STRUCTURAL REGULARITIES OF THE ACOUSTIC EMISSION SIGNAL GENERATION IN STEEL

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Introduction

The research is dedicated to the study of connection between the parameters of acoustic emission (AE) signals and the size of cracks and grains at steel deformation.

Various researchers suggest the importance of grain borders, as the sources and blockers of micro-cracks. But there is no consensus on the element of structure, which is responsible for the formation of micro-cracks. The majority of researchers confine themselves to the study of the middle size grains connection with the strength and plastic properties. Therefore, the study of size influence of different components of polycrystalline structure on the size of forming micro-cracks was of particular interest. In the meantime, it was necessary to find out, whether the connection between the size of micro-cracks and the amplitude of AE signals remained the same at the change of the grain's size. The preservation of such connection would confirm its justness and would show that the basic source of discrete AE in constructional steels is the formation of micro-cracks.

Results

Many researchers have proven the importance of steel grain boundaries as sources and stoppers of microfractures [1]. However, there is no one single opinion on what particular structural element is responsible for appearance of microfractures. The majority of researchers limit themselves to studying the medium-sized grain and its relevance in connection to structural behavior and plastic properties [2]. For that reason the research of correlation between the size of various components of the polycrystalline structure and the size of appearing microfractures was of much interest. Simultaneously, it was necessary to find out if the correlation between microfracture size and AE signal amplitude would remain should the grain size be changed. Preservation of such correlation would prove its validity and display that the main source of quantified AE in sectional steel is the appearance of microfractures.

The study of correlation between the size of microfractures that appear during straining of sectional steel and the sizes of structural grain, is conducted using the steel 08ГДНФЛ that underwent various modes of heat treatment.

Three modes of heat treatment were used to modify the grain size:

1. Heating up to 800 °C, 4 hour-long soaking, air cooling.
2. Heating up to 1050 °C, 4 hour-long soaking, air cooling.
3. Heating up to 1100 °C, 5 hour-long soaking, furnace cooling.

The acquired perlite-ferrite structure is shown in figures 1-3.

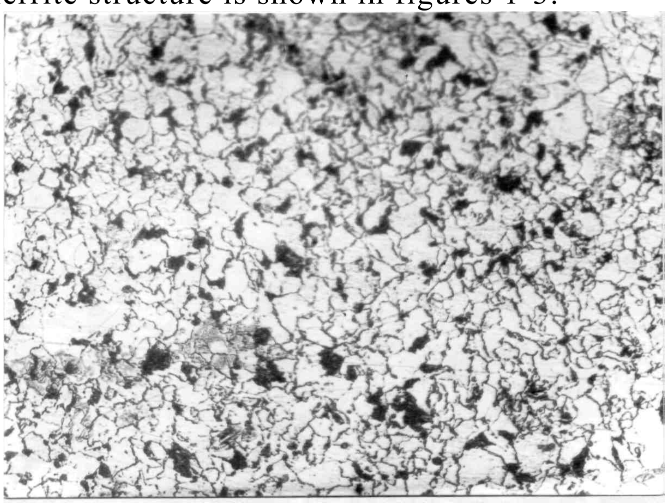

Fig. 1.Microstructure X250. First treatment.

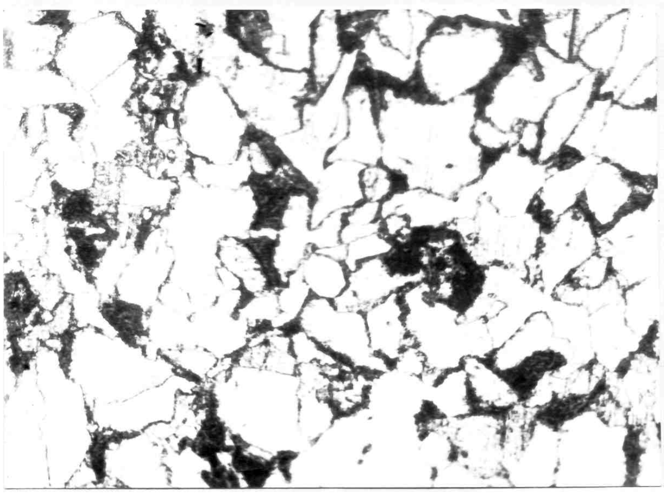

Fig. 2. Microstructure X250. Second treatment.

