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Appointing of surface topography parameters to describe the diffuse reflective properties of selected dielectrics

Abstract

The investigations have 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. For the analysis of surface topography the following parameters were selected: Sdr (the Developed Interfacial Area Ratio) and Sdq (the Root Mean Square Surface Slope). These selected parameters seem to be most suitable to describe the properties of the surface in the discussed aspect.

Keywords: thermographic measurements, surface topography, emissivity, reflection.

1. Introduction

The 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 to calculate this temperature using a remote temperature measurement systems. 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 [1, 2]. 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 provides 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.

2. Emissive properties of materials

Emissivity describes the object's ability to emit thermal radiation. Normally, object materials and surface finishing 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, since it depends on several parameters: temperature, viewing angle, wavelength, contamination or roughness [3–8]. The total radiative characteristics 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).

A highly reflective surface is often equated with a surface with low emissivity. On the other hand, a visible specular reflection can be an indicator of a highly reflective surface, but not in any case. For example, specular reflections of the ambient radiation can be seen on the thermal image of a glass surface (e.g. reflection of person doing the measurement), even though glass generally has high emissivity ($\varepsilon = 0.95 - 0.97$).The outlines of reflected objects in the measuring environment cannot be seen on the thermal image of a tape ($\varepsilon \approx 0.95$) stuck to the glass, this phenomenon is shown on Figure 1. It can be assumed that the ambient radiation is reflected specularly in outlines therefore does not depend primarily on the emissivity but on the structure of the surface. In order to determine the difference of structure of the glass and tape surfaces analyze of surface topography was conducted.

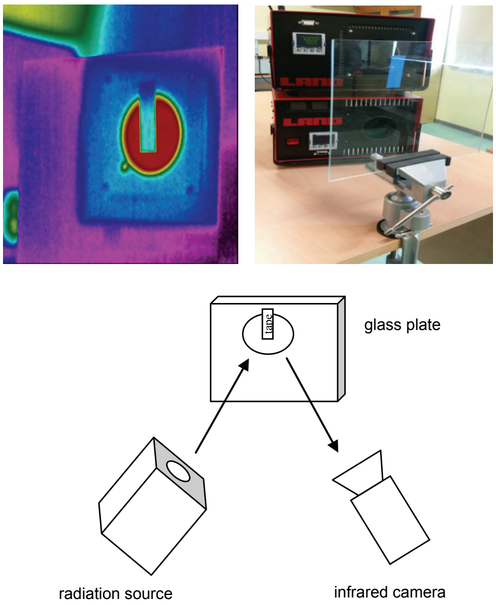


Fig. 1. Scheme of the measurement of reflected object

3. Surface topography analysis

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, the roughness analysis was based on 2D measurements, which gave two-dimensional characteristics of the surface. In last decades, the metrology of the surface layer dynamically developed 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. The Figure 2 illustrates the typical dilemma, where the profile measurement seems to be insufficient. Section (profile) measurement may miss important features on the surface (Fig. 2a). Most technical surfaces are anisotropic and profile measurement (2D) may be insufficient. This is one of the important reasons for extending the profile measurement to the 3D surface measurement (Fig. 2b and 2c). At present, 3D analysis of the surface geometry is widely accepted. In 2002, the ISO technical committee TC213 voted in favour of the creation of a new working group and assigned it the task to develop future international standards for areal surface texture. They developed a standard in which the 3D parameters are defined [9]. Referring to this standard, the 3D parameters can be divided into the following groups: amplitude parameters, functional parameters, spatial parameters, hybrid parameters, feature parameters.

