Evaluation of Surface Texture: A Case Study

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***Abstract*— Over time, many metrology techniques have been introduced to measure the surface roughness. However, this large number of techniques has made the selection of the right instrument for the desired measurement more and more challenging in the industrial and research environment. The main aim of this research paper is to understand in more details the techniques which are most appropriate and efficient to measure the surface roughness for certain surfaces. This is based on a realistic examination of various types of materials produced by various machining operations. Comparison of three metrology techniques is performed to define the best technique that can be used for this purpose. The measurement data from the metrology techniques was analysed in order to investigate how well the surface roughness calculated and described.**

Keywords—Surface ; Roughness; Metrology; Specimen; Steel.

I. INTRODUCTION

Surface metrology, which is the study of surface geometry, also called surface texture or surface roughness, is important to many disciplines, and is mostly used in the machining of precision parts and assemblies [1]. The overall aim of surface metrology is to measure and analyse a surface's texture (roughness) in order to understand how the surface texture is influenced by its history (for example, manufacture, wear and cracks) [2]. This ensures that the work piece will satisfy its function and ensure all the aspects of the surface's geometry are known and preferably controlled [3]. The overall aim of this research paper is to examine various types of materials (samples), using different metrology devices, in order to compare the limitation and/or capability of each instrument and to understand which is the most appropriate and efficient technique for certain surfaces.

II. THE RESEARCH METHODOLOGY

The following sets of specimens produced by various machining operations are to be examined, these include;

1) A sample of textured, galvanised steel. This surface contains features of two different height scales.
2) A soft polymer coating on a steel substrate specimen.
3) A steel sample that has been ablated by a laser, creating fine craters on the surface. The craters have a relatively sharp angle on the side wall, which will test the techniques' ability to probe into a feature.
4) A finely polished steel surface, which will have very low-amplitude surface roughness.

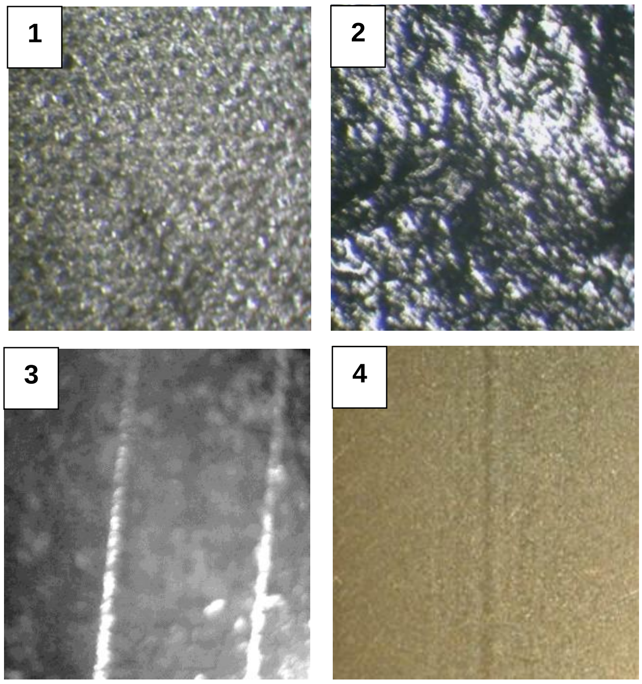

Fig. 1. *Set of samples produced by different machining operations: 1) galvanised steel, 2) polymer coating on steel, 3) laser ablated steel, 4) polished steel*

III. LITERATURE REVIEW

There are many instruments that can be used for 3-D or 2-D surface measurements, but selecting the right instrument is a very difficult task for operators. Reference [4] argues that the instrument which is going to be used for the surface metrology measurement should be chosen according to the function of the surface, taking into consideration the functional and geometrical parameters. However, Reference [5] argues that the starting point in choosing the most suitable instrument of a particular quantity in a factory or other systems is the specification of the instrument's required features: its resolution, sensitivity and dynamic performance.

