SELECTED ASPECTS OF WEAR OF FORGING TOOLS

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Abstract

The article presents results of conducted analyzes and laboratory experiments. During the forge tests a large amount of scale was observed during the forging process. Scale comes from the forging material C45 . Laboratory tests have been conducted - can scaling can affect abrasive wear. During the study, magnetic field was observed. Laboratory tests or magnetic fields have also affected the change in wear patterns. Tool tests have also seen a decrease in hardness as a result of long work. With the help of thermographic studies, laboratory conditions were determined. The 1.2344 tool steel was heated at different temperatures for a long time to see how the hardness changes in the top layer. The article presents the results of microhardness changes in the surface layer for these tests.

Keywords: Hot forging die, wear mechanism, forging, laboratory test

1. INTRODUCTION

The wear resistance of forging tools has been described in Polish and foreign literature for many years. New grades of hot steels are being developed, new coatings are applied which increase their wear resistance. In literature we can keep track of the progress of knowledge in this area, eg [1 - 7]. However, little is known about the impact of accompanying factors on the durability of forging tools. The author has in mind the presence and formation of iron oxides Fe_2O_3 and Fe_3O_4, the influence of temperature on the surface properties and magnetic induction of the forging tools in the machining and electro erosion treatment and other processes. The author has presented several may have influenced the course of the use of forging tools. Commonly used in the literature [6, 8 - 10] are the typical wear mechanisms associated with hot forging. These include: thermal fatigue [3, 4], plastic deformation [7, 8], cracking [5, 7] and abrasive wear [4, 6 - 8].

2. INDUSTRIAL TESTS

The durability of forging tools depends on many external factors. Thermal fatigue, abrasive wear, plastic deformations are the main mechanisms for the degradation of hot forging tools. However, there are several other factors that can significantly affect the durability of hot forging tools. In the discussed forging process, the influence of temperature on the top layer of tool steel 1.2344 and the influence of the presence of the magnetic field on the change of wear mechanisms was taken into account. Analyzed forging process takes place all the time. The factory in which the analysis was carried out Forge Jawor.

2.1. Effect of temperature on top layer properties

Figure 1 shows the results of thermovision IRD measurements during the forging process of a front wheel with a diameter of about 210 mm and a weight of about 3.0 kg. The forging is made of C45 steel and tool steel for hot work 1.2344. The forging temperature is ~ 1150 °C. The temperature of the tool cooled by graphite suspension is 250 - 270 °C. The temperature of the tools that are not cooled (upsetting) is about 500 °C. Tools for the second and third operations are periodically cooled. A graphite suspension with water (4 % graphite) is used. Fe_2O_3 and Fe_3O_4 are the main constituents of the scale. FeO iron oxide is not stable and its contribution is negligible. In addition, EDX studies have identified various organic contaminants (oils, greases and other surface contaminants). During the forging process (especially upsetting), a very large quantity of mill scale is removed from the forgings material, which is not removed from the lower forging tools (**Figure.2**).