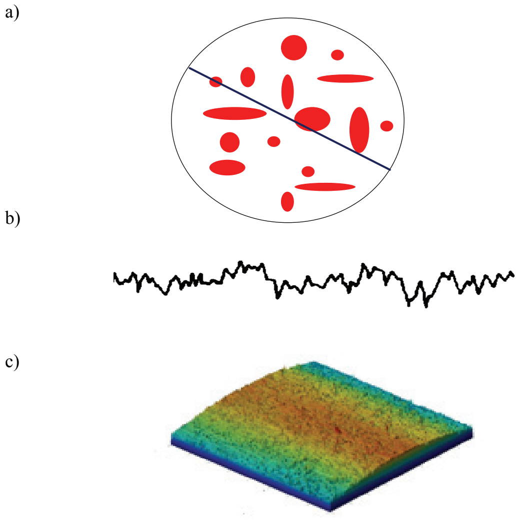


Fig. 2. Most technical surfaces are anisotropic and profile measurement (2D) may be insufficient: a) section (profile) measurement may miss important features, b) example of profile measurement, c) example of surface measurement

For the surface topography analysis, a set of functional indices are defined, 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 with the privileged texture direction. The representation of the polar spectrum clearly shows the privileged directions. The polar spectrum is used to determine the value of surface isotropy. A surface is said to be isotropic when it presents identical characteristics regardless of the direction of measurement. In other words, the higher the percentage value of isotropy is, the more characteristics of the surface stay the same in every direction.

4. Results and discussion

There are many methods available for the geometric and surface topography measurements, both contact and non-contact, micro and nanoscale approaches [10,11]. In the current research, the white light interferometry was applied: the 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 the operation, the system creates an interferogram from the examined surface, and the image is transmitted into CCD matrix [12]. A topographic map of the examined surface is produced, so that is one scanning path, dependent on the type of objective, a surfaces of dimensions up to 1×1 mm may be analyzed. Larger areas may also be scanned, but then the stitching of smaller scanned areas is required. Four samples were tested using a device NT100: two glass surfaces and two tape surfaces. For all surfaces, the measurement areas were 0.9×1.2 mm, 0.2×0.3 mm and 0.09×0.12 mm. For each area, five measurements of surface topography were made, which makes a total number of measurements 4×3×5 = 60 measurements). Sample images of the measured surface topography shown in Figures 3 and 4. Examples of surface polar spectrum are shown in the Figures 5 and 6.

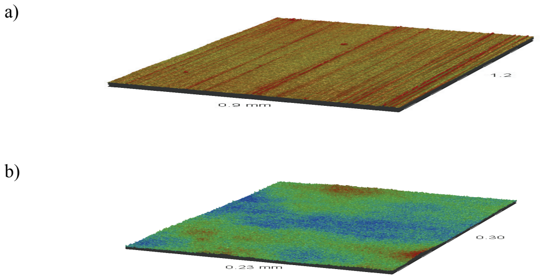


Fig. 3. Sample images of surface topography of glass:
a) measurement area 0.9×1.2 mm, b) measurement area 0.2×0.3 mm

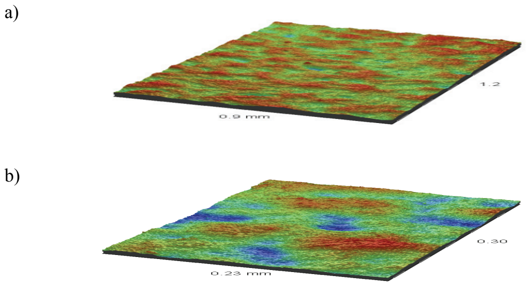
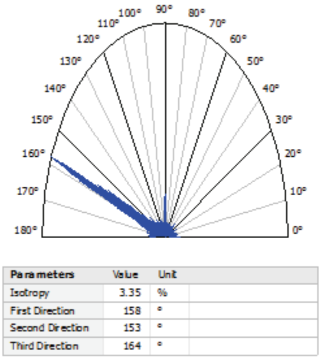
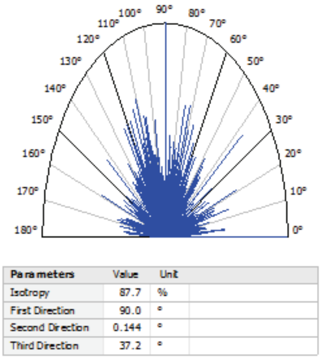


Fig. 4. Sample images of surface topography of tape:
a) measurement area 0.9×1.2 mm, b) measurement area 0.2×0.3 mm



Parameters	Value	Unit
Isotropy	3.35	%
First Direction	158	°
Second Direction	153	°
Third Direction	164	°

Fig. 5. Example of surface polar spectrum for glass surface (representing the texture directions and values of isotropy)



Parameters	Value	Unit
Isotropy	87.7	%
First Direction	90.0	°
Second Direction	0.144	°
Third Direction	37.2	°

Fig. 6. Example of surface polar spectrum for tape surface (representing the texture directions and values of isotropy)

A key problem in surfaces research is choosing parameters that characterise surfaces properties in such way that they correlate with surfaces topography geometry and functional behaviour.