Reference [6] claim that the capabilities of surface texture instrumentation can be achieved by using plots in the amplitude-wavelength plane, the plot gives the working capabilities of an instrument with regard to the instrument's attributes. However, Reference [7] recommended that, it is important to understand the properties of the sample, limitations of the technique used and the analysis required before carrying out the surface metrology. Reference [8] introduced the average value of the absolute heights over an entire surface (Sa), which can be obtained by adding individual height values without regard to sign and dividing the sum by the number of the data matrix.

$$S_a = \frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M}\left|\eta(x_i, y_j)\right| \qquad (1)$$

Where, M is the number of points per profile, N is the number of profiles. Sa is a very general and widely used parameter. This parameter is used generally to evaluate surface roughness.

IV. THE USED TECHNIQUES (INSTRUMENTS)

In order to achieve the main goals of this study, the following three metrology techniques are used to measure each provided sample where appropriate:

1). Stylus profilometry technique, both by two-dimensional linescans (2D) and three-dimensional mapping (3D) (e.g. Somicronic Surfascan).
2). A light interferometric method (e.g. Wyko).
3). Atomic Force Microscopy (AFM).

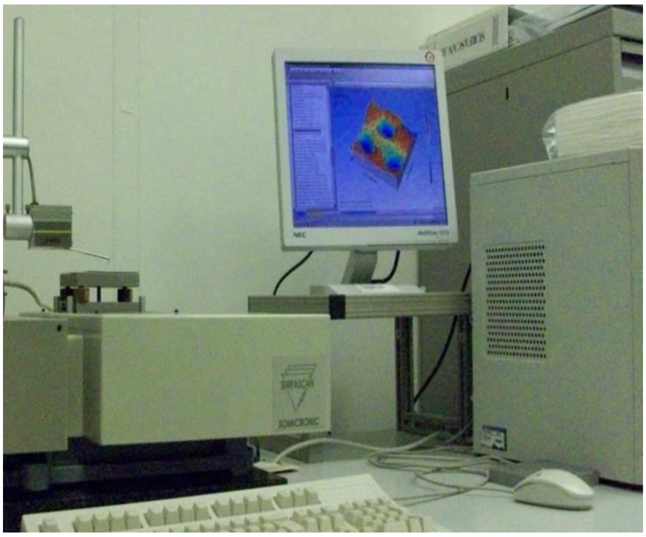

Fig. 2. *Surface Metrology Instrument: Somicronic*

Fig. 3. *Surface Metrology Instrument: Wyko*

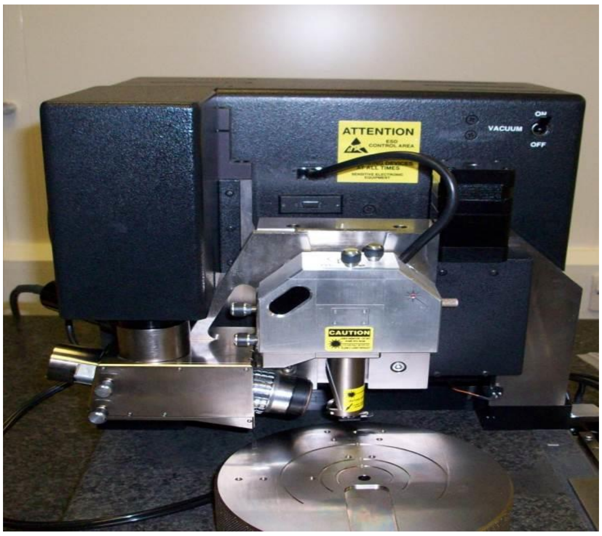

Fig. 4. *Surface Metrology Instrument: AFM*

The metrology laboratory where the above mentioned equipments are located having a specialised design for vibration minimisation, the temperature controlled to 20 ± 0.5 °C and is a class 10,000 clean room. The working principle, advantages and limitations of each instrument are explained intensively by [9] and the main features (specifications) of the systems have been clarified by [8].

