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A correlational study of areal surface texture parameters on some typical machined surfaces

Q.Qi[a]*, T.Li[a], P.J. Scott[a], X.Jiang[a]

[a] *EPSRC Centre for Innovative Manufacturing in Advanced Metrology, University of Huddersfield, Huddersfield, HD1 3DH, UK*

* Corresponding author. Tel.: +44-1484-471284; fax: +44-1484-472161. *E-mail address:* q.qi@hud.ac.uk

Abstract

A number of areal surface texture parameters have been adopted by standards bodies, namely ISO 25178-2, in which forty-one parameters within six groups are defined. The selection of the suitable areal parameters becomes an issue for a designer. The study of correlation among parameters is one of the ways to find the most suitable parameters for a specification. This paper presents a Spearman's correlation study of areal surface texture parameters on some typical machined surfaces. Sixty surfaces, produced by nineteen machining methods, have been assessed by the use of an optical instrument; the operators adhered to ISO 25178-3; and parameters defined by ISO 25178-2. The correlation results are classified by using five correlation levels. It details the correlations between different groups of parameters, together with the correlation of parameters within the same group. The results are presented in Spearman's rank correlation coefficient matrix and charts. A three-layer parameters tree is then proposed to help engineer in the selection of parameters.

Keywords: areal surface texture; spearman's correlation; height parameters; hybrid parameters; V parameters

1. Introduction

Areal characterisation of surface texture plays an increasing important role in control the quality of the surfaces of a workpiece [1, 2]. This is principally due to areal method is more accurate and comprehensive than traditional profile method. Recently, a number of areal parameters have been adopted by national and international standards bodies, namely ISO 25178-2 [3], in which forty-one areal parameters within six groups of parameters are defined. Those parameters can empower designers to describe their requirements more precisely.

In technique drawing, however, it is often only one (or few) parameter(s) being used. The selection of the most suitable areal parameters becomes an issue for a designer. He/she sometimes lacks confidence in parameter selection. The possible reasons are listed as following.

(1) The correlation of parameters (mainly based on the geometrical properties of a surface) and functional requirements are less understood [4].

(2) Some of the parameters have significant variability, generally contributed by type of instruments, parameter definitions and the inhomogeneity of the surface [5].

(3) Some of the parameters are partially or strongly correlated with other parameters.

Much has been written about the first two items listed above, but less is understood about item (3). In this paper, we will concentrate on the item (3) - the correlation study of areal surface texture parameters.

The study of correlation among parameters is one of the ways to find the most suitable parameters for a specification. For instance, in the study of the meaningful of areal parameters on some ground surfaces, Reizer et al [6] have used the correlation analyses in the selection of the parameters. The results of correlation study illustrate the degree of independence between parameters. Therefore, it can help engineers in many aspects, some are listed as follow.

- To enhance the efficiency in the development of the specification. It requires a good amount of time to carefully analyse the results of the forty-one parameters. To address this issue, a two-steps method can be used. In the first step, the engineers focus on several typical independent parameters until a significant parameter being found. The second step will concentrate on the parameters, which have strong correlation with the parameter found in first step, in order to find the most suitable parameter.

- To avoid over-specified requirement in technique drawing. If more than one parameter being used to specify a surface, it is expected that those parameters are not interchangeable.
- To develop a better interpretation of the previous work. Traditional profile parameters are widely used in the earlier work. The results of correlation study for areal parameters can help an engineer to develop a better interpretation of the previous work, and to link them with the latest technique in surface metrology.

Some of the relative studies have been carried out. In 2008, Rosen et al [7] have pointed out that strong correlation between two typical profile parameter families (i.e. height parameters defined in ISO 4287, and the bearing curve based *Rk* parameters defined in ISO 13565-2 and ISO 13565-3), based on the investigation on some commercial cylinder liner surfaces.

This paper aims to help engineer in selection of parameters by assessing the correlation among areal parameters on typical applications. A correlation study of four groups of ISO 25178 areal parameters on sixty surfaces has been undertaken. Section 2 details the samples and measurement condition. Section 3 presents the correlation analysis and discussion. Section 4 demonstrates a three-layer parameters tree according to the correlation and usage of the parameters. Section 5 presents the conclusion and further work.

2. Samples and Instrumentation

2.1. Samples

Sixty surfaces, produced by nineteen machining methods, have been selected in this study (listed in Table 1). According to the results of two previous industrial surveys [8, 9], those surfaces are typical in surface assessment.

