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ROUGHNESS OF SHOT-PEENED SURFACES - DEFINITION AND MEASUREMENT

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ABSTRACT

The ISO (or DIN) standards specify the bases fore determining the surface roughness. Shot-peened surfaces, however, are only dealt with in passing. There do not exist any exact measuring specifications taking into account the characteristics of shot-peened surfaces. That results in roughness values that are not always directly comparable with each other since they can be measured in different ways. This article exemplarily shows variations in measuring values occurring in spite of measurement in line with ISO. Finally, there is formulated a proposal for measuring the roughness and for indicating the roughness parameters of shot-peened surfaces taking into account the findings made.

KEY WORDS

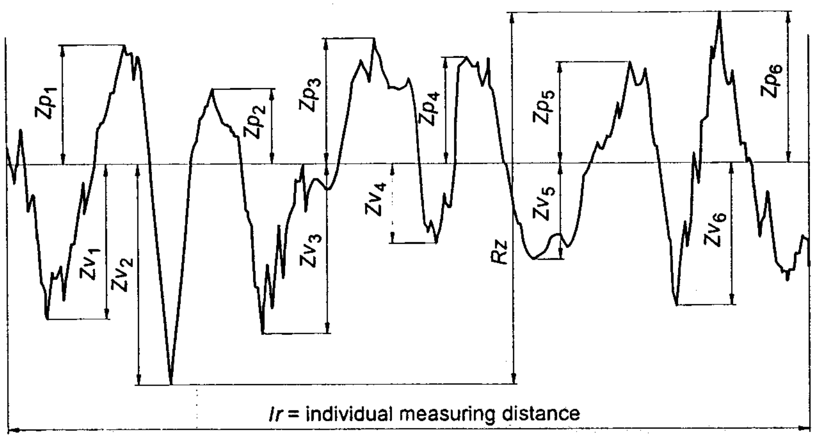
Shot-peening, Roughness, Measuring, Indicating, Surface Topography

Introduction

The International Standard (ISO) knows a large number of regulations that deal with the terms, measuring conditions. symbols and parameters of the roughness of surfaces. Particular mention shall be made of ISO 4287 and 4288. In industrial practice, surface roughness parameters are mainly determined with the help of electronic contact (stylus) instruments. It is, however, doubtful whether, in case of shot-peened surfaces, the measurement is always made correctly according to the ISO standard or whether the ISO standard provides sufficient help for a correct measurement. Sources of error comprise in particular the choice of the scanning length and of the limit wavelength differentiating the roughness profile from the ripple profile. This is especially difficult for a surface coverage clearly below 100% and for shot peening with large balls (Ø > 2 mm). While the ISO or German Standard (DIN) consider all types of surfaces and even mention the term shot-peening, they do not go into special conditions or special cases. This article shall show the resulting variations of measuring values that may occur. It starts with a brief summery of the definition of the surface roughness parameters indicated in most cases and a description of the characteristics of shot-peened surfaces.

Definition and Measurement of the Surface Roughness Parameters

The surface roughness comprises surfaces irregularities with relatively small distances that usually include any irregularities caused by the applied manufacturing process and/or other influences. These irregularities are considered within agreed limits. The mostly measured and indicated parameters of the roughness profile (*R*-parameters) are *Ra* and *Rz*. Since the introducing of ISO 4287 in 1997, these parameters have only been distinguished by their symbol and no longer by their designation. The definitions (see **Fig. 1**) are as follows: *Rz* - sum of the height of highest profile peak *Zp* and the depth of the deepest profile valley *Zv* within an individual measuring distance; *Ra* - arithmetical mean value of the amounts of the ordinate values Z(x) within an individual measuring distance *lr*.



[ISO 4287 : 1997]

Fig. 1: Roughness profile with measured quantities

Upon applying the profile method, the calculation of the values of the parameters *Ra* and *Rz* is usually based on five individual measuring distances. In that case, no index is attached to the roughness symbol.

