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Note

Tablet surface characterisation by various imaging techniques

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Abstract

The aim of this study was to characterise tablet surfaces using different imaging and roughness analytical techniques including optical microscopy, scanning electron microscopy (SEM), laser profilometry and atomic force microscopy (AFM). The test materials compressed were potassium chloride (KCl) and sodium chloride (NaCl). It was found that all methods used suggested that the KCl tablets were smoother than the NaCl tablets and higher compression pressure made the tablets smoother. Imaging methods like optical microscopy and SEM can give useful information about the roughness of the sample surface, but they do not provide quantitative information about surface roughness. Laser profilometry and AFM on the other hand provide quantitative roughness data from two different scales, laser profilometer from 1 mm and atomic force microscope from 90 μm scale. AFM is a powerful technique but other imaging and roughness measuring methods like SEM, optical microscopy and laser profilometry give valuable additional information.

Keywords: Laser profilometer; Atomic force microscope (AFM); Scanning electron microscopy (SEM); Tablet; Surface roughness

Optical microscopy and scanning electron microscopy (SEM) give an accurate image of the surface but they do not produce quantitative information about surface roughness. Surface roughness is an important factor, for example, in tablet coating, absorption and in particle–particle interactions. One of the surface roughness measurement methods is laser profilometry, which has previously been used with pharmaceutical compacts and pellets as a means of evaluating differences in roughness (Podczeck, 1998; Riippi et al., 1998; Newton et al., 2001).

In recent years the atomic force microscope (AFM) has become well established in powder technology. The AFM has been used to image the surfaces of various organic crystals (Danesh et al., 2000; Ward, 2001; Trojak et al., 2001). AFM also has very good resolution in organic samples compared to SEM and the optical microscope. Lateral (*X*–*Y* plane) resolution can be as good as 1 nm and height resolution about 1 Å. AFM data is a matrix of data points, which enables quantitative roughness and height measurements (Luo et al., 2001). The disadvantages of AFM are the small measurement area, slow speed and the need for flat samples.

The purpose of this study was to compare four different imaging techniques using smooth tablet surfaces made of potassium chloride (KCl) and sodium chloride (NaCl).

Test materials were analytical-grade NaCl and KCl (Riedel-de Haën, Germany). Tablets were compressed with a 13 mm evacuable IR tablet die (Specac

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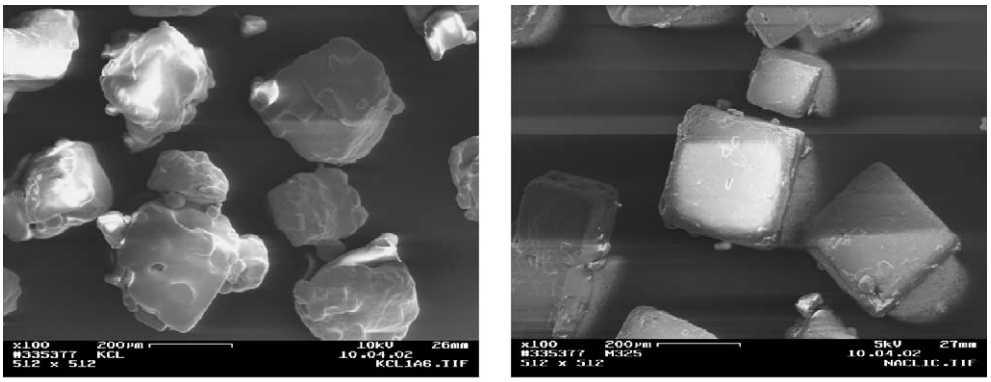

(a) (b)

Fig. 1. SEM micrographs of powders (a) KCl and (b) NaCl.

Ltd., United Kingdom) and a hydraulic press (Pye Unicam, United Kingdom). The compression forces were 30 and 80 kN and the compression time was 2 min with vacuum suction. Corresponding compression pressures were 225 and 600 MPa. Overall view of the tablet surfaces was taken by optical microscope (Leica DMLB, Leica Microskopie & Systeme GmbH, Germany) and a SEM (Zeiss DSM 962, Germany). Test materials were imaged by SEM in order to determine particle size and morphology.

