An Optical Approach to Estimate the Surface Roughness of Metals

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Abstract: A fiber optic sensor system is proposed to estimate the surface roughness of metals. This work is based on the principle of scattering of light by objects. A light beam from a laser source is focused onto the metal surface. The resultant specular and diffuse reflections from the surface are collected by the photodiode. The observed optical responses correlate well with commercial stylus instrument measured surface roughness values (correlation coefficient (R^2) = 0.9766). A consistent relationship is found between optical measurements and surface roughness values. The fiber optic sensor system can be used to estimate the roughness of metals due to any type of corrosion without erosion. [The Journal of American Science. 2007;3(3):49-53]. (ISSN: 1545-1003).

Keywords: fiber optic sensor, scattering principle, surface roughness, corrosion

1. Introduction

For obtaining quantitative estimation of surface roughness involves many different methods, using several different units of measurement (Beckwith, 2000), Skolnik (2000). Even though, number of mechanical techniques prove their competent ability to quantify the rough surfaces, the optical method, due to its non-contact and its applicability to in-process measurement, has been considered as best to perform measurements of surface roughness very quickly, Stedman (1988), Chen (2004), Stout (1984). This work is based on the scattering of light principle that has been dealt with by (Beckmann, 1987), (Kim, 1989), (Lavin, 1971), (Ogilvy, 1991), (Stover, 1990). The specular and diffuse reflection from ground and lapped metal surfaces had measured, Welford (2004). When the metal transits from smooth surface, which reflects light specularly, to a rough surface, a higher proportion of incident light is scattered diffusely. This transition can be related to surface roughness and it can be described as a point quantity using light scattering methods, averaging over the incident spot of the beam, Cahill (1999). The main limitation in using the optical methods to measure surface roughness is the absence of direct estimation of standardized and accepted parameters such as average surface roughness (*Ra*), and rms or quadratic mean roughness (*Rq*), Persson (1999). The complexity in direct estimation of roughness parameters using fiber optic sensor system was experienced by, Cahill (1999), Persson (1999) Dinghai (1991). Average surface roughness between 0.025 μm and 0.8 μm was estimated through vertical displacement at an incident angle of 60^o by Cahill (1999). Domanski (1992) had discussed about intensity based and polarization-based surface roughness measurements using optical fibers [15]. Recently Ganesh (2006) have suggested a fiber optic sensor system to estimate the corrosion of metals by measuring the changes in surface texture.

The goals of this study are to develop a fiber optic sensor system to measure the spatially resolved profiles of scattered light intensity in metal surfaces and correlate the optical results with a commercial stylus instrument measured roughness values. A computerized micromanipulator is used to move the fiber holder along the metal surface in XY direction. The stylus instrument is used to measure the roughness of metals at the same locations where the intensity profiles are measured. By correlating the surface roughness measured by stylus instrument with the results of scattered light intensity, it is possible to calibrate the fiber optic sensor measuring the intensity of scattered light in terms of surface roughness. The results show a consistent relationship between the changes in surface texture and optical measurements. To check the sensor reliability, a standard aluminum surface is used as a reference for all the measurements.

2. Experimental

The mild steel plate having weight composition of 0.54 Mn, 0.05 Si, 0.01 S, 0.01 P, 0.16 C and the rest of Fe, cut into identical pieces. The test samples are successively polished with the silicon carbide papers up to 800 grades and the intensity profiles are measured before corroding them. This finest specimen has a value of surface roughness, *Rq* = 0.21 μm. Each test sample is consented to corrode using test solution of various concentration of sulphuric acid (8ml, 16 ml, 24ml, etc.,) in distilled water. A total of 100ml of test solution is sprayed uniformly on each test material to obtain metal samples of different corrosion levels. The source unit consists of a helium ± neon laser operating at 10 mW of 633 nm output and detection unit consists of photodiode, S6865-02 is sensitive to optical radiation from 320 to 1100 nm (M/s Hamamatsu, Japan). The laser light is coupled into a 1 × 2 multimode fiber coupler, F-CPL-M12855 (M/s Newport, USA). Any scattered light is collected by the photodiode. The optical system consists of fiber that has the core diameter of 62.5 μm (M/s Newport, USA). The fiber tip is cleaned and cleaved. The cleave quality has been tested by monitoring the scattered stable, reproducible signals in the surfaces of aluminum, brass and copper. The stability of scattered signal is evaluated by focusing the laser light through fiber tip in the aluminum surface (Reflectivity =71%) into brass alloy (Reflectivity=80%) back to aluminum surface, into copper specimen (Reflectivity = 90%) and finally back to aluminum surface over a period of 20 min. The identical dimensioned metal samples are polished successively using silicon carbide metallurgical papers up to 800 grades and finally treated with diamond paste. During this stability analysis study, the fiber tip is kept vertically at the distance of 2.5 mm above the sample surface. The resultant data are monitored by moving the fiber tip along the surface through horizontal displacement at an interval of 10 μm. The variation in resultant signal of a cleaved fiber in various surfaces is shown in Fig.1.