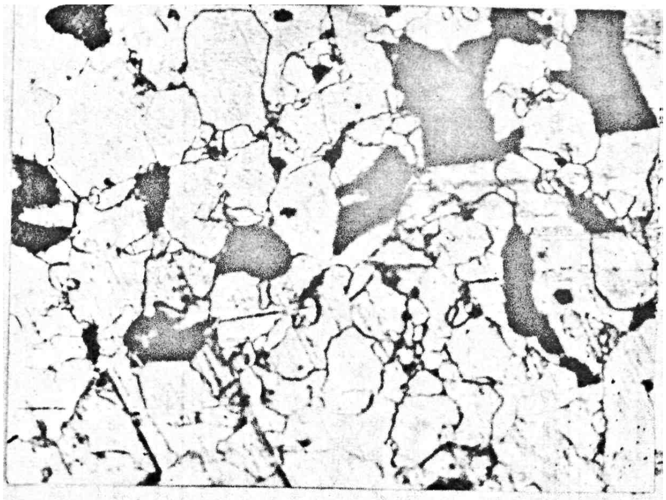

Fig. 3. Microstructure X250. Third treatment.

The measurement of structural element size was conducted using the Spector chord method [3].The way of ferrite grain and perlite colony distribution for chords and diameters on the work pieces processed using the second mode of heat treatment, is shown in figures 4-5.

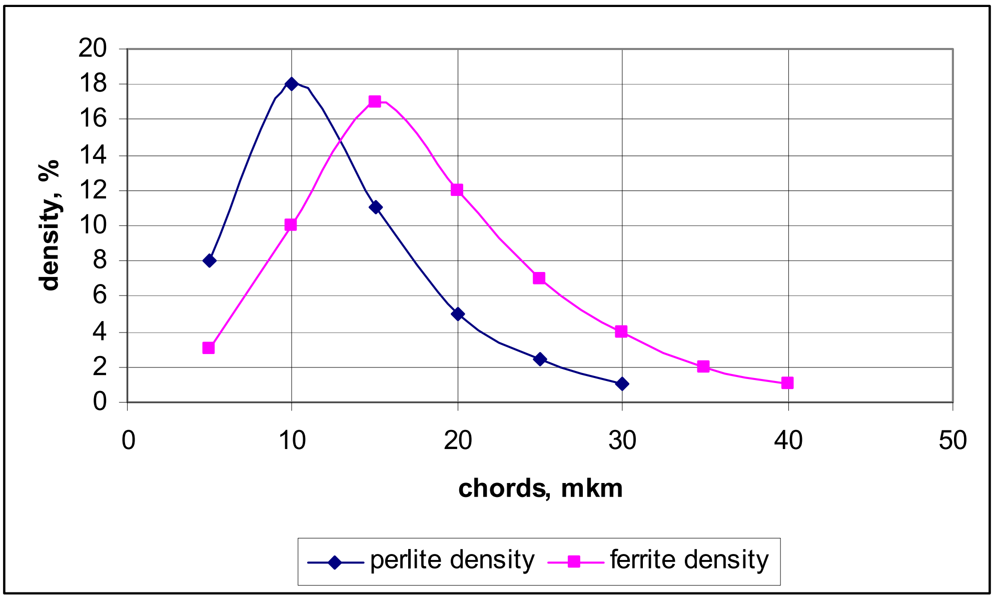

Fig. 4. Chord length distribution of perlite and ferrite grains. Second treatment.

