

**A comparison of stylus
and optical methods for
measuring 2D surface
texture**

Richard Leach and Anne Hart

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Centre for Basic, Thermal and Length Metrology

ABSTRACT

Due to the demanding dimensional specifications required by modern precision products a wide range of instruments and methods are being developed to establish an appropriate metrology infrastructure for surface texture. Increasingly, surfaces are being measured using non-contact optical probing techniques for which there are no internationally recognised specification standards. This lack of specification standards and other issues of calibration, along with the multitude of measuring instruments available, mean that it is difficult to obtain traceability to the definition of the metre. This report presents the results of a comparison of optical and stylus instruments. The National Physical Laboratory, two universities and four instruments manufacturers measured a ceramic sample and a nickel sinusoidal grating. The results show alarming differences between instruments based on different measuring principles and instruments using the same measuring principles.

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Approved on behalf of the Managing Director, NPL
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1. INTRODUCTION

In the past, the measurement of surface texture has been carried out primarily by making use of our senses of sight and touch. With a few technical modifications these methods are still used in industry today, *i.e.* most surface measuring instruments either use a contacting stylus or a non-contacting optical probe. Due to the demanding dimensional specifications required by modern precision products a large number of instruments and methods have been developed to establish an appropriate metrology infrastructure for surface texture measurement. A brief description of the traditional stylus method (see for example Whitehouse 1994, Thomas 1999) and a “generic” optical method is given in this report to show the basic principles, however there are many other methods that could be considered, such as scanning probe methods and optical scattering.

Stylus instruments are by far the most commonly used instruments for measuring surface texture today. The various elements of a typical stylus instrument, defined in ISO 3274 (1996), consist of a stylus that physically contacts the surface being measured and a transducer to convert its vertical movement into an electrical signal. Other components can be seen in figure 1 and include: a pickup, driven by a motor and gearbox (traverse unit), which draws the stylus over the surface at a constant speed; an electronic amplifier to boost the signal from the stylus transducer to a useful level; and a device, usually a computer, for recording the amplified signal.

The part of the stylus in contact with the surface is usually a diamond tip with a carefully manufactured shape. Owing to their shape and size, some styli on some surfaces will not penetrate into valleys and hence lead to a distorted, or filtered, measure of the surface texture. A recent study has shown that the actual radius of curvature of a stylus can be very different from its nominal value (Leach and Hart 2001). However, the effect of the stylus forces can also have a significant influence on the measurement results and too high a force will obviously cause damage to the surface being measured (Zahwi and Mekawi 2000).

Despite the stylus instrument being in use for many decades, there are a number of problems associated either with the operation of the instrument or with the interpretation of the results. For example, no instrument measures surface texture alone – with an inhomogeneous specimen a mechanical stylus will respond to both the topography and changes in the mechanical properties (elastic moduli, hardness) of the surface. Scale, both horizontal and vertical, is an important aspect of surface texture but it is still rare for instrument manufacturers to incorporate sound metrology into the scanning axes of their instruments and many users of instruments do not calibrate the movement of the scanning axes at all.

Over the years a great deal of attention has been given to the measurement of surface texture using optical techniques (see Leach 2000a, Smith 2002 for descriptions of the more common methods). The basic principle of optical measurement of surface texture may be illustrated with reference to interferometric and focus detection methods. Consider some form of optical interaction with a surface that allows local

height variations to be determined. Such methods will sample a different surface to that is sensed by a stylus instrument for a number of reasons:

1. In metals, non-homogeneity may give rise to apparent height changes of up to 10 nm due to the effect of the phase change on reflection.
2. In glasses or ceramics local refractive index changes and contaminant films produce nanometric changes (Raine and Franks 1985).
3. Phase changes at conducting surfaces vary as a function of incident angle.
4. Surface field anomalies caused by multiple scattering or sharp points acting as secondary sources of light, in addition to various edge and wall effects (Whitehouse 1999).

It is a common assumption that optical methods give numerically larger values for dimensional surface texture parameters because an optical probe reaches to the bottom of valleys whereas a stylus probe can “bottom-out”, *i.e.* not reach the bottom of some valleys. This is a highly dubious assumption and it is more likely that the high values for parameters are caused by the physical factors listed above.

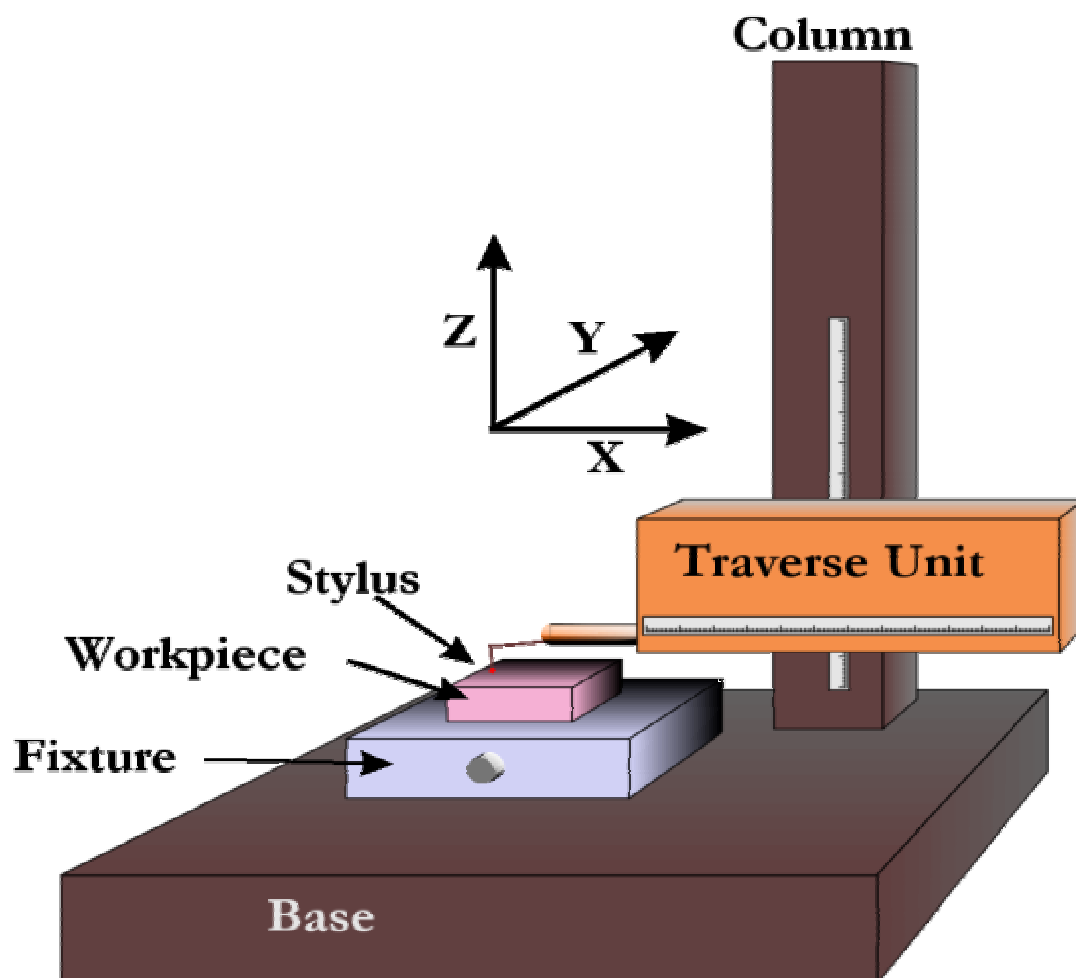


Figure 1 Elements of a typical stylus instrument (courtesy of Taylor Hobson)

Optical methods do not have the international standards infrastructure that supports the stylus method. This means that there are no formal methods for calibrating an optical instrument. Therefore, it is necessary to be very careful when using an optical instrument on a surface with changing physical characteristics. For example, if a glass step-height artefact is used to calibrate the vertical magnification factor of an instrument, it is risky to use the same calibration value when measuring the surface texture of a metal surface. Of course, this argument also applies to the stylus instrument, but the problems are not as pronounced.

One benefit of the optical methods over the stylus method is clear when one considers three dimensional measurements – an optical instrument is much faster than its mechanical counterpart.

Whatever technique is used to measure surface texture the assumption is made that the method is measuring the ‘true surface’. In practice this is not always the case. Kühle *et al* (2001) compared metal prosthetic femoral head (hip joint) surfaces using interference microscopy and atomic force microscopy (AFM). They observed significant differences between the two methods, but found that subsequent filtering of the AFM data brought the two sets of results into closer agreement. The results of two recent EC projects (Leach 2001a) reported large discrepancies between measurements using optical and mechanical instruments (see section 2).

Whilst there may be various physical reasons to explain the differences between different methods when measuring surface texture, the right calibration procedures and good measurement practice should ensure that different methods for measuring surface texture all determine the same value for surface texture. Appendix A illustrates that the same instrument can obtain very different results by using different instrument set-ups and operation modes (see also Muhl 2001).

This report describes a comparison of stylus and optical methods for measuring surface texture that was carried out following the alarming results reported by the EC projects described in section 2. The comparison used one sample (a nickel sinusoid) that, it was originally thought, all the instruments employed by the participants would be able to sample correctly, *i.e.* the results would fall within a few percent of each other. The other sample (a ceramic) was chosen as it was thought that the optical instruments would have more difficulty measuring this sample than the stylus instruments. These initial assumptions were not backed up by the results of the comparison. All the participants in the comparison were chosen either because they have a track record in surface texture measurement and research, or because they are manufacturers of high quality surface texture measuring instruments – there were no industrial participants.

2. RECENT EC COMPARISONS: CERANORM AND CALISURF

The results from the two EC-funded projects mentioned in section 1 are presented in this section. These comparisons have been carried out under strict guidelines with filter characteristics strictly specified and this point should be borne in mind when drawing conclusions from the results.

2.1 CERANORM

Project CERANORM was designed to address four areas of concern in the formulation of new specification standards for advanced ceramics. One work-package involved the circulation of pump-seal ceramic surfaces to ten EU industrial laboratories, one university and NPL. The results for a comparison of R_a values for four different surfaces are shown in figure 2 where laboratory 12 used an optical profilometer.

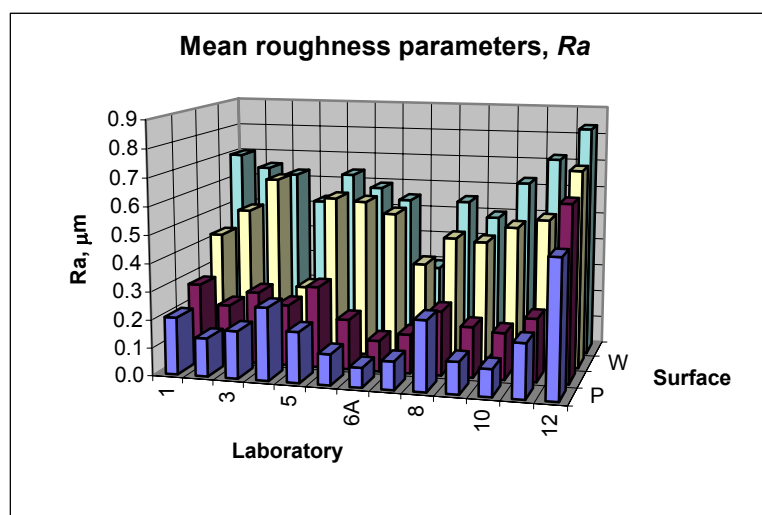


Figure 2 R_a results for the CERANORM project for four different surfaces

The project is described in more detail in Morrell and Cain (1999), but there were two main conclusions that are of interest in this report:

- The spread in results is very high and the difference between an optical method and the stylus methods is very alarming.
- The short-range roughness (*i.e.* high spatial frequencies) that is typical of a ceramic surface is not adequately represented by any of the instruments involved.

