Rev.Adv.Mater.Sci. 8 (2004) 79-81

OPTICAL PROPERTIES OF STEEL SURFACES SUBJECTED TO MECHANICAL POLISHING, ETCHING AND OXIDATION PROCESSING

Janusz Jaglarz[1], Łukasz Zięba[2], Jan Cisowski[1,2] and Jan Jurusik[2]

[1]Institute of Physics, Cracow University of Technology, ul. Podchorazych 1, 30-081 Cracow, Poland
[2]Center of Polymer Chemistry, Polish Academy of Sciences, ul. M. Curie-Sklodowskiej 34, 41-819 Zabrze, Poland

Received: November 20, 3004

Abstract. The reflection studies of steel samples subjected to mechanical polishing, etching and oxidation processes have been performed with an integrating sphere, along with atomic force microscopy (AFM) investigation. It appears that the total light reflection from the steel surfaces changes very little after mechanical treatment, but contribution of specular- and diffuse components of the optical reflection changes substantially. Etching in an HCl solution causes initially decreasing of roughness, but, after longer etching time, roughness increases by about 15%. During the optical studies of oxidation *in situ* in the free air, it has been found that roughness decreases rapidly during first 200 s and then it asymptotically goes back to its initial value.

1. INTRODUCTION

Reflection of light, or more generally, reflection of an electromagnetic wave, may be specular, diffuse or it may be a mixture of both. The specular reflection takes place on an ideal, smooth, polished metallic surface; in this case, the reflection angle is equal to the incident angle. Real metallic surfaces are non-ideal and exhibit some roughness and inhomogeneity resulting in that a part of light is reflected diffusely, i.e. there is no relation between reflection and incident angles. The specular reflection informs about the physical structure of the surface under study, while the diffuse reflection – about smoothness of the surface [1,2].

A surface subjected to mechanical, elastic or chemical treatment changes relation between specular and diffuse parts of the total reflectivity. Measuring the specular and diffuse components of the reflected light, one can calculate their ratio which, in turn, determines the gloss effect parameter describing the degree of the surface smoothness, becoming higher with increasing of the specular component in the total reflectivity.

For majority of steel surfaces, one deals with simultaneous specular and diffuse reflections. As a method to determine the intensity of light reflected from the rough surfaces the diffuse spectroscopy is used, being a universal tool allowing one to estimate the quality of surface by scattering light of different wavelength. The expression describing relationship between both kinds (specular and diffuse) of reflection and the root mean square (rms) surface roughness follows from the statistical treatment of interaction of an electromagnetic wave with a rough surface. In the first approximation, one gets [3,4]

$$R_{diff} = R_0 \exp\left[-\frac{(4\pi\sigma)^2}{\lambda^2}\right], \qquad (1)$$

where R_{diff} and R_0 are diffuse and specular components of the total reflected light, respectively, σ is the rms surface roughness and λ is the light

Corresponding author: Janusz Jaglarz, e-mail: pujaglar@cyf-kr.pl

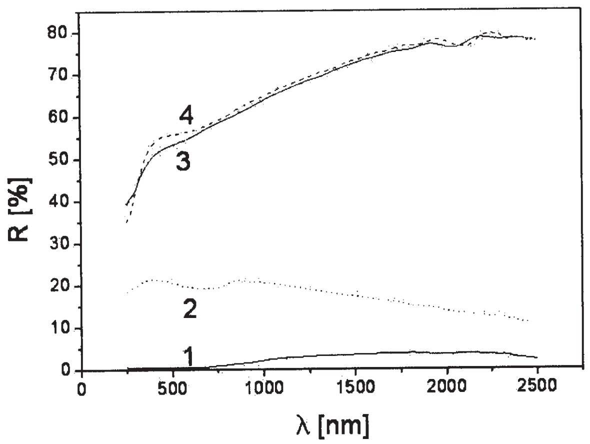

Fig. 1. Total and diffuse reflectivities as a function of wavelength for ST3SY steel, polished (1 – diffuse reflectivity, 4 – total reflectivity) and non-polished (2 – diffuse reflectivity, 3 –total reflectivity).

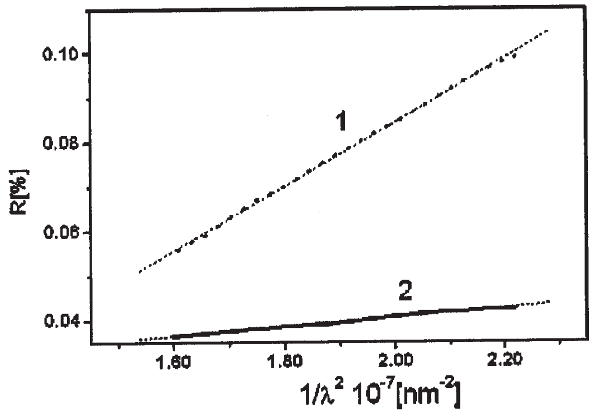

Fig. 2. Ratio of diffuse- to specular components of the reflectance coefficient as a function of $1/\lambda^2$ for ST3SY steel, polished (1) and non-polished (2). Dashed lines – experimental results, solid lines – fit to Eq. (2).

