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IMPACT OF TOOL MAGNETIZATION ON CHANGES IN THE SURFACE LAYER OF FORGING TOOLS

The paper presents a description of the phenomena occurring on the surface of the forging dies. A detailed analysis was made of 24 pre-forging dies due to the most intensive wear in this operation. To compare the results, new tools were also analysed. The research described in the study showed that the most dangerous factor for the hot forging process analysed is thermal-mechanical fatigue, which causes small cracks, which in turn quickly leads to the formation of a crack network on the entire contact surface of the tool with forged material. The second phenomenon is the tempering of the surface of the material for a long-term temperature effect. The presence of hard iron oxides in the form of scale from forging material is the accompanying phenomenon that intensifies the processes of tool wear. The paper presents the results of the analysis of the presence of residual magnetic field for forging tools and the results of laboratory tests of wear processes of tool steels for hot work in the presence of a magnetic field and in the presence of scale.

Keywords: hot die forging, wear mechanism, magnetic field, durability

1. Introduction

The issue of wear of tools in hot forging processes is widely described in the world literature. Unfortunately, there is very little information, test results and guidelines for magnetizing tools and the effect of magnetization on the process of surface layer degradation.

The most frequent mechanisms of wear of forging tools described in the literature are [1-6]:

- thermal fatigue,
- abrasive wear,
- mechanical fatigue,
- tempering of the surface layer of tools during work.

The description of these phenomena at the engineering level is quite difficult due to the impact of shaping forces, variable temperature fields (gradients), variable pressures and others. In addition, the previously described [7-8] presence of scale and the presence of residual magnetic field can intensify the wear processes of forging tools. Forging tools are made of steel for hot work. The most common types of materials are: 1.2343, 12344, 1.2713, 1.2999 and others. These steels must be resistant to the phenomena described above, especially at elevated temperatures.

2. Description of the actual working conditions of forging tools

The analysis of production processes took place in the matrix forge. The forgings most often made in this forge are for the automotive and agricultural industry and pressure fittings - joints, flanges, etc. Among the many factors characterizing forging processes were selected those that are rarely described but have a significant and direct impact on changes in properties in the surface layer of the material.

This factor is the temperature of the forging material, the presence of hard particles of scale and the presence of residual magnetic field (magnetization of tools).

The analysis of thermal conditions for randomly selected production processes is presented below. Figure 1 shows how to assemble the K type thermocouple in the forging material.

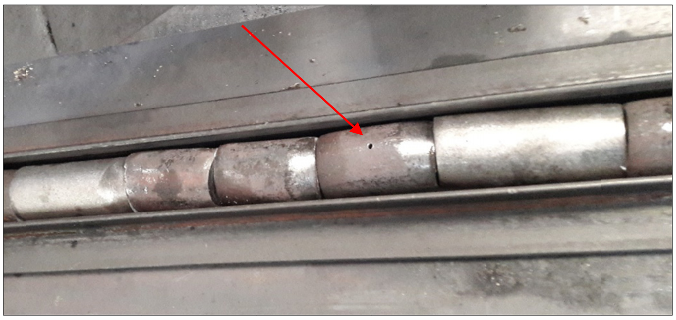

Fig. 1. Place of thermocouple assembly in the forging material

Attaching the thermocouple takes place after the material passes through the induction heater and then the material is forged on the crank press.

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a) **The forged "adapter" made of 42CrMo4 steel**, the temperature of heating the induction material is 1150°C.

The temperature in the production process is measured by pyrometers. For a more accurate analysis, a high-speed thermal imaging camera and thermocouple K tests were used along with a measuring system with a sampling time of 250 Hz. Figure 2 shows the results of the thermovision analysis. They confirmed that the temperature of the forging in the first operation is about 1150°C. The next step was to measure the temperature for the forging with the hole and the thermocouple placed inside. Figure 3 shows the results for the upsetting operation.

We can observe that the actual temperature inside the forging (1225°C) is much higher than on its surface (1151°C). We can also observe that during the upsetting process the temperature of the forging increases by about 17°C.

b) **"Forks/yoke" forged steel 16MnCr5 –** heating temperature of induction steel 1150°C

For this type of forgings, we can also observe that the temperature of the forging is greater inside and on its surfaces (Figs 4 and 5).