Before measuring the parameters, it must be determined whether the profile of the roughness profiles is periodic or random. In general, there is assumed a grooved profile with a regular (periodic) or irregular (random) course of the groove direction on the surfaces. The surface profile for measuring the roughness parameters will then be the intersection line between a plane and the surface. If the measuring direction is not defined, the work piece shall be arranged in such manner that the scanning direction (direction of profile section) is expected to yield the highest measuring values.

Characteristics of Shot-Peened Surfaces

In contrast to grooved surfaces as they are produced by methods such as turning on a lathe or planing, shot-peened surfaces show non-grooved surfaces. This is shown in **Fig. 2**. The German Standard DIN 4761 (Geometrical characteristics of surface texture; terms and definitions, symbols) describes the surface produced by shot-peening as flat-trough-shaped. Locally more or less sharply delimited impressions of a round to angular form are characteristic.

In case of a low surface coverage, individual ball impacts can also be described as impacts or, on thin sheets, as dents.

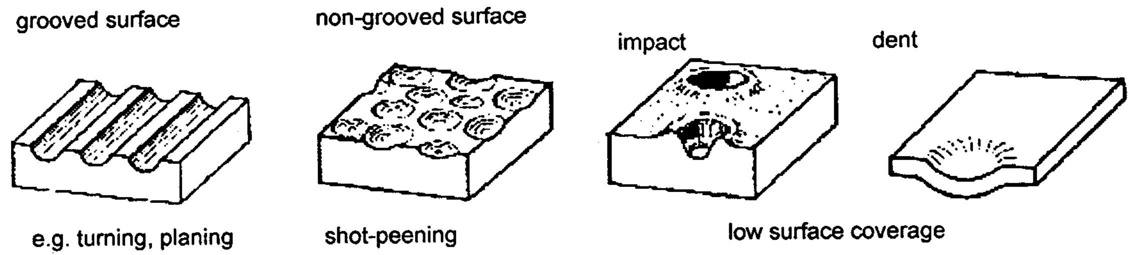


Fig. 2: Surface characteristics (DIN 4761, examples)

Due to the processing, the ball impacts are distributed on the surface. in a random, but, from a statistical point of view, uniform manner. Therefore, a shot-peened surface can be regarded as regular without, however, speaking of a regular course of the "groove direction". Therefore, a classification as an random roughness profile suggest itself. The surface profile can be represented in the following simplified form (**Fig. 3**).

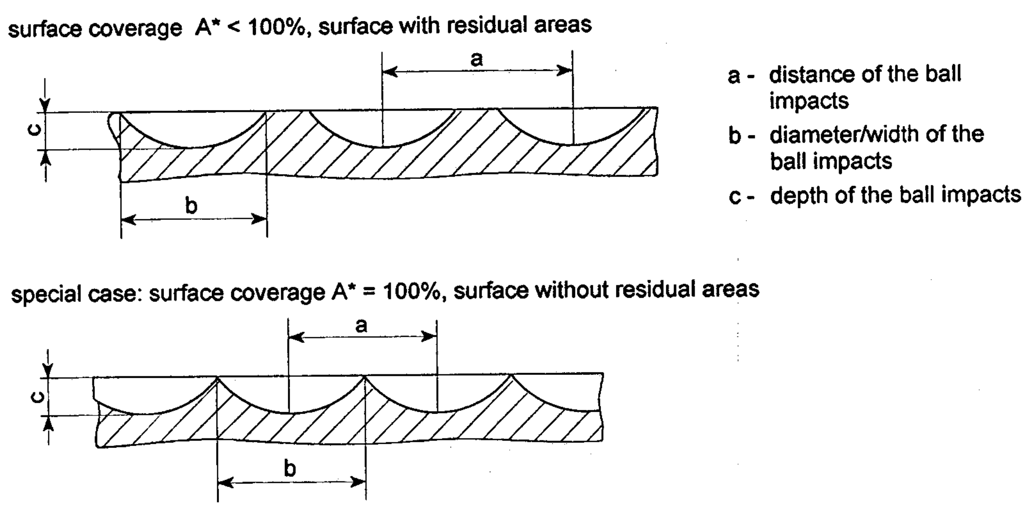
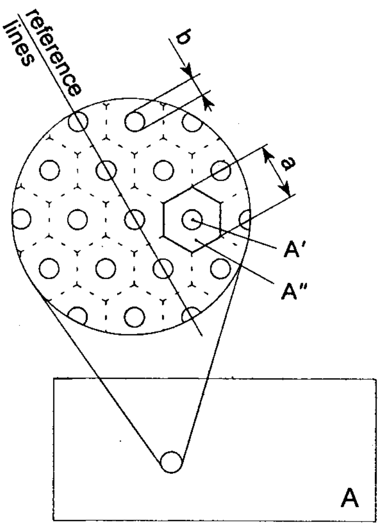