In this work, the surface properties are analysed from the perspective of specular reflections, so for this reason hybrid parameters may describe this phenomenon best. The hybrid property is a combination of amplitude and spacing. Any changes which occur in either amplitude or spacing may have an effect on the hybrid property. For the analysis of surface topography, the following parameters were selected: *Sdq* – the Root Mean Square Slope and *Sdr* – the Developed Interfacial Area Ratio. *Sd*r and *Sdq* parameters are defined as follows [9, 10]:

Sdr – the Developed Interfacial Area Ratio, 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, equation (1). In the case of a completely flat surface, it is 0, for the rough surface *Sdr* > 0 and it depends on the complexity of the surface. When a surface has any slope, its *Sdr* value becomes larger. Figure 7 shows the interpretation of this parameter.

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

where:

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

$$\left.\left(\begin{array}{c}\left[\Delta x^2 + \left(\eta(x_i,y_j) - \eta(x_{i+1},y_j)\right)^2\right]^{1/2} + \\ + \left[\Delta x^2 + \left(\eta(x_i,y_{j+1}) - \eta(x_{i+1},y_{j+1})\right)^2\right]^{1/2}\end{array}\right)\right\}$$

and

Δx, Δy – sampling interval in x, y direction,
M – the number of sampling points in one trace,
N – the number of sampling points in the area,
$\eta(x_i, y_j)$ – the residual surface, obtained by subtracting the last squares datum plane from the original surface, which is suitable for parameter evaluation,
$i = 1, 2, \dots, M-1$;
$j = 1, 2, \dots, N-1$.

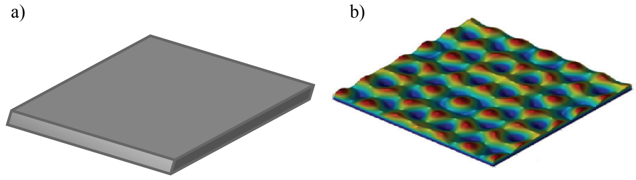


Fig. 7. Interpretation of parameter *Sdr*, a) *Sdr* = 0, b) *Sdr* > 0

Sdq– the Root Mean Square Slope. Surface slope comprising the surface, evaluated over all directions (in the discussed aspect: small angles better reflect light). It is described as follows:

$$Sdq = \sqrt{\frac{1}{(M-1)(N-1)}\sum_{j=2}^{N}\sum_{i=2}^{M}\left[\begin{array}{c}\left(\frac{\eta(x_i,y_j) - \eta(x_{i-1},y_j)}{\Delta x}\right)^2 + \\ + \left(\frac{\eta(x_i,y_j) - \eta(x_i,y_{j-1})}{\Delta y}\right)^2\end{array}\right]} \qquad (2)$$

Sdq is calculated as a root mean square of slopes at all points in the definition area. *Sd*q of a completely level surface is 0. When a surface has any slope, its *Sdq* value becomes larger. Depending on the software this parameter is expressed in the following units: degrees, µm/µm or dimensionless.

The experimentally obtained values of *Sdr*, *Sdq* and isotropy for the measured surface (area 0.9×1.2 mm) are shown in Table 1. Isotropy is defined [9,10,11] as the ratio of length of fastest decay of ACF in any direction to length of slowest decay ACF in any direction, where ACF is Autocorrelation Function.

For each analysed surfaces of glass and tape, five measurements of surface topography were made. Table 1 lists also the arithmetic average, standard deviation and range of these parameters from the series of measurements. Figures 8 to 10 present the average values of these parameters for the analysed surfaces graphically.

