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Statistical approach in fold crack distribution analysis

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Introduction

Different computer-aided assessments have been introduced lately as new techniques for quantitative surface damage characterisation. These methods are based on image processing and analysis and have similar concept of damage registration, digitization, and image feature calculus. However, they differ in sample preparation method, digitization process, and image processing steps. Furthermore, they have defined only one image feature, only for quantitative damage characterisation, instead of taking advantage of using additional features provided by the computer-aided assessment methods.

In this study, a new digital image feature, the fold crack distribution, has been introduced, analyzed and discussed its potential usage for fold-crack quality assessment. The fold crack distribution is intended to numerically determine the crack scattering over the folding line. For that purpose, descriptive statistics, mean values with standard deviations and coefficients of variation have been used.

Methods

In order to simulate the expanding tendency of surface damages glossy coated offset papers have been used in five different basis weights (90, 115, 130, 150 and 170 g/m^2). Prior to folding, the sample papers were printed on KBA Rapida 75 offset machine in full tone cyan to make the cracked surface properly visible. The folding process was done on Horizon AFC546AKT folding machine, using a buckle folding unit with standard rollers and gap adjustments. 50 samples of each paper grade were folded in both paper grain directions, in machine direction (MD) and cross direction (CD).

The image acquisition was done on Canon CanoScan 5600F flatbed scanner (resolutions of 1200spi, sRGB color space, no advanced image settings, file type BMP and color depth of 24bit). The scanning window was 4x25mm, and it was set up along the folding line. During the scanning process, the samples were mounted on a holder with five different inner angles (15°, 30°, 45°, 60°, 90°) or placed in a flat position (i.e. 180°). After the acquisition process, greyscale images were generated from the original RGB images via red channel extraction, while the binary ones were delivered using Otsu automatic thresholding segmentation. The folding line detection (position and direction) was determined by Hough transform. Large-scale print non-uniformity and detached coating particles were eliminated by custom masking technique.

The crack distribution calculus is based on the arithmetic mean value and its corresponding standard deviation of white pixels` sums registered in every row of the analyzed image. Lower values of standard deviation indicate that the surface damage is evenly distributed along the folding line, while higher values are corresponding to a few and/or bigger and disjoint damages.

Results

Although crack distribution is determined via standard deviation, the coefficient of variation is a more interpretable form. Therefore, results are presented in that manner.

The white pixel count values have an increasing tendency by increasing the sample papers' basis weight and have slightly higher values for CD folded samples (Figure 1b) than for MD folded ones (Figure 1b), although some deviations can be observed. These results follow the literature data and the primary hypothesis that papers with higher basis weight and thickness generate larger surface stresses during the folding process, especially in the cross direction (CD folding).

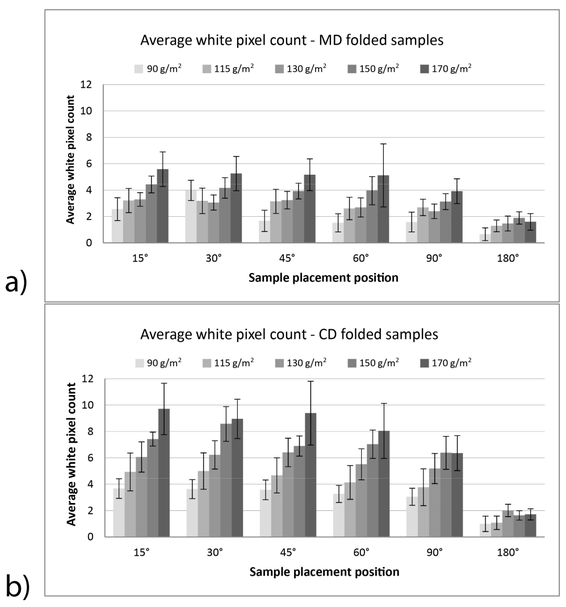

Figure 1 *Average white pixel count for machine (a) and cross folded samples (b)*

Results for the standard deviation of white pixel count suggest that all samples had more or less similar crack dispersion over the folding line, but a detailed visual analysis showed that this was not the case. Thus, the results in this form do not reveal much about the nature of the coating damage, due to the differences in the mean values. For appropriate data analysis in a case of varying mean values, the crack distribution metric should be defined via the coefficient of variation.

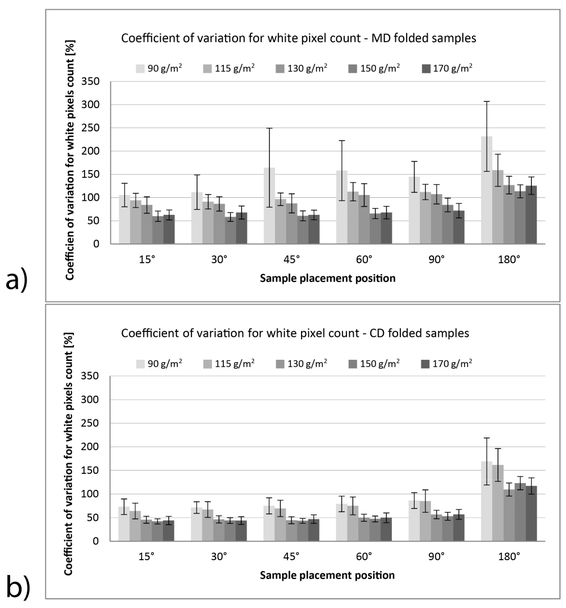

Figure 2 *Coefficient of variation for white pixel count of samples folded in machine (a) and cross direction (b)*

Results of coefficient of variation for white pixel count [%] (Figure 2a-b) have decreasing tendency by increasing the sample papers' basis weight and have significantly lower values for CD folded samples than for MD folded ones. Although, there are some minor deviations mostly for the thickest paper (170 g\m^2), the results follow gradual stepwise changes. For samples folded in cross direction, this trend is more emphasized and extends to thinner papers. These results indicate that even samples with lower basis weights get long and connected crack lines during CD folding. The more uniform, step-like decreasing of coefficient of variation values for MD folded samples (Figure 2a) indicates that basis weight has a more significant influence on the crack distribution in MD folding than in CD.

Discussion / Conclusion

The obtained results, in general, demonstrated that the mean white pixel count has an increasing tendency by increasing the basis weight of the substrates and had a slightly lower value for samples folded in the machine than cross direction. These results confirm the basic assumptions that on thicker substrates (i.e. on samples with higher basis weight), the crack lines are larger, longer or grouped and that the folding process generates higher surface destruction in cross than machine direction.

The basic concept of using standard deviation for crack distribution measure seems to be correct since lower values indicate evenly distributed surface damages, often in the form of long and thick crack lines over the entire folded area. In comparison, higher standard deviation values correspond to a few, small or medium, but usually disjoint cracks. However, instead of the standard deviation, the coefficient of variation can provide more accurate results for a more realistic characterization of crack scattering, regardless of the difference in mean values. Based on the obtained results, it can be concluded that the proposed approach to the calculation of crack distribution can serve as a new image characteristic for the qualitative measurement of the fold-crack resistance of coated papers.

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