Millimeter scale areas of the tablet surfaces were measured by a laser profilometer (UBM Microfocus Measurement System, UBM Messtechnik GmbH, Ettlingen, Germany), which was used to image and measure roughness of the tablet surfaces. The measurement range was $\pm 50\,\mu m$, the laser spot size was $1\,\mu m$ and the resolution was 1000 points/mm using image sizes 1 mm × 1 mm and 2 mm × 2 mm. Roughness parameters average roughness (Ra), the root mean square roughness (Rrms) and the peak to valley height (Rp–v) were calculated from 1 mm × 1 mm images ($n = 3$) and laser profilometer images 2 mm × 2 mm were drawn from data files using Mathematica 4.0 software (Wolfram Research, USA). AFM (Autoprobe CP, Thermomicroscopes, USA) was used to image the microstructure of the tablet surfaces from $10\,\mu m \times 10\,\mu m$ and $90\,\mu m \times 90\,\mu m$ areas. The surface roughness was calculated from $90\,\mu m \times 90\,\mu m$ areas. AFM imaging was performed in tapping mode with a cantilever which had a spring constant of the 3.0 N/m (Silicon cantilever NSCH11A, NT-MDT Ltd., Russia). AFM imaging was carried out in normal room conditions using a large area scanner ($100\,\mu m$ lateral scan size).

The particle sizes of the test materials were evaluated by SEM. Both test materials had a particle size around $250\,\mu m$ (Fig. 1a and b). NaCl particles had an obvious clear cubic crystal habit, whereas KCl particles were more irregular. The particle size and shape of the original test materials were still visible on the optical microscope and SEM images of the tablet surfaces (Figs. 2a–d and 3a–d). Both techniques showed that the smoothest tablet was the 80 kN KCl tablet (Figs. 2a and 3a). With both materials the lower 30 kN compression force yielded rougher tablets. This supports the earlier findings that a higher compression force usually produces smoother tablets (Rowe, 1979; Podczeck, 1998; Riippi et al., 1998).

Many features visible in the optical microscopy images were also visible in laser profilometer images (Fig. 4a–d). The laser profilometer showed that the "particle" areas were not at the same height level with each other. Laser profilometer images support the findings of optical microscopy and the SEM that KCl and higher compression pressure yielded smoother tablets (Podczeck, 1998; Riippi et al., 1998). There were some areas on the 30 kN NaCl tablet, which were not properly imaged by the laser profilometer (Fig. 4d). These image defect areas existed at the particle border areas. The image defects were caused by poor laser beam reflection from the tablet surface, a problem which affects to the height data and thus the reliability of the data.

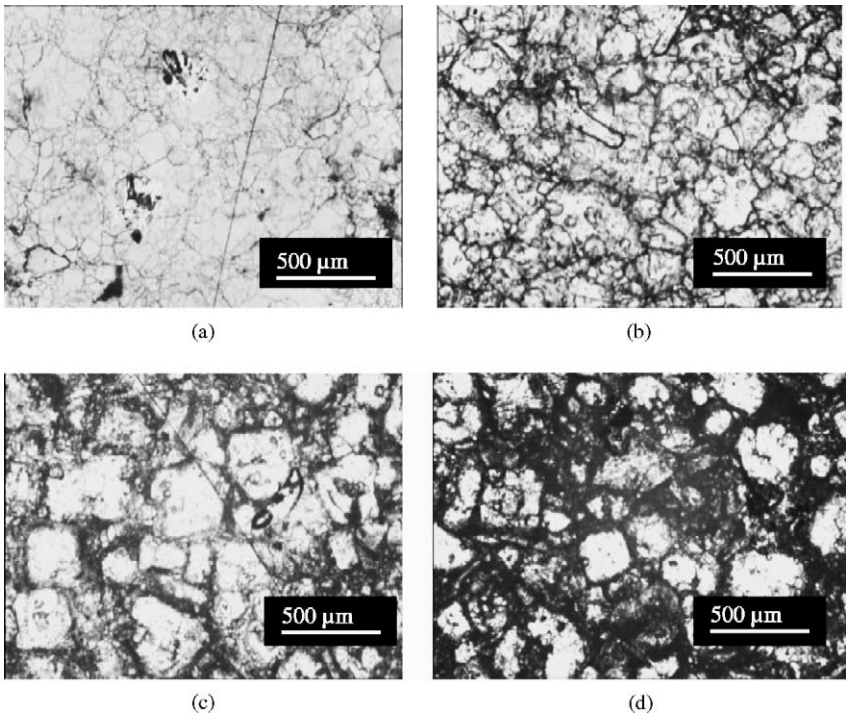

Fig. 2. Optical microscope images of the tablets (a) 80 kN KCl, (b) 30 kN KCl, (c) 80 kN NaCl, (d) 30 kN NaCl.

