New method for strengthening surfaces of heat treated steel parts

V Tarelnyk¹, V Martsynkovskyy¹, O Gaponova², Ie Konoplianchenko¹, A Belous¹, V Gerasimenko¹, M Zakharov³

¹ Sumy National Agrarian University, 160 G. Kondrateva Str., 40021, Sumy, Ukraine
² Sumy State University, Sumy, 2 Rymskogo-Korsakova st., 40007, Sumy, Ukraine
³ Regional Institute of Postgraduate Education, 5 Rymskogo-Korsakova st., 40007, Sumy, Ukraine

E-mail: tarelnik@i.ua

Abstract. There is described a method for strengthening surfaces of heat-treated steel parts, which includes technological procedures of carburizing by electroerosive alloying process (CEEA) and also nitriding processes. The nitriding process is simultaneously carried out with the CEEA operation for a period of time sufficient to saturate the surface layer of a part with nitrogen to the depth of a heat-affected zone. Thus, the process of so-called nitro-carburizing process performed by the EEL method (NCEEA) takes place. To reduce a surface roughness, the NCEEA process is carried out in at least two stages, with a decreasing a discharge energy value at each subsequent stage.

1. Introduction

One of the main indicators of machines quality is their reliability. The most common cause of machine failures is recognized not a breakdown, but wear and damage of working surfaces of their parts and operating units. As a rule, destruction of a part begins with destruction of its surfaces.

The use of strengthening and protective coatings significantly improves the quality of products in machine building, provides reliable operation of units and parts on severe operating conditions for equipment, allows reducing material and energy costs for a machine operation, and also lowering consumption of expensive construction materials. Therefore, studies aimed at creating new and improving of the existing protective technologies are of current interest and well-timed.

From the technical point of view, one of the simplest methods for strengthening parts is a surface electro-erosive alloying (EEA) method. It is characterized by such advantages as a local impact, low energy consumption, lack of volumetric heating of material, etc. While using the EEA method, it is possible to increase hardness of a metal surface by applying a material of higher hardness onto the same or providing a diffusion introduction of necessary chemical elements into a surface layer from the environment or from an anode material [1].

However, the electro-erosive alloying (EEA) of heat-treated parts subjected to high specific loads, for example the parts of dies, rolling mill shafts and other similar items does not always bring a desired result. The cause of some items failures is that after processing with the use of the EEA method, under a layer of increased hardness, there is appeared a tempering zone, that is, a zone of reduced hardness. This results in a so-called breakdown of the strengthened layer and, as a...
consequence, in an intensive wear of the item. In this case, processing by the EEA method might be harmful, especially if the permissible wear of the alloyed surface exceeds the thickness of the layer of increased hardness.

According to method [2], carrying out the process with the use of ionic nitriding (IN) method (either before the EEA method or after the same) provides eliminating of the zones of reduced hardness when using electrodes made of pure, hard, and wear resistant metals. In addition, a smooth change in the hardness of the strengthened layer and also increasing the total depth of the zone of the increased hardness are observed.

The disadvantage of this method is the low productivity of the process, since even with increasing productivity up to 0.4 cm²/min, undesirable roughness and continuity of the surface at the EEA process by chromium, tungsten and T15K6 hard alloy are, respectively, 4.6; 7.8 and 5.4 μm; and 90; 55 and 80%, which fact significantly narrows the scope of the method application for strengthening machine parts.

There is known a method of carburizing steel parts with the use of the electro-erosive alloying (CEEA) [3], which has a number of advantages, the main of which are: providing 100% continuity for the strengthened surface layer, increasing the hardness of the surface layer of the part due to diffusion-quenching processes, alloying can be carried out in strictly specified areas with no protection of the rest of the surface of the part, lack of volumetric heating of the part and warpage associated therewith; simplicity of the technology application, flexible binding to existing equipment; strengthening process does not require special preparation and high qualification of the worker.

In this method, there is used the discharge energy of 0.036 to 6.8 J and the productivity of 1.0 to 0.2 cm²/min.

At carburizing a steel part with the use of the EEA method, the thickness of the strengthened layer depends on the discharge energy and alloying period of time (the process productivity). Increasing the values of discharge energy and alloying period of time results in increasing the thickness of the strengthened layer. And in doing so, there is increased the value of a surface roughness. Thus, in the case of processing an item made of medium-carbon alloy steel 40 Ch (Ra = 0.5 mkm) with the use of the EEA method performed by a carbon electrode on the condition of the productivity of 0.2 cm²/min and the discharge energy of 6.8 J, the thickness of the increased hardness layer is more than 1.15 mm. The surface roughness corresponds to Ra = 11.7-14.0 μm.

There is also known the CEEA method, which is used to reduce the surface roughness of machine parts and, therefore, to expand the field of application thereof. This method is characterized by the fact that the CEEA process is carried out in stages with reducing the value of discharge energy at each subsequent stage [4].