Fig. 3: Simplified profile of a shot-peened surface

In case of a surface coverage below 100%, there remain residual areas between the ball impressions. A surface coverage of 100% represents the special case in which these residual areas of non-shot-peened sections do not exist. The mathematical model shown in **Fig. 4** can be used for the calculation of the mean distance of the ball impacts in case of a surface coverage below 100%. This model assumes a circular ball impact in the centre of a regular hexagon. Depending on the surface coverage A* and on the diameter of the ball impact b, there results the following equation for calculating the mean distance of the ball impacts:

$$\text{with } A' = \frac{b^2 \cdot \pi}{4}, \quad A'' = \frac{A}{n} = 2 \cdot a^2 \cdot \tan(22{,}5°), \quad A^* = \frac{A'}{A''} \quad \Rightarrow \quad a = 0{,}974 \cdot \frac{b}{\sqrt{A^*}}$$



A - machined area

A* - surface coverage [%]

A' - area of an individual ball impact (area of a circle)

A" - total area per ball impact (regular hexagon)

n - number of ball impacts on area A

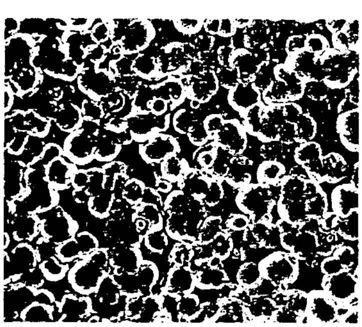
b - diameter of the ball impacts

a - (mean) distance of the ball impacts

Fig. 4: Model for determining the mean distance of ball impacts

The calculated value of the mean distance of the ball impacts can be used to estimate whether a chosen individual measuring distance includes a sufficient number of ball impacts when the surface coverage and the diameter of the impacts are known. For a roughness determination, a number of at least 10 ball impacts per individual measuring distance shall be aimed at in order to obtain reliable roughness values

As a comparison with the theoretical considerations, **Fig. 5** shows photographs of shot-peened surfaces with varying surface coverage.



surface coverage

<== A* = 80%

A* ≥ 97% ==>

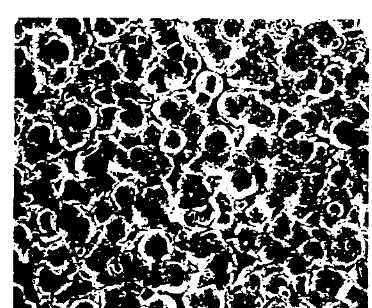


Fig. 5: Topography of shot-peened surfaces with varying surface coverage

It becomes clear that the ball impacts are distributed over the surface in a relatively regular manner. A measuring direction that is expected to yield the highest measuring values cannot be easily found. Nevertheless, there may occur considerable differences in determining the roughness depending on the position and length of the measuring distance. This shall be demonstrated with the help of the following test results.

