MEASUREMENT OF CHANGES IN SURFACE ROUGHNESS USING ULTRASONIC REFLECTION COEFFICIENT

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INTRODUCTION

The goal of this work is to develop a technique for on-line monitoring of surface topography. The monitoring of aluminum surfaces must provide reliable and fast distinction between "good" and "bad" surfaces. This project has investigated the feasibility of the ultrasonic reflection coefficient to measure differences in surface roughness. The standard deviations for the surfaces are 10 - 20 μm.

THEORY AND EXPERIMENTAL SET-UPS

Contact Measurements

Contact measurements were studied; experimental set-up is shown in Figure 1. The reflection coefficient $R_c(\omega)$ describes the reflection of the wave as it meets the buffer-couplant-sample interfaces, and is in general dependent on frequency (ω or f), surface roughness, couplant thickness, and material. The theoretical expression for the magnitude of $R_c(\omega)$ is [1]:

$$|R_c(\omega)| = \sqrt{\frac{\left(1-\frac{Z_1}{Z_3}\right)^2 \cos^2\left(\frac{\omega\cdot\partial x}{v}\right) + \left(\frac{Z_2}{Z_3}-\frac{Z_1}{Z_2}\right)^2 \sin^2\left(\frac{\omega\cdot\partial x}{v}\right)}{\left(1+\frac{Z_1}{Z_3}\right)^2 \cos^2\left(\frac{\omega\cdot\partial x}{v}\right) + \left(\frac{Z_2}{Z_3}+\frac{Z_1}{Z_2}\right)^2 \sin^2\left(\frac{\omega\cdot\partial x}{v}\right)}} \tag{1}$$

where Z_1, Z_2, Z_3 are the impedances of buffer rod, couplant and sample, respectively, v is the velocity in couplant, and ∂x is the couplant thickness. The echo from the front surface of the transducer is measured with the transducer in contact (FS_1) and not in contact (FS_2)with the sample [2]. The experimental reflection coefficient R_{exp} is computed using the fast-Fourier transforms of the echoes:

$$|R_{exp}(f)| = \frac{|FS_2(f)|}{|FS_1(f)|} \tag{2}$$

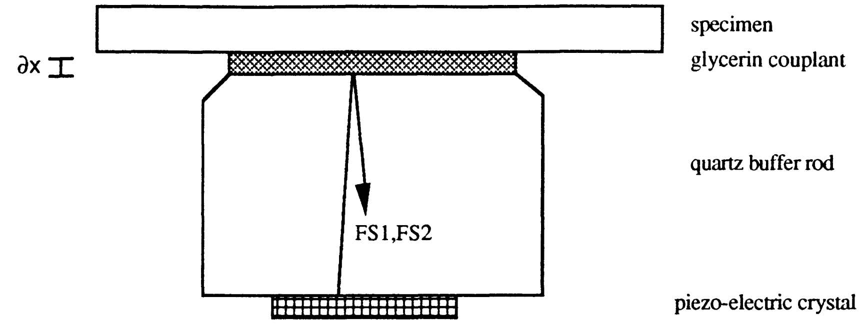

Figure 1. Experimental set-up for contact measurements. ∂x is the couplant thickness.

Immersion, Normal Incidence Measurements

An alternative to contact measurements is immersion measurements with normal incidence, as shown in Figure 2. Using a phase-screen approximation, an expression has been derived for this reflection coefficient [3]:

$$R_i(\omega)= R_o \exp(-2h^2k^2) \tag{3}$$

where R_o is the reflection coefficient of smooth surface, h^2 is the variance of surface heights and k is the wave number for water.

EXPERIMENTAL RESULTS

Contact Measurements

Three aluminum samples were used, produced using different surface preparation techniques: machined, grit blasted, and etched. For reference the reverse side of the machined surface was used as a smooth reference surface. This smooth reference surface was not specifically machined to be smooth, but it appears smooth at the scale of interest compared with the three prepared surfaces. The center frequency of the transducer is 5 MHz.

