ROUGHNESS MEASUREMENT PROBLEMS IN TRIBOLOGICAL TESTING

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Abstract In tribological measurement of thermoplastics against steel the surface roughness has a potential effect in dictating the frictional behavior of the material. In most cases the roughness of the specimen is measured before and after the test, where it affects the friction force and influences the mechanism involved. The roughness of the material is not the exact value and it has a deviance which depends upon the machining process used in preparing the surface. Generally, the direction of machining has an influence on the topography of the surface in case of turning, milling and drilling but in case of pressed components the direction has no effects. In order to maintain ideal test condition the surface roughness of the test materials has to be consistent for the given number of samples. Even though the test specimens are machined in the same machine with same parameters there are number of parameters involved in deciding the consistency of the surface roughness. The roughness of the surface are defined by number of parameters such as Ra, Rz and few 3D parameters in such a case narrowing down to a specific constant is vital. The results from the roughness is not made from one measurement were an average and deviance from several measurement decides that if two ideal samples has same or different roughness.

Keywords : roughness comparable, machined surface, Ra, Rz.

1 INTRODUCTION

The influence of surface roughness has an important role in tribology, because most off the time the friction and wear in two solids sliding against each other are encountered in several day-to-day activities [1]. Usually the surface description in the scientific articles is not appropriate and thus an overview is made on identifying the suitable basic surface parameters.

Surface texture is the repetitive or random deviation from the nominal surface which forms the three dimensional topography of the surface. Fig. 1. Show different representations of surface roughness having the same Ra- value (Ra~0.64)[2].

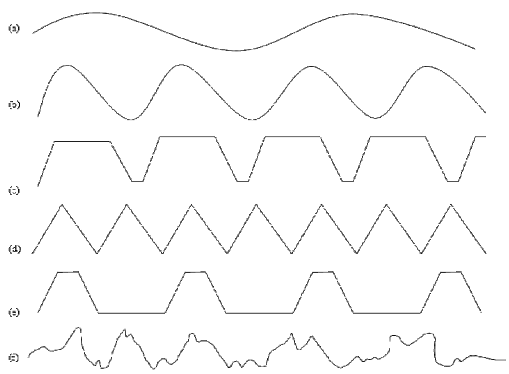


Figure 1. Various surface profiles having the same Ra value [Ra~ 0.64].

Roughness (nano-and microroughness) are formed by surface irregularities of short wavelength, characterized by peaks (asperities) (local maximum) and valleys (local minimum) or varying amplitude and spacing that are larger than molecular dimensions. These create the predominant surface pattern, which exhibits those surfaces features intrinsic to the manufacturing process.

Numerous techniques are used to quantitatively measure surface roughness which includes optical methods like optical interference and light scattering and mechanical methods, such as oblique sectioning and stylus profilometry.

Surface roughness most commonly refers to the variations in the height of the surface relative to a reference plane. It is measured either along a single line profile or along a set parallel line profiles (surface maps). It is usually characterized by one of the two statistical height descriptors advocated by the American National Standards Intitute (ANSI) and the International Standardization Organization (ISO). According with those statistical height descriptors they defined this parameters like, five extreme-value height descriptors are defined as follows: Ra is defined as the distance between the highest asperity and the mean line: Rv is defined as the distance between the mean line and the lowest valley: Rz is defined as the distance between the averages of five highest asperities and the five lowest valleys; and Rpm is defined as the distance between the averages of the five highest asperities and the mean line. The reason for taking and average value of asperities and valleys is to minimize the effect of unrepresentative asperities or valleys which occasionally occur and can give an erroneous value if taken singly. Rz and Rpm are more reproducible and are advocated by ISO. In many tribological applications, height of the highest asperities above the mean line is an important parameter because damage may be done to the interface by the few high asperities present on one of two surfaces; on the other hand, valleys may affect lubrication retention and flow.

The selection guide lines for the roughness value in respect to the function and manufacturing process is certainly not complete nevertheless the basics can serve as a reference (Fig. 2., the surface roughness is Ra in this case) . The overview shows that sliding surfaces with very low roughness value (Ra<0.4) often require a surface finish after turning or cutting, e.g grinding.