Tests for Determining the Roughness Parameters

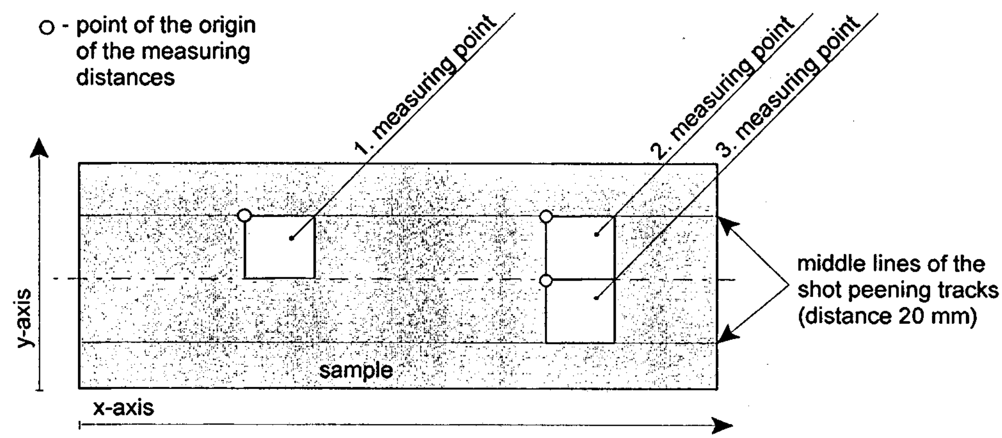
The tests were performed using an injector shot-peening cabin of the firm SCHLICK. There were produced two overlapping shot-peened tracks in a distance of 20 mm on each flat sample with the dimensions 100 x 40 x 70 mm. The shot-peened parameters chosen provided for a surface coverage A* of 97% or higher between the middle lines of the shot-peened tracks. The parameters such as feed speed of the shot-peening pistol, distance between nozzle and sample surface, angle of shot-peening impact, shot-peening pressure and shot-peening medium mass flow rate were kept constant during the tests with the help of respective devices. The materials and shot-peening media used as well as the test data are enlisted in **Table 1**.

Table 1: Shot-peening media, materials and test data

Shot-peening medium (abbreviation)	**grain size** (in µm)	**work piece material**	
		AlCuMg2 (3.1355)	16 MnCr5 (1.7131)
cast steel, round (GS-R)	200 - 400		●
	400 - 800		●
	800 - 1250		●
cast steel, edged (GS-K)	120 -420		●
	180 - 710		●
	300 - 1000		●
glass beads (MGL)	105 - 210	●	
	250 - 420	●	
	420 - 590	●	
test data:	• flat sample: 100 x 40 x 7 mm • two overlapping shot-peened tracks in a distance of 20 mm, surface coverage between the middle lines of the shot-peened tracks: A* ≥ 97% • injector shot-peening cabin Typ 151, Fa. Schlick • shot-peening parameters: - distance between nozzle and sample surface: 80 mm - angle of shot-peening impact: 75° (AlCuMg2), 85° (16 MnCr5) - shot-peening pressure: 5 bar		

There were examined samples made of 16 MnCr5 shot-peened with round and edged grain of cast steel of three different grain sizes as well as samples made of AlCuMg2 shot-peened with glass beads of three different grain sizes, too. These material - shot-peening medium combinations can be frequently found in the industrial practice and thus are not special cases. Before measuring the roughness with a electrical contact (stylus) instrument of the firm PERTHEN, limit wavelength and measuring distance were determined in the manner described in ISO 4288 for random profiles. Accordingly, a limit wavelength (individual measuring distance) of *lr* = 2.5 mm and a measuring distance of *ln* = 12.5 mm are to be chosen for all samples (range of application: *Ra* values from 2 to 10 µm, *Rz* values from 10 to 50 µm).

The roughness measurement was performed on 3 selected measuring points on the surface of the samples as schematically shown in **Fig. 6**. On each measuring point, starting from the point of origin and having a parallel distance of 1 mm from each other, there were performed 11 measurements in the direction of the shot-peening tracks (X) and 11 measurements in a direction turned round 90° (Y). Moreover, 11 measurements radially starting from the point of origin turned in 9°-steps (R) were made on each measuring point. It was the aim to determine whether or not the measured values vary and, if so, whether these variations depend on the direction of measurement or the measuring point and what their values are.



