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RELEVANT SURFACE TEXTURE PARAMETERS FOR DEEP DRAWING MADE METAL BEVERAGES

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Abstract: *Ecological aspect of lubricant dosage optimisation in deep drawing metal beverage processing directs our investigation to the textual surface parameters evaluation and selection. Considering that SRPS EN ISO 25178:2013 standard that is published in 2013 in the Republic of Serbia, the objective of this paper is to examine and quantify surface topography parameters that are related to voids. Surfaces imaging are conducted by atomic force microscopy and calculations of numerical values are completed by in-house made Matlab procedures. Results indicate the usefulness of selected set of S and V parameters for characterization of metal beverage surface after deep drawing processing. Selected set of relevant parameters may be used in further investigations and in industrial application in order to predict the surface volumetric lubricant retention capabilities.*
Key words*: Surface texture parameters, atomic force microscopy, lubrication.*

1. INTRODUCTION

In the food metal baverage manufacturers, the inner surface of can is just one of two sides of cup that is made by deep drawing. Consider the food safety it's the important side. Manufacturers use lubricant in deep drawing process and afterwards cans are rinsed with fluid or sprayed with vapour. Food consumers assume that cans are washed thoroughly either after production or prior to food filling. Authors are engaged in project that deals with ecologically based approach in sheet metal parts production. One of the aims of investigation is to diminsh lubricant amount and in this paper the set of relevant surface texture parameters will be presented in order to predict the surface volumetric lubricant retention capabilities.

The lubrication is essential for good quality sheet metal part fabrication and therefeore it cannot be eliminated from this metal forming process [1], but different type of lubricants suitable for food contact as well as environmental requirements can be select [2,3]. Also, the usage of die and punch coatings decrease coeficient of friction and therefore reduce amount of lubricant [4-6]. The surface topography and roughness are important factors in describing the lubrication of surface in deep drawing process. Therefore, an application of profile roughness parameters in deep drawing persist for decays and example of that can be seen in [7-9]. Unlike profile ones the areal surface parameters were hard to find in available references consider deep drawing process. The examples of the more appropriate characterization based on the areal parameters for the blank surface opposed to profile parameters are described in [10] and proving that areal parameters calculated for tinplate and can's surface offer insight into the surface changes throughout deep drawing process is given in [11]. In this paper we intend to investigate the areal surface parameters that are related to lubrications.

2. MATERIALS AND METHODS

We took samples from the cylindrical part of cans during industrial fabrication at metal food baverages factory that are situated in Belgrade, RS Serbia. Surfaces imaging are conducted by atomic force microscopy in NanoLab at University of Belgrade. Calculations of numerical values are completed by in-house made Matlab procedures based on SRPS EN ISO 25178:2013 standard that is published in 2013 in the Republic of Serbia.

2.1. Sample preparation

Mass production of cans in company FMP d.o.o Belgrade, is performed by a sheet feed press CEPEDA (component of the automated manufacturing line) by deep drawing. Cans are made of Double Reduced (DR550) tinplate sheets, that are cold rolled and tin coated steel with high strength and sufficient ductility. This kind of tin plate, before deep drawing, is exposed to lithography and lacquering processes. Magnus Draw Oil L-67 is used as lubricant during deep drawing processing. It is the high quality lubricating oil, formulated for pre-painted steel and recommended for two piece cans which might be subjected to incidental food contact, according to [12].

Samples for the experiment are taken from the cylindrical part of four cans after deep drawing with the ordinary process parameters. After cleaning samples were scanned in NanoLab at University of Belgrade.

2.2. Topography scanning

A commercial scanning probe microscope (JSPM 5200, JEOL, Japan) is used for this investigation. Commercial probe produced by MikroMasch, Estonia, CSC37/AlBS for general purpose is used for contact mode scanning. The probe is a three-lever chip that contains long cantilevers with a Single-Crystal Silicon tip that has conical shape. Typical uncoated tip radius is less than 10 nm, height 15-20 mm, full angle cone is less than 40° and the typical force constant is 0.3–0.65 N/m, resulting tip curvature radius is 40nm due 30nm aluminum back coating, as is stated in [13]. All experiments are performed at room temperature.

2.3. Surface roughness parametars calculation

Microscope JSPM5200 provide conventional roughness analysis for profile or surface based on following standard roughness parameters: average roughness parameter R_a, root mean square R_q, maximum difference between height R_z and 10-point average roughness R_{zijs}, interfacial surface ratio S_{ratio}, as well as histogram and bearing ratio curve of sample profile and area. Since the software WinSPM is made few years before standard ISO 25178 is introduces in Republic of Serbia, for profile and areal parameters the same designation R_a, R_q, R_z and R_{zijs} was used in reports.

In order to update JSPM5200 reports we ought to select group of parameters that will be in acordance to new standard's requirements and calculate their values by in–house made Matlab procedures.

We analyze the group that are consists 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 volume parameters dale void volume $V_{vv}(p)$, core void volume $V_{vc}(p,q)$, peak material volume $V_{mp}(p)$).

