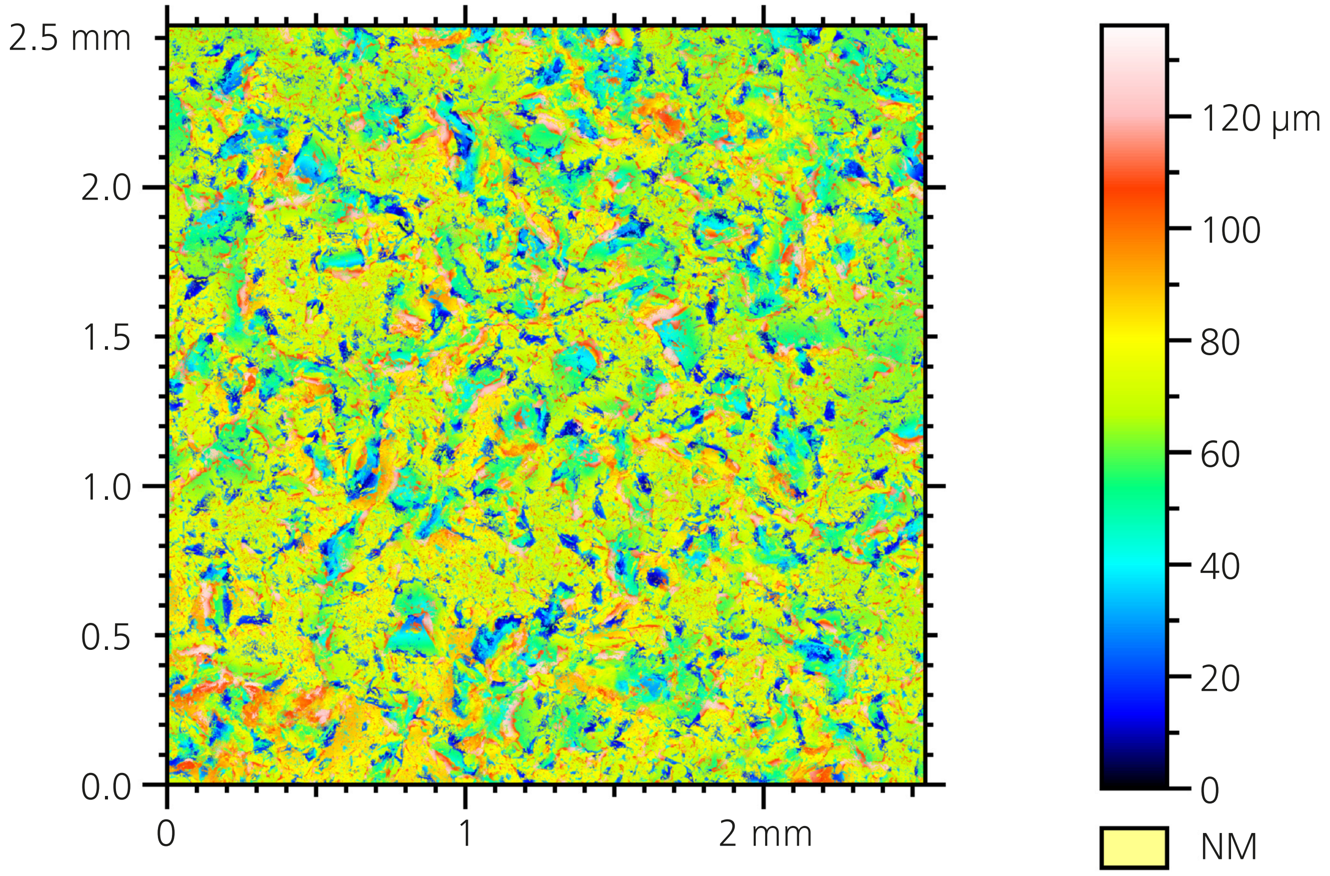


Assessing grit-blasted metal surfaces by confocal light microscopy and scanning electron microscopy

ZEISS Solutions for Metals

Assessing grit-blasted metal surfaces by confocal light microscopy and scanning electron microscopy