2.2. Measurement condition

The measurements were performed using a Talysurf CCI 3000 (Taylor-Hobson, UK, www. http://www.taylor-hobson.com). The numerical value of parameters is evaluated by SurfStand V5.0 (Centre for Precision Technologies, University of Huddersfield, UK), software package originating from the SurfStand project [10].

According to the usage of the parameters, twenty-one areal surface texture parameters within five groups are assessed (see Fig. 1). Their mathematical definitions are given in ISO 25178-2, and their discrete interpretations can be found in [11].

Each surface was measured three times. With 60 surfaces each of three measurements, 180 sets of measurement results have been obtained. Each data set comprises 1024×1024 surface heights at points defining a uniform grid with a sampling interval of 0.898883μm in *x*- direction and

Table 1. List of specimen (Rubert & Co. Ltd, UK)

No.	*Machining Method*	*Patches with different Ra values*						
315	Surface grinding		0.025	0.05	0.1	0.2	0.4	0.8
316	Cylindrical grinding		0.025	0.05	0.1	0.2	0.4	0.8
317	Flat lapping: Criss-cross		0.025	0.05	0.1	0.2		
	Flat lapping: Parallel		0.025	0.05	0.1	0.2		
318	Cylindrical lapping		0.025	0.05	0.1	0.2		
	Superfinishing		0.025	0.05	0.1	0.2		
319	Face turning						0.4	0.8
320	Cylindrical turning						0.4	0.8
321	End milling						0.4	0.8
322	Reaming						0.4	0.8
323	Horizontal milling						0.4	0.8
325	Shaping							0.8
326	Linishing					0.2	0.4	0.8
328	Vertical grinding					0.2	0.4	0.8
331	Spark erosion (EDM)						0.4	0.8
333	Hand filing						0.4	0.8
334	Castings							0.8
335	Honing			0.05	0.1	0.2	0.4	0.8
336	Polishing	0.0125	0.025	0.05	0.1	0.2		

Table 2. Selected nesting Indices for x- and y- directions

Ra value range	Nesting Indices	
(μm)	*x*- direction	*y*- direction
0.025-0.05	0.008mm-0.25mm	0.008mm-0.25mm
0.1-0.8	0.008mm-0.8 mm	0.008mm-0.8mm

0.899369μm in *y*- direction. The data sets were S-filtered, and second order polynomial fitting was used to remove form. For the evaluation of S-L surface texture parameters, general Gaussian Regression filter without boundary run-in/out [12] were used. The nesting indices in both *x*- and *y*- directions were applied according to the *Ra* value of the measured surfaces, see Table 2.

3. Spearman's correlation analysis and discussion

3.1. Spearman's correlation

Three correlation coefficients are the most commonly used, that of Pearson product-moment correlation, that of