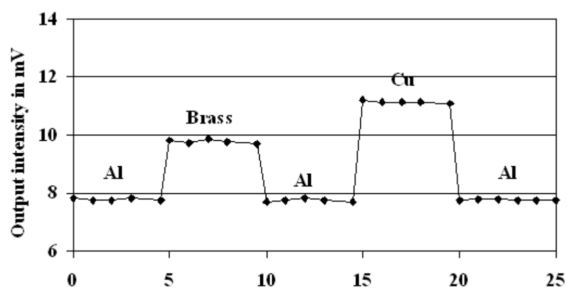

Figure 1. Stability of light signals analysis

It is observed that the sensor is free from errors due to intensity fluctuations caused by micro bending in the fiber, power supply fluctuations and thermal effects in the source for measurement region. An XY-motorized translational stage, T25XY-D/M is used to hold the fiber tip (M/s Thorlab Corporation, USA). A mechanical stylus instrument is used to make a reference measurement (Model: Perthen, Tip diameter: 2 μm). To measure the scattered light in corroded surfaces, the probe tip is mounted vertically in a computerized micromanipulator. The experimental setup is shown in Fig.2.

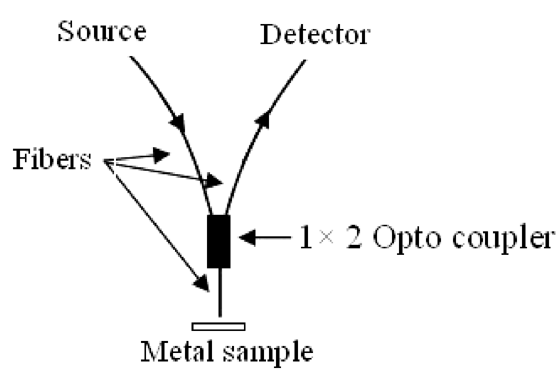

Figure 2. Schematic diagram of experimental setup

The motorized stage allows, moving the fiber tip horizontally in XY direction to the sample surface through a data acquisition board generated control signals. The fiber tip is held perpendicular to the sample surface. The metal area of 1cm × 1 cm is constituted for intensity measurement study. The intensity of the reflected light from the metal surface depends upon the surface texture of metal and stand-off distance between the surface and fibers tip. The intensity of scattered light is a function of concentration of corroding agent. Horizontal displacement measurements are carried out by mounting the fiber tip at a distance of 2.5 mm to the sample surface. Stand-off distance depends upon the numerical aperture of fibers. The data points are taken along the surface at 10 μm horizontal intervals. The constituted area of 1 cm2 is also subjected to surface roughness measurement using a stylus instrument. The average values of obtained optical measurements are plotted with the stylus instrument measured surface roughness values. It should be noted, the experiment is conducted in controlled atmospheric conditions for all the measurements. The use of the optical fibers facilitates the transmission and collection of the incident and scattered light intensities respectively. Any changes in surface parameter to be measured causes a change of the light property guided through the fiber. The fiber lead must be kept in a fixed orientation during data collection to minimize signal variations that are due to bend-induced losses. The fiber optic sensor is calibrated both before and after measuring the intensity profiles of each sample using the reference surface. Differences in calibration results before and after the intensity profile measurement are within 2% for all the data shown in this paper.

