CHANGES IN THE SURFACE STRUCTURE DURING COLD ROLLING OF CC-CAST ALUMINIUM

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Introduction

During cold rolling of twin roll cast aluminium there is a dramatic change in the surface structure of each step in the process due to thickness reduction, lubricant film thickness, speed, rolling pressure, temperature etc, and to the structure of the casting rolls. The last is generally determined by the build-up of a rough coating, together with process parameters as setback, pressure speed and temperature.

A main aim is to optimize the surface quality by understanding the deformation mechanisms of the surface region. Therefore the surface of the first few passes of cold rolling have been characterized, using a wide range of techniques to achieve the most complete information of the surface. An important aspect has been to evaluate the importance of the surface structure of the as cast surface on the subsequent development.

Experimental procedure

Specimens of twin roll cast aluminium were taken at both a relatively early stage of the lifetime of the casting roll. The coil were processed through a four-high reversible industrial cold rolling mill. The reduction from as cast (6–7mm) to final thickness (0.69mm) was taken in six passes, without inter-anneals. Specimens of the sheet and corresponding lubricant were taken at each pass.

The series of samples were characterized on the upper side. The characterization techniques used was optical microscopy (Leica MEF), scanning electron microscopy (SEM)(Philips 30X) and laser scanning microscopy (LSM)(Zeiss LSM). The optical microscopy has mainly been used with inclined illumination and a combination of interference contrast and polarized light to aid the visualization of the depth. The LSM where used in a confocal mode [3] [6] to achieve a three dimensional (3D) image of the surface. 3D images of selected large and small areas of the surface were Fourier transformed (Vision Science, FFT) to achieve the typical statistical trends [3].

Results

The surface of the sheet from the twin roll caster have some typical features (figure 1. One common features of the as cast surface is pickup grooves which can be followed closely by a shingle as sketched in figure 1a) [2] [5]. The size and presence of the shingle following the pickup groove differ with casting conditions. Cold rolling deform the grooves

