IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Experimental Research Into Generation of Acoustic Emission Signals in the Process of Friction of Hadfield Steel Single Crystals

IOP Conf. Series: Materials Science and Engineering **142** (2016) 012098 doi:10.1088/1757-899X/142/1/012098

Experimental Research Into Generation of Acoustic Emission Signals in the Process of Friction of Hadfield Steel Single Crystals

D V Lychagin[1,2*], A V Filippov[2,3], O S Novitskaia[3], E A Kolubaev[2,3], and O V Sizova[3]

[1] National Research Tomsk State University, Tomsk, Lenin av. 36, Russia
[2] National Research Tomsk Polytechnic University, Tomsk, Lenin av. 30, Russia
[3] Institute of Strenght Physics and Materials Sciences SB RAS, Tomsk, per. Academicheskii 2/4, Russia

E-mail: dvl-tomsk@mail.ru

Abstract. The results of experimental research into dry sliding friction of Hadfield steel single crystals involving registration of acoustic emission are presented in the paper. The images of friction surfaces of Hadfield steel single crystals and wear grooves of the counterbody surface made after completion of three serial experiments conducted under similar conditions and friction regimes are given. The relation of the acoustic emission waveform envelope to the changing friction factor is revealed. Amplitude-frequency characteristics of acoustic emission signal frames are determined on the base of Fast Fourier Transform and Short Time Fourier Transform during the run-in stage of tribounits and in the process of stable friction.

1.Introduction

There are chaotic and unsteady phenomena registered between two objects in the process of friction. A relative slip of objects in a tribounit results in intense interaction between micro-roughnesses of surfaces, coming in contact. Seizure, separation and shear of micro-roughness elements are typical for this interaction. Small dimensions of actual contact areas are the cause of a considerable growth of stresses and temperature on certain roughnesses peaks; furthering generation of intense deformation processes in the surface layer, and elastic strain waves in particular. Elastic strains are amongst the principal sources of acoustic signal generation [1]. The development of elastic variations in the process of sliding friction is connected with plastic shears and twinning, intergranular sliding in a polycrystalline object, phase transformations and fractures, involving micro-cracks and separation. In conditions of friction the surface layer of a metal is subject to changes, caused by the accumulation of defects, formation and further fracture of a defect structure layer, this sequence recurs then. As these phenomena occur, the elastic deformations are formed with a varying intensity, changing, therefore, the acoustic emission intensity as well [2].

* Corresponding author: D V **Lychagin** - dvl-tomsk@mail.ru

IOP Conf. Series: Materials Science and Engineering **142** (2016) 012098 doi:10.1088/1757-899X/142/1/012098

The detailed study, based on experimental testing, of all formation and fracture phases in the surface layer seems to be impossible, since the contact area of objects in a tribounit is inaccessible for direct observation. Hence, additional research procedures are required, capable of direct or indirect providing information on phenomena, occurring in a tribounit. One of these procedures is to register acoustic emission (AE) signals in the process of friction. Registration and analysis of AE signals is widely used to study strain and fracture in materials that are loaded statically and dynamically [1-2]. At the same time one should take into account the diverse spectrum of acoustic variations typical for the dynamic processes, such as friction. These phenomena include both processes related to the surface evolution under friction and variations of tribounit elements. The AE spectrum includes sound and ultrasound range frequencies, distinguished by random and periodic character, dependent on loading conditions and friction regimes [3]. A number of diverse phenomena with various frequency and intensity occur on the contact areas over the period of registering a single signal (frame) of acoustic emission [3].

The authors of papers [4-8] studied in details AE signals, arising in the process of friction. AE signals versus type (and quantity) of generating wear particles [4]; wear mechanism [5-7]; and the state of friction surface correlation dependence was determined [8]. However, despite the works mentioned above, additional experiments, reproducing various aspects of friction and material states in condition of frictional interaction are necessary because of diverse phenomena, occurring in the process of friction. One of the aspects in focus of researchers is strain hardening of metals and alloys. It is interesting to study as a typical example Hadfield steel, distinguished by the high level of strain hardening under static compression, tension, torsion, and impact test [9-16].