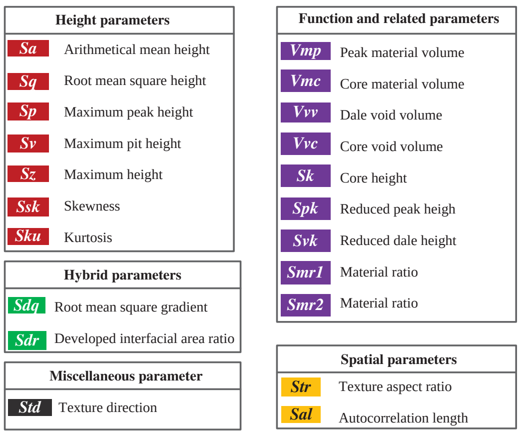

Fig. 1. List of areal parameters used in the assessment

Table 3. Spearman's rank correlation coefficient matrix

	Sa	*Sq*	*Ssk*	*Sku*	*Sp*	*Sv*	*Sz*	*Str*	*Sal*	*Sdq*	*Sdr*	*Vmp*	*Vmc*	*Vvc*	*Vvv*	*Spk*	*Sk*	*Svk*	*Smr1*	*Smr2*	*Std*
Sa	1																				
Sq	1.00	1																			
Ssk	0.40	0.38	1																		
Sku	-0.72	-0.68	-0.53	1																	
Sp	0.81	0.82	0.65	-0.48	1																
Sv	0.83	0.85	0.05	-0.37	0.60	1															
Sz	0.89	0.91	0.35	-0.43	0.87	0.90	1														
Str	-0.04	-0.04	0.14	0.11	0.06	-0.09	0.00	1													
Sal	0.61	0.62	0.31	-0.37	0.50	0.47	0.54	0.35	1												
Sdq	0.89	0.89	0.36	-0.57	0.80	0.79	0.87	-0.14	0.32	1											
Sdr	0.89	0.89	0.36	-0.57	0.80	0.79	0.87	-0.14	0.32	1.00	1										
Vmp	0.93	0.93	0.61	-0.66	0.92	0.72	0.89	0.02	0.58	0.87	0.87	1									
Vmc	1.00	0.99	0.41	-0.74	0.79	0.81	0.87	-0.04	0.60	0.88	0.88	0.92	1								
Vvc	0.99	0.98	0.47	-0.76	0.82	0.79	0.88	-0.05	0.59	0.88	0.88	0.94	0.99	1							
Vvv	0.96	0.97	0.21	-0.59	0.74	0.87	0.89	-0.05	0.60	0.87	0.87	0.86	0.95	0.93	1						
Spk	0.89	0.90	0.63	-0.61	0.95	0.67	0.88	0.02	0.56	0.84	0.85	0.99	0.88	0.91	0.82	1					
Sk	0.99	0.98	0.45	-0.76	0.81	0.80	0.87	-0.04	0.59	0.88	0.88	0.93	0.99	1.00	0.94	0.89	1				
Svk	0.93	0.94	0.14	-0.52	0.70	0.89	0.87	-0.08	0.58	0.85	0.85	0.82	0.92	0.89	0.99	0.77	0.90	1			
Smr1	0.19	0.21	0.51	-0.19	0.44	0.04	0.25	-0.07	0.16	0.26	0.26	0.41	0.16	0.25	0.13	0.46	0.20	0.09	1		
Smr2	0.47	0.46	0.77	-0.54	0.59	0.25	0.44	-0.03	0.24	0.49	0.49	0.61	0.47	0.55	0.31	0.62	0.54	0.26	0.55	1	
Std	0.03	0.03	-0.18	-0.01	-0.08	0.04	-0.02	-0.01	0.08	-0.04	-0.04	-0.04	0.02	0.00	0.07	-0.03	0.00	0.08	0.01	-0.19	1

Note:

- 0.80-1.00 very strong
- 0.60-0.79 strong
- 0.40-0.59 moderate
- 0.20-0.39 weak

Spearman's rank-order correlation, and that of Kendall's tau correlation. The Pearson product-moment correlation coefficient r is the most frequently used tools in the correlation study of surface parameters [6, 7]. Generally, correlation indicates how well two normally distributed variables move together in a linear way. In the case of non-normally distributed variables, it is often suggested to use the Spearman's (r_s) and Kendall's correlation coefficients (τ). Both approaches are not sensitive with outliers and data distribution. Therefore, they have advantages in terms of robustness and universalness. The Spearman's rank correlation coefficient is adopted in the correlation study proposed in this paper. This method is convenient to implement in the common statistic packages.

Table 3 shows the Spearman's correlation matrix. The strength of the correlation is described by the Spearman's correlation coefficient, denoted by r_s ($0 \leq r_s \leq 1.00$). Five levels are used according to the range of absolute value of r_s.

3.2. Correlation for parameters within the same group

Fig. 2 illustrates the correlation among parameters within a group. The detail definitions of parameters are given in reference [3, 11]. Four groups are detailed here. The miscellaneous parameter *Std* is not shown here as it is not correlated ($|r_s| < 0.19$) with other parameters.

3.2.1. Height parameters

Height parameters describe amplitude properties of a surface. It consists of three subgroups, that of average height parameters (i.e. *Sa* and *Sq)*, that of extreme parameters (i.e. *Sp*, *Sz* and *Sv*), and that of *Sku*/*Ssk* parameter (i.e. shape of a probability distribution, where *Ssk* represents the degree of symmetry of the surface heights about the mean plane, and *Sku* is a measure of the sharpness of the height distribution).

Fig. 2(a) shows that the correlation within the height parameter group. *Sa* and *Sq* shown the strongest correlation (1.00). They are considered as equivalent in this paper for the purpose of correlation analysis. *Sa*/*Sq* shows very strong correlation with extreme parameters *Sp*, *Sz*, and *Sv*. Among the extreme parameters, *Sz* also shows strong linear correlation with *Sp* and *Sv*.

Kurtosis *Sku* appears strong correlation with *Sa*/*Sq*, and shows moderate correlation with *Sp* and *Ssk*, and has weak correlation with *Sv*. This can be summarised as strong correlation with average height parameters and relatively low correlation with extreme height parameters.

