Preferred citation: R. Wilken, H.L. Baumgarten and B. Hartmann. Converting challenges to paper and board. In **Products of Papermaking**, *Trans. of the Xth Fund. Res. Symp. Oxford, 1993*, (C.F. Baker, ed.), pp 1569–1633, FRC, Manchester, 2018. DOI: 10.15376/frc.1993.3.1569.

CONVERTING CHALLENGES TO PAPER AND BOARD

H L Baumgarten, R Wilken and B Hartmann
Papiertechnische Stiftung PTS
Hess-Str 134
D-80797 München

ABSTRACT

The paper converting process forms part of that whole area of engineering known as conversion technology, which applies the rules and procedures acquired in converting to the manufacture of finished products from paper and board.

The resulting conversion techniques consist of a sequence of subprocesses in which certain changes in the state of the materials are brought about. The sum of these changes leads from the raw materials paper and board up to the final products.

For the reshaping, separating and connecting processes covered by this report, the specific characteristics and physical principles will be

described and the main options of technical realisation discussed. In a number of applied examples, details of the real physical mechanisms encountered in the individual processes will be gone into.

The state of knowledge just set out is required for optimised designing of paper and board articles as well as of the necessary procedures and machinery. It is furthermore an absolute necessity with a view to realising the best possible manufacturing processes whilst taking ecological and work hygiene considerations into account and putting the means of production to economical use.

INTRODUCTION

Within the overall area of engineering sciences, the paper converting technology as part of the processing technology focuses on an analysis, synthesis and industrial implementation of all "material forming processes in the area of material management which are shape and position dependent" [1.01]. It applies general regularities and working methods typical of the processing technology to the manufacture of finished products of paper and board [1.02]. The term paper converting technology is, however, not limited to these materials; it includes all materials that are used in combination with paper and board to manufacture paper conversion products, two typical examples being plastic films and adhesives. Being material oriented in nature, the paper converting technology is thus not restricted to paper converting plants alone. As is obvious from the diagram in Fig. 1.01, the process steps of paper converting are also employed in the fields of paper manufacturing (eg web transport), paper finishing (eg cutting) and coating operations as well as product usage (eg adhesive bonding).

By collecting work regulations and experiences as well as by systematising the existing knowledge, the paper converting technology creates the general and scientific preconditions for designing paper and board products, developing implementation processes and building suitable machinery and equipment. Based on the findings of the paper converting technology, realistic demand profiles are formulated for the raw materials paper and board. This review paper focuses on the field of tension between existing options of papermaking on the one hand and the requirements imposed by paper converting on the other.

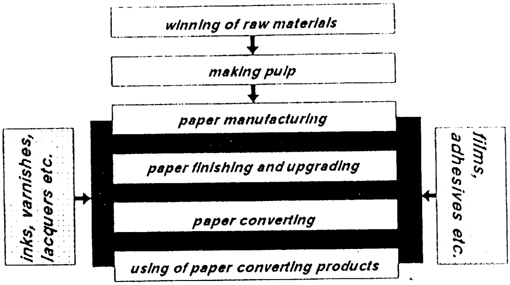


Fig. 1.01: From the winning of raw materials to the use of paper converting products. The hatched area designates the steps including processes from the paper converting technology.

In view of the highly variegated types of paper converting products, a number of different shape and position-dependent material shaping processes are required all the way from the raw material up to the finished product.

When looking at the origins and the production of certain final products, it will be found that they are the outcome of a well-arranged sequence of defined subprocesses in which specific processes are applied to modify the condition of the material to be processed (cf. Fig 1.02).

These elementary changes in the state and the specific processes required for this purpose may be brought into a system of order which is broken down according to the following six process categories:

Shaping processes
Processes that change the shape of the material to be processed.

Separating processes
Processes which locally destroy the structural cohesion of the material to be processed.

Connecting processes
Processes causing local structural cohesion within the material to be processed.

Processes for combining materials
Processes designed to change the usage properties of the material to be processed.

Transport processes
Processes taking place in, or using, machinery and which cause changes in location, amount or position of the material to be processed.

Printing processes
Processes transferring information onto the material to be processed.

Every paper converting process may be subdivided into a sequence of subprocesses, each of which includes one of the process steps mentioned.

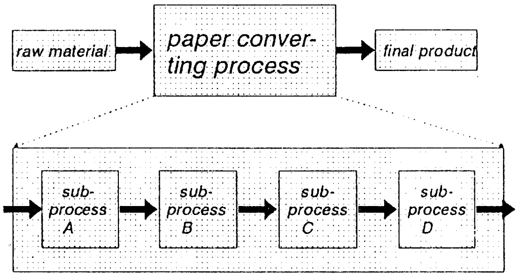


Fig. 1.02: The paper converting process as a well-arranged sequence of defined subprocesses.

As far as the fine structure of a subprocess and the single process step included in it are concerned, a three-stage principle of order may be assumed. The subprocess starts with stage 1, in which the material to be processed is prepared for the envisaged change of state. In stage 2 the state is actually changed and the new state is fixed in stage 3.

This paper starts out with a detailed analysis and structuring of the subprocesses of paper converting. Characteristic features of the individual stages will be illustrated on the examples of shaping, separating and connecting processes. At the same time, their technical feasibility will be discussed. Some selected examples will be presented to describe the physical processes actually taking place.

The analyses are targeted to identify those paper properties which are relevant for the process under discussion and which appear eligible for process engineering optimisation under a converting aspect. For effective optimisation, the individual subprocesses and processes call for a certain property profile of the material to be processed. Only in exceptional cases will the profiles of all subprocesses and processes be identical; normally, different or even contradictory property profiles will be required for the various processes. Fig. 1.03 gives a demand profile for a folding boxboard. It is impossible that paper and board meet all demands simultaneously and to an equal degree. Depending on the importance of a process for the overall paper converting process, a maximisation of the paper properties concerned may be advantageous even at the expense of other properties. Frequently, however, an optimisation of the entire property spectrum will be more beneficial than a maximisation of single characteristics. A decision will in each case depend on the boundary conditions arising from the triangle "application", "profitability" and "environment/ecology" (cf Fig 1.04)

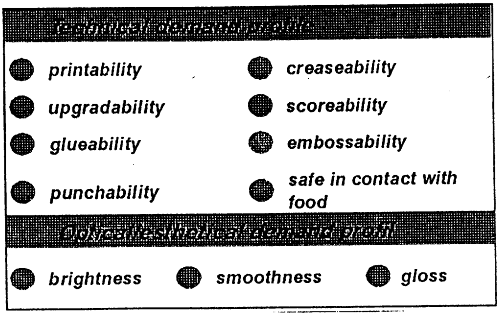


Fig. 1.03: Demand profile for folding boxboard. (See text)

Paper converting can only fulfil its specific tasks with the aid of optimum materials to be supplied by the paper industry. Paper manufacturers in turn are constantly faced with existing and novel demands and have to keep up with the technical progress in paper converting technologies. Finding viable solutions to these problems is an economic necessity and an engineering challenge at the same time.

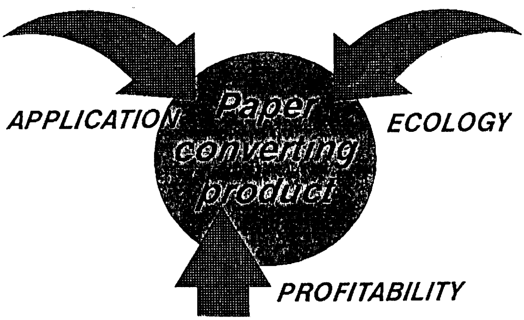


Fig. 1.04: The paper converting product within the triangle of application, profitability and ecology.

It would be beyond the scope of this paper to analyse - analogous to the process analyses described – material combining processes, transport processes and printing processes. These subjects have been covered in detail in other publications.

2 BASIC STRUCTURES OF THE PAPER CONVERTING PROCESS

As mentioned earlier, the processes required all the way from the raw material up to the finished product are in fact a well-arranged sequence of subprocesses in which specific processes are applied to achieve elementary changes of condition.

For a condition to be changed, there must be an original state and a final state. A state Z is determined by a multitude of parameters describing the properties, geometry, temperature and moisture content of the material to be processed.

If the original state is designated Z_x and the final state Z_y, the subprocess may be expressed as follows:

(1) $Z_y = T \bullet Z_x$

Transformation from the original to the final state is formally achieved by the operator T, the characteristics of which will be explained later.

The change of condition caused in the material to be processed is not normally achieved in a closed system, but it affects adjacent systems in many ways. Immissions of this kind may be of a technical and/or ecological as well as of a social nature.

