THE SURFACE 3D PARAMETERS TO DESCRIBE THE DIFFUSE REFLECTIVE AND EMISSIVE PROPERTIES OF SELECTED DIELECTRICS

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Abstract − The investigations has been performed in order to choose the specific roughness parameters which would inform the customer about the diffuse emissive and reflective characteristics of the adhesive tapes used in the thermographic measurements. To achieve that, a series of the surface topography parameters of various adhesive tapes (i.e. objects with diffusive reflective characteristics) and various glass plates (i.e. objects with directional reflective characteristics) has been examined.

Keywords: thermal imaging, surface geometry, emissivity

1. BASIC INFORMATION

Remote temperature sensing and thermal imaging systems are invaluable tools in various fields of science and technology. The fact that radiation is a function of object surface temperature makes it possible for a remote temperature measurement systems to calculate this temperature. However, the radiation measured by these measuring systems does not only depend on the object temperature but is also a function of its emissivity. Therefore, to measure the temperature accurately with IR system, it is necessary to know this parameter. Emissivity is one of the major sources of error in radiometric measurements. In the radiometric temperature measurements which require determination of the emission coefficient of the object, in industrial conditions are widely applied special adhesive tapes. Those measuring methods are described in the literature. It is agreed that the emission coefficient of those tapes should be larger or equal to 0.95, and this parameter is typically specified by the tape producer. Moreover, they have to have characteristics of the diffusion reflectors/emitters, but no manufacturer provide this kind of information. Thus, the investigations has been performed in order to choose the specific roughness parameters which would inform the customer about the diffuse reflective and emissive characteristics of the adhesive tapes used in the thermographic measurements.

Emissivity describes the object's ability to emit thermal radiation. Normally, object materials and surface treatments exhibit emissivity's ranging from approximately 0.05 to 0.99. A highly polished surface falls below 0.1, while an oxidised or painted surface has much higher emissivity.

Generally, emissivity is not constant, as it depends on several parameters: temperature, viewing angle, wavelength, contamination or roughness [1,2,3]. All total radiative properties of materials can only be regarded as function of viewing angle and temperature. Spectral emissivity as a function of wavelength decreases for metals, increases for dielectrics and is band - like for gases, liquids and same solids. A general characteristic, independent of the kind of material, is the variability of emissivity according to surface roughness. Emissivity increases with the increase of roughness. In particular the emissivity of metal, which is usually low, can considerably increase with roughness. Classification of emissivity models has been created under Fresnels's equation, Kirchhoff's low, Drude free electron theory (optically smooth surfaces) as well as applying bidirectional reflectance function (BRDF), geometric optics, and electromagnetic scattering theory (rough surfaces).

2. RESEARCH METHOD – SURFACE TOPOGRAPHY ANALYSIST

In the world around us, all the surfaces are rough. Most of surfaces are very complicated, and in order to describe it with certain values, the measurement and analysis of some parameters should be performed. Before 1980 roughness analysis was based on 2D measurements, which gave two-dimensional characteristics of the surface. In last decades, the metrology of the surface layer notes dynamical development as a science. This trend is the result of new technologies, especially in the motor, aircraft or electronic industry. During the last decades, many scientists and constructors became convinced that the third dimension should be added to the analysis. At present, 3D analysis of the surface geometry is widely accepted. In 2002, the ISO technical committee TC213 voted the creation of a new working group and assigned it the task of developing future international standards for areal surface texture. They developed a in which and the 3D parameters are defined (ISO 25178, 2008: Geometrical product specifications - Surface texture: Areal - Part 2: Terms, definitions and surface texture parameters).

The 3D parameters are divided into groups:

- amplitude parameters: Sa, Sq, Ssk, Sku, Sp, Sv, Sz,
- functional parameters: Smr, Smc,
- spatial parameters: Sal, Str, Std,
- hybrid parameters: Sdq, Sdr,
- functional parameters: Vm, Vv, Vmp, Vmc, Vvc, Vvv,

- feature parameters: Spd, Spc, S10z, S5p, S5v, Sda, Sdv, Sha, Shv.

For surface topography analysis are defined a set of functional indices making it possible to characterize surface zones involved in wear or contact phenomena. The useful tool is the polar spectrum. The Fourier spectrum, when it is integrated in polar coordinates makes it possible to determine the privileged direction of surface structures. The polar spectrum takes into account the power spectrum of the surface in each direction. The angle with the largest power spectrum corresponds to the privileged texture direction. The representation of the polar spectrum clearly shows the privileged directions. The polar spectrum is use to determine and quantified the value of surface isotropy. A surface is said to be isotropic when it presents identical characteristics regardless of the direction of measurement.