ZEISS Solutions for Metals

Author: Dr. Roger Barnett
Carl Zeiss Microscopy, Cambridge UK

Date: October 2017

Roughness governs the mechanical behavior exhibited at the interface between two materials, and controls many aspects of contact behavior – such as friction, wear, and lubricant retention. The strength of a bond between a coating and the substrate is significantly affected by roughness and cleanliness. The ability to non-destructively characterize a surface and understand its topography and roughness is, therefore, a powerful tool for understanding many aspects of surface behavior. Several samples of structural steel, stainless steel, and non-ferrous metal were grit blasted with alumina, using varying grit sizes. The surfaces were examined in detail using ZEISS LSM 800 and Smartproof 5 confocal light microscopes to obtain detailed 3D maps of each surface and assess roughness and topography. Information regarding the surface appearance and fraction of alumina grit embedded in the surface was obtained by electron microscopy using a ZEISS EVO 15 electron microscope with HDBSD detector. Particles of embedded grit were analyzed using ZEISS SmartPI software.

Introduction

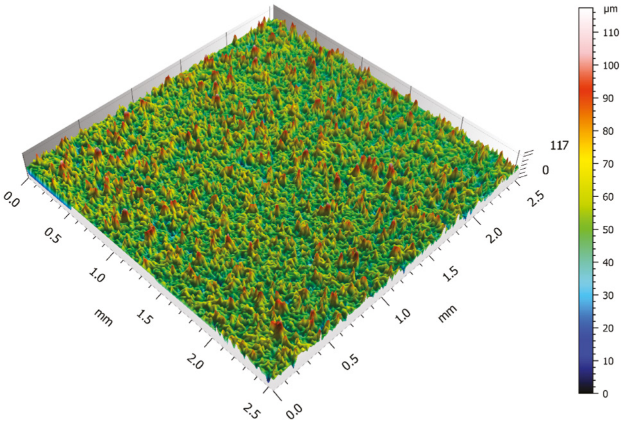
Grit blasting (or abrasive blasting) is the propelling of a stream of abrasive material against a surface, utilizing a high-pressure gas jet. The surface finish, surface topography, and surface roughness can be controlled by use of the correct abrasive material, dwell time, travel speed of the stream on the blasted surface, blast pressure, and other parameters.

The method is widely used and the applications of grit blasting are broad: removal of surface contaminants from fabricated components; surface preparation before painting, bonding or coating; roughening of surfaces prior to thermal spray coating; removal of burrs, surface roughening, or even providing a specified finish for cosmetic reasons.

A broad range of abrasive materials, offering differences of severity and particle size, are available. Options include alumina, silicon carbide, glass beads, walnut shells, copper slag and steel shot. The market for abrasive materials is estimated at over $260M in 2015 [1] (a figure which does not include the equipment required for blasting nor the total value of the blasted materials).

Control of roughness is key for most applications. Thermal spraying offers an example. A standard preparation step prior to thermal spraying is grit blasting. When depositing a coating on a metallic substrate by thermal spraying the adhesion is primarily due to mechanical keying. A roughened surface leads to higher coating-substrate bond strength. In contrast, when welding two components together, the bond is metallurgical rather than mechanical. Its strength is dependent on the material chemistry, microstructure, and the welding parameters.

Detailed characterization of the surface roughness and any embedded grit using ZEISS microscopy solutions is a necessity for understanding material behavior in critical industrial applications.



Grit Blasting of Reference Coupons

A series of coupons made from S355 structural steel, 304 stainless steel, copper, Inconel® 718, Ti-6Al-4V alloy, and ASTM F75 CoCr alloy were blasted using angular brown fused alumina (F80 grit, approximately 180 µm particles). Additional coupons of S355 structural steel and 304 stainless steel were blasted using different sizes of grit. TWI Ltd, a research and technology organization, developed a mechanized grit blasting facility. This was used to ensure consistency and control of parameters between runs. All blasting parameters besides material and grit size (e.g., blast pressure, stand-off distance, gun traverse speed, abrasive feed rate) remained constant between blasting runs. TWI Ltd supplied all coupons and carried out all blasting operations. All coupons were stored in airtight containers or desiccators between analyses to prevent corrosion and contamination (examples are shown in Figure 1).