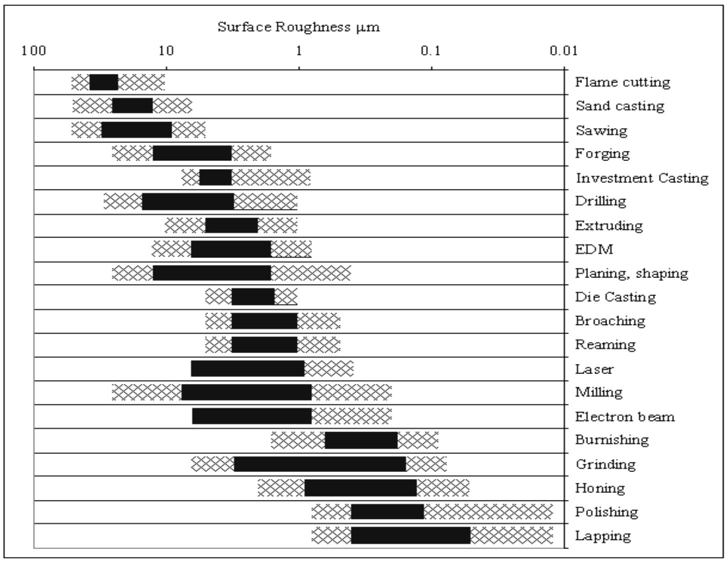


Figure 2. Limited selection of guidelines for surface roughness in respect to function and manufacturing process.

According with others studies [3] all the plastics tested against steel showed low coefficient of friction when mating rough surfaces but this also depends upon the external parameters like contact pressure and force. In different engineering plastics against steel showed that the plastics is characterized by a roughness of Ra=0.05-0.10 µm is mean that is a smooth surface and the steel material is characterized by a roughness of Ra=0.10-0.30 µm is mean that is a rough surfaces [4].

Materials	Smoot surface / coefficient	rough surface / coefficient
PA6-S355	Ra=0.05-0.2 / μ=0.2-0.4	Ra=0.5-1.5 / μ=0.4-0.6

In tribological application the surface roughness has significant effect on the friction force and wear. The aim of the article is to illustrate the appropriate values and methods from the surface measurements and on deciding the usage of parameters like Ra to Rz.

2 SURFACE ROUGHNESS OF SPECIFIC SURFACE AND STATISTICAL DISTRIBUTION

In the surface roughness measurement it is very difficult to measure at the same place every time and thus different values produced as a result of measurement. The working conditions in the machining process changes from time to time due to tool wear, dynamic phenomenon of chip formation, resonance of the machine and possible thermal shock. Describing roughness parameter of a specific surface one has to accept that a deviance exist all the time. Usually there are several independent parameters which has an effect on the surface roughness, so the Gaussian (normal) distribution can be used to resolve the deviance. When somebody use for example Ra=3.2 necessary to use an interval also (Ra=3.2±0.2). The size of the interval for the deviance basically depend on the machining process (condition of the tool, parameters of the machining) and the material (steel, polymer, aluminium).

A steel plate (S355) was ground and measured for the roughness on 24 different points (Table 1.), and the Fig. 3. shows the group of different values from the measurement in the whole group. The distribution of the values shows normal shape, because the peak is in the middle, and no other peaks can be found at the left or right side, and there is only one peak in the whole roughness group.

Table 1. Ra values of the grinded S355 plates

0,441	0,533	0,615	0,631	0,653	0,699	0,716	0,792
0,515	0,602	0,616	0,633	0,658	0,704	0,737	0,792
0,524	0,607	0,628	0,636	0,669	0,712	0,749	0,819

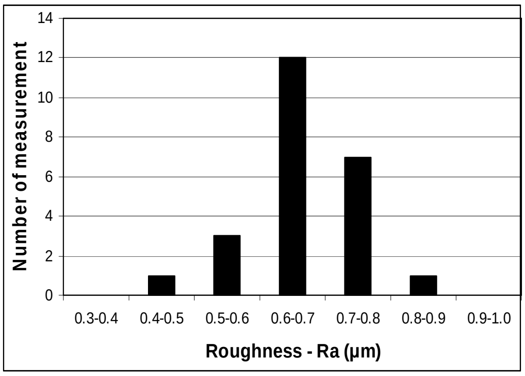


Figure 3. Roughness values of grinded plate.