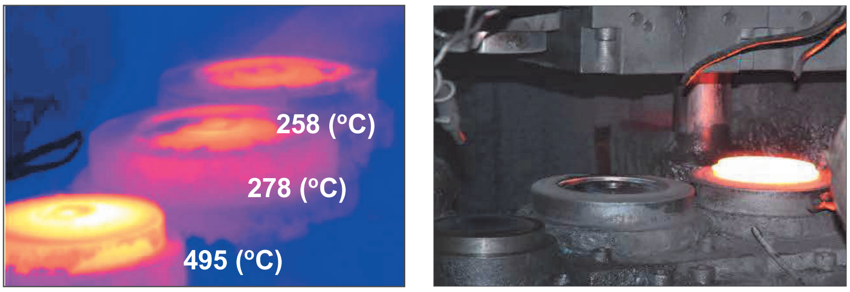

Figure 1 Tool temperatures during the forging process

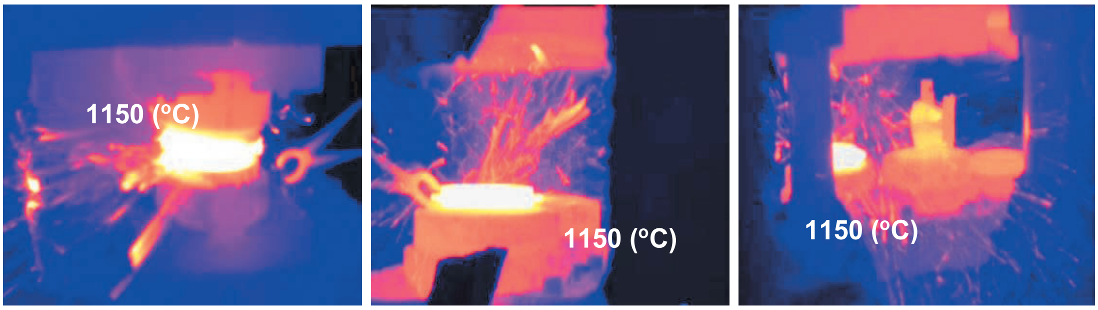

Figure 2 Visible scattering in each direction of scale of the forgings material

Part of the iron oxide comes from the forging material and the smaller part is formed on the tool material. The process of decarburizing and oxidation of tool steels for hot work is, as mentioned above, an equally important issue and the reason for increased wear of tooling tools. The general appearance of the scale from the forging material is shown in **Figure 3**. We can observe that it consists of different particle sizes. The part has a large part and a small angle of attack of the cutting planes. The hard particles of Fe_2O_3 and Fe_3O_4 are within the range of < 1.0 μm to > 100 μm.

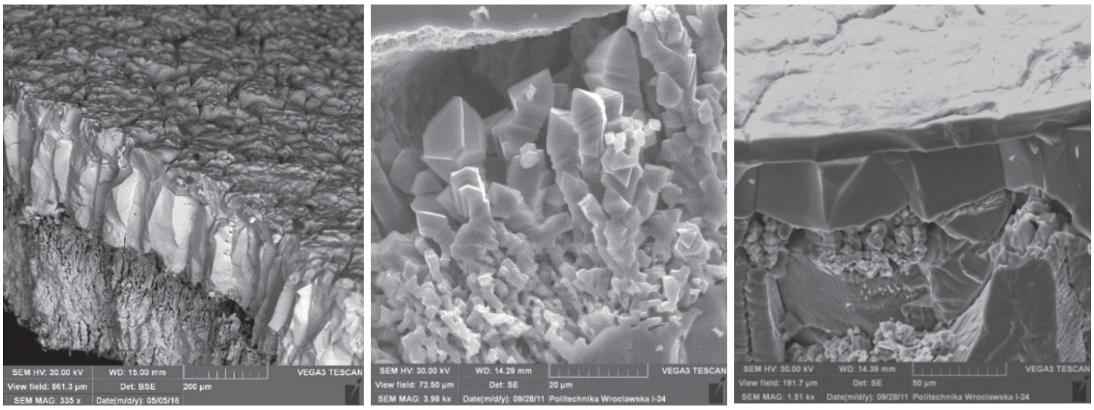

Figure 3 Appearance of scale taken from the forging material C45. SEM microscope

Scale hardness tests were performed on a microhardness tester at 10 g loading. The indentation time was 10 seconds. The results of the tests were obtained from 951 HV0.01 to 1347 HV0.01. Microhardness measurements were made on a LECO LM100AT micro hardness gauge at 100 g. In addition, research was conducted on the presence of residual magnetic field. Tool magnetization during machining and electro-erosion machining can be a big problem. The presence of the magnetic field causes a change in the mechanisms of wear of steam friction materials [11 - 13]. Both scale (Fe_2O_3 and Fe_3O_4) ferromagnetics and graphite diamagnetism are not immune to magnetic fields. The value of magnetic induction measured on the matrices was about 2.0 - 3.0 mT. As shown by literature research conducted by Mohamed M. K. [11], Yetim

A.F. [12], ZHOU Qiang [11], the influence of magnetic field does not remain indifferent to the effects of tribological wear. Depending on the lubricants used and the intensity of the magnetic field, the wear of the friction pairs is altered. In some cases, wear is increasing and others are decreasing. Studies on the influence of the presence of magnetic field and its impact on the scale particles and (coolant) graphite slurry are still ongoing.

2.2. Hardness of the top layer

The hardness of the material is determined by the heat treatment. Generally used hardening and double tempering range of 525 - 550 °C. Tools can also be nitrided. After hardening and double tempering the hardness of the material (top layer also) is about 500 HV. Depending on the tempering temperature we can adjust the hardness in the range of 460 - 570 HV. When using nitrided layers, the surface hardness rises to about 1200 HV. The nitrided layer size can be about 150 - 200 µm.

