CHARACTERIZING SURFACE ROUGHNESS BY FOURIER TRANSFORMATION

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Introduction

The surface structure of twin roll cast aluminium sheet, and its development through cold rolling is important for the quality of the final surface structure of the sheet. Every stage in the cold rolling process involves a specific change in the surface topology. This is caused by the thickness reduction, and in particular the general interfacial sliding. The specific effect on the surface structure is given by the surface structure and topology of the rolls, together with the lubricant film thickness and the friction conditions in the roll gap.

To be able to understand and control the evolution of surface structure through the cold rolling it is important to characterize the surface in a relevant and tailored manner. An important mean to achieve this, is to characterize the topology of the surface both statistical and microstructural, and in particular find relevant quantitative parameters which describe the change in surface characteristics of specific importance.

The present work has chosen to combine the imaging and measuring of surface topology made possible with the confocal technique available in the laser scanning microscope (LSM), with a Fourier transform of the confocal image. This give both topographical images of the surface which yield microstructural information, and Fourier spectra which collects comprehensive statistical information of the same area.

Experimental techniques

There are two essentially different stages in the description of a surface. The first is the imaging and measuring of the surface topology. The other is the calculation of parameters describing the topography and the systematical trends, related to specific topographical features of interest.

By imaging the surface in the LSM the problems of traditional roughness measurements are overcome, because there are no physical contact with the surface and there are an improved resolution due to the confocal technique avaliable in the LSM [4].

The confocal technique take advantage of the synchronical scanning of both a point source and a point detector, where the point source is focused on a very small area of the specimen and the point detector ensures that only light from this area is detected [4].The point detector also discriminate with respect to depth as shown in figure 1 [4], which illustrates how only information from the focal plan of the objective lense is detected.

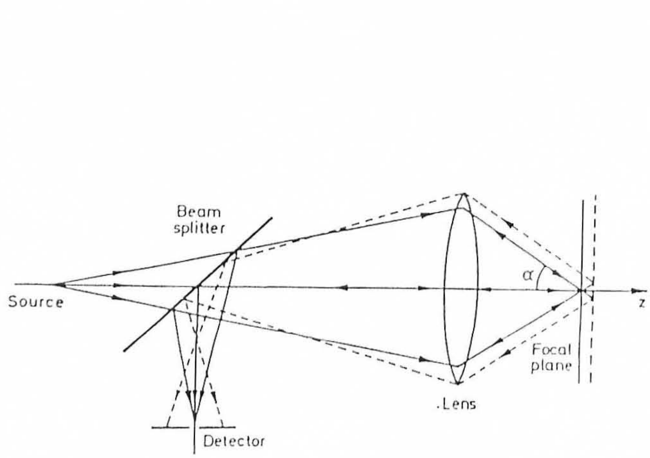


Figure 1: Sketch of the beam path in the confocal mode of the LSM which give the depth discrimination.

The laser beams reflected from the specimen is scattered through the objective lense and by the beam splitter such that only the beams from the focal plane is focused in the point detector. Other beams reach the point detector unfocused which means that strong signals from out of focus planes will not contribute to the detected signal. Thereby unwanted information outside the focal plane of the objective lens is discriminates and only a small axial interval of the specimen is imaged. A three dimensional representation of the surface topology is obtained by imaging a series of axial intervals and by image analysis add them together.

The quantification of the topography with traditional methods are typical in terms of the mean height distribution (CLA), the maximum peak to valley distance or Abbot curves (bearing length ratio) [1]. However, useful information about the distances between peaks, shape of the profile or directionality of the topology are lacking [3].

By combining the fast Fourier transform (power spectrum) and the 3D images of the LSM we get a statistical description of the surface features, which is supplementary to the traditional roughness parameters. The different elements of the spectrum is tried illustrated by a simple surface profile and is given in figure 2. The different wavelengths present in the profile is represented by the peaks of the spectrum. There are a three relatively large peaks at 33, 36 and 43μm, and we recognize that several of the smaller features in the profile are of this size. There are also a distinct peak at 22μm, which is easily found in the profile. Higher order peaks will normally occur since the new fluctuations will appear and the shape of the profile be matched. This can to some extent confuse the interpretation of the spectrum. However, the number and amplitude of the higher order peaks contain information of the shape of its wavelength or new wavelength. An example that a sinusoidal period will have no higher order peaks, while a square period of the same length will have components of all odd number high order. The information about directionality of the topology in real space is given by its normal in Fourier space.

