# SHOULDER ANGLE DETERMINATION WITH FLEXOGRAPHIC PHOTOPOLYMER PLATE MATERIAL

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**Keywords:** Shoulder Angle, Photopolymer Plates, Scanning Electron Microscopy, Flexography, Platemaking

**Abstract**

The shoulder angle and relief depth of dots on photopolymer plate material are hypothesized to be critical variables in flexographic continuous tone image reproduction. Prior to this research, shoulder angle had never been measured and therefore, only educated guesses could be made about how the plate making variables of face and back exposure effect shoulder angle.

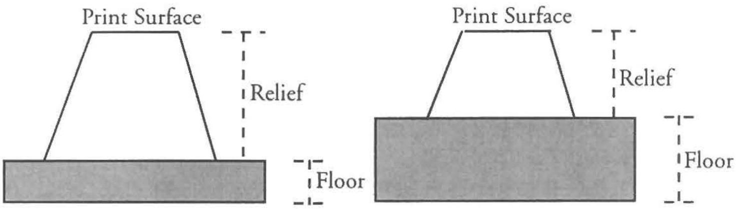
By utilizing scanning electron microscopy, the physical dot shoulder angle of various face and back exposure combinations were measured and statistically analyzed. The resulting printed dot areas were also measured and statistically analyzed. The following conclusions were drawn:

- as face exposure time increases, shoulder angle increases,
- as dot area increases, shoulder angle increases
- conventional 150 line screening results in greater shoulder angles than stochastic screening,
- less face exposure results in larger differences in shoulder angle by dot area,
- as shoulder angle increases, dot gain increases, within a given relief,
- both dot gain and shoulder angle plateau at the midtones.

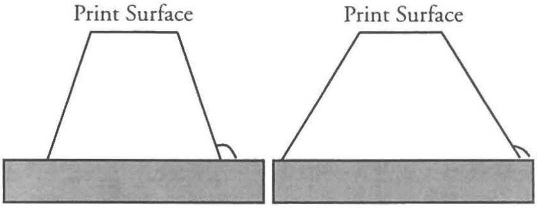
## Introduction

One of the primary characteristics of flexography is the use of flexible relief plates in which the raised surface is printed. It is the printing plate that functions as the vehicle for transferring the desired graphics onto the substrate. The photopolymer plate imaging process is perhaps the least studied and therefore one of the least understood of the flexographic print variables.

The printing plate, a light-sensitive polymer, requires two UV light exposures to be imaged. The first exposure is the "back exposure", it controls the relief, the distance between the print surface and the floor of the plate. The second exposure, the "face exposure", is through the negative of the image to be printed; it creates the image on the plate.




*Relief Depth Diagram*




*Shoulder Angle Diagram*

Although it had never been measured, longer face exposures are hypothesized to result in increased dot shoulder angles which should provide better support for highlight dots.

Prior to this research, data was not available to identify the relationship between plate face and back exposures and the resulting dot shoulder angles. Use of the scanning electron microscope and IMIX IMAGIST software made it possible to physically measure the angle of dots on photopolymer plates and statistically explain these relationships.

## Methods & Materials

### Determining Experimental Exposures

In order to determine face exposures that would yield significantly different shoulder angles, a preliminary experiment was necessary. The preliminary experiment was comprised of ten face exposures with four back exposures for two manufacturers photopolymer plate materials. The shoulder angle of the 2% 21µ stochastic dot area of every other face exposure was measured for all four back exposures from both plate materials (a total of 200 measurements).

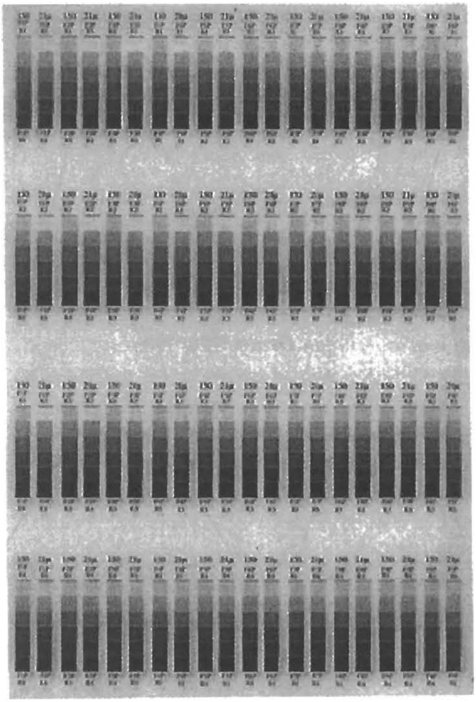


*Plate Exposure Test Design: Each row represents a single back exposure. Each column represents a single face exposure.*

Multiple regression for fitting multiple slopes statistical model was used to analyze the relationship between face exposure and shoulder angle. Based on the results of this analysis the following face and back exposures were selected for the experiment:

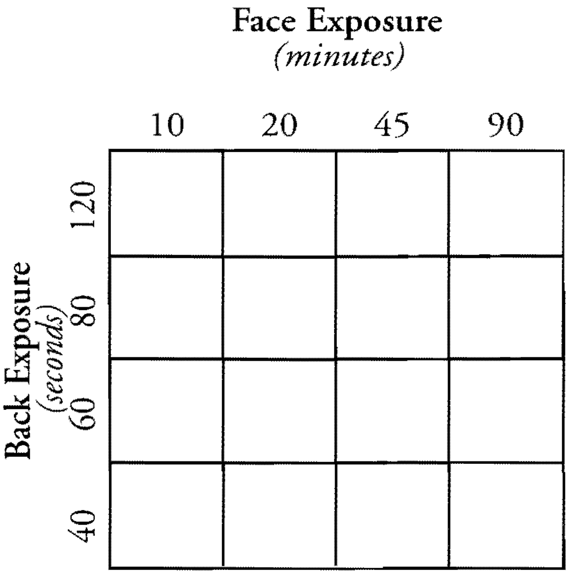



*Plate Face & Back Exposure Grid*

**Sample Collection**

Once four face and four back exposures were determined, the actual plates for the experiment were made. The test target was designed on an Apple Macintosh 7100/66 PowerPC in Macromedia FreeHand 5.5. The original photograph was scanned on a Screen DT-S1015A1 drum scanner. The image was captured and adjusted in Adobe Photoshop 3.0. The test target was output as negative film at 2400dpi via an AGFA SelectSet Avantra 25 drum laser Imagesetter and a Fuji FG950A film processor. AGFA Cristal Raster screening technology was employed to generate the 21μ stochastic images. The film density measures 4.26, all film dot areas except 90% measure within 1% of the targeted values using an X-Rite transmission densitometer model # 309T. The 90% patch measures within 3% of the target value.

