# FRACTURE SURFACES ANALYSIS OF MINE SUPPORT ROOT

Eva MAZANCOVÁ

*VSB - Technical University of Ostrava, Faculty of metallurgy and Materials engineering, Ostrava, Czech Republic, EU, eva.mazancova@vsb.cz,*

**Abstract**

The work deals with fractal response study of root of mine supports profile from carbon steel micro-alloyed with vanadium (0.12 %), niobium (0.04 %) and nitrogen (0.012 %) designated for mine supports. The profile was evaluated both after hot rolling and after subsequent straightening that showed different impact energy values, even when the feature of fracture surfaces did not differ significantly. It was reason for fractal response study which proofed important differences between both treated materials. For solution Mandelbrot-Richardson concept was used. Surface roughness parameters ($R_s$) and fractal dimensions (D) for root demonstrated higher values after hot rolling. In this case microstructure evaluation also showed lower acicular ferrite portion supporting balance between strengthening, toughness and elimination of harmful segregation banding.

**Keywords:** support profile, fracture surface, surface roughness parameter, fractal dimension, microstructure

## 1. INTRODUCTION

Mine supports belong to the group of low and/or middle carbon steels. Those materials has been loaded for a long time and simultaneously permanently influenced by mine atmospheres. During the life time period aging processes can also occur with due to the Cottrel´s or Snoeck´s atmosphere [1-3]. Ageing process is more often observed in materials with low carbon content, below 0.20 wt. %. Material with higher carbon content does not represent so important danger, because higher pearlite content superposes changes in ferrite [4]. Higher strengthening of mine supports with favourable plasticity are the principal demands for the up to date mine supports. Gümüş et al. [5] studied TH profile alloyed with molybdenum. This variant is more expensive than micro-alloyed materials, especially on the basis of Nb-V-N, being a suitable alternative, because the first two mentioned elements can form individual carbo-nitrides at different temperature levels and/or in the complex of the NbV(CN) type which are able the matrix to refine as well as to strengthen [6-8]. Mine supports profiles show different thicknesses, especially between the flange and the root, which often demonstrate different mechanical properties, especially strength and toughness. They were described also in the paper [9]. Microstructure characteristics, such as grain sizes, volume fraction of presented pearlite, of nucleated ferrite types, segregation banding, surface and under-surface decarburisation and other in-homogeneities, including cleanness of the used material naturally influence the above mentioned properties. Mutual relations between microstructure parameters and reached properties can be specified by use of fractal geometry. Unevenness of fracture surface reflects both frequency of cleavage and/or ductile areas and changes in polycrystalline grains orientation [10-13]. The presented paper is aimed at fracture surfaces of the notched-bar impact tests and on profile fractal analyses first of all in relation to the impact energy values and metallographic parameters.

## 2. EXPERIMENTAL MATERIAL AND TECHNIQUE

For investigation of surfaces of the TH29 profiles notched-bar impact tests of mine support were used. Samples were taken from the root both after hot rolling (HR) and after subsequent straightening (HR+S). Fractal analyses were performed at the distances of 0.4, 0.8, 1.4 and 4.0 mm from the notch-tip. Chemical composition of studied material was followed (in wt. %): 0.2 C, 1.5Mn, 0.4Si, 0.015Al, 0.12V, 0.04Nb, 0.012N. The rolling temperature corresponded to 980 °C. Average tensile test properties and impact energy values are summarized in **Table 1**. Samples were taken in the rolling direction. After straightening, yield stress (YS) increased by 56 MPa, impact energy (CV) values decreased by 22 J and elongation (Elong.) by 3.6 %. Tensile test values (TS) changes insignificantly.

