Influence Of Fibre Properties Of Paper On The Folding Quality Of Digitally Printed On-demand Products

Zeeshan Mehmood, B.Eng. and Prof. Dr. Volker Jansen

keywords: fibre rupture, folding, creasing, cracking of paper coating, coating, cracking phenomenon, ink splitting, coated paper, grain direction

Abstract

During folding, the paper is subjected to mechanical stress. Excessive stretching or compression of the paper fibres can cause the coating of the paper to crack or, in the case of uncoated papers, the fibres to rupture or the ink to split from the fibres. The degree of fibre or coating cracking and/or ink splitting are informed by the type of fibres, lignin content, the humidity of the paper, and by various chemical compounds used for filling, sizing and finishing. Quality defects occur in the spine or in the fold of single layer brochures and covers. The defects may result in the product no longer being usable or sellable, which may lead to technical complaints. The objective of this work is to analyze and compare the influence of the fiber direction of the paper (in machine direction [MD] and cross machine [CD] direction) by investigating the formation of cracks after folding. The aim is to identify other influencing factors besides the fibre direction (running direction) that can affect the quality of the fold.

Introduction

Meccanotecnica (Italy), a post press equipment manufacturer, have developed thread sewing machines for on-demand production, which can fold, collate and stitch digitally printed sheets to produce individualized or personalized pamphlets, brochures or books.

According to Meccanotecnica (2021) manufacturers of post press equipment are reportedly confronted with enquiries from customers who criticize fiber *cracking* in the fold[1]. Some industry representatives claim that fiber *cracking* predominantly occurs in digitally printed products and demand from the equipment manufacturers

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flawless production results, regardless of the printing technology, paper type or weight used for folding and stitching.

According to literature spine cracking is a common phenomenon in paper folding and just too well-known to post press manufacturers and binderies (Tech-ni-Fold 2015). It is particularly noticeable when dark ink is used as a background color on the cover, concealing the entire product including the spine.

The equipment manufacturers assert (Meccanotecnica 2021), that folding *in machine direction* (grain direction parallel to the spine or fold) is assumed to overcome cracking defects as it ensures that a large proportion of the fibers are not over-stretched (mechanical stress). To avoid an increased risk of cracking, folding *cross machine direction* (grain direction cross to the spine or fold) is therefore strongly discouraged. However, due to the smaller paper sizes, digital printers cannot fold in grain direction, as press manufacturers of digital printing systems advise their customers to choose the grain direction to be printed parallel to the direction of the printing press in which the paper travels (grain direction cross to printing cylinder). According to press manufactures this is in order to ensure a more stable paper run. If, however, sheets with a format of ISO SRA3[2] are folded to produce an ISO A4 format of the booklet, the spine will inevitably run cross the grain direction.

However, according to printers, some print results show that cracks also occur in machine direction. To overcome possible defects manufactures suggest the introduction of a creasing tool which is said to reduce the defect depending on the geometry of tool. Yet, not all creasing tools deliver the required results. Hence, the post press machine manufacturer Meccanotecnica, Italy (2021), asked Hochschule der Medien to further investigate the reasons for the cracking phenomenon.

One of the most important rules published on the subject of fibre tearing is that the fibres must run parallel to the fold, the so-called spine, to prevent the fibres from tearing. It ensures that the fibres are not overstretched during folding, according to the literature.

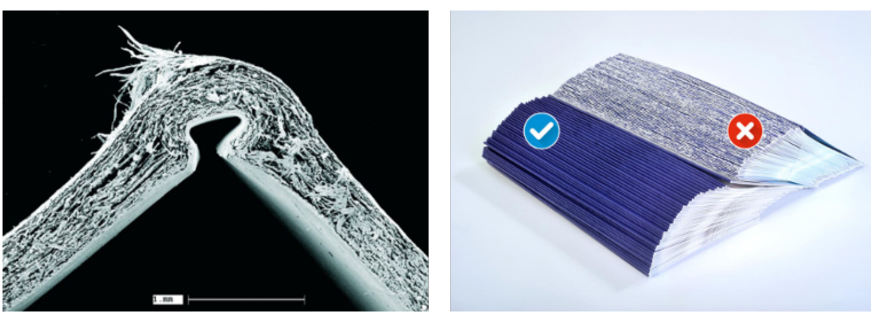

Fig. 1: *Fibre cracking in the spine*

Another published aspect is that the bending resistance of the paper influences the degree of cracking. Bending resistance is the ability to resist deformation under load and depends on the sheets' weight, thickness, ash content and type of fibre. It is assumed that the fibres obtained from mechanical pulp are less flexible and prone to rupture compared to chemical pulp. Fibres obtained from secondary pulp are classified as shorter and are therefore less susceptible to tearing.