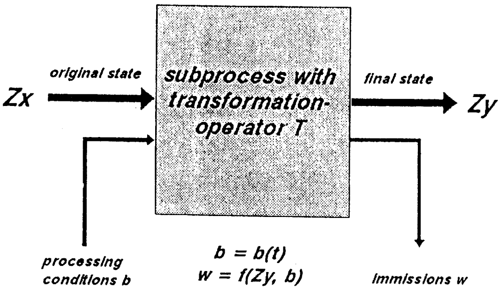


Fig. 2.01: The basic structure of a paper converting subprocess. (See text)

Formally, the immissions may be described by a vector w whose components depend on the final state Z_y and on additional time-dependent and/or time-independent processing conditions which in turn are made up of a multitude of constituents so that they may also be written as vector b:

(2) $w = f\,(Z_y, b)$

It follows that operator T, too, is influenced by the processing conditions b:

(3) $T = f\,(b)$

With (3) the transformation behaviour of the operator T becomes time-dependent if the processing conditions are time-dependent. A typical example of time-dependent processing conditions is the wear occurring on the machine element achieving the change of state.

The time-dependent operator T also allows transformations to be described in which characteristics of the final state Z_y depend on the gradient of the change of state. This is true in particular if the viscoelasticity of the paper is one of the influential parameters.

b includes time-independent processing conditions, too, such as those relating to the energy consumption of the machinery element concerned.

In the following, the structure of a subprocess will be explored in depth. As already mentioned at the beginning, a subprocess has a certain fine structure whose three components or stages are independent of the change of condition achieved in each case. The three components (stages) are illustrated in Fig. 2.02.

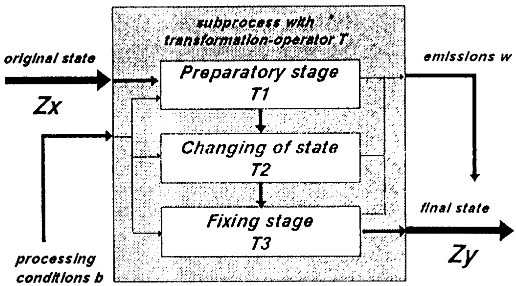


Fig. 2.02: The three-stage structure of subprocesses in the paper converting process. (See text)

The core and essential component of a subprocess is the process step actually causing a change of state. To this end, a tool or machine element is invariably applied. The change of state does not, however, result from the work of the tool or machine element alone, but is equally dependent on the way in which the material processed responds to the action of the tool. This means that the same tool will bring about different changes of state for different materials to be processed. This aspect is extremely important since it clearly illustrates the extent to which the material properties of paper and board influence the results of a subprocess and thus also the overall process. At the same time, it emphasises the significance of a profound knowledge of the material properties of paper whenever tools and machine elements are to be designed and constructed.

An ideal paper converting process thus simultaneously calls for an ideal design of tools or machine elements and ideal properties of the material to be processed.

A change of state is also effected in a preparatory stage ahead of stage 2. If stage 2, eg, requires a pronounced plastic deformability of the material to be processed, this deformability must be attained in stage I - unless it existed to a satisfactory degree as early as in the original state Z_0. To quote an example, stage 1 might include a change in the thermal condition of the material to be processed with a view to exceeding the glass transition temperature.

The subsequent stage 3 in turn serves to fix the change of state achieved in stage 2. In the above example, this would mean cooling down the material to be processed to temperatures below the glass transition temperature. Frequently, stage 3 will be a reversal of stage 1. Since the changes of condition brought about in these two stages are normally different from those of stage 2, the influential parameters in terms of paper properties will be different too.

There are certain interdependencies among the subprocesses of a paper converting process. The side effects w influence not only neighbouring systems in a general sense, but also subsequent subprocesses in varying degrees. For the process to follow, the characteristics of the final state Z_y play an important part in that this final state coincides with the original state Z_x for the subsequent process concerned. The manifold interdependencies between and within the subprocesses will be dealt with in detail later.

3 PROCESS SELECTION CRITERIA

Like most industrial products, a paper converting product is developed in response to market needs. First of all, a product idea is conceived and tentatively realised – perhaps in a hand-made model. The designing of a model is subject to the same influential factors as the product idea, namely marketing and design aspects, market needs and chances, creativity and innovation aspects. As a rule, technological aspects in terms of specific properties of the product material or suitable manufacturing processes are disregarded at this stage. However, if these aspects are left out for too long, severe problems may arise when realising the product idea with industrial manufacturing techniques (cf [3.01]).

The following decision criteria may be useful for in-time selection of proper process engineering techniques:

1 Geometry
Shape and dimensions of the paper material to be converted shall correspond to the working widths of available machinery.

2 Requirements imposed on material to be processed
The requirements imposed by converting processes on the material to be processed shall be in conformity with the material properties.

3 Quality
The scattering of properties of the material to be processed shall correspond to the quality demands placed on the finished product.

4 Productivity

The material to be processed shall be of a nature which permits trouble-free manufacturing at optimum productivity and minimum cost levels.

5 Side-effects

The material to be processed and the processing processes themselves shall be in conformity with environmental and health preservation as well as industrial hygiene needs.

6 Recycling

Valid rules of effective recycling management shall be adhered to.

The above criteria are useful for assessments of both the overall process and of subprocesses. This becomes evident from a few examples that are discussed below.

4 SUBPROCESSES OF PAPER CONVERTING

4.1 Separating processes

4.1.1 Introduction

Separation processes, which are used to locally destroy the structural cohesion of the material, are realised in the form of cutting and punching processes, which are used in all branches of paper converting. Separation processes are a typical example of how process techniques of paper converting can apply to the paper making process. In paper finishing, separating techniques are employed to cut wide rolls into narrower rolls or to make cut-size papers out of paper rolls.

For local disintegration of the material structure, forces are required which counteract the cohesion of the material. This work can be performed either mechanically or by other means, eg thermally. In modern paper converting, mechanical separation techniques are predominately being used.

Separation by mechanical means uses tensile or compressive stresses that are produced with a blade or knife within the smallest possible space. Separation is achieved when the stresses exceed the cohesive forces of the material itself. The various processes may be subdivided into process categories according to the means with which the stresses are produced (cf Fig. 4.1-01).

separating processes

destroys the local structural cohesion

<table>
<tr><td colspan="2">separating by mechanical work</td><td>separating by other kinds of work</td></tr>
<tr><td>tensile stresses</td><td>compres-sive stresses</td><td rowspan="2">e.g. separation by light-irridiation (Laser)</td></tr>
<tr><td colspan="2">superposition of stresses</td></tr>
</table>

Fig. 4.1-01: Breakdown of separation techniques according to the type of separation forces.

The forces required for separation can also be produced by non-mechanical means, a typical example being the laser cutter, which disintegrates the material along the line of separation in a light-induced process.

Although the laser cutting technology is not all too widespread in the paper industry, the authors will revert to it at the end of this paper in view of its specific operating principle. Instead, the report will emphasise conventional cutting techniques and their basic physical principles.

4.1.2 Basic physical principles of mechanical separation

The basic physical principles of separation will be discussed on the example of wedge cutting with a flat blade. The phenomena thus found are of a general nature and may be used in other forms of mechanical separation processes.

For the wedge separation process, a beam shaped or circular, flat or wedge shaped and sharpened tool is moved in a z-direction towards the material to be separated. Separation is achieved if the pressure applied by the cutting tool is sufficiently high. In general the necessary counterforce must be produced by a tool underneath the material. This tool is generally a hard plate. The plate can be done without if the blade moves quickly enough and the inertia of the material is sufficiently high to produce the counterforce on its own.

As already mentioned, separation starts as the blade is applied to the material. This non-pressurised state is illustrated on a true-to-scale example (cf. Fig. 4.1.-O2) of contact between a strip steel blade and the material. Strip steel blades of this kind are typically used for punching folding boxboard and board.

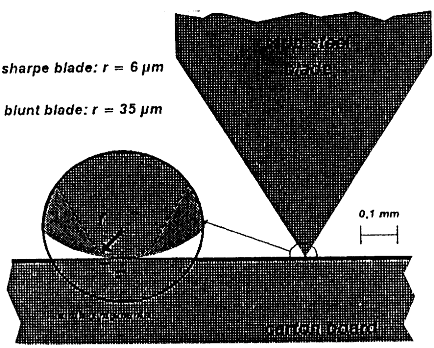


Fig. 4.1-02: Strip steel blade in contact with board in a true-to-scale drawing. For explanations see text.

When pressure is applied to the blade the material will be deformed and compressed. The compression profile will follow the profile of the blade. This means that compression will be highest close to the cutting line. If the motion of the blade were "frozen" for a moment, the qualitative distribution of forces and stresses would be as shown in Fig 4.1.-03. Among the influencing factors of the separation process are pressure F which the blade axis normally exerts on the material, and pressure F, which acts perpendicular to the wedge flank. The corresponding counter-forces are not shown.

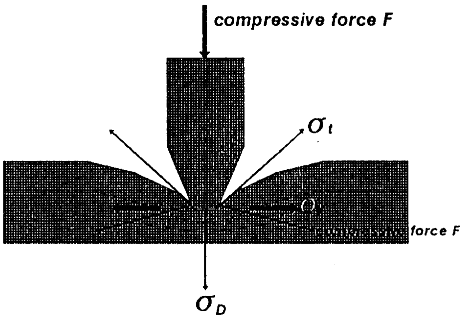


Fig 4.1.-03: Distribution of stresses caused by tensile and compressive stresses after a wedge shaped blade is applied to the material. See text for explanations.