2.2 CALISURF

A second project CALISURF was completed in 2000 and was designed to develop artefacts and methods for calibrating surface texture measuring instruments. Part of the project involved a comparison of sinusoidally modulated surfaces using: five atomic force microscopes (AFMs), two stylus instruments and two interferometers. The results for a 2.5 μm period grating are shown in table 1 and, once again an alarming spread in results can be seen. More importantly, there is disagreement between instruments of the same type, the Rt results for the two interferometers are different by a factor of three, the spread in the Rt results for the AFMs is around 110 nm and that for the stylus instruments is around 30 nm.

Instrument type	Rt / nm	Ra / nm
AFM 1	290	48
AFM 2	204	54
AFM 3	188	49
AFM 4	192	53
AFM 5	241	66
Interferometer 1	429	115
Interferometer 2	141	36
Stylus 1	179	47
Stylus 2	147	-

Table 1 Results of the CALISURF comparison

3. THE UK COMPARISON

A comparison of the capabilities of UK users and instrument manufacturers was organised by NPL. Six participants agreed to take part in the comparison. These consisted of NPL, two universities and three well-established instrument manufacturers. Two samples were circulated for measurement. The first was a ceramic sample consisting of an annular ring 2 mm thick with external and internal diameters of 55 mm and 35 mm respectively. This sample was one that had been used in the CERANORM project. The surface to be measured was polished and lapped, and was isotropic (*i.e.* it had no lay). The second sample was a calibration grating with sinusoidal form (ISO 5436-1: 2000). The grating had a nominal amplitude of 0.2 μm and a nominal period of 8 μm .

For this comparison the measurement conditions were stated and participants were requested to adhere to these conditions as closely as possible. These are given in table 2 and Appendix B presents the full set of guidelines. Where optical instruments were employed the participants were asked to use the nearest equivalent measuring conditions to the quoted stylus parameter. For example, if the measurement conditions required a stylus radius of 2 μm then an optical focus spot size of 2 μm should be used. All participants were requested not to exceed a scanning speed of 60 mm per minute and a stylus force of 120 μN , where applicable. The type of instrument used to make the measurements and its principle of operation were also requested.

	Ceramic sample	Sinusoidal sample
Stylus radius	2 μm	2 μm
Trace length	5 mm	0.25 mm
Evaluation length	4 mm	0.25 mm
Cut-off length	0.8 mm	> 0.25 mm
Scanning speed	5 mm min ⁻¹	0.2 mm min ⁻¹
Number of traces	5	5
Stylus Force	40 μN	20 μN

Table 2 Measurement conditions for UK comparison

Each participant made five measurements on each sample. In the case of the ceramic sample five profiles were measured along five radii spaced at approximately 72 °. In the case of the sinusoid the five traces were spaced approximately 0.2 mm apart along a central line perpendicular to the grating direction. All the samples were thoroughly cleaned and inspected at NPL prior to circulation (Hart and Leach 2001). NPL measured the samples at the end of the comparison.

Participants were requested to measure as many of the following parameters as they could:

R_p - maximum profile peak height
R_v - maximum profile valley depth
R_z - maximum height of profile
R_t - total height of profile
R_a - arithmetical mean deviation of the assessed profile
R_q - root mean square deviation from the assessed profile
R_{sk} - skewness of the assessed profile
R_{ku} – Kurtosis of the assessed profile
R_{Sm} – mean width of the profile elements

These surface texture parameters are fully defined in ISO 4287: 1997 and the Measurement Good Practice Guide No 37: 2001 – *The Measurement of Surface Texture using Stylus Instruments* (Leach 2001b).

4. INSTRUMENTS USED IN THE NPL COMPARISON

Six participants took part in the comparison although a seventh participant also contributed the results described in Appendix A. Seven instruments were used as one participant was able to measure the samples using a stylus and an optical system. NPL used the NanoSurf IV; a traceable stylus instrument that is described elsewhere (Leach 2000b) and has an expanded uncertainty in its vertical and horizontal axes of 1.3 nm at 95% confidence. The instrument type and principle of operation used by each participant is given in table 2. In total three stylus instruments and four optical instruments were used in the comparison.

Participant	Instrument type	Principle of operation
NPL	Stylus (NanoSurf IV)	Laser interferometry to provide traceability and measure stylus displacement
Manufacturer 1	Stylus	Variable inductance transducer to measure stylus displacement
University 1	Stylus	Variable inductance transducer to measure stylus displacement
University 1	Optical	Scanning white light and optical phase-stepping interferometry
University 2	Optical (same instrument type as University 1)	Scanning white light and optical phase-stepping interferometry
Manufacturer 2	Optical (different instrument type to those used by Universities 1 and 2)	Scanning white light and optical phase-stepping interferometry
Manufacturer 3	Optical	Focus detection (chromatic aberration method)

Table 3 List of instruments used in the comparison together with their principles of operation

Depending on the instrument and its mode of operation some participants used more than one strategy to measure the samples and to process the data. Table 4 gives a brief list of the measurement strategies used for each instrument type. The corresponding notations that are used throughout section 5 are also given in table 4.

Participant	Measurement strategy	Measurement Type
NPL	Stylus instrument (NanoSurf IV) using 0.8 mm cut-off Gaussian roughness filter for the ceramic sample and no filter for the nickel sample	Stylus1
Manufacturer 1	Stylus instrument using a 2CR roughness filter with a cut-off of 0.25 mm for the ceramic sample and 0.8 mm for the nickel sample	Stylus2 (2CR)
Manufacturer 1	Stylus instrument using Gaussian roughness filter with a cut-off of 0.25 mm for the ceramic sample and 0.8 mm for the nickel sample	Stylus2 (G)
University 1	Stylus instrument using 0.8 mm cut-off Gaussian roughness filter for the ceramic sample and no filter for the nickel sample	Stylus3
University 1	Optical instrument with x50 objective	Optical1 (x50)
University 1	Optical instrument with x10 objective	Optical1 (x10)
University 2	Optical instrument with x1.25 objective with no filter for the ceramic sample and with x20 objective using 0.025 mm cut-off Gaussian roughness filter for the nickel sample	Optical2
Manufacturer 2	Optical instrument with no filter	Optical3
Manufacturer 2	Optical instrument using a low pass filter to remove high frequencies	Optical3
Manufacturer 3	Optical instrument with a spot size of <2 μm using 0.8 mm cut-off Gaussian roughness filter for the ceramic sample and no filter for the nickel sample	Optical4

Table 4 The measurement strategies used in the comparison

5. RESULTS

The results are presented graphically in this section. Where possible the standard deviation for each set of results has been calculated and is shown by the error bars on the graphs. A supplementary smaller graph is given in cases where a set of results is an order of magnitude different from the others. In such cases the error bars are not shown on the supplementary graphs. Where no result is recorded for a system no measurement has been made of that parameter. Time constraints meant that NPL could only make measurements on the samples after they had been circulated to the other participants.

5.1 RESULTS FOR THE CERAMIC SAMPLE

Figures 3 to 11 give the results for measurements made on the ceramic sample for various surface texture parameters.