The temperature set on the induction furnace is also 1150°C, the temperature read by means of the infrared camera is 1062°C. The temperature inside the material is 1202°C. During the upsetting process the temperature increased to 1224°C.

c) **Forged flange type C22.8 steel –** temperature of induction heating 1150°C steel.

As in previous measurements and in this third case, the temperature of the forging read by the IRD camera is lower than that measured inside the forging (Figs 6 and 7). It was respectively 1166°C for IRD camera reading, and 1326°C for reading from thermocouple measurement in the forging. In the process of upsetting, the temperature of the material increased to 1359°C.

In all the analysed cases, the direct temperature in the forging is much higher than read by pyrometers on an induction heater and a thermal imaging camera. Several matrices were also analysed after removing various numbers of forgings. It was found that as the number of forgings increases, the hardness in the surface layer decreases (Fig. 10). The measurements were made 0.02 mm from the surface, using the Vickers method, HV 0.01.

Due to the influence of variable temperatures, the tool surface is subject to thermal fatigue. Another, very unfavorable phenomenon is the loss of the surface (tempering) of the surface layer due to the effect of the temperature of the forging [5-7,10]. It reduces the hardness in the top layer and increases the wear rate of forging tools.

Fig. 2. Stand for forging "adapter", temperature measurement after flattening operations, initial and finishing forging – temperature of the forging

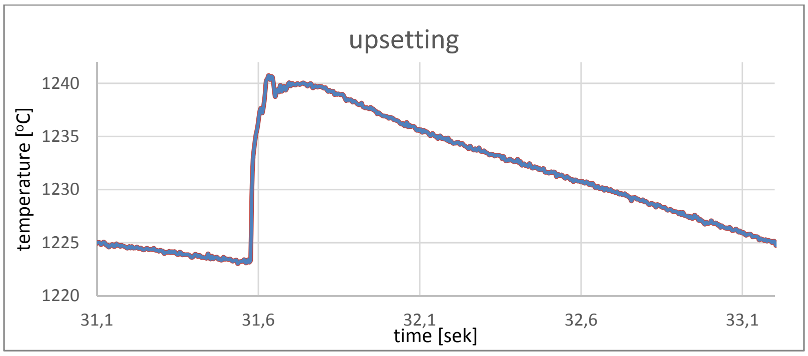

Fig. 3. The temperature of the forging measured in its axis during the upsetting process

Fig. 4. Stand for forging “yoke” forging, temperature measurement after flattening operations, initial and finishing forging – temperature of the forging

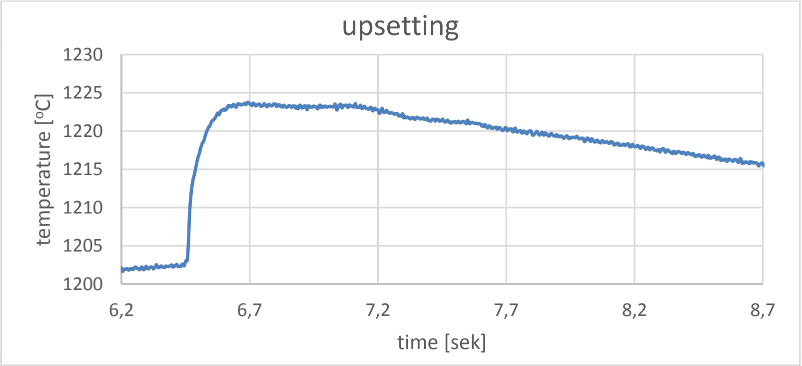

Fig. 5. The temperature of the forging measured in its axis during the upsetting process

Fig. 6. Temperature before each forging operation

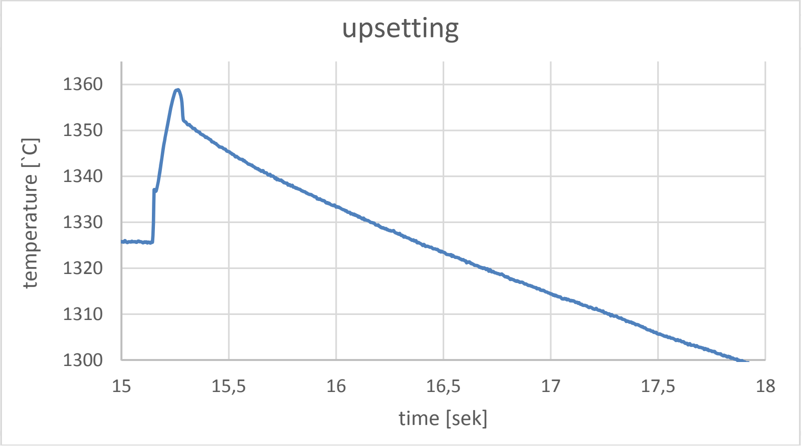

Fig.7. The temperature of the forging measured in its axis during the upsetting process

