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METAL SHEET SURFACE CHARACTERIZATION PRIOR TO AND AFTER PROCESSING BY AREAL ROUGHNESS PARAMETERS

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Božica Bojović [1], Bojan Babić [1], Aleksandar Žunjić [2]

[1] University of Belgrade-Faculty of Mechanical Engineering, Production Engineering Department, Kraljice Marije 16 11120 Belgrade, Republic of Serbia: bbojovic@mas.bg.ac.rs ; bbabic@mas.bg.ac.rs;
[2] University of Belgrade-Faculty of Mechanical Engineering, Industrial Engineering Department, Kraljice Marije 16 11120 Belgrade, Republic of Serbia: azunjic@mas.bg.ac.rs
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Abstract: *The surface topography and roughness are important in describing the lubrication of surface in deep drawing process. Although the profile parameters are commonly used for engineered surface roughness characterization in deep drawing, they don't contain information on spatial asperities and voids variation, real contact areas distribution and volumetric lubricant retention capabilities. Unlike the profile parameters, the areal parameters can map geometrical features of scanned surface area and provide insight into the functional behavior. The objective of this paper is to examine and quantify the changes in spatial roughness, which are occurring before and after deep drawing process. We evaluate eight areal amplitude parameters at tin plate and can surfaces. Since we investigate the possibilities of lubricant dosage optimisation from ecological aspect of deep drawing cans processing, the areal surface parameters that are related to voids are investigated. Results indicate the usefulness of selected set of areal parameters for characterization of tin plate surface prior to and after deep drawing processing. Selected set may be used for potential prediction of surface volumetric lubricant retention capabilities.*

Key Words: *Areal roughness parameters, Deep drawing, Lubricant retention*

1. INTRODUCTION

Roughness parameters well defined by ASME B46 Committee on Surface Texture were characterizing either profile or surface [1]. Eventually, to revise the existing profile standards and to define the areal surface texture parameters, the 25178 series of standards was developed by work group 16 in the ISO TC 213 in 2010 [2].

The profile parameters are still commonly used for engineered surface roughness characterization, mainly because of stylus instrumentations availability. Without intention to list all scholars and their work, some of the latest examples of the profile parameters role: in friction [3], in process optimization [4] and in response surface methodology [5] are mentioned here.

Profile parameters don't contain information on spatial asperities and voids variation, real contact areas distribution and volumetric lubricant retention capabilities. In spite of profile parameters, the areal parameters can map geometrical features of scanned surface area and provide insight into the functional behaviour [6]. According to [7], the voids at surface serve as micro-hydrodynamic bearing in case of full or mixed lubrication. Also they can be a micro-reservoir for lubricant in cases of starved lubrication condition.

The surface topography and roughness are important factors in describing the lubrication of surface in deep drawing process. Applications of profile parameters in deep drawing persist for decays, and for example that can be seen in [8, 9 and 10]. The characterization for the blank surface based on areal parameters is more appropriate as opposed to profile parameters, according to [11]. Since, it is hard to find the areal surface applications in deep drawing domain we intend to investigate the areal surface parameters that are related to lubricant dosage optimisation possibilities.

The objective of this paper is to examine and quantify the changes in areal roughness which is occurring prior to and after deep drawing process. We investigate ecological aspect of deep drawing can processing lubrication. Therefore, we have to select group of S-parameters that are mainly related to voids. From all "S-parameters", which are presented as "Birmingham 14" [1] and from those described at ISO 25178-701 standard [12], we evaluate eight.

Results prove that the selected group that are consists of the S-parameters have to be revised. We suggest only particular S-parameters that are affected by deep drawing process for processed surface assessment.

2. MATERIALS AND METHODS

Mass production of cans is performed on sheet feed press CEPEDA by deep drawing and trimming machine. Samples for the experiment are taken from tinplate before deep drawing processing (see Figure.1, sample No.1) and from the cylindrical part of can after deep drawing processing (see Figure.1, sample No.2).