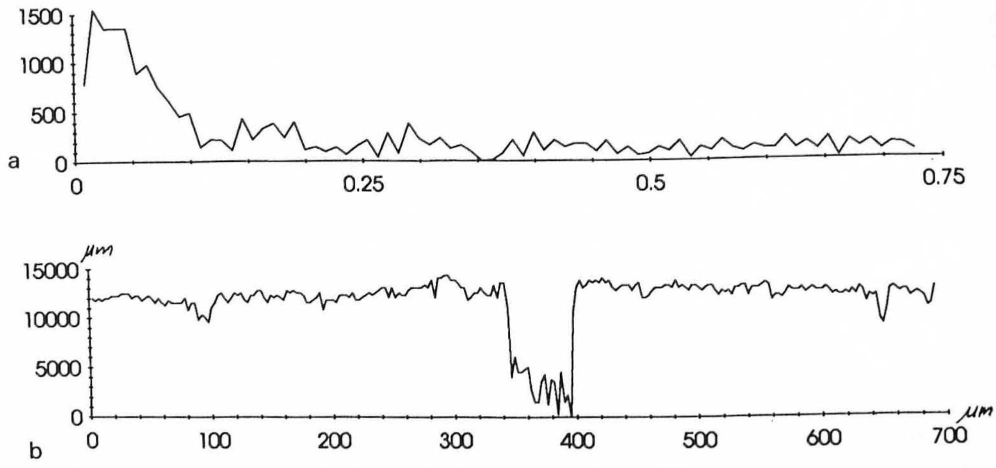


Figure 2: Example of a)Fourier spectrum from b)the single trace.

Experimental results and discussion

The LSM is superior to the other techniques by a the high lateral and axial resolution. Figure 3 show a comparison of a profilometer track and a 2D trace from the LSM of the same specimen, and we see that the resolution of the profilometer profile is lower than on the profile from the LSM. This is due to the high degree of smoothing of the profile by the stylus tip as it moves across the surface. Both the lateral and the axial resolution of the profilometer depends on the tip radius. While for the LSM profile it is given by the wavelength (λ) of the laser used and the numerical aperture (NA) of the objective lens. The lateral resolution (d_l) [4] is given by

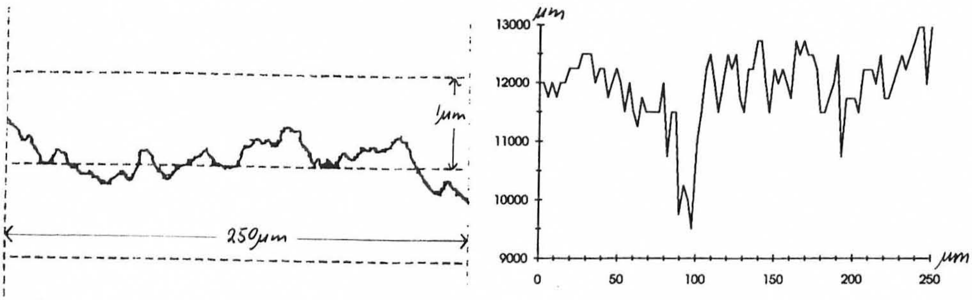
$$d_l = \frac{1.22\lambda}{NA_{obj} + NA_{cond}} \tag{1}$$

and the axial resolution (d_a) [4] is approximated by

$$d_a = 2d_l \tag{2}$$

By adjusting the wavelength of the laser or choosing an objective lens with a different numerical aperture it is possible to get a high lateral resolution for each specific purpose. The best resolution achievable in the LSM on rough surfaces is d_l=250nm and d_a=500nm. The difference in ideal resolution is also demonstrated as narrow cracks show up on the LSM profile, which are not seen in the profile from the profilometer (figure 3). This is caused by the stylus tip which can not follow cracks more narrow than its tip radius.