Fig. 4. Shows the calculated Gauss-curve based on the 24 measurement. The average point (Ra = 0.653) and the ± 2σ points (Ra = 0.467 and Ra = 0.840) is also marked in the figure.

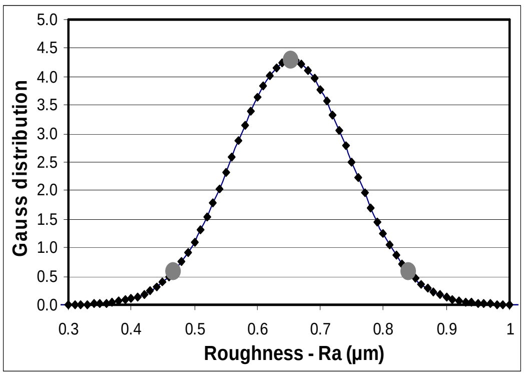


Figure 4. Gauss distribution base on 24 measurements.

The ± 2σ points show the limit, which 95% of the test results falls between the two points. In our case only one value is out of this range, which represents 4.2%. Table 2. contains the values which belong to different sigma criteria to explicitly show the values which are present outside the range.

Table 2. Effect of the sigma limits.

Sigma	Level	Ra interval (μm)	Average ± %	Result out of the range	
±1σ	68%	0.560-0.746	0.653± 14.2%	8 ps	33.3%
±2σ	95%	0.467-0.840	0.653± 28.4%	1 ps	4.2%
±3σ	99.7%	0.374-0.933	0.653± 42.6%	0 ps	0%

In normal technical practice an error of 5% is acceptable, which is accommodated inside the ±2σ range. Some specific fields ±3σ is also used, however, the application of ±1σ (also from the diagrams) are incorrect and leading to misunderstanding.

3 EFFECT OF THE MACHINING DIRECTION

Most of the machining process creates the roughness profile with respect to the direction of machining and the type of machining process itself has a direction factor on the surface profile. For example in case of turning or grinding the measured value dramatically changes when the measurements are made parallel or perpendicular to the feed direction. Milling has also this effect, but the differences of the values are relatively less. Some machining process exist which has minimal effect on the direction such as finishing sander or fine polishing. In case of polymers the pressing also has no directional effects of the roughness.

Fig. 5. Shows the surface roughness in case of grinding (different feed rates). Even though the samples are machined with same machining parameters a clear difference is seen between the parallel and perpendicular measurements seen from the Ra and Rz values which are not close to each other. In case of milling (Fig. 6.) both the group from parallel and perpendicular measurements are also seems separated but the differences are relatively less. The values in case of milling ten times bigger then the grinding, for this, the nominal values cannot be used to describe the parameter.

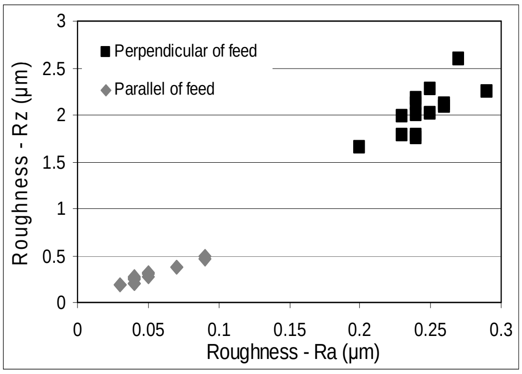


Figure 5. Effect of the measuring direction in case of grinding.

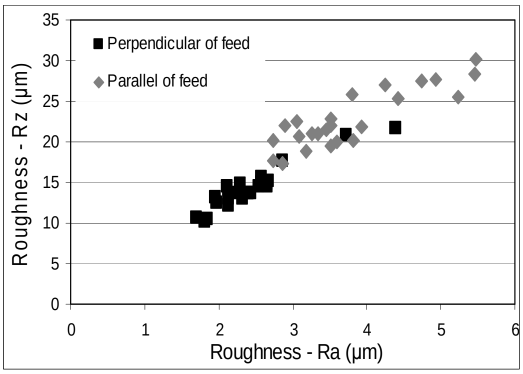
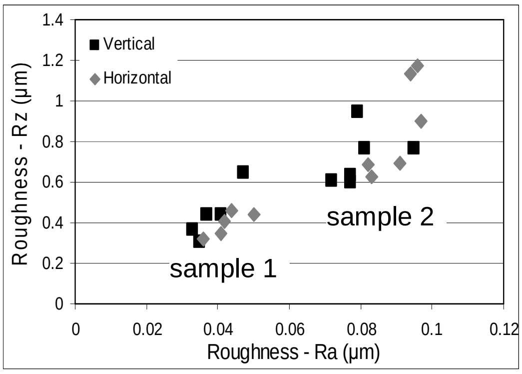


Figure 6. Effect of the measuring direction in case of milling.