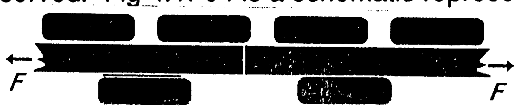
In a separation process, the tensile strain σ_y component in the paper plane which is a resultant of all existing tensile stresses (compressive strain σ_X caused by F, compressive strain σ_D produced by F as well as induced tensile stress σ_t) leads to locally defined breakage of the material at the point of maximum compressive stress directly beneath the blade edge. The tensile stresses thus occurring depend quite trivially on the applied compressive blade forces, less trivial is the complex influence of the blade geometry on the separation processes. In particular the wedge angle of the blade and the cutting edge geometry are of great significance. Although frequent attempts have been made to optimise the separation process by selecting the thinnest possible knife with the smallest possible cutting angle, it must be observed that the compressive stresses σ_t working perpendicular to the blade flank act synergetically. The blade geometry should be optimised depending on the composition of the material.

Now that the stresses and forces and their origins have been described, their effects on the paper may be discussed.

It follows from the above that a differentiation can be made between two types of mechanisms, namely those of genuine compressive stresses on the paper and those of tensile forces on non-compressed paper. During the real rupturing process, the two mechanisms are superimposed.

4.1.2.1 Rupturing mechanisms in compression free papers.

In the following, the effects of tensile stresses in compression-free papers will be looked at. Since paper is a layered structure consisting primarily of fibres and air-filled pores, the effects of tensile forces are absorbed in a fibre network composed of individual fibre crossings and fibre strands. It may thus be concluded that the elementary rupture mechanisms in paper consist of a rupturing or breaking of individual fibre strands and fibre crossings. A mixture of the two rupture mechanisms is also observed. Fig 4.1.-04 is a schematic representation of this situation.



model of Kallmes:

$$RBF = \frac{\text{breaking strength of single fibre}}{\text{shear resistance} \cdot \text{area of fibre crosses}}$$

Fig 4.1.-04 Schematic of elementary rupture mechanisms in paper with their vital parameters [4.1.01]. For explanations see text.

The rupture mechanisms are influenced by the type of fibres, the preparation of the fibres, the bonding of the fibres in the paper structure and the porosity of the paper.

A simple model describing the separation process was suggested by Kallmes [4.1.01]. The basic principles of this model will be briefly outlined below.

The basis is the relative bonding surface area, which is defined as the ratio of the complete bonding length to double the fibre length. It is thus a measure of the total shear forces necessary to separate the relevant fibre from the fibre network.

The state designated as critical RBF-value (RBF_{cr}) is that in which the total shear forces are directly equal to the tensile strength of the fibre concerned.

Papers breaking under tensile forces in the paper plane in terms of shear breaks of fibre crossings are characterised by a stretch at break which is proportional to their RBF-value. This form of rupturing takes place in bulky papers with weak fibre crossings, such as with tissue papers. Papers which rupture primarily due to fibre breakage may be distinguished by their RBF-values that are independent of the stretch at break. This is true for high-caliper papers with strong fibre crossings. In these papers the tensile strength is determined by the tensile elongation behaviour of the individual fibres.

Because of the very complicated structural network of papers, a mathematical analysis of rupture processes going beyond these comprehensible models is not possible.

4.1.2.2 Compression induced rupture

As the blade touches the paper, other forces become effective under the blade besides the tensile stresses compressing the paper.

Initially, this pressure is elastic. When the load exceeds a certain level, however, plastic deformation becomes irreversible and fibres and fibre crossings are finally damaged. This damage decreases the residual tensile strength of the paper. This can be experimentally verified as is evident from a cutting test with a beam shaped blade (cf. Fig 4.1-05). Before the paper starts to rupture, it is compressed to an almost completely pore-free state.

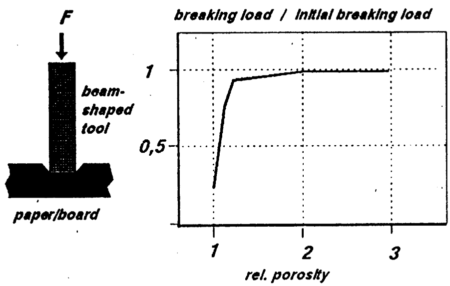


Fig. 4.1.-05: The remaining breaking strength determined by the ratio of the actual breaking load to initial breaking load dependent on the state of compression caused by the use of a beam-shaped cutting tool [4.1.02].

4.1.2.3 Summary

The cutting process via wedge cutting can be summarised as follows: as soon as the tensile forces built up on both sides of the blade exceed the reduced tensile strength of the compressed fibres, the material is separated. Rupturing starts in the area beneath the blade where compressive stresses are highest and continues according to the compressive stress gradient. The speed with which the rupture spreads is for the most part far greater than the speed with which the blade is applied so that a sudden decrease in blade pressure is experienced at the time of rupture.

4.1.3 Structure of the sub-process wedge cutting

The sub-process "Separation via wedge cutting" displays a fine structure like every other subprocess which can be subdivided into three phases:

Preparatory phase TI:
The preparatory phase can generally be described as conditioning. The rupture mechanism can be influenced to a certain extent according to the type of paper.

Execution phase T2:
Using a suitably shaped tool the material is compressed and structural damage is caused. At the same time, tensile stresses are caused in the sheet plane. As the two mechanisms are superimposed, rupture will finally occur.

Fixing phase T3:
After completion of the separation process the materials are put into a new position through outside forces or pressure from the blade flanks.

4.1.4 The influence of the paper on the separation process

Most separation processes serve to achieve clear-cut and dust-free edges. It thus follows that separation processes should have as few parts as possible which result in compression induced structural damage. Instead fibre breakage and rupture of fibre crossings through knife induced tensile stresses must predominate. This priority should be defined by the blade geometry as shown. However the influences of paper were already mentioned. Furthermore the compressibility of the paper and its elastic and plastic deformation behaviour are parameters which also influence the separability. These properties are as a rule not optimised in the interest of separability.

Finally the important relationship between the paper properties and in particular between the material composition of the paper and the wear of cutting tools was investigated.

4.1.5 An overview of the technical realisation of separation processes

4.1.5.1 Knife cutting processes

Cutting with knives or blades is the classic and most commonly used cutting process. As a result of the mechanical effect of the cutting tool, the cohesion of the material is destroyed without substantial material losses.

Once again a basic difference between the cutting principles wedge cutting and shear cutting is made. In wedge cutting the separation is produced through the wedging effect of the penetrating blade, in shear cutting through the shear effect of upper and lower cutting tools. Both techniques can be realised with flat and with circular blades. A special form of wedge cutting is the drawn cut. Here in addition to the pressure effect of the blade a translatory movement between the material and cutting tool takes place [4.1.03].

4.1.5.1.1 Wedge cutting

As already explained, a wedge shaped knife usually works against a cutting base in wedge cutting operations. Technical solutions are flat bed punches with strip steel cutting tools and single blade cutting machines. The most important parameters influencing the wedge cutting process and the quality of the cut are the wedge angle of the knife and the angle of the blade bevel, the sharpness of the blade, hardness and toughness of the blade material as well as the surface properties.

Wedge angle ß

The wedge angle as well as the bevel inclination have a great impact on the cutting process. Narrow blades cause higher tensile stress in material and affect the blade life due to increased wear. Single edged blades cause for example an asymmetrical distribution of tensile stresses in the material, double edged knives possess a higher durability. A diminution of the specific cutting force is achieved in the swing-cut via slanted drawing of the knife through the material (for example paper bundles) and through the pulling effect of the blade. The wedge angle of the blade used in each specific cutting machine and process varies greatly, this angle is however also influenced by the material to be cut.

Knife sharpness and cutting quality

It is generally known that blunt blades have a negative effect on the quality of the cut. Blunt blades cause less surface compression in the material whilst leading to a reduction in the induced tensile stress. Separation of the material requires higher cutting strength. It may happen in this case that the material is separated beside the blade rather than beneath it.

Blade wear

In most cases blade wear leads to blunting of the tool. The abrasive wear caused in cutting is therefore influenced by the material and by the filler in particular. Several investigations were performed on the problems of blade wear which are important for the tool use in industrial cutting machines [4.1.04-4.1.07]

It was found in a study of the relationship between the filler kaolin and knife wear that a rise in the kaolin content from 5-10% led to a reduction of usable time to approximately 30% [4.1.08]. Altogether only few reliable statements on the subject of wearing are known because of the great variety of influential parameters involved.

Cutting dust

The almost unavoidable production of cutting dust caused by the pulling out of fibres at the cutting edge during knife cutting is generally an impediment on subsequent production processes for example through the soiling of printing forms or other parts of the printing machine.

A strong fibre-fibre bonding has a positive influence on the cutting quality and on the reduction of cutting dust. On the contrary a reduction of the fibre bonding strength, for example through the introduction of humidity as is the case in many paper converting methods has a negative effect on cutting quality.

4.1.5.1.2 Wedge cutting, drawn cut

If the knife moves after coming into contact with material in the cutting direction then frictional forces take effect analogously to wedge cutting between the blade and the material. An example of a processing machine which displays this type of process is a high speed diagonal cutter.