The design integrated all four face exposures onto one plate with a single back exposure. Therefore, eight plates were made: one for each back exposure for both plate materials.

*Test Target Design: A single back exposure with four face exposures.*

A Kelleigh Corp. model 210 flatbed plate exposure and drum processor unit with Optisol and a Kelleigh 2430 Light Finisher model #237 was used to make all eight plates in two days. For each back exposure, both plate materials were exposed and processed simultaneously to minimize variability between materials.

There were two scales at the edge of the plate in each quadrant. These were cut from the plate and used for measuring shoulder angle via scanning electron microscopy.

The interior of the eight plates were printed to relate the shoulder angle and relief depth combinations to dot reproduction.

## Sample Preparation & Mounting

A total of 64 scales, 384 dot areas, were sampled for measurement. These scales were cut from the plates as close to the scales as possible with scissors. No border was placed around the scales during test target design. Scissors were determined to be the least destructive method of sample cutting by comparing this method to liquid nitrogen freezing and breaking. The polymer appears to be too amorphous to "snap" even under extremely cold conditions such as -320°F of liquid nitrogen.

A very thin layer of 99.9% gold foil was vaporized onto the samples using an Anitec LTD Coater, Hummer X model. The coater applies approximately 350 angstroms of gold to each sample. There are 10,000 angstroms in one micron. Such a thin layer sufficiently provides conductivity for scanning without altering the shape, surface or size of the dots.

After coating, samples were mounted onto metal bars machined at 90° using double-sided tape. The bars were then mounted onto the stage and placed into the vacuum chamber of the SEM.

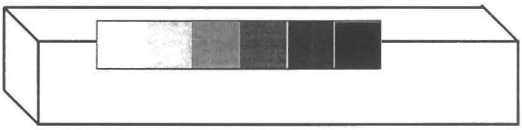


*Plate sample mounted onto metal bar for scanning*

**Analytical Equipment**

The measurement of shoulder angle was accomplished by scanning the edge of each dot area with a Jeol model JSM-IC848 SEM. Each scanned image was transferred onto a Sun Sparc5 workstation and the angle measured via the Prinston Gamma Tech Unix-based IMIX IMAGIST version 7 software.

Because the samples were mounted on edge against the 90° metal bar, the SEM tilt was maintained at 0°. The aperture setting was 3, the working distance was maintained between 24-30mm. The KV setting was held constant at 15.0 and a Tungsten K/Type filament was employed. Magnifications ranged between 130X and 330X. Altering the magnifications did not affect shoulder angle measurement.

**Measurement Methods**

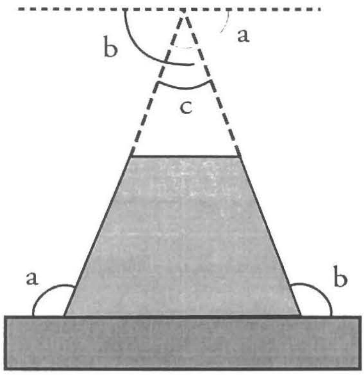
Appropriate sample size was determined by applying the variance measured in the preliminary samples to the "margin of error" formula. Measuring 5 dots per dot area provides a 95% confidence level that the sample average dot shoulder angle will be +/-3° of the population average.

$$n= \{(Z_{A/2})^2 * S^2\} / E^2$$

$$n= \{ (1.96)^2 * (6.8)\} / (2.29)^2 = 4.98$$

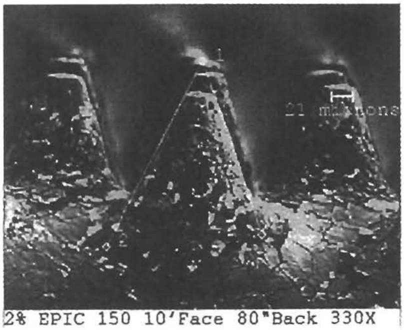
Considerable time was spent determining the most reliable method for measuring shoulder angle. It was determined, after exploring many possible methods, that measuring the angle created by the intersection of the slopes of both sides of the dot was the most accurate. In order to arrive at the shoulder angle, the following formula is applied:

(angle "c" + 180°) / 2 = the average shoulder angle of the dot.




This was determined to be the best method because it is relatively easy to measure the slope of the sides of the dot; but difficult to measure the base of the dot. Also, this measure provides the average of both sides which eliminates the possibility of skewed data occurring by only measuring one side of a dot which may be tilting slightly.

In order to further minimize measurement variability, all 1908 measures were taken by the author within two weeks.



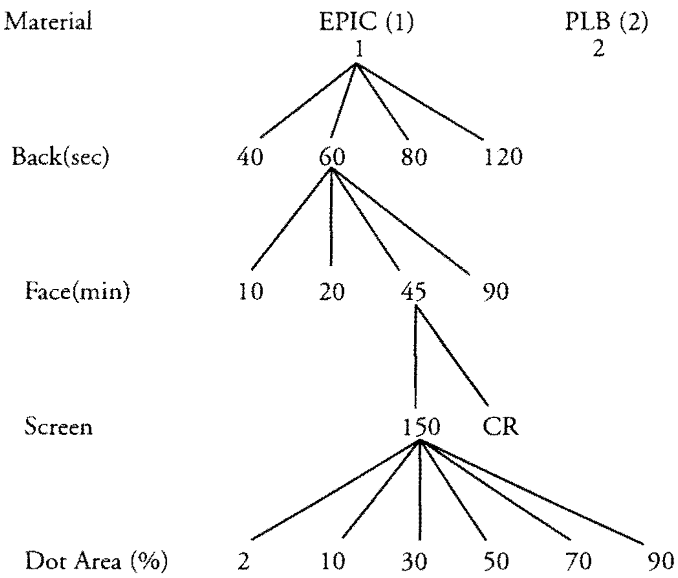
**Analysis Methods**

A Hierarchical Designed Experiment was analyzed using Multiple Analysis of Variance (MANOVA) and Least Squares Means (LSMeans) techniques.

The attribute of relief depth was determined to not be affected by face exposure and therefore is reported only by back exposure for each plate material.

The MANOVA is comprised of 5 independent main effect variables: material, back, face, screen and dot area. It is also comprised of 10 cross-product terms representing all possible pairs of the above independent variables. There is a single dependent variable, shoulder angle. The results are based upon an alpha (A) of 0.05 (meaning there is a 5% risk of rejecting the null hypothesis when it is true; concluding a difference exists between treatments when, in fact, they are the same.) There is a total of 384 treatments (2 material * 4 back expo * 4 face expo * 2 screens * 6 dot areas).

