Characterisation of gravure cylinders

M.F.J. Bohan, A.M. Clist, T.C. Claypole and D.T. Gethin

Keywords: measurement, gravure cells, ink transfer

Abstract

The shape and volume of engraved cells are critical to the performance of the gravure printing process. A slight discrepancy between the desired and actual cell volume, can lead to a significant change in volume of ink transferred, forcing the press crew to apply compensation to the ink in order to achieve the correct colour balance. Traditionally the volume of the cells engraved in a gravure cylinder have been estimated by optically measuring the width of the cell on the surface (by optical microscope, usually combined with image processing) and inferring the cell volume from a knowledge of the engraving tool geometry. This can lead to significant differences in ink transfer from notionally identical cylinders.

As part of a fundamental study into the release of ink from cells in gravure printing process, an accurate method of characterising the engraved cell geometries was required. The angles of the sides of the engraving preclude the use of stylus techniques to obtain this information and also limit the ability to make accurate casts of the surface. White light interferometry was used to characterise both the engraving and the surface finish at several stages during the production of gravure cylinders. It was used to calculate the cell volume, which was compare with that estimated using traditional means and with the performance on the press. A 2μm difference in depth was found between identical engravings on three cylinders. This was sufficient to change the printing characteristics of the cylinder to the extremes of the adjustments available to the press crew.

The cells where also examined using a montaging microscope. The microscope achieves high magnification with depth of field capable of viewing from the whole height of the cell, by scanning the microscope and then recombining the in focus areas of the images to produce a complete picture. This offers the ability to examine the cell walls, which will also aid the understanding of the ink release mechanism.

The white light interferometer was used both in the laboratory and in the field to characterise gravure cylinders. Despite its high capital cost, the press time, which this method could save by improving the predictability of the process, could eventually lead to its adoption as a routine means of quality assurance. This study of the methods of characterising the engraved cells and the fundamental principles of ink release also has implications for other processes such as flexography and pad printing.

Introduction

The volume of a cell will be key to the ink transfer from a gravure roll to a substrate. The method commonly employed within the industry is to utilise the top surface and infer the volume from these measurements using a predefined cell shape and the stylus angle. The interpretation of the shape and therefore volume can lead to significant differences between nominally identical cylinders with the resultant changes on the press that are required to obtain a colour match.

Considering the ink release from a cell, the ink transfer can be summarised as shown below in equation 1

$$\text{Ink Transfer} = f_n(c) + f_n(i) + f_n(p) \qquad \ldots 1$$

where $f_n(c)$ is a function of the cell, $f_n(i)$ is a function of the fluid rheology and $f_n(p)$ is a function of the process. To predict the ink transfer each of these functions need to quantified and accurately modelled. Before the characteristics of the cell that effect the ink transfer can be quantified, the cell first needs to be accurately measured. This paper focuses on the different methods for measuring a cell and shows a further refinement of the methods to obtain an accuracy better than 0.5%

Measurement methods

Different measurement methods are available to evaluate engraved cells. These include microscopy, fluid volumetric, replicates, collaging con focal microscopy and white light interferometry, all of which will be discussed in detail. Additional methods include scanning electron microscopes and atomic force microscopes. However, these methods are off line processes, may not be capable of measuring cylinders and may require the cylinder to be sectioned for measurement. As such they are not considered applicable to the investigation.

Microscopy is the traditional method used for the examination of gravure cylinders. A microscope is placed on the cylinder and focussed onto its surface, which can then be examined visually. Measurements of the top surface of the cylinder only can then be made, typical measurements are shown in Figure 1. The method also allows a visual assessment of the non-image areas. The accuracy of the measurement depends on the operator control and the volume of the cell is then inferred from the stylus geometry. No geometrical data or surface roughness measures can be made with this technique, though it is fast and easy to use.