Ssk shows strong correlation with *Sp*, and appears moderate correlation with *Sa*/*Sq*, and shows weak correlation with *Sz*. In terms of surface function, a comparatively large positive *Ssk*, say *Ssk*>1, may indicate the presence of a few spikes on the surface which may largely determine the value of *Sp*. The result indicates that the symmetry of the surface height is mostly effect by the extreme peak heights (*Sp*) rather than the maximum height (*Sz*).

3.2.2. Functions and related parameters

Two groups of parameters were analysed in this type, i.e. *V* family and *Sk* family. Both derived from areal material ratio curve, *Sk* family includes a set of parameters *Sk*, *Spk*, *Svk*, *Smr1* and *Smr2* defined from ISO 13565-2 [13]; and the *V* family (including four parameters *Vmp*, *Vmc*, *Vvc* and *Vvv*) are calculated from the material volume and void volume from the material ratio curve.

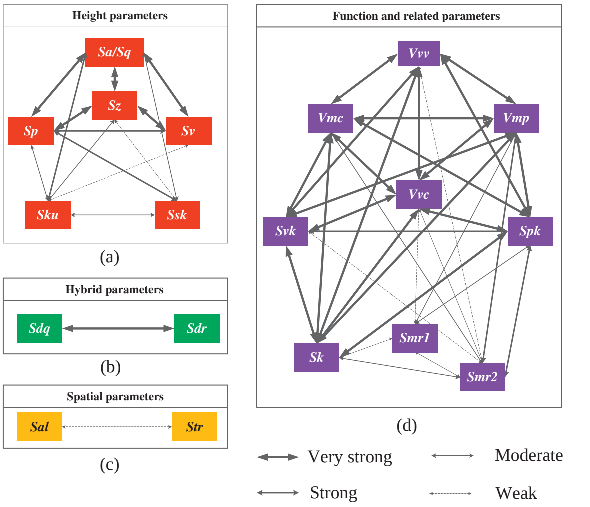

Fig. 2. Correlation of parameters within the same group

The correlations between functions and related parameters appear more essential, as most of them shown very strong correlations with each other, and most of the correlations appear linear property. This can be seen from very strong correlation between four parameters from *V* family. It is also highlight the strong correlation between *V* parameters and *Sk*, *Svk* and *Spk*, which is most likely to be a result of derivation from areal material ratio curve.

3.2.3. Spatial parameters

Spatial parameters *Sal* (auto-correlation length) and *Str* (texture aspect ratio) are defined to describe the spatial properties of the scale-limited surface. The correlation of two parameters is very weak. This is possibly due to the large variability of R_{max} on different machined surfaces.

3.2.4. Hybrid parameters

Parameters *Sdq* (root mean square gradient) and *Sdr* (developed interfacial area ratio) describe the hybrid property, i.e. a combination of height and spacing properties. Two parameters show very strong correlation.

3.3. Correlation between parameter groups

Fig. 3 shows correlation of parameters between groups; it is presented with reference to the level of correlation. There are three groups at the very strong level; and four groups at the strong, moderate and weak levels. Therefore, the relationship between groups is very complex. The only independent group is miscellaneous parameter.

3.4. Summary of correlation analysis

According to the correlation analysis of this assessment, some particular conclusions are as follows:

- *Sa* and *Sq* are interchangeable from correlation point of view due to the strongest correlation (r_s = 1.00).