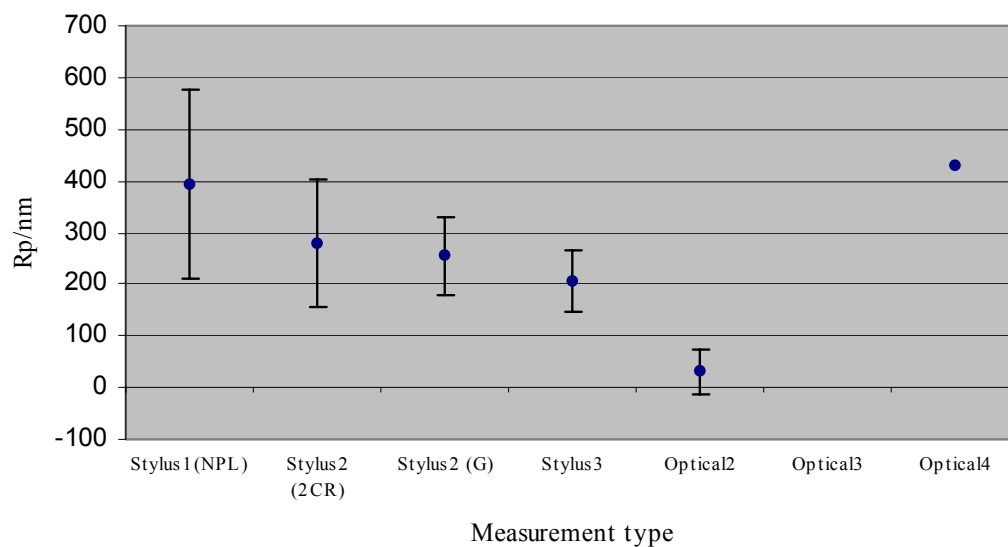


Figure 3 Results for measurements of R_p on the ceramic sample

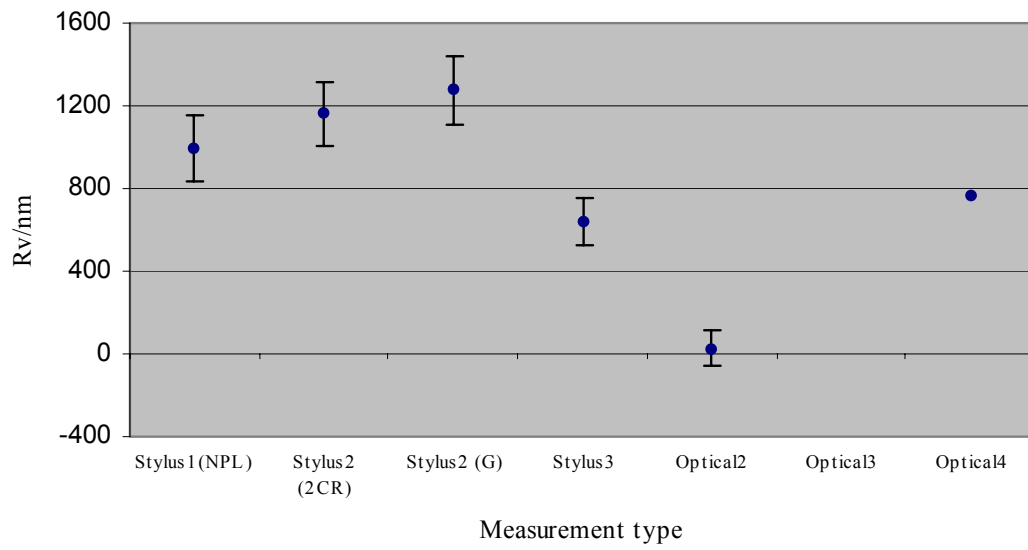


Figure 4 Results for measurements of R_v on the ceramic sample

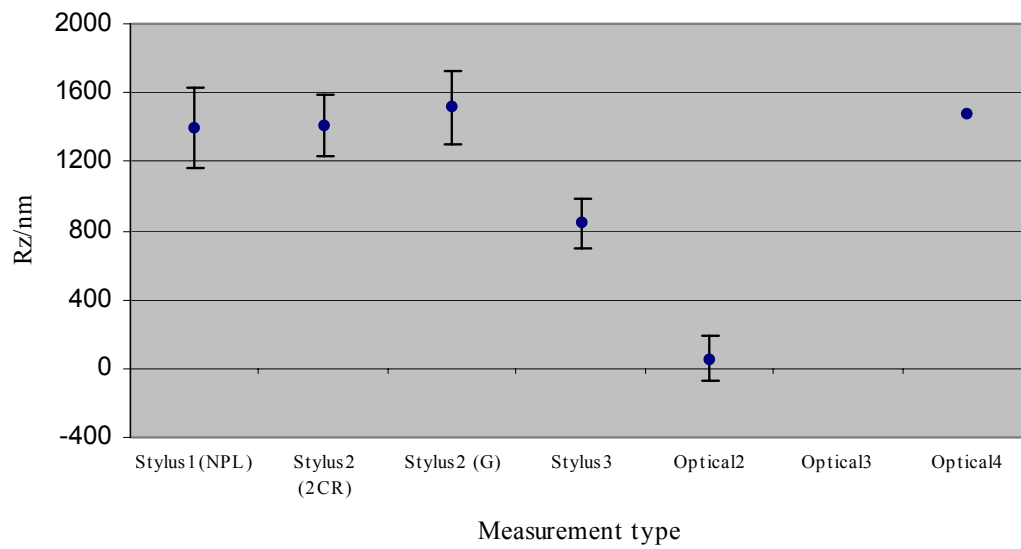


Figure 5 Results for measurements of R_z on the ceramic sample

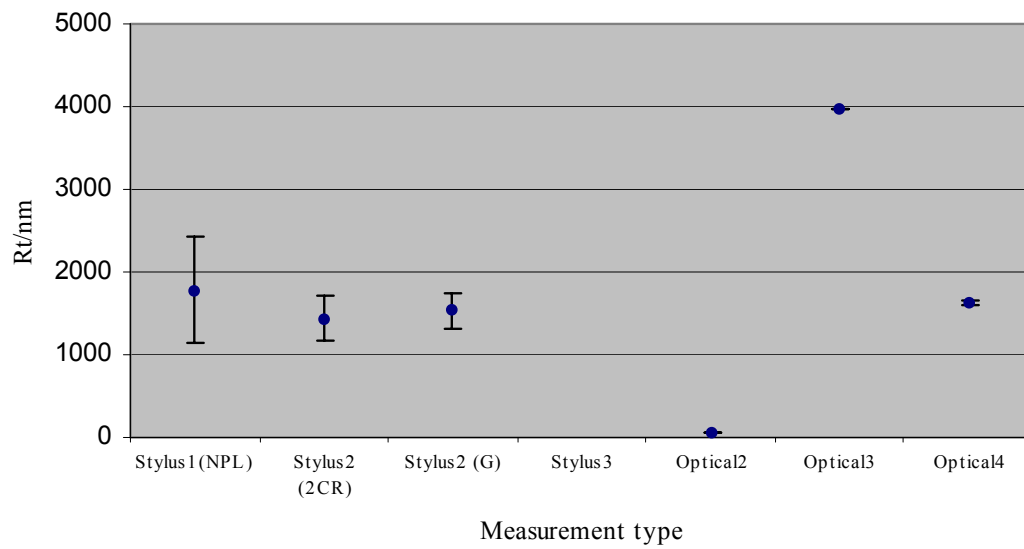


Figure 6 Results for measurements of R_t on the ceramic sample

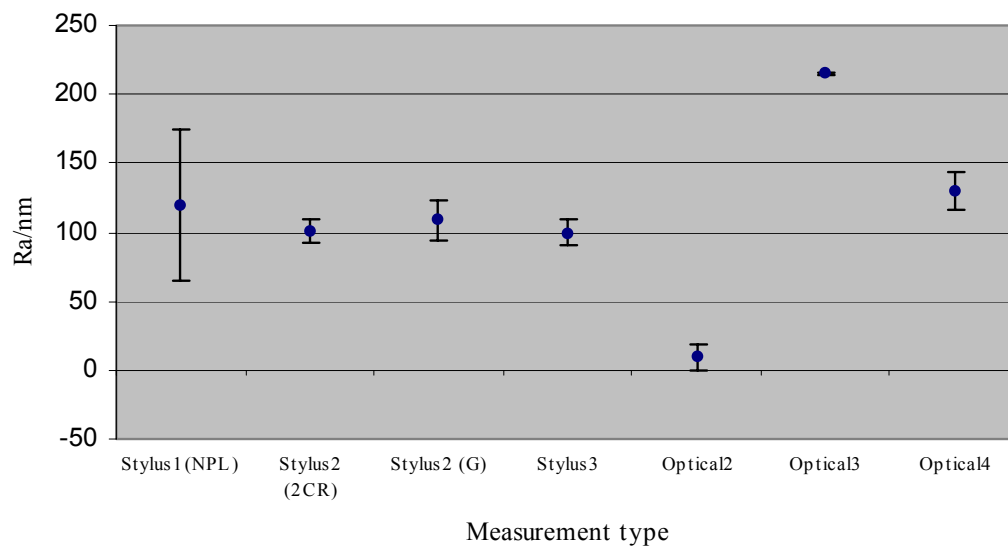


Figure 7 Results for measurements of R_a on the ceramic sample

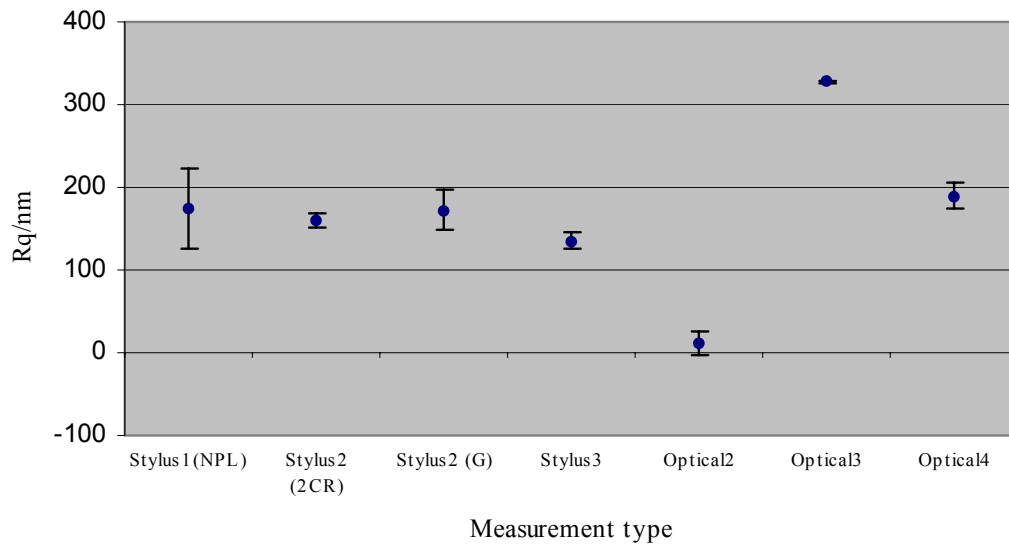


Figure 8 Results for measurements of R_q on the ceramic sample

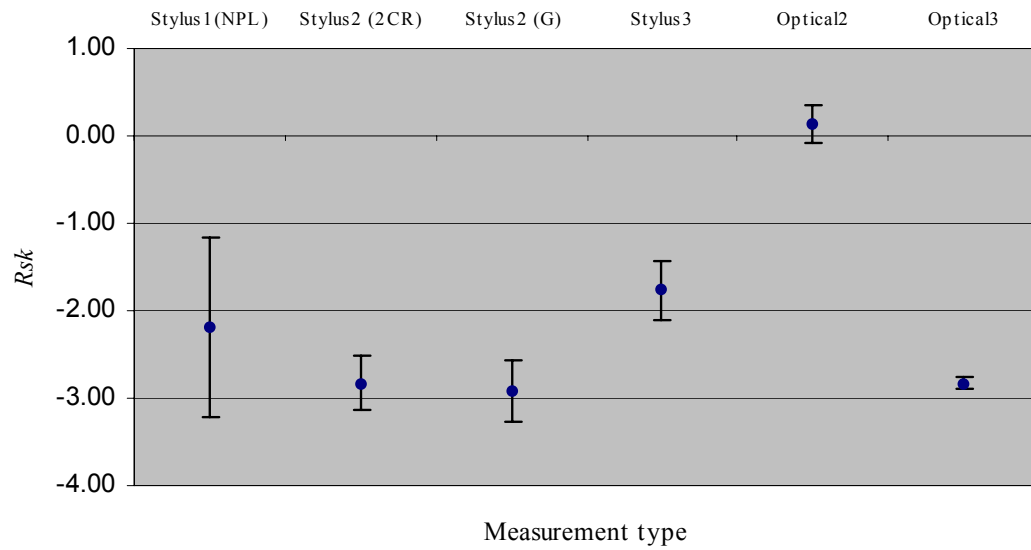


Figure 9 Results for measurements of R_{sk} on the ceramic sample