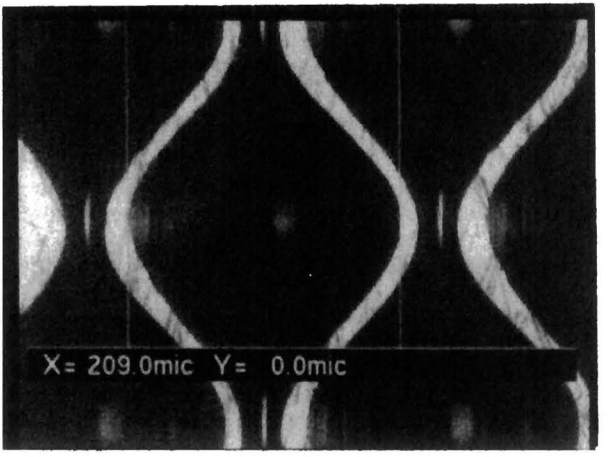

Figure 1 Microscope measurement image of a gravure cell

Volumetric methods use the application of a known volume of fluid to a cylinder. This method can be applied to the measurement of anilox rolls and for pad gravure cylinders. A measured volume of fluid is applied to an area of the cylinder and doctored with a blade to ensure that the fluid fully fills the engraved cells. By transferring this fluid onto a piece of substrate, a volume measurement may be inferred from a division of the amount of fluid applied by the area covered. For accurate analysis this requires a relatively large area of

even coverage, normally a minimum of $7cm^2$. In practice however, it is difficult to ensure that the cells have been filled, and so an incorrect volume can be calculated. In addition, this method only provides evidence of volume and not of either geometry or roughness.

Several replicate methods are available to examine gravure cylinders. In these methods a viscous fluid, such as resin is applied to the cylinder, and is squeezed into the cylinder surface to take the shape of the cells. Once the fluid has set, it can be removed and analysed via microscopy (optical, electron, or atomic force), or interferometry. These methods have the advantage of allowing remote measurement from the cylinder but the accuracy of the measurement depends on the impression of the surface being faithful. Once the replicate is made a second analysis system is required, producing a slow total time for measurement, whichever system is employed for post analysis. In addition, the errors will be propagated through the analysis, resulting in a less accurate method than applying the second analysis system alone.

Collaging con focal microscopy uses an optical microscope to digitally capture an image of a surface or cell. The microscope uses a high magnification lens with a small depth of field. As a result, wherever the microscope is focussed only a very small section of the image will be in focus. The system scans through the engraved cell and a final image is produced, being a composite of the many images captured. The system can be difficult to calibrate and measurement times of 20 minutes plus for individual cells also provide a major draw back to the method. It does however, provide an excellent visualisation tool, as shown in the gravure cell in Figure 2 where the wear on the chrome surface can be seen.

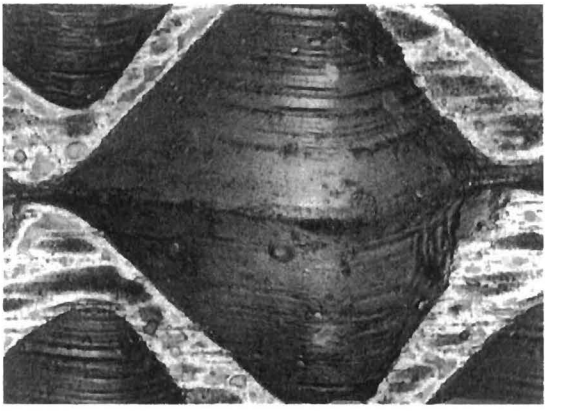

Figure 2 Image from a gravure skin measured using a collaging con focal microscopy

In white light interferometry provides a fast non-contact measurement method for surfaces. A beam of non-coherent white light is divided by a beam splitter, half going to a reference mirror, and half to the surface under examination. The reflected light from the substrate is then recombined with the reflected light from the reference mirror, and interference patterns are observed. By analysis of these patterns, it is possible to generate a three-dimensional picture of the surface. Typical measurements obtained by the equipment are shown in Figure 3. This shows the chromed surface of the cylinder and the engraved cell. The precise position of each pixel can be known to a precision of greater than 10nm, and from this data, many parameters regarding a cell can be calculated from volume to geometry and the internal roughness of the individual cell walls. This provides a fast accurate method to quantify cells. The optics on the instrument have been manipulated to increase the amount of data being detected by the system. Previous utilisation resulted in 5% to 30% of the internal cell data being available. This has now been increased to generally greater than 90%, in many instances up to 97% of data is collected.

