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Application of Finite Elements on Non-Linear Deformation of Flexographic Photopolymer Printing Plate

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***Abstract*—Printing offers the possibility of producing mass quantities of a wide variety of electronic components and devices quickly and at lower cost. Flexography is mainly used for packaging applications, but is also a potential method for the micro manufacture of electronic devices, smart packaging and RFID. Fine solid lines of high quality are essential to enable printing of ink tracks for electronic applications. Plate characteristics are among a number of process parameters that will influence print line quality, which will affect the electrical performance of printed tracks. Deformation of the photopolymer plate is an important factor in determining the line quality. Therefore, an investigation into plate deformation is vital.**

A numerical model of close multiple lines has been developed and used to examine its deformation under a range of printing conditions. An Ogden constitutive model was used to describe the response of the photopolymer plate material. A series of uniaxial tension and pure shear experiments was carried out to provide mechanical properties of the photopolymer. In validation of the material model, numerical results agree well with the experimental data in both simple tension and pure shear. Numerical models were then used to determine the change in line profile, as the deformations occur on a microscopic level and cannot be assessed experimentally. The simulations yield information on line width increase due to plate deformation. However, the predicted line width is smaller than that of printed line measured using image analysis. The difference in line width is due to ink spreading and by relating the numerical results with those from the printed copy; the proportion of increase in line width due to the deformation of the printing plate has been quantified at 53 to 69%.

***Index Terms*—Flexography, Printing Electronics, Finite Element, Ink spreading .**

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I. INTRODUCTION

Principally, printing processes could be divided into two categorises as shown in Fig. 1 [1] and to fulfil the emerging demand, a significant amount of research on both conventional and non-impact printing has been carried out. Flexography is one of the most basic forms of printing as it simply transfers the image with its image carrier or printing plate onto the substrate (*see* Fig. 2). The plate is inked using an anilox roller and the process is similar to a rubber-stamping process. But despite its apparent simplicity, a vast number of parameters affect this process, which need to be understood fully, especially when the precision requirements of printing electronics is being addressed [2]. Solid line proved to be better than dot printing due to even layer of thickness and to ensure continuity of conductivity [3]. Flexographic printing is particularly attractive for this application because it features a simple ink train and subjects the ink to lower levels of stress. However, for success in electronic applications, there is a requirement for close control of registration and this implies the need for understanding how the lines formed on the printing plate will deform and distort as image transfer takes place within the printing nip [4]. In verifying the printing quality and reliability, further investigations on other printing parameters has been carried out and analyzed [5][6].