**Table 1** Mechanical properties of the root after hot rolling and after subsequent straightening

| Treatment | YS | TS | Elong. | CV |
|---|---|---|---|---|
| | [MPa] | [MPa] | [%] | [J] |
| HR | 511 | 701 | 24.7 | 48 |
| HR + S | 567 | 711 | 21.1 | 27 |

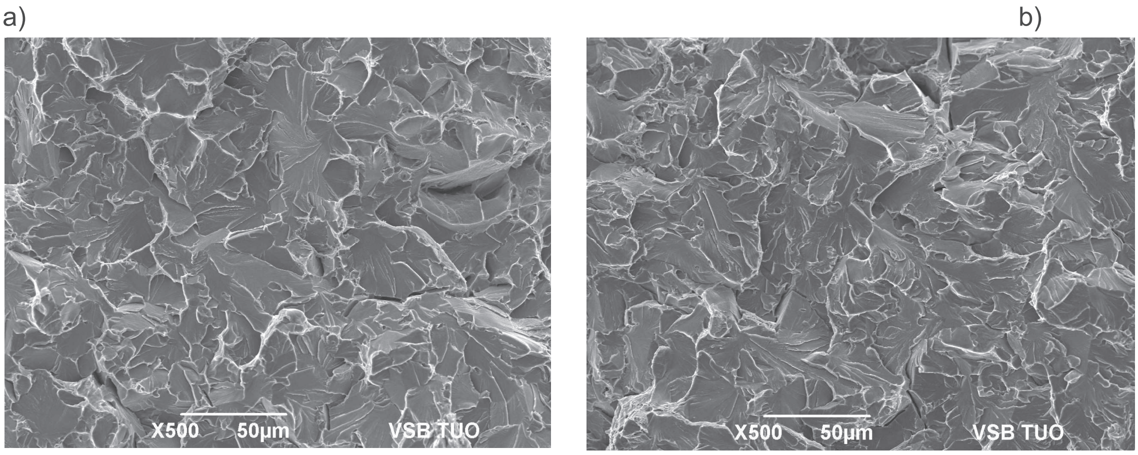


**Fig. 1** Fracture surface of notched-bars impact tests a) root after HR, b) root after HR+S

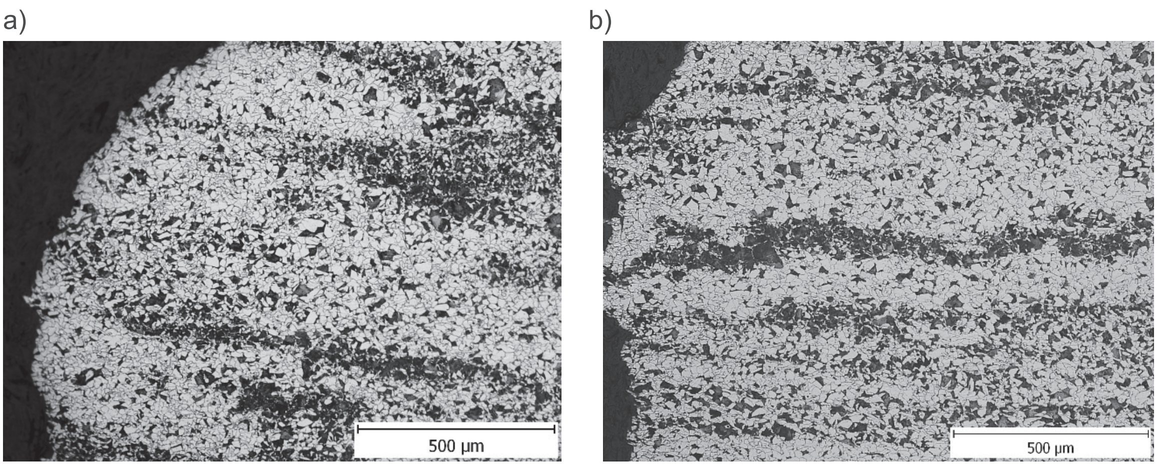


**Fig. 2** Micrograph of notched-bars impact tests under fracture surface (longitudinal direct.) a) root after HR, b) root after HR+S

## 3. MICRO-FRACTOGRAPHIC AND MICRO-STRUCTURAL ANALYSIS

Micro-fractographic analysis was realized using the electron SEM JEOL JSM-6490 LV equipped with the X-ray EDA analyser. Microstructure and fractal analyses were performed with use of the light microscope OLYMPUS IX 70 with the IMGE PLUS programme allowing e.g. measurement of the phase volume fraction.