Two major effects on the measured reflection coefficient were found by contact experiments. Specifically, the external pressure exerted on the contact transducer affects the measured reflection coefficient. Also, variations exist across the sample surfaces.

To examine the effect of the external pressure applied to the contact transducer, the relative pressure was increased and the measured spectrum varied. At the center frequency of the transducer, the percentage change in magnitude spectrum was 13.2, 3.86, 5.51, and 1.39% for the smooth, etched, grit blasted, and machined surfaces, respectively. The premise of this technique is that the pressure on the transducer should be increased until the amplitude of the measured signal is unchanged. Even with considerable applied pressure, this constant amplitude was not reached.

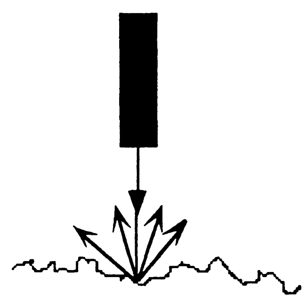

Figure 2. Experimental set-up for immersion, normal incidence measurements.

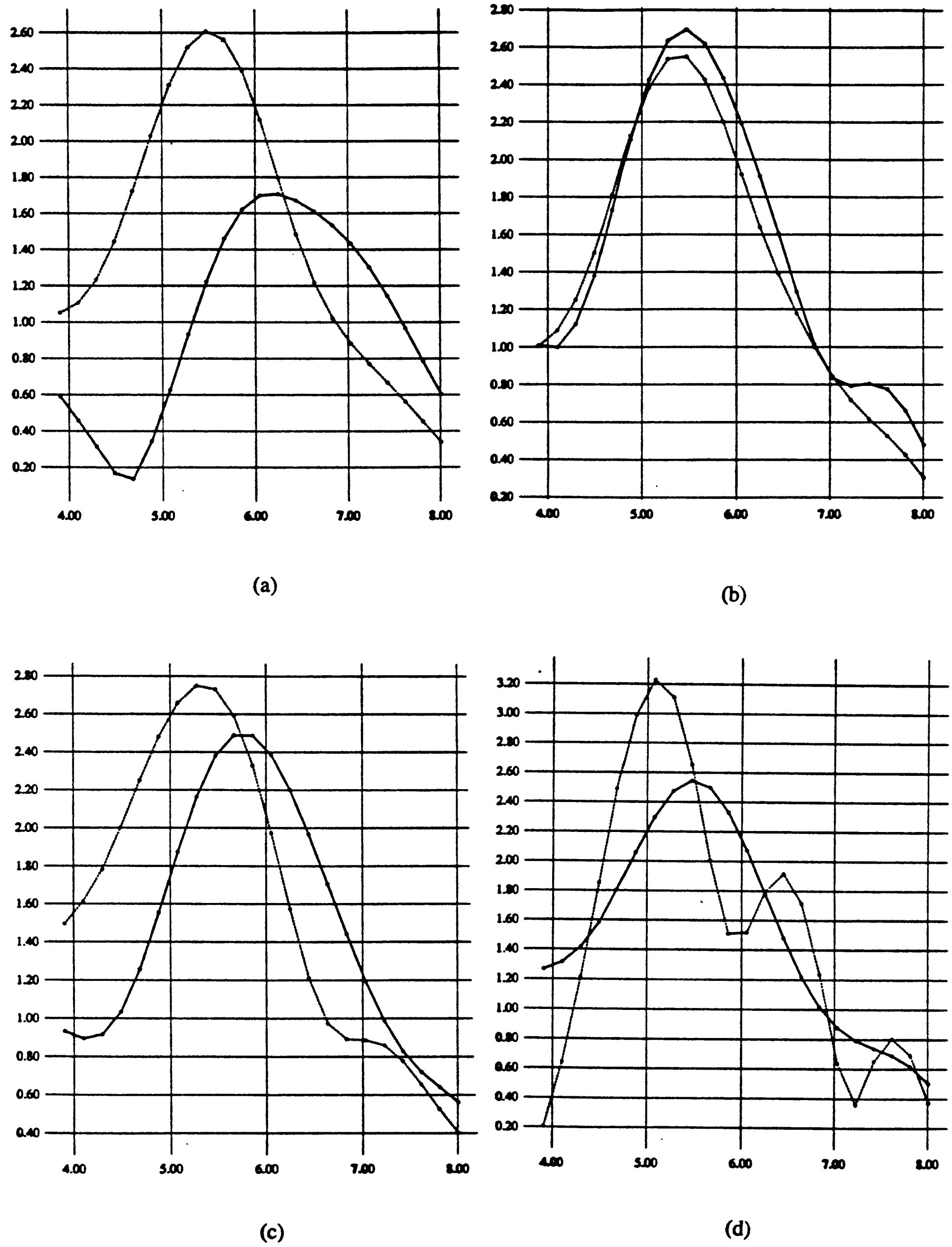

Figure 3. Measured magnitude spectra for contact measurements using different locations versus frequency, MHz. (a) smooth, (b) etch, (c) grit blasted, (d) machined