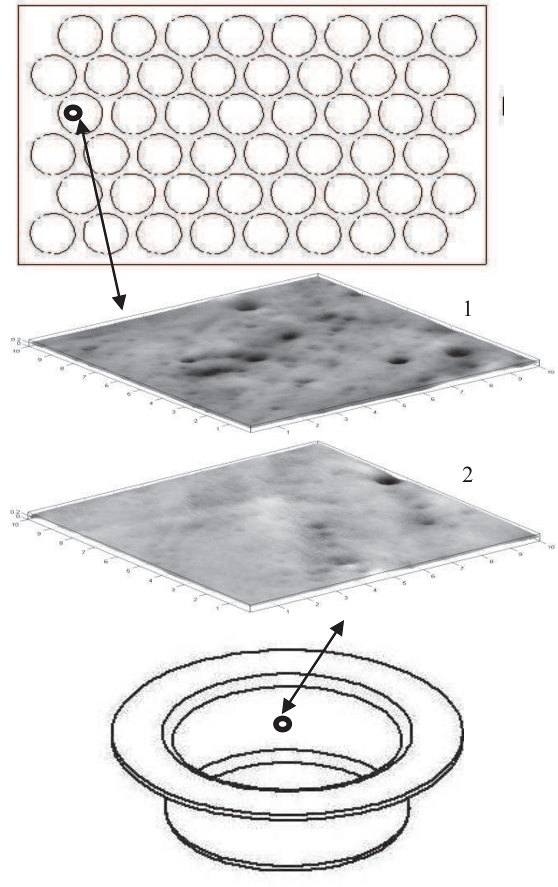

Figure 1. Topography images gathered using semi-contact mode by NTEGRA Prima SPM: position 1- tinplate sample and position 2- can sample

2.1 Sample preparation and image scanning

For experiment was used DR550 tin plate material. Double reduced tin plate sheets (DR 550) are made of cold rolled and tin coated steel with high strength and sufficient ductility. This kind of tinplate, before deep drawing, is exposed to lithography and lacquering processes.

We found very suitable technical specifications of NTEGRA Prima scanning probe microscope. Possible industrial application in the can factor’s environment are based mainly on the specific scanning head, that can be configured to serve as a stand-alone device for specimens of unlimited sizes [13]. Additional, NTEGRA Prima has a built-in optical system with 1 µm resolution, which allows imaging the scanning process in real-time.

Imaging is performing by semi-contact mode that is permitted onto softer and easy to damage materials, such as tinplate coated by lacquer. Topography images of tin plate and can surface are exported in tiff and asc file formats.

2.2 S-parameter determination

Group of selected parameters are consist of four areal amplitude parameters (arithmetic S_a and S_q root mean deviation, skewness S_{sk} and kurtosis S_{ku} of surface height distribution), single hybrid parameter (developed surface area ratio S_{dr}) and three areal functional indexes (surface bearing index S_{bi}, core fluid retention index S_{ci} and valley fluid retention index S_{vi}).

Although, the functional indices are superseded by volume parameters in the ISO 25178 standard, we prefer them because the unit less numbers are more suitable for surfaces comparison in this case.

The surface topography image size of 256×256 pixels, is considered as matrix filed by surface height in each pixel denoted as $z(i,j)$. Such a matrix represents an intensity image type with greyscale map. Matrix size of 256^2 defines number MN. The amplitude parameters are based on surface departures above and below the mean plane $\bar{z}$ of topography image.