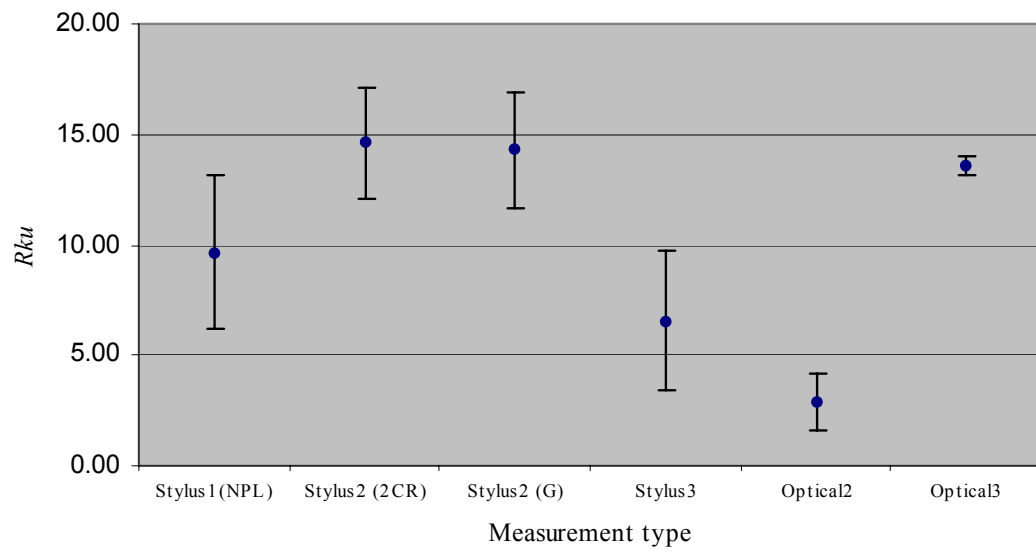


Figure 10 Results for measurements of Rku on the ceramic sample

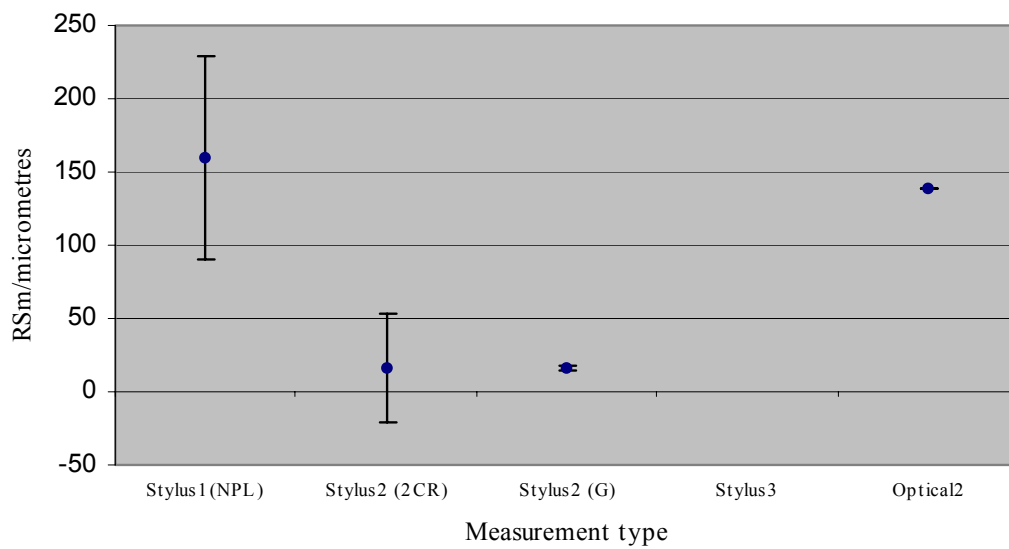


Figure 11 Results for measurements of RSm on the ceramic sample

5.2 RESULTS FOR NICKEL SINUSOID

Figures 12 to 20 give the results for measurements made on the ceramic sample for various surface texture parameters.

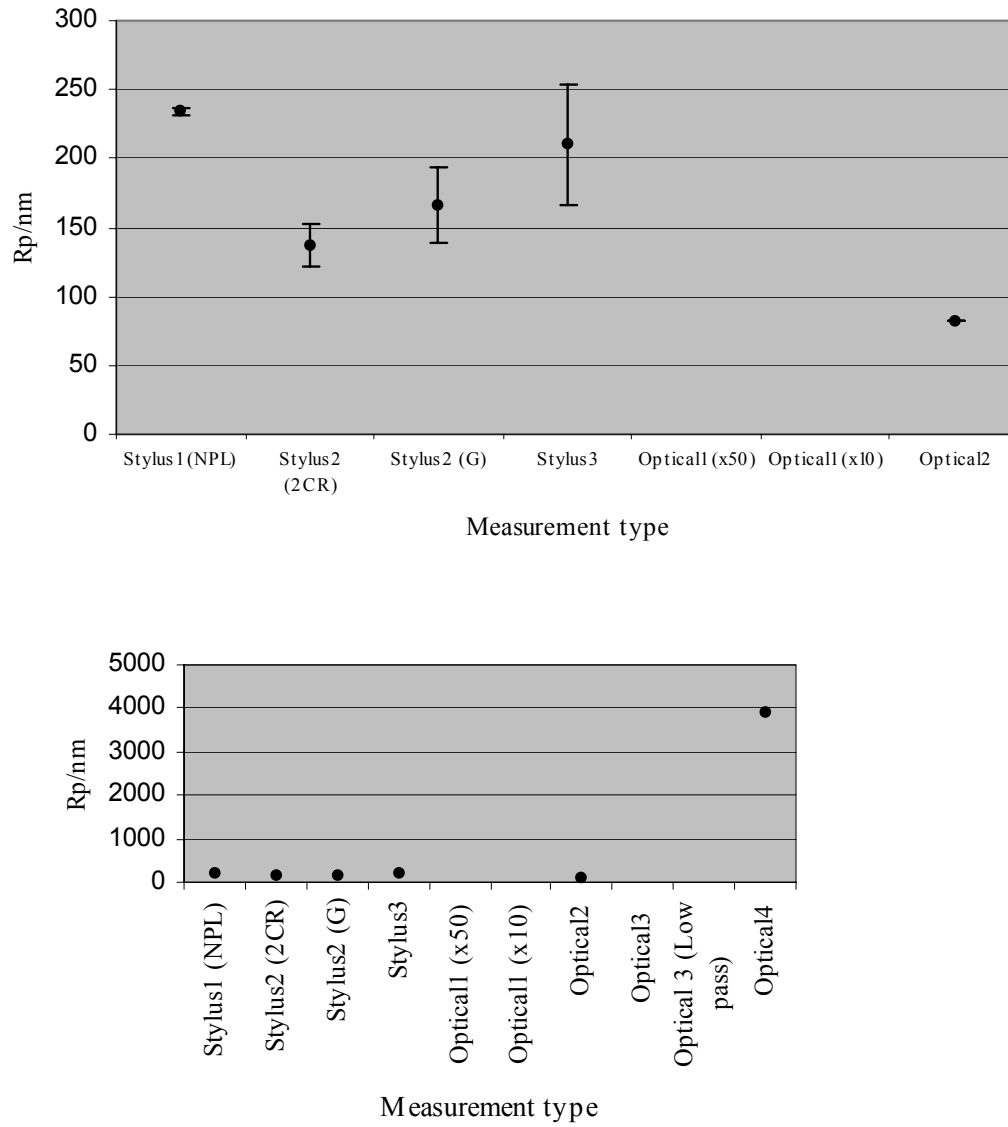


Figure 12 Results for measurements of R_p on the nickel sinusoid

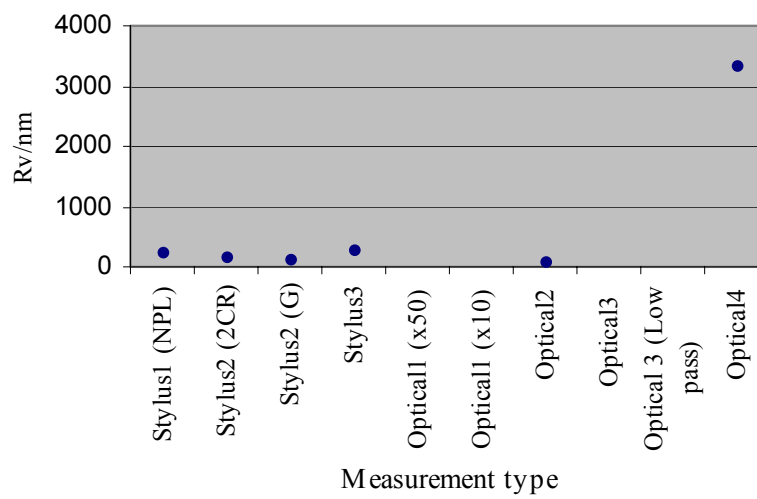
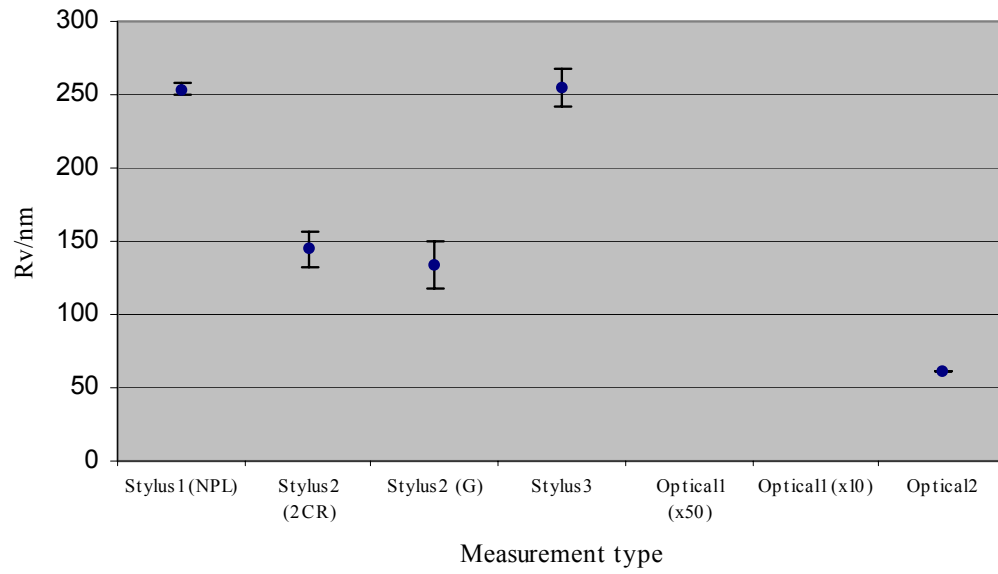


Figure 13 Results for measurements of R_v on the nickel sinusoid

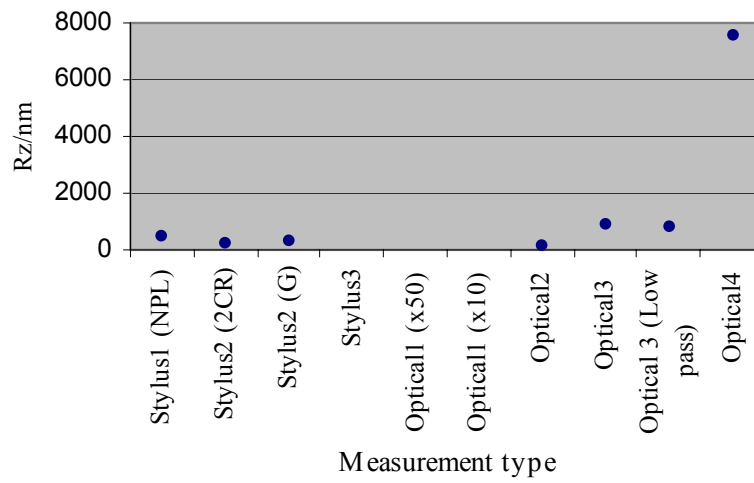
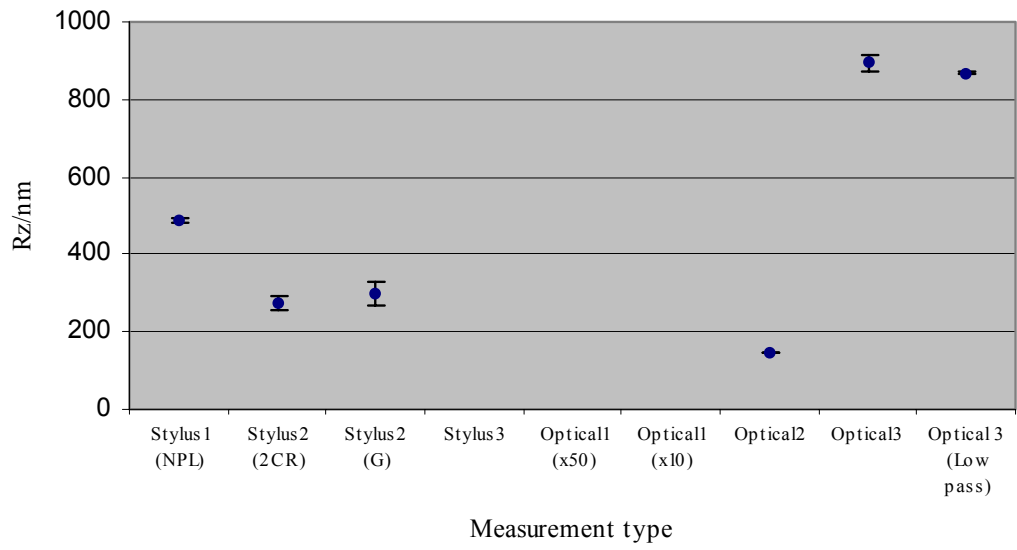