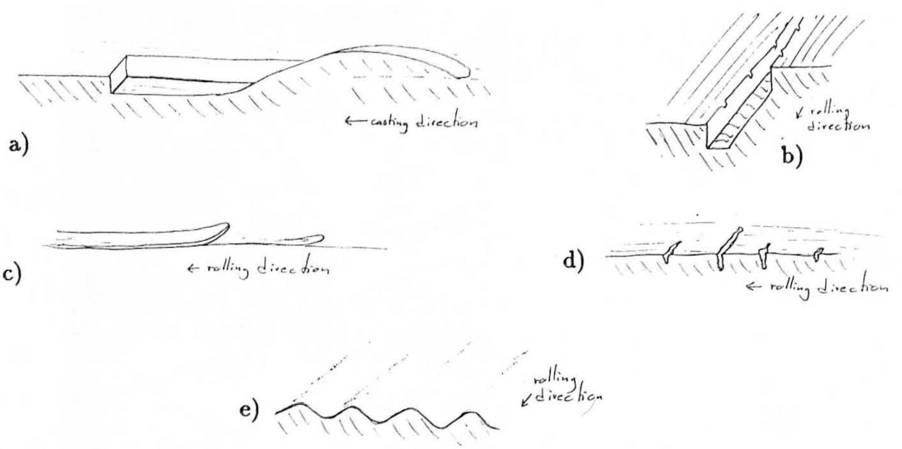
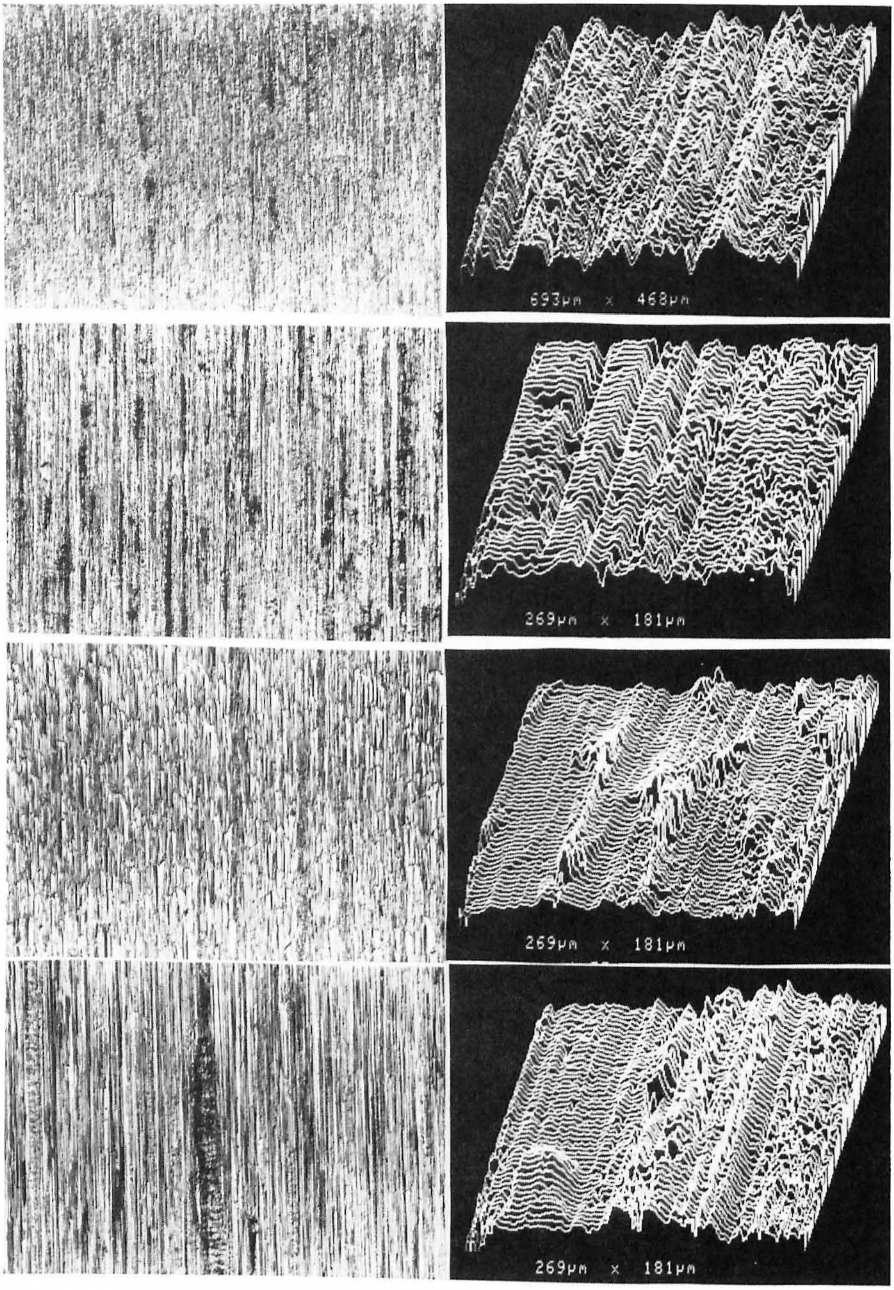


Figure 1: Typical surface features of cold rolling. a) pickup groove, b) gorge, c) shingle, d) cross hatches and e) rolling ridges.

and produce additional surface features as shingles, rolling ridges and cross hatches. The pickup groove is deformed into a long, narrow, steep sided gorge (figure 1b) which can survive flattened through three passes if the initial depth is large enough. The width of the groove is kept through the deformation, while the depth decrease and the length increase with the extension of the sheet. The Fourier specter transversal to the rolling direction reveal the persistence of the grooves through the different passes. Large shingles are formed from gentle hills, as well as smaller ones are probably due to local high friction points, which cause a local smearing out (figure 1c) [2]. During extension and deformation of the sheet parts of the surface region may crack transversal to the rolling direction (figure 1d) due to shear fracture or cracking of thin surface films. The distances between the cross hatches are found in the Fourier spectra parallel to the rolling direction together with a measure of the depth. Rolling ridges are formed as the structure of the rolls interacts with the sheet and affected by the lubrication film. Typical wavelength of the rolling ridges can be found in the Fourier spectra.