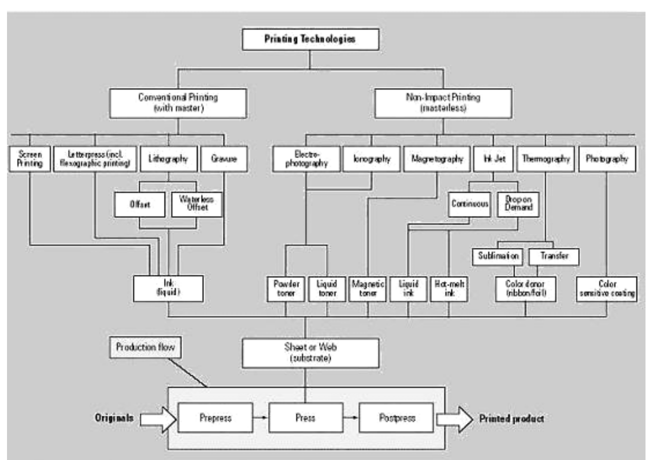

Figure 1: Printing processes

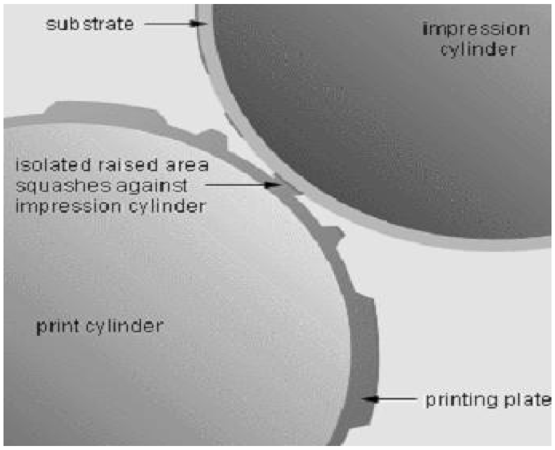

Figure 2: Schematic of flexographic printing process

II. EXPERIMENTAL

A. Material characterization

The definition of a material model is an essential requirement for accurate numerical simulation of any process. Polymeric materials are inherently nonlinear and difficult to characterize for the purpose of incorporation into a numerical model. However, procedures for doing this are becoming established through simple compression and shear tests. Two photopolymer sheets were cast at 2.73mm thickness for this test. Test samples were prepared, two pieces 25mm wide for tensile test and two pieces 40mm wide for pure shear tests. Tests were conducted using an Instron 4301 fitted with a load cell having a range of 1000N at TARRC. The tensile test piece were loaded sequentially to 50%, 100%, 150% and 200% of strain at 1%/sec and this was repeated two times to condition the material and the data recorded on the third test was then used. The pure shear test pieces were loaded sequentially to 47%, 92%, 142.5% and 192.5% strain. These values were chosen so that the strains would have the same I_1 values despite the low width to height ratio in tensile test and high width to height ratio in pure shear loading as discussed by Feichter, Major and Lang [7] where it can be written as

$$I_1 = \lambda_1^2 + \lambda_2^2 + \lambda_3^2 \quad (1)$$

where I are the strain invariants and λ are the extension ratios. The force and displacement were recorded at 1Hz throughout the tests, using a PICOtech ADC-16 and the results are as shown in Fig. 3 displaying tensile test and pure shear at 50% strain. The result shows that these photopolymers are stress softening where the slope of the extension curved increased, as the previous maximum strain is approached and later fall close to the virgin material as the maximum strain is exceeded. Evidently the result shows hysteresis and large set as when the force applied was dissipated to heat upon the breaking of particle bonding [8]. Later, from the experimental results shown in Fig. 3, an up-curve line profile was selected from the 100% strain both in tensile and pure shear test. In computing the strain, the offset at the end of the loading cycle was deducted.

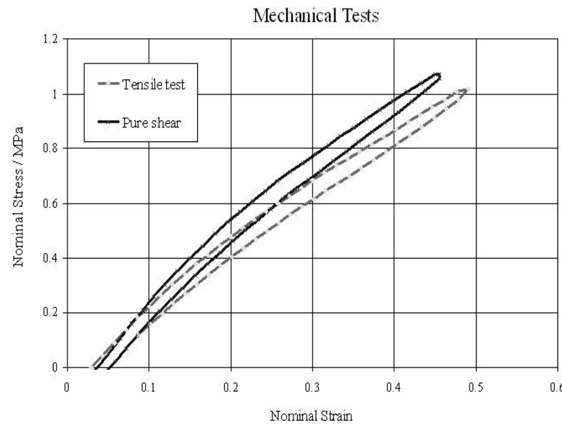

Figure 3: Mechanical property test

Material evaluation was carried out starting with simple hyperelastic models in the form of Neo-Hookean and Mooney-Rivlin formulation to seek a good agreement between the experimental data and material law (see Fig. 4 and Fig. 5). In this instance a third order Ogden model was chosen as it is necessary to predict the material behavior in a more adequate way [9]. The third order Ogden model is written

$$W = \sum_{i=1}^{3} \frac{2\mu_i}{\alpha_i^2} (\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3) \quad (2)$$

where *W* is the strain energy density, μ are the Ogden shear moduli α are the Ogden exponents.

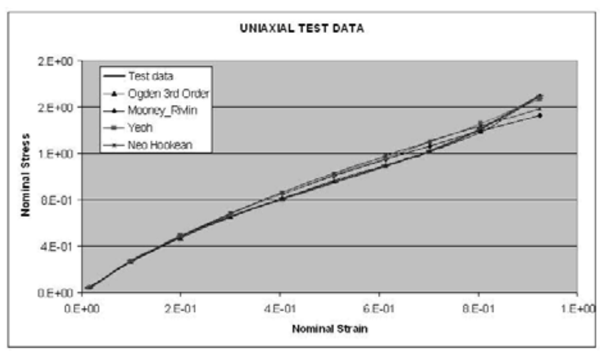

Figure 4: Uniaxial test

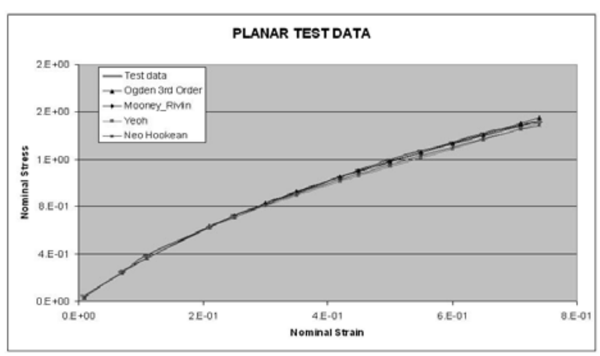

Figure 5: Planar test

Subsequently, an Ogden strain energy function with N=3 shows that the predicted results agree well with the experimental data and gave a stable result for all strains. Based on the validation result in Fig. 4 and Fig. 5, the material model parameters are listed in Table 1 and will be used in the following finite element analysis (FEA).

