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Change of Void Volume of Steel Sheet Rough Layer after Deformation by Roll with Given Surface Roughness

Valery Belov[1,a], Evgeny Gubarev[1,b*], Danil Begletsov[1,c] and Oksana Krivko[1,d]

[1]Microtopography Research Center, Nosov Magnitogorsk State Technical University, Magnitogorsk, 455000, Lenin st., 38, Russian Federation

[a]belovalkon@mail.ru, [b]john_g@mail.ru, [c]d.begletsov@gmail.com, [d]chudinka_o@mail.ru.

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Abstract. New 3D metrology and new possibilities of modern measuring equipment allows observing in more details the process of metal surface layer deformation by rough surface of roll. The article covers the question of the change in the void volume of steel sheet rough layer at different section levels of rough layer by roll with different surface roughness.

Introduction

Earlier [1-4], the distribution of rough profile ordinates was presented as integral function with the percentage ratio of heights η_h to maximum height of roughness Rt plotted along one axis and the percentage ratio of height sum inside profile η_b to profile length L plotted along other axis. This graph was called material ratio curve or Abbott-Firestone curve. Later it was shown that it is more reasonable to plot the absolute value of ordinates in μm instead of percentage ratio of heights η_h to maximum height of roughness Rt.

When we change the view from 2D to 3D parameters [5-9], these graphs are plotted in the same way. The vertical axis is the ordinates of profile scale, while the horizontal axis is a percentage ratio of sum of the areas given at height h to nominal area surface S_0. This curve cannot be called Abbott-Firestone curve anymore and it allows determining the volume of voids of rough layer and the volume of material of rough layer at any section level of surface. In modern standards, this section level is placed either at the level of maximum heights of roughs (for tribology purposes) or at the level of minimum height of valleys (for determining oil-adsorption and amount of cover layer) or at the level of mean line (for determining microtopography characteristics).

Fig. 1 shows the procedure of determining these characteristics. Fig. 2 shows definitions of four main volume characteristics of rough surface according to standards [3, 4].