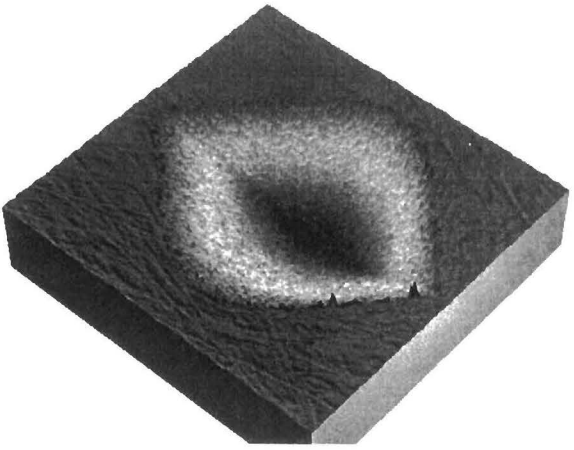

Figure 3 Gravure cell measured using a white light interferometer

Analysis of gravure cells

The white light interferometer allows the accurate 3D analysis of the engraved cell. This provides data relating to the volume, geometry and roughness. Typical cell geometry is shown in Figure 3, to allow ease of interpretation the vertical data has been inverted, Figure 4. The land area can be used to quantify the surface characteristics of the chrome. The figure clearly shows an offset in the engraving with the bottom of the cell out of line with the start and finish of the cell engraving.

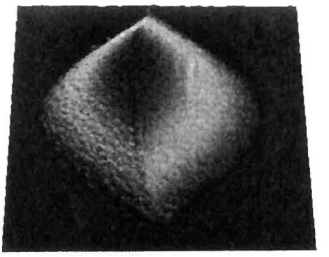

Figure 4 Imprint of a gravure cell using white light interferometry

The volume of the cell can be calculated using each pixel data point from the scan and integrating to produce a volume. However, the surface of the chrome is rough and this leads to complications in the definition of the top of the cell. Typical roughness values, R_a, of chrome are between 0.3 and 0.6 microns and this can give rise to significant variations in the cell volume. Figure 5 shows a schematic of the surface roughness and the planes from which the volumes can be measured, in relation to the surface roughness. From this it is possible to calculate the volume to either the top of the roughness, bottom of the roughness or to the mean surface height.

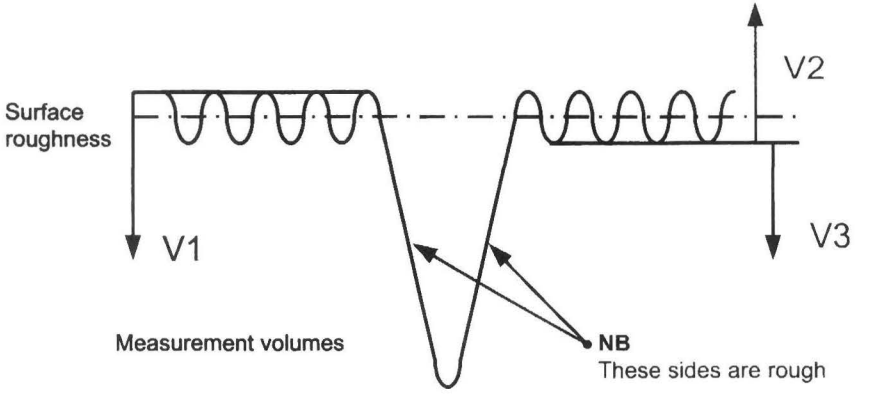

Figure 5 Schematic of cell geometry

The resultant change in volume through a typical gradation scale is shown in Figure 6 for the three surface positions. These show the significant effect the position of the top surface has on the volume. It also indicates that not only does the volume of the cell need to be measured, but also an indication of the fill level within the cell is important. For the cells analysed the R_z value was 1.6 microns and this resulted in a change in volume of 13 percent for the solid coverage area.