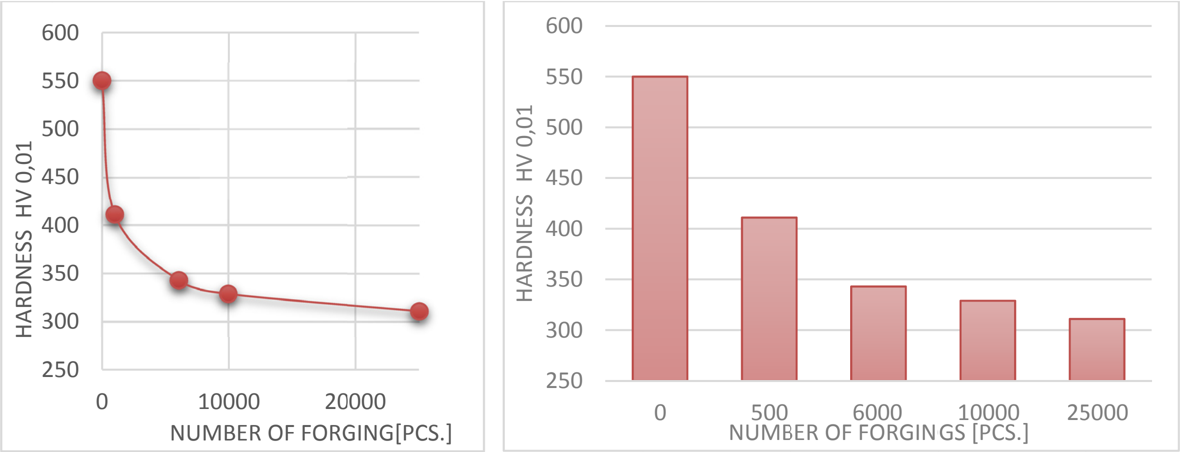

Fig. 8. Hardness in the surface layer as a function of the amount of forging die upsetting

3. Scale in forging processes

The author wrote earlier about [5-6] about the influence of the presence of scale on the durability of tool steels for hot work. The hard particles that fall off the forging cause much faster wear of the tool material. The hardness of the scale material is very high. The hardness testing of scale on a microhardness tester was performed at 10 g load. The indentation time was 10 sec. The results of hardness in the range from 951 HV0.01 to 1347 HV0.01 were obtained from the tests. Figure 9 shows the detachable scale from the forging material. Also visible is the scale on the lower die for upsetting. Figure 10 presents the results of SEM microscopic examination of the scales discussed.

In Figure 10, we can observe that the particle size of Fe_2O_3 and Fe_3O_4 is in the range from <1.0 µm to > 100 µm. Scale is very brittle and very hard [10].

Fig. 9. Visible scale chipping from the forging material and lying on the lower upset dies