• measuring point: 10 mm x 10 mm
• on each measuring point 11 measurements in a parallel distance of 1 mm or turned radially around 9°

• arrangement of the measuring distances on the measuring points

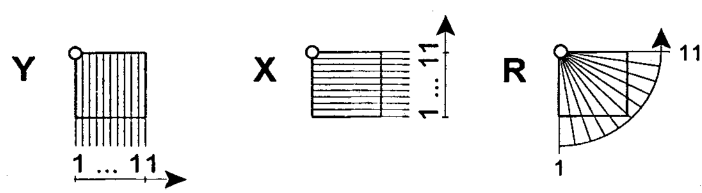


Fig. 6: Measuring process with information on the location of the measuring points and the arrangement of the measuring distances

In order to determine whether there exist any clear tendencies or dependence of roughness parameters on the measuring direction, there were formed the average values of the respective 33 measurements (11 measurements per direction on the three measuring points). **Table 2** shows some representative results indicating also the maximum deviation from the average value.

Table 2: Influence of the measuring direction on the roughness parameters (examples)

Work piece material / shot-peening medium		arrangement of the individual measuring distances Y	X	R
AlCuMg2 glass beads (MGL 105 - 210)	*Ra* [µm]	$3{,}45\ ^{+0{,}23}_{-0{,}22}$	$3{,}46\ ^{+0{,}24}_{-0{,}16}$	$3{,}49\ ^{+0{,}21}_{-0{,}21}$
	Rz [µm]	$22{,}04\ ^{+2{,}00}_{-1{,}81}$	$22{,}41\ ^{+2{,}06}_{-1{,}55}$	$22{,}59\ ^{+1{,}78}_{-1{,}80}$
16 MnCr5 cast steel, round (GS-R 0.2 - 0.4)	*Ra* [µm]	$2{,}87\ ^{+0{,}17}_{-0{,}17}$	$2{,}93\ ^{+0{,}31}_{-0{,}29}$	$2{,}86\ ^{+0{,}25}_{-0{,}22}$
	Rz [µm]	$18{,}81\ ^{+1{,}16}_{-1{,}04}$	$19{,}02\ ^{+2{,}19}_{-1{,}81}$	$18{,}84\ ^{+1{,}52}_{-1{,}96}$
16 MnCr5 cast steel, edged (GS-R 0.18 - 0.71)	*Ra* [µm]	$4{,}39\ ^{+0{,}22}_{-0{,}21}$	$4{,}33\ ^{+0{,}35}_{-0{,}28}$	$4{,}25\ ^{+0{,}25}_{-0{,}22}$
	Rz [µm]	$32{,}00\ ^{+2{,}67}_{-1{,}91}$	$32{,}17\ ^{+2{,}74}_{-2{,}62}$	$31{,}82\ ^{+1{,}52}_{-1{,}63}$

It turns out that the average values in part show clear differences. As an example, the *Rz* values shall be mentioned that were measured after shot-peening the aluminium alloy with glass beads. However, there are not visible any clear tendencies or dependence of the roughness parameters on the measuring direction. One time, the average value of the measurements in Y direction shows the highest value (16 MnCr5, GS-K 0.18 - 0.71: Ra), and another time, the average value of the measurements in X direction (16 MnCr5, GS-R 0.2 - 0.4: *Ra* and *Rz*). Within the 11 measurements per measuring point, there weren't visible any clear tendency or dependence either. The material - shot-peening medium combination, that are not mentioned did not show a deviating behaviour.