V. EXPERIMENTAL WORK AND RESULTS

Before starting the measurement procedure, attention was paid to the sample preparation as the current kind of measurements require high quality sample preparation to obtain high precision results. Therefore, contamination on the surfaces was removed by using an appropriate cleaning method (Isoclene solvent). Because if it had not been removed, this would influence the measuring results considerably; particularly for the surface that has a very low-amplitude roughness, such as polished steel.

A series (four) of measurements were conducted for each specimen at different places (relocation) in order to obtain a stable mean value of the studied parameter. The following table shows the Stylus and Wyko measurement results. Nevertheless, AFM clearly shows its limitation in mapping large-scale features and height due to its small horizontal and vertical measurements ranges.

TABLE I. SA PARAMETER STABLE MEAN VALUE FOR EACH SAMPLE (STYLUS AND WYKO)

Surface Roughness	**Instruments**			
	Stylus			***Wyko***
	3D at 20 µm spacing	*3D at 10 µm spacing*	*2D*	
Coated Steel Sample				
Sa (µm)	11.4325	11.3385	1.7525	1.4105
Laser-ablated Steel Sample				
Sa (µm)	0.0825	0.09175	0.084	0.2495
Polished Steel Sample				
Sa (µm)	0.0707	0.0710	0.06975	0.0475
Galvanised Steel Sample				
Sa (µm)	1.545	1.56975	1.0485	1.4535

A. Discussion of Stylus Measurement Results

The following bar shown in Figure 5 is an example compares (Sa) parameters values of 2D and 3D Stylus measurements for the Galvanised Steel specimen.

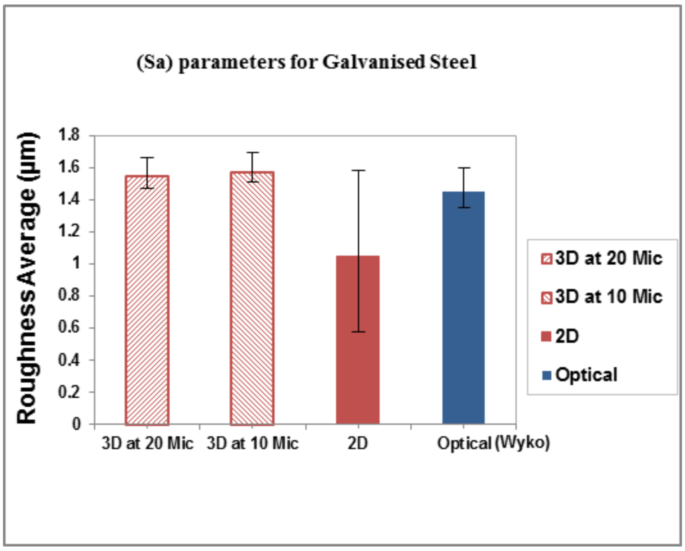

Fig.5. *Comparison between Sa parameters. The bars are the mean value of 4 measurements.*

As it can be seen, 2D parameters and the corresponding 3D parameters at 20 µm spacing are generally lower than the corresponding 3D parameters at 10 µm spacing. This is can be justified as the following, when measuring 3 dimensionally at 10 µm spacing, the measurement time will be more longer and this will help to measure the surface with more than hundred times where many data points of the surface can be collected. Therefore, the measured parameters values will increase as well. However, for 2D measurements the stylus measure the surface in one single trace and in a very short time and that will not give chance to the stylus to collect much more data when compared with 3D measurement and the parameters values will be lower than 3D measurements due to the small measured area.

Figure 6 shows a number of pits on the coated steel specimen. These pits have made the results in Table (1), which have been obtained by 3D measurements and 2D is very different. One reason of that is when using 3D that it is possible to obtain the full effect of pits. However, with 2D there is no guarantee that the effect of the pits can be included.