We perform custom-made Matlab procedures for calculation of S_a, S_q, S_{sk}, S_{ku}, S_{bi}, S_{ci} and S_{vi} are based on equations (1-4), that are adapted from [1] in order to serve for AFM image characterization.

$$S_a = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M}\left|z(i,j)-\bar{z}\right| \tag{1}$$

$$S_q = \sqrt{\frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M}\left(z(i,j)-\bar{z}\right)^2} \tag{2}$$

$$S_{sk} = \frac{1}{MN\cdot S_q^3}\sum_{j=1}^{N}\sum_{i=1}^{M}\left(z(i,j)-\bar{z}\right)^3 \tag{3}$$

$$S_{ku} = \frac{1}{MN\cdot S_q^4}\sum_{j=1}^{N}\sum_{i=1}^{M}\left(z(i,j)-\bar{z}\right)^4 \tag{4}$$

The hybrid parameter is defined by equation (5). For the developed surface calculation is used the fractal dimension method that is presented in [14] and adopted for the total interfacial area $\Sigma\Sigma A_{i,j}$. We calculate the sum of tiles that cover image over the scanned sample size A that is equal to 10µm x10µm in this case.

$$S_{dr} = \frac{\sum_{j=1}^{N-1}\sum_{i=1}^{M-1}A_{ij} - A}{A}\cdot 100\% \tag{5}$$

The functional indexes are related to the given heights h, which are normalized in accordance of the RMS deviation. For the truncation 5% from the top the height is denoted as $h_{0.05}$ and index S_{bi} represent all material that may be worn away for a given depth. This index is calculated as equation (6) stated.

$$S_{bi} = \frac{1}{h_{0,05}} \quad (6)$$

The volume *V(h)* is void volume enclosed between truncation plane at a given level in percentages. In equations (7, 8) the void volume that correspond to 5% and 80% level, are calculated as a sum of all pixels height that belong to empty space.

$$S_{ci} = \frac{V(h_{0.05}) - V(h_{0.8})}{MN \cdot S_q} \quad (7)$$

$$S_{ci} = \frac{V(h_{0.8})}{MN \cdot S_q} \quad (8)$$

For each section the pixels belong to a surface are coloured white and considered as binary 1. The rest of the surface image belongs to valleys, so they represent an empty space that is supposed to fill with lubricant. Those pixels are coloured black and are considered as binary 0. The sums of black pixels multiple by there's heights are the void volume.

3. RESULTS AND DISCUSION

Topography images size 256x256 pixel are gathered from sample size 10μm x10μm. Maximal height reveals in report is 374nm for the tin plate image and 251nm for the can image. Calculated S-parameters are shown in Table 1.

Table 1. Tin plate and can surfaces S-parameters

S-parameter/index	Tin plate	Can
Sa	23.53nm	11.07nm
Sq	32.80nm	16.27nm
Ssk	2.32	2.99
Sku	7.68	15.78
Sdr	17.51%	11.64%
Sbi	0.34	0.02
Sci	4.52	2.61
Svi	0.01	1.43

The areal arithmetic mean deviation S_a is one of the first introduced the areal parameters. Despite S_a insensitiveness for spatial distribution of the asperities and equalization of peak and valley with same value, it may be used for comparison in a case of monitoring tin plate ironing during deep drawing process. In this case, max height is reduced for 33%, and arithmetic mean is decreased for 53%.

The root-mean-square (RMS) deviation of the surface S_q is a dispersion parameter as the root mean square value for the surface asperities. This parameter is more sensitive to extreme data values and it is sample standard deviation. Since the RMS decrease, it could be concluded that deep drawing process make surface more compact.

The skewness of topography height distribution of surface S_{sk} maintains surface polarity and therefore is useful to distinguish surface with predominantly deep valleys (negative value) from the one with large number of peaks (positive value). This parameter is positive prior to and after processing, which indicates surfaces with predominantly peaks. Additionally, S_{sk} may be used for monitoring changes in the highest peaks that occur during deep drawing process. Consider to the similar values of the skewness, there is no significant change in peak occurrence.

The kurtosis of topography height distribution of the surface S_{ku} indicates the normally distributed surface (Gaussian distribution) if its value is approximate 3. Otherwise, non-normally distributed high peaks and deep valleys cause large S_{ku} value. If S_{ku} value is less than 3, then the surface topography is composed of gradually varying asperities. In case of deep drawing surface processing, this areal parameter is higher than 3 prior to and after deep drawing. Twice bigger value of kurtosis after deep drawing indicates changes as line-like folds caused by process itself.