Figure 1 *Example grit blasted coupons. Top: Ti-6Al-4V after blasting with F80 grit alumina. Bottom: 304 stainless steel after blasting with F60 grit alumina. Samples provided by TWI Ltd.*

Confocal Laser Scanning Microscopy for 3D Profilometry

The main feature of a confocal microscope is an aperture (pinhole), where using laser light in this confocal beam path and scanning in the X-Y plane generates an image where in-focus information is bright while out-of-focus information remains dark. By changing the distance between objective lens and sample, the sample is optically-sectioned and an image stack-generated. Intensity distribution of a single pixel through the image stack gives information on the corresponding height and allows generation of a height map and combined image.

Following cleaning with isopropyl alcohol to remove any handling contamination, thin strip areas (0.06 mm x 2.9 mm) were scanned using the ZEISS LSM 800 with a C Epiplan Apochromat 20x/0.7 lens and a 405 nm blue laser. These strips were suitable for determining R values (2D measures of roughness according to ISO 4287) by use of a polyline traversing back and forth across this strip. An automation routine was set up in ZEISS ZEN software to automatically focus and rapidly acquire strips from multiple samples sequentially without human intervention. Figure 2 shows an example strip.

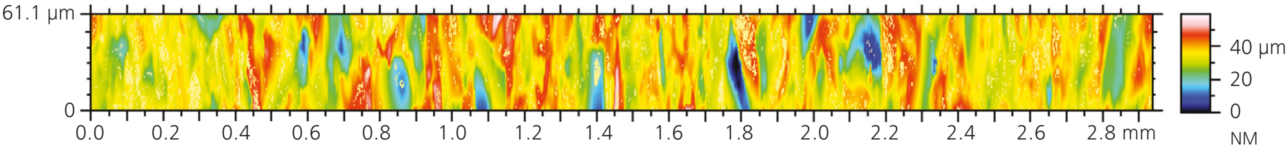


Figure 2 *Height map of S355 structural steel surface, blasted using F80 grit. Map taken using ZEISS LSM 800 with Epiplan Apochromat 20x/0.7 lens and 405 nm LED light source and 405 nm laser. Sample provided by TWI Ltd.*

We scanned a series of larger areas (2.5x2.5 mm) with a resolution better than 1.5 µm/pixel. Maps were captured using both a Smartproof 5 and a LSM 800 using an Epiplan Apochromat 20x/0.7 lens and a 405 nm LED light source and 405 nm laser, respectively (Figure 3). Automated routines were used within ZEISS ZEN software to automatically and sequentially capture relevant areas from several samples. A sufficiently large sampling area (and length) was selected to ensure a representative sample and for the correct application of the appropriate high-pass and low-pass filters (ISO 4287) for noise and waviness removal (Figure 4.)

Roughness Measurement

There are several ways to assess roughness. With sufficient resolution, measurement of height variations along a known sampling length leads to a 2D roughness profile curve. It is important to separate the waviness (average height difference over the sampled region) and form (overall shape of the sample) from the micro-scale roughness. This separation is carried out by applying a low-pass filter to remove noise, followed by a high-pass filter to remove the waviness, as specified in ISO 4287.

According to ISO 4287 there are many varieties of parameters determinable from this filtered curve, each of which quantifies a different aspect of the surface topography. Two of the most common are measurements of the surface amplitude Ra and Rz, where Ra is the mean deviation of the height from the average of all values and Rz is the sum of the maximum peak height and maximum valley depth over the sampled length. A single section of the filtered region may serve as the length to be assessed, or the profile can be taken from a multiple-segment line covering representative regions of the sample surface, as shown in Figure 5.

