[1.]Ilia ZUMBILEV, [2.]Angel ZUMBILEV

STUDYING THE POSSIBILITY THE ACOUSTIC EMISSION TO BE APPLIED IN THE PROCESSES OF MATERIALS DESTRUCTION

[1-2.]Technical University of Sofia – Branch Plovdiv, BULGARIA

Abstract: The aim of the present paper is to study the possibility to use acoustic emission for studying the processes of microcracking and fracture of thermally and chemical-thermal treated materials. The obtained results show that the acoustic emission can be used as an indicator of pre-destructive processes for thermally treated and nitrided materials. It has been established that the values of K_Q (AE), defined for a material in a non-destructive way in laboratory conditions, can well serve in production as a criterion of forthcoming brittle fracture.
Keywords: acoustic emission, fracture, thermally treated steels, nitriding

INTRODUCTION

Reliability and exploitation life of tools and details depends mainly on origination and propagation of cracks, expressed by the following characteristics – fracture toughness K_{Ic} and critical opening of the crack banks δ_{Ic} [4, 5, 6, 9].

In addition to wear at high contact loads and high temperatures, resistance against formation of cracks on the surface is essential for tools for hot working.

Tool steels for hot working, being not very plastic, are very sensitive to brittle fracture. About 70% of the reasons for failure of the molds for casting nonferrous alloys under pressure are due to magistral and thermal cracks [4,5].

A number of methods for studying the processes of formation and development of cracks in multi-layer systems have been described in [1,2,1-13]. Common disadvantage of most of these methods is that they are applied after completion of the fracture. One of the most modern methods for studying the processes of microcracking and fracture in the matrix and its adjacent thin layers is acoustic emission.

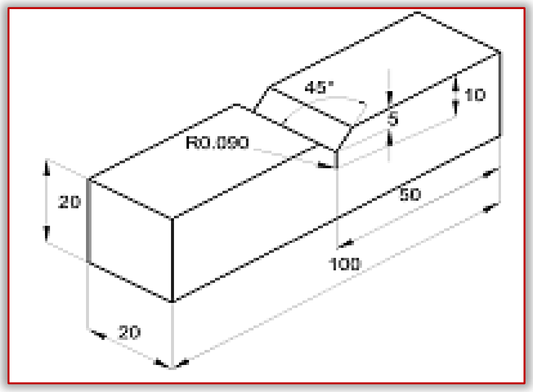
The acoustic emission (AE) is based on physical phenomena, related to radiation of acoustic impulses in the material. The sources of AE can be divided into two groups. The first one characterizes the phenomena, related to plastic deformation: twinning of the crystals, slipping along the grain boundaries and, most of all, own motion of the dislocations [1,2,11]. The phenomena, related to the motion of the dislocations are less energetic. They are registered by a continuous AE. The second group consists of the more pronounced energetic phenomena, accompanying the mechanisms of fracture: formation and propagation of the micro-crack, intercrystalline and transcrystalline fracture, phase transformations etc. These phenomena are registered by an impulse AE.

The impulse type acoustic emission is observed in materials when suddenly mechanical energy of elastic deformation is released, at the moment of microcracking or propagation of cracks. Energy release in the deformed material goes discreetly as a series of individual acts, registered as AE-impulse and AE-phenomena (events) in a minor volume of the material. Then they propagate in the form of waves of elastic deformation (stress waves, AE-waves) throughout the volume. Registration of the spectrum and the parameters of AE, radiated by a material, subjected to deformation, gives significant information about the mechanisms of the process of crack formation and fracture.

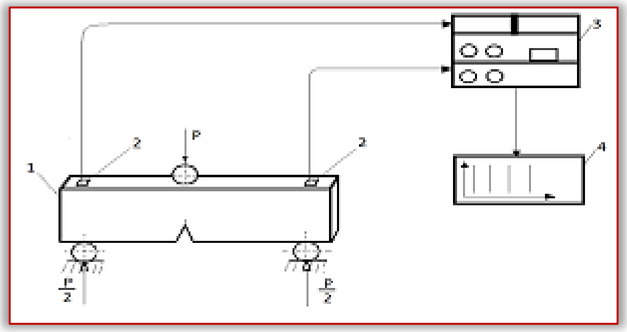
The aim of the present paper is to study the possibility to use acoustic emission for studying the processes of microcracking and fracture in thermally treated materials.

