

# Metallographic studies of vessel steel samples: ДС, 35Г / 40Г and steel 20 by fractal analysis

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**Abstract — Metallography is a complex of studies and a number of analytic actions focused on the research (investigation) of macro- and micro-structures of metals as well as the research of the mechanism of metal structure formation, and dependence of structure influence on the metal characteristics. Thus the objective of this paper research is to find the interconnection between the data received for the structures with the help of the metallographic analysis and the method of fractal analysis.**

**Keywords — metallography; steel; fractal; analysis; structure; metal;**

## I. INTRODUCTION

Metallographic study of the samples needs enough accuracy while selecting them, their preparation, polishing and pickling samples and while studying samples' structure [1]. Traditional methods of macro- and micro-analysis are widely used while studying metal structure and its effect on the metal characteristics [2]. In the article we also demonstrate the method of fractal analysis, that allows to define micro-/macro-photography of the structure by introducing the volume of fractal dimension. Fractal dimension of a quantity was introduced by B.B. Mandelbrot and was used to study the metal surface fracture [3, 4]. Fractal analysis method was successfully used while studying the process of metals and alloys cracking [5].

Fractal geometry methods were effective for the analysis of self-structuring phenomena in dissipative systems and made it possible to discover changes in the fractal dimension of a quantity with the metal characteristics [6].

In our article we are studying the metallographic pattern of samples structure and its fractal dimensions. The samples were cut out from some points of the objects from the vessel steel Дс, 35Г/40Г, 20. Two types of samples were used: sample  $D_i$  from the place deformation free/having minimum deformation, sample  $W_i$  from the place having the deformation. All the samples had been manufactured under the standard technique using diamond pastes of different dispersivity. Then the samples were analyzed for "contaminants" – content of nonmetallic inclusions. The decisive role in the process of studying the nonmetallic inclusions effect on steel quality has their size, form, chemical and physical characteristics, as well as their location in relation to the grains of the casted meal. The mentioned above inclusions properties depend on the steel chemical characteristics, method of its melting. Moreover, these factors can change in a wide range even while using the same method of steel production.

The traditional method to control the inclusions fraction is to analyze macro- and micro-sections of the specific size from the particular point of the cut-out by light microscopy. The size calculation and evaluation are made by hand. The metallographic analysis was conducted on "Neophot-32" microscope under different increments. To detect the micro-structure we used etching in 4% solution of nitric acid in spirit.

## II. MATERIALS AND METHOD

Nonmetallic inclusions appear as a result of a number of physical and chemical phenomena that take place in a melted or solidified metal in the

process of its manufacturing. Nonmetallic inclusions in steel are alien bodies that destruct its structure homogeneity. That is why, their effect on mechanical and other properties can be rather significant.

The calculation of nonmetallic impurities in the metal samples was delivered according to State standard GOST 1778-70 ("Steel. Metallic methods of estimation nonmetallic inclusions") [7], by comparing with the standard scales on the polished not etched surface of the micro-section of the metallographic specimen under the 100-magnification [7].

First, 12 samples were cut out. At the first stage they were studied on one of the axes (plane perpendicular to the axis) (Fig.1) for having nonmetallic inclusions.

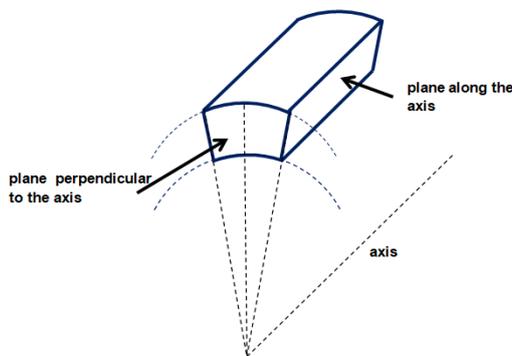


Fig.1. Study of the sample cut out from one of the sides.

From the data data certificate of the object we took the results of the spectrum analysis given by the plant-manufacturer (Table 1) and the results received in the Laboratory of Chemical Analysis of the E.O.Paton Electric Welding Institute (Table 2).

Table1. The results of spectrum analysis of sample metals

Percentage of fraction of total mass									Steel
C	Si	Mn	S	P	Cr	Ni	Cu	Mo	
0,43-0,53	0,17-0,37	0,7-1,0	<0,045	<0,045	<0,35	<0,25	-	-	Д, Дс, ТУ 14-157-15
0,32-0,40	0,17-0,37	0,7-1,00	<0,035	<0,035	<0,30	<0,30	<0,30	-	35Г, ГОСТ 4543-71
0,17-0,24	0,17-0,37	0,35-0,65	<0,040	<0,035	<0,25	<0,30	<0,30	-	20, ГОСТ 1050-88

### III. RESULTS AND DISCUSSION

From the vessel steel samples we cut out the samples which then were studied with the help of spectral analysis. The results were then compared with the State standard GOST (Table1, Table 2).