As **Fig. 1** demonstrates it, the studied fracture surfaces showed trans-crystalline cleavage morphology with slightly higher and/or lower portion of ductile ridges. At the first sight no important dissimilarities were observed, even when the impact toughness values from the **Table 2** demonstrated these significant differences. Microstructures of the roots under the fracture surfaces are shown in **Figs. 2a** and **b**. Segregation banding is a typical feature. Microstructure of the root after hot rolling showed ferrite, 52 % of pearlite on average, and very low portion of acicular ferrite in comparison with the sample of the root after hot rolling and subsequent straightening as it is demonstrated also in **Fig. 3**.

a) b)

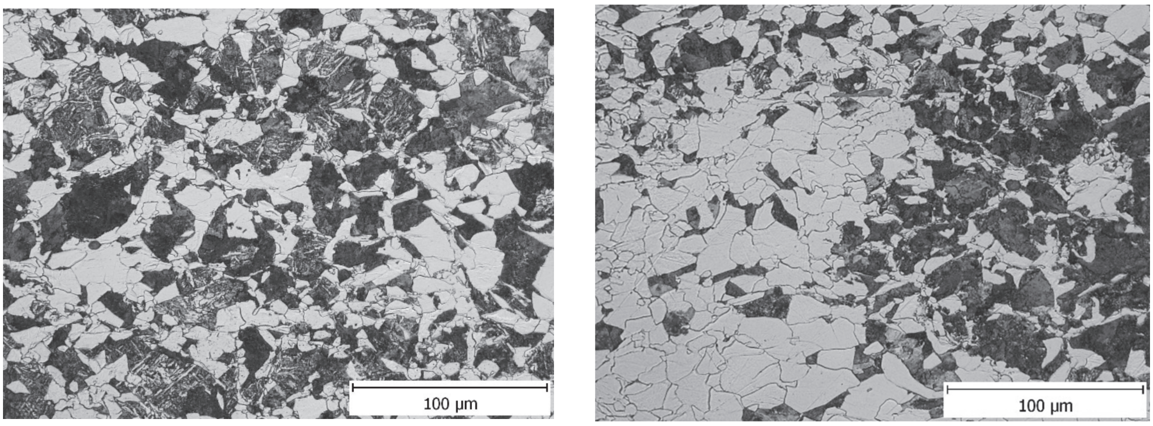


**Fig. 3** Micrograph from the notched-bar impact tests under fracture a) root after HR, b) root after HR+S

The second mentioned root showed 41 % of pearlite on average. Average grain size (according to the ČSN EN ISO 643) of the root after hot rolling corresponded to 8.4 µm, in the second case it was 11 µm. Banding of material after hot rolling (according to the ČSN 420469) corresponded to the 2C2-3 grade, while in the second case to the 2C3 grade. In both evaluated materials cleanness (ČSN ISO 4967) at the level of A1 (sulphides) and of D1.5 and/or D2 (oxides) was found. Of course, all those parameters might have influenced the impact toughness values and consequently the fracture surface profile. Cleanness of both treated profiles did not practically differ. Slightly higher segregation banding (2C3) in the root after the subsequent straightening should have acted as a more effective obstacle against cleavage crack propagation in transverse direction. In the root after the hot rolling the higher pearlite appearance could be compensated by the formed slighter acicular ferrite portion supporting both strengthening of the matrix and its toughness [10, 14]. The acicular ferrite presence is also an evidence of the localised faster cooling after hot rolling [14, 15].

## 4. FRACTAL RESPONSE AND DISCUSSION OF RESULTS

The fractal analyses of fracture profile were carried out in four (0.4-0.8-1.4 and 4 mm from the notch tip) positions of the notched-bar impact test (10x10x55 mm). The length of the profile lines was evaluated using magnifications of 800x - 1000x and the step-size corresponded to 1.5 - 3 - 5 and 10 µm. The evaluation was based as in the former works [10, 12], on an implementation of the Mandelbrot-Richardson equation [13]:

$$L = K \cdot \varepsilon^{1-D} \qquad (1)$$

The $L$ is the measured length varying according to the $\varepsilon$ level, $K$ represents a constant and the, where $\eta$ corresponds to the average step-size. After substituting $\varepsilon$ into the eq. (1) we obtain:

$$L = K^{D} \cdot \eta^{1-D} \qquad (2)$$

K can be considered as a constant hence the eq. (2) can be written as:

$$1 - D = d \log L / d \log \eta \qquad (3)$$

From the slope of *log L* vs. *log* $\eta$ the fractal dimension $D$ can be determined. The $D$-value also reflects roughness level of the fracture surface. Parameter of the linear roughness $R_L$ can be expressed in the following manner [12, 16]:

$$RL = L / L' = R0 \cdot \eta^{1-D} \qquad (4)$$

where $L$ represents the normalised length of the surface profile, $L'$ linear length of the sample, and $R_0$ is a constant. Further, on the basis of knowledge of the $R_L$ the parameter of the surface roughness $R_S$ can be calculated as it was described already previously [12, 13]:

$$Rs = (4/\pi) \cdot (RL - 1) + 1 \qquad (5)$$

The given relation makes it possible to describe modification of the fracture surface to its unit basis surface [13, 16].

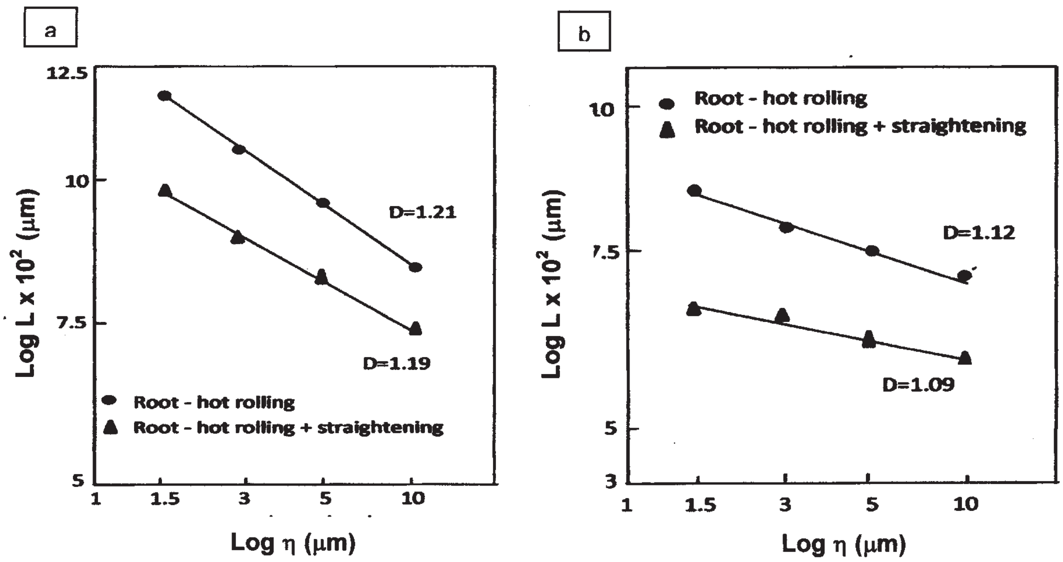


**Fig. 4** Log L vs log $\eta$ for material of root a) 0.4 mm and b) 4 mm from the notch tip

**Table 2** Surface roughness parameters (*Rs*) at various distances from the notch tip for the step of 3 µm

| Distance | | 0.4 | 0.8 | 1.4 | 4.0 |
|---|---|---|---|---|---|
| [mm] | | | | | |
| HR | *Rs* | 2.80 | 2.75 | 2.15 | 2.10 |
| HR + S | *Rs* | 2.40 | 1.95 | 1.90 | 1.75 |