Figure 14 Results for measurements of R_z on the nickel sinusoid

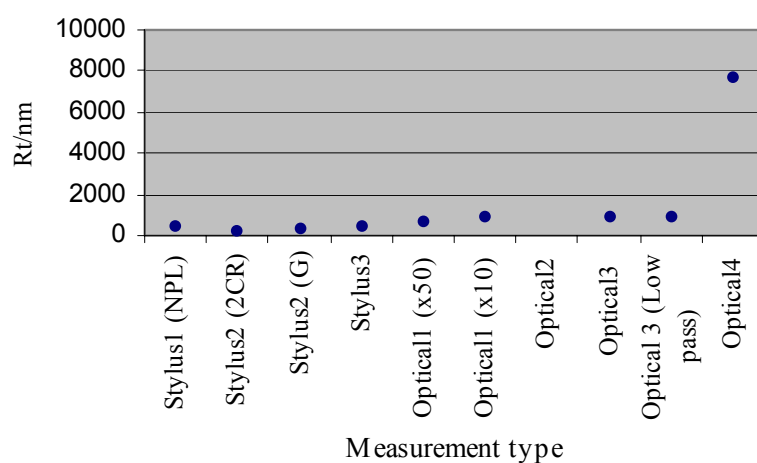
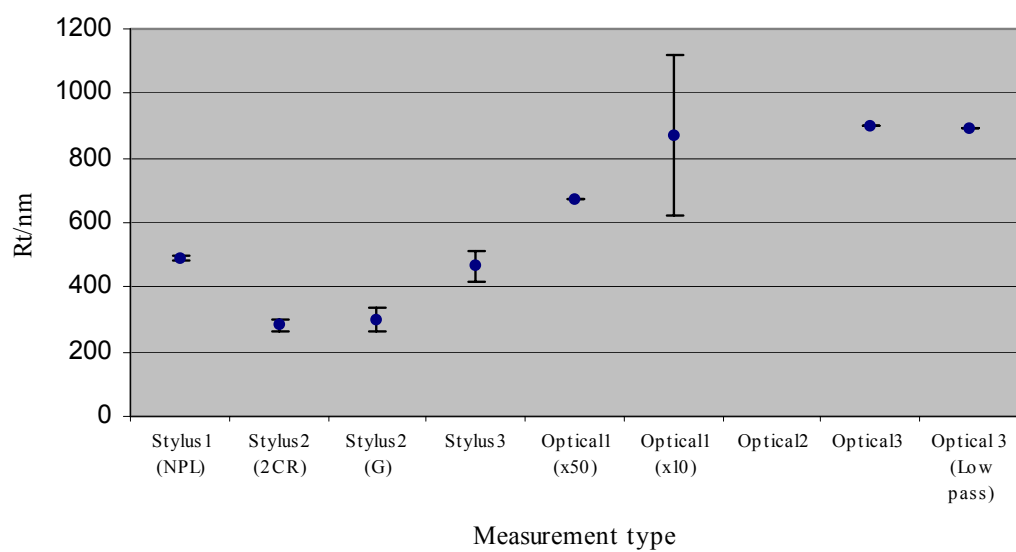


Figure 15 Results for measurements of R_t on the nickel sinusoid

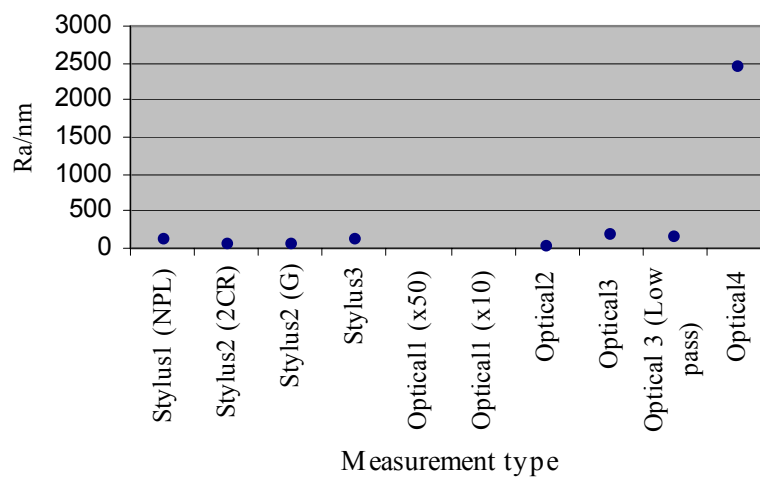
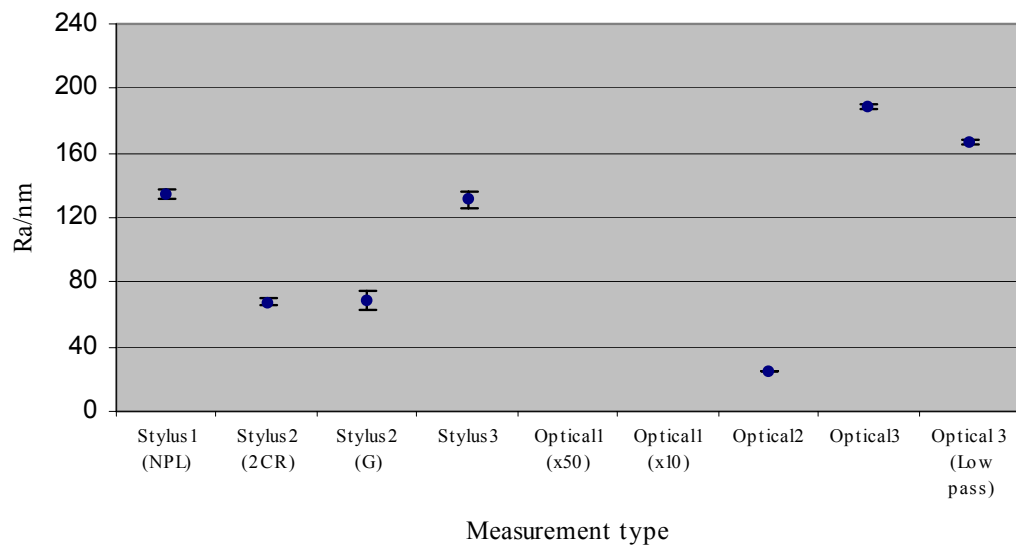


Figure 16 Results for measurements of Ra on the nickel sinusoid

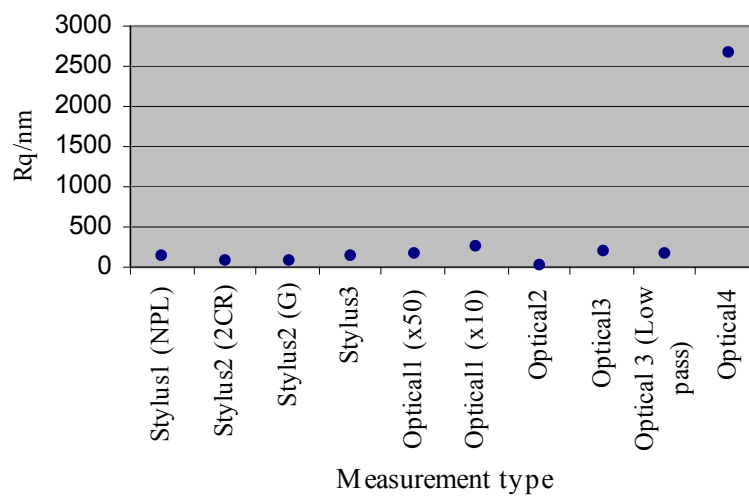
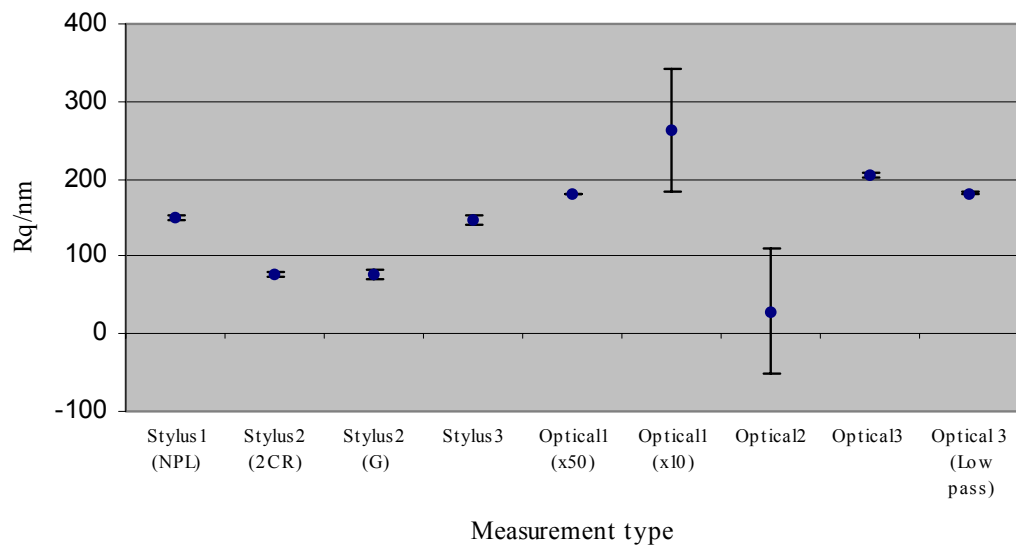