The relation of AE signals to friction specifics of polycrystalline Hadfield steel has been already studied [3, 17-18]. The authors [17] have revealed the influence of AE signal parameters on friction behavior and wear. When forming the surface layer fiction factor is increased together with the growing median frequency of AE signal, which is conditional on origination of high-frequency components in the signal spectrum. The friction factor, median frequency and AE energy signals diminish as the surface layer fractures and wear particles are separated. On the base of frequency and time analysis [18] it is revealed that quasi-periodic bursts of AE intensity are interrelated with formation of wear particles. Since analysis and interpretation of AE signals generated in the process of friction are complex, there is a necessity to search for experimental procedures, reproducing certain material behavior in conditions of friction. One of these procedures is based on the use of single crystals, which makes it possible to control their strain behavior via selecting the crystal-lattice orientation and loading conditions.

The aim of the work is to study how generation of AE signals is related to deformation processes in Hadfield steel single crystals, arising in the surface and subsurface layers under dry sliding friction.

2. Methods of research

Single crystals are grown by Bridgman technique in helium atmosphere and homogenized in a noble gas for 24 hours at 1373 K. The specimens were cut by an electroerosion machine. As cutting out is completed, orientation of contraction axis in a single crystals is $[\overline{10}\,\overline{7}\,\overline{1}]$ and that of friction axis is $[\overline{3}\,4\,2]$. The specimen dimensions: height (L) – 10 mm; width (b) and thickness (a) – 1.3 mm. Cut out specimens are stored in helium atmosphere for an hour at 1050˚C and water-tempered to fix the austenite structure. The defect surface layer is removed via grinding. The hardness of a tempered single crystal is 180 HV. Sliding friction of single crystals is carried out by a tribotester TRIBOtechnik according to the scheme "pin – on – disk" (see Figure 1) at ambient temperature 25˚C. The normal load is 4 N (2.3 MPa, taking into account the friction surface area); sliding speed is 0.1 m/s. Each of three trials lasts 3 hours. A counterbody is a steel 40X disk with hardened surface, the hardness of which is 36 HRC. The friction surface topography of Hadfield steel single crystals and wear grooves on the counterbody are studied by confocal laser scanning microscope LEXT OLS4100. The parameters of AE signals, generated in the process of sliding friction are analyzed by a registering module EYA-2 (ЭЯ-2) developed at Togliatti State University.

IOP Conf. Series: Materials Science and Engineering **142** (2016) 012098 doi:10.1088/1757-899X/142/1/012098

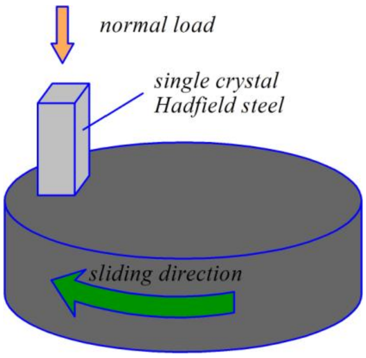
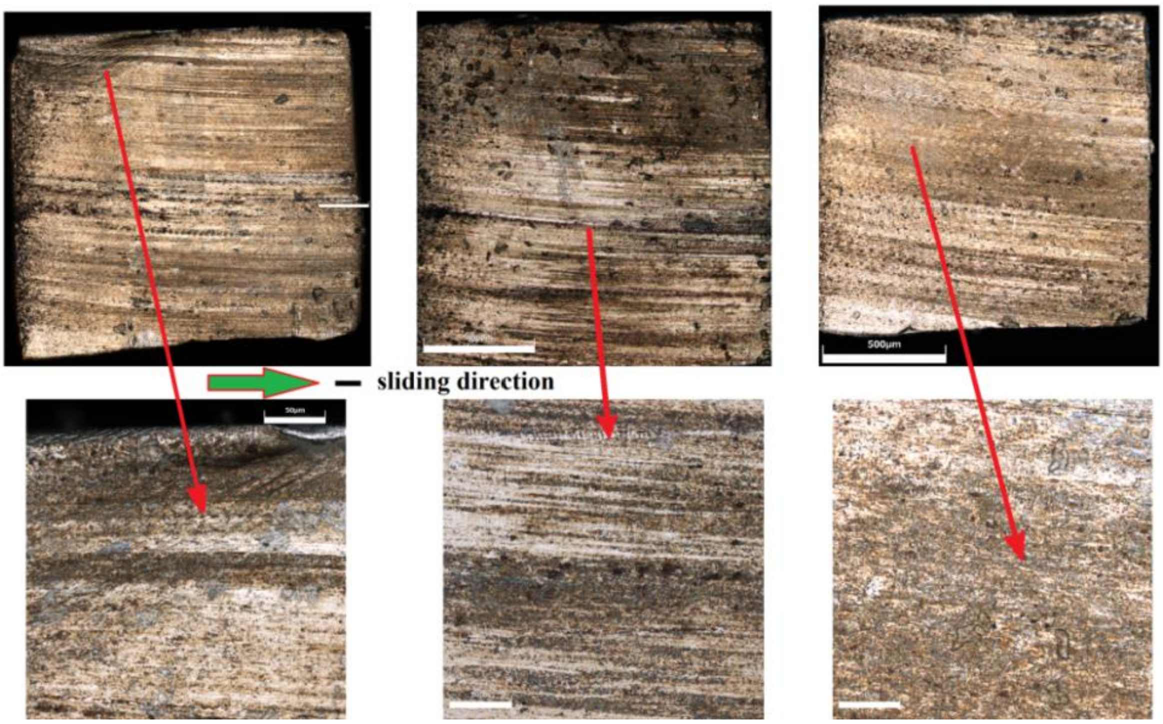