METHODOLOGY OF STUDY

Experiments were conducted with steel BH11 BS4659 (4X5MФС - ГОСТ), from which standard samples with a notch for three-point bending were produced [7,8] – Figure 1.



a)



b)

Figure 1 - a - sample, b – block-scheme of the experiment
1- sample, 2- sensors, 3- AE systems, PAC 3000/3104, 4-printer

The spherical waves, emitted by the source, were transformed into surface AE-waves (stress waves), and registered by the sensor (2), attached to the sample (1). The mechanical energy of the acoustic-emission impulse was converted into an equivalent electrical signal. After filtration it was fed into the pre-amplifier and from there – into the analogue part for additional amplification and processing by the computer block of the AE-equipment PAC 3000/3104 (3).The processing of the characteristics of the AE-signal (duration, rise time, impulses, amplitude, energy etc.) was carried out by the microcomputer of the AE-system and could be printed by a printing machine (4). The experiments were conducted at room temperature.

The samples were thermally treated in a vacuum furnace VKUQ -Degussa, and then part of them were subjected to ion nitriding in the installation ION-20. After the thermal treatment the samples were grinded at R_a = 0,32μm. The modes of thermal treatment and ion nitriding are given in Table 1.

Table 1 - Modes and results from the ion nitriding of steel BH11

№of the sample	t_{hard} °C	$t_{temp.}$ °C	HRC	$t_{nitr.}$ °C	P_{NH3} Pa	τ h	$HV_{0.1}$	$\delta_{tot.}$ μm	$\delta_{c.z.}$ μm
215	1040	600	51	530	300	7	1168	240	6
249	1040	650	46	530	300	10	1100	270	8

It was proved by metallographic and fractographic analysis that the tip of the notch was not nitrided after nitriding.

The resistance against crack propagation was defined for three-point bending of the samples by means of a universal testing machine INSTRON 1343 at velocity of loading 0,5mm/min. The motion of the crack banks (V_9) was registered at room temperature by a console tenso-resistive perceiver with sensitivity 2,5 μV/mm, base 10 mm and step 2 mm, having the diagram force (P) – crack banks motion recorded at the same time (V_9).

For studying the AE-activity in three-point bending and fracture of the samples a four-channel AE-system PAC 3000/3104 (USA) with wide-band sensors Wd was used – Figure 1. The sensors were placed on a sample, locally doped with silicon paste, and fastened by special springs, providing constant pressure. The sensitivity of the sensors was controlled by the imitator of Hsu. At total amplification of 80 dB (40 dB pre-amplification) and constant threshold of 1V, a registered signal of 98 dB from the imitator was taken as good sensitivity.

For clearing out and correct interpretation of the results from the acoustic-emission (AE) tests, calibration curves were obtained based on metallographic and fractographic analyses, concerning the different structural states. The obtained graphical and tabular AE-information was cleared at the maximum from the influence of noises by appropriate conduction of the experiments and consequent analysis of the data.