2. RESEARCH METHOD – SURFACE TOPOGRAPHY ANALYSIST

There are many methods for available for geometric and surface topography measurements: contact and non-contact, micro and nanoscale approaches [4]. We have tested the application of white light interferometry for this purpose – optical surface profiler Veeco NT1100. The Vertical Scanning Interferometry (VSI) principle is realized by continuous vertical movement of the objective, the area of maximal interference corresponds whit subsequent examined levels. During operation, the system creates an interferogram from the examined surface, and the image is transmitted into CCD matrix [5]. A topographic map of the examined surface is produced, so that is one scanning path, depending on the type of objective, a surfaces up to 1x1 mm may be analyzed. Larger areas may also be scanned, but the stitching of smaller scans is required. Four samples were tested Four samples were tested using a device NT100: two glass surfaces and two tape surfaces. For all surfaces the measurement areas were 0.9x1.2 mm, 0.2x0.3 mm and 0.09 x0.12 mm. For each area, five measurements of surface topography were made(a total of 4x3x5 = 60 measurements). Sample images of the measured surface topography shown in Figures 1 and 2.
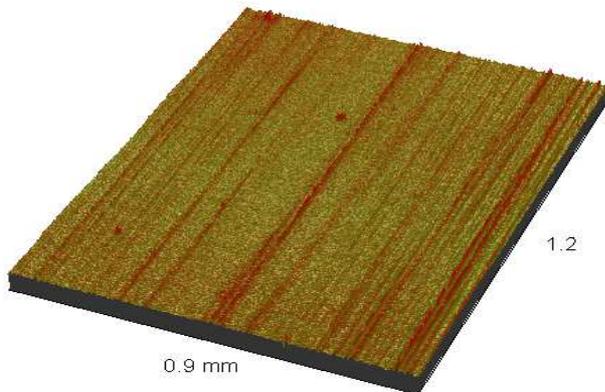

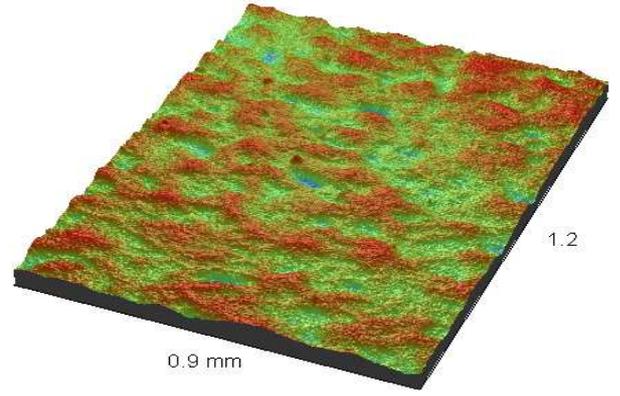Fig. 1. Sample images of surface topography of glass, measurement area 0.9×1.2 mm

Fig. 2. Sample images of surface topography of tape, measurement area 0.9×1.2 mm

For the analysis of surface topography the following parameters were selected: Sdq, Sdr. These selected parameters best describe the properties of the surface in the discussed aspect. They are defined as [6]:

Sdr – the Developed Interfacial Area Ratio (1), is expressed as the percentage of additional surface area contributed by the texture as compared to an ideal plane the size of the measurement region. In the case of a flat surface is 0, the rough Sdr > 0 and depends on the complexity of the surface.

$$Sdr = \frac{\sum_{j=1}^{N-1} \sum_{i=1}^{M-1} A_{ij} - (M-1)(N-1)\Delta x \Delta y}{(M-1)(N-1)\Delta x \Delta y} \cdot 100\% \quad (1)$$

where:

$$A_{ij} = \frac{1}{4} \left\{ \left(\frac{\left[\Delta y^2 + \left(\eta(x_i,y_j) - \eta(x_i,y_{j+1})\right)^2\right]^{1/2}}{+ \left[\Delta y^2 + \left(\eta(x_{i+1},y_{j+1}) - \eta(x_{i+1},y_{j+1})\right)^2\right]^{1/2}} \right) \cdot \left(\frac{\left[\Delta x^2 + \left(\eta(x_i,y_j) - \eta(x_{i+1},y_j)\right)^2\right]^{1/2}}{+ \left[\Delta x^2 + \left(\eta(x_i,y_{j+1}) - \eta(x_{i+1},y_{j+1})\right)^2\right]^{1/2}} \right) \right\}$$