The known method uses the values of discharge energy of 0.036 to 6.8 J and productivity of 14.0 to 2.0 cm²/min.

Despite above mentioned obvious advantages, the main one of which is a decrease in the surface roughness level of machine parts while maintaining the proper quality of the surface layer (the absence of microcracks, the availability of a layer of increased hardness, 100% continuity, etc.), this method has a number of drawbacks. First of all, this is a decrease in the microhardness of the surface layer as a result of tempering at a repeated (stage-by-stage) surface treatment by a graphite electrode, but with the use of a lower value of the discharge energy. In addition, along with the decrease in the microhardness of the surface, there is also decreased the depth of the layer having increased hardness.

In order to eliminate the above mentioned drawbacks, there has been developed a method for strengthening surfaces of heat-treated steel parts [5], which, like the methods known from the prior art, comprises both the operation performed by the EEA method and the operation performed by the IN method, wherein the IN operation has been being performed either before or after the EEA operation for a period of time that is sufficient for saturating the surface layer of the part with nitrogen to the depth of the thermal influence zone. The EEA operation is performed with a graphite electrode under condition characterized by the values of discharge energy of 0.1 to 6.8 J and productivity of 0.2 to 4.0 cm²/min. At the same time, the CEEA process is performed in at least two stages with decreasing
the value of discharge energy at each subsequent stage, the first stage of alloying by a graphite electrode being performed at the values of discharge energy of 0.1 to 6.4 J and productivity of 0.2 to 4.0 cm$^3$/min, and the second one - at the values of discharge energy of 0.1 to 2.83 J and productivity of 0.2 to 2.0 cm$^3$/min.

In this case, the CEEA stage by stage process performed before the IN process results in decreasing the microhardness in the heat-affected zone (i.e., a zone of reduced hardness can be formed under the layer of increased hardness), and the CEEA process performed after the IN process for a period of time sufficient to saturate the surface layer of the part with nitrogen to the depth of the thermal zone influence results in eliminating the hardness failure.

The same results can be achieved if the IN process has been being conducted before the CEEA process for a period of time sufficient to saturate the surface layer of the part with nitrogen to the depth of the zone of thermal influence. And to reduce the surface roughness, the CEEA process should be carried out in stages, while reducing the value of discharge energy at each subsequent stage. In this case, the hardness in the zone of a thermal influence does not decrease, because the properties of the nitrided surface do not practically change at repeated heating up to 500-600 °C, while at heating a carburized and strengthened surface to 225-275 °C, its hardness has been decreasing.

At the use of the CEEA method for processing a steel nitrided surface, there is occurred a process similar to the process of so-called nitrocarburization, only in this case, the processes of saturations of the surface with nitrogen and carbon proceed alternately, in comparison to the traditional nitrocarburization method whereat the above mentioned saturation processes have been taking place simultaneously.

Despite a number of positive results presented above, the present method is not devoid of shortcomings. They are as follows: first of all, it is a long duration of the IN process (up to 24 hours), high costs of both electricity and required reagents, manufacturing of a witness sample to monitor the results of the process of strengthening, and the need to protect separate areas of a part surface, for example threads, from strengthening. Consequently, the technical problem of improving the quality of heat-treated parts has not lost its relevance.

To overcome the above said drawbacks, there has been developed a method for strengthening the surfaces of heat-treated steel parts, which, like the methods known from the prior art, includes the CEEA process, but which is significantly different in that nitrogen is supplied to the alloying zone. In this case, two processes, namely, the CEEA process and nitriding one have been taking place simultaneously. Such a method is essentially a method of nitrocarburizing by the EEA method (NCEEAA).

Thus, the purpose of this work is to improve the technology of strengthening heat-treated parts at the expense of combining the methods of CEEA and nitriding by carrying out the EEA process with a graphite electrode in the environment of nitrogen.

2. Methodology and consideration of results
To study the processes of carburization and nitrocarburization by the EEA method, there were used special samples made of 40 Ch steel, which were heat-treated similarly to the method disclosed in publication [5] to obtain the value of hardness of 3900-4000 MPa. The samples were made in the form of coils consisting of two disks, 50 mm in diameter and 10 mm in width, connected by a spacer of 15 mm in diameter, which has two technological sections of the same diameter, Figure 1. The surface of the disks was ground to obtain Ra = 0.5 μm.
The CEEA and NCEEA processes were automatically carried out using the unit of EIL-8A model. Table 1 shows the main modes of its operation, as well as the recommended period of time for alloying 1 cm$^2$ of a part surface (the EEA process productivity). For a storage capacitor capacitances: C = 20 $\mu$F and C = 300 $\mu$F, the unit had 8 operating modes.