The Fig.7. Shows the measurements from a pressed polymer sheet where is no difference in the sample surface on both the directions (the grey and the black dots are in one cluster). The two groups in fig is because of the different material of the two samples. It is also interesting that pressed surface has ten times smoother surface than the grinding. In tribology it is well known that in polymer-steel contacts, smoother surface helps to the adhesion characteristics. Using finishing sander also produces smooth surface without directional effect. On the Fig. 8 the dots are in the same group.

4 RELATIONSHIPS BETWEEN RA AND RZ NOMENCLATURE

From the previous figures it is seen that Ra and Rz parameters are not dependant on each other but on the other hand they are not completely independent as well, because they are calculated values from the same primary profile. In most cases it is necessary to convert the two values, for this some approximate method are exist.



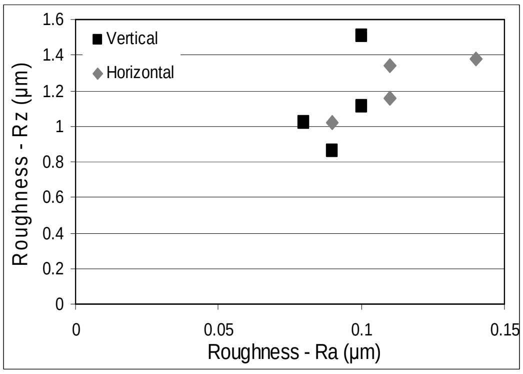


Figure 7. Effect of the measuring   Figure 8. Effect of the measuring

direction in case of polymer pressing.direction in case of using finishing sander.

One well known factor is Rz=4·Ra which cannot be used all the time. The basic problems is that this equation is not sensitive to the Gaussian distribution. In the real application if the engineer choose Rz=15 (from the drawing) but from the machined part we can measure just Ra, we should use an other equation (Ra=Rz/7.5) to get Ra=2 which means the machining process produces values between Ra<2, that means Rz will be less than 15. On using the first equation (Rz=4·Ra), we get Ra=3.75, but on the Fig. 9. it is clearly sene if we measure Ra=3.7 under the machining, we can easily measure Rz=15-27, which is not appropriate. So if Rz is unknown we should use Rz = 4·Ra, but if Ra is unknown we should use Ra=Rz/7.5. This two equation are the borders of the commonly used machining process. But for specific machining this borders could change. Table 3. contain the equations of the borders for different parameters.

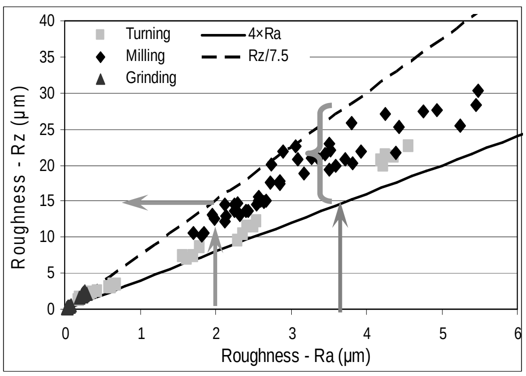


Figure 9. Connection between Ra and Rz in case of different machining.

5 HOW CAN COMPARE TWO DIFFERENT SURFACE

In a set of values from the measured surface parameters it is possible to calculate the mean and the standard deviation, but to decide to the values are same the f-test and t-test should be used.

These calculations does already exist but the aim is to sort out the correct one between several parameters (Ra, Rz…) and directions effects. From the different values of Ra and Rz correlation cannot be made to make a certain surface. Fig 10. and Fig 11. show the results of different grinded steel plates in parallel and perpendicular directions. As you can see there is difference in the values of Ra and Rz between the perpendicular and the parallel measurements. Measurements parallel of the machining has less influence so the difference rather belongs to the results from the measurements in the perpendicular direction (Fig. 12).