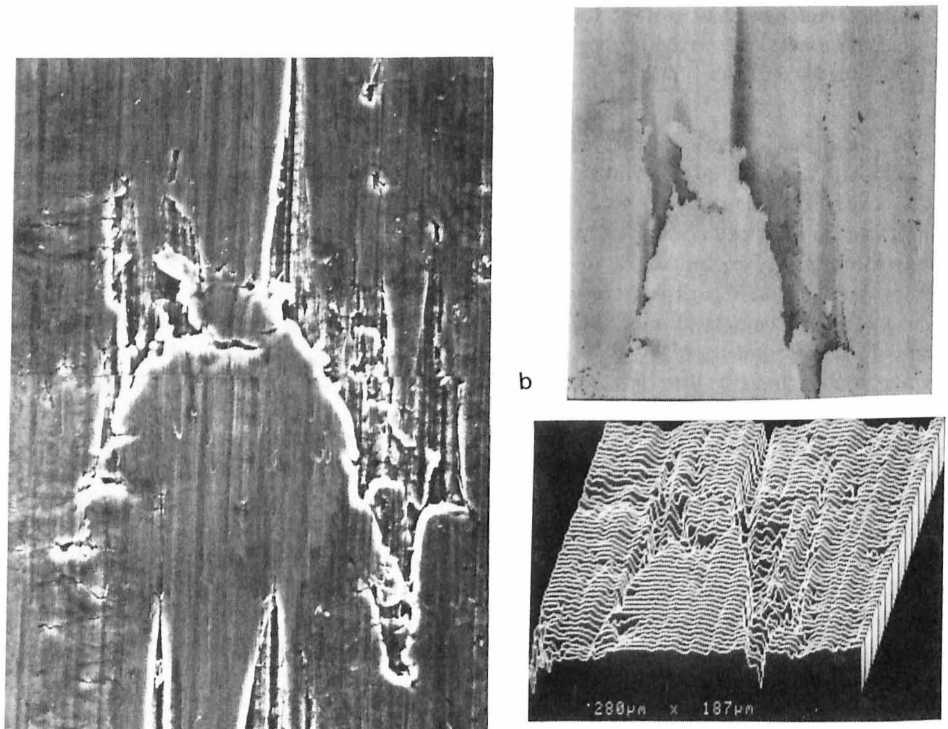
There are different ways to present the information gained from topography measurements. The most used options in the LSM are the image of extended depth of focus



a

b

Figure 3: Profiles from both a) the profilometer and b) the LSM.



b

c

a

Figure 4: Representation of the surface roughness measurements from the LSM as a)SEM image, b)grey scale image and c)3D-image.

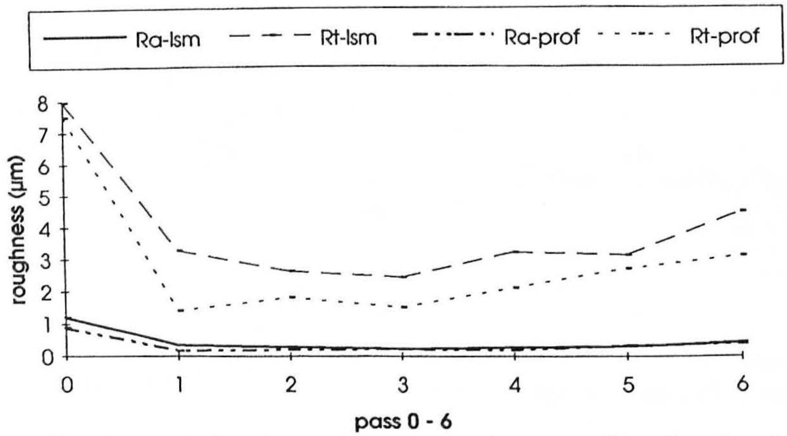


Figure 5: Development of surface roughness normal to the rolling direction through the cold rolling process represented by traditional roughness parameters, calculated from both the profilometer and the LSM.

(EDF), the three dimensional (3D) image and the grey-scale image (figure 4). Since the LSM also can be operated in a traditional mode, topography can be measured in carefully chosen areas [2]. This together with the fast visualization of specific surface features and the high resolution, the LSM present a tool which ease the detailed characterization and visualization of surface topology.

However, the LSM soft-ware give today only the traditional roughness parameters where statistical aspects of only the height distribution for a given trace or area can be found. The information of lateral distribution is available, which open the opportunity to statistically quantify these elements with repeat to regular spacings, their shape and variations within these.

Calculation of the traditional roughness parameters from both the profilometer and the LSM show clear difference in the parameters. Figure 5 show the mean height distribution (R_a) and the maximum peak to valley distance (R_t) calculated for the different passes of cold rolling of a twin roll cast aluminium sheet. The LSM parameters are slightly larger than the data from the profilometer for both R_a and R_t, this can be caused both by the deformation of the surface by the profilometer stylus tip or the finite radius of the stylus tip, which give a limited resolution of the profilometer compared to the LSM. This give that the quality of the parameters is increased by the LSM due to the improved resolution.

