Image Fixing Quality Assessment: a Crease Test Apparatus

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Abstract

The fixing quality of printed images has been characterized by the adhesion strength between the image layer and the substrate, and by the cohesion strength within the image layer. A simple tape test and a crockmeter test have been widely used to evaluate adhesion and cohesion strength respectively. The demand for using other fixing quality test methods and more reliable assessment methods has been increased due to the extensive application of color printing, advances in printing technology, the use of a wide range of substrates, and inaccuracy and poor reproducibility of the tape and the crockmeter tests. Recently pen-offset, crease, bending and rolling tests have been widely used in the printing industry.

An alternative crease test apparatus has been designed and constructed in the author's laboratory. The apparatus can apply either static or dynamic pressure on the image sample while the load is traversing on the back of the image. The authors have developed image-processing algorithms compiled into open source software to evaluate the crease line image. To characterize and quantify the test result, a crease test number (CTN) has been defined, which is a product of the grey level shift on the damaged image area and the width of the crease line. The crease test apparatus and in-house image processing software can provide more information with high reliability. It can be applied efficiently to examine the crease test performance of printing samples. And it can be a valuable research tool in the R&D stage of printing technology development.

This paper will introduce the crease test apparatus and the methodology for analyzing crease line images using image processing technology.

Introduction

The process of fusing printed images onto substrates is a critical step in any known printing process. In electrophotography, it is usually accomplished using a hot-roll contact fusing device or non-contact radiant heating, such as infra-red or flash fusing. Cold pressure fixing processes have also been used in some applications. The fix quality of printed images after fusing is characterized by the adhesive strength between the image layer and the substrate, and the cohesive strength within the body of the image layer. In some applications, the image gloss level is also an important characteristic to assess fixing quality [1-3]. Achieving desirable image gloss through fusing not only improves the appearance of the image to satisfy end users, but also enhances abrasion resistance. To assess the adhesion and cohesion strengths, many test methods were developed and widely used, such as Scotch tape test, rubbing test including Crockmeter, Sutherland Rub and Prűfbau tests, pen-offset test and crease test.

The Scotch tape test method (ASTM D3359-02 [4]) has been widely used to evaluate the adhesion strength of the printed image to a substrate. In this method, the Scotch permanent tape is applied to the image area with one finger stroke at constant pressure. The tape is then removed and assessed for optical density before and after the application. The adhesion strength is determined by calculating the residual image density on the tape normalized to the original image density.

The Crockmeter test (F1319-94(2005) [5]) has been extensively used to evaluate the cohesion strength. The amount of imaging particles transferred onto the surface of a white cloth by rubbing has been used to characterize the cohesion strength of the image. As an optional procedure, the optical density change before and after rubbing has also been used to judge the cohesion strength or abrasion resistance of the printed image.

Both the tape test and the Crockmeter test are relatively easy to use and the results are simple to interpret. The results can also be classified against pass or failure criteria to enable the introduction of the fixing quality control procedures for the printed images. However, there are some intrinsic problems related to these two methods. In the tape test, the force applied by a finger stroke has significant influence on the amount of toner removed by the tape. Different assessors may apply different forces and even the same assessor may apply different forces at different times. In the Crockmeter test, the image sometimes becomes more even after testing, leading to an increase in optical density. The optical density values depend on the selection of representative spots from the image samples as well. On many occasions, after the tape or Crockmeter test, the samples become uneven and patchy. This usually results in the densitometer providing inconsistent optical density readings. In the Crockmeter test, measurement of the optical density on the cloth is sometimes problematic. All these problems make it difficult to correlate the optical density results from tape and Crockmeter tests with those from visual observations and, hence, to achieve consistent performance from those devices.

Hartus [6] developed a modified tape test technique to measure the adhesion force. In his work, the Scotch permanent tape was applied to the print and also the mobile part of a friction meter. A controlled and repeatable force was applied to the tape by a mechanical means. The tape was then pulled from the paper at a defined speed and angle. An image processing technique was employed to assess the peeling residues. Hartus claimed that the modified tape test enabled a direct measurement of the adhesion force.

To assess abrasion resistance, Sutherland Rub Tester (ASTM D 5264-98 [7]) and Prűfbau Tester [8] have also been used in the printing industry.

