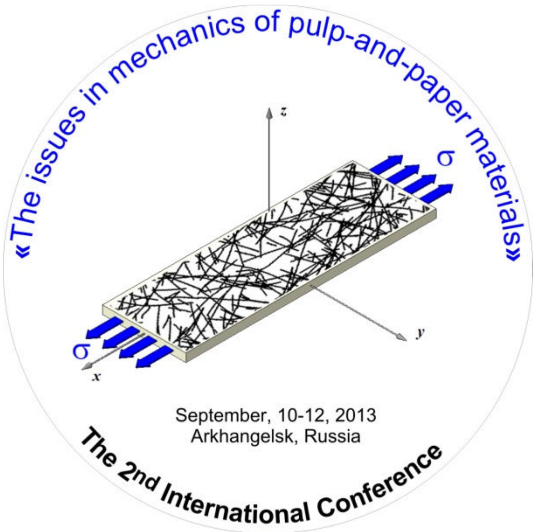
Ministry of Education and Science of the Russian Federation
Northern (Arctic) Federal University named after M.V. Lomonosov

THE ISSUES IN MECHANICS OF PULP-AND-PAPER MATERIALS



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THE FORMABILITY OF PAPER-BASED MATERIALS: THE ROLE OF EXTENSIBILITY AND OTHER MECHANICAL PROPERTIES OF PAPER

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One major limiting factor for the paper-based packaging is the poor formability of paper materials. However, very little is known about formability. The major factors contributing to the formability of paper-based materials were studied in this work. Extensibility was identified as the crucial formability factor in the processes with the fixed blank, thus, combined approach to improve extensibility was suggested.

СПОСОБНОСТЬ К ФОРМОВАНИЮ БУМАГОПОДОБНЫХ МАТЕРИАЛОВ: ВЛИЯНИЕ УДЛИНЕНИЯ ПРИ РАЗРЫВЕ И ДРУГИХ МЕХАНИЧЕСКИХ СВОЙСТВ БУМАГИ

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Одним из основных ограничивающих факторов для использования бумаги и картона в упаковочных материалах является их плохая способность к формованию. Следует отметить, что данный вопрос недостаточно изучен на данный момент. Факторы, влияющие на способность формования бумаги в трёхмерные формы, были изучены в данной работе. Удлинение при разрыве определяет глубину формы в процессах с фиксированным положением бумажного полотна.

INTRODUCTION

With all advantages of paper as a packaging material it yet cannot compete with packaging made of plastics in terms of attractiveness of the package design, and ease of processing. Paper packaging appears in rather simple geometrical forms, while plastics can be formed to multiple shapes. The main limiting factor for the production of advanced 3D-shapes from paperboard is the poor formability or, in other words, the limited ability to withstand certain types of plastic deformations without damage [1].

Formability can be defined as a complex mechanical property which determines performance of material in the forming process. Formability depends on several mechanical properties of paper, which can be regarded as components of formability: elongation, compressive strain, compressive strength, and paper-to-metal friction [2]. However, actual role of each mechanical property in respect to the maximum depth of shapes, appearance of the shapes, and the runnability in the forming process is not clear. Moreover, relative importance of formability components is varying according to the type of the forming equipment, and forming conditions [3].

In this work, results of forming experiments with three different forming devices were linked with the mechanical properties of the paper. Formability of seven different commercial paperboard samples was evaluated using variables reflecting the maximum depth of the shapes, and visual appearance. Further, these parameters were compared with the tensile strain, compressive strength and strain, and paper-to-metal friction coefficient. Additionally, novel combined approach to improve the extensibility of paper up to 25%-points was suggested.

EXPERIMENTAL

Seven different samples of paperboard supplied by Stora Enso Oyj were taken for experiments. Three different forming devices were used for the characterization of the formability, they shown in the Figure 1.

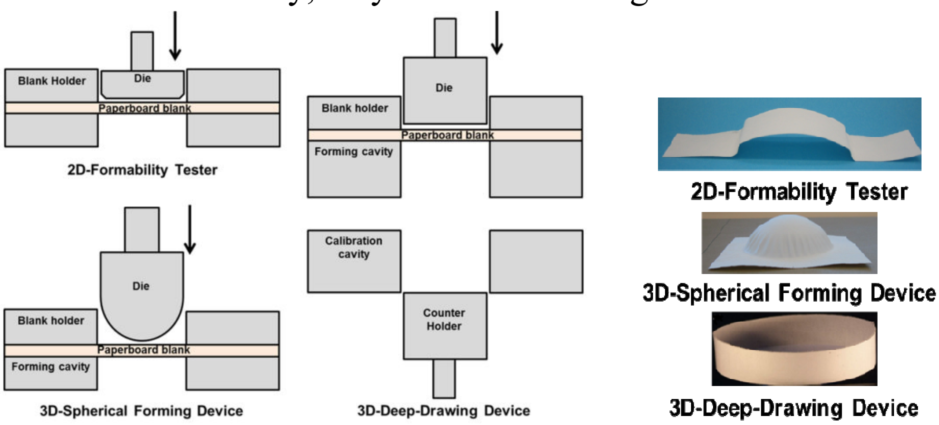

Figure 1. Schemes of operation and images of the shapes for 2D-formability tester, 3D-spherical forming device, and 3D deep-drawing device