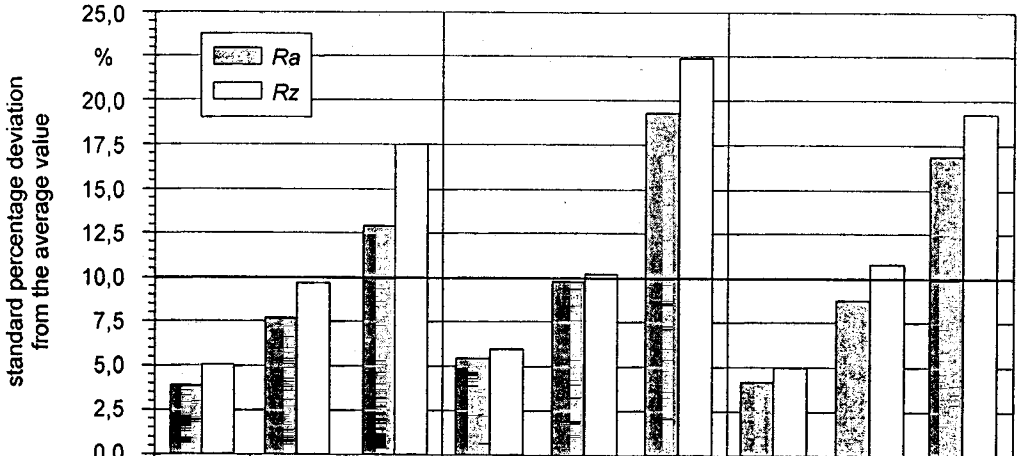
Then the average values of the 33 measured values taken on each individual measuring point were calculated in order to determine whether or not there exist any clear tendency or dependence of the roughness parameters with regard to the measuring point. **Table 3** shows some representative results indicating also the maximum deviation from the average value.

Table 3: Influence of the measuring point on the roughness parameters (examples)

Work piece material / shot-peening medium		measuring point 1	2	3
AlCuMg2 glass beads (MGL 105 - 210)	*Ra* [µm]	$3{,}50\ ^{+0{,}20}_{-0{,}14}$	$3{,}43\ ^{+0{,}23}_{-0{,}19}$	$3{,}48\ ^{+0{,}22}_{-0{,}27}$
	Rz [µm]	$22{,}48\ ^{+1{,}99}_{-1{,}65}$	$22{,}19\ ^{+2{,}17}_{-1{,}42}$	$22{,}38\ ^{+1{,}60}_{-2{,}15}$
16 MnCr5 cast steel, round (GS-R 0.2 - 0.4)	*Ra* [µm]	$2{,}91\ ^{+0{,}33}_{-0{,}22}$	$2{,}86\ ^{+0{,}29}_{-0{,}22}$	$2{,}89\ ^{+0{,}21}_{-0{,}21}$
	Rz [µm]	$18{,}83\ ^{+2{,}38}_{-1{,}32}$	$18{,}69\ ^{+1{,}64}_{-1{,}81}$	$18{,}77\ ^{+1{,}33}_{-1{,}67}$
16 MnCr5 cast steel, edged (GS-R 0.18 - 0.71)	*Ra* [µm]	$4{,}35\ ^{+0{,}33}_{-0{,}26}$	$4{,}36\ ^{+0{,}29}_{-0{,}23}$	$4{,}27\ ^{+0{,}21}_{-0{,}24}$
	Rz [µm]	$32{,}04\ ^{+2{,}51}_{-1{,}95}$	$32{,}28\ ^{+2{,}63}_{-2{,}73}$	$31{,}67\ ^{+2{,}44}_{-1{,}80}$

Here as well, no clear tendency or dependence of the roughness parameters are apparent. There do exist differences between individual measuring points, but not in a regular manner. However, all measurements clearly showed considerable fluctuations of the measuring values. As an example, the roughness parameters of the steel sample treated with round shot-peening medium (16 MnCr5, GS-R 0.2 - 0,4) ranged from 16.88 to 21.21 µm for *Rz* and from 2.64 to 3.24 µm for *Ra*.