The friction caused during the pulling cut and the frictional heat produced have been shown experimentally (4.1.09). The heat created is partially absorbed by the paper and also leads to a heaving up of the blade. The temperatures developing directly on the blade are difficult to determine and even theoretical calculations hardly lead to practically usable results.

Measurements with simple circular blades without a countertool have shown that the complete vectoral cutting forces as a sum of applied force and drawn cutting force decrease as the proportion of drawn forces increases. This phenomenon is explained by the fact that the frictional heat has the effect of reducing the strength of material or, alternatively, the blade is to be seen as a type of micro-saw which catches the individual fibres and separates them.

4.1.5.1.3 Shear cutting

In contrast to the pressurised wedge cutting, in shear cutting two cutting tools work against each other. As the two tools get into contact, shear forces are produced which are directed towards tilting the material and forcing the tools apart [1.02].

Suitable countermeasures are the use of a press beam which holds the material down on one side (open cut with flat blade) and regrinding the tool (circular blade), which however leads to increased blade wear.

Furthermore a force component works in the direction of the material in addition to the forces from the upper and lower cutting tool which tend to displace the material.

The determining material property in shear cutting is the shear stiffness. This is the resistance of the material against the shear forces. As in all fibrous materials the shear stiffness depends on the orientation of the fibres. Therefore a cut along the MD-direction means less fibres must be cut than in a cut in CD-direction. As a result varying cutting forces result in MD and CD cuts if the same tool is used, and the quality of cut can be varied [4.1.05]. For example the shear stiffness of a special carton board in CD is approx 38 MPa and in MD approx 30 MPa.

The wedge angle is particularly important in the rotation shear cut. If thick or hard materials are cut into small strips an excessive wedge angle can lead to a bending of the materials. On the other hand for the sake of blade stability this wedge angle should be as high as possible. In general both of these demands can be satisfied with the angle of approximately 87°.

With regard to the demands placed on the material to be processed by shear cutting the following applied: since virtually all papers and boards must be cut, a special optimisation of the cutting material properties is not possible. The demands must be therefore made on the cutting tools and machines: wedge angle, cutting angle, blade sharpness and wearing strength must be matched to the material.

4.1.5.2 Water jet cutting

The cutting of corrugated board is particularly problematic with conventional tools because the cutting process leads to greater or lesser compression in the vicinity of the cut [4.1.10, 4.1.11].

Since the mid 1970s a new cutting technique for MD cutting of corrugated board – water jet cutting has been employed. It achieved a certain degree of popularity in the late 1970s and early 1980s. The material is separated by a high powered water jet. The speed of the water on leaving the nozzle is around 1000 m/s [4.1.12].

At these speeds the water jet cuts the papers fibres. Open, straight, non-crushed cut edges with the resultant favourable properties of MD cut corrugated board as well as the absence of cutting dust are the results. In spite of its advantages this cutting technique has not been able to assert itself in particular because the investment costs, costs of wearing parts (nozzles and seals) as well as the repair costs are simply too high. Furthermore the new developments in the area of rotating wedge cutting have brought back advantages and justification to conventional knife cutting processes.

4.1.5.3 Laser cutting

Laser cutting processes are an almost universal technique with which almost all known solid materials can be cut. The physical working principle of laser material processing is the transformation of the laser beam on the surface of the material into heat which is used as processing heat. Depending on the surface temperature reached the material is welded (temperature above melting point) or separated (temperature above evaporation point).

The use of a laser contains a number of advantages over conventional cutting processes as a result of the laser properties. Since no contact takes place between the laser and the material during heating, an even cutting quality is produced and no tool wear is experience. Since, in contrast to knife cutting no compression of the paper takes place advantages are to be found in the cutting of bulky papers. The unique feature of laser beams as opposed to other light sources is their high focusability which makes a great concentration of power necessary for the evaporation of the material. With special lenses the energy can be directed towards any part of the material which provides a high great degree of accuracy and the possibility of coupling it with automatic processing devices.

As a result of the interaction of the laser beam with the surface of the material a complex correlation exists between the material properties and the laser processability of the particular material. As a result the absorption of the laser beam as a basis for the heating of the material surface depends on the reflection of the beam by the surface. Nearly all non-metals including paper display a good absorption rate and allow suitable cutting speeds [4.1.13].

4.2 Reshaping processes

4.2.1 Introduction

Reshaping processes serve to alter the shape of the material; the mass and composition of the material remain for the most part unchanged. Reshaping processes can lead via an elementary process step to the desired final state of the material. Examples of this are corrugating, embossing, drawing and rolling etc. The creasing process as an example of a reshaping process in which the folds are prepared takes place in two steps, the first, creasing, serves to prepare the position of the folds. The final change of shape takes place in the following process step "folding'.

In order to change the shape of material, mechanical or thermo-mechanical work must be performed.

The mechanical reshaping forces which work on the material are tensile, compressive or shear forces.

The reshaping forces are therefore commonly classified according to their effect. In this manner compressive and folding reshaping processes are differentiated. Compressive reshaping occurs, for example, in supercalendering (satinage), pressing and embossing, while drawing, folding, corrugating, creasing, edging, rounding, winding, bordering, rolling etc belong to the folding reshaping processes [1.02].

Reshaping processes require a reshapable material. Paper and board are visco-elastic materials in which the shaping of the plastic or elastic material characteristics is greater or lesser according to the existing conditions. The plastic formability can be enhanced by providing for suitable conditions. However too high a formability can interfere with subsequent process steps. The process steps of "reshaping" may therefore be broken down as follows:

Preparatory phase TI:
Increasing the plastic formability through, for example raising the temperature and/or moisture content.

Execution phase T2:
Reshaping under the influence of suitable forces.

Fixing phase T3:
Recreating the starting conditions through, for example withdrawal of heat or moisture.

Because of the importance of bending-reshaping processes and compressive reshaping processes, only these two processes will be further considered, with corrugating and creasing being discussed as practical examples.

4.2.2 Physical and physico-chemical basis of reshaping

4.2.2.1 Deformation under the influence of mechanical forces.

Paper rheology which concerns itself with the form changes of paper under the influence of various forces makes possible within certain limits, a theoretical description of reshaping processes [4.2.01 - 4.2.04].

In the various reshaping processes only compressive reshaping processes (embossing, corrugating) or bending reshaping processes (folding, creasing) occur. Whereas in compressive reshaping forces work exclusively in a standard direction on the paper, the bending-reshaping processes are of a more complex nature, since compressive and tensile stresses act on the paper surface in different places.

Reshaping behaviour under the influence of tensile stresses.
The classic entry into paper rheology was via the analysis of the stress-strain behaviour of paper. A typical stress-strain curve for paper with intermediate stress relief (cyclical stress experiment) is displayed in Fig 4.2.4-01. Up to the yield point F the paper nearly behaves like an elastic body. After further stress is applied, plastic deformation of the paper occurs, which is explained by the shearing

of fibre connections in the fibre network. After the tensile stress is withdrawn (point A), the elongation returns to point A: the paper has been irreversibly deformed.

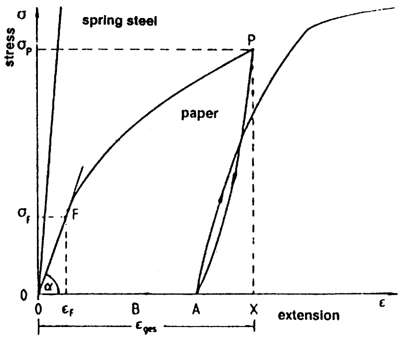


Fig 4.2.4-01: Stress-strain curve for paper with intermediate stress relief according to [4.2.05]. Explanations in text.

Formulations for the description of this deformation behaviour are offered by phenomenological-rheological models composed of ideal elastic elements (Hooke's elements), ideal viscous elements (Newtonian elements) and ideal plastic elements (St Venant's elements).

As an example of such a model a 4-parameter model is shown in Fig. 4.2.4-02 (Burger model). The Fig illustrates the response of such a Burger system to a sudden change in tensile stress.

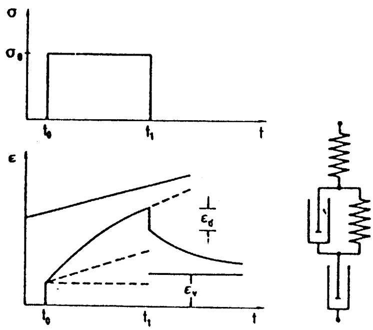


Fig. 4.2.4-02 Example of a rheological model for the stress-strain behaviour of paper acc. to [4.2.05]
σ_0 = Rectangular tensile stress impulse in the time t_1 - t_2
ϵ_V = Viscous elongation
ϵ_d = Elastic elongation

In spite of the apparently good correlation between the example of the rheological model with the observed behaviour in paper the capabilities of such models are limited. The reason for this is the number of extra parameters which need to be considered in real reshaping processes. Examples of such parameters are the former usage and the rate of reshaping [4.2.03, 4.2.04]. Furthermore the temperature and moisture content of the material have a strong influence on the elongation characteristics [4.2.05]. Another important parameter for the stress-strain behaviour of paper (and thus a potential parameter in reshaping processes is the composition of the paper (type of fibre and beating as well as filler material).