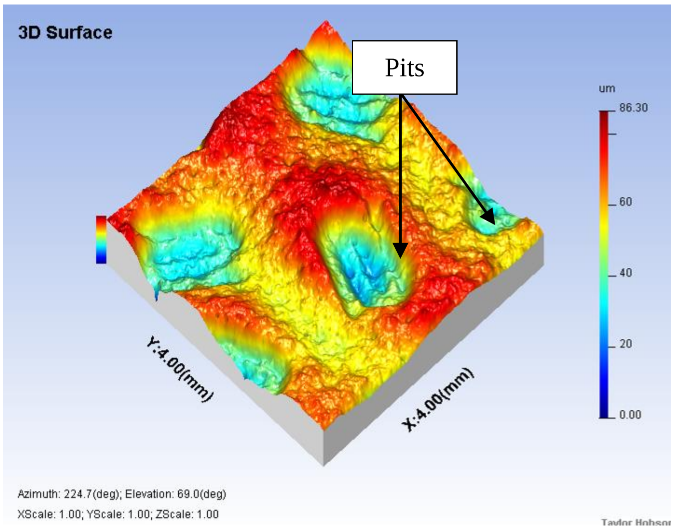

Fig. 6. *3D Coated Steel samples' surface topography*

As far as the stylus measurements involve interaction between the real specimen surface features and the stylus tip; the stylus shape, stylus load and the dynamic characteristic will play very significant role on the measured results. For instance, the stylus instrument has led to damage for most of the measured samples (e.g. laser-ablated steel and polished steel). This can be considered as one of the disadvantages of using this technique. Figures below show the scratches on the specimens' surfaces.

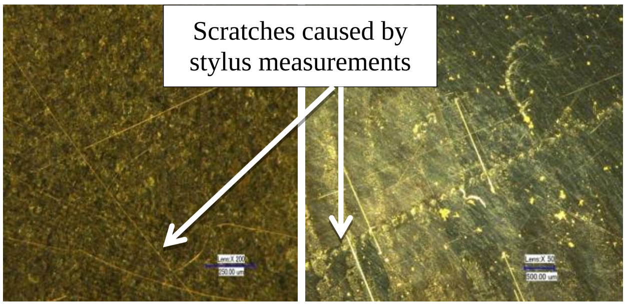

Fig. 7. *A microscope view shows damage of the specimens' surface after the measurement*

B. Discussion of AFM Results

It is known that the large range resolution, the greater possibility of integrating as many features of the surface topography as possible. In this study, only four of the proposed samples were measured by AFM instrument using contact mode, however, except the turned rod which has a very high size and very rough surface and that made it impossible to be measured by this instrument as AFM is being used mostly for micro and nano-scales samples and for smooth surfaces.

Furthermore, it worth saying that AFM clearly shows its limitation in mapping large-scale features and height due to its small horizontal and vertical measurements ranges. For example, looking at the surface topography of laser-ablated steel specimen, the instrument clearly shows its limited ability to measure many of craters which has been created on the specimen. Whereas, the stylus has measured most of the fine craters that were created on the surface as shown in the following figures.