Figure 17 Results for measurements of R_q on the nickel sinusoid

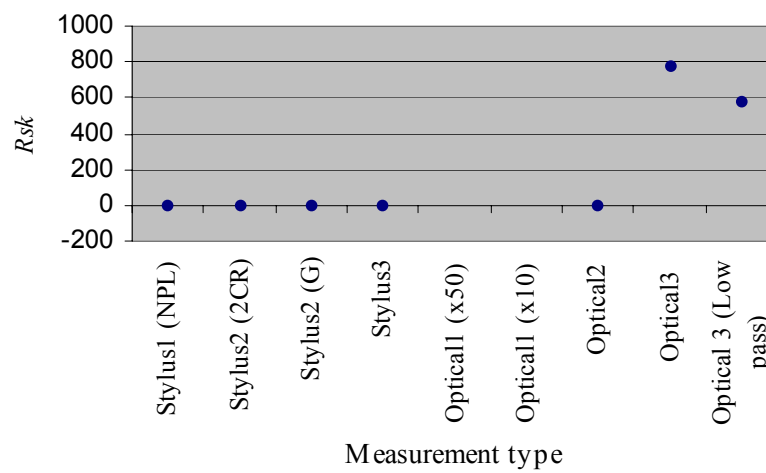
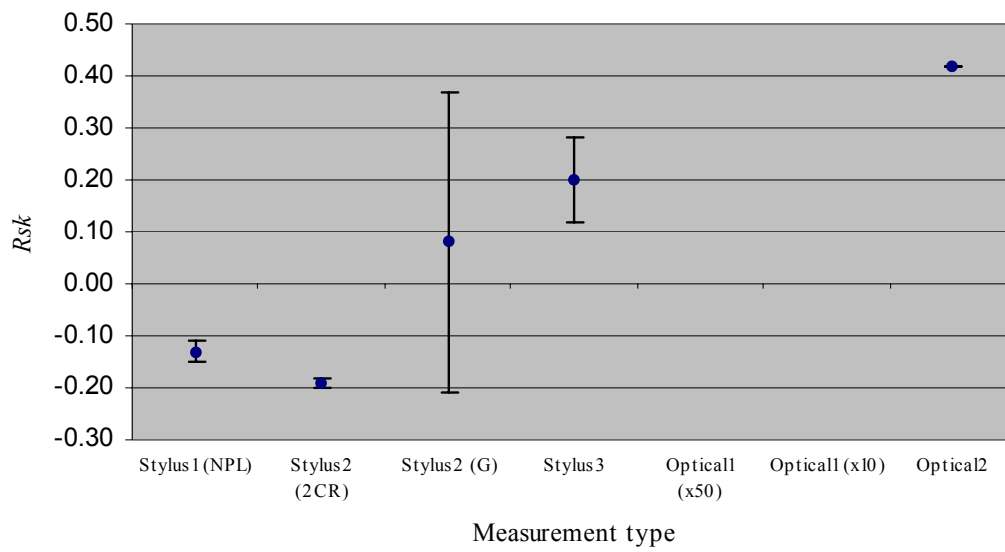


Figure 18 Results for measurements of R_{sk} on the nickel sinusoid

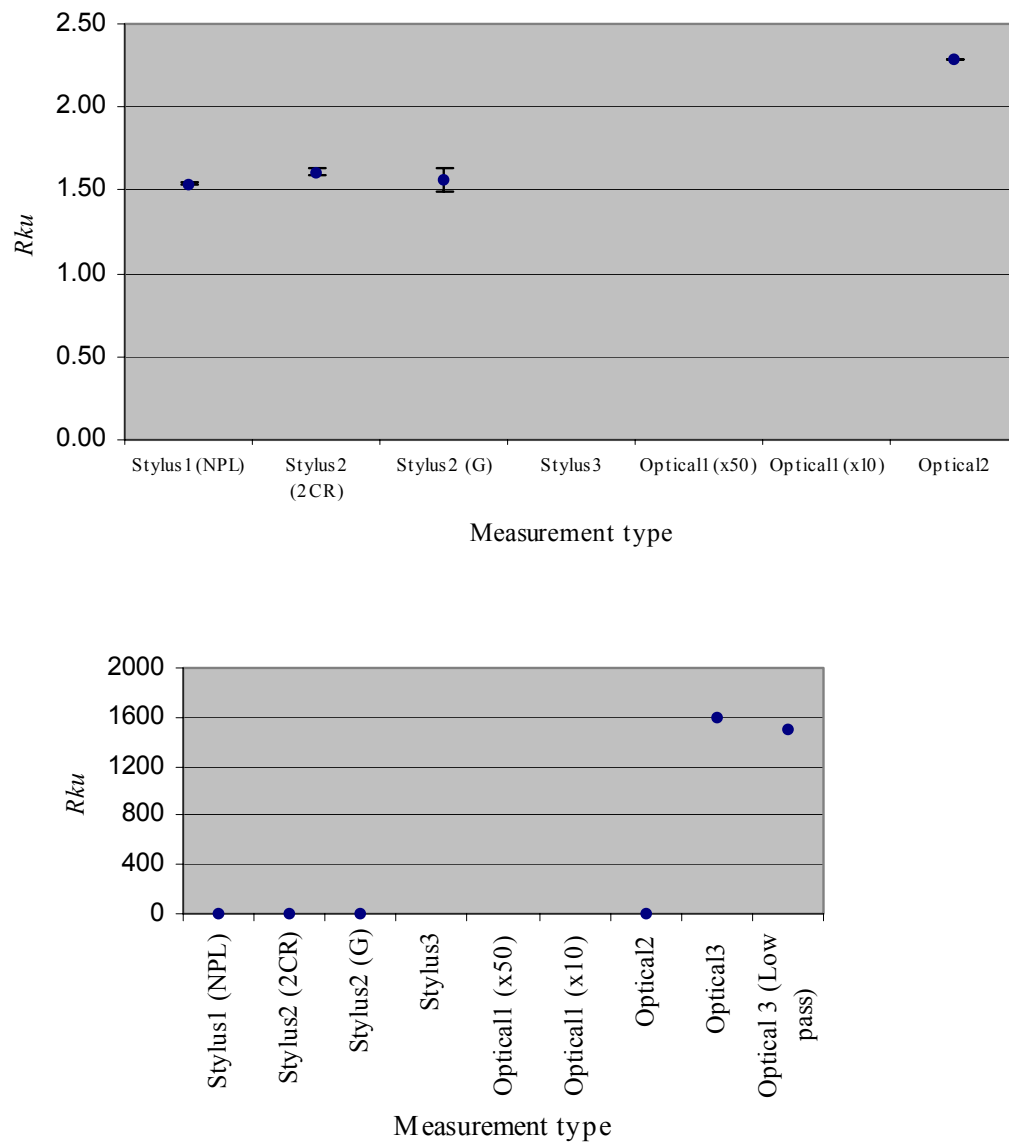


Figure 19 Results for measurements of Rku on the nickel sinusoid

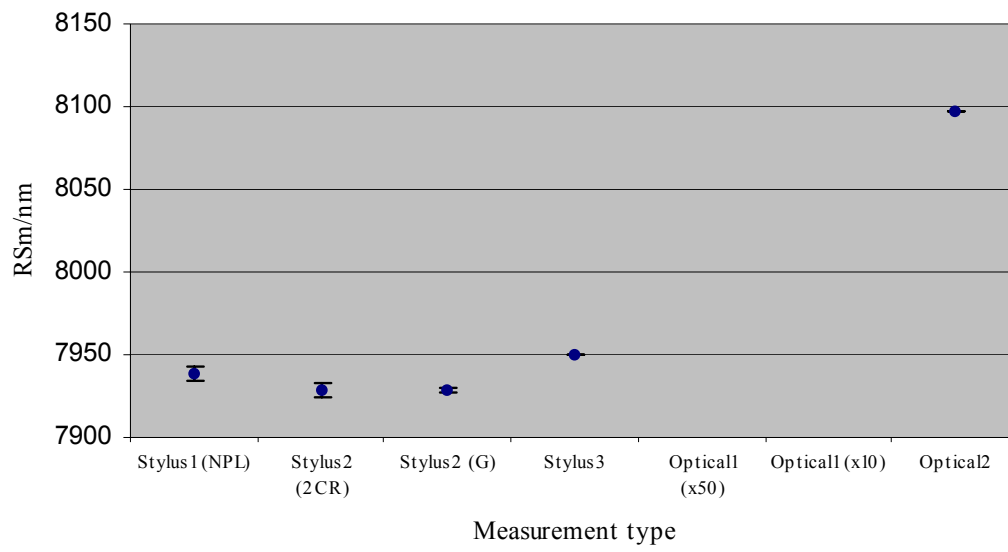


Figure 20 Results for measurements of R_{Sm} on the nickel sinusoid

6. DISCUSSION OF RESULTS

6.1 CERAMIC SAMPLE

With the exception of *Stylus3* for R_v , R_z and R_{ku} , the stylus instruments are all in good agreement with each other as well as *Optical4*. Comparing the profiles (not given here as this would compromise the anonymity of the participants) measured using *Stylus3* and the other stylus instruments it is clear that the instrument is not reaching the bottom of some of the valleys. This would explain why R_v is comparatively low and consequently so is R_z . This does not, however, explain why R_{ku} is comparatively low. Despite the guidelines given to the participants, the *Stylus3* instrument only used one stylus with a radius of 10 μm . This would explain the low values of R_v and R_z .

The *Optical2* instrument gave consistently lower values for the dimensional parameters (*i.e.* those with units of metres) by a large margin. It also gave a low value for R_{ku} and a high positive value for R_{sk} (all the other results are negative for this parameter which would be expected for this highly skew surface). Looking at the measured profiles from this instrument it is evident that it has not measured the “true” surface. Appendix A goes some way to explain the apparent discrepancies with this type of instrument.

The *Optical3* instrument gave high values for R_t , R_a and R_q . Looking at the measured profiles suggests that this instrument has not taken enough data to fully sample the surface, but this does not explain comparatively high values for dimensional parameters – under-sampling would normally be expected to lead to unrealistically low values.

The R_{Sm} values measured by *Stylus2* and *Stylus3* are low compared to the other instruments but agree well with each other. This suggests that the problem lies with the algorithm used to calculate R_{Sm} . A recent study has shown that the definition of the R_{Sm} parameter is mathematically ambiguous and could lead to the differences reported here (Leach and Harris 2002).

6.2 NICKEL SINUSOID SAMPLE

The results with the sinusoid sample show that there are large variations between the measurement results. The *Stylus2* and *Stylus3* instruments are giving results that are lower than the other stylus instruments. Looking closely at the instrument controls for the *Stylus2* and *Stylus3* instruments it was discovered that the short wave filter was set at $\lambda_s = 8 \mu\text{m}$, *i.e.* the period of the grating. This was in spite of the filter settings being specified in the guidelines. Since the filter had a Gaussian weighting function, 50% amplitude transmission would be expected at this filter cut-off frequency – applying this correction brings the results closer to that of the NanoSurf IV instrument.

As with the ceramic sample the results for the *Optical2* instrument are not in good agreement with other instruments. Once again, visual analysis of the shape of the measured profile showed that it was very different from that that would be expected.

University 1 reported poor agreement between the sets of results using the optical instrument at two settings. Cross checks showed that the instrument was working correctly but giving unexpected results. Subsequent ‘tuning’ of the instrument by the manufacturer enabled it to cope properly with these samples. A synopsis of the manufacturer’s report is given in Appendix A.

The results for the *Optical4* instrument are very different from all the other instruments. In some cases the value for the parameters are an order of magnitude higher than those of the NanoSurf IV instrument. Possible explanations for this are that this focus detection instrument has a field of view of 10 μm and a spot size of less than 2 μm and discrepancies in its measurement could be due to more than one reflection entering the detection system. Moreover, nickel is a highly reflecting material ($r = 0.54$) and this can, apparently, upset the focus detection optics. Other sources of uncertainty for the optical instruments are the curvature of the sinusoid, multiple scattering and finite aperture effects.