# Hierarchical Experimental Design



The primary function of the MANOVA is to answer three questions:

*1. Is there a difference between treatment means?* This is determined by comparing the "General Linear Model" P-value to alpha=.05. It was determined that not all treatment means are equal. Therefore various combinations of material, back, face, screen and dot area result in different shoulder angles.

*2. Does the model fit?* Do the independent variables considered in the experiment have a significant impact on the dependent variable, shoulder angle? Determined by $R^2$, C.V. and residual analysis.

$R^2$ is the "coefficient of determination"; it reveals the proportion of the variation in shoulder angle that is explained by the independent variables {(SSmodel / SStotal)*100}. The greater the $R^2$ value, the better the model explains the variability present. The $R^2$ for the MANOVA in this experiment is 0.82; therefore, 82% of the variability in shoulder angle is explained by the independent variables and their interactions.

The C.V. is the "coefficient of variation"; this measure allows comparison of variables that have different units. It is simply the standard deviation divided by the mean of the data (s/y-bar). The lower the C.V. value, the less the dependent variable varies. The lower the C.V. value, the better predictor the sample mean is of the population mean. In general, a C.V. of 5% or less is most desirable. The C.V. for the MANOVA in this experiment is 2.97; therefore, the sample standard deviation is approximately 3% of the sample mean.

Residual analysis confirms that the observed error is constant, independent of shoulder angle and normally distributed. Therefore, it may be concluded that the model provides a good fit and conclusions can be drawn from the LSMeans analysis.

*3. Are the selected independent variables valid predictors of shoulder angle?* Determined by comparing the independent variables P-values to alpha=.05 under "TypeIII Sums of Squares". Upon comparison of the various P-values to alpha, it was determined that all independent variables and cross-product terms, except for "material*screen", are valid predictors of shoulder angle.

Least Squares Means is a linear regression tool allowing the detection of differences among treatments. It is a standard error paired differences comparison. If the experimental design is good, lsmeans will detect statistically significant (95% confidence level) differences between treatments for shoulder angle.

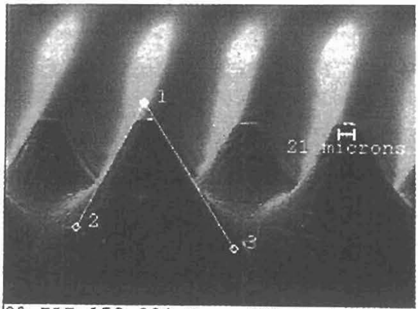
A spreadsheet in Microsoft Windows'95 Excel software was used for data collection. The data was downloaded into SAS (Statistical Analysis Software) for analysis. Graphs were created in JMP version 3 statistical software for the Apple Macintosh.

The results and conclusions discussed in the following section are based upon the analysis of the MANOVA and LSMeans.

## Results and Conclusions

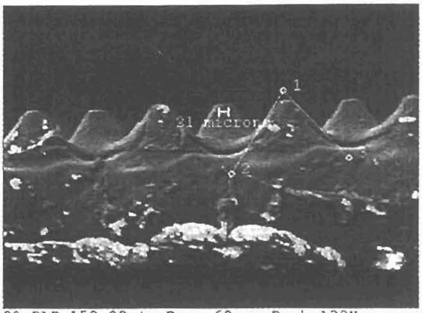
### Material*Back

For PLB(2) material, back exposure does not impact shoulder angle; there is not a statistically significant difference in shoulder angle by back exposure. For EPIC(1) material, it appears to have limited influence, some back exposures are statistically different from others, although no trend exists.



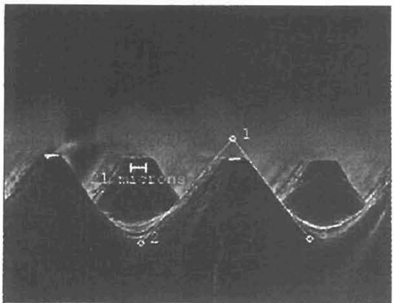

2% PLB 150 90' Face 40" Back 230X

*40 second back exposure*




2% PLB 150 90min Face 60sec Back 130X

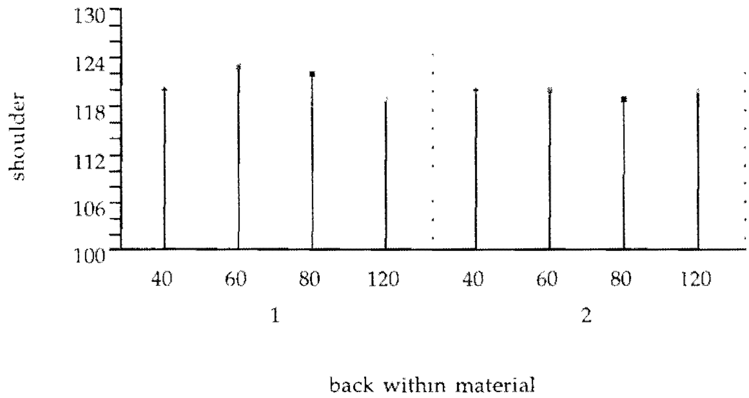
*60 second back exposure*




2% PLB 150 90min Face 80sec Back 230X

*80 second back exposure*

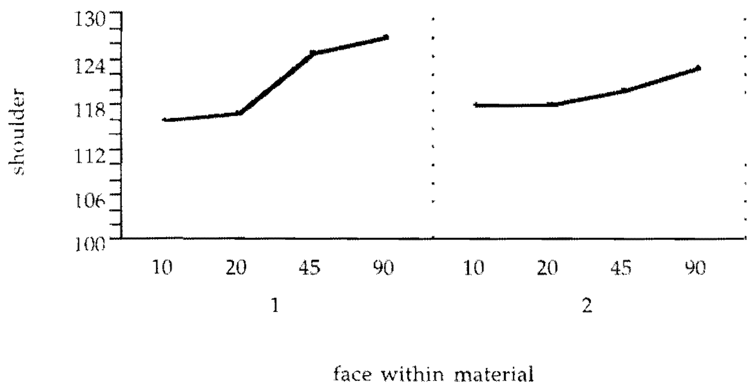
Material*Back

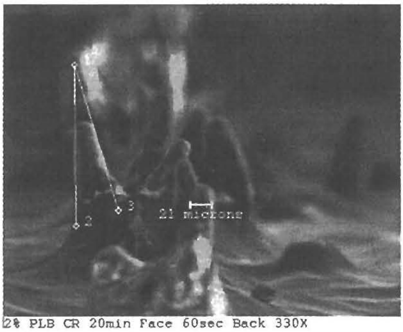



## Material*Face

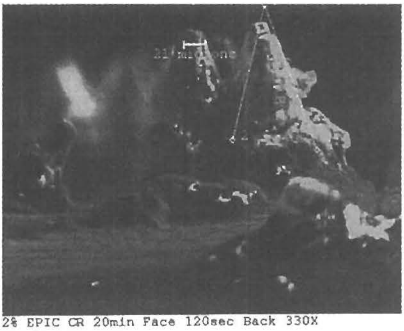
Although there is not a statistically significant difference between the 10 and 20 minute face exposures for either material, the 45 and 90 minute face exposures were significantly different from one another and from the 10 and 20 minute face exposures. In general, as face exposure increases, so does shoulder angle.