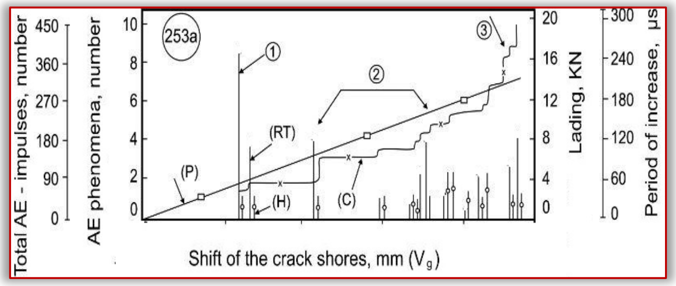
EXPERIMENTAL RESULTS AND ANALYSIS

Thermal threaded simple bodies

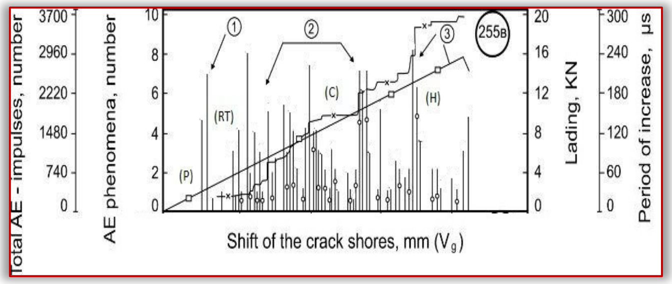
The acoustic-emission parameters: number of AE-events (H), AE-impulses (C), rise time (RT), AE-energy (E), AE-amplitude (A) and pressure (P) are shown in dependence on the displacement of the crack banks (V_9) – Figure 2.

The experimental results from the acoustic-emission activity of the vacuum-thermally treated samples (№ 253 и № 255) speak of brittle fracture with clearly expressed character.

The fracture is in the linear (elastic) zone of the curve "pressure – displacement (opening) of the crack banks" without any signs of stable growth of the crack in microscopic aspect. The differences in the slopes P – V_9 for the two samples (Figure 2) are due to structural distinctions – grain structure, distribution, size and shape of the carbides.



(a)



(b)

Figure 2 - Change of the AE-parameters and the load in dependence on the displacement of the crack banks for the thermally treated samples

AE-phenomena with low energy, amplitude and impulses but with sufficient rise time were observed even at the lowest values of the load. They are denoted in Figure 2, zone ① and indicate the beginning of formation of a new zone of plastic deformation in front of the crack tip. In this zone from 20 to 60% of the load AE-phenomena with increased number of AE-impulses, energy and amplitude are observed but with shorter rise time, what is an evidence of the beginning of a brittle micro-cracking.

Such AE-signals of brittle materials are related to fracture or to de-cohesion of the carbides and the intergranular brittle fracture at micro-level. Most probably fracture of the carbides begins, together with microcracking in local areas, near the crack tip [3,4]. Low-energetic AE-signals are also observed, which are due to the fracture of most of the disperse carbides (Figure 2a, zone ②). A common feature of the samples in this series is the appearance of signals with high amplitudes and energy, with very short rise time and duration under a load, close to the fracture load. These AE-signals can be taken as a harbinger of the end of the unstable brittle fracture. In Figure 2 they are separated in zone ③ of the AE-tests.

These signals are due to the growth of microcracks and the formation of the facets, observed at the fractures of the samples by means of a scanning electronic microscope (SEM) – Figure 3.