The principal difference between these forming devices is in presence or absence of paperboard blank sliding in the process, in the 2D-Formability tester and 3D-spherical forming device sliding is prevented, while in deep-drawing, blank is sliding to the cavity under the certain tension created by blank holding force. In the deep-drawing process, wrinkles are the most important quality characteristic of the shapes. The character of the wrinkles distribution is the reflection of the uniformity of mechanical load distribution on the surface of the shape. The frequencies of the wrinkles were measured using light microscope. The mean value of the distance has been taken as the result. An example of the side wall with the wrinkles can be found in the Figure 2.

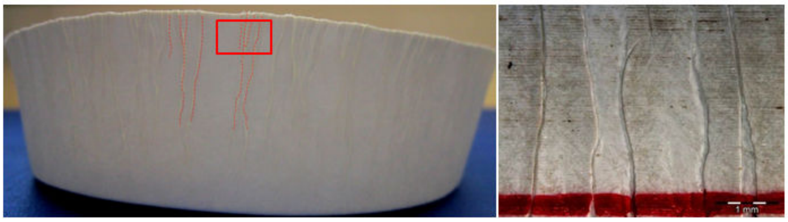

Figure 2. The image of shape with wrinkles and microscopic image of wrinkles

The evaluation of the visual appearance of the shapes was based on following hypothesis: short distance between wrinkles means that there are lot of small and shallow wrinkles while long distance means that there are fewer wrinkles, highly irregular in their dimensions, which indicates poor appearance of the shape.

RESULTS

Forming of paperboard

In the forming processes where paper blank fixed firmly, material would yield in straining deformation, and thus should have sufficient elongation, in order to produce shapes deep enough to have practical relevance. The relation between the elongation of materials and formability is being an indication of such fact. The correlation between formability strain (2D-formability tester) measured at 70°C and the elongation of the commercial samples is shown in the Figure 3.

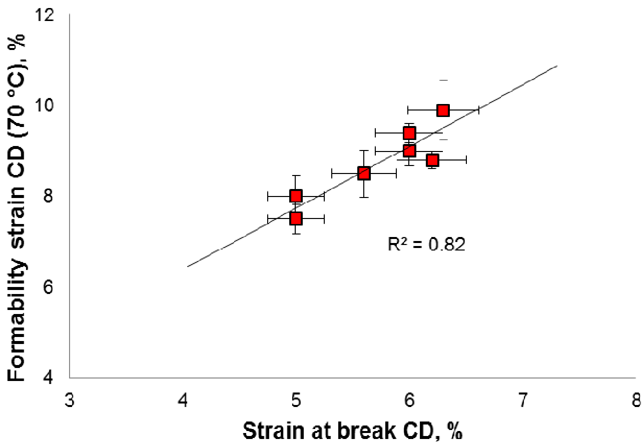

Figure 3. The correlation between formability strain in CD measured at 70°C and the strain at break value (CD) of the commercial samples

In deep-drawing, paperboard is forced to slide against the forming cavity under certain force caused by the slot tightening of the paper between the die and the forming cavity (forming gap ≤ 0,7 x thickness of the material). The transverse compressive deformation is resisted by the frictional forces.

The relation between the frequency of the wrinkles on the side walls of the shapes and coefficient of the dynamic friction is shown in the Figure 3.

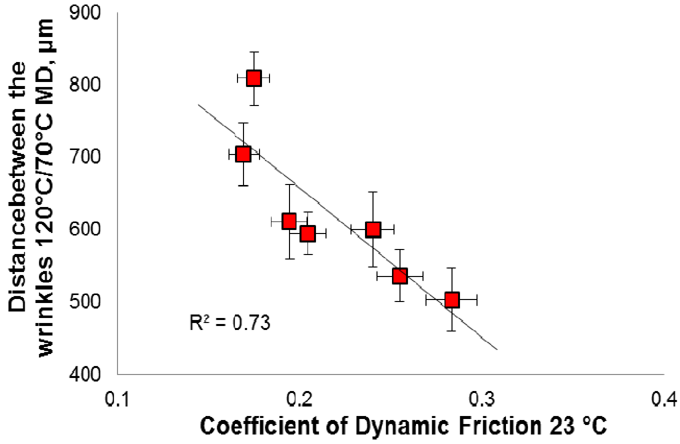

Figure 3. The relation between coefficient of the dynamic friction measured at 23 °C and distance between the wrinkles 120/70 °C

As can been seen from the Figure 3, high coefficient of dynamic friction has a positive influence on the wrinkles distribution. It can be suggested that the frictional forces prevent displacements caused by compression deformation, which decreases the area where wrinkle would be formed. Despite of the fact that the high coefficient of dynamic friction may improve visual appearance of the shape, it can also increase the probability of fractures, and may contribute to discolouration (darkening) of material at high temperature [3].