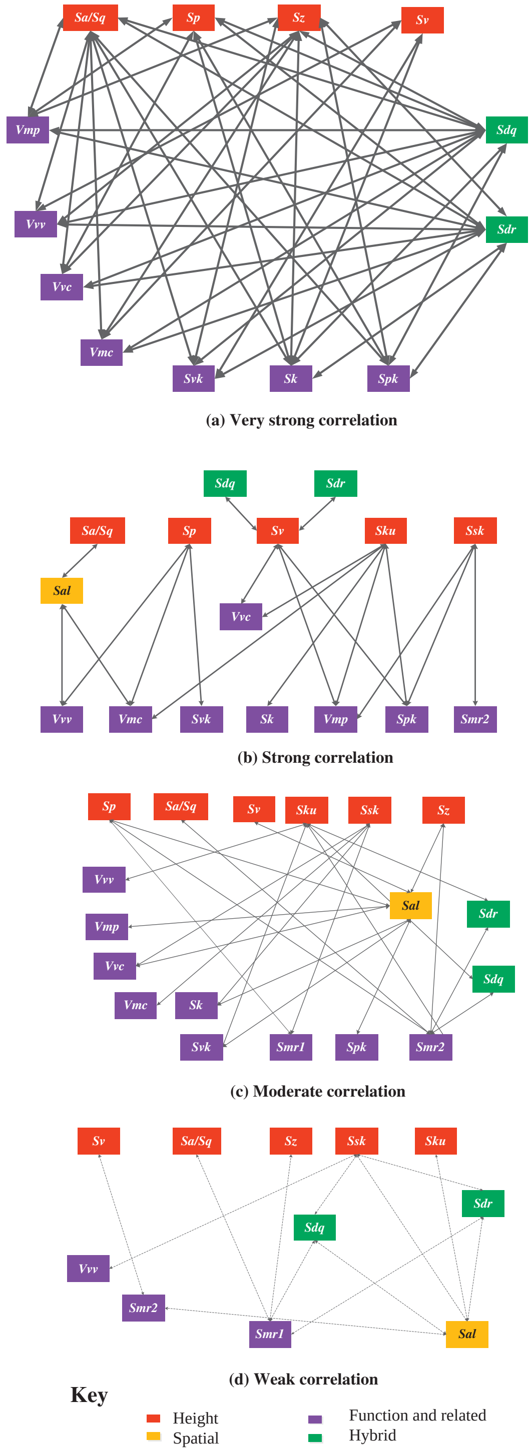

Fig. 3. Correlation between groups

- *Std* is the most independent parameter which has very weak link ($|r_s|$<0.19) with other parameters.
- *Sa*/*Sq* are the most representative parameter(s). They have very strong link with most of parameters.

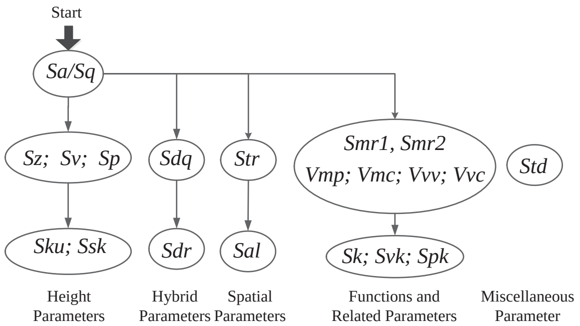

Fig. 4. A three-layer parameter tree for the selection of parameters

- The relationship of parameter group is very complex. From correlation point of view, we cannot say that any two groups are interchangeable; or any group is indispensable (except the miscellaneous parameter *Std*).

4. Parameter selection strategy

Traditionally, the parameters are classified in a tree structure according to their family group (e.g. [2]). Its structure is developed based on their original of the definitions. An engineer is required good knowledge in their mathematical definitions, and links them with the functional requirement based on her/his experience.

In this paper, we aim to develop a parameter selection strategy for engineers who have less experience. It develops with following two considerations:

(1) Correlation of the parameters: It can give us the following characterisation of parameter:

- Interchangeable: We assume that the results in the very strong level means the parameters are more interchangeable, while those in very weak level are not interchangeable.
- Representativeness: If only one parameter is selected, this parameter will have a better coverage.

(2) Usage of the parameters: The technique drawing is used as a communication tools between engineers. The widely used parameters make the communication easier. In this paper, the usage of the parameters is based on surveys [8, 9] and expertise.

Based on the results discussed in Section 3 and above consideration, we propose a three-layer parameter tree for the selection of the parameters (see Fig. 4).

Layer 1 is the start point for parameter selection. There is only two parameters in the layer 1, that of *Sa* and *Sq*. This is due to they are the most representative (see Section 3.4) and widely used. As *Sa* and *Sq* are interchangeable, engineer only need to select one parameter, i.e. *Sa* or *Sq*.

The second layer includes twelve parameters (i.e. *Sz*; *Sv*; *Sp*; *Sdq*; *Str*; *Smr1*; *Smr2*; *Vmp*; *Vmc*; *Vvv*; *Vvc*; and *Std*) from five groups. The parameters in layer 2 normally have higher usage than the parameters in the layer 3. *Std*, as the most independent parameter, is selected although the usage is quiet low.

5. Conclusions and future work

The paper presents a correlation study on the parameters of areal surface texture on some typical engineering surfaces. The correlations between parameters and groups have been assessed. The results have been used to develop a better understanding of the interchangeability and representativeness of parameters. It highlighted the most independent parameter (i.e. *Std*), and the most representative parameters (i.e *Sa* and *Sq*). Furthermore, a three-layer parameter tree is proposed based on the interchangeability, representativeness and usage of the parameters.

The further possible work can be carried on are listed as follows: (1) to extend the coverage of the parameter selection tree by including more parameters and assessing more surfaces; (2) to undertake case studies by the use of the parameter tree.

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