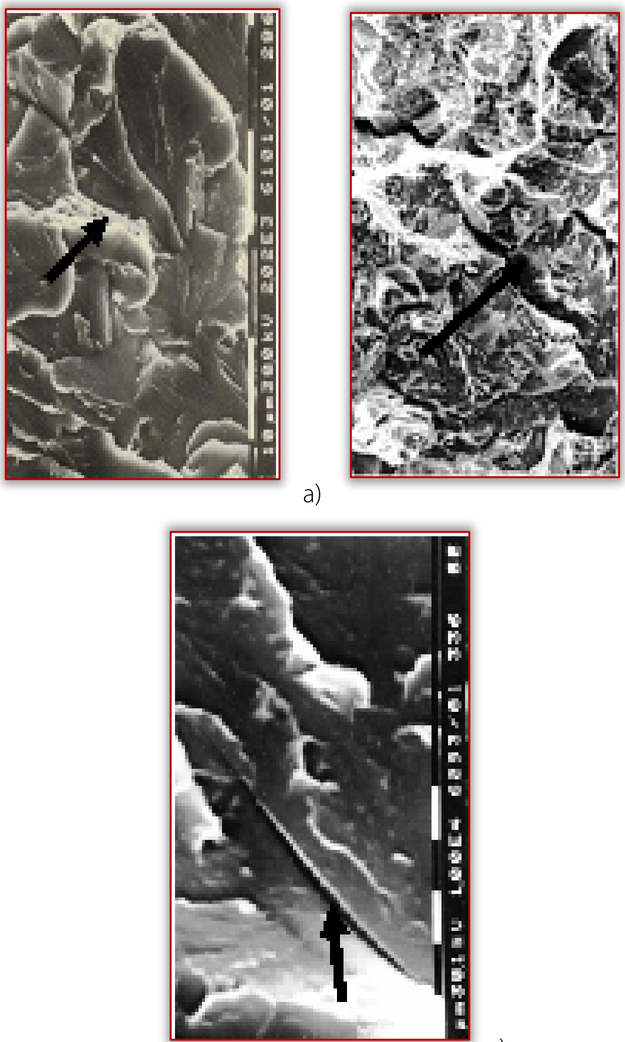


Figure 3 - Fractographs of thermally treated samples after tempering at: a, c - 600^0C; b- 650^0C

Isolated carbides were observed by means of SEM in the vicinity of the crack tip at the possible boundary of the zone of micro-plastic deformation, and they are sources of AE-signals. Zones of blunting the crack tip and its successive unstable growth after reaching the critical micro-stresses for initiating the unstable brittle fracture were also observed. Facets with big areas, free of micro-pores, prevail in these zones. Together with the increase of the temperature of tempering, sections of micro ductile fracture are observed around the facets – Figure 4.

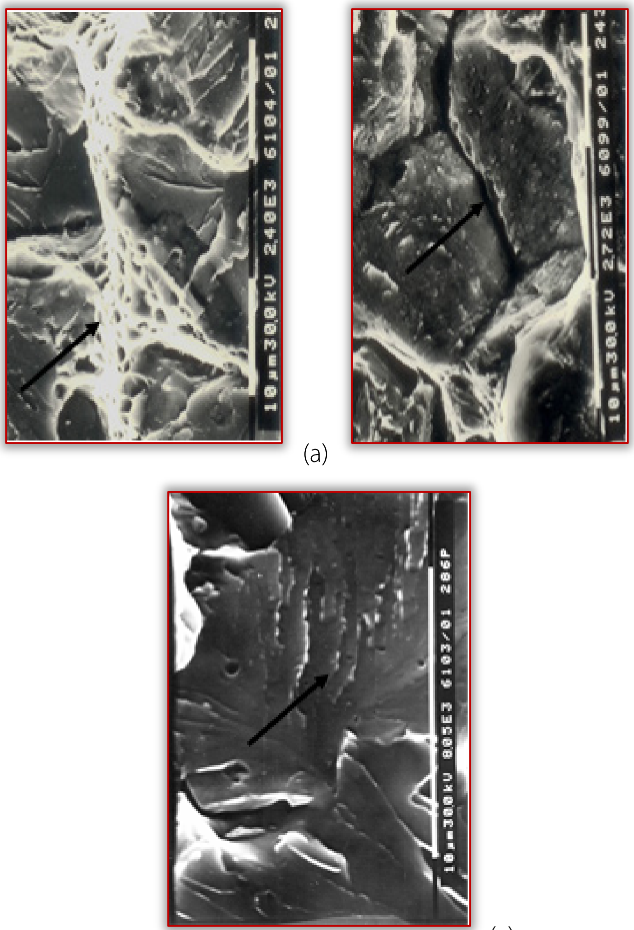


Figure 4 - Fractographs of thermally treated samples after annealing at: a, c - 600^0C; b- 650^0C

These sections, in addition to the increased content of carbides, are the reason for the increased AE-activity in the sample, tempered at 923K (650°C). The inter-crystalline cracks prevail in this sample and contribute to emitting high-energy AE-signals both in zone ② and ③ - Figure 4b. It can be confidently asserted that all processes of internal and inter-crystalline brittle structure emit AE-signals, which can be registered.

Together with the increase in the temperature of tempering, overall increase of AE-activity is observed, which is best expressed in graphical representation of the total (cumulative) AE-energy depending on the load – Figure 5.