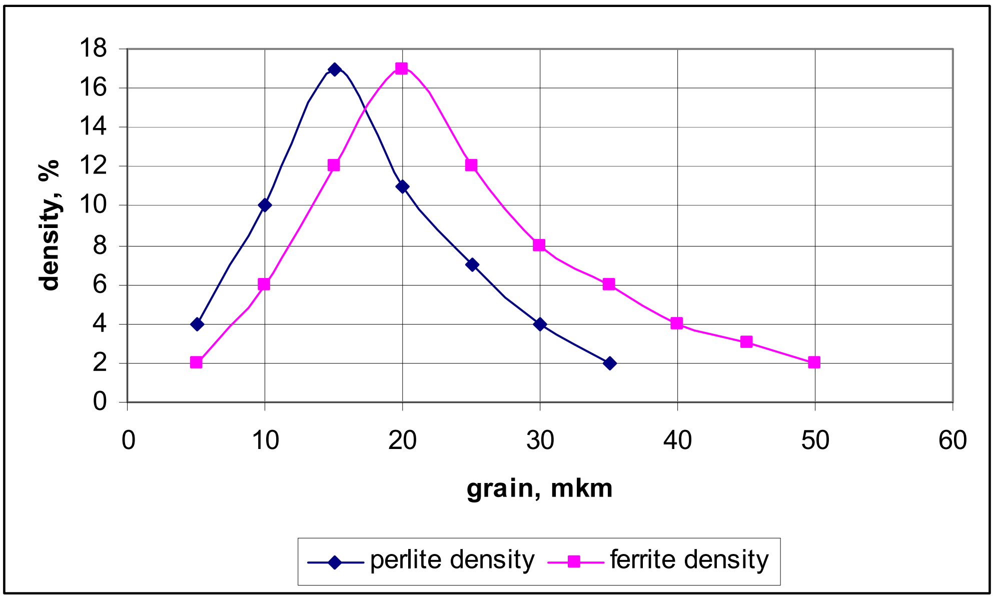

Fig. 5. Diameter length distribution of perlite and ferrite grains. Second treatment.

The figures show that in this case the ferrite grain sizes exceed the sizes of perlite colonies. Additionally, which was to be expected, the grain size exceed the chord size at every structural element.

The statistical data that allows describing these distributions for all modes of heat treatment are available in table 1.

To study the influence of steel structure on microfracture size and AE signal amplitude we conducted testing of samples for straining in three batches. Sample testing was carried out using the "IMASH" device, which allowed applying straining at a permanent speed and monitoring the sample surface in a microscope.

Special samples with ducts at grip portions were prepared for registering AE. The face side of the sample was brushed up for microscope monitoring.

Table 1

Statistic parameters of grain length distribution

Treatment	Structure parameter	Maximum probable grain length, mkm	Average grain length, mkm	Standard deviation, mkm
1	Fh	6	9	2
1	Fd	7	11	2
2	Fh	10	21	3
2	Fd	14	21	6
2	Ph	7	13	3
2	Pd	10	15	3
3	Fh	16	30	8
3	Fd	27	35	7
3	Ph	21	35	5
3	Pd	29	43	6

Fh - Chord length distribution of ferrite grains,
Fd - Diameter length distribution of ferrite grains,
Ph - Chord length distribution of perlite grains
Pd - Diameter length distribution of perlite grains

Usage of a two-channel AE devices helped determine the emission source coordinates and define the control area on the working face of the sample. The introduction of control area allowed for exclusion of gripping noise and conduction of amplitude analysis only of those signals that came from the test portion of the sample.

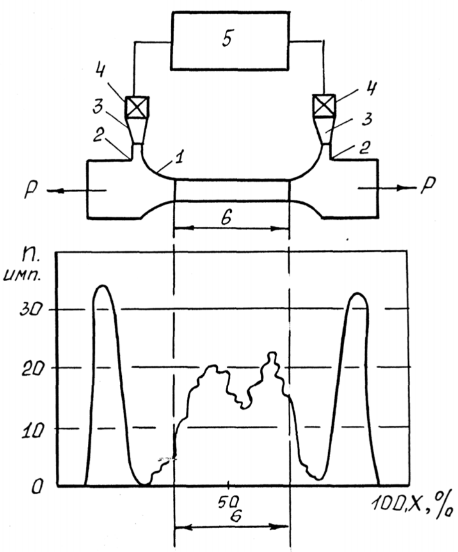

Fig.6. IMASH engine testing scheme and AE pulse displacement distribution.