Fracture surface evaluation was realised by the graded unit steps $\eta$ in the range from 1.5 to 10 µm. Figures. 4 a, b demonstrate dependences of *log L* on *log* $\eta$ for the above mentioned ranges. From the slopes of the dependences the fractal dimension values $D$ were determined. Dependences show linear character. **Table 2** summarises the $R_S$ parameters, which were found at the constant unit step $\eta$ of 3 µm at the evaluated distances from the notch tip of the notched-bar impact tests. As it from **Fig. 4**a, b follows the lower impact toughness values are connected with the lower portion of ductile ridges. In those cases a shorter fracture profile $L$ are found. The lower slope of the plotting *log L* against *log* $\eta$ the lower the $D$-values are revealed. The data from **Table 2** also correlate with the $R_S$ parameters. Differences between fractal dimensions $D$ corresponded to 1.6

% for the distance of 0.4 mm from the crack tip and to 3 % for 4 mm from the crack tip. For the same distances from the notch tip (0.4 and 4 mm) the surface roughness parameters $R_S$ differed by 14.3 and by 16.7 %.

The determined fractal dimension *D* in dependence on the distance x from the notch tip is shown in **Fig. 5**. Fractal dimension corresponds to the Charpy V values and to the distance from the notch tip. The central area (x=4 mm) demonstrates the lowest fractal dimension level. From the results presented in **Fig. 5** and **Table 2** it can be stated that fractal characteristics have not quite singular response in the frame of one fracture surface. The results can be taken as reliable parameters characterising the localized fracture response. Disadvantage of this method consists in the fact, that fractal characteristics do not include different development of plastic deformation under the fracture surface, because plastic deformation influences total energy balance during the fracture formation. Under the notch tip of the notched-bar the fractal parameters show the highest level, thanks to the vaster plastic zone formation immediately in front of the crack tip. Hence, differences of structural rupture at different distances from the notch tip of the notched-bar during the notched-bar impact test reflect dissimilar fractal properties as it can be seen in Figs. 4b and 5 and **Table 2**. In any case fractal results specify image of micro-fractographic response.

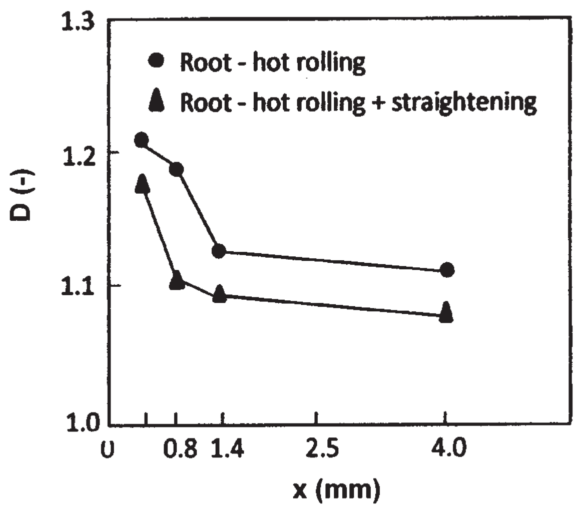


**Fig. 5** Fractal dimension D in dependence on distance x from the notch tip of the notched-bar impact test for root after HR and/or after HR+S

## CONCLUSIONS

Roots of the TH29 profile of the mine supports after hot rolling (HR) and/or after subsequent straightening (HR+S) were investigated. After HR+S the YS increased by 56 MPa and CV values decreased by 22 J. After both treatments micrographs of central fracture surfaces of the notched-bar impact tests did not show diametrical differences, unlike the notch impact values or fractal analysis evaluation.

Fractal dimensions of the HR profiles always demonstrated higher values than those after HR+S. Central areas of the investigated fracture surfaces also always showed the lowest fractal dimension values. Differences between the fractal dimensions D corresponded to 1.6 % for 0.4 mm distance from the notch tip, and to 3 % for a 4 mm distance. In spite of the specific fractal parameters character in different evaluated areas, the fractal parameters give deeper information about micro-fractographic response.

Cleanness and segregation banding grade of both treated profiles did not practically differ. Slightly higher segregation banding (2C3) in the root after the subsequent straightening should act as a more effective obstacle against cleavage crack propagation in the transverse direction. In the root after HR the higher pearlite presence could be compensated by slighter presence of acicular ferrite. The unequal acicular ferrite presence in the microstructure is also an evidence of the localised faster cooling from the rolling temperature.