Only one optical instrument (*Optical2*) reported a value of RSm and this was very different to the results with the stylus instruments. Also, despite the comment in section 6.1, the values for RSm measured by the stylus instruments are in agreement. The agreement is probably because the nickel sample has a very well defined wavelength structure and is not affected by the ambiguities in the definition of RSm .

7. CONCLUSION

It is clear from the work presented here that there are many problems that plague the field of surface texture measurement. More often than not the measurements taken with the stylus instruments and optical instruments do not agree; but even instruments that appear to be using the same measurement principle can give different results in excess of their reported uncertainties. Most participants in the comparison reported that they calibrated the vertical displacement of their instruments using a glass step-height artefact. Whether it is then possible to use this calibration value when making measurements of surface texture and have any confidence in the results is problematic. It is worth noting that most of the commercial instruments used in the comparison were not using the most recent ISO definitions of the parameters.

In order to improve confidence in surface texture measurements proper procedures for calibrating an instrument in a given measurement scenario and for a given surface need to be applied. This would seem to be a time consuming process when different types of surface and materials are involved, but the comparison described here shows that a great deal of care is necessary when interpreting surface texture data.

Stylus instruments do have the luxury of a specification standards infrastructure – this is not yet the case for optical instruments. However, the standards only cover 2D measurements. Despite such an infrastructure there is still a need for good practice and a clear understanding of which surface texture parameter is useful for which application to filter down from the standards to the shop floor. NPL's Good Practice Guide (Leach 2001b) on surface texture measurement is a first step to getting good practice to the shop floor (and, indeed, into the universities!). However, further guidance is necessary as highlighted by this report.

8. ACKNOWLEDGEMENTS

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APPENDIX A

Appendix A presents results that were reported following the completion of the comparison with the aim of explaining the discrepancies experienced with the optical interferometers. To this end the nickel sinusoid sample was re-measured by the manufacturer of the *Optical1* and *Optical2* instruments. The following report was submitted to NPL.

Measurement of a Sinusoidal Sample using a White Light Interferometric Profiler

Influence of Magnification and Measurement Results on Roughness

The Sample

- Sinusoidal sample
- Pitch= 8um
- Amplitude= 500nm

Considerations

■ **Magnification.**

The procedure noted a FOV of 250um x 250um for stylus measurements. For optical profilers this would require a using a 10X objective.

For a grating type measurements, high slope and high aspect ratio, a magnification with as high as possible should be used.

■ **Measurement Mode. VSI v. PSI.**

PSI is the preferred measurement mode. Although the amplitude is greater than 150nm (1/4 wavelength) , there are no surface discontinuities making PSI mode preferable to VSI.

EVSI may also be used.

VSI images for surfaces with sharp features can be dominated by “batwings”.

■ **Hardware.**

Objective Focus

Uniform Intensity across the Field of View.

50X PSI

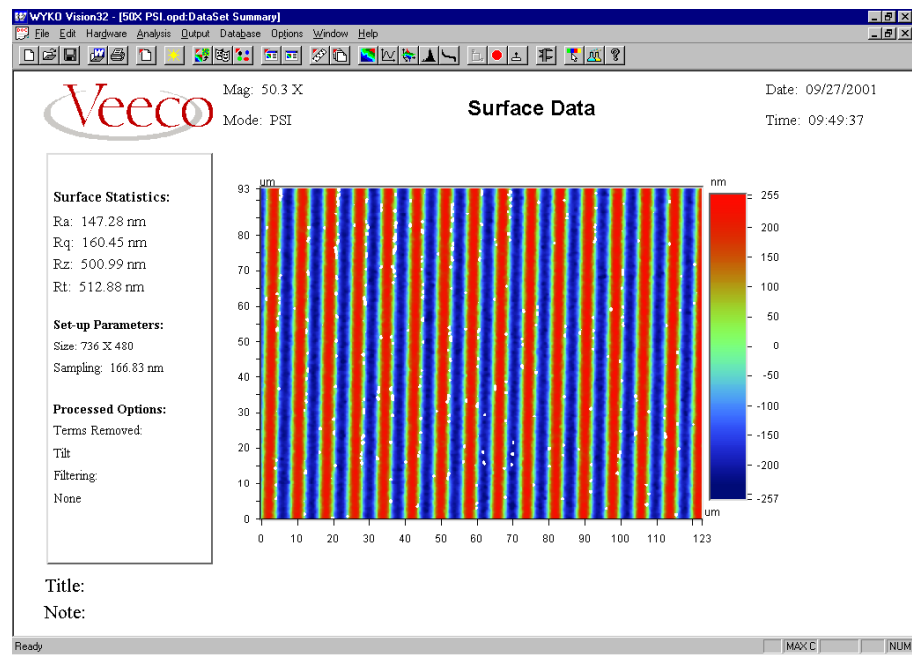
■ **The correct measurement parameters for this sample are:**

- Magnification- 50X
- Measurement Mode- PSI (or EVSI if available)
- Unwrapping Algorithm- Enhanced
- Autofocus (optional)- This would help with repeatability of measurement. Autofocus can set best focus to within a few nanometers. It's difficult to be as repeatable when focusing eye.

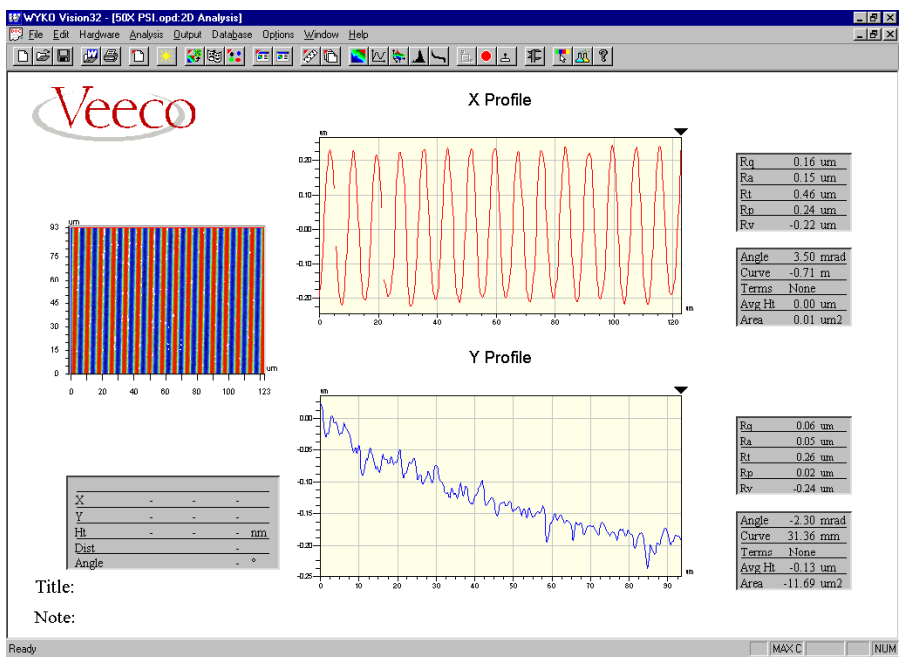
■ **Results**

- The following 2 slides clearly indicate this choice of options produce a sharp image of the sinusoidal surface.

50X PSI- Contour



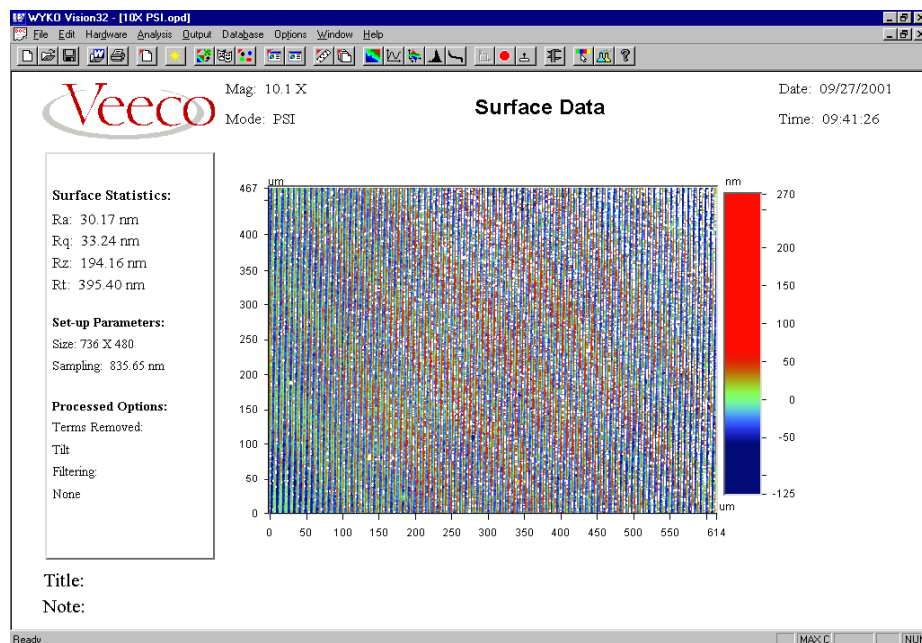
50X PSI- 2D



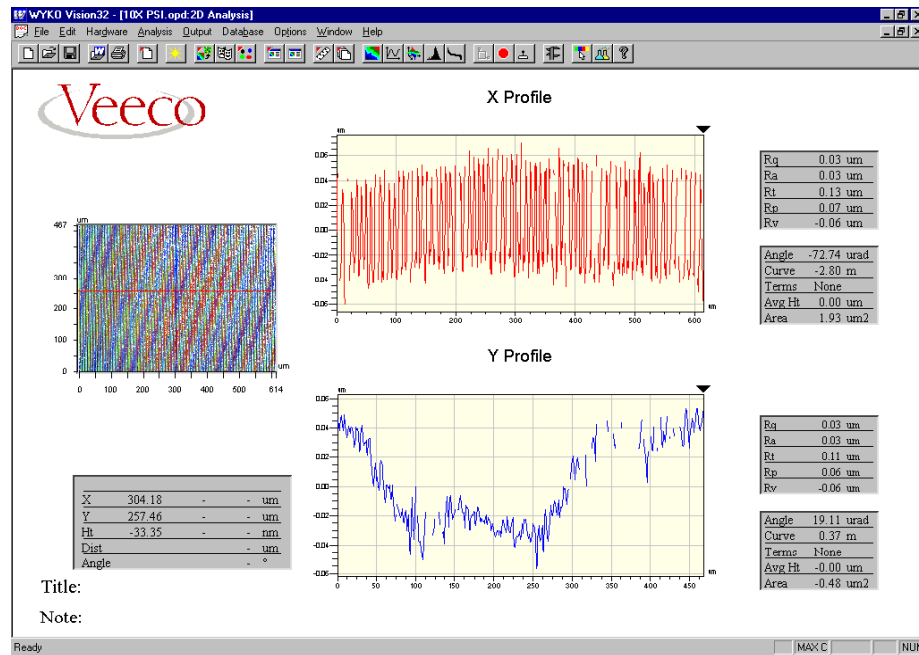
10X PSI

- Although PSI produces a clean image of the sample at 10X, it is obvious that the NA of the objective prevents the measurement from actually representing the topography of the sample.
- The Ra, Rq and Rt are lower than expected.
- What is most likely occurring is light has not reached the the bottom surfaces of the sample. Light has scattered off the walls and produced a false bottom.
- Also, there are not enough pixels to describe the peak and valley, hence there is an additional rounding of the surface producing lower Roughness values.