3. Results and Discussion

The results of typical data run are shown in Fig. 3.

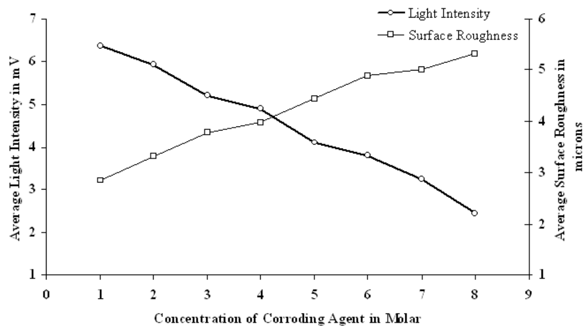

Figure 3. Comparison of average light intensity and average surface roughness for each molar concentration of corroding agent

The stylus instrument measured values are shown for comparison. The intensity based roughness measurement is strongly dependent on distance characteristics which are the essential problem of the method. However, for every single configuration of multimode optical fibers**,** there is an optimized insensitive region of the displacement characteristics (fiber-optic head - rough surface) for which resolution of roughness measurement is high enough to differentiate various rough surfaces, Domanski (1989). The scattered optical signal at 633 nm is decreased with the increasing concentration of corroding agent. It is assumed that increasing in the concentration of sulphuric acid, increases the number of sulphur ions reacting with metal ions in the surface leading to samples with various surface corrosion levels. This assumption is subsequently justified by the results obtained (Fig.3).

Overall net reactions on the surface area,

$$Fe + H_2SO_4 \rightarrow FeSO_4 + H_2O$$
$$Fe + H_2O \rightarrow Fe(OH)_2 \rightarrow Fe_2O_3$$

Initially when the concentration of corroding agent (H_2SO_4) is low, the surface is lightly corroded. Hence the metal surface reflects more light than it scatters. As the concentration increases, the scattered light component increases and the reflected light component decreases. Moreover, the observed variations in scattered light intensity are correlated well with the surface roughness. These results are highly repeatable. The data in Fig. 4 show the correlation between the optical scatter at 633 nm and the stylus instrument measured values (data extracted from Fig.3).

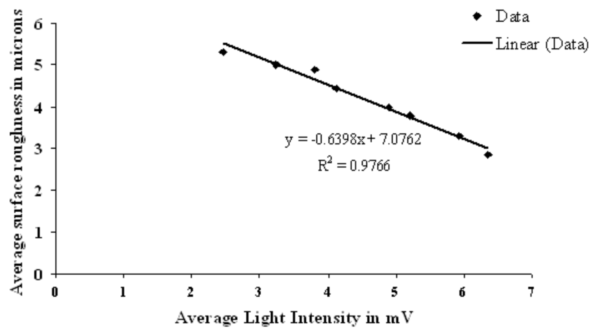

Figure 4. Correlation between average light intensity and average surface roughness

The correlation coefficient (*R2*) over many trials is always greater than 0.8923 and as high as, *R2* = 0.9766 in some tests (as presented in figure 4). The developed optical sensor possesses the advantages of low cost and long lifetime. With its uncomplicated experimental setup, this fiber-optic method allows differentiating the values of surface roughness in the range 0.12 µm – 5.32 µm (*Rq*) based on measurement of light scattered intensity from the rough surface. This implemented optical approach is immune to small displacements and vibrations, such as those which occur in production control or on-line measurements. Further experiments are under way to resolve the mechanisms involved in the measured optical responses and to develop a unique correlation between surface roughness and scattered light intensity.

4. Conclusion

The developed fiber-optic sensors show the large optical responses in rough surfaces. The observed response agrees well with mechanical stylus roughness measurements, with R^2 = 0.9766. The surface roughness measured in the present work represents an average value for a surface area of 1 cm^2. The surfaces measured with this optical system are classified in the same order as when using a stylus instrument. One of the limitation of this technique is that surface roughness of a metal is expected to reach the saturation value when the top layer gets completely corroded, resulting in total scattering of light. Any further increase in the thickness of the corroded layer may be detected by analyzing other characteristics of the scattered electromagnetic wave.

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