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} are based on equations (1-4), that are adapted from [14] in order to serve for AFM image characterization.

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

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

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

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

The hybrid parameter is defined by equation (5). For the developed surface calculation the fractal dimension method is used that is presented in [15] 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.

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

In order to calculate three volume parameters we use custom made procedures in Matlab. Surface texture is truncated by the planes at a height corresponding to chosen level. For each section the pixels belong to a surface are colored 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 colored black and are considered as binary 0. The sums of black pixels multiple by there's heights are the void volume.

Peak material volume $V_{mp}(p)$ is the volume of material from the height corresponding to the material ratio level p=10% to the highest peak. Dale void volume $V_{vv}(p)$ corresponding to the default value of level p= 80%. Core void volume $V_{vc}(p,q)$ corresponding to the levels p=10% and q= 80%.

3. RESULTS AND DISCUSTION

We conduct surface roughness assessment at AFM images, which are gathered after deep drawing processing. Topography images size 256x256 pixel are gathered from sample size 10μm x 10μm. Maximal height reveals in WinSPM report for each can image and considers as input value for Matlab calculations. Calculation of S and V roughness parameters values are completed by in-house made Matlab procedures. In this section the calculated parameters' values for four samples are presented in Table 1 and discussed afterwards.

Table 1. Can surfaces' S and V parameters

a) S parameters

	S_a [μm]	S_q[μm]	S_{sk}	S_{ku}	S_{dr}[%]
Mean	0.0558	0.0686	1.5766	2.9603	10.7504
Max	0.0846	0.1008	1.8294	4.1522	13.4105
Min	0.0188	0.0230	1.4415	2.3776	7.4066
Std	0.0280	0.0331	0.1754	0.8220	2.4850

b) V parameters

	V_{mp}[μm³/μm²]	V_{vc}[μm³/μm²]	V_{vv}[μm³/μm²]
Mean	0.00018	0.1357	0.0013
Max	0.00064	0.1940	0.0025
Min	0.00001	0.0636	0.0006
Std	0.00010	0.0543	0.0008

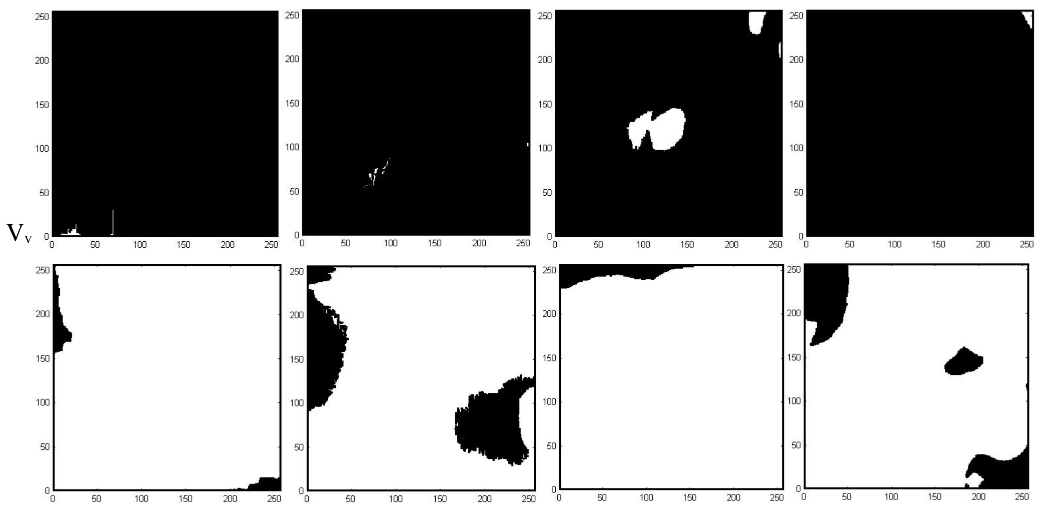
The areal arithmetic mean deviation S_a is insensitive for spatial distribution of the asperities and equalizes peak and valley with same value. The root-mean-square deviation of the surface S_q is more sensitive to extreme data values. Put them both side by side, we have to conclude that the S_q is more appropriate dispersion parameter for deep drawing processed inner surface of can compares to S_a. This areal amplitude parameter may be used for comparison in a case of monitoring tin plate ironing during deep drawing process.

The skewness of topography height distribution of surface S_{sk} has positive values for all images which indicate surfaces with predominantly peaks. The values of kurtosis of topography height distribution of the surface S_{ku} are around 3, which indicates predominantly the Gaussian distribution of high peaks and deep valleys for the images. Based on values for mean and standard deviation which are shown in Table 1, the skewness doesn't provide considerable information that can be used for surface

distinguish and therefore the kurtosis is chosen as meaningful distribution parameter for cans' inner surface.
The developed interfacial area over the sampling area defines ratio S_{dr}, which 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. In this particular case ratio S_{dr} are approximate 10% and can serve as surface flattening indices.
For cans' surface the binary images, that represent bearing area at 10% and 80% from the top, are shown in Figure 1. For each section the pixels belong to a surface are colored white and the rest of the surface image that are colored black are empty space that is filled with lubricant.
Sections with few white spots on black colored background represent all material that may be worn away for a given depth of 10% of the S_q. Those sections are related to peak material volume V_{mp} and may provide insight into the amount of material available for seal engagement. Sections with few black regions on white colored background represent deep valleys under a given depth of 80% of the S_q. Those sections are related to dale void volume V_{vv} and may be useful in indicating the entrap lubrication volume.