As the number of forgings is increasing, the hardness of the surface layer decreases due to the influence of the variable temperature fields. These changes are caused by cyclical heating while forging and cooling with a graphite slurry. Already after several thousand forgings, the hardness of the nitrided layer falls to about 550 HV. **Figures 4** and **5** show the microhardness graphs as a function of the distance from the surface (after the forging of 9000 forging tools). In **Figure 4**, micro hardness changes of the nitriding matrix. **Figure 5** shows microhardness changes for the nitrided matrix.

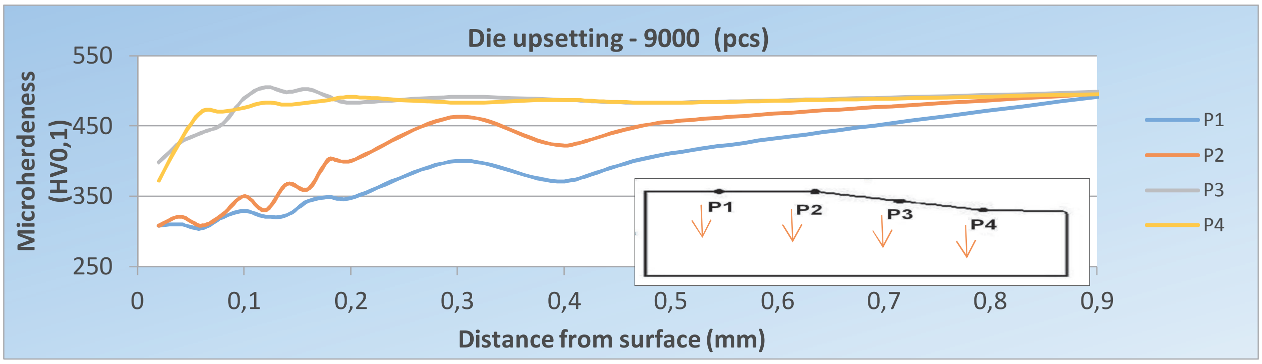

Figure 4 Hardness changes for nitrided matrix (9000 pieces of forgings)

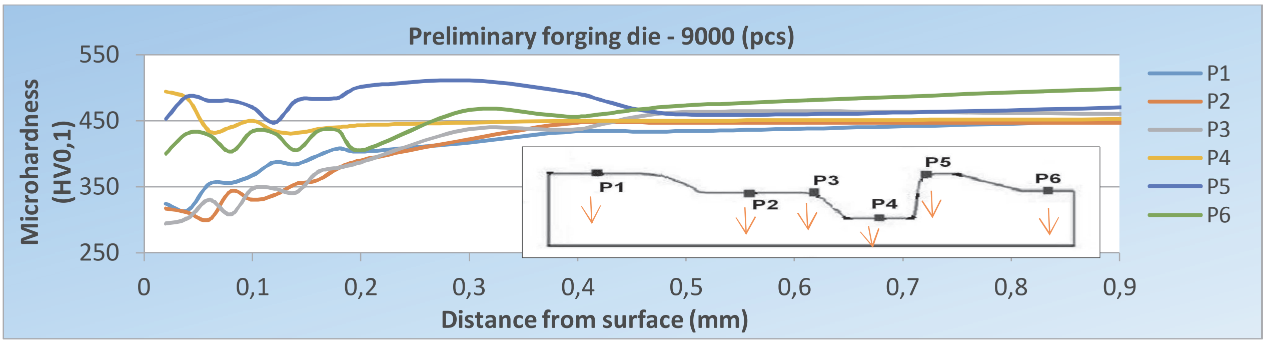

Figure 5 Hardness changes for nitrided matrix (9000 pieces of forgings)

Microhardness tests were performed at several measuring points. Hardness changes depend on contact time, flow path pressure, and more. The graphs show the results where the hardness changes in the top layer were the highest. They concern flat surfaces where contact with the forging material is the longest and the flowing path of the material is greatest. The average shelf life of these forged tools is 10 - 15 thousand forgings. Based on the analyzes, the dependence of the change of the hardness of the surface layer as a function of the number of forging and the distance from the surface was developed. The dependence was made on the swelling matrices that did not have a nitrided layer. The results are shown below in **Figure 6**.Similar dependencies have already been determined by J.H. Kang [1, 2] Depends on his development tools, where the consumption was the largest. He modified the Archard adhesive wear model, recognizing that hardness is a function of time (number of forgings).