Sdq – the Root Mean Square (2) Surface Slope comprising the surface, evaluated over all directions (in the discussed aspect: small angles to better reflect light).

$$S_\Delta q = \sqrt{\frac{1}{(M-1)(N-1)} \sum_{j=2}^{N} \sum_{i=2}^{M} \left[\left(\frac{\eta(x_i,y_j) - \eta(x_{i-1},y_j)}{\Delta x}\right)^2 + \left(\frac{\eta(x_i,y_j) - \eta(x_i,y_{j-1})}{\Delta y}\right)^2 \right]} \quad (2)$$

The values of Sdr, Sdq and isotropy for the measured surface are shown in Table 1 and Table 2. Figures 3 and 4 are showing example the surface isotropy and Figures from 5 to 7 are showing the average values of Sdr and Sdq parameters for the analyzed surface.
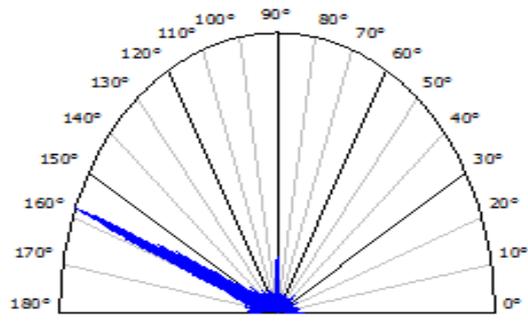
Parameters	Value	Unit
Isotropy	3.35	%
First Direction	158	°
Second Direction	153	°
Third Direction	164	°

Fig. 3. Sample images of glass surface isotropy
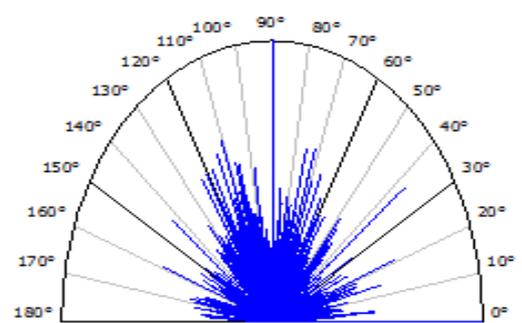
Parameters	Value	Unit
Isotropy	87.7	%
First Direction	90.0	°
Second Direction	0.144	°
Third Direction	37.2	°

Fig. 4. Sample images of tape surface isotropy

Table 1. The values of Sdr, Sdq and isotropy for surface of glasses of 0.9 x 1.2 mm area.

GLASS I			
No. measured area	Sdr [%]	Sdq [deg]	Isotropy
1	0.003	0.433	0.820
2	0.005	0.600	2.840
3	0.008	0.739	3.350
4	0.004	0.492	2.600
5	0.004	0.508	8.400
arithmetic average	0.005	0.554	3.602
standard deviation	0.002	0.119	2.846
range	0.005	0.306	7.580
GLASS II			
No. measured area	Sdr [%]	Sdq [deg]	Isotropy
1	0.001	0.225	21.700
2	0.001	0.222	22.900
3	0.001	0.279	25.450
4	0.001	0.218	25.300
5	0.001	0.218	25.200
arithmetic average	0.001	0.232	24.110
standard deviation	0.000	0.023	1.708
range	0.000	0.061	3.750

Table 2. The values of Sdr, Sdq and isotropy for surface of tapes of 0.9 x 1.2 mm area.

| TAPE I			
No. measured area	Sdr [%]	Sdq [deg]	Isotropy
1	1.458	9.774	58.200
2	1.518	9.971	37.400
3	1.554	10.090	44.000
4	1.484	9.866	39.800
5	1.460	9.784	87.700
arithmetic average	1.495	9.897	53.420
standard deviation	0.041	0.134	20.790
range	0.096	0.316	50.300
TAPE II			
No. measured area	Sdr [%]	Sdq [deg]	Isotropy
1	2.049	11.578	56.200
2	2.795	13.609	59.200
3	2.451	12.730	75.700
4	2.489	12.773	68.000
5	2.513	12.859	55.600
arithmetic average	2.459	12.710	62.940
standard deviation	0.267	0.727	8.685
range	0.747	2.030	20.100