AFM imaging was done on a chosen flat area in order to get as big an image as possible. The best areas to image were the faces of the large "particles". In the case of the 30 and 80 kN KCl tablets borders between particles were smoother in the NaCl tablets. Increasing compression pressure made the KCl and NaCl tablets smoother and less porous (Fig. 5a–d). The characterisation of tablet surfaces in the literature has not been widely discussed but it has been shown that increasing compression pressure could yield smoother tablet surfaces (Sindel and Zimmermann, 2001; Muster and Prestige, 2002). Surface features on the 80 kN KCl tablet were very smooth and had round shapes but the surface shapes of the 30 kN tablet were much sharper and the surface was much rougher (Fig. 5a and b). The situation with NaCl tablets seemed to be quite similar to the KCl tablets (Fig. 5c and d). According to the literature with NaCl there is a decrease in porosity between 225 and 600 MPa compression pressures (compression forces 30 and 80 kN) (Adolfsson and Nyström, 1996). With 600 MPa compression pressure NaCl is very close to the zero porosity. The 80 kN NaCl tablet was smoother and its surface was full of layer structure which might be due to recrystallisation of the NaCl. The NaCl tablet compressed with lower pressure also had large cracks on its surface which reflects the greater roughness and porosity.

Laser profilometer roughness values suggested that KCl tablets were smoother than NaCl tablets (Table 1). It can also be concluded that higher compression pressure decreases the roughness of the tablets, which has already been shown with other materials (Podczeck, 1998). Ra values of the KCl tablets were smaller than

Table 1
Laser profilometer roughness parameters of 1 mm × 1 mm areas of tablets (mean ± S.D., $n = 3$)

Tablet (kN)	Roughness parameters		
	Ra (µm)	Rrms (µm)	Rp–v (µm)
KCl 80	0.20 ± 0.02	0.43 ± 0.31	24.6 ± 22.1
KCl 30	0.26 ± 0.02	0.43 ± 0.07	31.4 ± 7.2
NaCl 80	0.33 ± 0.03	0.46 ± 0.02	17.7 ± 3.6
NaCl 30	0.63 ± 0.25	1.67 ± 0.81	66.5 ± 20.2

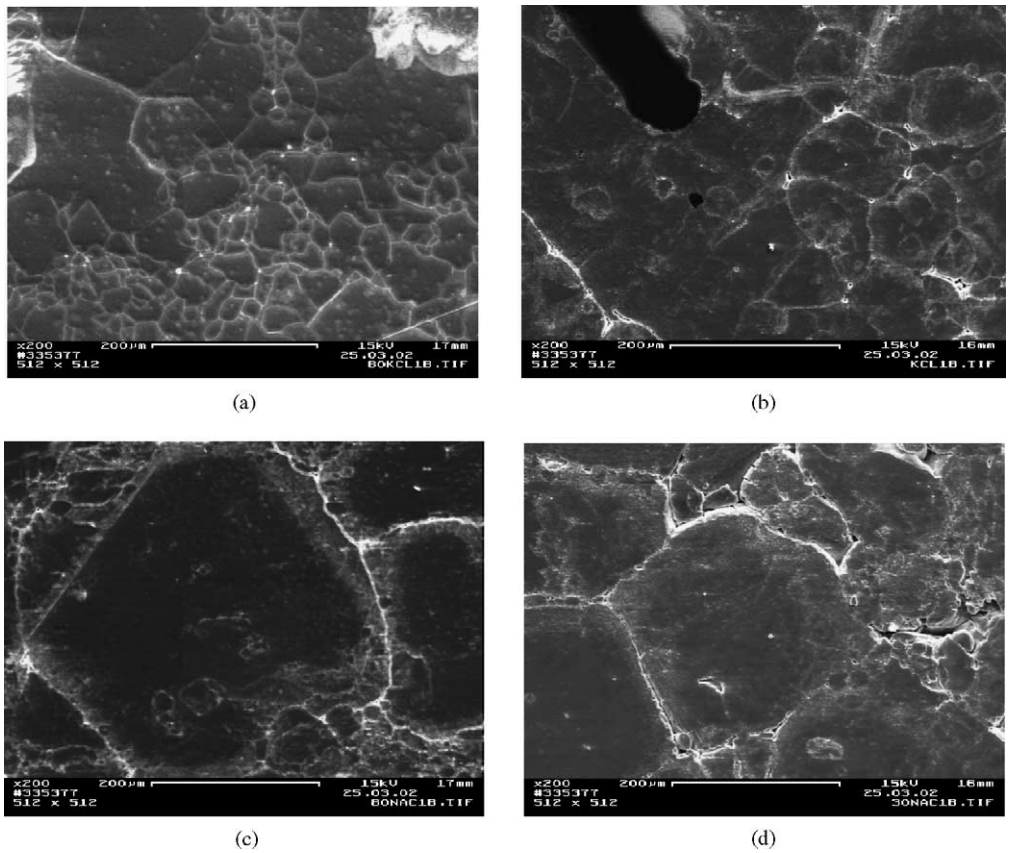

Fig. 3. SEM micrographs of the tablets (a) 80 kN KCl, (b) 30 kN KCl, (c) 80 kN NaCl, (d) 30 kN NaCl.