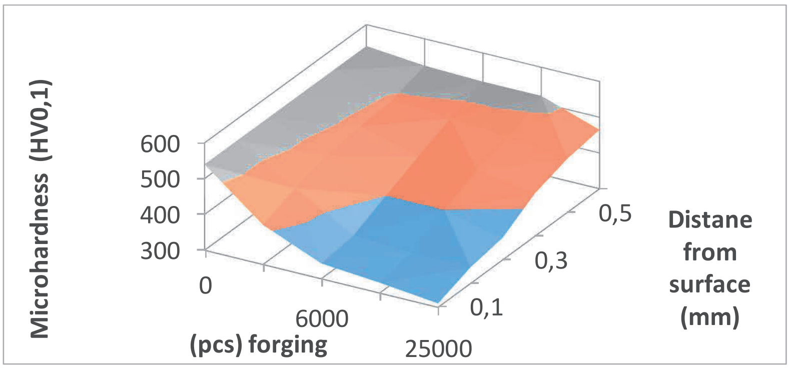

Figure 6 Changing microhardness of the 1.2344 steel upsetting tools as a function of the number of forgings and the distance from the surface

3. LABORATORY TESTS

As part of the research, laboratory tests have been performed to investigate the effect of elevated temperature on the surface properties and the influence of the presence of scale and magnetic field on surface changes during the wear process of the forging tools.

3.1. The effect of temperature.

The tests were performed at elevated temperatures for tool material 1.2344. They range from 200 to 800 °C. The paper presents the most interesting research results. The samples were heated in a furnace without a protective atmosphere. This corresponds to the actual conditions during the forging process. Samples were heated at different times and temperatures. The results are shown in **Figures 7** and **8**.

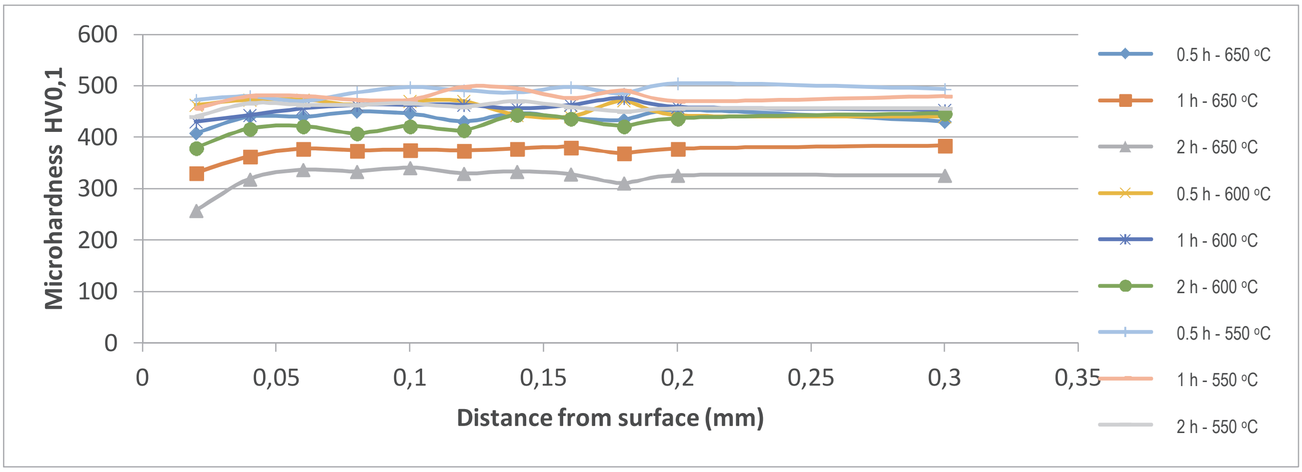

Figure 7 Influence of heating temperature and time in the furnace on the distribution of hardness as a function of the distance from the surface. Material 1.2344 without nitriding

The following conclusions can be drawn from the research carried out. As the temperature increases, the hardness of the top layer decreases. For nitrided tools with 1200 HV0.1 to about 600 HV0.1. On the other hand, for tools unmounted from 500 HV0.1 to about 260 HV0.1.