The variation of the measured reflection coefficient across a surface is not negligible. Figure 3 indicates the variation in the measured spectra between two different surface positions. These variations can be overcome by averaging over many surface positions. Figure 4 shows that after sixteen averages across each surface, the measured spectra settle to within 1% variation from the previous average at the center frequency. Note the slower

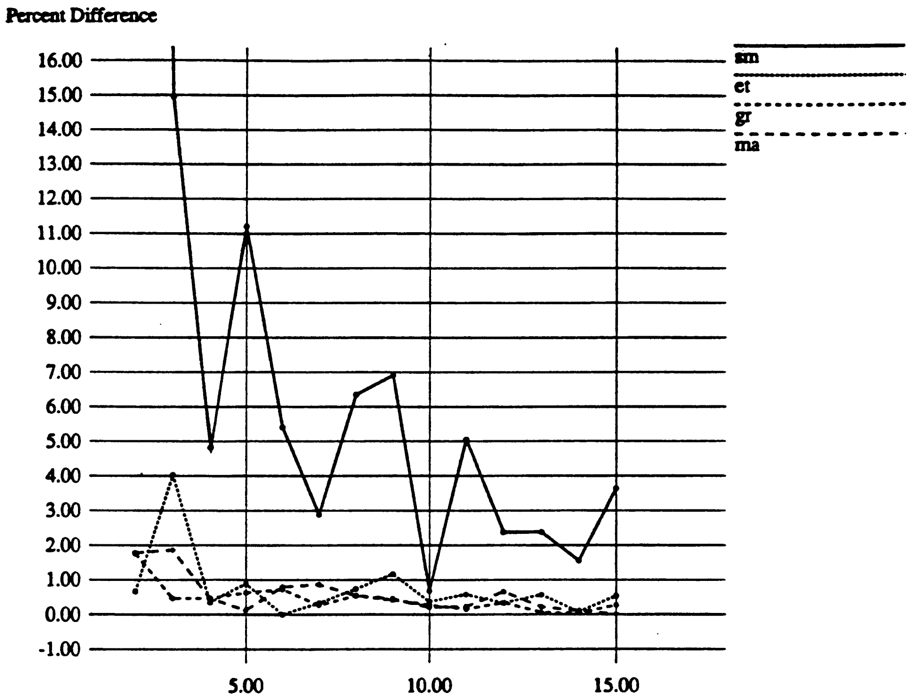

Figure 4. Percent difference for contact measurements versus number of averages. sm = smooth, et = etched, gr = grit blasted, ma = machined

convergence rate of the average for the smooth surface than for the three prepared surfaces. This is due to non-uniformity in the smooth surface.

The effects of applied pressure and surface variations were minimized by maintaining approximately constant pressure and by averaging over four locations for each surface. A comparison of the surfaces was made with these controls applied. Figure 5 shows the average reflection coefficient measured for each of the four surfaces.