The developed interfacial area over the sampling area defines ratio S_{di} reflects hybrid property of surface that is combination of amplitude and space. This parameter is expressed as the percentage of additional surface area contributed by the texture as compared to an ideal plane the size of sampling area. This parameter significantly decreases after deep drawing process. In this particular case ratio S_{di} can serve as surface flattening indices.

For tin plate's surface the binary images, that represent bearing area at 5% and 80% from the top, are shown in Figure 2. In Figure 3, the can's surface binary images at the same truncations levels are shown. The three functional areal parameters S_{bi}, S_{vi} and S_{ci} are indices that are derived from bearing area ratio curve as the ratios of the S_q over the specified height.

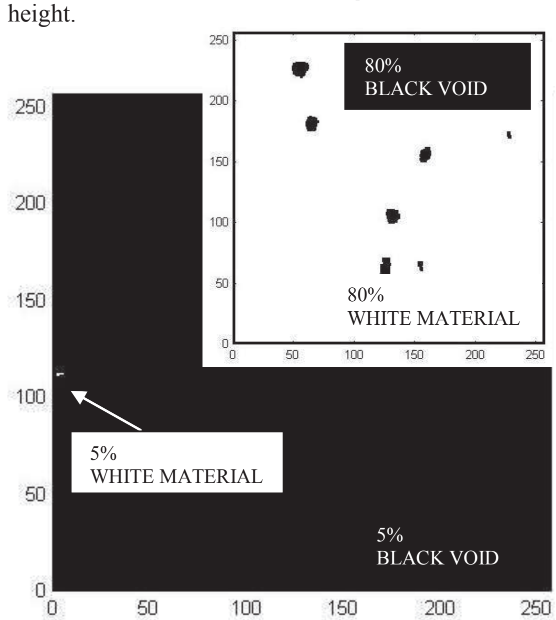

Figure 2. Tin plate's surface binary images at 5% and 80% truncated levels

Surface bearing index $S_{bi,}$ is the ratio of the RMS deviation over the surface height at 5%. This index can characterizes the upper zone of the surface involved in wear phenomena, and material available for sealing engagement. In case of deep drawing process with lubrication, the decrease of surface bearing index after the process, indicates the better sealing property of tin plate surface, which is good.

The ratio of the void volume at the core zone over the RSM deviation S_{ci} indicates the main void volume acting as a lubricant reserve. The larger value for tin plate surface indicates good property. In case of worn surface this index decreases and additionally it may be used for confirmation of wear process that occurs during deep drawing.

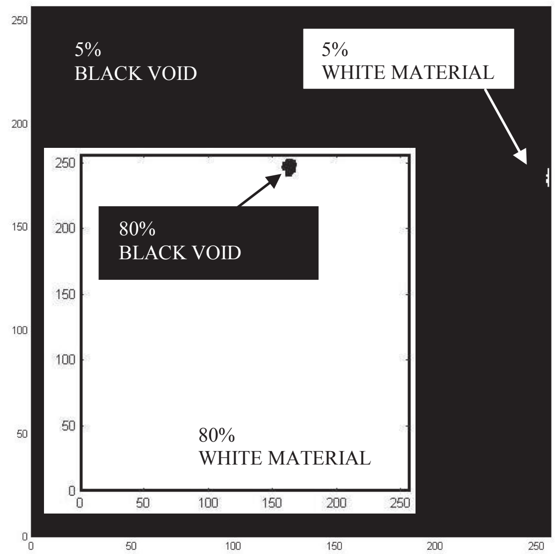

Figure 3. Can's surface binary images at 5% and 80% truncated levels

The ratio of the void volume at the valley zone over the RMS deviation S_{vi} indicates the void volume of the deepest valleys. The significant differentiation in values indicates the better fluid retention in case of can surface. This conclusion seems inadequate if the presented binary images are compared. The plenty black spots appear at tin plate surface against the single deep valley at can surface. However, the depth of presented valleys and the maximal surface height have great impact on volume and therefore S_{vi} index is sufficiently higher for can surface.