the Ra values of the NaCl tablets compressed with the same compression pressure (Table 1). In the Rrms values differences are negligible except in the case of 30 kN NaCl tablet which was three times larger than the others. Variations in Rp–v values were large and the results overlap each other. Therefore, Rp–v values of the laser profilometer did not give good reliable information about the roughness. The difference in all the roughness values between KCl 80 and KCl 30 kN tablets was statistically negligible. On the other hand, there was statistical difference between the Ra and Rrms values of the 30 and 80 kN NaCl tablets. The difference in Ra and Rrms values between KCl 30 kN and NaCl 80 kN tablets were small, but larger than between KCl 80 kN and KCl 30 kN tablets. The reflection problems with the 30 kN NaCl tablet surface already mentioned caused some error points in the height data. The error points increased the roughness of the 30 kN NaCl tablet since one of the areas measured had markedly larger Ra value (0.92 μm) than the other two (0.48 and 0.49 μm). Images drawn from the profilometer data helped in finding these reflection points. The roughness measured by the laser profilometer mainly reflects the roughness caused by the powder particles and their deformation under compression.

Since AFM measures roughness in a very small area such measurements should always be viewed with extreme caution. In this case the roughness was measured on a 90 μm × 90 μm flat areas ($n = 4$) on the tablet surface. These areas were on the top of "particles" which were visible on the surface. AFM roughness values suggested that KCl tablets were smoother than NaCl tablets as in the case of the laser profilometer (Table 2). Again, it can be concluded, that higher compression pressure decreases the roughness of the surface. Peak to valley values measured with AFM