Material*Face

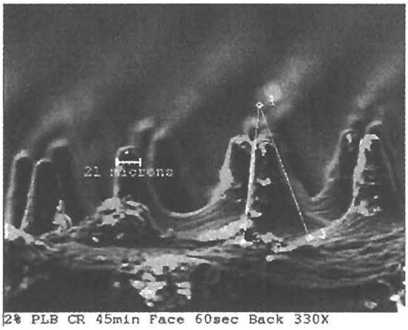




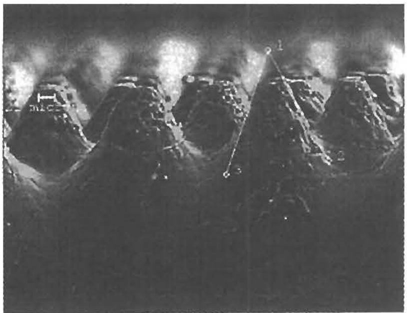

2% PLB CR 20min Face 60sec Back 330X



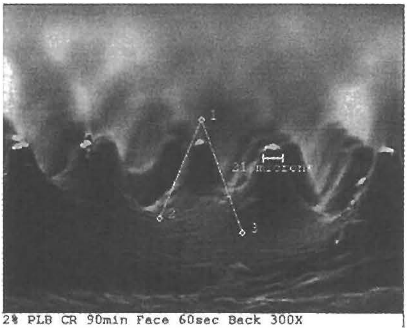
2% EPIC CR 20min Face 120sec Back 330X



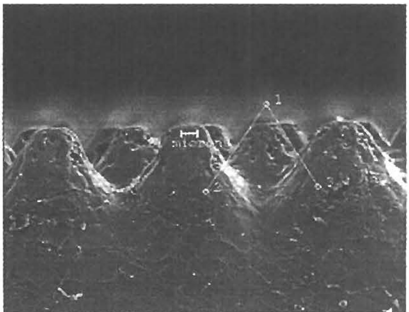

2% PLB CR 45min Face 60sec Back 330X



2% EPIC CR 45min Face 120sec Back 250X



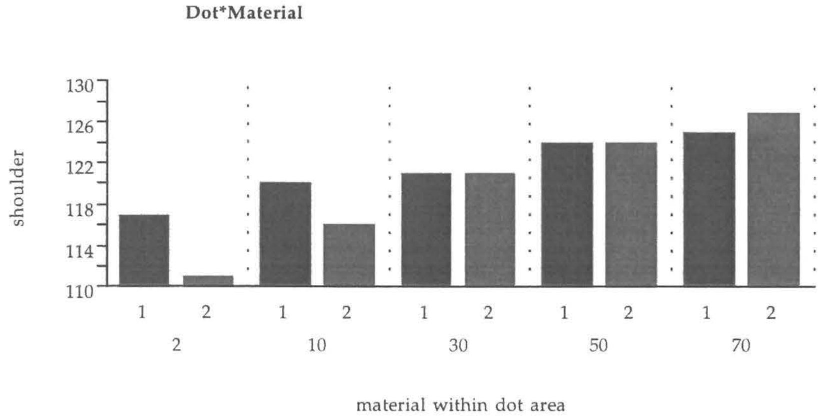
2% PLB CR 90min Face 60sec Back 300X

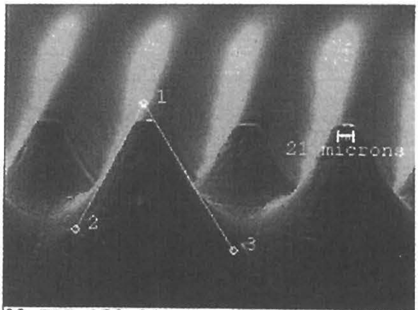


2% EPIC CR 90min Face 120sec Back 250X

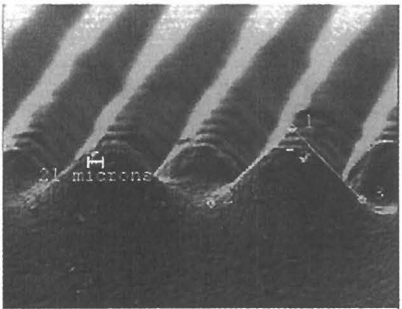
## Material*Dot

In general, EPIC(1) material appears to image highlight dots faster than PLB(2) material, resulting in larger shoulder angles for highlight dots. As dot area increases, shoulder angle also increases; however, the rate of increase is different for the two materials studied.