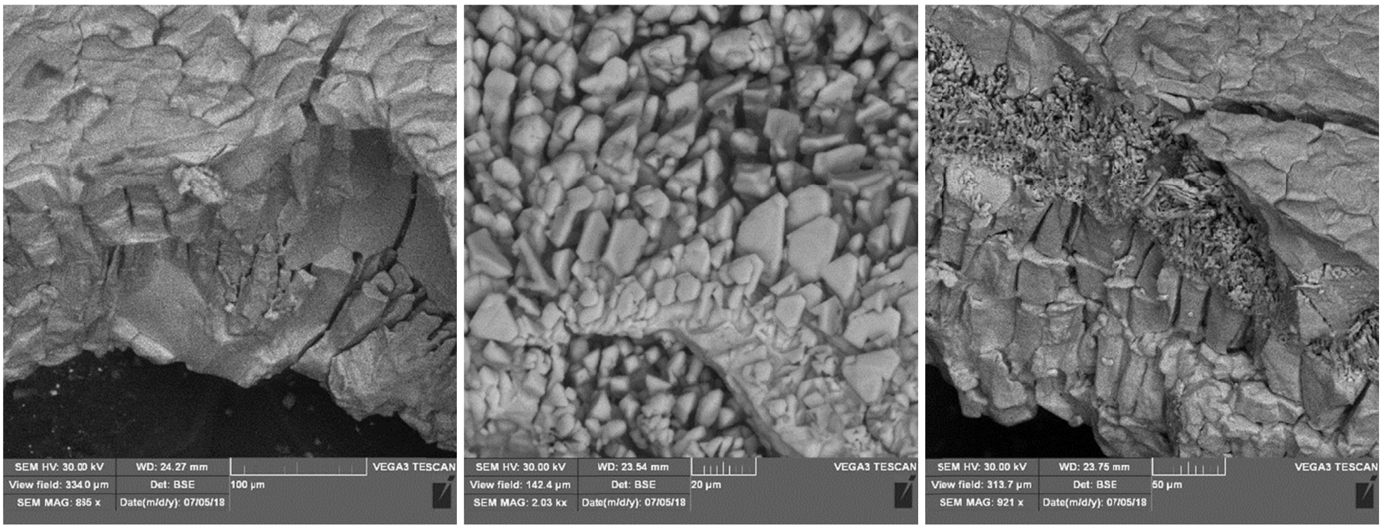

Fig. 10. Surface topography of scale chipped from forging material – steel C45

4. Residual magnetic field of forging tools

Additionally, tests were carried out for the presence of residual magnetic field. Magnetizing tools during machining and spark erosion machining can be a big problem. The presence of a magnetic field causes a change in the mechanisms of wear of the friction pair of ferromagnetic materials [7-9]. Both scale (Fe_2O_3 and Fe_3O_4) ferromagnetic as well as graphite diamagnetics do not remain indifferent to the effects of the magnetic field. The value of the magnetic induction measured on the 24 analyzed items (Fig. 11) with tools was about 1.6-3.7 mT.

The analysis carried out concerned the tools already in operation and several new tools. The obtained results clearly show that the level of magnetization of new and used tools in the forging process is almost identical. On the basis of this, it can be assumed that magnetization arises in the processes of preparing tools, eg cutting, machining, erosive machining and others.

5. Laboratory tests

The following study will present the results of laboratory tests. As part of the research, an attempt was made to oscillate wear of tool material for 4 friction conditions:

- steel – steel consumption without the influence of magnetic field,
- steel – steel consumption with the influence of magnetic field,
- steel – steel in the presence of scale,
- steel – steel in the presence of scale and magnetic field.

Under laboratory conditions, wear tests were performed under oscillating friction conditions. The sample material (about 470 HV) is steel 1.2344. The counter-sample is a steel ball with a hardness of about 700 HV. The sample scheme is shown in Figure 12.

The counter-sample probe ended with a spherical surface with a radius of r = 1.25 mm and performed an oscillating mo-

Fig. 11. Exemplary tools and selectet results of the residual magnetic field analysis

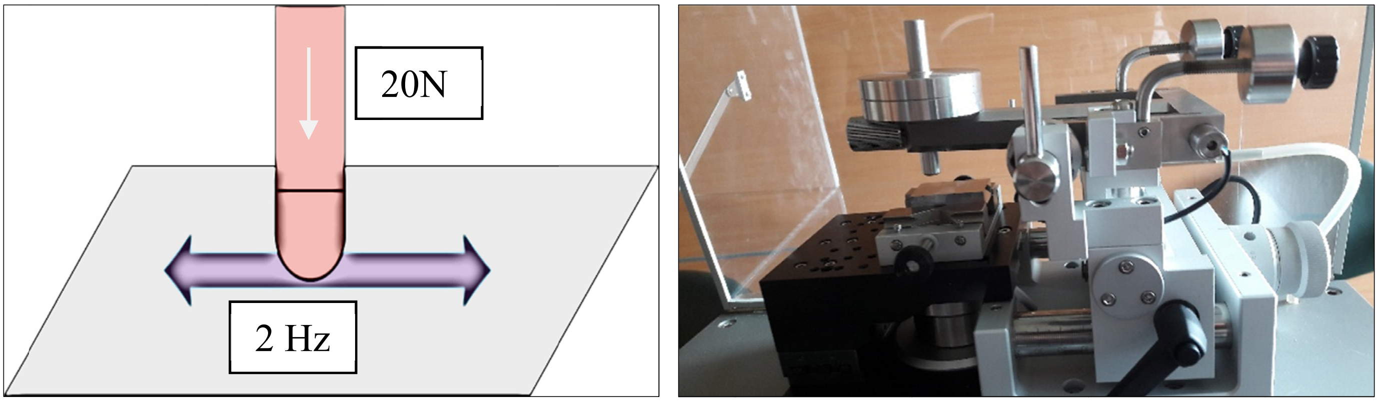

Fig.12. Principle of performing an oscillatory test and view of the tribotester for testing