1- spacemen, 2 – waveguide, 3 – cone, 4 – AE transducers, 5 – AE system, 6 – control zone.

The samples were strained to the yield limit of the material

Appearing microfractures were measured in sample with no strain removal (fig. 7); we registered all microfractures starting from the size of 2 micrometers. The example in figure 8 shows size distribution of microfractures in a sample from batch #2 that was processed using the second mode of heat treatment.

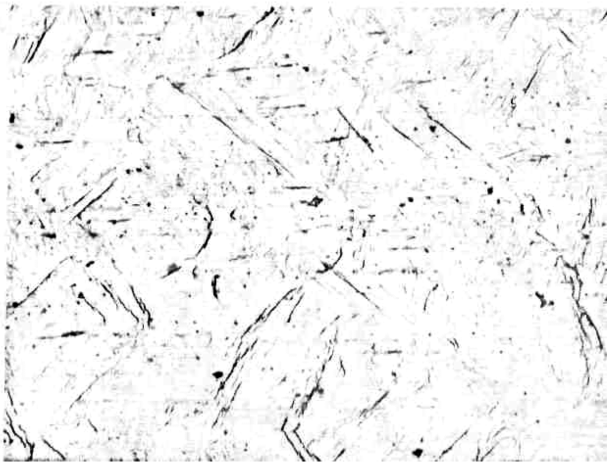

Fig 7. Microcracks on polished specimen surface.

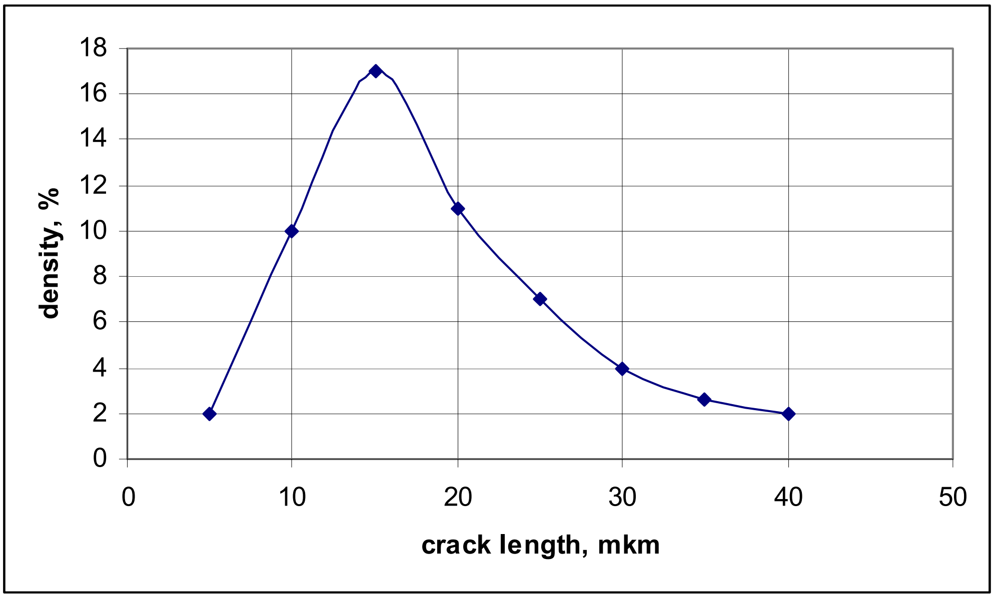

Fig.8. Microcracks length distribution in strained specimen. Second treatment.

Parameters for the size distribution of microfractures are displayed in table #2.