Figure 1. Scheme of «pin-on-disk» friction test

3. Results and discussions

The images of friction surfaces of Hadfield steel single crystal tested three times are shown in Figure 2.



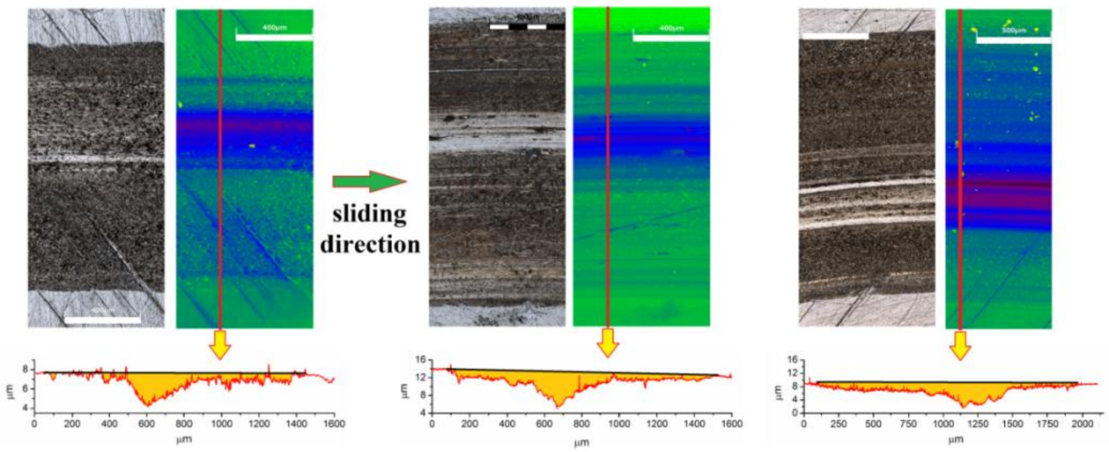
a) b) c)

Figure 2. The friction surface of Hadfield steel single crystal: (a) - the first trial, (b) - the second trial, (c) the third trial

As the first trial is completed, there is a small area with strained relief on the friction surface. The surface roughness Sa=0.12 μm. After the second trial there are no strain lines (wrinkles) on the tested surface, the surface roughness rises up to Sa=0.35 μm. Moreover, there is some craterlike wear debris on the surface, which can be referred to oxidative fatigue wear. After the third trial abrasive and oxidative wear scars can be seen on the tested surface as well. The surface roughness Sa=0.5 μm.

The images of friction track surface on the counterbody after three trials are presented in Figure 3, the heights are distributed and typical profile of its cross section is given.