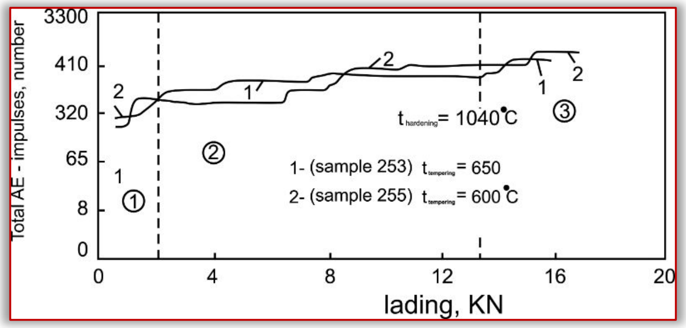


Figure 5 - Change of the total energy with respect to the load of the studied samples

The increase in plasticity of the material leads to an increase in the AE-activity at the low values of loading, due to the larger zone of micro-plastic deformation in front of the crack tip – zone ①. Zone ② is characterized for all samples by comparatively uneven frequency of appearance of high energy AE-phenomena. In zone ③ the AE-phenomena with high energy for samples, tempered at 873 K and 923 K, are an excellent indicator of the end of the brittle fracture. The quantitative characteristics of the fracture of the thermally treated samples is made by means of the parameter "total (cumulative) energy" and expressed in Figure 6.

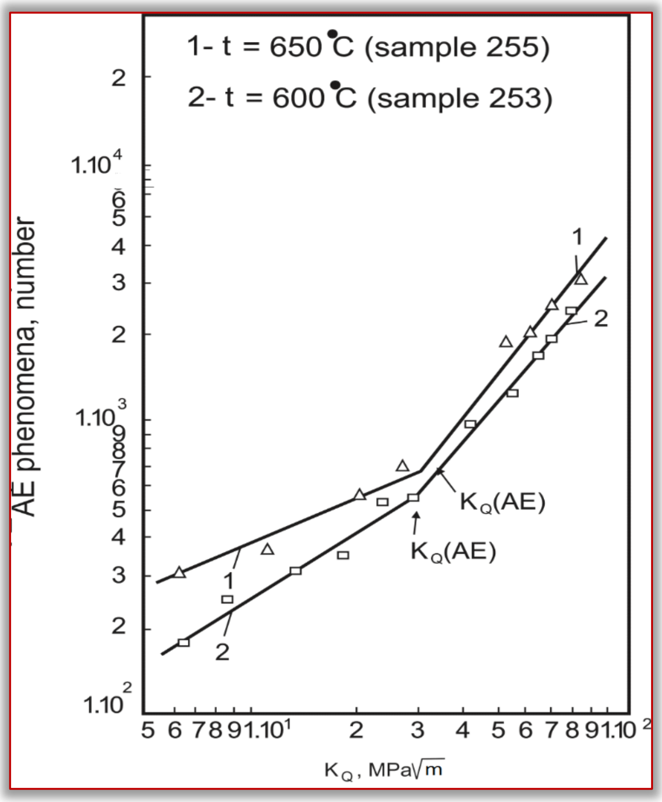


Figure 6 - Change of the total energy with respect to K_Q

From Figure 6 it can be seen that at temperature of tempering the steel 923 K (650°C), the value of K_Q (AE) is the highest, what shows that the number of sources of AE is bigger.

The points of breakage on the graphs, denoted by K_Q (AE), are the beginning of unstable fracture. Reaching this moment of loading, value of K_Q and total AE, unsteadily growing "quasi brittle" crack starts developing in the material.

The values of K_Q (AE), defined in a non-destructive way in laboratory conditions for the material, can serve well in production as a criterion of its forthcoming brittle fracture.

— Nitrided simple bodies

The acoustic-emission parameters: AE-impulses (C), rise time (RT) and pressure (P) are shown in dependence on the displacement of the crack banks (V_9) – Figure 7.

The experimental results from the acoustic-emission activity of the ion nitride samples (215, 249) speak ofbrittle fracture with clearly expressed character and are presented in Figure 7 and Figure 8.