The wearing of the surface during cold rolling produce aluminium fines which are both deposited on the sheet and washed out into the lubricant. The morphology of the aluminium fines has generally two typical characteristics, relatively smooth or agglomerates of thinner fines together with lubrication residues. The size distribution of fines from the different passes are similar for the first three passes, with the exception that the smallest fines ($<10\mu$m) which is most abundant in the lubricant from the first pass.

There is a many pickup grooves on the surface of both coils, as seen in figure 2a), and table 1. The surface of the sheet is heavily flattened in the first cold rolling pass, but there are some deep and relatively long gorges. There are clear signs of free deformation of the bottom surface of the gorges, as seen in figure 2b), where we see the typical appearance of a surface deformed without a surface sliding against it. The gorges have very steep valley sides where the upper part of the valley side is partly cracked. There are also cross hatches directly following some of the gorges (figure 2b). Some of these places are partly interconnected with the structure at the end of the gorges. This is confirmed in



x 53 Figure 2: Surface structure of the upper side of coil new. a) zero pass, b) first pass, c) second pass and d) third pass.

the parallel spectrum (figure 3b) where a larger number of small wavelengths (between 10 and 2.5μm) are present. The surface between the gorges are relatively flat but have some small shingles. When we compare the Fourier spectra transversal to the rolling direction for the zero and the first pass (figure 4a and b), we see that the wavelengths present are similar, but the amplitudes are reduced in the first pass. This means that the surface are flattened in the first rolling pass but that the width has not changed (figure 2). The large wavelengths (20–80μm) which correspond to the width of the pickup grooves in the zero pass are less reduced than the general surface structure. The transversal spectrum shows also some small wavelengths (<10μm) corresponding to the rolling ridges between the gorges.

In the second pass the surface has become completely covered by shingles. The shingles are almost homogeneous in size (figure 2c). The tip of the shingles points out of the surface. The transversal spectra (figure 4c) show that the range of both the larger and shorter wavelengths are increased and the amplitude becomes larger. The large wavelengths (20–80μm) correspond to the width of the "shadows"(i.e. reminiscent of the pickup grooves) seen in figure 2c). The parallel spectrum contain distinct preferred wavelengths (figure 3c) with a decreased amplitude of the shortest wavelengths, which show that the there are typical spacings between the cross hatches in this pass.

The shingles of the second pass are completely removed by the third pass and patches of rough cross hatches along the rolling direction appear (figure 2d). The cross hatches can have different shapes, but the opening is always less than the width. The areas between the cross hatches are dominated by rolling ridges. The transversal spectra of the third pass (figure 4d) show a large decrease in the amplitude of the wavelengths less than 10μm, which means that the rolling ridges with short wavelengths are decreased. For the smaller wavelengths we see some of the same characteristics in frequency distribution as of the zero and first pass, which is also seen in the images where the narrowest rolling ridges are very similar. There is a small increase in the amplitude of the intermediate wavelengths (60–10μm) and the corresponding rolling ridges are thereby more abundant in the surface. As seen in the parallel spectrum (figure 3d) there are intermediate spaced cross hatches.

Discussion

The topology of the as cast surface and in particular the pickup grooves determines to a large extent the surface topology during the subsequent cold rolling of the aluminium sheet. The cast sheets can have differences in size and number of pickup grooves on the surface, and consequently the evolution will be quantitatively different.

In the first pass there is a major deformation of pickup grooves into gorges, and formation of shingles on the surface areas between the gorges. The amount of gorges and their size reflects the amount and size, especially depth, of the pickups grooves.