IOP Conf. Series: Materials Science and Engineering **142** (2016) 012098 doi:10.1088/1757-899X/142/1/012098



a) b) c)

Figure 3. Images of the friction track, distribution of heights and cross section profile after the first (a), second (b) and third (c) trials.

The friction track profile on the counterbody is a non-uniform one in the cross section after the first trial, its area is 1100 μm^2, and the maximal depth is 3.6 µm. After the second trial the sectional area of the friction track rises up to 3500 μm^2, and the depth is 9.8 µm. The third trial results in the increase of the friction track sectional area up to 4400 μm^2, although the profile depth diminishes to 7 µm. The sectional area of the friction track increases due to gradual but non-uniform wear of the counterbody surface. The decrease of the track depth is conditional, in its turn, on more uniform wear depth distribution in the track section as testing gets longer.

The graphs, displaying varying friction factor value and AE waveform envelope are given in Figure 4.

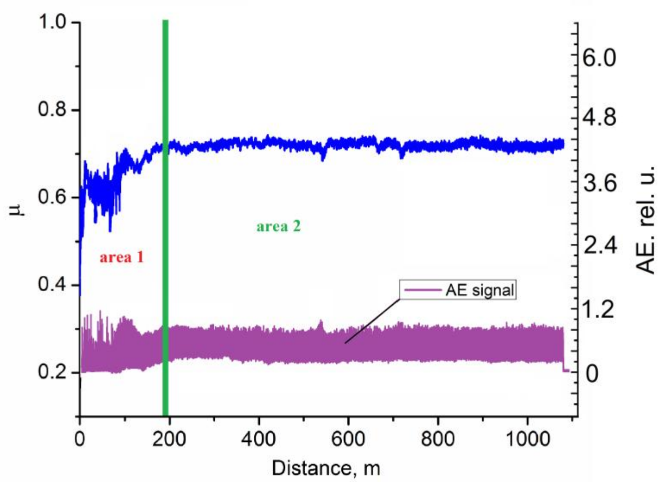


Figure 4. The change of friction factor over the three sequential trials and typical form of the waveform envelope of AE signal

Significant variations of friction factor values and AE signals are typical for the run-in area («area 1» see Figure 4). The value of AE signal waveform envelope rises because of the growing number of deformation events when running-in a tribounit. These strains are caused by intense formation and fracture of contact areas, separation and detachment of wear particles. In the area of stable friction («area 2» see Figure 4) slight variations of friction factor and AE signal are registered.

Periodic variations of friction factor are interconnected with the oxidative mechanism of the specimen wear. In the process of friction the surface layer of a specimen is deformed and a fine strain

IOP Conf. Series: Materials Science and Engineering **142** (2016) 012098 doi:10.1088/1757-899X/142/1/012098

structure is formed. Accumulation of some strain results in failure of this layer and separation of tiny oxide and metal particles (see Figure 5).

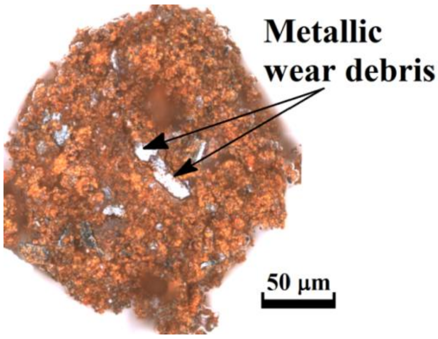


Figure 5. Optical image of wear particles

When analyzing frames of the registered AE signal in more details, it is revealed that type and amplitude-frequency characteristics of signals differ much in the areas of run-in and stable friction. A typical AE signal registered in the run-in area of a tribounit, intensity of the spectrum power and varying central frequency of signal are shown in Figure 6. Central frequency varies in the range 130...225 kHz. The highest intensity of the spectrum power (50 rel. u.) is in the frequency range ~175 kHz. In the area of stable friction the frame of AE signal consists of a sequence of AE peaks with various amplitudes (see Figure 7). The highest spectrum power intensity of this frame is twice as low as that of the frame in the run-in area of a tribounit. The central frequency of AE signal frame is in the range 125...305 kHz. The frame segment with a highlighted sequence of peaks agrees with the area of falling central frequency of signal (see signal area in Figure 7).