Recently the pen-offset test has become more popular and acceptable in the printing industry. In this test, the image is placed face down on another piece of paper that is the same as the image sample, and a ball pen is used to write on the back of the image sample. Toner particles from the image are transferred to the blank paper during the pen writing. The assessment on this offset image can characterize the fix quality of the printed image. Mao and

Ozerov [9] designed and built a bench type pen-offset test apparatus to apply a controlled and consistent force to a ball pen. The pen is driven by a friction driven carriage to draw a straight line on the back of the print sample. The footprint or the offset image left on the reference paper is then analysed by in-house image processing software. The pen-offset number (PON) is used to characterize the test result.

In the crease test (ASTM F1351-96(2002) [10]), the fused image is bent and then folded under a specific weight with the toner image to the inside of the fold. The damage to image and substrate is examined by visual observation. The crease line can be rubbed to determine if the image has been loosened. Tse et. al. [11] applied a modified crease test method combined with an automated image analysis system [12] to verify their fusing test procedure. Katja Sipi [13] measured optical density from the crease area. Adhesion percentage was determined as the ratio of these density values.

The authors have built a modified crease test apparatus. The apparatus can apply either static or dynamic pressure on the image sample while the load is traversing the back of the image. An image-processing module has been developed and compiled into open source software, ImageJ [14], to analyze the crease line. A crease test number (CTN), which is calculated by multiplying the grey level shift of the crease line image and the width of the crease line, has been used to characterize and quantify the crease test result. The crease test apparatus and in-house developed image processing module can provide more information on fusing quality and uniformity.

The crease test apparatus and the methodology for analyzing the crease line image by image processing technology are described below.

Description of Crease Test Technique

Crease Test Apparatus

A photograph of the dynamic crease test apparatus is shown in Figure 1. It includes a large metal platform, press bar, spring scale, and a dynamic force application stage (inserted on the top left in Figure 1). The metal platform can transverse from left to right and vice versa. Pressure to create a crease line on the image sample is applied from a spring scale and through a steel press bar that has a flat surface underneath. The sample is secured on the left side by a folder clamp. The wedge shaped dynamic force application stage enables the spring force to increase continuously by 500 grams across 15 cm. The spring applies a minimal pressure at the left side and a maximal pressure at the right side. A cam system is used to stop the platform and raise the press bar at the completion of the crease test to enable removal of the sample.

The apparatus is also capable of conducting conventional static force crease tests by removing the metal wedge stage and adjusting the spring force.

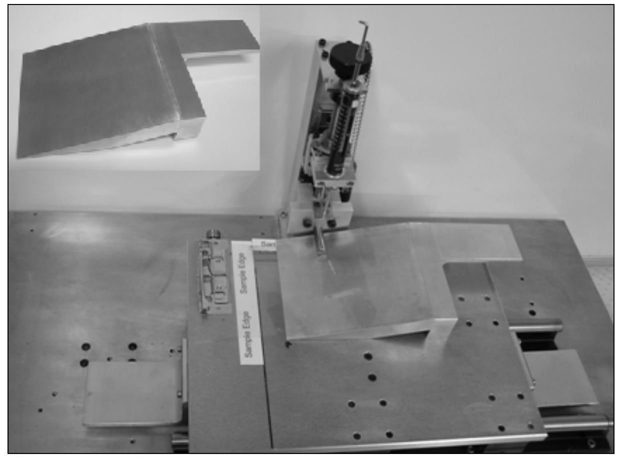

Figure 1*. Photograph of the dynamic crease test apparatus.*

Procedure of the Crease Test

The printed image is carefully bent with the image inside. It is then placed along the sample edge lines on the left and on the top, rested on the large metal plate or the wedged stage. The bent sample is covered with a transparency film that is secured at left by the folder clamp and pressed by a 15x5x1.5 cm metal block, which is placed on top of the transparency film and about 5 cm away from the sample edge, to ensure a crease line occurs in the desired image area. After the crease test, the image sample is removed from the apparatus, unfolded and loose toner particles along the resulting crease line are wiped away with a clean cotton swab. The crease line is then scanned by a professional graphic scanner, and an image file is saved for image processing. Figure 2 shows a typical crease line after a dynamic crease test.

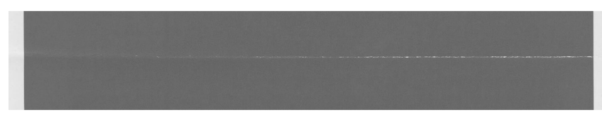

Figure 2*. Scanned image of a typical crease line after the dynamic crease test.*

Characterization of Crease Line by Image Processing Module

The resulting crease line can be characterized by visual inspection, by optical density measurement or by image processing. Due to the narrow width of a crease line, the optical density measurement on the crease line is extremely difficult. Visual assessment is very subjective and the result is greatly dependent on the assessor's experience. The result is also not easy to communicate. The authors have employed image processing technology to assess the crease line because the result can be quantified, and the assessment can be accomplished by any operator after minimal training.