Compressive deformation behaviour

The deformation of paper and board by forces acting perpendicular to the paper surface is aimed at reshaping in terms of the paper thickness. In principle reshaping by tensile and compressive forces is possible, but only compressive reshaping is of practical importance. Compressive reshaping is found in the most varied forms in paper converting, eg embossing in combination with hot stamping foil printing.

Creasing is another example. Compressive reshaping is also used in the area of paper production and in supercalendering in particular. An overview of the compressive reshaping behaviour of paper is given in [4.2.06 - 4.2.08].

A description of the compressive reshaping process in the case of supercalendaring is possible with the empirically derived "supercalendar equation" [4.2. 09]. With this equation a correlation is established between the change in paper thickness during supercalendering and the process parameters temperature T, material moisture content F, linear force L and the roll geometry

$$\epsilon = A + \mu \bullet V_A$$

where

ϵ = permanent reduction of the specific volume by supercalendaring.

V_A = the specific volume before supercalendering
A = material coefficient

and for the intensity factor μ:

$$\mu = a_O + a_L \bullet \log L + a_G \bullet \log G + a_R \bullet \log R + a_T \bullet T + aF \bullet F$$

is valid with:
R = equivalent roll diameter
G = machine speed

The supercalendering equation has been confirmed in many experimental studies. Alongside the parameters, which describe the effect of the compressive tension, it illustrates the great influence of moisture content and temperature of the material on the reshapability of paper and board.

The reshaping speed, former usage as well as fibre type and filler material are important as parameters also in the description of material deformation in the z-direction dependent on the deforming force.

In addition to the rheological material properties, the geometry of the reshaping tool defines the specific processing resistance during reshaping.

Bending deformation behaviour

The bending-reshaping behaviour of paper and board is characterised by the tensile and compressive forces taking effect in the sheet plane, which introduce high shear stresses into the material. This shear stress can lead to a layer separation within the material. As a result of the development of this deformation and the underlying deformation processes the bending behaviour ought to be described by means of several parameters. A differentiation can be made between three areas of deformation to which certain states in the material can be attributed:

- area of elasticity, limited to small bending angles. The proportionate elastic forces are responsible for the back-swelling-forces occurring,
- elastic-plastic transition zone,
- plastic area with plastic structural changes.

As a result of the simultaneous appearance of various states of tension and deformation in the material, a rheological description of real bend-reshaping processes such as creasing or corrugating is difficult. Analytical equations like the supercalendering equation, which describe the complete process of bending-reshaping, are unknown.

4.2.2.2 Factors influencing viscoelasticity

The influences of temperature and moisture content on the breaking and reshaping properties of paper and board are known. Descriptions of these phenomena are given in the pertinent research literature, two publications of which will be referred to [4.2.10, 4.2,11].

Influences of temperature and moisture content

Paper fibres show certain analogies to thermoplastics regarding the temperature dependency of their stress-strain behaviour as a result of their structure and material composition. Many methodical observations on the reshaping behaviour of paper originate in the physics of plastics or plastic processing technology (eg [4.2.12, 4.2.13]).

A clear drop in the Young's module in paper was measured as the temperature and moisture content rose (eg. [4.2.14, 4.2.15]). Paper fibres display a glass transition temperature which, when exceeded, causes the Young's module to drop again suddenly. For the most important components of paper fibres, lignin, hemicellulose, cellulose, these glass transition temperatures are based on the existing pure chemical materials. (cf. Fig 4.2.5-01). The "chemical composition" of papers, which are defined by fibre type and additives as well as by moisture content and temperature, allows the reshaping behaviour to be influenced within certain limits (see also Fig. 4.2.5)

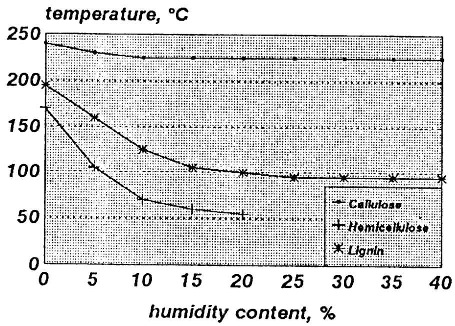


Fig. 4.2.5-01 Glass transition temperature of cellulose, lignin and hemicellulose depending on water content, acc. to [4.2.16]. Explanations in text.

4.2.3 The individual phenomena

4.2.3.1 Practical example: Corrugating

4.2.3.1.1 Introduction

Corrugating means a wave-formed reshaping of flat corrugating basepaper in the presence of heat and dampness and by using a heated corrugating roll which produces periodic stiff corrugations.

The corrugating process is an important sub-process of corrugated board manufacture. Corrugated board itself is a classic example of a lightweight material. With minimum usage of material it provides a maximum of bending stiffness by using other liner papers of high elasticity, which are attached to each other at wide intervals by means of a corrugated roll.

4.2.3.1.2 The reshaping process in corrugation.

The process by which corrugated medium of strict periodicity is formed from a flat web may be understood as a bending-reshaping process which is realised with the aid of suitably shaped tools.

For reasons of application technology and productivity, rotating tools - ie the corrugator roll - have been introduced in the process. This tool arrangement has led to problems going beyond the actual reshaping process which relate to the roll intake geometry and the frictional relationships (see Fig 4.2.2-04). This complication will not be discussed here, instead the reshaping process should be seen as a separate event. For technical applications refer to the literature [4.2.17-4.2.19].

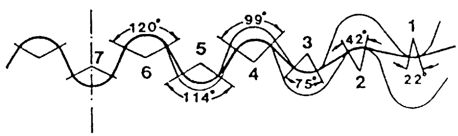


Fig. 4.2.2-04: Feeding of the basepaper web into the corrugating zone [4.2.20]. Explanations in text.

To investigate the reshaping process the demands being placed on the basepaper web will be once more gone into. When calculating the stretching or crushing of the paper during corrugation, it will be found that the elongation on the outside position is approximately

8% with a corresponding crushing of 8% in the inside position [4.2.20] (see Fig. 4.2.6-01).

These stresses would overlap with the stresses arising in practice from the web tension which would raise the tensile stresses even further and would reduce the compressive stress. The stretch at break of paper lies however between 1-3%. The corrugating process must lead to rupturing of the paper.

As was already mentioned the corrugating process in the corrugation zone is a thermo-plastic process which takes place at corrugating roll temperatures of 170ºC, at contact pressures of 60-70 kN/m and at moisture contents of 7-9% of the material. Noteworthy is that the reshaping temperature is clearly below the glass transition temperature of cellulose at the same moisture content. Several authors demand corrugating roll temperatures of approx 225ºC [4.2.19]. The fact that lower corrugator roll temperatures suffice indicates that it is enough if only one component of the paper - probably the lignin - is heated to above the glass transition temperature to ensure the formation of a stable wave form.

This wave form is fixed by cooling off the material to temperatures below the glass transition temperature.

4.2.3.2. Practical example: Creasing

4.2.3.2.1 Introduction

Creasing is used to prepare fold lines. It is a requirement in order to fold a flat object along a specific geometric line in order to form it into a three dimensional body. Creases are for example necessary for the production of true-to-dimension hollow bodies of paper or board which have many uses as packaging. The function of creasing is to form a geometric folding line along which the bending resistance or bending stiffness is reduced.

The simplest form of creasing is called pre-creasing. It is characterised by a line-formed compressive reshaping of the material causing a reduction in thickness and thus also in local bending resistance. This is however only possible in the case of thin papers, since with thicker papers repeated folding or stretching operations would lead to breakage.

Folding lines are produced in paperboard and board in a complex process which is mainly characterised by tensile reshaping rather than compressive reshaping. This creasing process is called hollow creasing.

In very thick papers a satisfactory fold line cannot even be produced by means of hollow creasing. The necessary reshaping has to be effected by crushing. Crush creasing will not be discussed here. For the sake of completeness it should be mentioned that fold lines can also be produced by separating processes, such as scoring and perforating.

4.2.3.2.2 The reshaping process in hollow creasing and folding around the crease line.

Hollow creasing is as a rule carried out with tools having two parts, ie the creasing blade and the creasing matrix. The arrangement of the two tools can be seen from Fig. 4.2-05.

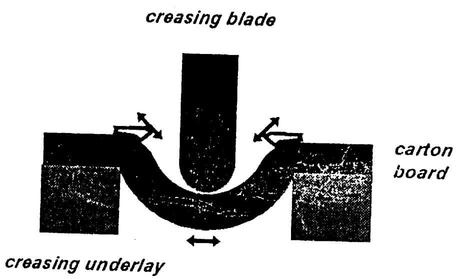


Fig. 4.2-05 Tool construction principles for hollow creasing and the tensile and compressive stresses caused in the material by creasing [1.02]

The crease line is produced by the creasing blade which moves in the direction of the matrix: In the course of this movement, the material is deformed and forced into the matrix while compressive and shear stresses occur which are also shown in Fig. 4.2-06.