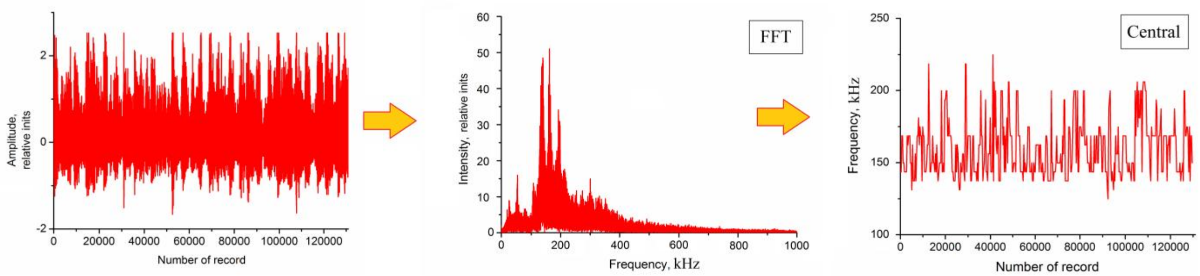


Figure 6. Typical AE signal in the run-in area in the process of Hadfield steel single crystals

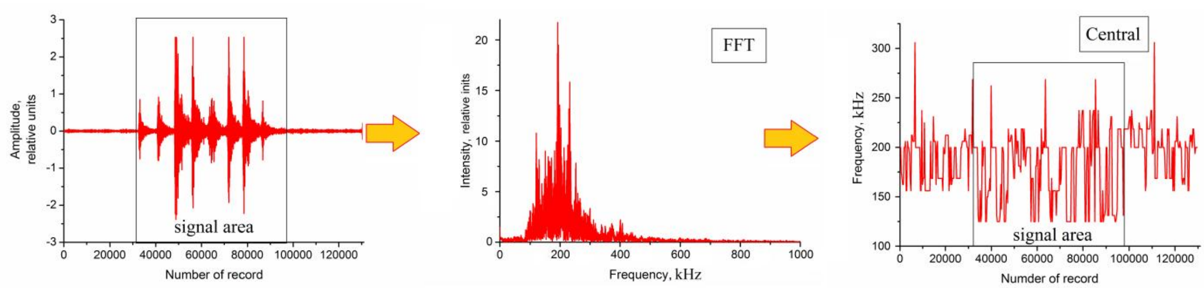
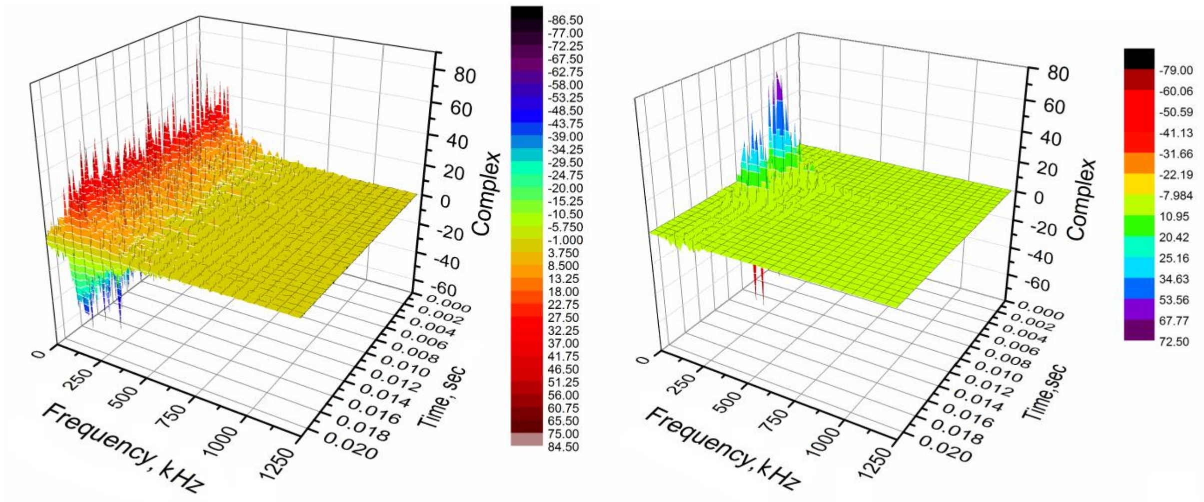