i	μ_i	α_i
1	0.558990602	2.43353171
2	8.312974642 E-06	20.2986905
3	0.421299462	-1.05804646

Table 1: Material law parameters for flexography printing plate

B. Line construction and modeling

In this particular paper, the geometry of a 0.6mm wide line was constructed. The method of determining the detail geometry is described fully by Yusof, Simon, Claypole and Gethin [10] and the coordinates were obtained from an interferometer image and a typical example is shown in Fig. 6. The final form of the line section, including polynomial fits applied to different segments is shown in Fig. 7.

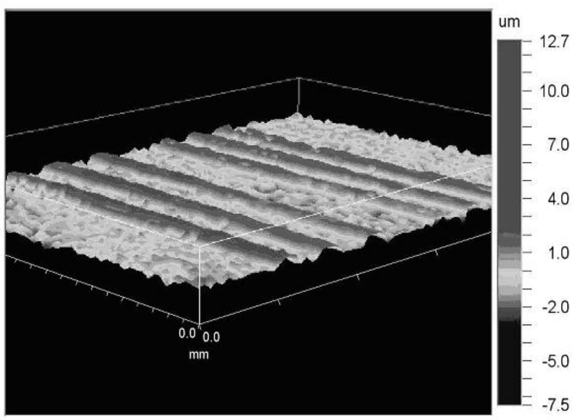

Figure 6: Interferometer scans of printing plate's surface profile.

The constructed line was modeled using commercial finite element software (Elfen) to explore the effect of five different impression levels on the deformation of the lines on the plate. Using the material characterisation, a non-linear hyperelastic model was developed and capable to simulate large compression of an essentially small line. The simulation also includes the impact of the mounting tape since this can have a major impact on print quality. This assumes a simple linear elastic model for which the material parameters are defined with Young's Modulus of 0.4611Nmm^{-2}, 0.45 Poison's Ratio and 5.48E^{-7} kg/mm^{-3} of density [11].

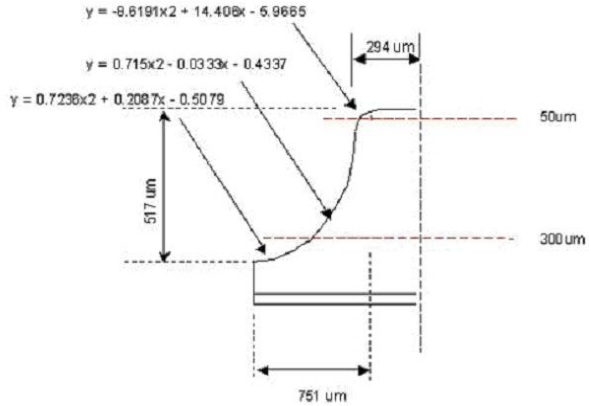

Figure 7: Line construction for modeling

A FEA model was developed to define the contact between the plate and substrate that is capable of capturing the evolving contact area that depends on engagement and the influence of friction at this junction. For this study, a frictionless or perfectly lubricated contact was assigned [10].

III. DISCUSSION

An exemplary of finite element analysis of the printing plate passing through the nip junction as seen from the contour plot in Fig. 8, the printing plate deforms sideways on the x-axis when it comes in contact by the impression cylinder. The figure shows the existence of barreling and spreading due to sliding at the contact between the elastomer and impression cylinder. Although a perfectly lubricated model was assigned, the printing plate clearly shows of a concentrated stress points at the edge of the printing plate and a relax stress in the middle of the model close to the line shoulder.

Results from the finite element simulation runs focusing on the details of the deformed line were then transferred to a spreadsheet to establish the geometric contour of the line (see Fig. 9). Thus it is possible to predict the line expansion (due to barreling and sliding) during the engagements.