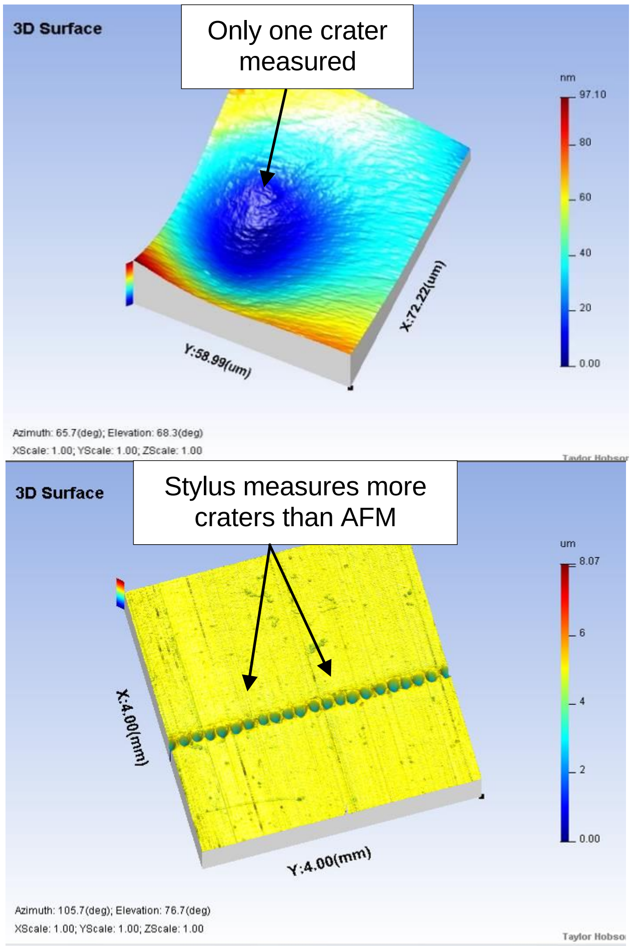

Fig. 8. *Limitation of AFM for measuring laser ablated steel sample*

This study gave a wide conception of that AFM probably is not suitable for measuring all of the proposed samples due to the nature of the surfaces.

C. Discussion of Optical Profiler (Wyko) Results

As far as this study included different samples to be measured, the technique shows its limited ability to measure low reflectivity surfaces (e.g. coated steel specimen), because focus detection system requires a finite amount of light to be reflected back into the detector so low reflectivity surface cannot be measured reliably. Moreover, the disadvantages associated with this technique are shown in the following figure, which explores a large number of spikes and sharp pits that have very small width are being falsely produced on the surface topography of the polished steel specimen and registered in the surface data; these data will not truly represent the real parameters values of the measured surface. These spikes might be falsely produced due to the technique limitations.

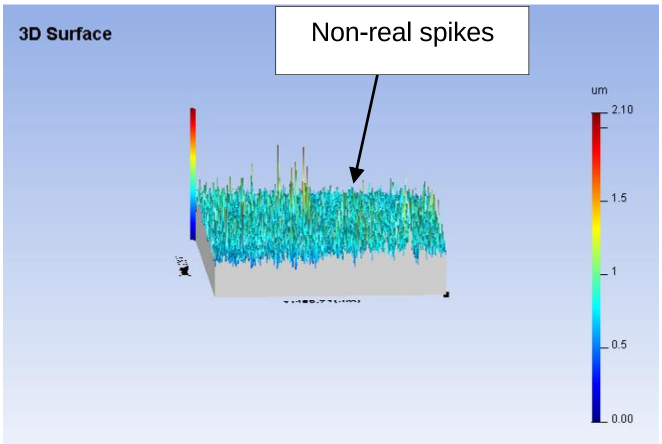

Fig. 9. *Non-real spikes produced by optical technique*

VI. CONCLUSION

In reviewing 2-D and 3-D surface metrology techniques it can be stated that, each of the above studied instruments is based on very different measurement principle, with its own particular advantages and disadvantages with respect to errors, resolution, range and applicability as a result of that the conclusion can be summarised in the following points:

- The stylus is the only instrument in active contact with the surface under test. Thus, both the shape and dimensions of this pick-up are critical factors and will strongly influence the information that retrieved from the surface.
- Although AFM has the highest resolution of all the considered instruments in both vertical and horizontal direction, it proved to be not suitable for measuring the proposed samples due to its small vertical and horizontal ranges.
- Wyko instrument exaggerate the topography by adding non-real spikes and non-existent peak features which will not give a meaningful comparison with the other proposed techniques as it affects Sa parameter value.

Finally, there are still numerous areas of research are extending of this research paper in which further studies are recommended. These might include the inclusion of other 3D surface metrology parameters.

Acknowledgment

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