Referring to all 99 measured values per sample, all material shot-peening medium combinations showed standard percentage deviations from the average value between 4 and 6% for the roughness parameters *Ra* and *Rz* (see **Fig. 7**). Considering the 10 extreme values (i.e. the same range), the standard percentage deviation is about 10%. The inaccuracy of the measurement becomes particularly evident when forming the standard percentage deviation of only 4 extreme values (again with the same range). That way, there result standard percentage deviations ranging from 13.0 to 19.4% for *Ra* and from 17.6 to 22.5% for *Rz*. This applies to all material shot-peening medium combinations considered in the examinations.



standard perc. deviation	99 values	10 extrem values	4 extrem values	99 values	10 extrem values	4 extrem values	99 values	10 extrem values	4 extrem values
Ra :	4,0%	7,8%	13,0%	5,5%	10,0%	19,4%	4,2%	8,8%	16,9%
Rz :	5,1%	9,8%	17,6%	6,0%	10,4%	22,5%	5,0%	10,8%	19,3%
material shot	Al Cu Mg 2 MGL 105 - 210			16 Mn Cr 5 GS-R 0,2 - 0,4			16 Mn Cr 5 GS-K 0,18 - 0,71		

Fig. 7: Influence of the number of measurements on the standard percentage deviation from the average value, with an equal range

The results show very clear that a single measurement or a small number of measurements of the roughness does not form a sufficient basis for indicating the roughness parameters of shot-peened surfaces. For determining the roughness parameters of shot-peened surfaces, it is therefore recommended to perform at least ten measurements an any point desired and in any direction desired the average value of which shall then represent the roughness of the surface. That way, a standard deviation of about 10% is to be expected. In case of a surface coverage clearly below 97% and unevenly shot-peened surfaces, that value may also be clearly higher. That was established in tests the results of which are not presented in these paper.

Another examination dealt with the influence of the setting values of the electrical contact (stylus) instrument (limit wavelength or individual measuring distance and length of the measuring distance) specified in ISO 4288 for random profiles depending on *Rz* or *Ra*. As an example, the limit value *Rz* = 10 µm shall be mentioned. With the ISO specification of *lr* = 2.5 mm and *ln* = 12.5 mm for *Rz* > 10 µm, there results an average (10 measurements) for

Rz of 32 µm for the material shot-peening medium combinations 16 MnCr5 and GS-K 0.18 - 0.71. If however, for reasons of space, due to carelessness or false assessment of the roughness to be measured, values of *lr* = 0.8 mm and *ln* = 4 mm (range Rz ≤ 10 µm) are set, a measurement on the same points will result in an average value for *Rz* of only 24 µm!

Summary and Proposed Measurement

At first, it was shown that the determination of the roughness parameters of shot-peened surfaces is only insufficiently reflected in the ISO standard that in general is based on the assumption of grooved surfaces. That may lead to errors in selecting limit wavelength and length of the measuring distance. But even with a correct selection (according to ISO) of the setting values of the electrical contact (stylus) instrument, the measured values clearly vary. That was shown by means of nine material shot-peening medium combinations and is rooted in the characteristics of shot-peened surfaces. Furthermore, it was proven that there does not exist any clear dependence of the measured values on the measuring direction and the measuring point in uniformly shot-peened surfaces having a surface coverage of $A^* \geq 97\%$. Thus, the following proposal shall be formulated for the measurement and indication of the roughness of shot-peened surfaces: For determining the roughness parameters of shot-peened surfaces, ten measurements on any point and in any direction shall be performed the average value of which shall then represent the roughness of the surface. A standard deviation of about 10% is to be expected. The electrical contact (stylus) instrument shall be generally set to *lr* = 2.5 mm and *ln* = 12.5 mm. If, e.g. for reasons of space, it should be necessary to select other values, such values should be specified when indicating the roughness, for example *Rz* (0.8/4).

References

1. ISO 4287: Geometrical Product Specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters (ISO 4287 : 1997).
2. ISO 4288: Geometrical Product Specifications (GPS) - Surface texture: Profile method - Rules and procedures for the assessment (ISO 4288 : 1996).
3. DIN 4761: Geometrical characteristics of surface texture; terms and definitions, symbols (1978).