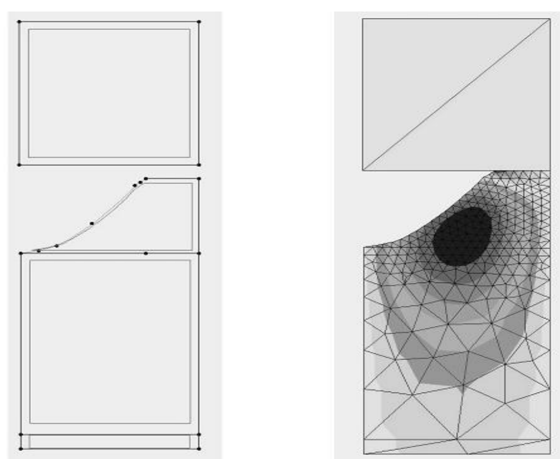

Figure 8: Finite element contact evolution

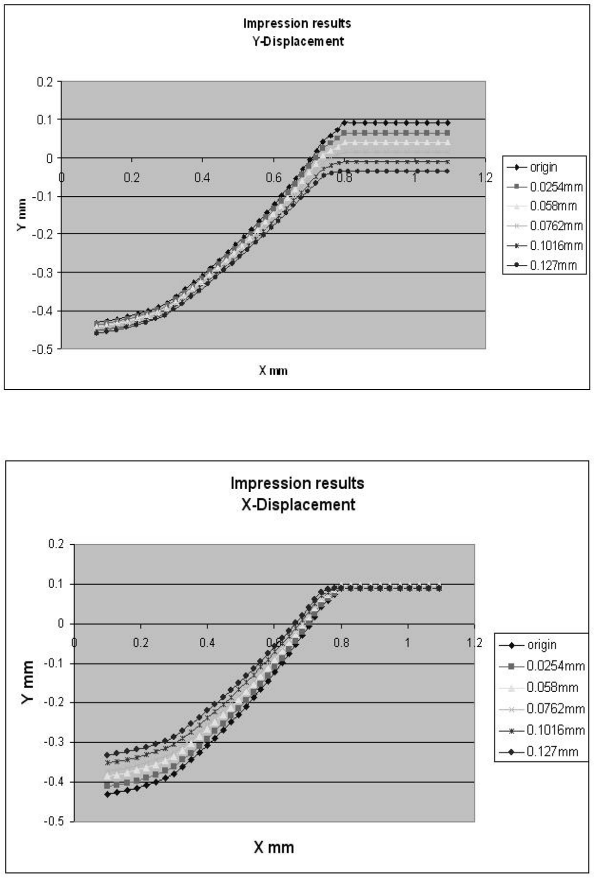

Figure 9: Impression results on X -lateral and Y-lateral displacements

These may be compared with the printed line width and by doing so enable to capture the influence of ink spreading during the image transfer process, which is summarized in Table 2.

No	1	2	3	4	5
Engagement	0.0254	0.0508	0.0706	0.1016	0.1275
Actual printed line	1.207	1.234	1.241	1.269	1.287
Non linear prediction	0.6351	0.6636	0.8111	0.8502	0.8880
Ink spreading %	47.38%	46.22%	36.64%	33%	31%
Linear prediction	0.6350	0.6632	0.8107	0.8175	0.8442
Ink spreading %	47.39%	46.26%	34.67%	35.58%	34.41%

Table 2: Predictions of line width through FEA and actual impression results (mm)

Further comparisons between the non-linear models could also be made against the linear model as shown in Fig. 10. Bould, 2004 [11] and Hamblyn, 2005 [13] discussed on assigned material properties where some were derived from standard texts [12], while others was determined through experimentation. Fig. 11 and Fig. 12 shows that non-linear and linear model differ largely when pressed with the highest engagement at 0.1275mm. With the non-linear model, the node after the last node came to contact and the line shoulder moved closer to the impression plate, leaving a smaller surface area hence an assumption of higher velocity ink squeezing might occurs which may be the cause of halo effects in printing.

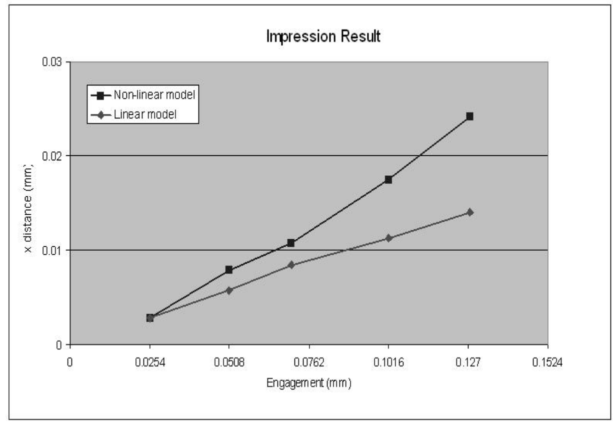

Figure 10: Comparison between models on impression result

A pressure profile was also obtained from the FEA and a comparison of contact pressure between the models could also be observed as seen in Fig. 13.