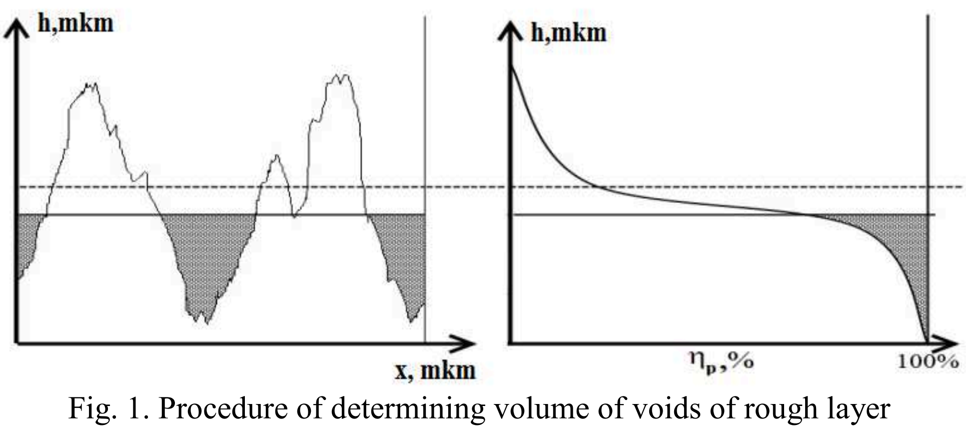


Fig. 1. Procedure of determining volume of voids of rough layer

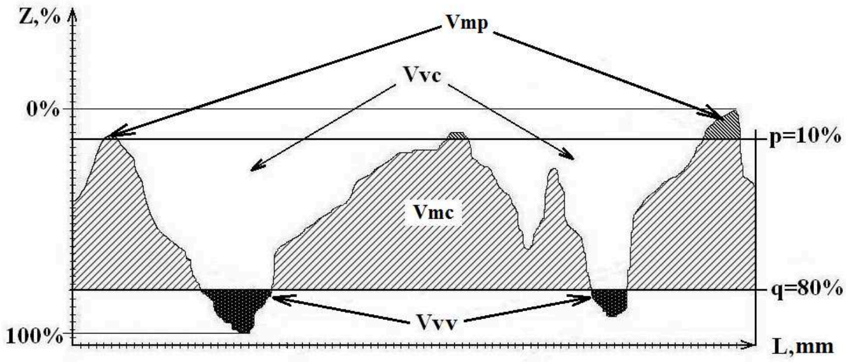


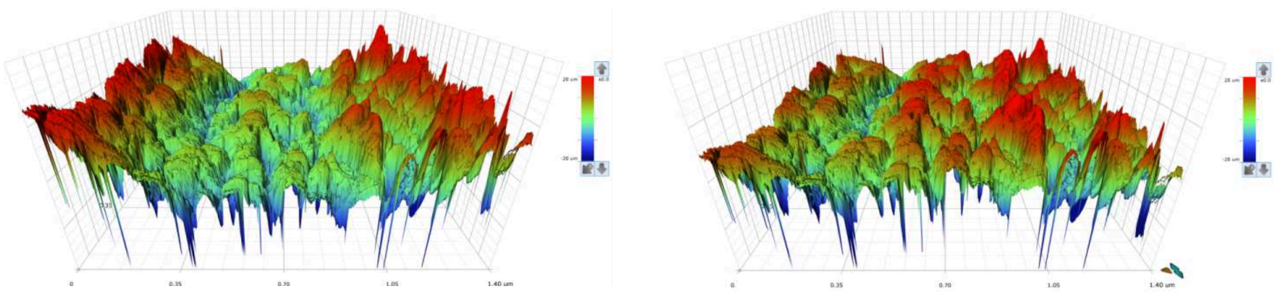
Fig. 2. 3D volume characteristics of rough surface layers

The problem

Until now, the description of rough surface formation processes by roll with rough surface was made by profile quantitative and functional characteristics [10-14]. The use of 3D rough surface characteristics [15-21] allows describing surface formation processes in more adequate and modern way. We must note that 3D volume characteristics that were used in this study have no 2D equivalents. They enable layer-by-layer description of rough surface formation process and evolution of differences in this layer formation process. The article covers the question of rough surface void volume change at different section levels in deformation by roll with different surface roughness.

Research and Instrumentation

The research involved the equipment of Microtopography Research Center, MSTU. The deformation of samples was made on rolling and tearing rig [19] with rolls having the diameter of 40 mm with different surface roughness. The surface roughness of rolls and samples was measured by Contour GT K1 and MarSurf XR20 with XT20 surface analyzers. Hardware and software of optical surface analyzer Contour GT K1 allows measuring the area of contact and depth of roll penetration [22, 23]. By knowing the value of load, one can calculate the pressure in deformation zone. The software of Contour GT K1 also allows excluding macro-deformation and analyzing only rough surface (see Fig. 3).



Fragment of sample surface with roll macro imprint | Fragment of sample surface after exclusion of roll macro imprint

Fig. 3. Fragment of sheet surface with roll macro imprint and fragment of sheet surface after exclusion of roll macro imprint

Object of study

The samples of automotive steel sheet DC01 [20] with the thickness of 0.8 mm and the width of 7 mm were used. The pressure in deformation zone was calculated from load on work rolls and area of imprint of work roll on the sample.

To determine microtopography characteristics, mean arithmetic value of rough surface height Ra (amplitude characteristic of rough layer) and profile peak count per unit length (1/cm) RPc (frequency characteristic of rough layer). Ra and RPc parameters were measured for base length of 0.8 mm. Initial roughness of samples was Ra=0.2 μm (for the base length of 0.8 mm). RPc was not measured for such smooth surface.

Experimental conditions

The pressure in the deformation zone was calculated using the load on work rolls and the area of imprint of the work roll on the sample.

The deformation ratio was estimated according to conventional equation:

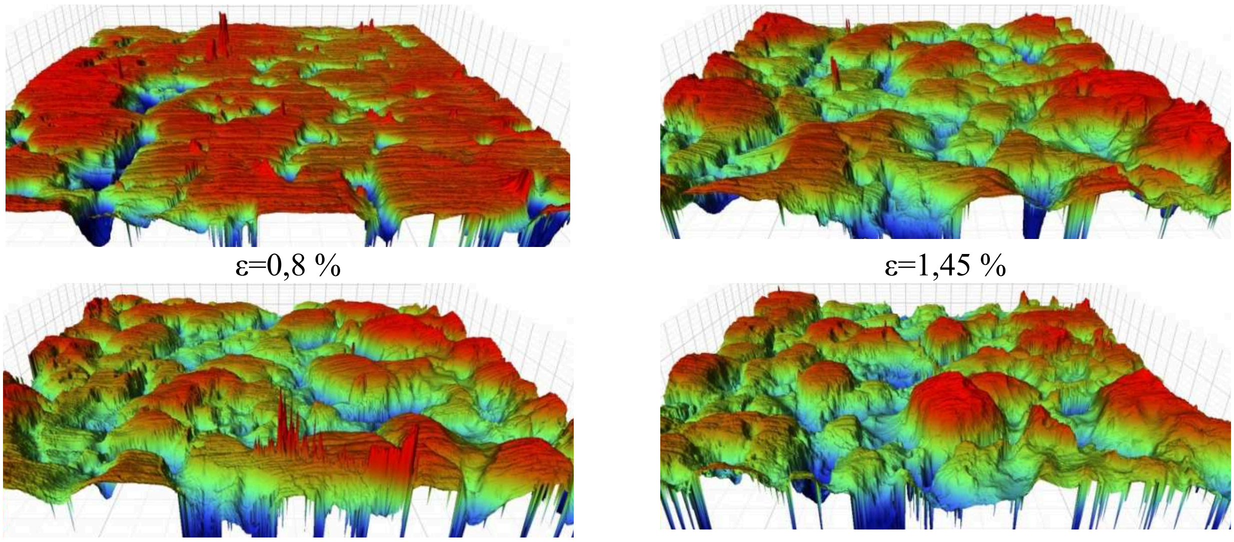
$$\varepsilon = \frac{h_0 - h}{h_0} \cdot 100\% , \qquad (1)$$