In addition, it is generally assumed that visible cracking in the spine of coated papers is due to cracks in the surface coating, while cracking in uncoated paper is due to the rupture of fibres. To reduce the tendency to crack, humidification is recommended. It is suggested that the paper be conditioned at a relative humidity of 60% and a temperature of 23 degrees Celsius (Holik 2013).

Is it really that simple? Hence, the research question is raised: Are the relevant factors from literature research which lead to cracking the sole reason for a visible *cracking line* on the spine after the folding process?

As shown in figure 2, the research objectives comprise an analysis and an evaluation of the cracking phenomenon followed by an examination of possible causes and applicable methods of prevention.

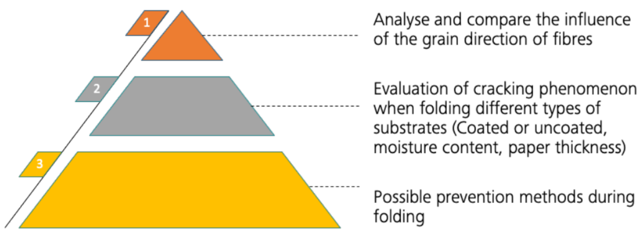

Fig. 2: Research objectives

Fig. 2: *Research objectives*

Methods and Materials

The methodology of the analysis was to print coated and uncoated paper grades with liquid toner ink in variable data printing and with oil-based ink in offset printing, fold them on a conventional folding machine used in an offset workflow and compare the folding quality with the results obtained from a workflow used for finishing digital print products.

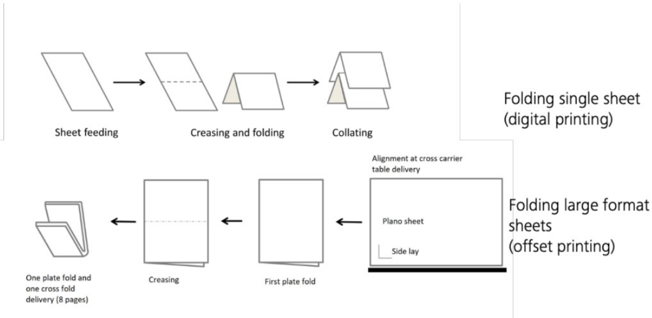

Fig. 3: *Two principles*

Two test series were scheduled, a preliminary and a main test series. For the preliminary testing various coated and uncoated paper types (suitable for digital printing and ranging between 120 g/m^2 and 250 g/m^2) were printed with a black solid ink layer (thickness ≈ 1 μm) using digital printing (HP Indigo) and offset printing (Heidelberg Speedmaster). As shown in figure 3 two folding principles were used, first the folding was done by buckle folding (MBO K70) and by single sheet folding in a thread sewing machine for on-demand production (Meccanotechnica UNIVERSE). The same creasing tool by tech ni fold was used on both machines. The reason why two different systems were used is due to the way the industry deals with impositioned sheets. In offset printing, large impositions with 8, 16 or 32 pages are usually used (see figure 3). After printing the sheets are folded three or four cross. This always leads to the fact that the resulting spine of a folding sheet is folded less sharply due to the overlapping number of individual paper layers, whereas a digitally printed sheet features a single fold to produce a final folding sheet. The spine of each single sheet is therefore inevitably a sharper fold. The pre-test included a number of analyses. First of all, the ash content of the individual papers was measured to determine the fibre content.

The series of preliminary tests done was to draw a first comparison on how different printing and folding techniques affect the folding behavior and the quality of the spine under different folding, print and paper conditions.