In a study by Scott [15], the whiteness/darkness of an image was analysed based on grey level change by comparing the crease line and the image sample. The concept of the grey level has been adopted in this study.

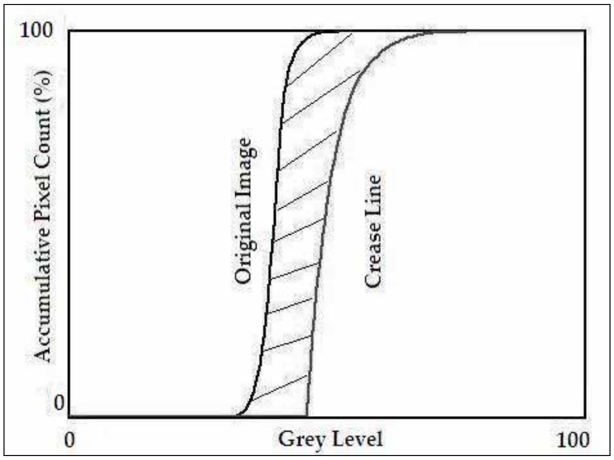

***Figure 3**. A plot of accumulative pixel count (%) of image sample and crease line.*

The crease line has two main features, lower optical density due to image particles lost and width of the crease line. The first feature is a change in grey level value of individual pixels. Figure 3 shows a plot of the cumulative pixel count in percentage versus grey level. The area enclosed by the original image and the crease line can be obtained by integration. The outcome from the integration is also equal to the difference in average grey level between the original image and the crease line. The area can be defined as a grey level shift or grey level increase on the crease line. It can be normalized in a range from 0 to 100, and is defined as the normalised grey level shift (NGLS). A positive NGLS indicates a reduction of the optical density on the crease line.

The second characteristic is the crease line width. By considering the NGLS and the crease line width, a new characteristic number has been derived to describe the crease line, which is a product of normalised grey level shift (NGLS) and the width of the crease line in mm, and it is denoted as crease test number (CTN). The CTN has a clearly defined physical meaning. It is proportional to the toner particles loss per unit length on the crease line.

The authors have developed an image processing module and compiled it into ImageJ to process the crease line image. In the dynamic crease test, the crease line is first divided into small segments, and then a CTN is derived for each segment. Figure 4 shows a typical plot of the crease test number versus applied crease force. In this plot, the CTN is increasing with increased crease pressure, becoming constant after the force exceeds a critical value. The fluctuation of the CTN plot is an indication of the non-uniform fixing quality of the fused sample.

Fundamentals of Crease Test

Overview of Image Damage by Crease Test

During the crease test, paper substrate and image were subjected to bend, then a hard crease line was created on the paper under pressure, and the image was damaged.

Damaged image fragments can remain on the substrate or detach and peel away from the substrate depending on the adhesion strength between the substrate and the image. The damaged image width or area per unit length is related to toner and image properties, such as the fracture toughness of resin and integrity of the image matrix etc, and also related to paper substrate properties.

In general the adhesion force can be classified into two categories: “basic adhesion” and “practical adhesion”. For an ideal planar interface, the basic adhesion strength corresponds to the summation of all atomic and molecular bonding forces acting between the adjoining material surfaces. In practice, however, the interfacial region can depend on many parameters, such as substrate surface morphology and physical inter-locking. In the case of image fixing on the paper substrate, the latter plays a dominant role.