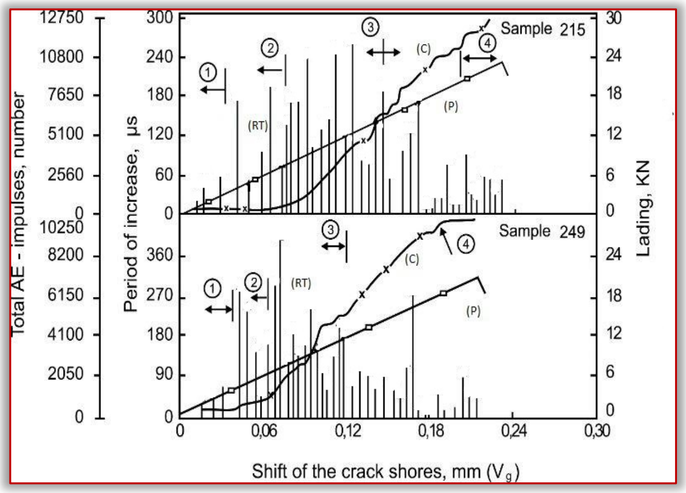


Figure 7 - Change of the AE-parameters and the load with respect to the displacement of the crack banks for the ion-nitrided samples 215 and 249

The fracture of the ion-nitrided samples is in the linear elastic zone of the curve P-V_9. The AE-activity of the samples is with considerably lowered AE-parameters at low loads. Figure 7, number ①denotes this zone of low AE activity, in which the rise time of the registered AE phenomena is below 60μs, and the AE-impulses are with low intensity. The AE-phenomena, registered in zone ① are due to premature microcracking of the layer, when the deformation at small loads is sufficient to achieve the critical destructive stresses for the imperfect (defective) micro-sections of the layer [14,15]. This confirms the assumption that these stresses do not necessarily lead to microcracks in the matrix. The assumed micro-cracking in the defective sections of the layer is also supported by the fact that the layer has a significantly higher modulus of elasticity and it will crack before the tensile strength of the matri is reached.

In the three-point bending processes of reduction of the residual compressive stresses occur. This is also accompanied by plastic deformation of the layer. The formation of a zone of plastic deformation in front of the crack tip and in the layer is the reason for the observed AE-activity in zone ②Figure 7. It is with comparatively high values of rise time. In the third zone ③, characterizing mainly the processes of brittle fracture of the matrix, linear rise of the total number of AE-impulses is observed.

This type of distribution of the AE-impulses is characteristic of the processes of fracture, evenly distributed in time or with respect to the load and containing elements of ductile fracture. It is possible to isolate a fourth zone ④in the studied samples, where the AE-activity is with lowered parameters again. It corresponds to the final brittle micro-cracking of the layer and the fracture of the whole sample.

For the cumulative distribution of the AE-energy four zones can also be distinguished, what confirms the assumed behavior at fracture, causing the corresponding AE-activity – Figure 8.

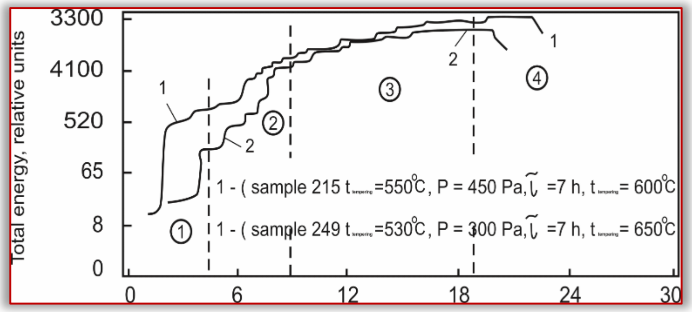


Figure 8 - Total energy change with respect to the load for the nitridd samples

It can be noted in conclusion that two types of AE-activity are observed in the studied samples. They are characterized by four zones of AE-activity:zone of premature microcracking of the layer; zone of plastic deformation in front of the notch tip; zone of brittle fracture of the matrix and zone of final microcracking and fracture of the sample.

The AE-activity can be used as an indicator of pre-fracture processes in nitride details and tools. Based on the carried acoustic-emission and fractographic analysis, the following probable mechanism of fracture of anitrided body, subjected to static loads, is suggested.