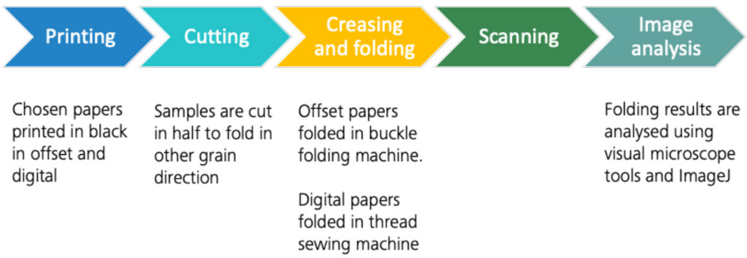

Fig. 4: *Methodology of preliminary tests*

An important aspect of the main tests was to analyze and compare the influence of the fiber direction of the paper (in machine direction and cross machine direction) by investigating the formation of cracks after folding. The intention was to identify more influencing factors besides the fiber direction (running direction), gauge, bending resistance and coating that can affect the quality of the fold. Specific specific substrates were selected from the preliminary test that showed conspicuous results. These were then folded again in the main test series to assess the influence of grain direction (fiber direction) on the formation of cracks in the fold, with the aim of identifying suitable prevention methods when folding papers.

The aim of the main tests was to determine the influence of fiber direction on cracking in the paper and to evaluate the paper condition and its performance during the folding process. For the methodology of the main tests see figure 5. It was to find out whether the *cracking* actually occurs due to fiber *ruptures* on uncoated paper or *surface cracks* in the coating of coated paper grades. In the main tests, the images of the spine were quantitively examined with the Java-based Image processing software Image J.

ImageJ is a free image analytical software offering ready-to-use tools that produces objective and quantitative data. It can display, edit, analyze, process, save, and print 8-bit colour and grayscale, 16-bit integer and 32-bit floating point images, and is used for measuring structures on microscope images. It can read the images produced on the Keyence 3 D microscope which the student used for his analysis.
The results illustrate the extent of the cracks in the fold, which were evaluated and assessed using a Keyence 3 D microscope and the ImageJ analysis software. Consequently, the percentages of cracked areas along the fold line in different substrates were analyzed and correlations between fiber, paper chemistry and machine printing were found. It shows that the methods used in this analysis provide useful information on the various factors that influence fold quality. It was established that the development of measures against cracking in the fold requires a deeper understanding of the production process starting from the composition of paper to the printing and finishing process. In addition to the grain direction, there are important factors related to paper, ink and the surrounding climatic conditions that can have an adverse effect on the quality of the final fold. The composition and strength of paper as well as the appropriate creasing tool can influence the fold quality and reduce cracking.

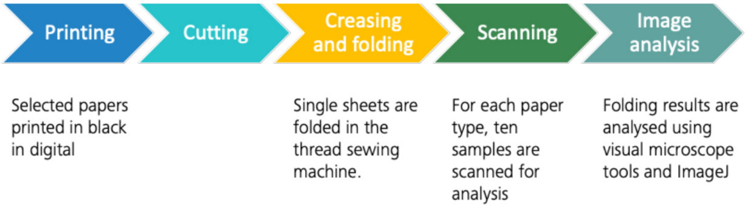

Fig. 5: *Methodology of main tests*

Results and Discussion

After selecting the area to be analyzed, a set of parameters were defined such as threshold values to help obtain data. The image was inverted and the pixels in the image resulting from the white cracks were counted. Counting the number of white or black cells is an objective way that perfectly represents the cracked area percentage along the folding line. The lower the percentage, the smaller the cracked area on the surface.

All steps performed when using imageJ were recorded in a macro so that image J could automatically analyse other images with the same steps.

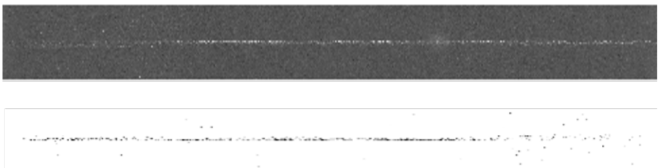

Fig. 6: *Folding results analysed using ImageJ*

The images analyzed with the 3-D microscope also showed that fiber cracks do not usually occur in digital printing on uncoated paper. Instead, a phenomenon of ink splitting occurred due to poor adhesion of the ink to the fiber. Such phenomena did not occur in sheets printed by offset, indicating that the ink is applied differently and the anchoring process is stronger.