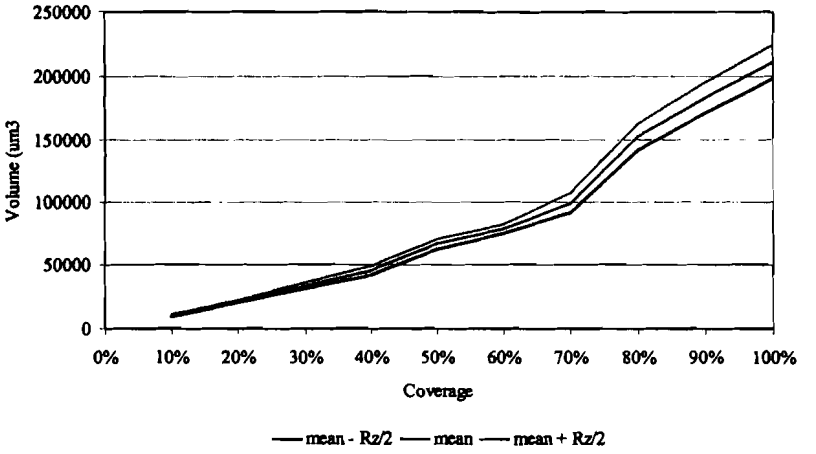

Figure 6 Volumetric analysis of cell related to surface roughness

The accurate measurement of the cell volume allows the comparison with different theoretical volume models. For the comparison an 80% cell, engraved with a 130 stylus is used, the cell dimensions can be measured as 137.9 μm wide by 153.3 μm long. The volume was compared to those for either a cone or rhombus pyramid using the width, length or combination of both to define the base. The depth of the cell is calculated from the width and stylus used. The results of the volume measurement compared to the actual volume are shown in Figure 7. This show that the cone analysis consistently overestimates the volume while the pyramid underestimates, typical configuration used is shown in P3 using the cell width and length, an underestimate of approximately 20%. However, once the analysis is transferred to the whole of the tonal scale the differences are not consistent, with different analytical methods being optimal. This indicates that no one simplistic method is appropriate to calculate the cell volume. It may be possible to calculate an approximation, however, none of these will be as accurate as the measurement as the shape will always be inferred.

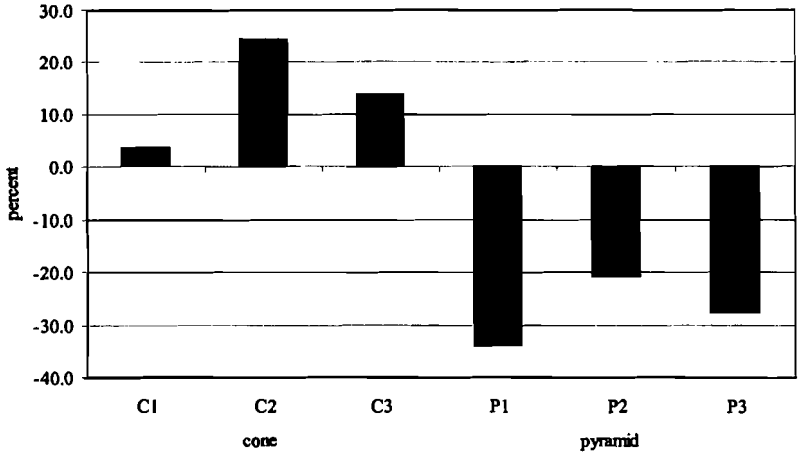

Figure 7 Volumetric comparative analysis of a typical 80% gravure cell

Consistency of engraving

The variability of engraving was analysed using three identical test strips that were engraved across the width of a cylinder. The cells at 10% intervals were analysed and the results for the average cell volume for each of the strips are shown in Figure 8. These indicate that it is only at the high volumes (greater than 70%), with the high engraving power, that there is any significant variation in the volume, with an 8% difference being evident at the 100% coverage between two of the engravings.