This could be important information especially in case of lubricant volume optimization for ecological requirements satisfaction. The dale void volume parameter V_{vv} may be useful in indicating the potential remaining volume resulting in lubricant entrapment that will be difficult to wash.
For that reason, the presented materials volume parameters are useful when considering lubrication behaviour phenomena. The best sealing property among four surfaces consider parameter V_{mp} has surface C, the worst surface B and surfaces A and D have the similar appearance and consequently approximate the equal value. Topography core will keep very low amount of lubricant in case of surface B and others perform suitable lubricant behaviour according to parameter V_{vc}. From ecological point of view the best behaviour exhibits surface A with the lowest value of parameter V_{vv} which is in accordance to visual perception of black deep valleys distribution. In case of surfaces B and C, which have the similar values but quite unlike deep valley distribution, parameter V_{vv} demonstrates superiority compares to visual guiding conclusions. In Figure 2, 3D topography images for four samples are presented.

	A	B	C	D
$V_{mp}[\mu m^3/\mu m^2]=$	0.000044	0.000010	0.000639	0.000047



$V_{vv}[\mu m^3/\mu m^2]=$	0.000645	0.001021	0.000988	0.002492

Fig. 1. Surface sections at given depth - 10% (upper row) and at 80% (lower row)

The core void volume V_{vc} indicates a measure of the void volume provided by the surface between depths of 10-80% of the S_q. This is useful when considering fluid flow during lubrication. The volume parameters are presented in Figure 1. The parameters values provide necessary additional information for adequate conclusions.
Comparison of the materials volume parameters for four images shown in Figure 1, may differentiate surfaces in terms of lubrication sealing, flow and entrapment. The peak material volume V_{mp} should be important parameter that can detect desired sealing can's surface behavior. The core void volume V_{vc} is useful to establish how much lubricant will fill the surface normalized to the measurement area between the 10% and 80% ratio values.

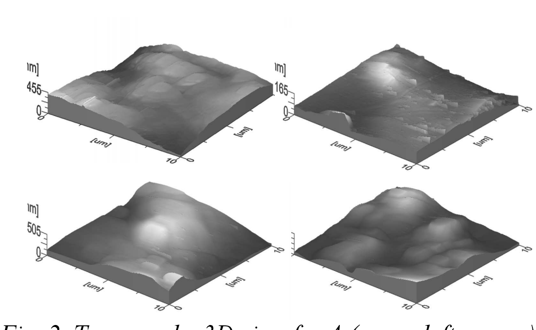


Fig. 2. Topography 3D view for A (upper left corner), B (upper right corner), C (lower left corner) and D (lower right corner)samples

The best lubricant behaviour from ecologically aspect perform surface denoted with A since its dale void volume parameter is the lowest and core void volume has acceptable value even though peak material volume is low. In Figure 2 the surface denoted by A is the one without too deep valleys. The surface D has ecologically unaccepted topography with very deep valleys surrounding by high peaks that will entrap lubricant. It will be difficult to wash out lubricant and therefore convinient to contact and contaminate the food.

4. CONCLUSION

Criteria for the more appropriate food metal beverage surface regarding ecologically accepted lubrication are based on imperative "grant high connected peaks in favour of sealing, provide undisturbed flow and diminish entrapped lubricant hard to wash out".

Therefore we conduct surface roughness assessment at AFM images, which are gathered after deep drawing processing. In this paper we point out S and V parameters role in characterization of the metal food beverage surface and potential lubrication behaviour:

- Areal parameter S_a is inappropriate dispersion parameter for deep drawing processed can inner surface. Therefore it shouldn't be calculated.
- Parameters S_q and S_{dr} are chosen as surface flattening indices.
- The skewness S_{sk} doesn't provide considerable information that can be used for surface distinguish and therefore it shouldn't be calculated.
- Kurtosis S_{ku} value close to 3, indicates surfaces predominantly normally distributed deep drawing processed can inner surface.
- Low values of $V_{mp}(10\%)$ prevent sealing, which effect lubricant squeezing during the deep drawing process. That affect to the amount of vested lubricant.
- Values of $V_{vc}(10\%,80\%)$ indicate preserved lubricant volume that participate in deep drawing process.
- Low values of $V_{vv}(80\%)$ are desirable to avoid lubricant entrapment and subsequently food contamination.

Finally, as result of presented investigation, we select set of six surface roughness parameters that are relevant for characterization of metal beverage surface after deep drawing processing. Selected set of relevant parameters may be used in further investigations and in industrial application in order to predict the surface volumetric lubricant retention capabilities.

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