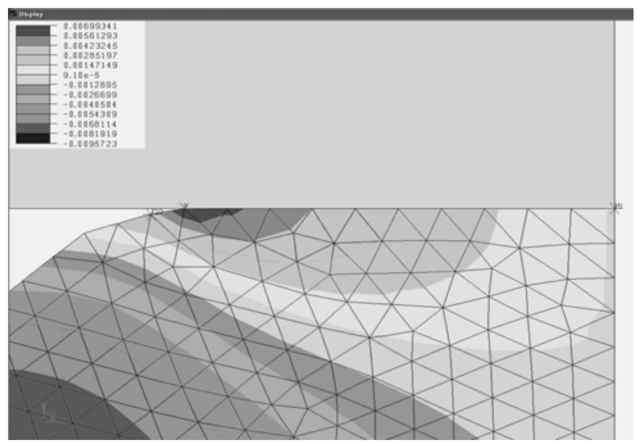

Figure 11: FEA with linear elastic material model

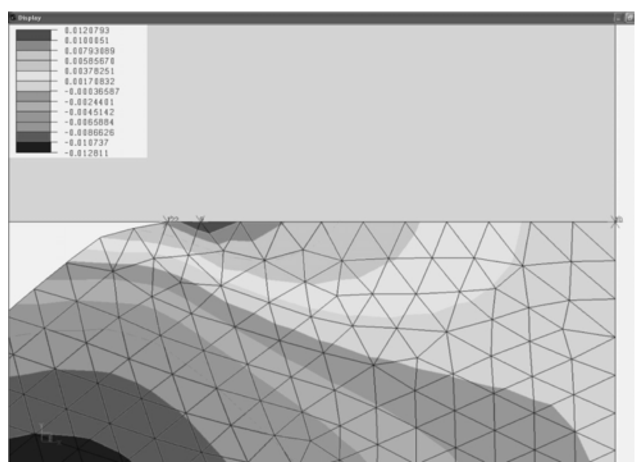

Figure 12: FEA with non-linear hyperelastic material model

Furthermore in non-linear model having the engagements of 0.1275mm, the contact pressure chart shows that the last node that came in contact has a declined pressure value instead being the last point that came into contact with the impression cylinder. This shows that either this point has just barely came into contact and not subjected to high pressure from the impression cylinder yet or might be the absolute cause of halo effects itself.

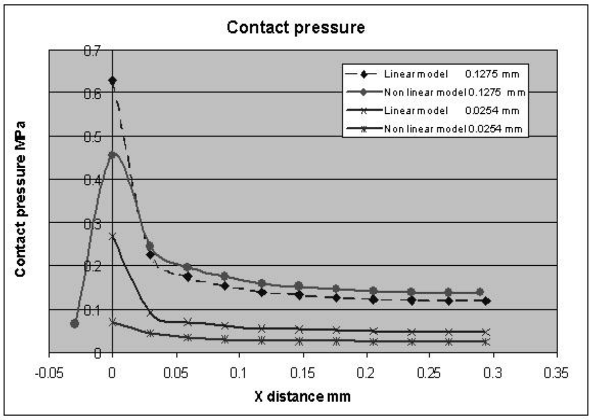

Figure 13: Contact pressure comparison chart

IV. CONCLUSION

In this study, we can conclude that the actual line width (inks transfer) increased with the increasing engagement. Also that the printed line width are larger than that has been predicted through FEA(plate deformation) due to ink spreading mechanism. We can also conclude that through a non-linear large deformation modeling, a more precise calculation of ink spreading could be achieved as the results obtained by the non-linear hyperelastic models are closer to the actual printed results compared to a linear model. The high stress at the edge of the printing plate during the engagement as shown on the FEA stress contour profile also means that this is the point where the printing plate will most likely first to be worn out due to stress from the impression cylinder and also from the abrasion by the particles inside the ink thus degrading the plate quality and its life span along with the critical printing registration and prints reproducibility. This study also conclude the need to further model on the pressure profiles upon the ink which will help to determine the ink spreading mechanism and whether this is the absolute cause of halo effects.

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