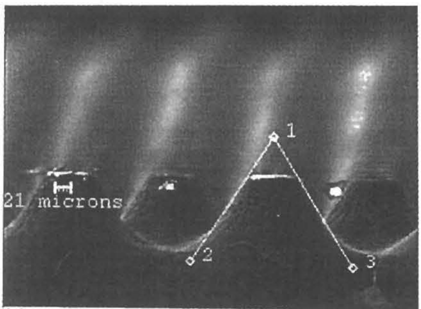


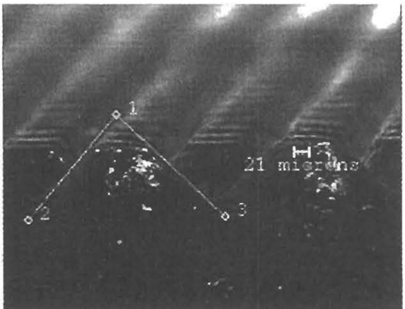

2% PLB 150 90' Face 40" Back 230X



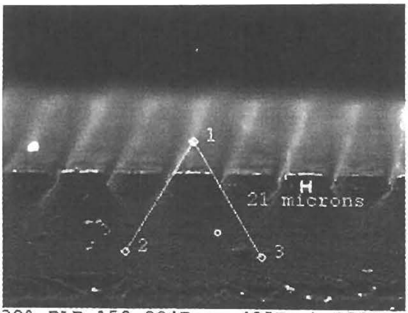

2% EPIC 150 90' Face 40"Back 230X



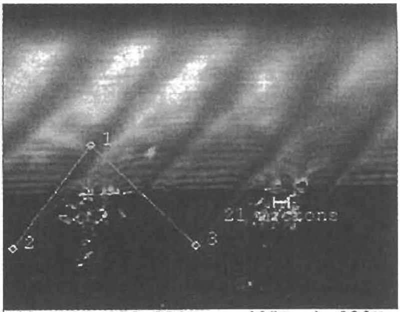

10% PLB 150 90' Face 40" Back 230X



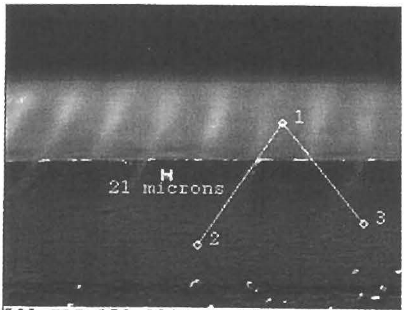

10% EPIC 150 90'Face 40"Back 230X



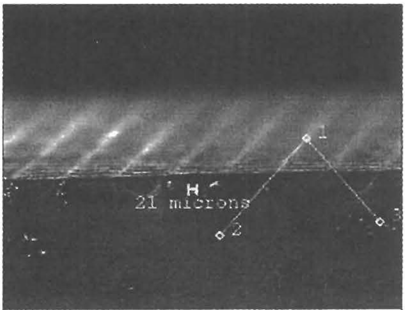
30% PLB 150 90'Face 40"Back 130X



30% EPIC 150 90'Face 40"Back 230X



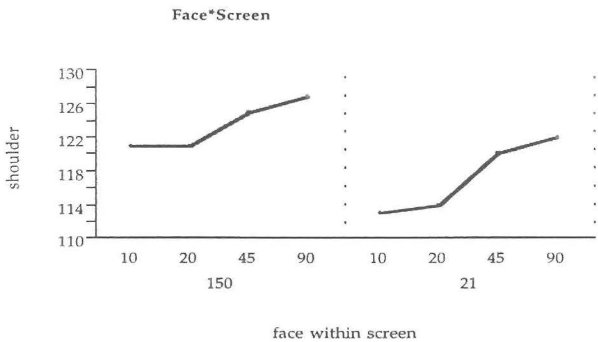
50% PLB 150 90'Face 40"Back 130X

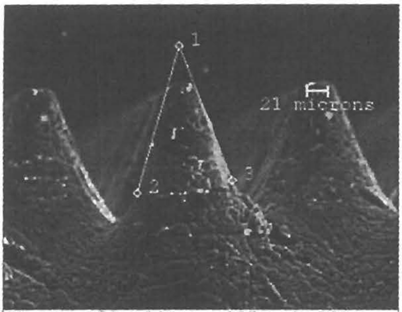


50% EPIC 150 90'Face 40"Back 130X

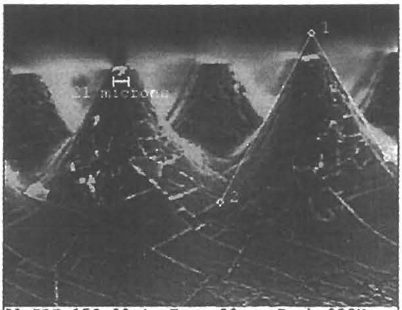
## Face*Screen

Within a given face exposure, big differences in shoulder angle exist between screening methods. Conventional, 150 line screen, results in greater angles than stochastic screening. To match an average 150l.s. shoulder angle, in a given dot area, with stochastic screening requires roughly 2.5X - 9X longer face exposures. For example, the 150l.s. shoulder angle resulting from a 10 and 20 minute face exposure is equal to the stochastic shoulder angle of 45 and 90 minute face exposures.