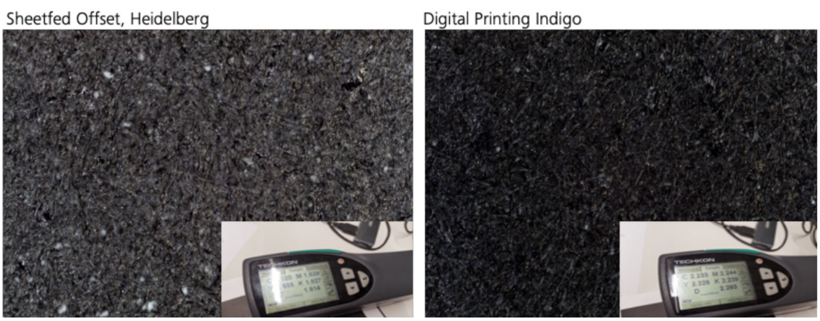

Fig. 7: *Comparison of ink lay-down*

The results can be explained with the different binder systems used in the ink. Liquid toner stays on the fibre, whereas the oil-based binder of offset tends to penetrate the fibre. However, the level and type of size and a possible surface primering have an influence too.

According to figure 7, the papers printed in offset showed a higher percentage of cracking than the ones printed in digital contrary to the hypothesis.

It was expected that a sheet consisting of several pages would have fewer cracks in the fold than a single-folded sheets due to the larger number of sheets lying above each other. Hence the fold would not be as pronounced.

Figure 8 below shows different papers and their tendency to develop crack structures in grain direction (MD) or cross the grain direction (CD) during folding.

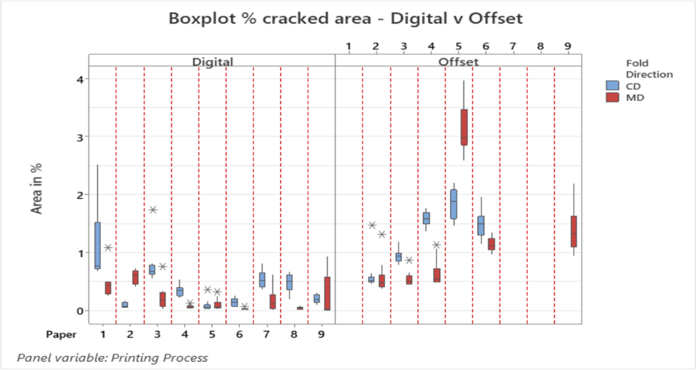

Fig. 8: *Degree of cracking in MD and CD*

However, the result contradicts the general assumption that digitally printed papers (papers 1 to 9 on the left side of the diagram) that have been folded have a higher level of fiber cracking. The results suggest that the opposite is true.

According to an analysis of the ink laydown, the PE binder in Indigo inks result in a higher ink layer, which with is between 1…3 µm in thickness. Offset uses varnish made of hard resin and vegetable oils which result in an ink layer thickness of 0.5…1.5 µm. Densitometric measurements show higher values for the liquid toner inks.

Paper printed with HP liquid toner ink is darker in color meaning the ink density is greater. The lower values with offset ink are a result of pin holes formed on the surface of offset printed papers. These pinholes are not due to fiber or coatings cracking. The pinholes are the result of a lower layer thickness of the ink layer. They are easily detectable by the image processing software imageJ.

Some papers show better results when folded in the cross the grain direction (CD) while other perform better when folded parallel to the grain direction (MD). Factors affecting these results are of various kinds. They include the synthetic sizing agents, which play a role in the ink acceptance of the fiber. Sizing can be used to reduce the tendency for ink to be absorbed due to the capillary of the fibers, and synthetic polymer sizing can decrease the surface energy of the fibers, resulting in reduced ink adhesion to individual surface fibers.

Depending on humidity, fibers either absorb or lose moisture. How much moisture they lose depends on the type of pulp and how it is treated in the pulping process. If pulp is intensely beaten the surface area increases and more moisture can be absorbed. The absorption effect can be directly influenced by the use of specific synthetic size agents. If paper is left too long in stack it can lose moisture. Dry paper fibers are prone to cracking when exposed to physical stress. A relative humidity of between 45 and 55% at around 20 to 24 degrees Celsius is considered sufficient to prevent the paper from losing too much moisture, which would ultimately lead to an increased observation of fibre rupture on the spine during folding (Sappi 2, 2006:8).