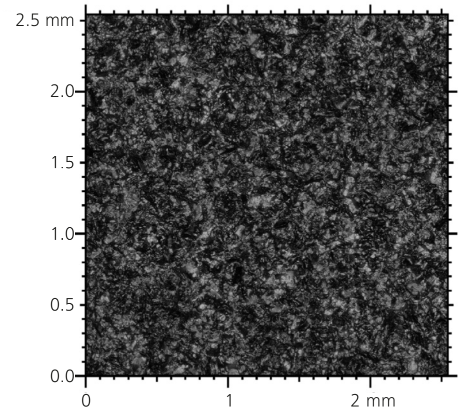


Figure 3 *304 stainless steel surface, blasted using F80 grit. Image taken using ZEISS Smartproof 5 with Epiplan Apochromat 20x/0.7 lens and 405 nm LED light source. Sample provided by TWI Ltd.*

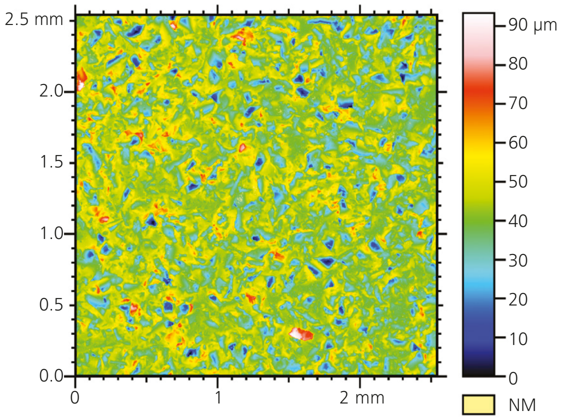


Figure 4 *Height map of S355 structural steel surface blasted using F60 grit, after application of a low-pass filter. Map taken using ZEISS Smartproof 5 with Epiplan Apochromat 20x/0.7 lens and 405 nm LED light source. Sample provided by TWI Ltd.*

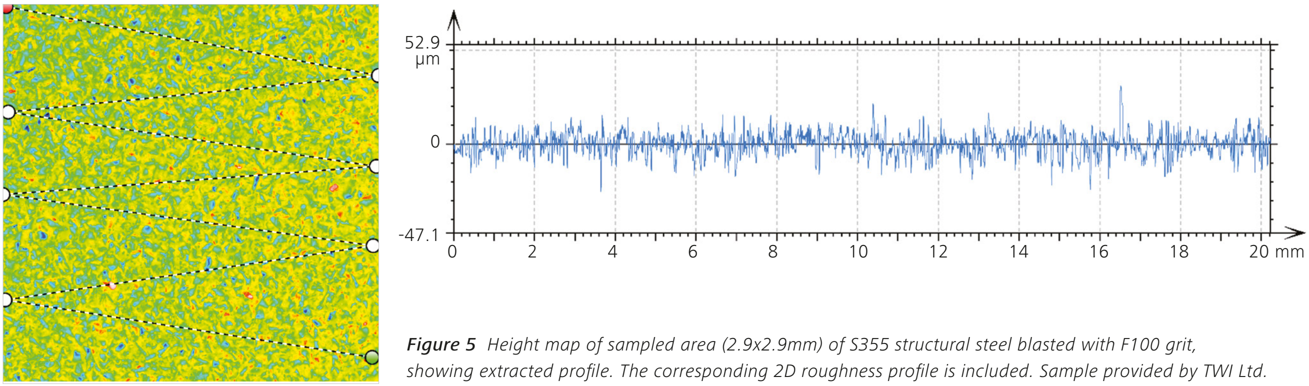


Figure 5 *Height map of sampled area (2.9x2.9mm) of S355 structural steel blasted with F100 grit, showing extracted profile. The corresponding 2D roughness profile is included. Sample provided by TWI Ltd.*