Figure 7. Typical AE signal in the stable friction area of Hadfield steel single crystals

The frequency-time analysis based on STFT (Short Time Fourier Transform) provides a more detailed visual image of varying frame frequency of AE signal over the period of its registration. Images of STFT AE signals in the areas of run-in and stable friction are given in Figure 8. As one can see in the presented graphs, frame frequencies of AE signal in the run-in area are distributed quite uniformly with well pronounced peaks over the whole period of time. At the same time only two pronounced AE signal frequency bursts are registered in the area of stable friction, they decay quickly in the frequency range 250…500 kHz, but drag on up to 1 MHz.



a) b)

Figure 8. Short time Fourier transform of AE signals in the run-in (a) and stable friction (b) areas

4. Conclusion

The experimental research into sliding friction of Hadfield single crystals based involving registration of AE signals allows of the following conclusions:

1. In the process of friction the fine surface layer of Hadfield steel is deformed and typical strain structures alongside with wear particles are formed.
2. A run-in to stable friction area transition moment of a tribounit can be detected quite precisely using registration of AE signals.
3. Amplitude-frequency characteristics of typical AE signals, generated in a tribounit at various wear phases are determined when analyzing AE signal frames relying on FFT and STFT.
4. The obtained results can be used for the development of a system to monitor the condition of a tribounit.

Acknowledgments

The reported study was partially supported by RFBR, research project No. 16-08-00377 a. The authors wish to thank Prof. Yu. I. Chumlyakov for providing test samples.

References

[1] Christian U and Ohtsu G M. 2008. *Acoustic Emission Testing*. (Springer)
[2] Baranov V, Kudryavtsev E, Sarychev G and Schavelin V 2007. *Acoustic emission in friction* (Elsevier)
[3] Rubtsov V E, Kolubaev E A, Kolubaev A V and Popov V L 2013 *Tech. Phys. Let.* **39 2** 223-225
[4] Haze A, Wada M and Mishina H 2008 *Wear* **265** 831-839
[5] Haze A, Mishina H and Wada M 2013 *Wear* **308** 142-147
[6] Haze A, Mishina H and Wada M 2012 *Wear* **292-293** 144-150
[7] Haze A, Wada M and Mishina H 2014 *Tribol. Int.* **72** 51-57
[8] Haze A, Mishina H and Wada M 2009 *Journ. of Adv. Mech. Design* **3 4** 333-344

[9] Karaman I, Sehitoglu H and Chumlyakov Yu I 1998 *Scr. Mater.* **38 6** 1009-1015
[10] Chumlyakov Yu I, Kireeva I V, Litvinova E I, Zakharova E G, Luzginova N V, Karaman I and Sehitoglu H 2000 *The Phys. of Met. and Metallography* **90 1** 1-17
[11] Karaman I, Sehitoglu H, Gall K and Chumlyakov Yu I 2000 *Acta Mater.* **48** 1345-1359
[12] Karaman I, Sehitoglu H, Beaudoin A J, Chumlyakov Yu I, Maier HJ and Tome C.N. 2000 *Acta Mater.* **48** 2013-2047
[13] Karaman I, Sehitoglu H, Chumlyakov Yu I, Maier H J and Kireeva I V 2001 *Metal. Mater. Trans. A.* **32A.** 695-706
[14] Karaman I, Sehitoglu H, Chumlyakov Yu I, Maier H J and Kireeva IV 2001 *Scripta Mater.* **44** 337-343
[15] Gumus B, Bal, B, Gerstein G, Canadic D, Maier H J, Guner F and Elmadagli M 2015 *Mat. Sci. Eng. A.* **648** 104-112
[16] Astafurova E G, Tukeeva M S, Zakharova G G, Melnikov E V and Maier H J 2011 *Mat. Charact.* **62** 588-592
[17] Kolubaev E A, Kolubaev A V and Sizova O V 2010 *Tech. Phys. Let.* **36 8** 762-765
[18] Dobrynin S A, Kolubaev E A, Smolin A Y, Dmitriev A I and Psakhie S G *Tech. Phys. Let.* **36 7** 606-609