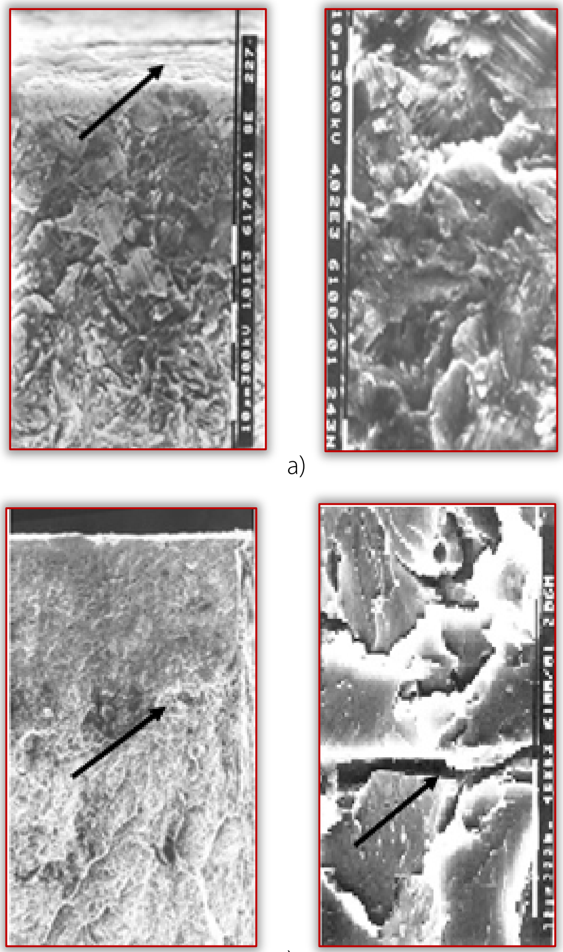
At low initial pressure (P) of the ion-nitrided sample - up to 6 KN -in front of the notch tip at both its ends, where a nitride layer is present, processes of reduction of the residual compressive stresses occur, on the one hand, and, on the other hand, premature deformation of the layer and its microcracking occurs due to its high modulus of elasticity – Figure 7, zone ①. Microcracks are formed first in the combined (white) zone and then in the diffusion zone (Figure 9a).

This is due to the higher brittleness of the combined zone. For these loads the micro-deformations in the diffusion zone are sufficient for achieving the critical destructive stresses in the imperfect (defective) sections of the layer, primarily the areas with high density of dislocations around the nitride (carbonitride) depositions [14,9].

At these initial loads micro-cracks are not formed in the non-nitrided matrix, what is due to the lower modulus of elasticity and the arising (because of that) lower stresses in it at the same levels of deformation. On the other hand, the matrix is much more plastic than the nitrided layer.

Only at heavier loads plastic deformation occurs in front of the notch in the matrix – Figure 7, ②. This causes microcracking of the biggest carbide particles, having the highest density, which are located in the plastic zone or in closest proximity to it, which leads to appearance of microcracks in the matrix as well [4,5,9]. The closest to the layer newly formed microcracks do not propagate in it, since the diffusion zone prevents from plastic deformation occurrence at these stresses.

The propagation of the microcracks in the layer is also impeded by the residual compressive stresses and the higher hardness of the layer.



a) b) c) d)

Figure 9 - Fractographs of the ion-nitrided samples

After certain level of loading, conditions arise for propagation of the formed micro-cracks both in the layer (combined zone and diffusion zone) and in the matrix. Some microcracks in the matrixandthe layermoveandmergeto forma larger (magistral) crack, which propagates along the boundary between the diffusion zone and the matrix – Figure 9c,d – most probably where the compressive stresses are very low or change their sign. The crack develops unsteadily after reaching the critical micro-stresses for initiating brittle fracture (Figure 7), zone③. This magistral crack, located at the boundary between the layer and the matrix obviously has the greatest contribution to the process of splitting off the layer and fracture of the nitrided body. Naturally, the other cracks in the layer and the matrix also have their influence on this process. The nitrided layer breaks last - (Figure 7), zone③.

CONCLUSIONS

Acoustic emission can be used for studying pre-fracture processes, going on in thermally treated and nitrided materials.

The values of K_Q (AE), defined in a non-destructive way in laboratory conditions for the material, can serve well in production as a criterion of forthcoming brittle fracture.

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