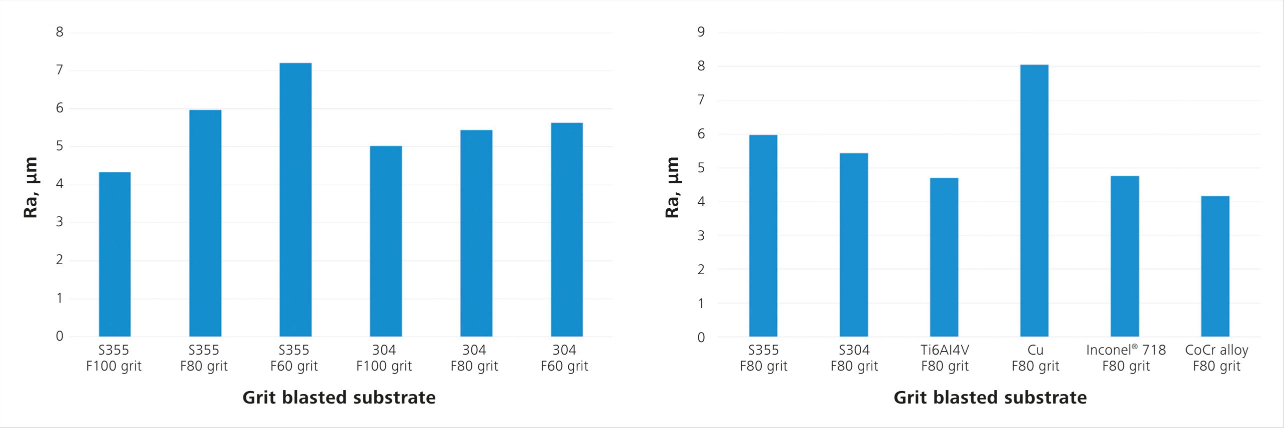
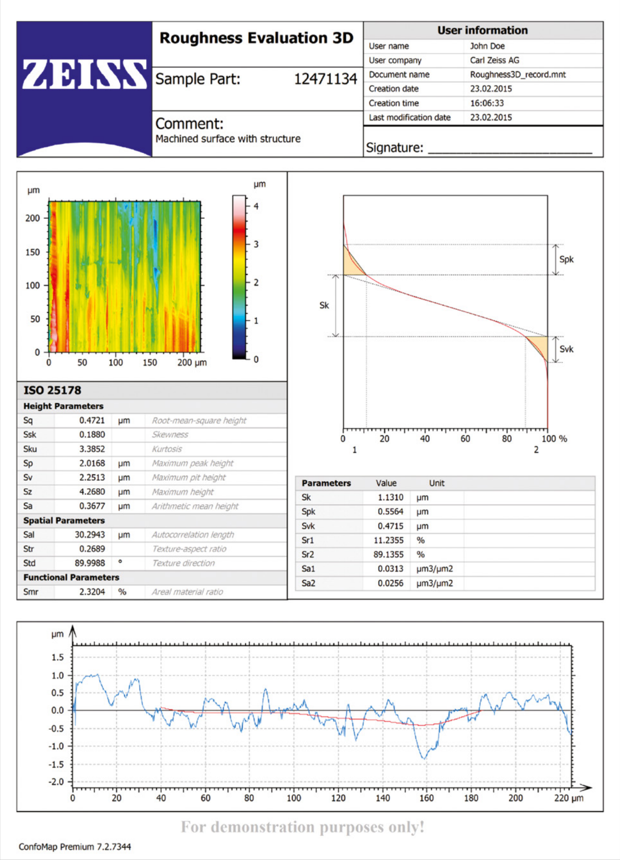


Figure 6 *Roughness (Ra) values for all assessed surfaces. Left - Influence of grit size on roughness. Right - Effect of substrate material on roughness. Samples provided by TWI Ltd.*

Compiling results from all samples assessed (Figure 6), and choosing Ra as a representative measure of the surface roughness, we observed several trends. The use of coarser grit leads to a rougher surface, as would be expected. The effect of coarser grit on roughness is reduced for 304 stainless steel, due to the harder substrate. When equivalent grit sizes are used, material hardness controls the observed roughness for softer materials (like copper), which display higher values of Ra.