**Table 1. Operating Modes for the Unit of EIL-8A model.**

| Mode Number | EEA Process Productivity cm$^2$/min | Discharge Energy W, J |
|-------------|-------------------------------------|-----------------------|
|             | C=20 $\mu$F  | C=300 $\mu$F  | C=20 $\mu$F  | C=300 $\mu$F  |
| 1           | 0.14-0.13    | 0.25-0.20    | 0.01         | 0.14         |
| 2           | 0.14-0.13    | 0.33-0.25    | 0.014        | 0.22         |
| 3           | 0.17-0.14    | 0.33-0.25    | 0.02         | 0.28         |
| 4           | 0.20-0.17    | 0.50-0.33    | 0.024        | 0.35         |
| 5           | 0.25-0.20    | 1.0-0.50     | 0.03         | 0.42         |
| 6           | 0.25-0.20    | 1.0-0.67     | 0.034        | 0.49         |
| 7           | 0.33-0.25    | 2.0-1.0      | 0.038        | 0.56         |
| 8           | 0.33-0.25    | 2.0-1.0      | 0.043        | 0.63         |

The samples were fixed in the lathe chuck, and thereafter they were processed applying the following methods:

- The CEEA method by stage-by-stage alloying with the graphite electrode of EG-4 (OST 229-83) grade at the discharge energy of 0.42 J (stage 1) and 0.14 J (stage 2), and at the productivity of 0.4 and 0.2 cm$^2$/min, respectively;
- The NCEEA method by stage-by-stage alloying with the graphite electrode of EG-4 (OST 229-83) grade at the discharge energy of 0.42 J (stage 1) and 0.14 J (stage 2), and at the productivity of 0.4 and 0.2 cm$^2$/min, respectively;
- The method of nitrocarburization is carried out at the expense of using a device that is attached to the vibrator of the EEA unit (Figure 2).

Due to the fact that at the NCEEA process, there is occurred cooling of the part portion being alloyed with a nitrogen stream, the productivity at the NCEEA process is twice reduced at the both stages, which fact doubles the process time for nitrocarburization.

The strengthened samples were cut to obtain the segments intended for preparing thin sections. The thin sections were examined on an optical microscope Neofot-2, whereon, there was estimated the quality of the layer, its continuity, thickness and structure of the under layer zones, namely, the diffusion zone and the thermally influenced zone. Simultaneously, there was carried out a durametric analysis to evaluate the distribution of microhardness in the surface layer and along the depth of a thin section starting from the surface.
Figure 2. Device for supplying gas to the alloying zone: 1 – vibrator; 2 - mandrel for gas supply; 3 - gas inlet fitting; 4 – electrode; 5 – joint for connecting the vibrator to the EEA generator.

The microhardness measurements were performed with the use of the RMT-3 microhardnessmeter by pressing a diamond pyramid with a load of 0.05 N.

At all the stages of the process, the surface roughness was measured on the profilograph-profilometer of mod. 201 and of Caliber plant production.

Table 1 shows the microhardness distribution in the surface layer of the 40Ch steel samples having been heat-treated for hardness of 3900–4000 MPa and strengthened by various methods, and also the results of the influence of those strengthening methods on the roughness of the strengthened surface layer being formed.

Table 2. Results of processing the 40Ch Steel Samples surface layers by the CEEA and NCEEA methods.

| Method of Strengthening | Microhardness, MPa (Measuring Step ~ 30 μm) | Ra, μm |
|-------------------------|--------------------------------------------|--------|
| CEEA                    | 7010 3800 4300 4100 3900                  | 0,8    |
| NCEEA                   | 10500 6200 5300 4300 4000                  | 0,7    |

Figure 3 shows the microstructures of the surface layer of 40Ch steel and the microhardness distribution on the depth of the layer during carburization and nitrocarburization by the EEL method.
Analysis of Table 2 and Figure 3 shows that at the CEEL process of the 40Ch steel samples, under a layer of increased hardness, a tempering zone is located ("hardness dip"). In this case, this zone is located at the depth of ≈ 60 - 70 μm and is 3800 MPa.

Having been carried out on the above mentioned conditions, the NCEEA process eliminates the characteristic "hardness dip", with a general increase and a gradual decrease of the values of hardness in the transition zone. The surface roughness reduction at the NCEEA process is explained by the protection of the alloying zone with a flow of nitrogen from the ambient air (oxidizing) environment.

3. Conclusions
1. It has been stated that on strengthening heat-treated parts, the EEA process of the surface layer by carbon should be combined with nitriding, and in order to reduce the surface roughness, the NCEEA should be carried out in stages with reducing the discharge energy at each stage.

2. It was determined that the greatest microhardness (10500 MPa), the depth of the zone of increased hardness (120 μm), and the lower roughness (Ra = 0.7 μm) are recorded at the NCESEA process.
References

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