The compressive stresses acting locally on the matrix edges lead as a rule to irreversible compression of the material by approximately 10%. The high shear stresses occurring within the material loosen the bonds between the individual layers. These structural changes contribute towards successful folding.

As the material is forced into the matrix under the action of the creasing blade, the material would be excessively stretched unless non-deformed areas are simultaneously redrawn. Creasing is therefore dependent on the point where the board is clamped relative to the crease. As a rule, the adjacent crease line is taken as clamping point. If the crease is permit break-free reshaping, the stretch at break of the material ϵ should not be exceeded at any point. It is important here to ensure that the stretch at break of the material is not to be determined by the same free clamping length as the distance between the clamping points. Fig 4.2-06 shows how the relative elongation depends on the free clamping length.

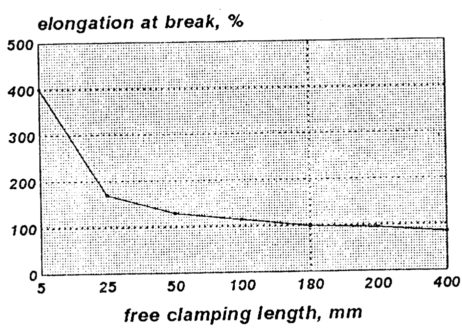


Fig 4.2-06: Relative stretch at break vs free clamping length [4.2.21]

To allow subsequent folding along the crease line, a certain degree of cleavage in the material must be achieved. The higher the quotient of elasticity with small free clamping lengths and the cleavage stress of the material, the more easily delamination will occur [1.02]. Since the E-module is dependent on the machine direction of the material, the creasing tool geometry must be optimised for creasing in the MD and CD directions.

When the material is folded in the outside position, additional elongation occurs which must be kept smaller than the permissible value. According to [1.02] the elongation characteristics of the material are less important for the creasing result than is the ratio of material thickness in the non-deformed area to the thinnest areas in the material produced during folding.

4.2.3.3.3 Demands on the material

From the above explanations a number of features can be derived which a creasing material should exhibit:
Uniform thickness to provide the same creasing conditions at all points of the creasing tool.

High material flexibility to avoid tearing of the material in the outside positions.

High compressibility in order to allow elastic folding. High ratio of elasticity module to cleavage tension to ensure trouble-free delamination of the material.

4.3 Connecting Processes

4.3.1 Introduction

Connecting processes provide for structural cohesion at certain points. They are needed, for example, to form a three-dimensional hollow body from a flat form (eg folding box blanks) or to make a usable book from single printed pages. Functions other than structural cohesion can be integrated into the connection, for instance by a hinge.

The joint thus created always produces a non-homogeneity in the paper or board. This non-homogeneity may have an impact on the usable properties of the finished products. Forces introduced steadily into the flat form will cause greater or lesser non-homogeneities of tension distribution. Connection points can only be put under as much strain as the amount of tension which the paper is capable of withstanding. Each connection process therefore relies on the optimization of a particular spectrum of paper qualities in order to avoid a non-homogeneous consistency in the finished product.

Two groups of connecting processes can be distinguished, namely material connections and frictional connections. Bonding and sealing belong to the first group where as all other connections belong to the frictional group. The main point of interest in the following will be the material connections, the other connections will quickly be passed over.

4.3.2 Frictional connections

The elementary sub-processes in frictional connections take place in three stages - as explained in section 2, which can be completely different for the individual process groups. A rough overview of the structure of the stages is shown in Table 4.3.2-01. Frictional connections are with a few exceptions spliced connections whose construction is schematically illustrated in Fig.4.3.2-01.

Table 4.3.2-01: Elementary steps in the sub-process "frictional connections" with phase 1 (preparation), phase 2 (execution) and phase-3 (fixing).

•	Examples of converting processes		
	Sewing Stitching	Riveting Screwing	Knurling
T1	Stitching in	Punching	Knurling
T2	Wire, thread leading through	Mounting screw rivet	Action of knurling tool
T3	Fixing	Fixing	Drying

Some properties of frictional spliced connections should be explained with the clipping as an example.

In order for the forces working on the joint to be transmitted in a manner which creates a bond, close contact must be established. This is effected by means of an open clip which is stuck through both parts of the connection and then closed. When being closed, the clip exerts considerable surface pressure on the.joined parts. As a result of the compressibility of the paper this leads to a greater or lesser deformation of the paper, whose extent can be minimized by the closing mechanism and modelling ability of the clip. The deformation caused by the clip can be measured eg by tension optical methods (4.3.-01).

As explained a concentration of stresses is caused by forces introduced into the connection. The most important question for the load carrying capacity of the connection is the steepness of the transmission of tension from the peak of tension to the uniformly stressed paper areas.

The mechanisms which finally lead to a breaking of the connection when the stresses exceed a limit value specific to the material, are identical to those which were discussed in part 4.2 on separation processes. Of course in addition to the stresses the damage caused to the surface form by piercing and boring must be taken into account. Their notching effects can cause early breakage of the material. With regard to the load carrying capacity of frictional connections the tear growth resistance of the paper is a crucial criterion. The construction of the connecting elements must always ensure that the amount of stress and the notching influence of piercings are kept as small as possible.

An important application of clips as a means of joining is folding boxes (4.3.-02). 02) . Not least for ecological reasons, clipping has superseded other methods, such as taping, and has been further developed into modern mechanical clipping devices (4.3.-03).

A further use of clipping and its close neighbour sewing in the process variant "sewing" is in bookbinding. For the proper design of the connecting elements in a book block there are a number of recommendations (4.3.- 04) which will not be further entered into at this time.

A special place in frictional connections is occupied by knurling not least because no other connection element is needed. A detailed description of the process is to be found, for example in (4.3.-05), at this point only the unusual features will be mentioned. The bond is achieved by proper meshing of the fibre network of the two connecting parts. The elementary process steps in knurling are contained in Table 4.3.2.01. The preparatory phase 1 consists of the wetting of the paper to produce the necessary formability. In the execution phase 2, the papers are joined by compressing without tearing under the action of the knurling tool. Suitable papers should be made of long-fibred and high-freeness pulps, be of high bulk and contain little or no size. The fixing finally takes place by drying.

In summary it can be found that frictional connections with the exception of knurling require paper with high tensile strength, low compressibility and high tear growth resistance.

4.3.3 Material connections

4.3.3.1 Introduction

Material connections differ greatly from frictional connections. The point of connection contains no deformation in an unstressed state. Introduced forces are distributed over a large area through the connecting element - the adhesive layer - and produce stresses to a much smaller extent. The high load carrying capacity resulting from material connections and their easy realisation in terms of converting technology is the reason for their great importance in paper converting.

Material connections are realised via sealing and bonding. In the case of bonding the connecting element is the adhesive layer, which is created using adhesives. In the case of sealing the paper must be coated with a suitable sealable material, which is re-activated at the connecting point either thermally or through pressure and then sets up the bonding element.

Thermally activated sealing (hot sealing) is widely used in the area of flexible packaging. Pressurised sealing (cold sealing) is used when the filler material must not be exposed to heat. A further important area of usage is in envelope flaps.

There are no fundamental, merely slight differences between bonding and sealing. It will suffice therefore to only examine one of these processes more closely, in this case bonding.

Characteristic of the "bonding" process is the use of an adhesive which by definition is a non-metallic material, which can join adherends via adhesion and cohesion effects (4.3.3-01). In spite of this simple definition, bonding is a complex procedure which must be treated in more detail.

4.3.3.2 The processing technology of bonding: An overview

As already mentioned an adhesive is necessary in order to join paper and board objects through adhesion and cohesion.

Adhesion is considered to be caused by the general interactive forces acting between the molecules of the adhesive and the molecules of the surface of the adherend (4.3.3-02). In the case of paper these forces are secondary valency forces and van der Waal's forces and hydrogen bonds. Main valencies (chemical bonds) only play a minor role.

The identifying feature of secondary valency forces is their very short range (4.3.3-03). When the adhesive is applied, it must be available in a form allowing its molecules to come into sufficiently close contact with the adherend surface (in molecular terms) for secondary valence bonding to be achieved with the highest possible density.

These conditions can be met with a liquid adhesive, which can wet the surface. Wettability is therefore of fundamental importance for bonding.

With regard to the theory of wettability as a surface energy phenomenon, the extensive literature may be referred to, for example (4.3.3-05-4.3.3-10). Regarding the wettability for adhesion there are differing points of view. Some authors assign spreading particular importance and conclude that adhesion only occurs when the free surface energy of the adhesive is less than the critical surface energy of the adherend τ_C, as defined by Zisman (4.3.3-12). Other authors (4.3,3-13) prefer the description of the wetting procedure as a dynamic process, which leads to the formation of an interface between the adhesive parts in which spreading is not absolutely necessary. Furthermore it is considered that in most cases of usage of adhesive, the adhesive cannot spread on the adhesive surface but that a forcible wetting follows in which the complete surface of the object is not completely wetted and need not be completely wetted.