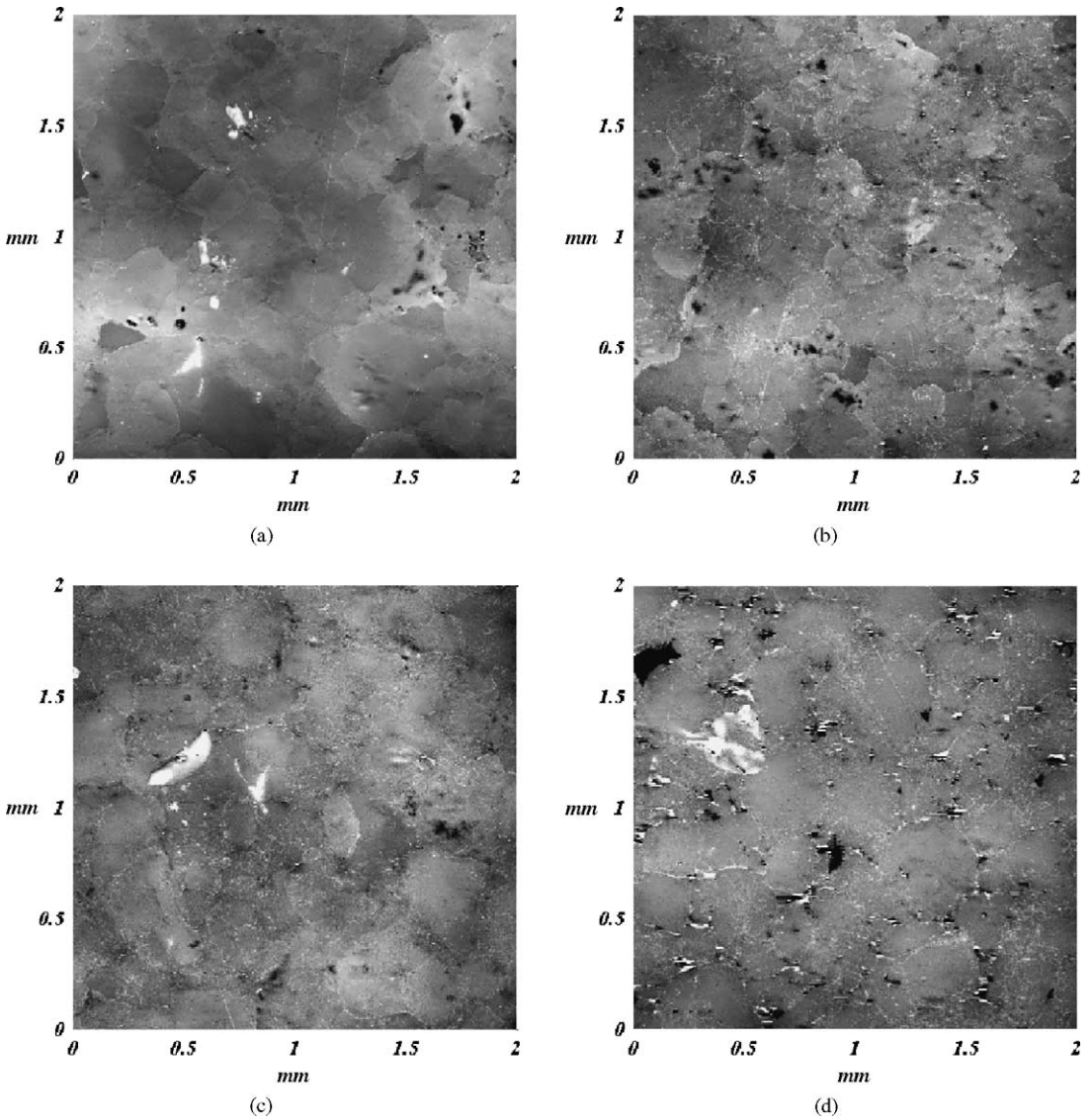

Fig. 4. Laser profilometer micrographs of the tablets (a) 80 kN KCl, (b) 30 kN KCl, (c) 80 kN NaCl, (d) 30 kN NaCl.

Table 2
AFM roughness parameters of 90 μm × 90 μm areas of tablets (mean ± S.D., $n = 4$)

Tablet (kN)	Roughness parameters		
	Ra (nm)	Rrms (nm)	Rp–v (nm)
KCl 80	9.71 ± 1.1	14.3 ± 0.1	319 ± 28
KCl 30	19.0 ± 0.4	26.8 ± 1.9	563 ± 120
NaCl 80	16.8 ± 1.4	25.7 ± 2.4	531 ± 97
NaCl 30	22.7 ± 2.6	38.9 ± 0.9	1190 ± 390

seemed to give similar results than the Ra and Rrms values. The result in Rrms and Rp–v values between KCl 30 kN and NaCl 80 kN tablets overlap, but there was small difference between the Ra values. Since the AFM measurements were made on the top of the particles, the AFM roughness data reflects the roughness of single crystalline particle and its deformation under the compression, not the roughness of the whole tablet.

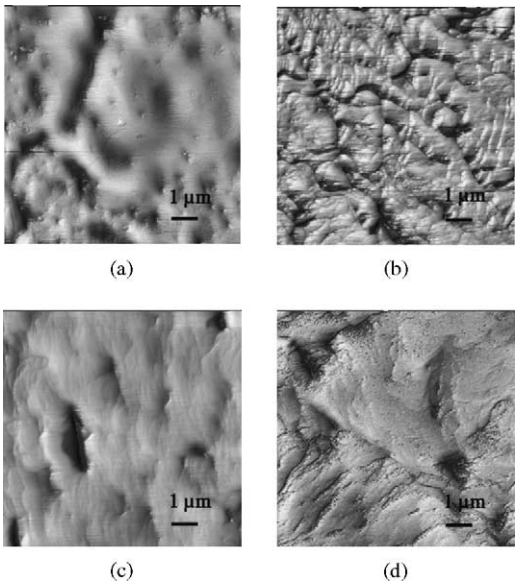

Fig. 5. AFM micrographs of the tablets. (a) 80 kN KCl tablet measurement area 10 μm × 10 μm, height 100 nm. (b) 30 kN KCl tablet measurement area 10 μm × 10 μm, height 320 nm. (c) 80 kN NaCl tablet measurement area 10 μm × 10 μm, height 300 nm. (d) 30 kN NaCl tablet measurement area 10 μm × 10 μm, height 350 nm.

Although there are many new imaging techniques available, optical microscopy is still a very efficient technique, which yields information that the SEM and AFM are not able to provide. Roughness measurements complement the image data and give quantitative information about height differences. The laser profilometer roughness data reflects the roughness of the whole tablet and AFM roughness data the roughness of single crystalline particle. AFM is a powerful technique, but other imaging and roughness measuring methods like SEM, optical microscopy and laser profilometry offer additional valuable information.

Acknowledgements

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