As seen in figure 5 both R_a and R_t decreases dramatically in the first pass of cold rolling, and increase again in the few last ones, but we need to analyze the surface features responsible for these changes? By introducing the Fourier transformation of the digitized image of the topographic map, a statistical description of the lateral features is possible. The Fourier spectra transversal to the rolling direction (figure 6) is used in this example since the strongest topography variations are in this direction. Only the first few passes of cold rolling is used to demonstrate the potentials of the method.

The different peaks of the transversal spectra (figure 6), correspond to the magnitude

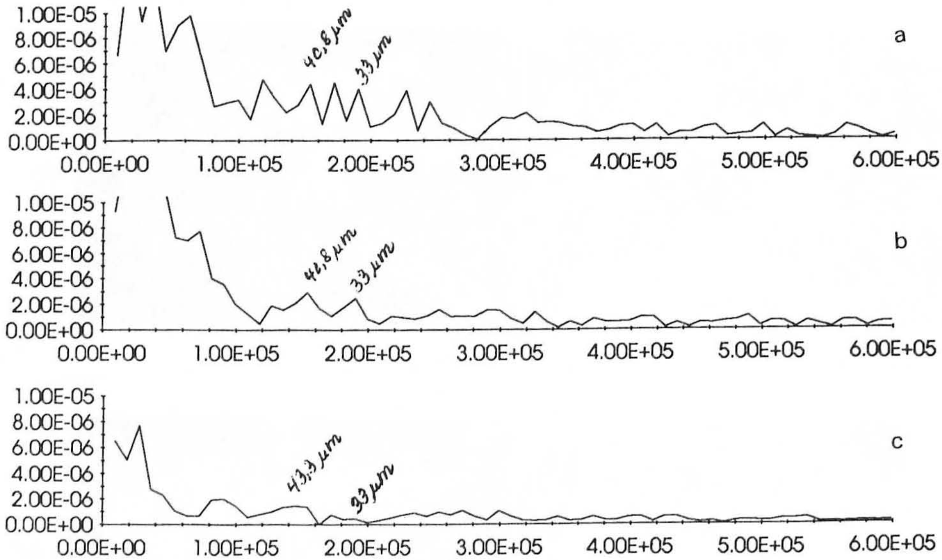
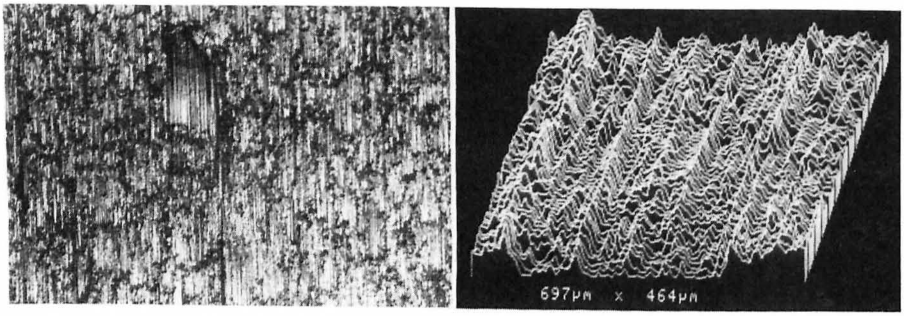


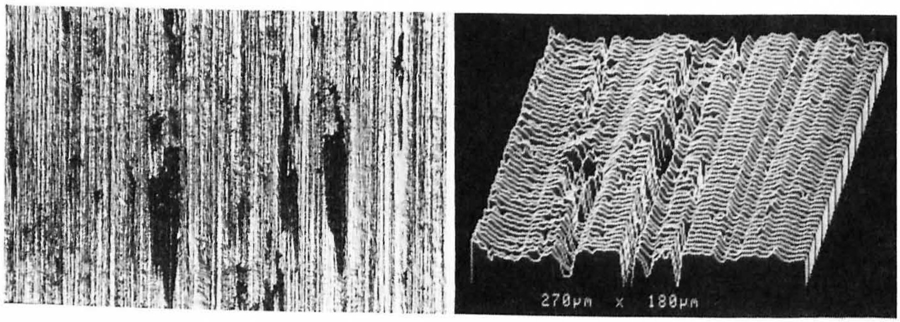
Figure 6: Fourier spectra of the first few passes of cold rolling of aluminium sheet. a)initial sheet, b) first pass and c) second pass.