Table 3. Relationships between the surface parameters.

Unknown parameters	Measured parameters	Border
R_a	R_z	$R_a = \frac{R_z}{7,5}$
R_a	R_q	$R_a = \frac{R_q}{1,4}$
R_z	R_q	$R_z = \frac{R_q}{0,3}$
R_z	R_a	$R_z = 4 \cdot R_a$
R_q	R_a	$R_q = 1 \cdot R_a$
R_q	R_z	$R_q = 0{,}15 \cdot R_z$

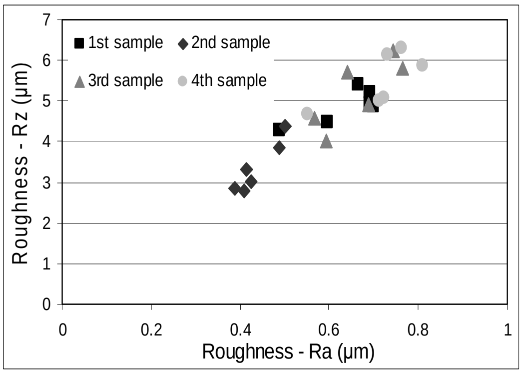


Fig. 10. Different grinding samples (perpendicular of feed).

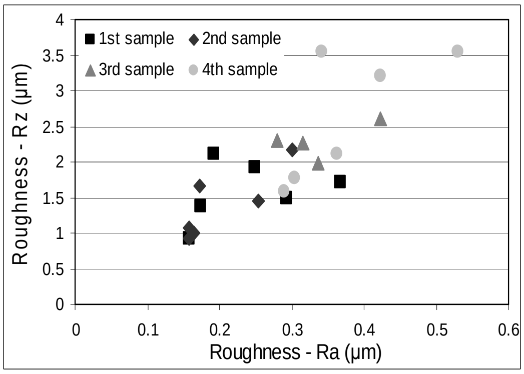


Fig. 11. Different grinding samples (parallel of feed).

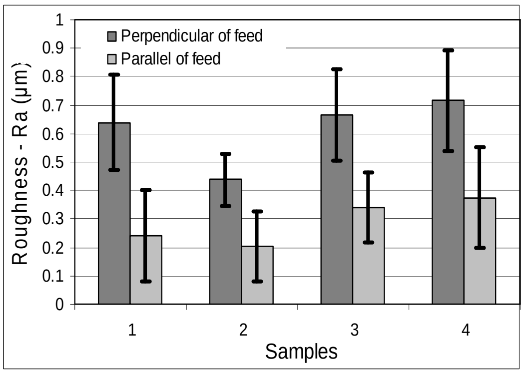


Figure 12. Roughness of different samples and directions.

At first the t-test shows that the deviances of the plate are the same (usually this is true, because of the same machining process). If the t-test is good, f-test show the results are different or same. In our case the second sample is different from the others, the other three are same. From the experiments it is clear that using the values of Ra or Rz are almost same to compare different surfaces. The parallel values are much closer then the perpendicular. In case of parallel the difference is just between second and fourth samples. It is important to know the two surface are same and better to use the statistical method for identifying the parameters (Ra, Rz..) which can be used as a reference in the further experiments. In our case the second sample was regrinding to achieve the same surface.

6 CONCLUSION

In tribological experiment surface roughness is one of the important parameter. Because of that a comparable a specific surface roughness is needed. Unfortunately, sometimes even with the same machine and tool results in different surfaces. In the roughness measurement it is possible to calculate the average but it is also important to calculate the standard deviation. Direction effect is vital considering the roughness measurement. In case of turning and grinding the parallel and the perpendicular values are completely different. In case of milling also has direction effect but relatively less because the values are closer to each others. Some machining techniques have no directional effect (finishing sander, pressing).

Between the surface roughness parameters (example Ra and Rz) exist some approximate method to change each other, but this methods are sensitive to the directions. To compare two surface the f-test and t-test should be used. Easy way is to not compare all the parameters, but just the one perpendicular to the feed. Result of the statistical method practically are the same in case of the different surface roughness parameters (Ra, Rz…). If the samples surfaces are not the same it is worth to remac hine the different sample.

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