where h_0 and h are the thickness of the sample before and after application of load to cylindrical indenter in the contact zone, mm.

Optical surface analyzer Contour GT K1 allows measuring the volume characteristics of rough layer with given height position. In the experiments, for the calculation of void volume, the thickness of rough layer was 0.05Rt, and the position of rough layer was calculated from the top of the highest point of the profile in percentage of Rt, where Rt is the thickness of rough layer.

Results of experiment

Fig. 4 shows rough surface of the sample after different pressure in deformation zone. These visually noticeable differences now can be described by the change of volume characteristics of rough surface layers.



ε=0,8 % ε=1,45 %

ε=2,38 % ε=2,69 %

Fig. 4. Change of surface topography of sample with different ε

The use of new 3D volume parameters and modern measurement equipment allows making a measurement of volume characteristics at given level of section of rough layer depending on the force and penetration of cylindrical roll with the diameter of 40 mm for three types of rough surface (see Fig. 5).

On the figures to left, the vertical axis corresponds to layer-by-layer change of volume of voids that are

$$\Delta V_1(i)=V(i)-V(i+1), \quad (2)$$

Where V(i) is void volume on level i, ml/m^2,
V(i+1) is void volume on the next lower level i+1, ml/m^2.

To weaken the influence of conditions in deformation zone on the experimental results (e.g. the presence of absorbed molecules and oxide layers on the surfaces of the roll and the sample, deformation conditions etc.), the difference between layer-by layer changes of rough layer void volume and the same value at minimal pressure in deformation zone were considered (see figures to the right in Fig. 5):

$$\Delta V_2\,(j)=V(k_j\,)-V(f_j), \quad (3)$$

where $V(k_j)$ is void volume on level j and at minimal pressure in deformation zone σ_{min}
$V(f_j)$ is void volume on level j and at pressure $\sigma > \sigma_{min}$

Experimental data in Fig. 5 shows that the change in rough layer void volume depending on layer level has two clear-cut zones.

The first zone is a zone of fixed volume parameters that are determined by lower layers of rough surface (the thickness is about 0.3Rt).

The second zone is a zone of changing volume parameters that are determined by upper layers of rough surface (the thickness is about 0.7Rt).

As it was expected, the uppermost layers of the sample surface while deformed expand their void volume in the most extreme way. When we go deeper, these changes decrease in exponential way. We must also note that while increasing the pressure in the deformation zone, level-by-level change of void volume in the second zone also increases.

Conclusion

The article presents the research of void volume change at different section heights of steel sheet rough layer after deformation with roll with different surface roughness. The experimental results are presented.

The article is intended for specialists that deal with designing technologies for producing automotive steel sheets with given surface topography. The experimental conditions are close to real manufacturing conditions of sheet temper rolling after annealing in deformation zone pressures and in rough surface parameters after electrical discharge texturing of rolls.