For one of the samples (D<sub>3</sub>) fractal dimensions were calculated by the method of fractal analysis under different increases (Fig.2).

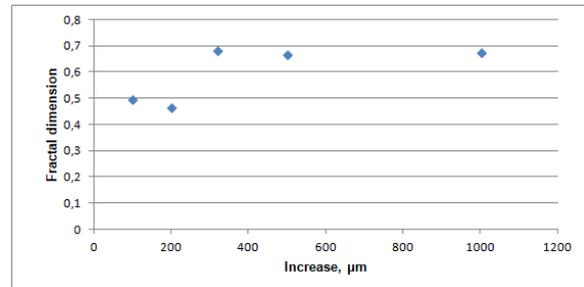


Fig.2. Dependence of fractional dimensions on sample structure increase.

These data show the clear picture of the range where fractional dimension is invariant. Thus, while comparing, it is worth working with the pictures taken under similar multiplication.

Table2. The results of the spectrum analysis of the samples metal (experimental data)

Percentage of fraction of total mass									Steel/ Sampl e	
C	Si	Mn	S	P	Cr	Ni	Cu	Mo		
0,512	0,512	0,336	0,54	0,027	0,014	0,140	0,128	0,362	Дс/ D <sub>1</sub> W <sub>1</sub>	
0,563	0,563	0,311	0,84	0,032	0,009	0,117	0,150	0,169	Дс/ D <sub>2</sub> W <sub>2</sub>	
0,40	0,40	0,32	0,94	0,023	0,030	<0,1	0,05	0,056	35Г(40 Г)/ D <sub>3</sub> W <sub>3</sub>	
0,36	0,36	0,32	0,85	0,025	0,017	0,073	0,027	0,045	0,009	35Г/ D <sub>4</sub> W <sub>4</sub>
0,19	0,19	0,29	0,54	0,02	0,011	0,07	0,05	0,08		20/ D <sub>5</sub> W <sub>51</sub> W <sub>52</sub> W <sub>52</sub>

Then the sample was grinded and polished with the following estimation of the nonmetallic inclusions. The received photographs under the increases of 200 were used for the investigation of 'impurity'. The

fractal dimensions were calculated for the received photographs (Table 3.).

Table3. Fractal dimensions data for each sample.

Sample number	Fractal (fractional) dimension, D
D <sub>1</sub>	0,482
W <sub>1</sub>	0,397
D <sub>2</sub>	0,382
W <sub>2</sub>	0,464
D <sub>3</sub>	0,498
W <sub>3</sub>	0,254
D <sub>4</sub>	0,538
W <sub>4</sub>	0,444
D <sub>5</sub>	0,302
W <sub>51</sub>	0,558
W <sub>52</sub>	0,715
W <sub>53</sub>	0,506

The impurity of non-metallic inclusions under State standard GOST 1778-70 is given below:  
**Sample D<sub>1</sub>.** Most inclusions are pointed oxides. The impurity with them corresponds to mark №1 in 'a' line on the scale "pointed oxides". It is worth mentioning that on the sample edge on one side the number of such type oxides increased up to the mark 3a-4a. The following types of inclusions can also be observed:

Sulphides extended along the 2б mark of rolled products (sometimes 3б) on the scale "lined sulphides".

Sulphides having the fibre form seen under huge increments (x1000).

Sulphides with the oxides inclusion (they are oxisulphides).

Dispersed silicates of the tubular form in a small amount.

Lined oxides: mark 0, sometimes 1a (rarely).

**Sample W<sub>1</sub>.**

Pointed oxides: mark 1a in the sample centre and 3a-4a on the edge.

Lined oxides: mark 0, sometimes 1a (rarely).

Lined sulphides: mark 3б.

Sulphides with the inclusions of oxides, sulphides of the fibre form.

Dispersed silicates of the tubular form in a small amount.

**Sample D<sub>2</sub>**

Pointed oxides: mark 1a

Line oxides: mark 0 (rarely 1a)

Lined sulphides: mark - 3 б

Sulphides of the fibre form (x1000)

Oxisulphides

Dispersed silicates of the tubular form in a small amount.

**Sample W<sub>2</sub>**

Pointed oxides: mark 1a

Lined oxides: less than 1a ("0")

Lined sulphides: mark - 3 б

Sulphides of the fibre form (x1000)

Oxisulphides

Tobular-dispersed silicates – rarely.

In samples D<sub>3</sub>, W<sub>3</sub>, D<sub>4</sub>, W<sub>4</sub> (35Г/40Г) we found complex sulphides of iron and manganese expanded (prolonged, stretched) along the rolled stock. Such inclusions prevail. We could also observe the oxides in the form of lines and in different location. Under the increment of 500-1000 sulphides in the fibre form, oxisulphides and dispersed inclusions of tobular silicates were found.