Table 2

Statistic parameters of crack length distribution

Treatment	Maximum probable grain length, mkm	Average grain length, mkm	Standard deviation, mkm
1	7.5	10	2
2	14	19	6
3	17	27	8

To compare the microfracture distribution with size distribution of structural elements we used the Kolmogorov criterion described in [4]. Each distribution was divided into 30 equal intervals. In a turn-based fashion the structure element distribution was cumulatively compared to the microfracture distribution, taken as a benchmark. The normalized maximum deviation λ between two distributions and the probability P (λ) to have the deviation value exceeding λ, are displayed in table 3.

The table shows that in all three cases the microfracture distribution is equal in size to the ferrite grain chord distribution. The microfracture distribution is similar to distribution of random chords, since a microfracture is in essence a random plane dividing a grain in two. This plain is not necessarily a longitudinal central plane. Therefore its trace on the surface of a metallographic specimen is a random chord

Table 3

Maximum normalize deviation value between cumulative microcrack distribution and structural length distribution

Treatment	Structure parameter	λ	P(λ)
1	Fh	0.64	0.8
1	Fd	0.78	0.6
2	Fh	0.52	0.9
2	Fd	0.75	0.65
2	Ph	1.35	0.05
2	Pd	0.86	0.5
3	Fh	0.6	0.9
3	Fd	1.8	0.003
3	Ph	1.12	0.15
3	Pd	2.36	0.001

It is known that in the majority of cases size distribution of grain obeys to a logarithmically normal law:

$$\psi(d) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\left[\frac{(\ln d - \ln d_0)^2}{2\sigma^2}\right]} \qquad \{1\}$$

We have tried to describe size distribution of ferrite grain and microfractures in a formula {1}. For that empirical relations (fig. 4, 5, 8) were reformed in a logarithmic scale along the size axis. Using standard formulas we calculated the average logarithm of size for elements, chords, microfracture length and dispersion. Using the acquired parameters for each experimental distribution, we formed a theoretical logarithmically normal distribution and made their comparison using the Kolmogorov criterion. For all distributions the maximum normalized deviation λ never exceeded 0,3. It goes to show that these distributions are described using a logarithmically normal law, with the probability value of 1,0.

Now let us go examine the data on AE signal amplitude distribution, acquired from the control area of the samples during their straining. The amplitude distribution of signals was visually similar to AE signal distribution, acquired earlier using the steel type 25 ХН3МФА. Using the method described in [4] we approximated the amplitude size distribution of fractures using the function:

$$f_1(A) = C_1 A^{C_2} \qquad \{2\}$$

$$f_2(L) = C_3 L^{C_4} \qquad \{3\}$$

The coefficients for the three batches of differently heat-processed samples, calculated using the least square method are displayed in table 4.

Using these coefficients, we calculated the dependences of AE signal amplitude on the size of appearing microfracture and presented them below in the order of increasing of heat processing mode number:

$$A = 0.03L^{1.38} \qquad \{4\}$$

$$A = 0.01L^{1.64} \qquad \{5\}$$

$$A = 0.01L^{1.68} \qquad \{6\}$$

Table 4

Degree dependence coefficient value for 2 and 3 form

Treatment	$f1(A)=C_1*A^{C_2}$		$f2(L)=C_3*L^{C_4}$	
	C1	C2	C3	C4
1	2.8	-2.6	2.5	-3.21
2	1.3	-2.25	2.6	-3.05
3	0.7	-1.9	2.2	-2.49

In these formulas the fracture length is expressed in microns and the AE signal amplitude is expressed in microvolts. The exponent was calculated using the regular method described in [4]. The multiplying constant was deduced from the minimal registered size of a microfracture, which was for this instance changed from 38 microns to 45 microns, and the minimal registered signal amplitude, which for this device constituted 5 microvolts. All the acquired formulas, without major mistake, can be replaced with one formula:

$$A = 0.02L^{1.5} \qquad \{7\}$$

which offers satisfactory description for all the empiric results.

Conclusions

The existence of a uniform dependence of AE signal amplitude on the appearing microfracture size and the size of structural elements, confirms the conclusion that the main AE signal source in sectional steel is the appearance of microfractures; the microfracture size distribution behavior and, accordingly, the amplitude distribution of AE impulses, is defined by the size distribution of structural elements.

Bibliography

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