It is however demanded in practice that the surface energy of the liquid adhesive be smaller than that of the paper surface. In many cases it has been shown that the surface energy of the paper should not be less than 32 mN/m [4.3.3-14] if it is to be bonded with normal packaging adhesive. It should however be pointed out that surface energy is by no means the only influence on adhesion.

While the surface energy of liquids can be measured directly [4.3.3-15], the surface energy of solid objects can only be measured indirectly for example using the contact angle method [4.3.3-16, 4.3.3-17]. The practical use of this method is not problem free, in particular when the measurement is of coarse, porous and heterogeneously formed materials such as paper.

Convincing solutions to the problem of measuring surface energy of paper have not been found to date. As has been mentioned there are other starting points for the explanation of adhesion. The diffusion theory has been tried and proven as a means of understanding adhesion between certain polymeric materials. It has further been attempted to explain adhesion in terms of electrostatic forces, which however explain not all but at least certain aspects of adhesion. Overall electrostatics have been accorded a smaller role in adhesion. Finally mechanical adhesion was mentioned, in which adhesion is explained as a bonding between the adhesive and the pores and capillaries of the adherend. In fact mechanical adhesion can be merely considered a supportive function.

The adhesiveness in the contact between adhesive and adherend does not occur automatically, but only after the adhesive partners have been suitably matched, particularly in terms of their polarity characteristics. The cohesion forces of adhesive films of uniform molecules are always of an attracting nature. The cohesion strength is for the most part dependent on the molecular mass of the adhesive molecule.

It was already mentioned that adhesion requires the adhesive molecules to be in a state of high molecular mobility. This can be achieved by using low molecular adhesive molecules, which in turn affects subsequent film cohesion unless the molecular mass of the adhesive is later increased raised by polymeric reaction. Another method is found in the use of molecules with a greater molecular mass which can form cohesive films which however must be put into this state of higher molecular mobility via solvents or other additives.

In both cases a non-cohesive or low-cohesion and mostly liquid adhesive is used. A cohesive bonding layer is however necessary in the adhesive connection. The load carrying capacity of the finished adhesive joint, which is affected by film cohesion, if of practical interest. Of prime importance is however the transition time from the state of application to the set cohesive state. The paper or board has a strong influence on this time of transition. A knowledge of the structure of the most important adhesive systems is necessary for a detailed discussion of this matter.

4.3.3 Formulations of selected adhesives and basic characteristics of their film forming and setting mechanisms

As mentioned above an adhesive consists of a basic material which is brought to a state of sufficient molecular mobility with the aid of additives. Processing technology exerts considerable demands on the rheological properties of the application state.

The often conflicting demands on an adhesive with regard to cohesion and adhesion can as a rule not be met by a basic material whose material composition is homogeneous. Rather the basic material of adhesives consists already of several components, with which its range of properties is matched as closely as possible with the demands of its usage. Furthermore adhesives contain additives as a rule with which they are specifically tailored to their processing and usage properties.

In most cases the film formation in the basic material follows through the withdrawal of the additive. In the film formation phase the concentration of binders rises constantly, as a result of which the viscosity of the binder also increases. In hot melt adhesives the binder concentration does not naturally change, the viscosity increases here with the decrease in temperature. In the case of reactive adhesives the polyreaction takes over the function of the withdrawal of the additive, which also gives rise to an increase in viscosity.

It is of no importance in what state of film formation the adhesive is when the bond line is loaded initially, but only the degree of viscosity. Roughly it may be shown that:

$F \bullet t = \mathrm{const} \bullet \cap$

F is a force acting in a z-direction, t the time of application of the force and $\cap$ the viscosity of the adhesive in the adhesive layer. The constants contain among other factors the geometry of the adhesive layer.

Great differences are displayed by the adhesive systems with regard to setting speed. While the cooling process in hot melt adhesives takes place within a few seconds the reaction time of reactive adhesives can, depending on side effects take several days. In all other adhesive systems the setting speed is dependent on the mechanisms which lead to the withdrawal of the auxiliary agent. Solvent adhesives set comparatively quickly compared to aqueous adhesive systems if solvents with a low boiling point and relatively rapid evaporation are used. In contrast the evaporation of water in aqueous adhesive systems plays a relatively minor role, the important contribution being accorded the penetration of the water into the adherends.

4.3.4 The individual phenomena

The processing step "Bonding" should now be analysed in detail. To start with, it can be divided into three larger sections:

Phase 1: Preparation

In the preparatory phase the conditions for the wetting of the adhesive surface by the adhesive are produced, in which the surface energy for example, through a corona preparation is raised [4.3.4-01]. This treatment, successfully used in plastic processing, is in the case of paper only necessary in a number of exceptional cases. Other forms of preparation are, for example, roughening, in order to increase the effective contact area between the paper and the adhesive [4.3.4-02].

Phase 2: Execution

The execution phase contains for the most part the processing step "formation of the bonding layer". It is formed by two successive sub-processes, the application of the adhesive to a connecting part (formation of the adhesive film) and the binding of the joint parts (formation of the bonding layer). A certain length of time passes between these two sub-processes designated as open assembly time which is important in application technology (see para 4.3.5). Both sub-processes are characterised therein, that the adhesive wets the adhesive surface and the auxiliary agent partially or completely soaks into the joint parts.

Phase 3: Fixing

The execution phase is finally followed by the fixing phase, in which the bonding layer through the application of pressure is set to the extent that agreed stresses can be withstood. Between phases 2 and 3 also comes the so-called closed assembly time which - like the open waiting time is important in application technology (see para. 4.3.5).

The most important process in the fixing phase is the setting of the adhesive layer. In this phase while still under the influence of pressure additional wetting and penetrating processes can take place. A schematic overview of phases 2 and 3 is shown in figure 4.3.4-01 [4.3.4-03].

	Elementary steps of the bonding process	
T1	Preparation of adherend's surface	Chemical or physical surface treatment
T2	Forming the bond line	Application of adhesive and assembling the adherends
T3	Fixing	Holding under pressure for a suitable time

Fig. 4.3.4-01: Processes in the execution and fixing phases of the process step "Bonding". Explanations in the text.

As mentioned the paper or board have a strong influence on the "Wetting" and "Penetration" processes. Wetting depends for the most part on the surface energy of the adhesive surface and of the adhesive, penetration in contrast from the capillary structure of the adherend and the composition of the auxiliary agent used in the adhesive. To estimate the speed with which the volume of the auxiliary agent in the adhesive diminishes, the following equation may be used [4.3.4-04]:

The penetration takes place more quickly the lower the viscosity η of the auxiliary agent is, the greater the representative capillary radius r is and the better the capillary walls are wetted by the auxiliary agent. That means the higher the surface energy of the auxiliary agent is and the greater the wetting angle of the capillary wall.

The material composition of the adhesive changes continually as a result of the penetration whereby the change in the surface energy

also takes place. The auxiliary agent will, in penetrating the adhesive surface also influence its surface energy. For this reason no reliable statements can be made about the current wetting state in the adhesive process. To a large extent stationary conditions first arise after the completion of the fixing phase, which are however no longer accessible to measurement. These correlations make it impossible to reach conclusions regarding the expectable bonding strength of the adhesive film on the adhesive surface because of considerations of surface energy. There have been attempts to calculate from the measured surface tension of adhesive films which set without contact to the adhesive surface and from the surface energy of adhesive surface, the interfacial tension which would be found through the contact of adhesive and adherend and to correlate these to measured adhesion [4,3,4-04]. It was shown that the adhesion measured was greatest when the calculated interfacial tension had a value of zero. For measuring processes for interfacial tension one is referred to the appropriate literature.
In many rapidly occurring adhesive processes the wetting phase is very brief. It was demonstrable however that for the evaluation of the adhesivity of paper and board the short time wetting behaviour in these adhesive processes is of great importance. It was therefore the subject of much research [4.3.4-05, 4.3.4-06].

The influence of paper and board on the setting of adhesives has been thoroughly treated. In the case of emulsions and solutions this occurs as mentioned, completely or partially through the soaking of the auxiliary agent into the paper, whose capillary structure, expressed as a representative capillary diameter and the wettability of the capillary will are important factors [4.3.4-03].

The setting speed is also influenced by properties of the adhesive, whereby for example the water retention value plays an important role [4.3.4-05].

A further important aspect is the separability of the surface of the connecting part. During the setting process the auxiliary agent alone should soak in not the base material. The separability of adhesives can for example be chromatographically investigated [4.3.4-06].

In emulsion adhesives the separation between water and emulsified phase is on the paper surface is quantitatively approximate even if the pore radius of the paper is greater than the average particle radius [4.3.4-06]. Also in papers with great volume of pores an increase in the specific adhesion does not occur.

The setting of hot melt adhesives occurs entirely through heat withdrawal if one ignores the synergetically acting crystallisation effects. Hot melt adhesives set more quickly if the paper has a high heat transmission capability. Measuring of the heat transmission on of paper is difficult, however efficient means of measurement were developed for certain cases. On the whole the heat transmission of paper increases if the void volume decreases and the filler material increases.