wavelength. When $\lambda >> \sigma$, Eq. (1) can be approximated by

$$R_{diff} = R_0 \frac{(4\pi\sigma)^2}{\lambda^2}. \quad (2)$$

2. RESULTS

Measurements of optical reflection from steel surfaces have been performed using an integrating sphere of type *d*/0° (meaning the diffuse illumination with the 0° angle of collecting light) [5], connected with a spectrophotometer. The method used allows one to separate the light intensity reflected from sample in the specular mode from the diffusive part of radiation. In the first step, we have performed measurements of the total and diffuse reflectivity coefficients (in the wavelength range 250 – 2500 nm) of non-polished steel surface, cut with a diamond saw. Then, we have carried out the reflectance measurements of the same surface subjected to the mechanical polishing using a diamond paste.

Fig. 1 shows the wavelength dependence of the total and diffuse reflectivity coefficients for polished and non-polished steel ST3SY surfaces. It can be seen that the surface polishing does not practically affect the total reflectivity, but it changes proportion between diffuse and specular components of the reflected radiation. For the polished surface, the diffuse component is at the level of a few percent, while for the non-polished surface the diffuse component is much higher. The total reflectivity coeffcient for polished surface is very close to the non-polished one.

Fig. 2 presents the diffuse component of the reflectivity coefficient as a function of $1/\lambda^2$. It can be seen that, in such coordinates, this dependence is linear in the long-wave part of spectrum, in accordance with Eq. (2). From fitting of this equation to the experimental data in the range 2000 – 2500 nm, the values of roughness have been determined as being equal to 43 and 167 nm for polished and non-polished surfaces, respectively.

In order to verify the optical results, we have performed the AFM measurements of the same polished surface in different points. The roughness found for local areas of the surface is in the range 40 – 55 nm, in agreement with the optical data.

In the next step, the steel samples, before and after polishing, have been subjected to etching in the 13% HCl solution, at 340K and during 1 – 15 minutes. It has been found, with the integrating sphere, that etching causes initially decreasing of roughness of both polished and non-polished surfaces, but, after longer time, roughness increases by about 15%.

In normal conditions in the free air, every steel sample after etching undergoes the natural oxidation process. This process has been observed continuously by measuring the total and diffuse reflectivities from oxidizing surfaces. Fig. 3 shows relative changes of roughness as a function of time for the steel surface subjected previously to etching in the HCl solution. These changes are smaller for

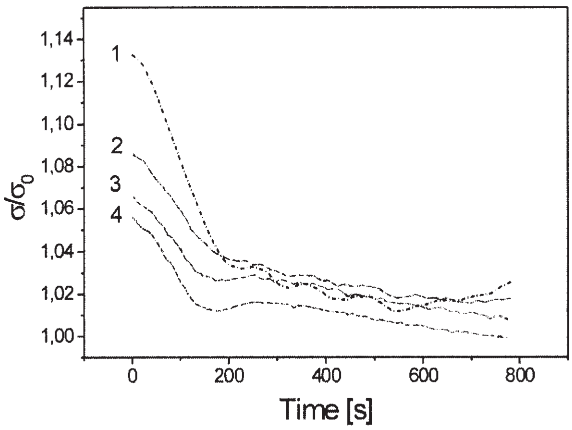

Fig. 3. Relative change of roughness of ST3SY steel surfaces as a function of oxidation time in free air, after etching in an HCl solution (1 and 2 – non-polished steel, 3 and 4 – polished steel; etching time: 30 and 20 min, respectively).

the polished surface than for non-polished one. Roughness of all samples oxidizing in the free air decreases during the first 200 s and, after a longer time, roughnesses asymptotically reach their initial values.

3. CONCLUSIONS

Measurements of the light reflectivity from surfaces of steel samples subjected to mechanical polishing, etching and oxidation processes have been performed using an integrating sphere. It appears that mechanical polishing changes appreciably relative contribution of the specular and diffuse components of the total reflectivity which, in turn, is practically independent of the surface treatment.

It has been also found that etching in an HCl solution causes initially decreasing of the roughness of both polished and non-polished surfaces but, after longer etching time, roughness increases and the observed changes are of the order of 15%. During the optical studies of oxidation *in situ* in the free air, it has been found the roughness of both polished- and non-polished surfaces decreases with time; such changes occur rapidly during first 200 s and then roughnesses asymptotically return their initial value. Smaller area of polished surfaces with respect to non-polished ones decrease susceptibility on etching and oxidations processes.

REFERENCES

[1] J.M. Hollas, *Modern Spectroscopy* (Wiley, Chichester, UK, 1996).

[2] P. Beckmann and B. Spizinochino, *The Scattering of electromagnetic waves from rough surfaces* (Pergamon Press, Oxford, UK, 1963).

[3] H.E. Bennet and J.O. Porteus // *J. Optical Soc. Amer.* **51** (1961) 123.

[4] J.C. Stover, *Optical scattering. Measurements and analysis* (SPIE, 1990).

[5] J. Workmann and A. Springsteen, *Applied Spectroscopy* (Academic Press, 1998).