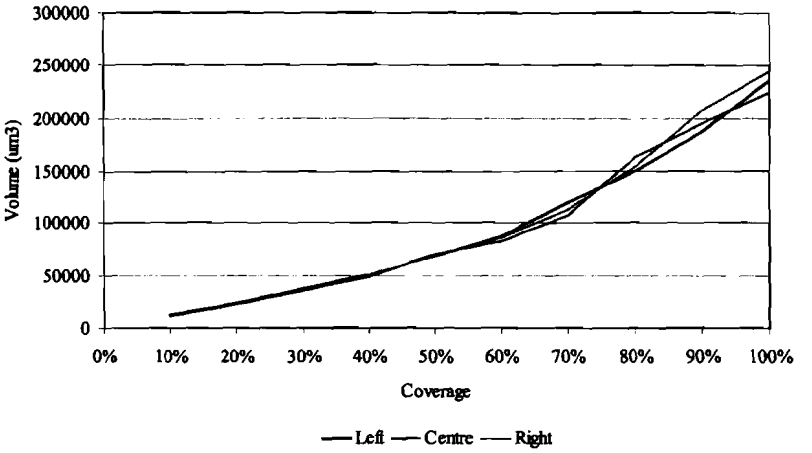

Figure 8 Volumetric analysis of three identical engravings

By considering the depth, Figure 9, it can be seen that this does not follow the same trend as the volume, with variations in depth throughout the whole of the coverage range. The responses of the curves show an approximately linear increase in depth with coverage. In addition, the depth gives only part of the story with regard to the volume, as can be seen at the 100% coverage. Here the left and centre engravings have the same depth but show a 4% change in volume, Figure 8.

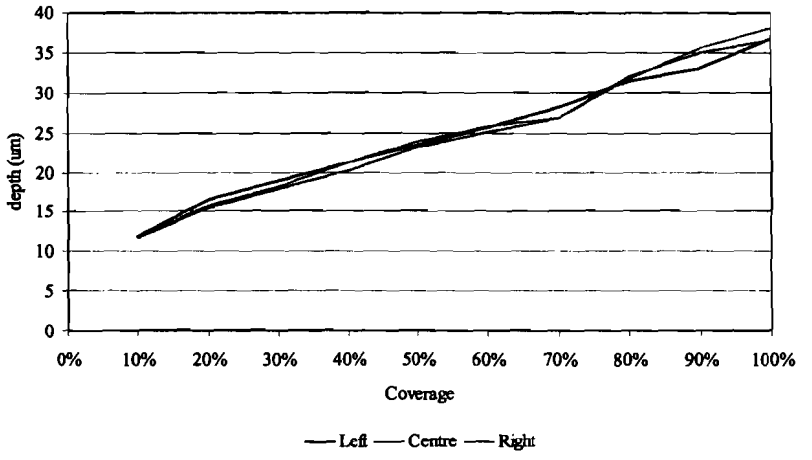

Figure 9 Depth analysis of three identical engravings

It was shown earlier, Figure 4, that the bottom of the cell was offset from the axis of the cell. This has been quantified through the full tonal range, Figure 10, showing variations in between the different engravings but also within each of the gradation scales. There is no clear trend within the measurements, indicating that the changes are caused primarily by the change in the crystalline structure of the copper. Additional trials have shown that this offset angle is also dependent upon the machine type and configuration and will be reported on in a later publication.

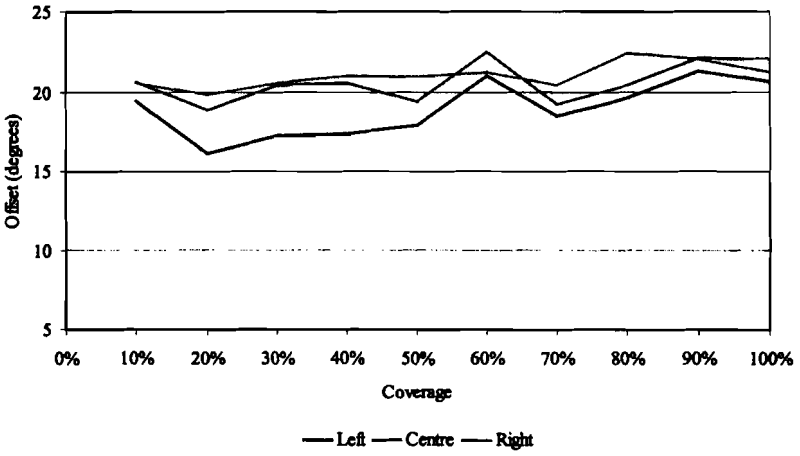

Figure 10 Offset angle analysis of three identical engravings

The effect of internal cell surface roughness on the ink transfer has not been evaluated with respect to gravure printing. However, it has shown that the transfer mechanisms within a nip contact are altered by the roughness of the surface in the contact [1], [2]. Measurements using the interferometer have shown that it is not a constant. The surface roughnesses of the four cell walls were calculated and the results are shown in Figure 11. These show that in general as tonal coverage increases so the roughness of the surface increases. There is a difference between the roughness of the cell wall surfaces, most notably for the high coverage areas. These differences can be explained by using metal chipping theory [3].

