysis was carried out for a diamond tool that operates under the influence of other loads. Analysis of the influence of the main chemical elements on the properties of carbon steels, of which the cutting tools of a hydraulic tool are currently manufactured, showed that it is possible to increase the efficiency and quality of the hydraulic tool’s cutting edge of a by electromagnetic welding. The process of electromagnetic surfacing provides for the formation of thin layers of protective coatings, with a thickness of 0.1...0.6 mm per side, as well as high bonding strength of the deposited coating with the substrate with minimal heat generation and melting of the substrate material. However, this method may be implemented only in industrial environments.

The most desirable is the method of surfacing, which is convenient to use outside the production facilities, directly on the site of emergency response. That is, the equipment for surfacing the cutting edge on the cutter should be small and not heavy enough to move it without additional mechanization. Since Steel 30HGT provides the greatest number of working cycles preceding blunting (analogs: in Germany – 30MnCrTi; in the Czech Republic – 14231), it is important to take into account the distinctive properties of this particular steel when choosing a method of surfacing. According to the study [20], this steel has significant limitations on weldability. For this, manual arc welding and resistance spot welding are most suitable, heating and subsequent heat treatment [20] are recommended. Considering the fact that manual arc welding as a method of metal surfacing is widely tested, reliably reproducible, allows for surfacing in any conditions outside the fabrication facility and is carried out with non-bulky equipment [21,22], it is proposed to use manual arc welding. This will increase the life of the hydraulic rescue tools.

4. Conclusions

1. When conducting rescue operations with the use of hydraulic rescue tools, under the action of friction and cyclic loading, the cutting edge of the tool’s cutter is rapidly blunt or destroyed. This reduces the effectiveness of rescue work. This is explained by the fact that the cutter is made of Steel 65G, which is applicable for work in conditions of high wear resistance, but without shock loads.
2. It was established experimentally that the greatest number of working cycles preceding blunting is given by Steel 30HGT, while the manufacturer's steels, Steel 65G and Steel 12M, are destroyed after 180 and 200 working cycles, respectively. Other steels are not destroyed, but are suitable for fewer cutting cycles.
3. To reduce the cost and increase the efficiency of rescue operations, it is proposed to perform surface hardening of the tool’s cutter by fusing the steel 30HGT (analogues: in Germany – 30MnCrTi; in the Czech Republic – 14231) cutting edge onto it. Analytical research has shown that manual arc welding as a method of welding metals is widely tested, reliably reproducible, allows for surfacing in any conditions outside the fabrication facility and is carried out with non-bulky equipment.

Acknowledgements

The authors' team is grateful to the management of the National University of Civil Defense of Ukraine for the opportunity to conduct scientific research in the field of increase the effectiveness of cutting tools for rescue work.

Additional information

The work was carried out within the framework of scientific studies on the subjects of the Department of logistics and technical support of rescue operations, Applied Mechanics and Environmental Technologies Department of National University of Civil Defence of Ukraine.

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