Tab. 1. The results of the experiment (area 0.9×1.2 mm)

	GLASS I			**GLASS II**		
No. measured area	*Sdr*, %]	*Sdq*, deg	Isotropy	*Sdr*, %	*Sdq*, deg	Isotropy
1	0.003	0.433	0.820	0.001	0.225	21.700
2	0.005	0.600	2.840	0.001	0.222	22.900
3	0.008	0.739	3.350	0.001	0.279	25.450
4	0.004	0.492	2.600	0.001	0.218	25.300
5	0.004	0.508	8.400	0.001	0.218	25.200
Arithmetic average	0.005	0.554	3.602	0.001	0.232	24.110
standard deviation	0.002	0.119	2.846	0.000	0.026	1.708
range	0.005	0.306	7.580	0.000	0.062	3.750
	TAPE I			**TAPE II**		
No. Measured area	*Sdr*, %	*Sdq*, deg	Isotropy	*Sdr*, %	*Sdq*, deg	Isotropy
1	1.458	9.774	58.200	2.049	11.578	56.200
2	1.518	9.971	37.400	2.795	13.609	59.200
3	1.554	10.090	44.000	2.451	12.730	75.700
4	1.484	9.866	39.800	2.489	12.773	68.000
5	1.460	9.784	87.700	2.513	12.859	55.600
Arithmetic average	1.495	9.897	53.420	2.459	12.710	62.940
standard deviation	0.041	0.134	20.790	0.267	0.727	8.685
range	0.096	0.316	50.300	0.747	2.030	20.100

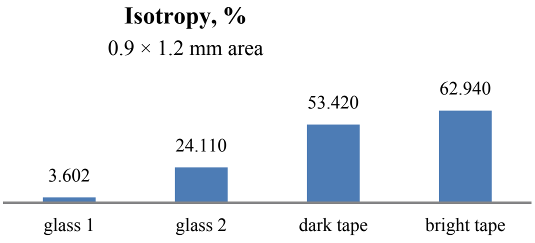


Fig. 8. The average values of isotropy

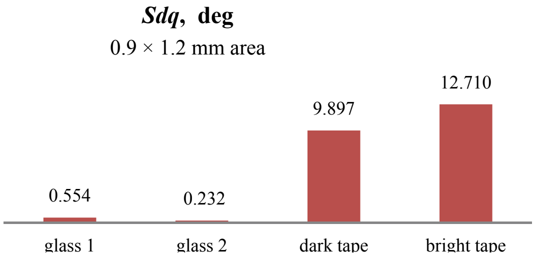


Fig. 9. The average values of *Sdq* parameters

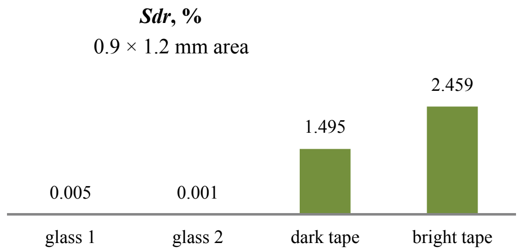


Fig. 10. The average values of *Sdr* parameters

5. Conclusions

Based on the performed investigations the following conclusions can be drawn:

- a clearly visible specular reflection may be an indicator of a reflective surface. However, highly reflective is not always the same as highly specular. The reflected infrared radiation which is seen in the Fig. 1, does not depend on the reflectivity of the surface only. The surface topography plays substantial role in the process of reflection,
- the useful surface 3D parameter corresponding with those reflective surface properties could be a parameters *Sdr* and/or *Sdq*. These are hybrid parameters – combination of amplitude and spacing. Any changes which occur in either amplitude or spacing may have an effect on the hybrid property,
- in case of the glass plates, *Sdr* 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),
- values of *Sdq* parameters are smaller for glass surfaces, which confirms that this surface may better reflect radiation,
- the values of isotropy have significant differences for glass and tape surfaces, and they are bigger for tapes.

Despite the glass and the tape have the similar emissivity, they reflect the infrared radiation in very different way. The proposed hybrid surface topography parameters *Sdr* and *Sdq* in large extend correspond with the above phenomena and may be used to describe reflective properties of the surfaces of similar emissivity.

Manufacturers of tapes, used in IR thermography describe the properties of their products using parameters like emissivity, operating temperature etc. The performed investigations may be an indication for them to extend the specification with the parameters related to surface geometry.

6. References

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