Acknowledgements

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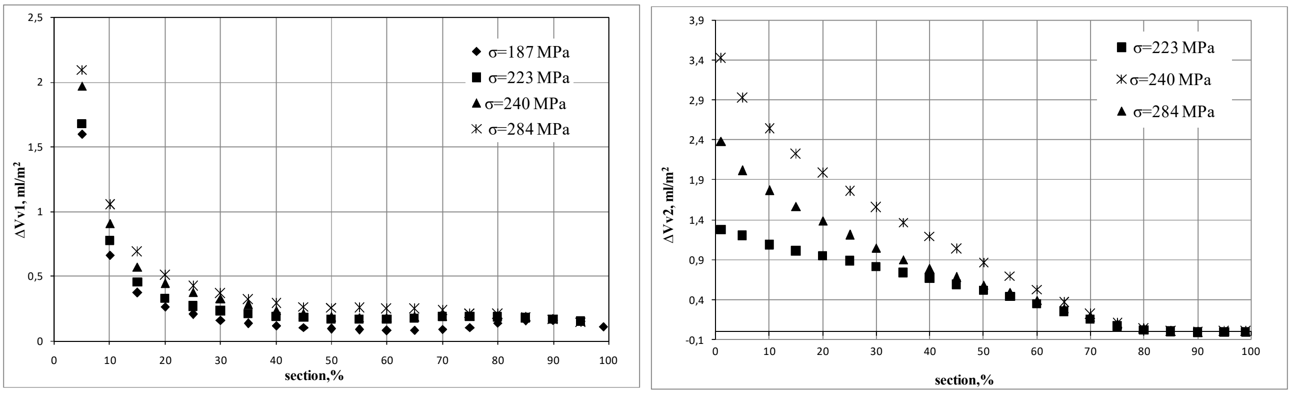
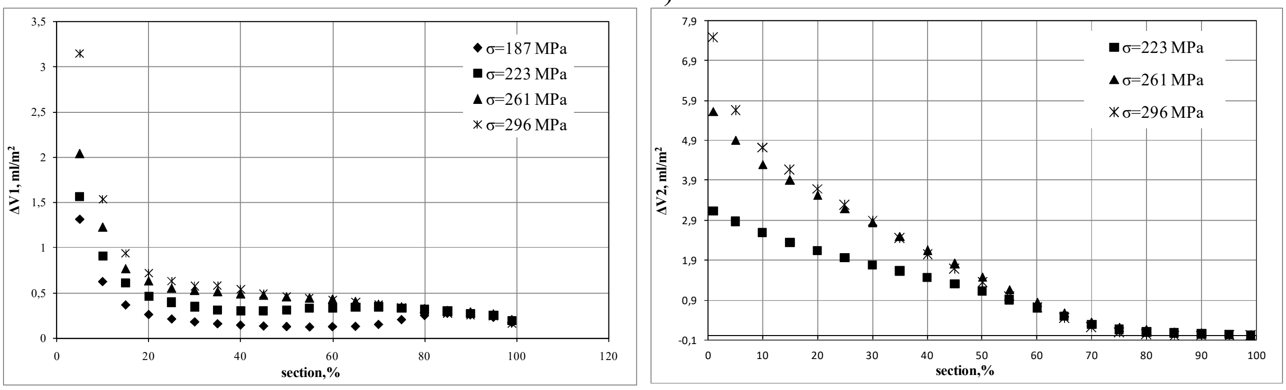
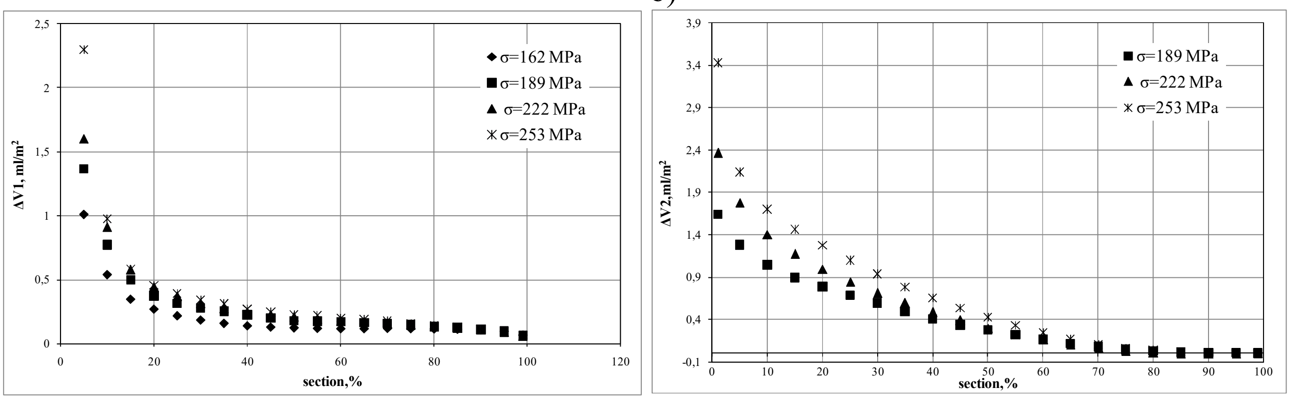


a)



b)



c)

Fig. 5. Change of void volume in layer-by-layer sections at different pressures in deformation zone and at different roughness of roll a) Ra=4.2 µm; RPc=58 1/cm; b) Ra=5.03 µm; RPc=54 1/cm; c) Ra=8.3 µm; RPc=37 1/cm.

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