of the different wavelengths or periods normal to the rolling direction, and each surface have a characteristic spectrum. In the transversal spectrum of the zero pass (figure 6a) we see that wavelengths between 35 and 80μm have relatively large amplitudes. By comparison of this with the optical micrographs and 3D images in figure 7 we see that this is the typical width of the large pickup grooves of the as cast surface. The pickup grooves are deformed into gorges [2] in the first rolling pass where the width of the gorges is about the same as of the pickup grooves. The transversal spectrum of the first pass show that only the lower range of wavelengths (35–40μm) are preserved, which indicates that only more narrow pickup grooves survive from the zero to the first pass. There are two dominating periods in this area (40.8μm and 33μm) and their amplitude are 3 10^{-6} and 2.5 10^{-6}. The same two peaks in the spectrum of the zero pass is 4.4 10^{-6} and 4 10^{-6} respectively. The amplitude of these two periods has been reduced by a factor 1.5 and 1.6, compared to 1.3 which should be expected from the thickness reduction. This implies that there are relatively more reduction in the surface region than of the sheet itself, and therefor a major roughness decrease. The optical micrograph of the surface of the second pass (figure 7 c), which are taken with inclined illumination, shows some vague shadows on the surface with similar width as the gorges in the first pass. In the 3D image it is difficult to see any surface feature of this size, but the transversal spectrum of the second pass reveals a large rounded peak about 43.3μm, and the amplitude of this peak is 1.5 10^{-6}. This give a reduction from the first to the second pass by a factor 2.0 which again is more than the thickness reduction of 1.6. For the smallest wavelengths, there are the



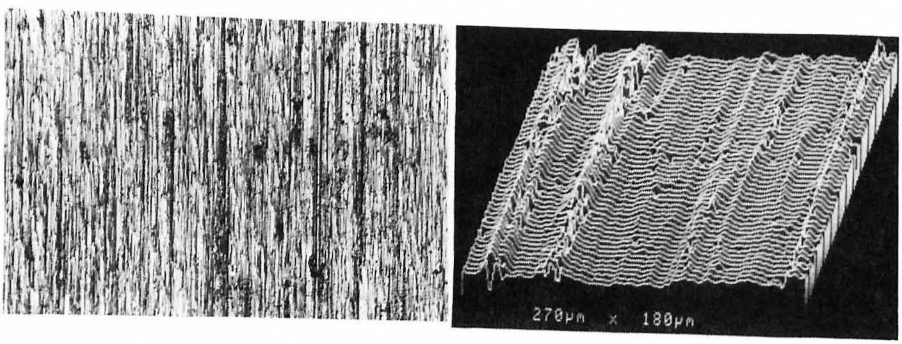
10µm

Fig. a



2µm

Fig. b



2µm

x 53

Fig. c

Figure 7: Surface structure and topology through the first few passes of cold rolling. a) zero pass, b) first pass and c) second pass.

same reduction of amplitude, but it is not obvious that it is the same surface irregularities which is deformed. This is comparable with the optical micrographs and the 3D image where we only see small surface irregularities in the areas between the gorges in the first pass, while there are strong topography in the zero and second pass.

Conclusion

To be able to gain new information about the deformation mechanisms in the surface region during cold rolling of aluminium sheet, it is found useful to employ new techniques in combination with traditional metallographic characterization methods. This has been exemplified in the present work and we believe that valuable results can be obtained.

By use of the LSM together with Fourier transformation of the 3D image, we get both the possibilities of imaging of topology in connection with quantification of statistical features in the lateral dimension of the surface topology. The calculated wavelengths, amplitudes and phases of the Fourier transformation, give a quantified description of for instance pickup grooves and rolling ridges as given as examples above. As was shown for the deformation of the pickup grooves, we both gained information of the degree of deformation in the surface region compared to the sheet and the survival of the grooves through rolling. This can also be used to follow extension of the spacing between cross hatches and formation of new ones during rolling.

The advantages of this new combination of techniques gives us an unique tool in the further work of characterization of the surfaces of metal working processes with the aim of gaining understanding of deformation mechanisms, and to be able to relate relevant parameters to the process itself.

Acknowledgements

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References

[1] E.J.Abbot and F.A.Firestone, Mechanical Engineering, vol.**55**, pp.569, 1933

[2] L.Gjønnes, ICAA4 1994

[3] L.B.Sargent jr., Y.H.Tsao, ASLE Trans.vol**23**, 1, pp.70, (1978).

[4] T.Wilson, in "Confocal microscopy" edited by T.Wilson,p p.1, 1990.