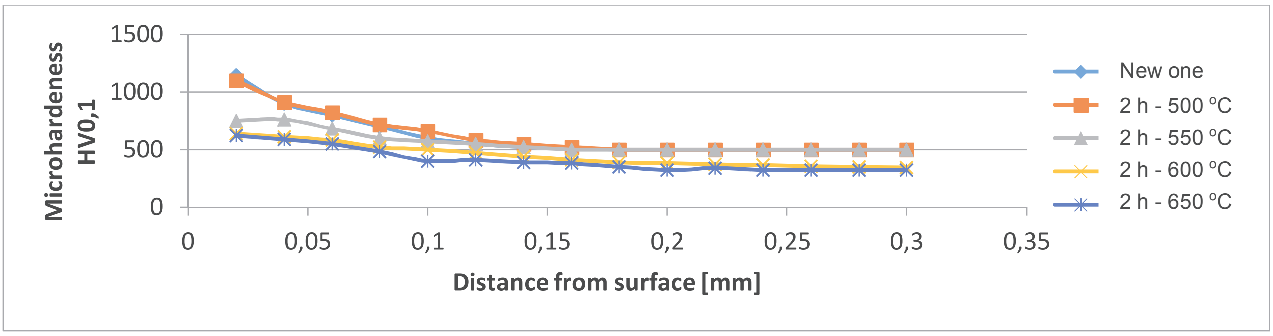

Figure 8 Influence of temperature and heating time on the furnace on the distribution of hardness as a function of the distance from the surface. Material 1.2344 after nitriding

The observations concern the temperature of 650 °C and the heating time in the furnace 2.0 h. For these parameters, the greatest hardness decreases in the surface layer were noted. Results for other times and temperatures are shown in **Figures 7** and **8**.

3.2. Study the effect of scale and magnetic field on wear mechanisms.

In the laboratory, wear tests were performed in oscillatory friction conditions. Sample material (about 470 HV) is 1.2344 steel. The counter is a steel ball with a hardness of about 700 HV. The counter rod ended with a spherical surface with a radius *r* = 1.25 mm and made an oscillatory motion of 10 mm amplitude with a frequency of 2 Hz. Oscillator pin load 20 N. The magnetization value for the third sample was about 5 - 10 mT. Measurements of magnetic induction were done with a HIRST Magnetic Instruments GM08 tachometer at room temperature.

Test conditions:

a) Steel - Steel, no lubrication. (**Figures 9a** and **10a**)
b) Steel - Steel, with the addition of Fe_2O_3 and Fe_3O_4 scale. (**Figures 9b** and **10b**)
c) Steel - Steel, with the addition of scale Fe_2O_3 and Fe_3O_4 and under the action of the magnetic field. (**Figures 9c** and **10c**)

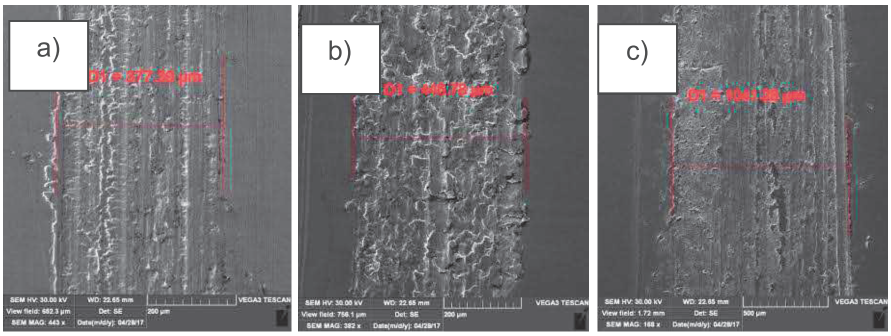

Figure 9 Results of measurement of the track width for different test conditions. Electron Microscope-SE detector

Description of the changes on the surface of the material being tested. The width of the measuring path **Figure 9a** - 377 µm, **9b** - 447 µm and **9c** - 1041 µm. Steel - Steel, no lubrication. An image of typical abrasive wear determined by micro-cutting (visible long cracks). Cracks in the form of stepping typical of low-fat surface fatigue. Numerous features and furrows. Track width 377 µm. Steel - Steel, with the addition of Fe_2O_3 and Fe_3O_4 scale**.** Abrasive and adhesive wear. Abrasive products (ground material) pressed in the test track - very large amount. No abrasive paste on the sample being tested. The width of the wear path is 447 (µm).