Immersion, Normal Incidence Measurements

The aluminum samples used for the contact measurements were too small for immersion testing. Different samples were prepared by machining and sanding. Again a total of four samples was used. The smooth sample was machined to be significantly smoother than the other three samples at the scale of interest. Two samples were machined at different lathe speeds to result in surfaces of visibly different roughness. The final sample was prepared by first machining and then sanding. The result of these preparations was three surfaces rougher than the prepared smooth surface. Note that for the immersion measurements the smooth surface is used as a reference for the determination of the reflection coefficient and therefore in the following results the reflection coefficients are determined for the three machined rough surfaces. These measurements were made using a 2.5 MHz transducer and a 5 MHz transducer.

The major effect noted in the immersion measurements was variation across the surface of a given sample. Repeatability problems that were present in the contact measurements (i.e., the effect of the applied external pressure) were eliminated by the nature of the immersion measurements. The variations across each surface for the immersion measurements made with the 2.5 MHz transducer are shown in Figure 6.

The effect of the surface variations was minimized by averaging over four locations for each surface. A comparison of the surfaces was made with these controls applied.

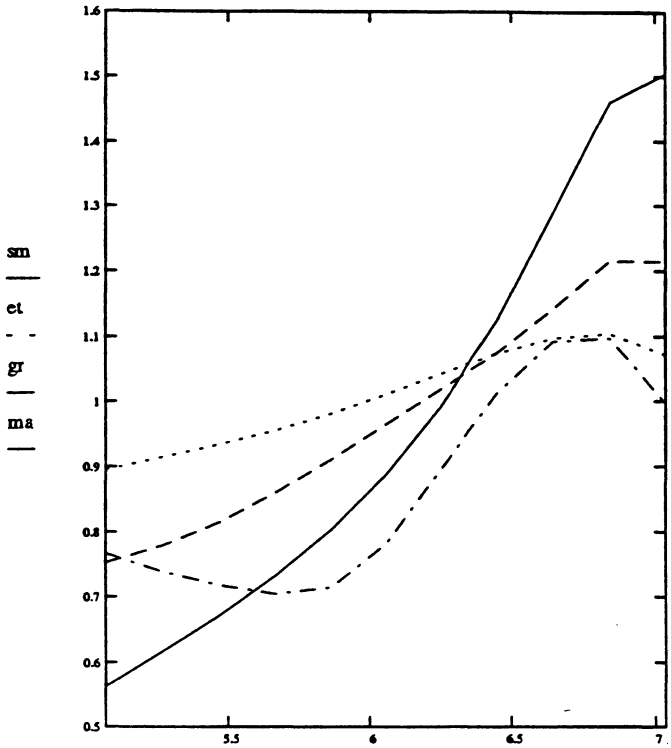

Figure 5. Measured reflection coefficients for contact measurements, averaged, versus frequency, MHz. sm = smooth, et = etched, gr = grit blasted, ma = machined

Figure 7 shows the average reflection coefficient measured for each of the three surfaces with the 2.5 MHz transducer and Figure 8 is a result from the 5 MHz transducer.

FUTURE STEPS

We are currently obtaining larger samples so that we can do both contact and immersion testing on the same samples. The variances in the contact measurements indicate that a mechanical set-up is called for, which we will build. More accurate experimental apparatus for insuring normal incidence for immersion testing is also called for. We also plan to determine which range of frequencies is most sensitive to the range of roughnesses of interest for our particular industrial application.

ACKNOWLEDGMENTS

This work is supported by the Ford Motor Company.