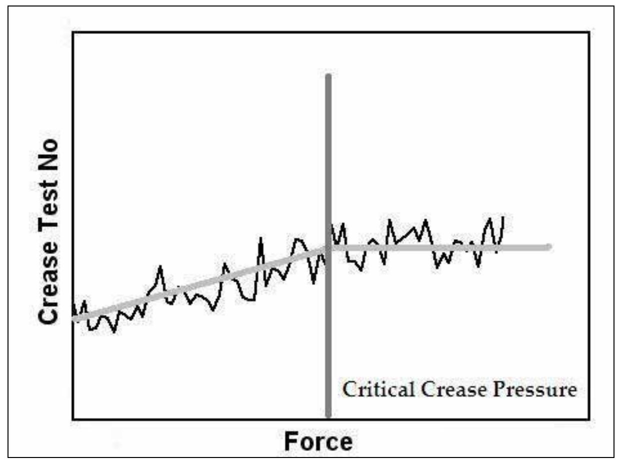

***Figure 4**. A typical plot of CTN versus applied force.*

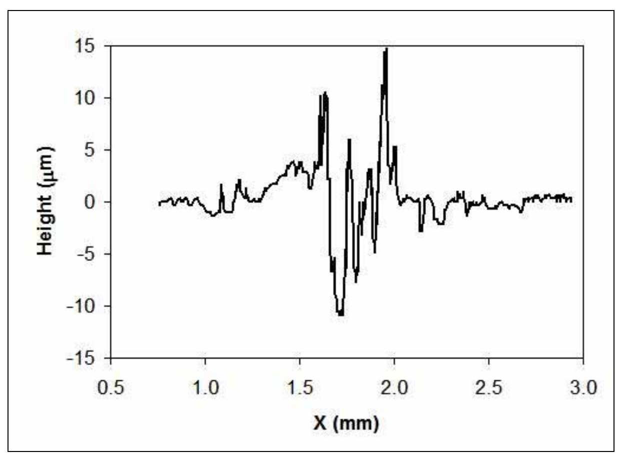

***Figure 5**. A typical surface profile of a paper substrate in the vicinity of hard crease line. A coated paper was used in the trial and a constant 500 gram force was applied.*

The damage to the image in the vicinity of the hard crease line is caused by bending. The curvature along the folding line decreases as the pressure increases. It can also be due to the paper substrate and the image layer having different physical properties that lead to different curling radii after the pressure is removed.

The damage on the hard crease line is due to the image being folded and also due to paper structure deformed.

Paper Deformation

The paper substrate is deformed after bending, folding and unloading of the pressure. The deformation has components of plastic and elastic deformation. The plastic deformation is permanent, and is not recovered when the pressure is unloaded. The elastic deformation is recovered upon removal of the load. The surface profile for a crease line on paper has been investigated. Figure 5 is a surface profile of the crease line on a coated paper. It shows that a permanent deformation has occurred in the region surrounding the crease line on both sides of the paper. For normal office printing paper, the width of the deformed area can be as much as 1.5 mm depending on the applied force and the thickness of the substrates.

Image Damage

After the crease test, the damaged image can remain on the substrate or peel off. For image fragments that come off the substrate, the following progressive stages must occur: crack matrix creation, crack saturation, interfacial de-bonding and fragment breaking.

The crack creation is a result of tensile stresses within the image layer during bending. The tensile stress is a function of the radius of curvature of the bending paper or image layer. Figure 6 is a SEM image of a crease line. On this sample, a section of the image of about 0.3 mm wide has been completely destroyed. Outside this region, the image has also been partially damaged as some cracks are observed. The size of damaged image fragments can be as large as 0.03x0.25 mm. On this SEM photo the coated layer on the paper substrate has also been damaged.

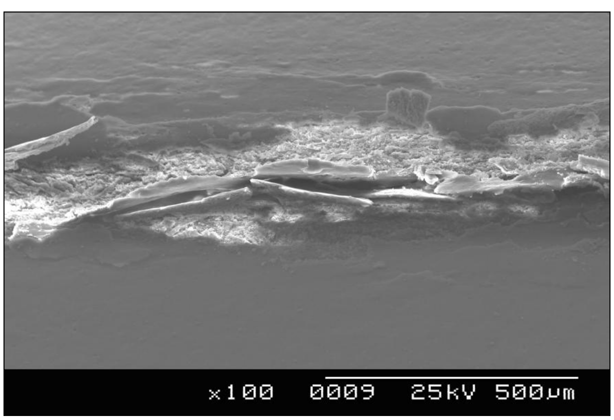

***Figure 6**. SEM image of the damaged image in the surrounding area of crease line. Loose image fragments were not removed for this SEM analysis.*

Examples of Crease Test

Crease Performance of Printing Samples from Commercial Printers

Two image samples (A and B) that were produced from commercial printers have been used in the investigation. The samples have identical patterns of solid strips of 4.5 x 15 cm. Both images have optical densities about 1.45 ODU as measured by Gretag Machbeth Spectrolino. Before the crease test, the image samples were conditioned in a room with stable relative humidity and temperature for 24 hours. Figure 7 is a plot of CTN versus applied crease force. The result reveals that 1) sample A has better crease performance than sample B when the crease force is higher than 300 grams, but has a wider crease line width at crease forces below 420 grams (Figure 8); 2) the resin in sample A is more likely to crack at low crease force but cracked image fragment can remain on the paper substrate, and resin in sample B is likely to be completely damaged under high crease force, with a wide crease line. In conclusion, the resin in sample A has higher fracture toughness than the one in sample B.