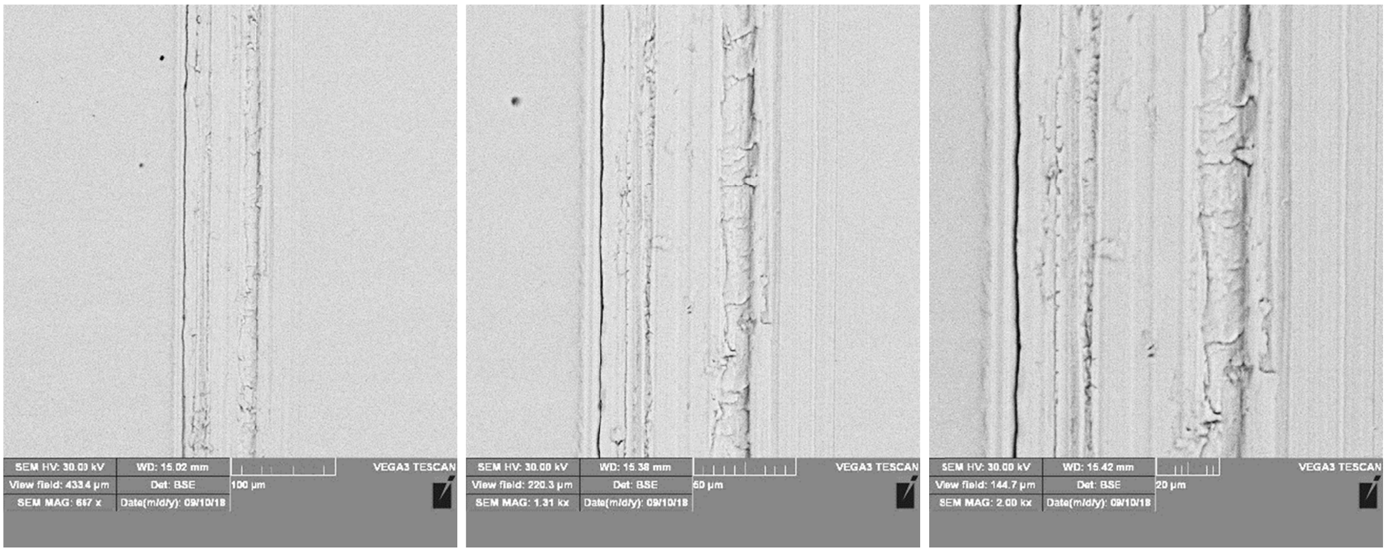

Fig. 13. Trace of wear for steel-steel material pair without magnetic field

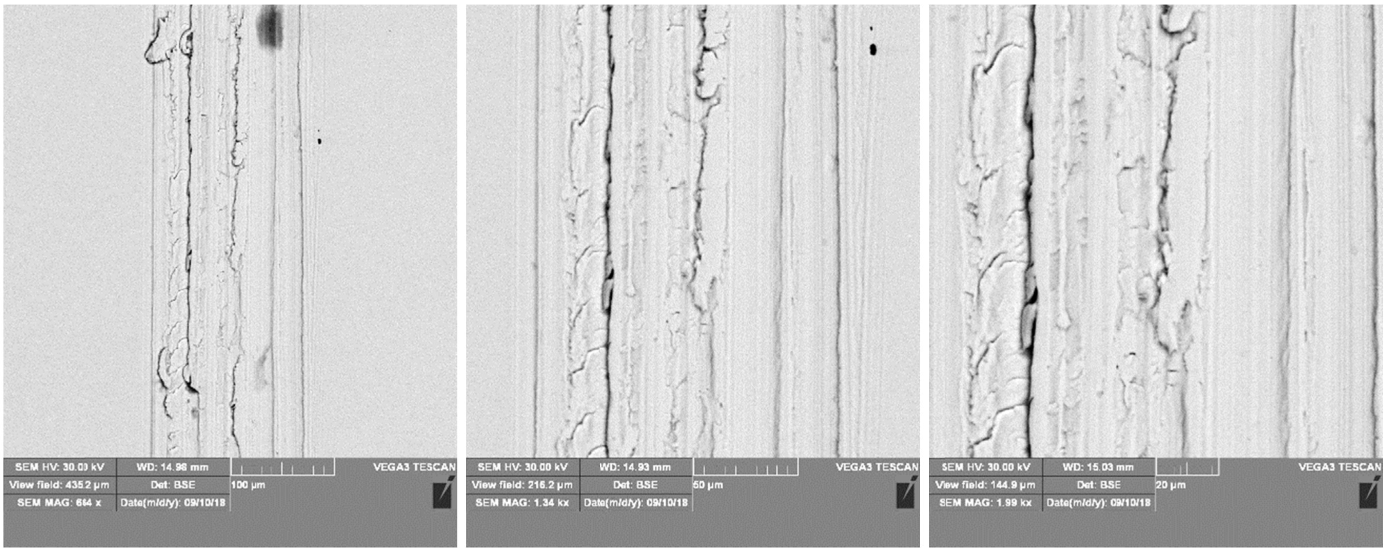

Fig. 14. Trace of wear for steel-steel with a magnetic field

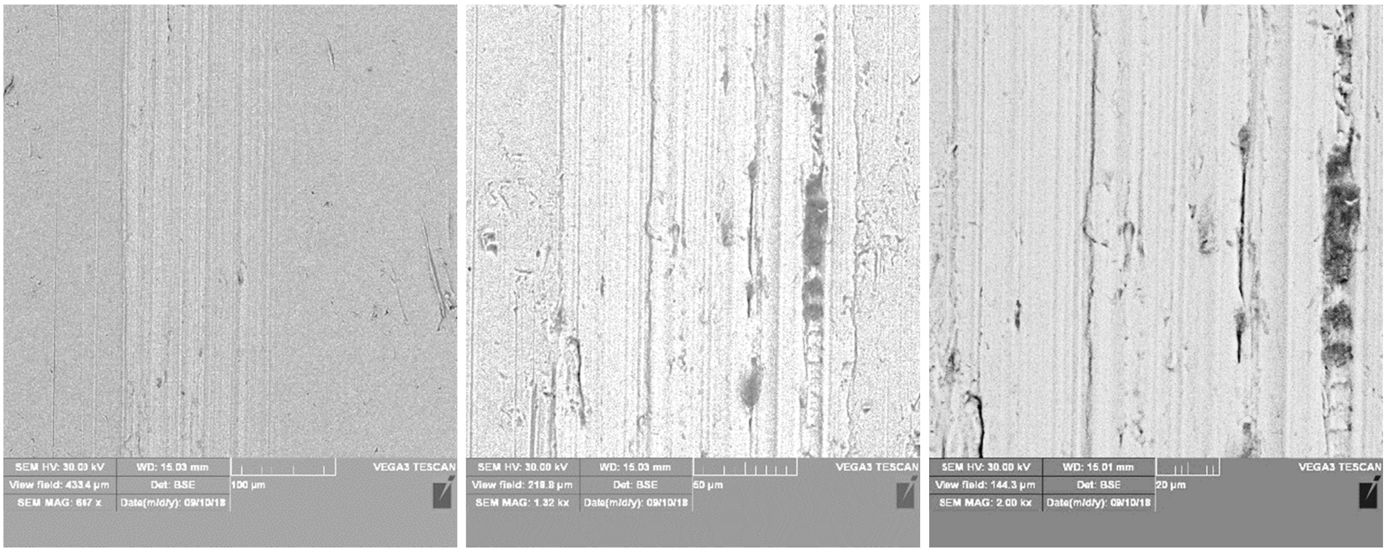

Fig. 15. Trace of wear for steel-steel material vapor in the presence of scale

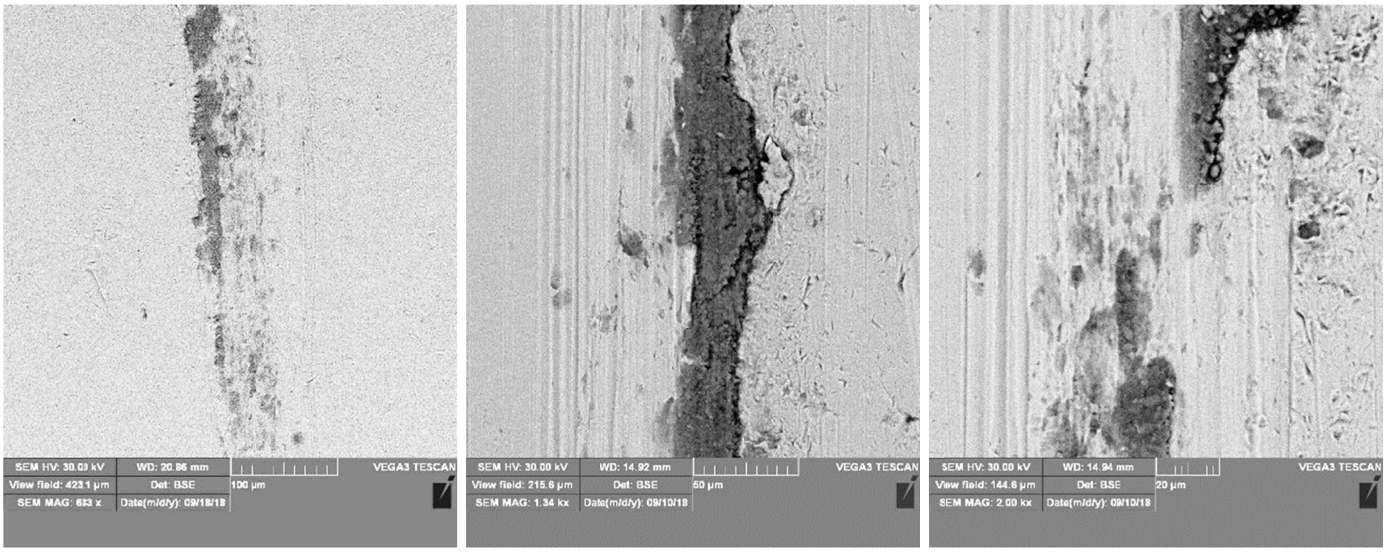

Fig. 16. Trace of wear for steel-steel material vapor in the presence of scale and magnetic field

tion with an amplitude of 10 mm with a frequency of 2 Hz. Load on the 20 N oscillator stem. The magnetization value for the magnetic field test was about 3.5 mT. Figures 13-16 show the SEM image of wear marks for various tribological conditions.

Figure 13 shows the SEM microscopic image of the wear path for a **steel-steel material pair without magnetic field interaction**. Image of a typical abrasive wear determined by micro-scratches (long scratches visible – Fig. 13). Cracks in the stepped form typical of low-cycle surface fatigue. Numerous scratches and furrows along the entire length of the test track.