10X PSI- Contour



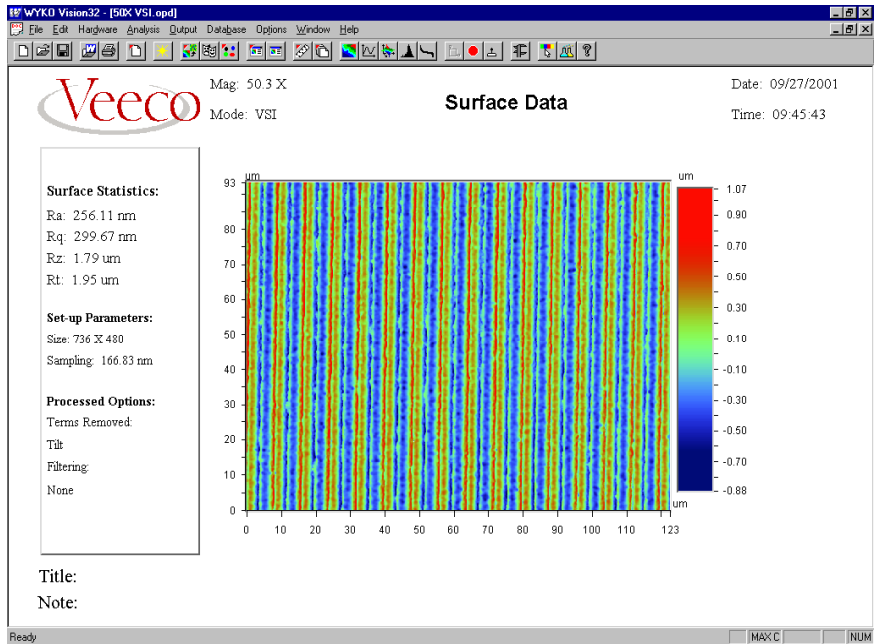
10X PSI- 2D



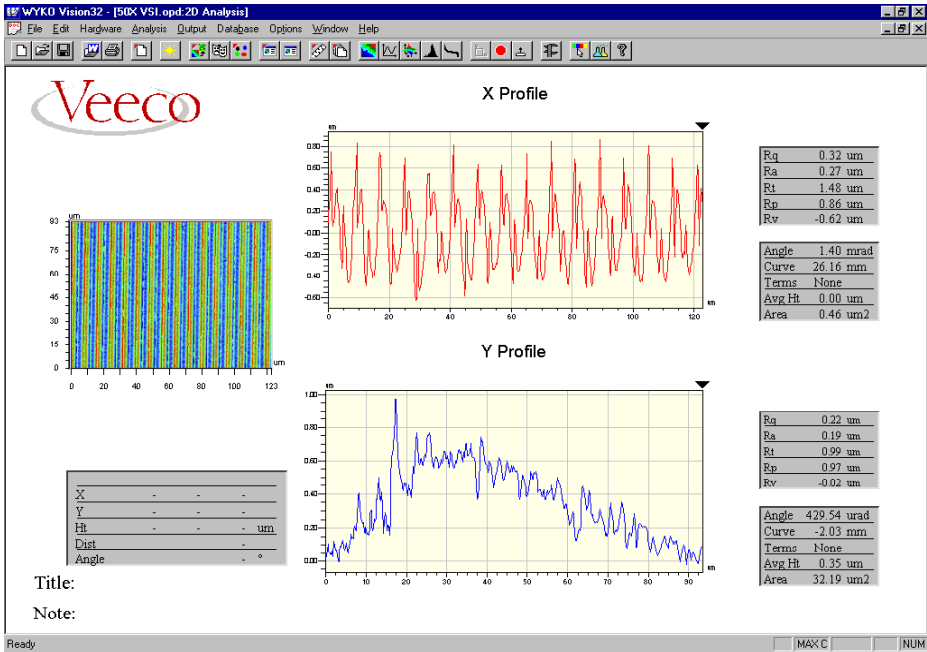
50X VSI

- Diffraction from the surface of the sample has produced “batwings”.
- The Roughness values are considerably higher than expected due to the batwings.

50X VSI- Contour



50X VSI- 2D



Summary

- **With proper consideration for the surfaces that are to be measured, excellent data can be obtained on a myriad of surfaces. Sinusoidal surfaces, although challenging, can be measured with excellent repeatability.**
- **Excellent agreement between tools can be expected. Data off 4 tools resulted in a range of 10nm for the Ra measurement.**

APPENDIX B

The following is a copy of the guidelines given to the participants. Note that in the table of participants the names of the participants have been omitted for reasons of anonymity.

Ceramic sample mini-comparison - guidelines and information for participants

A.1 INTRODUCTION

As part of SMT Project SMT4 - CT96 - 2078 “CERANORM” a comparison of the surface texture of certain ceramic surfaces was carried out. The principle purpose of one of the work packages was to conduct an interlaboratory exercise to study the ability of a range of laboratories to employ the conditions given in CEN ENV 623-4 in making surface texture measurements, and to determine the range of results and the reliability of the measurements. The surfaces used were developed during manufacture of pump seal components. NPL was the task leader and eleven further laboratories, from both industry and academia, were involved, ten from Europe and one from Brazil. For reasons of confidentiality the laboratories names and the results of the comparison are not available to the participants of this mini-comparison. It must be pointed out that NPL and Warwick University were involved with the SMT project but will be treating this comparison as a totally different exercise.

A.2 PARTICIPANTS

The participants shown in table 1 have agreed to take part in the mini-comparison. NPL will act as the co-ordinator and will analyse and report the results. Each participant is given six weeks to complete the measurements.

A.3 THE SAMPLES

There are two samples for the comparison:

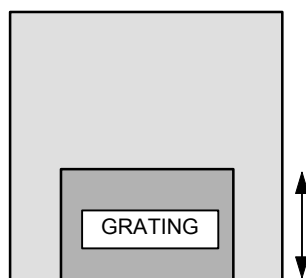
A.3.1 Ceramic sample

The ceramic sample takes the form of an annular ring that has an outside and inside diameter of 55 mm and 35 mm respectively and is 2 mm thick. The surface to be measured has been polished and lapped and is isotropic, *i.e.* it has no lay.

A.3.2 Sinusoidal sample

The sinusoidal sample was manufactured at NPL and takes the form of 50 x 50 x 0.125 mm nickel shim with a 30 x 20 mm grating as shown in the figure. Note that the

arrows show the direction of the grating's lay. The grating has a nominal amplitude of $0.2\text{ }\mu\text{m}$ and a nominal period of $8\text{ }\mu\text{m}$.



Laboratory	Contact person
National Physical Laboratory Centre for Basic, Thermal & Length Metrology Dimensional & Optical Metrology Section Queens Road, Teddington Middlesex TW11 0LW	Richard Leach Tel: 020 8943 6303 Fax: 020 8614 0420 E-mail: richard.leach@npl.co.uk
University 1	-
University 2	-
Manufacturer 1	-
Manufacturer 2	-
Manufacturer 3	-

Table 1 - The participants

A.4 PREPARATION

The ceramic sample is simply contained in a plastic, snap-shut bag. The sinusoidal sample is contained within a polypropylene box with no packing. The sinusoidal sample is held in place by a strip of sticky-back-plastic that does not contact the actual grating. Packing such as cotton-wool or tissue paper should not be used when transporting or storing the sinusoidal sample.

The samples should not need cleaning and should be treated with the same respect as an optical surface. If particulates can be seen with the naked eye a filtered air blower should be used to blow them off the surface, but do not use the aerosol air blowers -

we have found in the past that they can leave a contaminant film on the surface. If for whatever reason the surface becomes dirty (dust, finger grease, etc.) contact me and we will discuss appropriate cleaning methods.

A.5 MEASUREMENT PARAMETERS AND PROCEDURES

The requirements for the measurements (table 2) should be adhered to as closely as possible and any variation should be reported. Where optical instruments are employed the nearest equivalent measuring condition to the quoted stylus parameters should be used, for example, stylus radius of 2 μm , optical focus spot size of 2 μm . Again, variations from the quoted conditions should be reported. The stylus force should not exceed 120 μN and the scanning speed should not exceed 60 mm min^{-1} .

	Ceramic	Sinusoidal
Stylus radius	2 μm	2 μm
Trace length	5 mm	0.25 mm
Evaluation length	4 mm	0.25 mm
Cut-off length	0.8 mm	> 0.25 mm
Scanning speed	5 mm min^{-1}	0.2 mm min^{-1}
Number of traces	5	5
Stylus force	40 μN	20 μN

Table 2 - Measurement conditions

Five measurements of each sample should be made. In the case of the sinusoid the five traces should be spaced roughly 0.2 mm apart along a central line perpendicular to the grating direction. In the case of the ceramic sample five traces should be taken along five radii spaced roughly 72° around the circumference.

The following table should also be to state the measurement parameters that were used by each instrument. Please feel free to use as many different measuring instruments as possible, including stylus, optical and scanning probe instruments. The table below has been filled in for the NPL NanoSurf IV instrument as an example, but is included in electronic form in Appendix 1.

	Ceramic	Sinusoidal
Instrument name	NanoSurf IV	NanoSurf IV
Principle of operation	The NanoSurf IV is a stylus instrument with laser interferometric length measurement in the vertical and horizontal directions.	The NanoSurf IV is a stylus instrument with laser interferometric length measurement in the vertical and horizontal directions.
Spatial resolution	2 μm	2 μm
Scanning speed	5 mm min ⁻¹	0.2 mm min ⁻¹
Stylus force (where applicable)	40 μN	20 μN
Method of calibration	Laser interferometry	Laser interferometry
Low-pass filter characteristics	0.8 mm cut-off phase correct filter with Gaussian weights	No filtering used
High-pass filter characteristics	No filtering used	No filtering used

A.6 STATEMENT OF RESULTS

As many surface texture parameters should be quoted as possible, provided they are described in ISO 4287 (1987). Uncertainties ($k = 1$) and the standard deviation (σ_{n-1}) of the five measurements should be quoted with each parameter if this is possible. It is assumed the variation in the uncertainties over the five traces will be negligibly small and only an average value need be quoted. The table in Appendix 2 should be used to state the results.

Appendix 1 Table to report measurement conditions

Institute name:

	Ceramic	Sinusoidal
Instrument name		
Principle of operation		
Spatial resolution		
Scanning speed		
Stylus force (where applicable)		
Method of calibration		
Low-pass filter characteristics		
High-pass filter characteristics		

Appendix 2 Table to report results

Institute name:

	Ceramic	Sinusoidal
Maximum profile peak height, R_p		
Maximum profile valley depth, R_v		
Maximum height of profile, R_z		
Mean height of profile, R_c		
Total height of profile, R_t		
Arithmetical mean deviation of the assessed profile, R_a		
Root mean square deviation of the assessed profile, R_q		
Skewness of the assessed profile, R_{sk}		
Kurtosis of the assessed profile, R_{ku}		
Mean width of the profile elements, R_{Sm}		
Root mean square slope of the assessed profile, $R_{\Delta q}$		