Table 1:

	pickup groove gorges	shingles	cross hatches	R_t (μm)	R_a (μm)
0. pass	pickup grooves are totally covering the surface depth: 5–15μm width:20–80μm length:100–200μm			12.3	1.45
1. pass	the pickup grooves are deformed into gorges depth:5–10μm width:10–30μm length:1000–3000μm	there are shingles between the gorges width: 3–6μm length: 10–20μm	cross hatches are connected to the gorges	9.0	0.86
2. pass	the gorges can be seen as "shadows" in the image and in the transversal spectrum	shingles are completely covering the surface width: 40μm length: 80μm		7.0	0.67
3. pass		the shingled of the surface have disappeared	there are mostly cross hatches on the surface width: 4–50μm	5.0–9.0	0.60

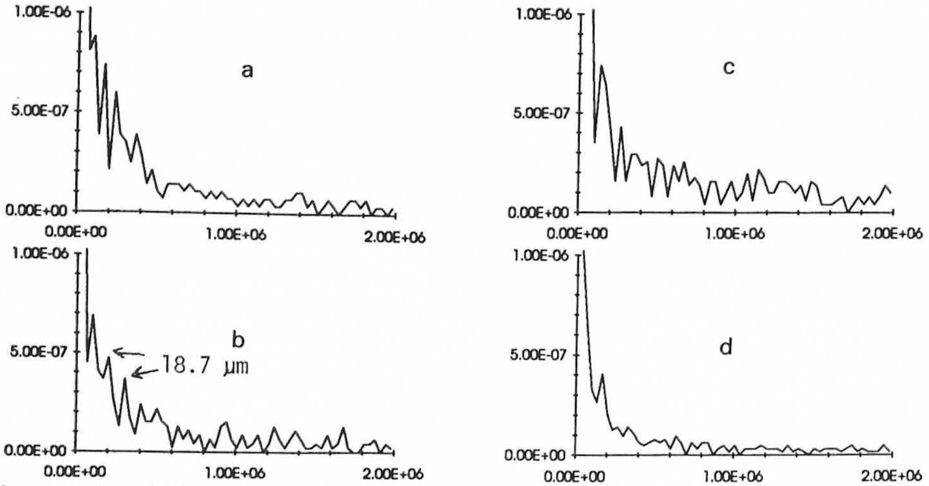


Figure 3: Parallel Fourier spectra of the upper side of coil new. a) zero pass, b) first pass, c) second pass and d) third pass.

The second pass is dominated by shingles which totally covers the surface.

The third pass introduce cross hatches and rolling ridges in addition to continued formation of shingles. The roughest as cast sheets might still have some gorges on the surface.

During deformation of the pickup groove structure they are reversed into the cold rolling gap, so the uphill part enters the roll gap before the groove. The excess material partly smears out as there is no resistance over the cavity of the pickup groove (figure 5b). The width of the pickup groove is kept through the roll gap (table 1), as it deforms into a narrow gorge. This is confirmed by the transversal Fourier spectra which show the same range of wavelengths for the pickup grooves in the zero pass and the gorges in the first pass. The free deformation observed of the bottom of the grooves support that they are cavities which have been deformed without contact in the first rolling pass. By comparing the general topology of the zero and first pass, we see a flattening of hills and peaks but distinct depressions remains as deep gorges. Similar observations has been made by Atala and Rowe [1] on rolling of both v-grooves and sand-blasted material. In the second pass, shallow valleys can faintly be recognized in the optical image having a width similar to the width of the gorges. The width can also be found in the transversal spectrum of the second pass which implies that there are still some superstructure due to the gorges from the last pass present in the surface region even though the second pass appears optically to be fully covered by shingles.

The large shingles in the second pass can be caused by sharp edges or features protruding out of the surface from the first pass will increase friction locally and smear these out into shingles on the surface (figure 5c) [4]. The difference in speed between the sheet and the rolls in the outlet zone will give the length of the shingle tongue together with the amount of excess material. When the shingles produced is long enough to overlap, the surface will appear to be totally covered by evenly sized shingles (figure 2c).