Steel-steel with magnetic field (Fig. 14) – visible wear path. Abrasive wear in the form of micro-scratches (long cracks), visible stepped cracks and plastically deformed material along the wear path.

Steel-Steel, with the addition of Fe_2O_3 and Fe_3O_4 scale without magnetic field interaction. Abrasive and adhesive wear (visible hollows after cutting out the material). Abrasive wear products (base material) pressed in the test track. Visible only few abrasions of the abrasive material on the test sample (dark fields) – Figure 15.

Steel-Steel, with the addition of Fe_2O_3 and Fe_3O_4 scale and under the influence of magnetic field. Intensive abrasive wear Intense application of the material to the counter-sample has been observed. This is related to the nature of the test under the influence of the magnetic field. Visible evidence of abrasive material (dark boxes in Fig. 16).

The tests carried out unequivocally indicate that during the formation of furrows in the wear path, the material in the form of scale has a tendency to rest and crease along the track. It is caused by the presence of a magnetic field. For the test without a magnetic field, no so much sticking to the scale was observed at the place of wear. The presence of a magnetic field (magnetization of tools) can have a significant impact on the wear characteristics of forging tools.

6. Conclusions

The analysis of wear processes in industrial and laboratory conditions allows to formulate the following conclusions:

1. During the steel hot forging processes, the presence of scale in the shapes of forging tools and the forging material was high. The presence of scale (Fe_2O_3 and Fe_3O_4) can intensify the wear process.
2. The strong interaction of variable temperature fields reduces the hardness of the tools in the surface layer. The decrease in hardness is a function of time and temperature.
3. The presence of scale, scale and magnetic field causes a change in the mechanisms of wear of tool steel for hot work 1,2344.

Acknowledgments

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