For coated papers the elasticity of the synthetic polymer binder agents in the coating plays a deciding role. It depends on the polymeric chemistry used. Low elasticity of the binder system can lead to an increased tendency to cracking, which can be exacerbated by insufficient relative humidity. It reveals that influence of the grain direction cannot be sole reason for cracking in the fold. With the introduction of customized creasing tools with rubber blades, we can reduce, but not completely prevent, the formation of cracks on the paper. With uncoated paper, for example, the use of a creasing tool with a blunt rubber blade can largely prevent the ink from splitting. Ink splitting can be observed on sized papers suitable for digital printing, especially when using PE binder-based liquid ink systems.

This is due to the lower surface tension of the PE based oil compared to the varnish used in offset inks. Less intermolecular forces can form. Only lamination encloses or encapsulates the surface of the paper and will eliminate cracking.

Conclusion

In practice, there are various factors to consider when folding, depending on the production equipment. The settings of the creasing tool to be used are important before creasing. The appropriate crease width for the creasing tool should be chosen according to the grammage recommendations of the manufacturer. If the crease width channel is too wide (in relation to the paper gauge) then a good crease cannot be formed because the paper has too much leeway. A creasing channel that is too narrow leads to displacement of the material and compression in the fold, which in turn increases the risk of cracking in the fold as well as fold breaking.
When setting up a folding machine, the paper has to fold along the creasing line; otherwise, the creasing line deforms, which may damage the paper structure. Additionally, the crease to be formed must be linear, centered and of the correct depth. The creasing line may also deform if the creasing tool has geometric irregularities, such as sharp edges. Therefore, you must always inspect whether the creasing tool is still intact.

Cracking is less likely to be noticed if we do not print darker solid areas over the fold. Therefore, it is advisable not to print over the fold. It would also be recommended to test the folding behavior of printed paper with unprinted paper to determine how the different printing techniques influence the cracking in the fold.

The relative moisture content of the paper is essential for avoiding fold breaking. Paper that is too dry tends to break more quickly because it is brittle and has lost its suppleness. The ideal relative humidity level for paper storage should be between 45% and 55% (Sappi 2, 2006: 8). A climate cabinet may be used to determine how different humidity levels can affect the moisture content of the paper and therefore the printing and folding results. conclusions about the extent to which the cracking in the fold depends on the composition of fibers and coating cannot be drawn with regard to the papers tested, since the composition of the fibers and the coating is unknown. What is known is that in order to obtain an optimal folding result, the paper properties can be influenced by several factors. The strength of the paper plays an important role and it can be influenced by the type of the substrate. From the investigations in the main tests, the influence of the grain direction could not be eliminated by creasing the paper before folding. Despite using the recommended crease channel widths for each paper type, some substrates produced better results when folded in the cross-machine direction while others performed better in the machine direction. During the investigations, other factors have also been identified that can influence the fold quality. Some of these include the strength properties of paper as well as the fiber content and composition of the paper. Additional factors include the bending stiffness of the paper as well as the elasticity of the binder. As a result, the selection and processing of raw materials can be coordinated to make papers with desirable properties for printing and folding. The image-analytical evaluation methods used provided an objective and quantitative way of representing the cracked areas along the folding line. However, other experimental tools such as a scanning electron microscope (SEM) could have been used to examine the folding line in more detail. Furthermore, other analytical software can be explored to evaluate and compare the cracking phenomenon in different substrates alongside the ImageJ software program. Figure 9 summarizes the results and gives some indications of reasons and remedies.

● Negligible ●● Visible ●●● Strongly visible

DEFECT	EFFECT		REASON	REMEDY
	MD	CD		
Fibre rupture	●●	●●	Moisture content low; Geometry of crease	Use dehumidifiers; Scoring knife
Ink splitting	●●●	●●●	Binder and size Adhesion of ink Type of ink	Type of creasing tool
Coating crack	●●	●●	Elasticity of binder Type of coating	Lamination

***Fig. 7:** Comparison of ink lay-down*

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Citations

1. Quality defects in the spine are characterized by ink splitting or fibre cracking a white line which reveal blank fibres or fillers that lay underneath the printing ink.

2. SRA3 = supplementary raw format A3. It slightly larger than its corresponding “A3” paper size. For example, a finished sheet of A3 paper is 420mm x 297mm, but SRA3 is 450mm x 320mm.