**Sample D<sub>3</sub>**

Pointed oxides: mark less than 1a ("0")

Lined oxides: mark 2a (chains of oxides)

Lined sulphides: mark 3a-3б (sometimes 4a)

**Sample W<sub>3</sub>**

Pointed oxides: mark less than 1a

Lined oxides: mark 2б (sometimes 3a)

Lined sulphides: mark 2б (sometimes 3a)

**Sample D<sub>4</sub>**

Pointed oxides: mark less than 1a

Lined oxides: mark 2a

Lined sulphides: mark 3б

It is important to note that oxisulphades can hardly be found in this sample

**Sample W<sub>4</sub>**

Pointed oxides: mark less than 1a ("0")

Lined sulphides: mark 3б

Lined oxides: mark 1a (chain of oxides)

The description of non-metal inclusions in samples D<sub>5</sub>, W<sub>51</sub>, W<sub>52</sub>, W<sub>53</sub> (steel 20)

The main part of these inclusions is oxides inclusions of the uniform location. We found also oxisulphides, sulphides stretched along the rolling stock, globular silicates in small amount, single nitrides and oxinitrides of the regular geometric shape. Lined oxides were not found.

**Sample D<sub>5</sub>**

Pointed oxides: mark 3a in the centre and 4a on the edge

Lined sulphides: mark 1a

**Sample W<sub>51</sub>**

Pointed oxides: mark 2a (sometimes 3a)

Lined oxides: mark 1б (rarely) and in some the most "contaminated" places lined sulphides had mark 1a or less ("0")

**Sample W<sub>52</sub>**

Pointed oxides: mark 3a  
 Lined sulphides: mark 1a

**Sample W<sub>53</sub>**

This sample was very “pure” as for the non-metal inclusions. Impurity for all the types of inclusions was less than in the State standard GOST.

Under the increments of 500-1000 dispersed oxides, tubular silicates and oxisulphides were found.

**CONCLUSIONS**

In our study a set of tests and analytical procedures was carried out. The main focus was on the investigation of macro- and micro-structures of metals.

The results of the conducted investigation are the following: samples spectrum analysis was carried out (Table 2); the dependence of fractal dimensions on the increases was analyzed (Fig. 2); fractal dimensions were calculated (Table 3), the dependence of fractal dimensions on non-metal inclusions was analyzed (Fig.3, Fig.4), as well as the dependence of fractal dimensions on the wall thickness.

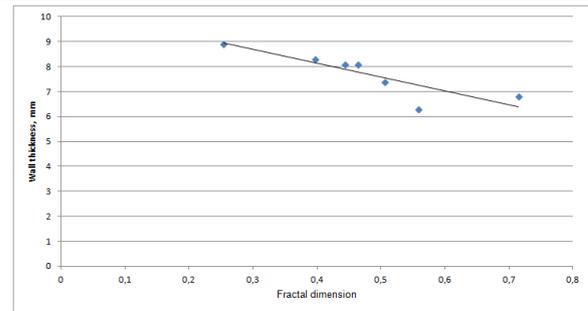


Fig.5. The interdependence between the wall thickness and the fractal dimensions.

During the investigation it was found out that fractal dimensions change according to the non-metal inclusions for different metals and this requires more detailed approach and study; fractal dimensions decrease with the increase of the wall thickness; under different increments a slight change of fractal dimensions was observed but for more accurate study it is worth using one increment to discover the interdependence.

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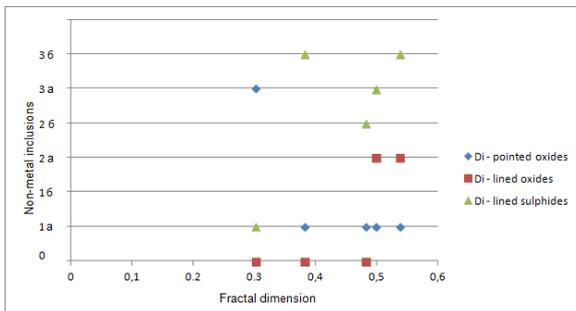


Fig.3. The dependence of fractal dimensions with the results from the non-metal inclusions for samples D<sub>i</sub> from the place without deformation or with the minimum deformation.

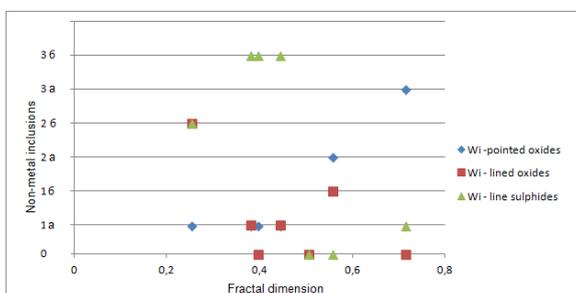


Fig.4. The dependence of fractal dimensions with the results of non-metal inclusions for samples W<sub>i</sub> from the place with the deformation.