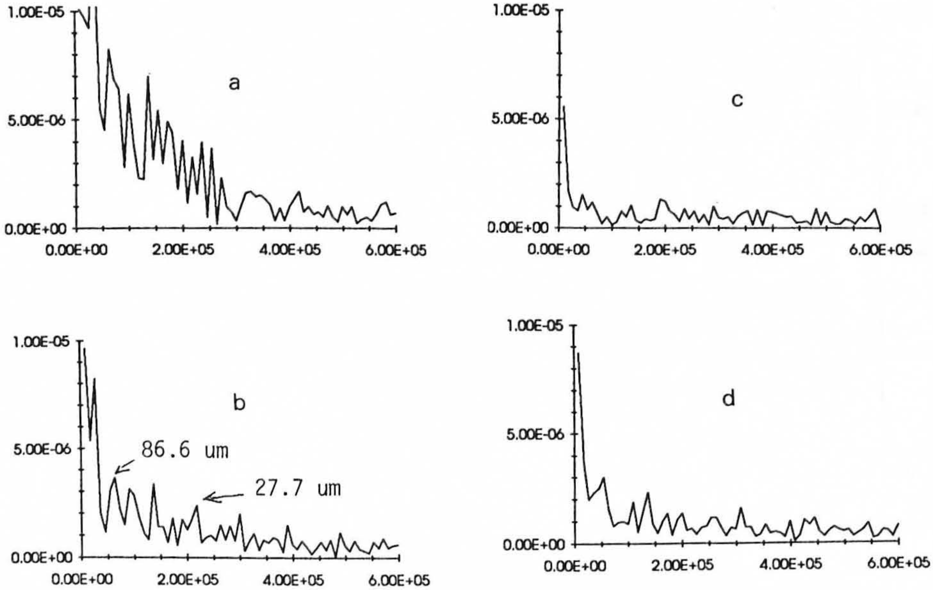


Figure 4: Transversal Fourier spectra of the upper side of coil new. a) zero pass, b) first pass, c) second pass and d) third pass.

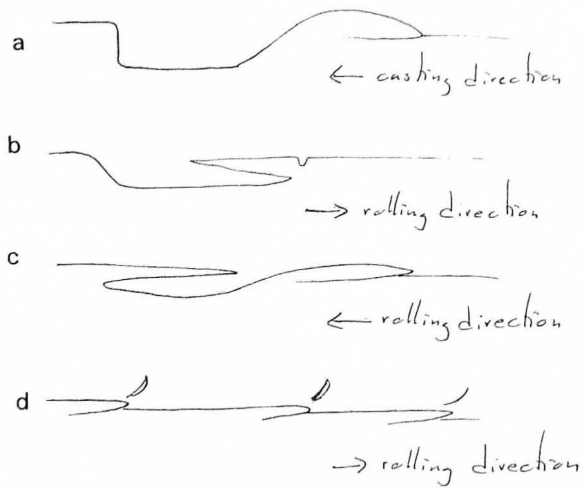


Figure 5: Sketch of the deformation of a pickup through the different stages of the cold roll gap. a) zero pass, b) first pass, c) second pass, d) third pass.

When the sheet is reversed into the third rolling pass, the tip of the shingles pointing out of the surface (figure 2c) is teared of as the shingle is hardened during deformation of the surface and the shingled appearance of the surface is lost (figure 5d). The extension of the sheet also give an extension of the surface region. This give a further thinning of the shingles from the last pass, which might be only partly welded to the bulk sheet due to entrapment of lubricant residues [1]. The stretching of the surface region will thereby result in an unsupported deformation of the surface region in relation to the bulk sheet and instabilities in the surface films as seen in figure 2d).

Conclusion

During cold rolling of twin roll cast aluminium sheets the surface deforms in a way which is typical for each pass in the cold rolling mill. The initial surface topography of the aluminium sheet is of great importance to the quality of the end product.

The rough pickup grooves of the as cast surface result in large gorges in the first pass. The shingles in the second pass which are smeared out on top of these gorges is probably only pointwise welded to the bulk sheet. The shingle is hardened and the ends is teared of in the third pass, and the shingle, without support from the bulk, deforms as a very thin sheet and we get cross hatches in the surface region.

The use of a wide range of techniques and the development of new techniques in connection to the characterization of the microstructure of metal surfaces has brought a possibility to understand some of the deformation mechanisms to which the surface of aluminium sheet undergo during cold rolling. As demonstrated above specific surface features can be followed during deformation as we see the pickup grooves deform into gorges and almost disappear in the second pass. The deformation sequence suggested above has in some extent been confirmed by the observations in the different passes, but further experiments is needed to verify the deformation mechanisms of the cold roll gap.

Acknowledgements

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