Studying the height variation of an appropriate sampling area, rather than a sampling line, easily extends roughness measurements into 3D. Several 2D roughness parameters have 3D equivalents according to ISO 25718. For example, the parameter Sa is the mean deviation of all heights from the mean plane of the sampled surface. Similarly, Sz is the sum of the maximum peak height and maximum valley depth in a sampled area. The techniques can be applied to almost any surface, whether deliberately roughened or not. Measurements from a machined surface are given in Figure 7, assessed using Confomap software. Again, a sufficiently large sampling area must be selected to ensure a representative sample and also for application of the relevant high-pass and low-pass filters to remove both noise and waviness.



Roughness Evaluation 3D

Sample Part: 12471134

Comment:
Machined surface with structure

User information	
User name	John Doe
User company	Carl Zeiss AG
Document name	Roughness3D_record.mnt
Creation date	23.02.2015
Creation time	16:06:33
Last modification date	23.02.2015

Signature: ____________________

ISO 25178			
Height Parameters			
Sq	0.4721	µm	*Root-mean-square height*
Ssk	0.1880		*Skewness*
Sku	3.3852		*Kurtosis*
Sp	2.0168	µm	*Maximum peak height*
Sv	2.2513	µm	*Maximum pit height*
Sz	4.2680	µm	*Maximum height*
Sa	0.3677	µm	*Arithmetic mean height*
Spatial Parameters			
Sal	30.2943	µm	*Autocorrelation length*
Str	0.2689		*Texture-aspect ratio*
Std	89.9988	°	*Texture direction*
Functional Parameters			
Smr	2.3204	%	*Areal material ratio*

Parameters	Value	Unit
Sk	1.1310	µm
Spk	0.5564	µm
Svk	0.4715	µm
Sr1	11.2355	%
Sr2	89.1355	%
Sa1	0.0313	µm3/µm2
Sa2	0.0256	µm3/µm2

For demonstration purposes only!

ConfoMap Premium 7.2.7344

Figure 7 *Example 3D roughness measurements of machined surface with structure, according to ISO 25178.*

Embedded Grit

Grit blasting leads to a roughened surface, with the topography determined by the blasting media and parameters. A certain fraction of the blasting media may embedinto the surface during blasting, either as complete particles or more commonly as smaller fragments. This incidence of embedding can lead to the formation of local crevices and can affect corrosion behavior, crack initiation, coating adherence, and several other factors. Understanding the amount, size, and shape of the embedded grit is critical. The blasted surfaces were cleaned with isopropyl alcohol to remove any contamination from handling or atmospheric exposure and then examined using a ZEISS EVO 15 electron microscope. The HDBSD detector was used to enhance contrast between the embedded alumina (dark) and the metal (light). Figure 8 shows an example.

Using the backscattered electron images and associated EDS data, a representative area was examined using the ZEISS SmartPI software. This technique allows automatic identification of particles for analysis. An example is shown in Figure 9 with particles color-coded according to their size. A table of some typical results is displayed in Figure 10.

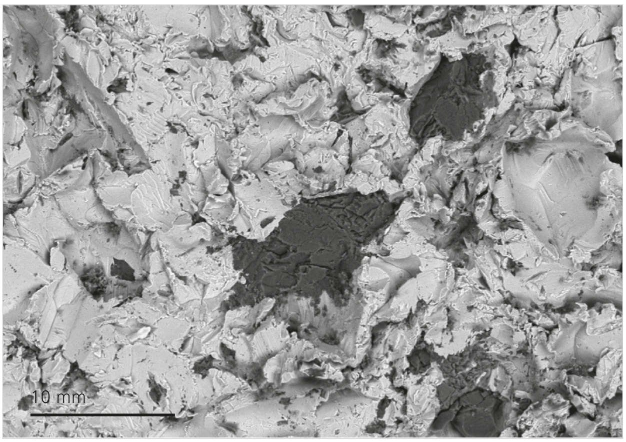


Figure 8 Surface of S355 structural steel examined using ZEISS EVO 15 electron microscope with HDBSD detector. The embedded alumina grit is clearly visible. Sample provided by TWI Ltd.