4. CONCLUSION

When we talk about surface macro or micro metrology, then we consider the surface measurement and characterization and the instrumentations. Regardless of stylus or optical instrumentation use, scanning electron or probe microscopy exhibit, together with uncertainty, traceability and calibration issues we have to deal with the areal roughness parameters in order to shed light on tribology, wear phenomena, lubrication and specifics surface functional applications.

We conduct surface roughness assessment at AFM images, which are gathered prior to and after deep drawing processing. Calculated S-parameters values in both cases offer insight into the changes that surface going through:

- Areal parameters S_a, S_q and S_{dr} are decrease proving surface flattening and ironing.
- Skewness S_{sk} and kurtosis S_{ku} indicate surfaces with predominantly peaks which are non-normally distributed. The line-like folds caused by process itself cause the higher parameters value.
- Areal bearing index $S_{bi,}$ indicates the better sealing engagement of tin plate upper zone of the surface.
- Fluid retention indexes for core S_{ci} and deep valley S_{vi} provide information about the resulting void volume for lubrication leakage, in transition from tin plate to can.

In this paper we point out S-parameters role in characterization and comprehend potential role for prediction in case of tin plate deep drawing.

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REFERENCE

[1] Stout, K.J, Sullivan P.J, Dong, W.P, Mainsah E, Luo, N, Mathia, T, Zahuani, H, *The development of methods for the characterisation of roughness in three dimensions,* Publication EUR 15178EN Commission of the European Communities, 1993.

[2] http://isotc213.ds.dk

[3] Meneses, P.L, Kishore, Kailas, S.V, Lovell, M.R, *Friction and transfer layer formation in polymer-steel tribo-system: Role of surface texture and roughness parameters*, Wear, Vol.271, No9-10, pp.2213-2221, 2011.

[4] Asiltürk, İ, Akkuş, H, *Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method,* Measurement, Vol.44, No9, pp. 1697-1701, 2011.

[5] Routara, B.C, Sahoo, A.K, Parida, A.K, Padhi, P.C, *Response surface Methodology and genetic algorithm used to potimize the cutting condition for surface roughness parameters in CNC turning*, Procedia Engineering, Vol.38, pp. 1893-1904, 2012.

[6] Suh, A.Y, Polycarpou, A.A, Conry T.F, Detailed surface roughness characterization of engineering surfaces undergoing tribological testing leading to scuffing, Wear, Vol.255, pp. 556-568, 2003.

[7] Reizer, R, Galada, L, Dzierwa, A, Pawlus, P, Simulation of textured surface topography during a low wear process, Tribology international, Vol.44, pp. 1309-1319, 2011.

[8] Lubbinge, H, ter Haar, R, Schipper, D.J, *The influence of plastic bulk deformation on surface roughness and frictional*

behaviour during deep drawing processes, in book The third body concept, pp. 705-711, Elsevier Science, 1996.

[9] Masen, M.A, de Rooij, M.B, *Abrasive wear between surfaces in deep drawing,* Wear, Vol.256, No6, pp.639-646, 2004.

[10] Manabe, K, Shimizu, T, Koyama, H, Evaluation of milli-scale cylindrical cup in two-stage deep drawing process, Journal of Materials Processing Technology, Vol.187–188, pp. 245–249, 2007.

[11] Meiler, M, Pfestorf, M, Geiger, M, Merklein, M, The use of dry film lubricants in aluminum sheet metal forming, Wear, Vol.255, No6, pp.1455-1462, 2003.

[12] SRPS EN ISO 25178-701:2013

[13] http://www.ntmdt.com/

[14] Bojović, B, Investigation of interaction of engineering surfaces condition and fractal geometry, PhD Thesis (in Serbian), University of Belgrade, 2001.