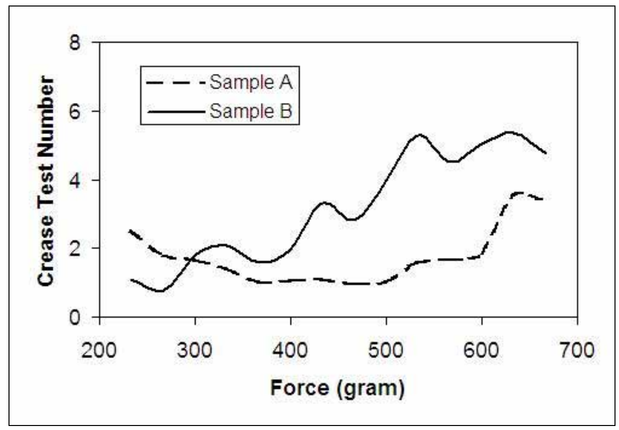

***Figure 7**. Plot of crease test number versus dynamic crease pressure. CTN was averaged from three repeated trials.*

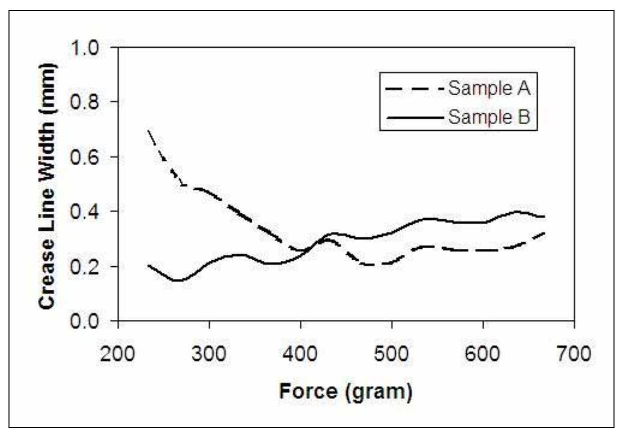

***Figure 8**. Plot of crease line width versus dynamic crease pressure. Data were averaged from three repeated trials.*

Impact of Relative Humidity

The effect of relative humidity on the crease performance has been investigated. The samples were conditioned in the evaluation room with stable relative humidity and temperature for 24 hours. All samples used in the investigation have identical patterns of solid strips of 4.5 x 15 cm and have almost identical optical densities of 1.45 ODU as measured by Gretag Machbeth Spectrolino. The static crease test results are listed in Table 1. The results show that a better crease test result has been obtained at lower relative humidity of 40%. As the relative humidity is increased, crease test performance decreases but becomes constant above about 60%. The slightly worse crease test result at high relative humidity may be due to increased water content causing a weaker interfacial adhesion force.

Table 1 Static crease test result at various relative humidity. The data are obtained from average of three trials on cyan image patterns. Crease force was 400 grams. The image samples were printed from a commercial offset printer.

Relative Humidity	CTN
40%	2.4
60%	4.0
80%	3.9

Conclusion

The modified crease test method has been improved by a dynamic crease force application and by utilization of the image processing technology. The crease test is not only capable of performing routine fixing quality test, but also capable of revealing more information about toner formulation. The quantitative results from the crease test apparatus are easy to communicate to printing professionals. The apparatus is easy to operate, and the result is reliable.

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Author Biography

Dr Charlie M MAO received B.Eng and M.Eng degrees in China in the early 1980s, and a Ph.D. in Australia in 1995. After working as a university lecturer in the area of mining technology, and as a research scientist in soil science, he is now a principal scientist/project manager at Research Laboratories of Australia. Since joining RLA in 1996, he has been investigating image development and process optimisation, developing image quality analysis methods, and innovating image fixing testing apparatus and analyzing procedures. His theoretical and experimental work has contributed to the steady advance of novel liquid electrophotographic technologies.

Alvin Chowles received his MSc and PhD degrees in South Africa at the University of Port Elizabeth. After working as a university senior lecturer, and as a researcher in material science and renewable energy technologies, he is now senior research scientist at Research Laboratories of Australia. Since joining RLA in January 2004 he has been investigating mechanisms of image development, process optimisation, and toner management and recycling in liquid electrophotography. He is also responsible for the development and advancement of high-speed digital printing at RLA.