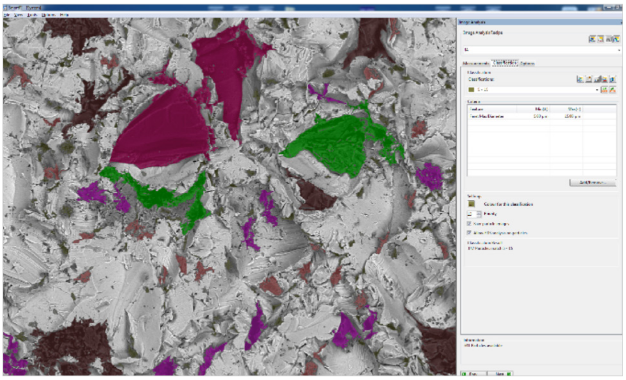


Figure 9 Using SmartPI for segregation of alumina particles on the surface of S355 structural steel after grit blasting with F80 grit. Sample provided by TWI Ltd.

Particle ID	Area (µm²)	Feret Max (µm)	Feret Mean (µm)	Compactness
324	213.12	25	21.73	7.98
156	127.22	26.28	20.15	15.16
127	296.34	27.5	24.06	13.81
153	240.06	27.59	24.46	12.56
194	149.52	28.08	23.46	19.55
286	146.82	29.22	23.08	9.66
290	307.41	30.6	27.07	7.85
163	190.08	31.85	24.73	13.88
64	106.26	37.43	26.73	17.05
316	195.91	40.41	28.51	14.1
282	260.12	42.89	30.52	8.24
308	367.88	43.51	34	25.22
136	538.5	52.07	40.8	10.4
7	838.73	58.38	49.28	7.29
2	979.42	63.12	49.45	10.56
287	1043.77	72.92	54.02	11.01
45	827.8	81.12	60.89	31.47
295	2338.84	87.31	73.69	27.97
134	1258.1	103.28	79.9	30.72
79	2711.36	111.42	86.11	35.35
3	6939.43	172.6	132.8	23.9

Figure 10 Particle size and shape data for all particles >25 µm diameter in the view shown in Figure 9. Compactness is calculated as (Diameter / Maximum Diameter) and relates to roundness. A compactness of 1 indicates a circular feature. Sample was provided by TWI Ltd.

The SmartPI software package allows determination of a wide range of information for each particle. Available information includes chemical composition, Feret diameter, area, and almost all standardized size or shape parameters. These data points can be segregated and classified according to specifications freely definable by the user.

Conclusion

The size of grit used during blasting strongly affects the roughness of the prepared surface, but the magnitude of this effect varies depending on the substrate material. Softer substrates (e.g., copper) have rougher surfaces than harder substrates when following the same blasting operation with the same abrasive material.

Rapid, precise, and accurate measurement of these roughened surfaces was made possible by a combination of optical and scanning electron techniques. ZEISS confocal microscopes facilitated quantitative measurements of surface topography parameters and ZEISS scanning electron microscopes allowed detailed assessments of surface damage. Embedded grit, surface deformation, voids, and crevices were all made clearly visible. The above techniques, combined with ZEISS software solutions can be used to understand and obtain quantitative information about almost any surface features and aid productivity and process development.

References

[1] Sandblasting Media Market Size By Product (Aluminium Oxide, Silicon Carbide, Steel Grit, Steel Shot, Glass, Sodium Bicarbonate, Corn Cob, Staurolite, Coal Slag, Copper Slag, Silica/Si Sand, Garnet), Industry Analysis Report, Regional Outlook (U.S. [Gulf Coast], UK, Germany, China, Brazil, UAE, Saudi Arabia), Application Potential, Price Trends, Competitive Market Share & Forecast, 2016 – 2023, July 2016, Global Market Insights Report GMI514

EN_42_013_245 | CZ 11-2017 | Design, scope of delivery and technical progress subject to change without notice. | © Carl Zeiss Microscopy GmbH

Carl Zeiss Microscopy GmbH
07745 Jena, Germany
microscopy@zeiss.com
www.zeiss.com/microscopy