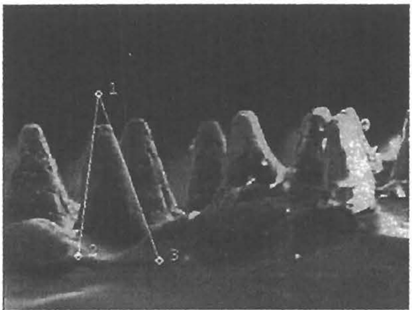




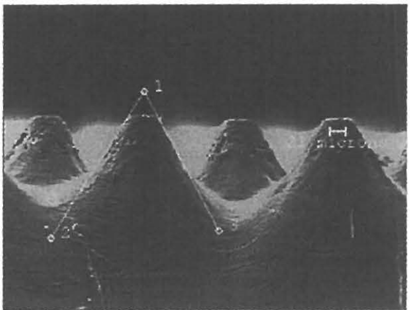
2% PLB 150 10'Face 80"Back 330X



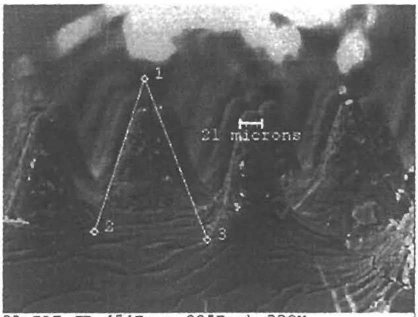
2% PLB 150 20min Face 80sec Back 230X



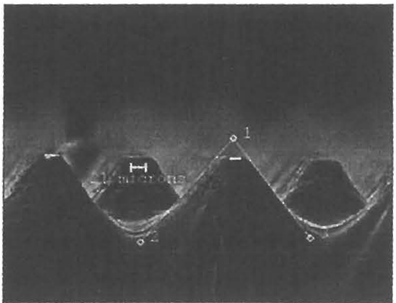
2% PLB CR 20min Face 80sec Back 330X



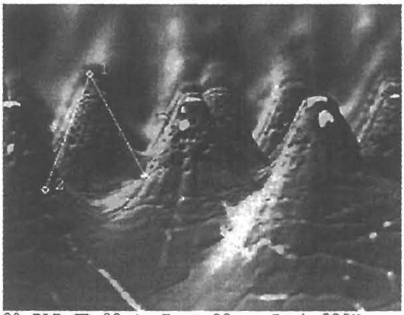
2%PLB150 45'Face 80"Back 230X



2% PLB CR 45'Face 80"Back 330X



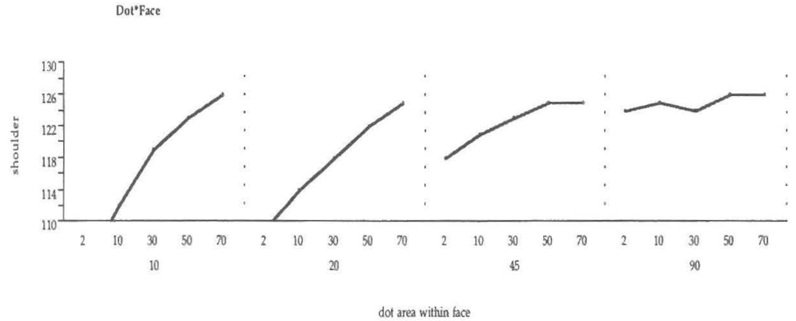
2% PLB 150 90min Face 80sec Back 230X

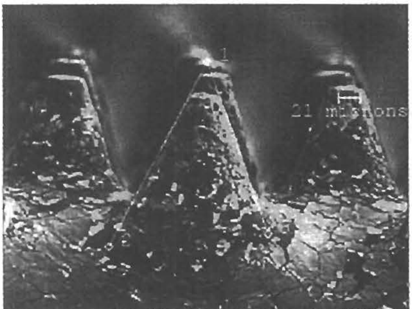


2% PLB CR 90min Face 80sec Back 330X

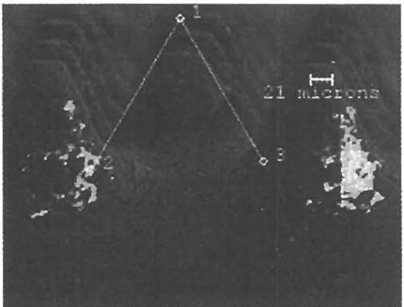
## Face*Dot

In general, less face exposure results in larger differences in shoulder angle by dot area. As dot area increases, shoulder angle increases. However, as face exposure increases, the shoulder angle does not change significantly by dot area. The 90minute face exposure demonstrates this phenomenon; the biggest differences in shoulder angle occur in the highlights and midtones.

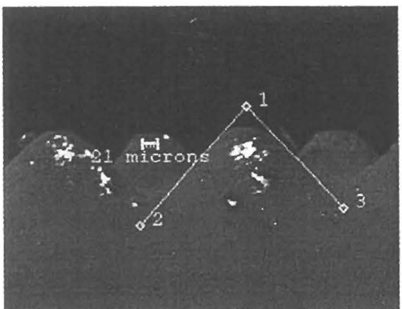


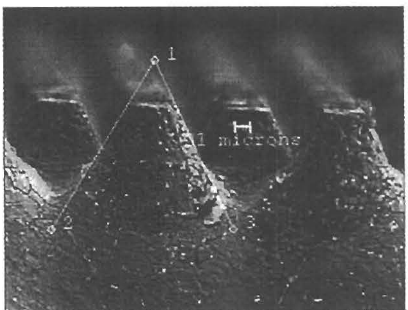

2% EPIC 150 10'Face 80"Back 330X



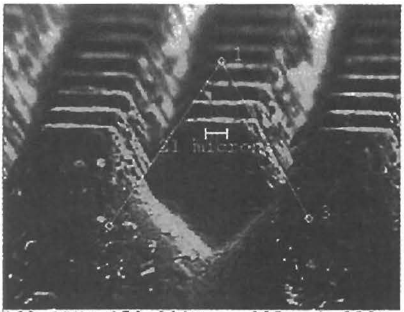

2% EPIC 150 20'Face 80"Back 330X



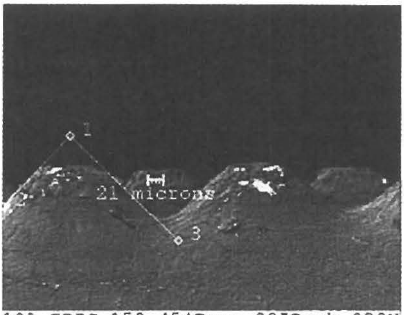

2% EPIC 150 45'Face 80"Back 230X



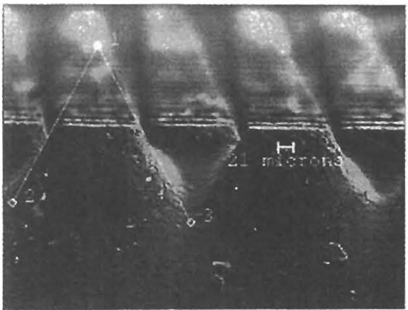

10% EPIC 150 10'Face 80"Back 230X



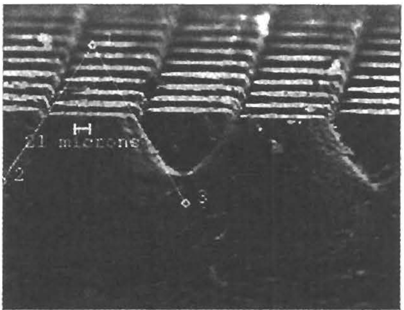

10% EPIC 150 20'Face 80"Back 330X



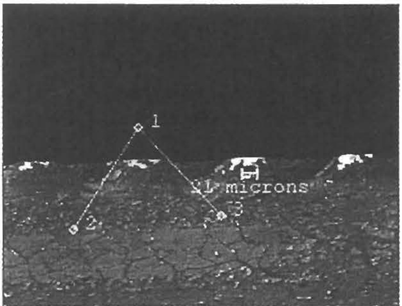

10% EPIC 150 45'Face 80"Back 230X




30% EPIC 150 10'Face 80"Back 230X




30% EPIC 150 20'Face 80"Back 230X

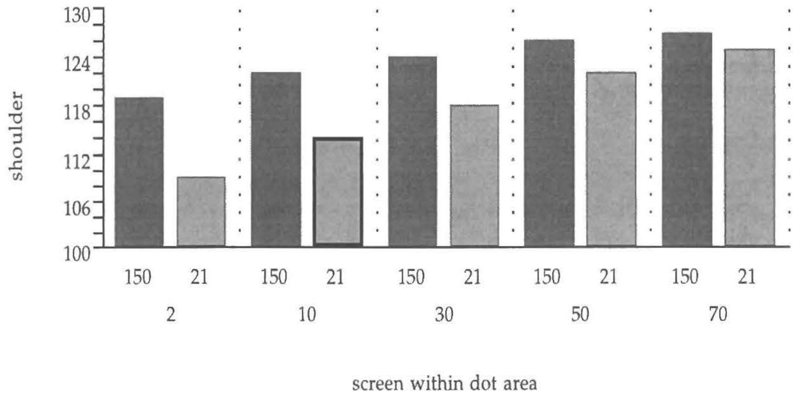


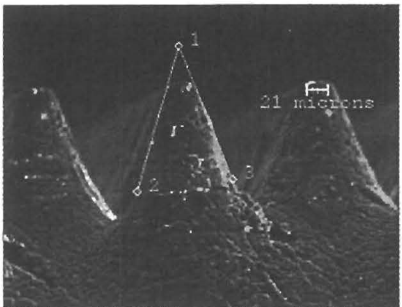

30% EPIC 150 45'Face 80"Back 230X

**Screen*Dot**

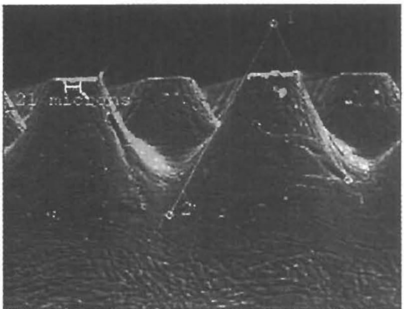
In general, as dot area increases, so does shoulder angle. Conventional screening (150l.s.) yields greater angles than stochastic screening. There is not a statistically significant difference between the 2% 150 line screen shoulder angle and the 30% stochastic screen shoulder angle.