Sdr [%]
0.2 x 0.3 mm area
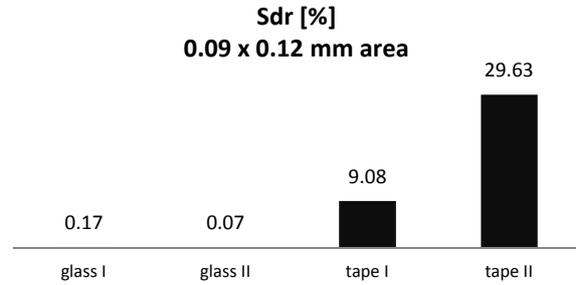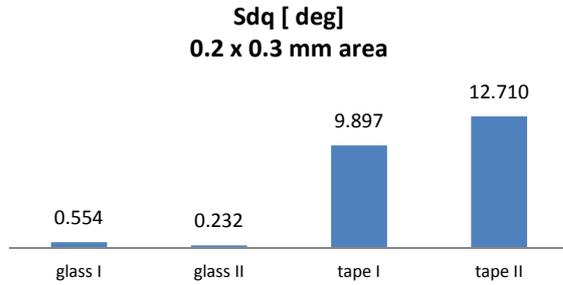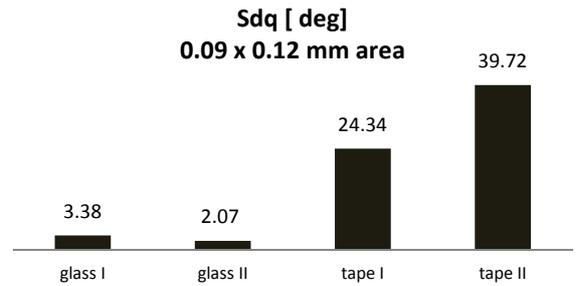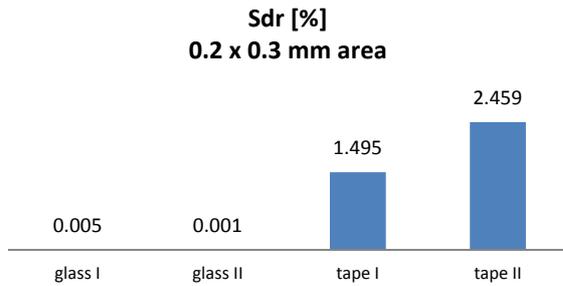
Fig. 5. Average values of selected parameters
for the analyzed surface of 0.9 x 1.2 mm area

Sdq [deg]
0.09 x 0.12 mm area

Fig. 7. Average values of selected parameters
for the analyzed surface of 0.09 x 0.12 mm area
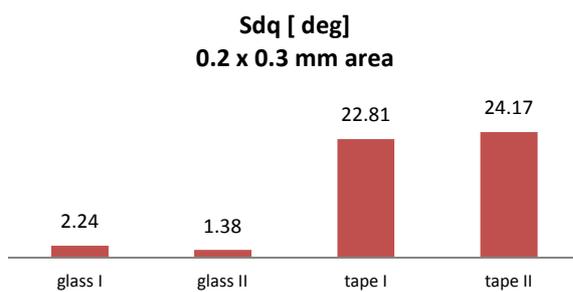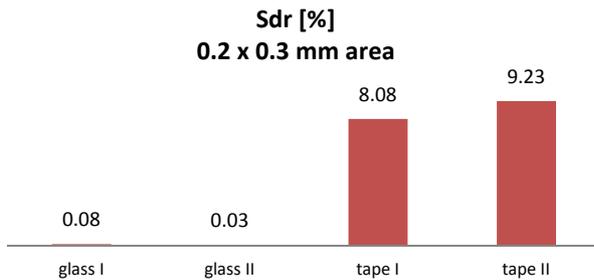
Sdr [%]
0.2 x 0.3 mm area

Fig. 6. Average values of selected parameters
for the analyzed surface of 0.2 x 0.3 mm area

4. CONCLUSIONS

The investigations has been performed in order to choose the specific roughness parameters which would inform the customer about the diffuse emissive and reflective characteristics of the adhesive tapes used in the thermographic measurements.

We analyzed six groups of 3D surface parameters: amplitude parameters, functional parameters, spatial parameters, hybrid parameters, functional parameters, feature parameters. The performed investigations proved with no doubts that the useful parameter corresponding with those characteristics could be a parameters Srd or Sdq. In case of the glass plates, their values are almost zero (very smooth surface), and in case of the adhesive tapes their values are larger than 1 (surface with many micro cavities and valleys). These selected parameters best describe the properties of the surface in the discussed aspect.

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