Wrinkles are the consequence of the compressive stresses caused by lateral contraction of blank in forming. The relation between frequency of the wrinkles and compressive strain of the paperboard is shown in the Figure 4.

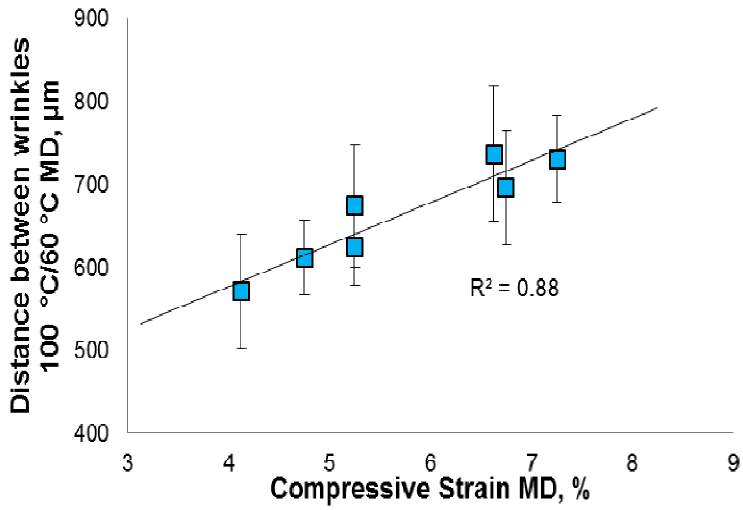

Figure 4. The correlations between compressive strain in MD and the distance between the wrinkles

The correlations in the Figure 4, show that the compressive strain is one of the crucial factors that determine frequency of wrinkles formation. The lower compressive strain paper has the shorter distance between the wrinkles, and therefore appearance of the shapes is better.

Combined approach for the improvement of extensibility

It was shown that the extensibility is the primary property that control depth of the shapes in such processes as hydroforming, vacuum forming, embossing, and hot pressing. By the improvement of the extensibility to new high levels it is possible to increase competitiveness of paper in comparison with plastics, on a packaging market. Extensibility of paper relies on the properties of single fibres, bonding between them, and structure of the fibre network. The combined approach for the improvement of the extensibility of paper-based materials was compiled based on the throughput consideration of these principal factors. This approach can be seen from the Figure 5

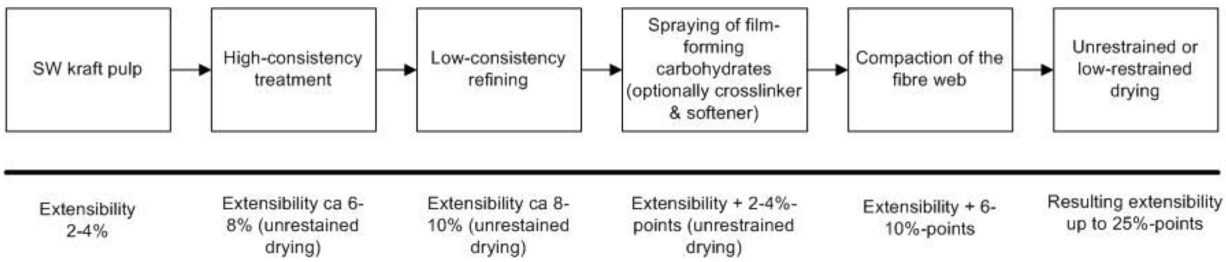

Figure 5. The treatments on the fibre and fibre-web levels applied to improve extensibility of paper

The combined approach showed in the Figure 5 combines treatments primarily on the fibre level (refining), improvement of bonding via spray addition of carbohydrates, with the consequent compaction of the formed fibre web. In order to fully utilize shrinkage potential of the paper it should be dried unrestrained or with minor restraint. The refining procedure and spray addition of carbohydrates were described in previous publication [4].

Certain hydrocolloids have an ability to form films; once this film is transferred onto paper it binds with fibres and stays primarily on the surface. Upon drying, carbohydrate film is starting to shrink, and commonly shrinkage potential of film is higher than this of paper, which is providing additional drying shrinkage to whole film-paper structure. This yields in improved extensibility. Compaction (can be referred as microcreping or Clupak®) is the in-plane compression treatment of wet (dryness ca. 60 %) paper which provides additional extensibility, primarily via buckling of fibres. The combination of aforementioned treatments allowed to produce with the elongation greater than 25%, additionally this paper has performed well in the 3D-forming process.

CONCLUSIONS

1) The requirements for adequate formability depend on the forming process. In processes with sliding blank it depends primarily on the metal-to-paper friction and compressive strain, while in the processes where blank is fixed firmly it depends on the extensibility.

2) Combined approach which unites treatments on fibre and fibre network levels may increase extensibility of freely dried paper up to 25 %.

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