Screen*Dot



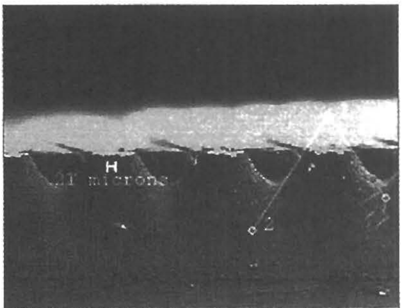




2% PLB 150 10'Face 80"Back 330X

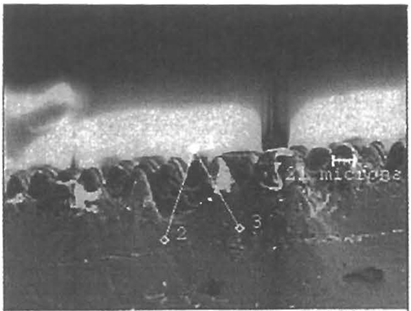



10% PLB 150 10'Face 80"Back 230X

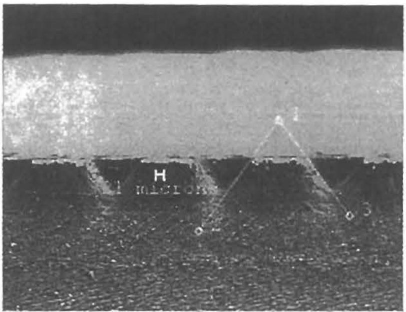

10% PLB CR 10'Face 80"Back 330X



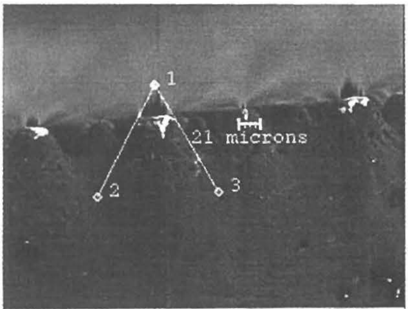

30% PLB 150 10'Face 80"Back 130X



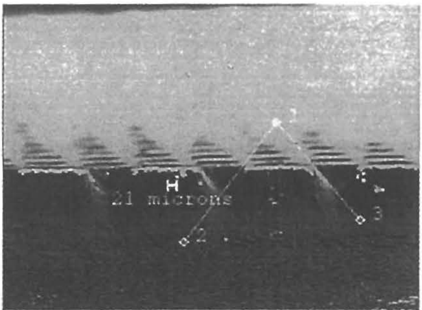
30% PLB CR 10'Face 80"Back 330X



50% PLB 150 10'Face 80"Back 130X



50% PLB CR 10'Face 80"Back 330X

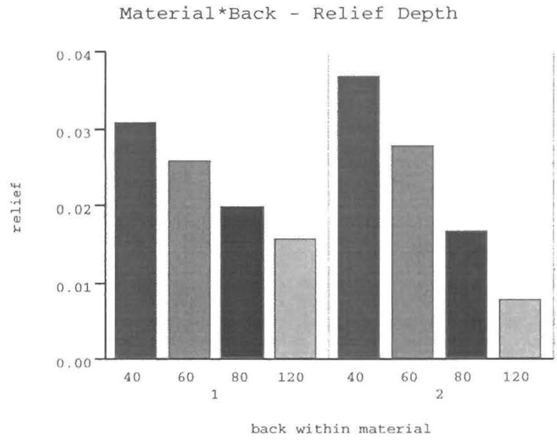


70% PLB 150 10'Face 80"Back 130X

70% PLB CR 10'Face 80"Back 330X

## Material*Back

In general, as back exposure time increases, relief depth decreases. There is an inverse relationship between these two variables. However, the slope for PLB(2) material is considerably steeper than for EPIC(1) material.