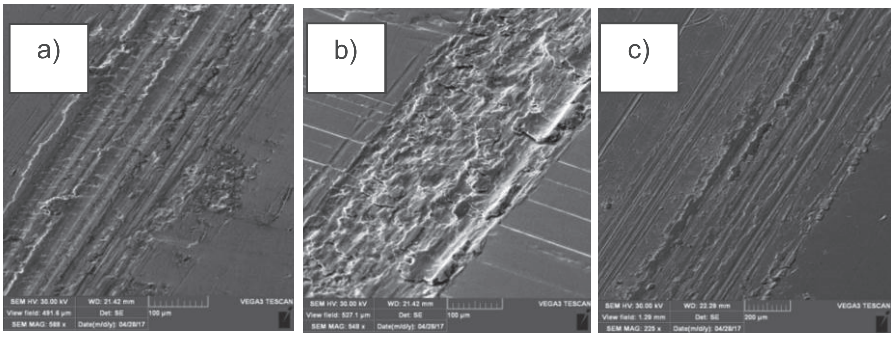

Figure 10 View of the wear path for different test conditions. Electron microscope-SE detector

Steel - Steel, with the addition of scale Fe_2O_3 and Fe_3O_4 and under the influence of the magnetic field. Intensive abrasive wear track width 1041 µm. An intensive application of the material to the counter was observed. This is related to the nature of the sample under the action of the magnetic field. Visible stickers of abrasive material. (Dark elements in **Figures 9c** and **10c**). The third test is the widest of all three wear trace tests.

4. CONCLUSIONS

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

1) During the hot forging of C45 steels, there was a high presence of scale in the patterns of forging tools and for forgings. The presence of scale (Fe_2O_3 and Fe_3O_4) can intensify wear processes. EDX studies have confirmed that the scavenger tested is very hard iron oxide particles. These particles are ferromagnetics.
2) Strong impact of variable temperature fields reduces the hardness of tools in the surface layer. The decrease in hardness is a function of time and temperature (**Figure 6**).
3) The presence of scale and scale and magnetic field causes a change in the wear mechanism of tool steel for hot work 1.2344.
4) As indicated in the literature and research conducted, it is necessary to get rid of the magnetization of tools in their preparation processes.

REFERENCES

[1] KANG J.H., PARK I.W., JAE J.S., KANG S.S., A study on die wear model considering thermal softening (II):Application of the suggested wear model. *Journal of Materials Processing Technology*. 94 (1994)

[2] KANG J.H., PARK I.W., JAE J.S., KANG S.S., A study on a die wear model considering thermal softening: (I) Construction of the wear model, *Journal of Materials Processing Technology*. 96 (1999) 53-58

[3] GRONOSTAJSKI Z, HAWRYLUK M., KASZUBA M., MARCINIAK M., NIECHAJOWICZ A., POLAK S., ZWIERZCHOWSKI M., ADRIAN A., MRZYGLOD B., DURAK J. The expert system supporting the assessment of the durability of forging tools. *International Journal of Advanced Manufacturing Technology*. 2016. 82 (9): 1973-1991

[4] ZWIERZCHOWSKI M., HAWRYLUK M., Structural analysis of hot forging dies with regard to their life. *Maintenance and Reliability*. vol. 2/2009: 31-41

[5] SOKOLSKI M., SOKOLSKI P., Strength estimation of the impact zone - A critical area of the tools of the hydraulic hammers. *Archives of Civil and Mechanical Engineering*, Volume 16, Issue 4, Pages 767-776, (2016).

[6] ALTAN T., *Cold and hot forging fundamentals and application*, ASM Internation, Ohio, 2005.

[7] WERONSKI A., HEJWOWSKI T., *Thermal fatigue of Metals*. M. Dekker Inc. New York 1992.

[8] RAUCH L., CHMURA A., GRONOSTAJSKI Z., POLAK S., PIETRZYK M., Cellular automata model for prediction of crack initiation and propagation in hot forging tools. *Archives of Civil and Mechanical Engineering*, (2016).Volume 16, Issue 3, Pages 437-447

[9] BERTI G. A., MONTI M., Thermo-mechanical fatigue life assessment of hot forging die steel, *Fatigue & Fracture of Engineering Materials & Structures* 28, 11, 1025-1034, 2005

[10] MOHAMED M. K., ALAHMADI A., ALI W. Y., ABDEL-SATTAR S., Effect of Magnetic Field on The Friction and Wear Displayed by The Scratch of Oil Lubricated Steel. *International Journal of Engineering & Technology IJET-IJENS* Vol:12 No:06, p. 137-143

[11] ZHOU Q., XU R., The action and analysis of magnetic field on the lubricants and wear products in the process of wearing. *SCIENCE IN CHINA* (Series A) 2001vol.44, p.267-272

[12] YETIM A.F., KOVACI H., ASLAN M., CELIK A., The effect of magnetic field on the wear properties of a ferromagnetic steel. *WEAR* Volume 301, Issues 1-2, April-May 2013, Pages 636-640.