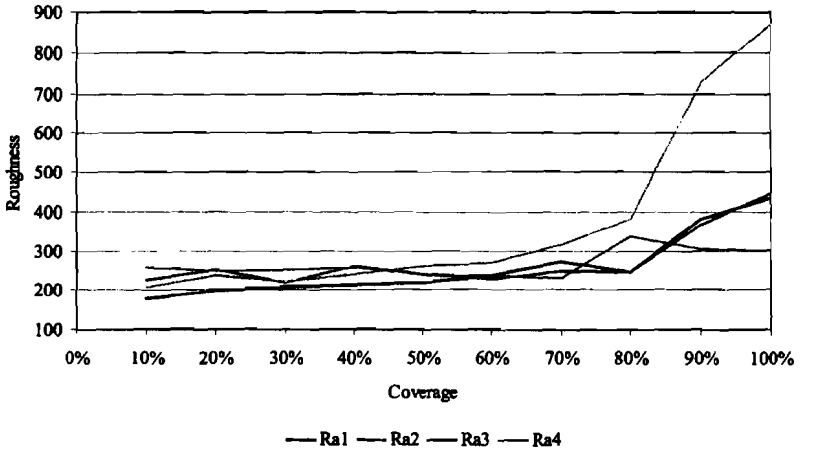

Figure 11 Internal surface roughness of engraving

Discussion

The measurement method described allows the accurate definition of the cell characteristics. Analysis of the repeat engraving showed there were variations in volume, geometry and roughness of the cells. These changes were not consistent throughout the whole of the tonal range. Also the analysis showed there was variation in the geometry for the same tonal coverage. For instance, the 100% cells had the same depth but a 4% difference in the volume.

The work has shown that there are a number of variables within the definition of an individual cell. From this it is now possible to quantify the characteristics of the cell and evaluate the ink transfer mechanisms taking place using the following equation.

$$\text{Ink transfer} = f_n(v) + f_n(g) + f_n(r) + f_n(i) + f_n(p) \qquad \ldots 2$$

$f_n(c)$ is a function of the volume, $f_n(g)$ is a function of the geometry, $f_n(r)$ is a function of the cell wall roughness, $f_n(i)$ is a function of the fluid rheology and $f_n(p)$ is a function of the process.

Ongoing work is evaluating the effect of the ink and the process. Preliminary results from trials on the printing from the cells have shown that volume while being a significant effect on the printed colour, is not the only term with respect to the cell release characteristics and final printed colour. The geometry and surface roughness also have an effect on the ink transfer.

Conclusions

An accurate and fast method for the characterisation of engraved cells has be outlined that can be used in a production environment, with an accuracy greater than 0.5% in volume. This has allowed the measurement of volume, cell geometry and the roughness of the internal surfaces of the cell to be quantified.

The theoretical calculations used in many cases utilising the surface characteristics of width and length and the stylus angle can give rise to significant differences between the calculated and actual volumes. The error will also vary dependent on the coverage.

The consistency of cells engraved on the same machine show significant variation in the cell volume, geometry and roughness that may lead to changes in the printed ink colour.

Acknowledgements

The authors wish to acknowledge the financial support of the European Community, EPSRC, ELWa, Welsh Development Agency, European Regional Development Fund and the Rotogravure Printing Technology Group

References

1 Hooke, C. J. "The behaviour of low amplitude surface roughness under line contacts", Proc. Instn Mech. Engrs, Part J, Journal of Engineering Tribology, 1999, 213(J4).

2 Bohan, M.F.J., Claypole, T.C. and Gethin, D.T. "Roughness modelling of soft elastohydrodynamic lubrication contacts" ECCOMAS CFD 2001.

3 Boothroyd, G. "Fundamentals of metal machining and machine tools", McGraw Hill, 1985.