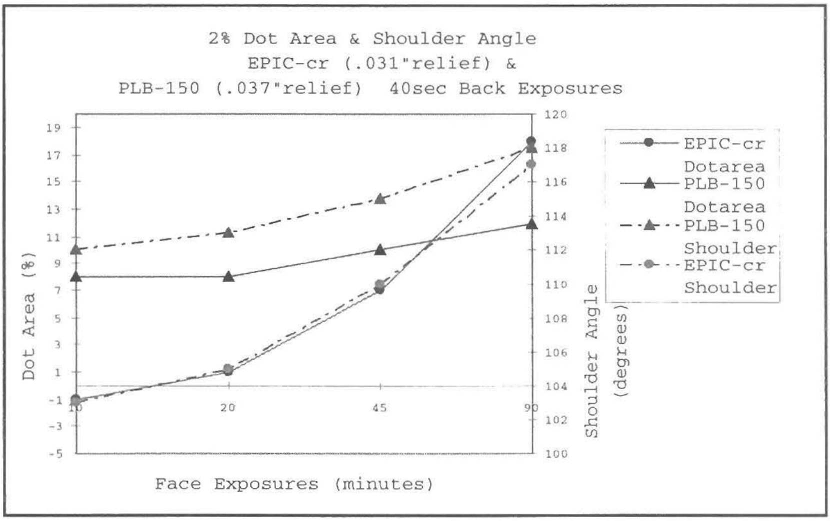


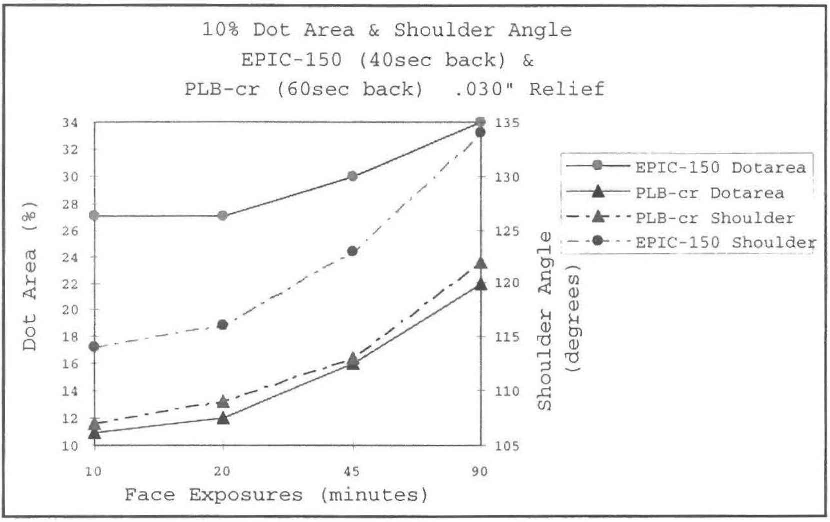

## Shoulder Angle and the Printed Dot

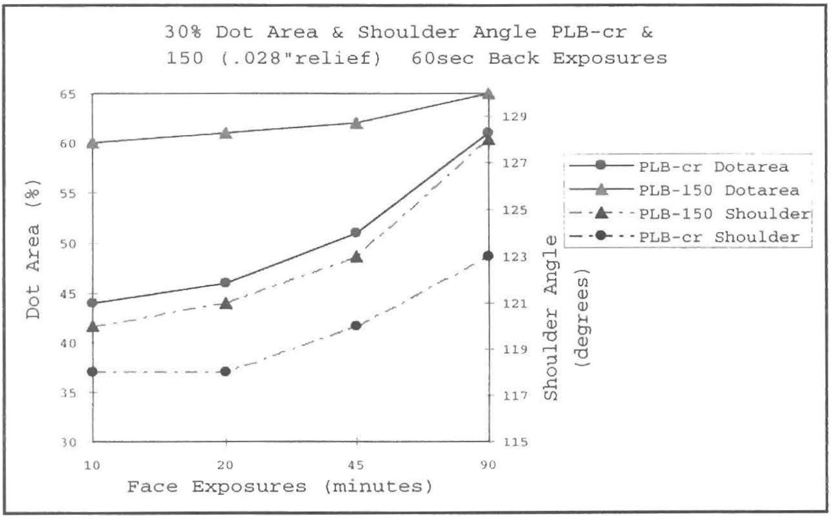
There is a positive correlation between dot gain and shoulder angle. As shoulder angle increases, dot gain also increases.

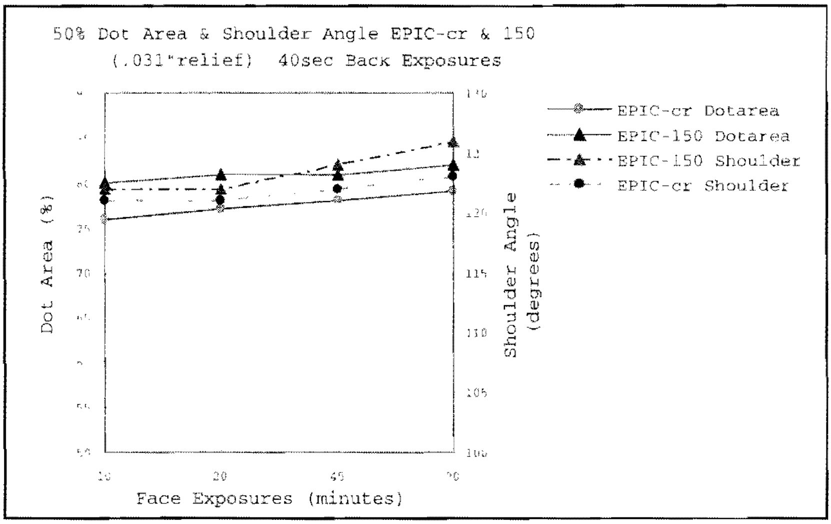
Both shoulder angle and dot gain appear to plateau at the midtones through the shadows. These variables are no longer responsive to changes in face exposure.

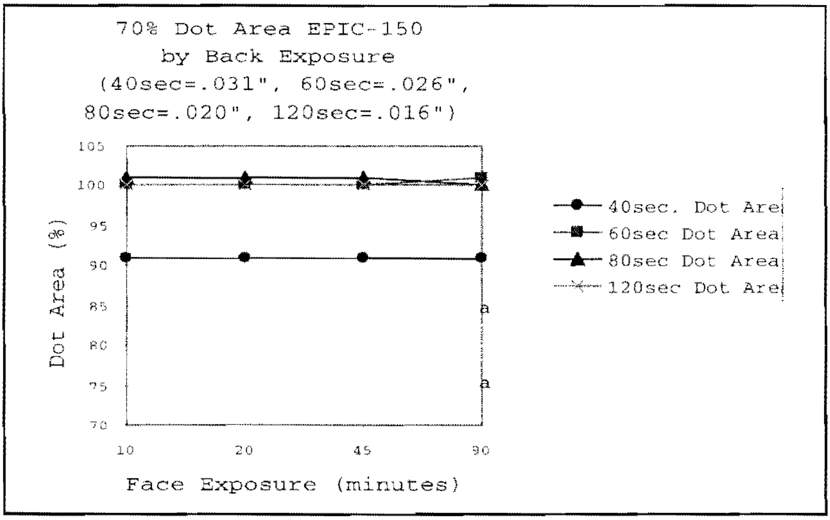
The following graphs illustrate the relationship identified in this research between shoulder angle and printed dot area throughout the tonal scale. Both conventional and stochastic screening is included.




10% Dot Area & Shoulder Angle
EPIC-150 (40sec back) &
PLB-cr (60sec back) .030" Relief
Dot Area (%)
Shoulder Angle (degrees)
Face Exposures (minutes)
EPIC-150 Dotarea
PLB-cr Dotarea
PLB-cr Shoulder
EPIC-150 Shoulder


30% Dot Area & Shoulder Angle PLB-cr &
150 (.028"relief) 60sec Back Exposures
Dot Area (%)
Shoulder Angle (degrees)
Face Exposures (minutes)
PLB-cr Dotarea
PLB-150 Dotarea
PLB-150 Shoulder
PLB-cr Shoulder


50% Dot Area & Shoulder Angle EPIC-cr & 150
(.031"relief) 40sec Back Exposures
Dot Area (%)
Shoulder Angle (degrees)
EPIC-cr Dotarea
EPIC-150 Dotarea
EPIC-150 Shoulder
EPIC-cr Shoulder
Face Exposures (minutes)


70% Dot Area EPIC-150
by Back Exposure
(40sec=.031", 60sec=.026",
80sec=.020", 120sec=.016")
105
100
95
90
85
80
75
70
Dot Area (%)
10
20
45
90
Face Exposure (minutes)
40sec. Dot Are
60sec Dot Area
80sec Dot Area
120sec Dot Are

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