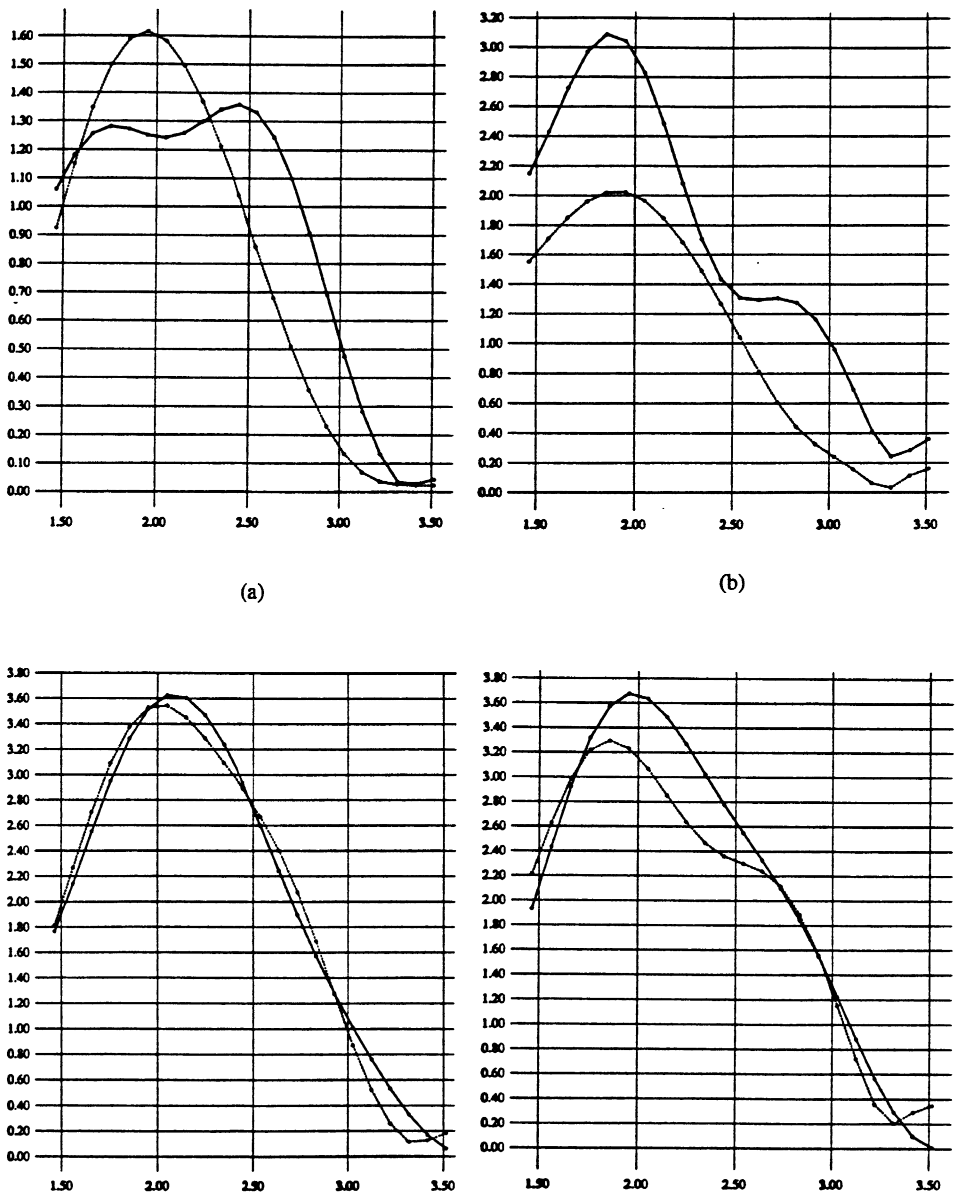

Figure 6. Measured spectra for immersion measurements using different locations versus frequency, MHz. (a) smooth, (b) etch, (c) grit blasted, (d) machined