## ACKNOWLEDGEMENTS

***This work was created within the projects SP 2014/62 "Specific research in metallurgical material and process engineering" and No. L01203 "Regional Materials Science and Technology Centre - Feasibility program" funded by Ministry of Education, Youth and Sports of Czech Republic.***

## REFERENCES

[1] PLUHAŘ, J. *Physical Metallurgy and Limited States of materials* (in Czech). The 1st. Ed., SNTL, Praha, 1987, p. 420.

[2] PUŠKÁR, A. HAZLINGER, M. *Breach and Components Fractures* (in Slovak). The 1st. Ed. EDIS, TU of Žilina, 2000, p. 295.

[3] FIALA, J., MENTL, V., ŠUTTA, P. *Structure and Materials Properties* (in Czech). The 1st. Ed. ACADEMIA, Prague, 2003, p. 572.

[4] MAZANCOVÁ, E., HOLEŠINSKÝ, J. Selected Properties of Mine Supports. In: Proc. *METAL2012,* Ed. TANGER, s.r.o. Ostrava, Brno, 2012, pp. 756-762.

[5] GÜMÜŞ, S., ERŞIR, E., ZEREN, M., KÖSE, G., FINDIK, E. Dilatometric investigation of the effect of heat treatment on the microstructure of hot rolled mining support profile. In: Proc. *METAL2012*,Ed. TANGER, s.r.o. Ostrava, Brno, 2012, pp. 1-6.

[6] VADANIK, M., DELLASEGA, D., MANNUCCI, A. Characterization of Grain-boundary Precipitates after Hot-ductility Tests of Microalloyed Steels. *ISIJ Int.,* 49, 3, 2009, 4546-451.

[7] TENDO, M. Effects of nitrogen, niobium and molybdenum on strengthening of austenitic stainless steel produced by thermo-mechanical control process. *ISIJ Int.,* 41, 3, 2001, 262-268.

[8] BAKER, T.N. Processes, microstructure and properties of vanadium microalloyed steels. *Mat. Sci. Technol.,* 25, 9, 2009, 1083-1088.

[9] BANNENBERG, N. Procedures for Successful Continuous Casting of Steels Microalloyed with Nb, V, Ti and N. In: Proc. of conf. *Microalloying´95*, Pittsburgh , Pa, Ed. Iron and Steel Soc., 1995, pp. 83-89.

[10] VILLEGAS, R., REDJAIMIA, A., CONFENTE, M., PERROT-SIMONETTA, M.T. Fractal Nature of Acicular Ferrite and Fine Precipitation in Medium Carbon Micro-alloyed Forging Steels. In: Proc. *New Developments on Metallurgy and Applications of High Strength Steels.* Ed. Asoc. Argentina de Materiális. Buenos Aires, 2008, (CD-ROM).

[11] KANG, Y., BHADESHIA, H.K.D.H. Roughness of Bainite, *Mat. Sci. Tech.*, 22, 6, 2006, 650-652.

[12] MAZANCOVÁ, E., MAZANEC, K. Fractal Analysis Using to Fracture Surface Evaluation of Stainless Steels with Higher Strength (in Czech). *Met. Mater.*, 37, 1999, 184-190.

[13] MAZANCOVÁ, E., RUSZ, S., RUCKÁ, Z., MAZANEC, K. Acicular Ferrite and Bainite Micro-fractographic Response. *Trans. of the* VSB-*Technical University of Ostrava*, Mechanical Series,55,3, 2009, 45-50.

[14] MAZANCOVÁ, E., SCHINDLER, I., RUCKÁ, Z. Mechanical Properties of the C-Mn Steel Cooled by Various Rates from the Finishing Rolling Temperature. *Met. Mater.*, 63, 4, 2010, 78-81.

[15] BYUM, J.S., SHIM, J.H., CHO, Y.W., LEE, D.N. Non-metallic Inclusion and Intragranular Nucleation of Ferrite in Ti-Killed C-Mn Steels. *Acta Mater.*, 51, 2003, 1893-1606.

[16] BANERJI, K. Quantitative Fractography: a Modern Perspective, *Met. Trans., 19A,* 1988, 961-971.