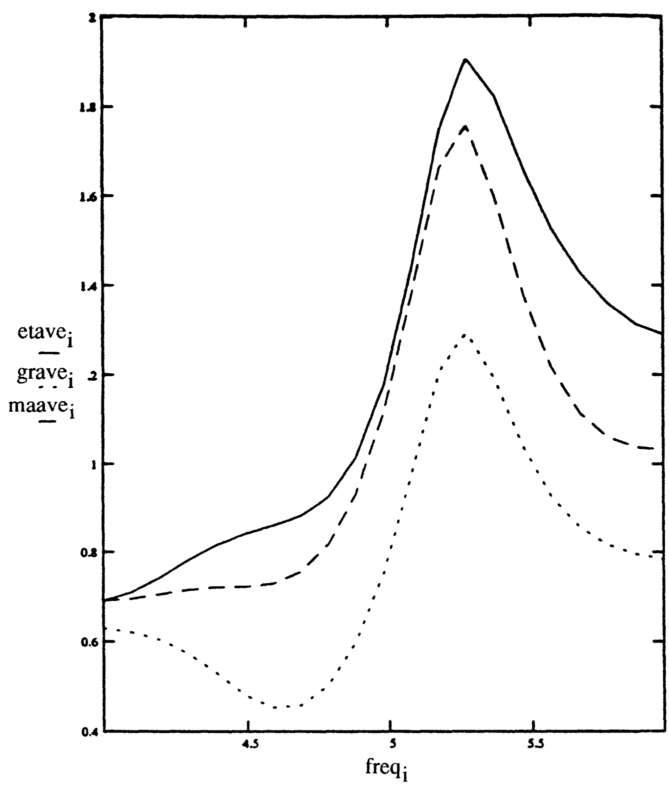

Figure 7. Measured reflection coefficients for immersion measurements, averaged, 5 MHz transducer, versus frequency, MHz. et = etched, gr = grit blasted, ma = machined

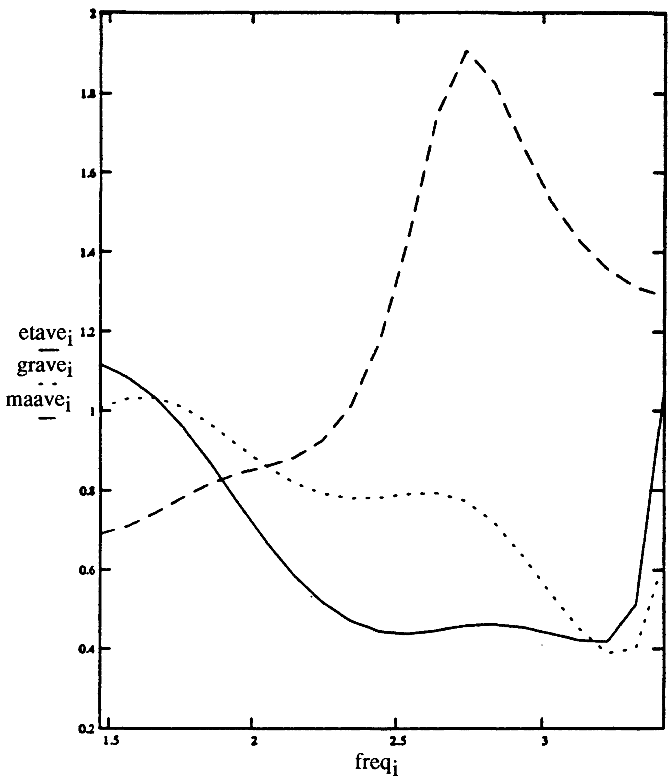

Figure 8. Measured reflection coefficients for immersion measurements, averaged, 2.5 MHz transducer, versus frequency, MHz. et = etched, gr = grit blasted, ma = machined

REFERENCES

1. Kinsler, L.E., et. al., Fundamentals of Acoustics, 3rd edition, 128 (1982).
2. Generazio, E. R., "The Role of the Reflection Coefficient in Precision Measurement of Ultrasonic Attenuation," Mat. Eval. 43, 995 (1985).
3. Nagy, P. B., J. H. Rose, "Surface Roughness and the Ultrasonic Detection of Subsurface Scatterers," J. Appl. Phys. 73, 566 (1993).