The durability of a bond will always be shown to be the result of the interaction of paper properties, adhesive properties, bond line geometry and type of stress. Flap bondings have naturally the highest resilience when exposed to shear forces. The stress analyses lead one to expect that the durability of the joint will increase if the thickness of the adhesive layer is increased. As the thickness of the adhesive layer increases, its cohesion decreases. These two conflicting effects cause an optimal layer thickness which is around 20 µm as experience has shown [4.3-22].

Particularly critical forms of stress for spliced joints are shear forces. They lead to stress concentrations at the edges of the adhesive layer, which can only be withstood by paper if its tear-resistance is sufficiently high. In coated papers a firm bonding of even the outside layer of pigment in the coating binder is necessary. Shear demands require a high degree of creep resistance on the part of the adhesive.

4.3.5 Practical example: Production of folding board boxes

Folding boxes are highly important as packaging means. They are manufactured in a specific sequence of processes from special types of boards whose manifold requirements have been discussed at the beginning.

Next the complete process of folding box manufacture including its most important production steps will be described, which will serve as a further example for the ordered interlocking of process steps in paper converting (cf Fig 4.3.-O2)

Starting from flat boards the first step in the process is printing and upgrading. The processing steps "Printing and Upgrading" can be further subdivided into smaller sub-processes.

sub-process	*change of state*
↓	*Zo: Tambour*
paper finishing ↓	*Z1: sheets of board*
printing/upgrading ↓	*Z2: printed sheets*
punching/creasing ↓	*Z3: folding box blank*
glueing ↓	*Z4: folding box, flat-lying*

Fig 4.3.-02: The complete processes in folding box manufacture including its most important production steps will be described, which will serve as a further example for the ordered interlocking sub-processes and a description of each change of state.

The process steps "Punching and Creasing" contain a combination of processes which are separating and reshaping processes. Figure 4.3.5-02 shows the typical use of folding boxes a result of the process steps "Punching and Creasing".

In order to allow three-dimensional hollow bodies to be made out of the flat folding box blanks the flaps must be 'joined in a bonding process with the opposite area of the blank. This takes place in the process step "Bonding" in the folder-gluer. The folder-gluer creates flat lying folding boxes; the thus created change of state is only an intermediate step towards the three-dimensional hollow body, which will later be formed out of the flat lying folding boxes in a packaging process.

The processes taking place in the folder-gluer can be further subdivided into subprocesses. The result is shown in figure 4.3.-03.

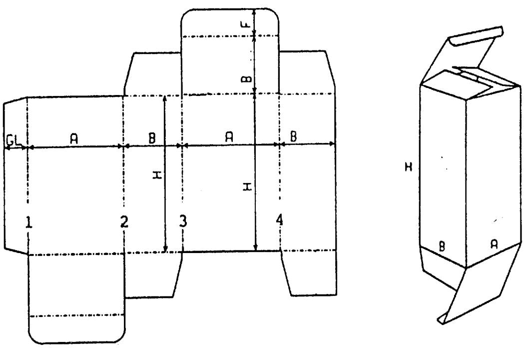


Fig. 4.3.-03: Example of a folding box blank with dimensions A * B * H. The crease lines are numbered. GL: Flap. Explanations in text.

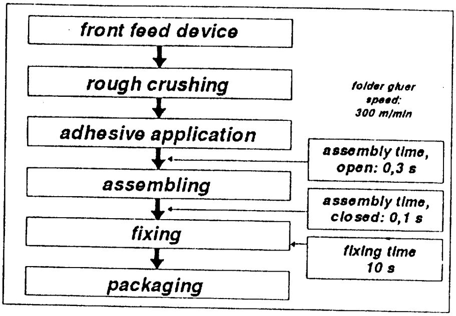


Fig. 4.3.-04: Process steps in the folder-gluer. Explanations in text.

After the feeding of the blanks the crease lines 1 and 3 (see Fig 4.3.5-02) are formed by folding forwards and backwards by approximately 100°. This process step facilitates subsequent forming of the box during packaging. After the application of adhesive on the adhesive splice GL the crease lines 2 and 4 are folded in such a manner that the folding splice and the opposite area can be assembled. The bond line thus created is then set in the pressing station and after enough setting of the adhesive the flat-lying box arrives in the outlet of the machine where it will be packed for the delivery.

The process step "Bonding" in the folding box bonding machine should now be looked at in more detail. As was mentioned the process begins with the application of an adhesive layer on the adhesive splice. A layer application device or a jet application device are used to apply the adhesive in a narrow strip.

The bonding processes taking place after adhesion were explained above and need not be repeated here. The dynamics of the adhesive are more important in particular a discussion of the "open assembly time" and the "closed assembly time". The first depends on the speed and the construction of the folder-gluer. In modern high speed machines it comes to around 0.3s. the closed assembly time can be reckoned at 0.2s. Finally the duration of the fixing phase comes to 10s. In the outlet of the machine forces act on the adhesion which are generally caused by the back swelling of the creased cardboard. In order to withstand these forces it is necessary that the viscosity of the adhesive in the adhesive layer has risen enough. However the construction of the adhesive joint and its arrangement in the folding box are also decisive in its resistivity.

Unfortunately the increase in the viscosity of the dispersion during the film formation cannot be measured directly. Information regarding the setting rate is obtained by measurement of the peel resistance of the bond line vs. storage time. There are standardised laboratory methods whose description can however be ignored as this point. With the selection of several examples it will now be shown in how much the folding box bored influences the setting of the emulsion adhesive, via the use of the mentioned measuring techniques. As can be seen from Fig. 4.3.-05 the setting of the adhesive film is finished after approx 10 seconds if uncoated duplex board (UD2) is used. Bond lines in folding boxes made of this board have reached for the most part their final strength when they reach the machine outlet after the fixing phase. On the coated side however of high-grade pulp board the same process takes 35s and on the more absorbent backside 20s. In this case the set of the adhesive layer is not finished in the machine outlet and the danger will arise that the back swelling of the board is greater than the strength of the adhesive joint.

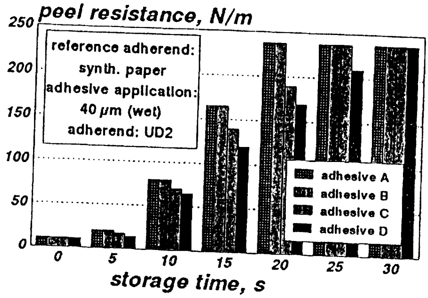


Fig. 4.3.-05: Peel resistance of bond lines vs. storage time.

A further and no less important influence of the setting speed depends on the adhesive and its composition. Even if the carton has a high absorption capability an adhesive only hardens slowly if it has a high water retention capability. From experience the spectrum of variation between adhesives is narrow in comparison to the spectrum variation between boards (cf: Fig. 4.3.-06). As a complete result it is found that in the use of absorbent types of board and "quicker" emulsion adhesives the hardening is already finished at the end of the fixing phase. By less absorbent, and in particular with fine folding box board setting is not finished at the end of a fixing phase moreover the adhesive is still in a viscous state. In this case it should be seen to that the adhesive remains carefully fixed in a machine outlet. Otherwise the bond line can be completely opened by the back swelling forces of the board.

The low setting speed of emulsion adhesives causes therefore a hindrance for the productivity of modern high speed folding box adhesive machines. To combat this hindrance is a challenge for the manufacturers of folding boxes and to at least the same extent for the manufacturers of emulsion adhesives.

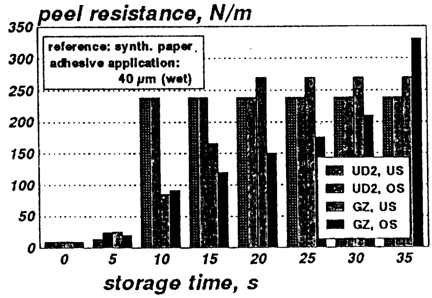


Fig. 4.3.-06: Peel resistances of bond lines vs storage time. Explanations in text.

5 SUMMARY

In this paper, a detailed account is given of the paper converting process with its elementary process steps. Specifically, the three processes "Separating", "Reshaping" and "Connecting' have been described in terms of their physical basic processes and their realisation by process engineering techniques. It has been found that, depending on the type of process, the dominant influences are either those of tool/machine tool or those of material properties. It is just a few material properties which appear relevant for all three types of process. Actually, each type of process has a specific demand profile for the paper or board material used. These requirements are summarised in Fig. 5.-01.

	process influenced by	
process:	*material to be processed*	*tool/machine for processing*
separating	[redacted]	[redacted]
shaping	[redacted]	[redacted]
connecting	[redacted]	[redacted]

Fig.5.01: Listing of some selected process-relevant properties of materials

Initially, reference was made to the three influential factors determining paper converting, namely ecology, profitability and application. As far as paper manufacture is concerned, it is clearly obvious at the end of this report that paper manufacture has to meet the challenges of the process steps which were selected as examples (see Fig. 5.02).

Separating process:	**mechanical properties** (compressibility) **other properties** (composition (dust, abrasion))
Shaping process:	**mechanical properties** (elongation at break, modulus, cleavage resistance) **thermal properties** (glass transition temperature)
Connecting process:	**mechanical properties** (internal bond, strength of coating colour) **surface properties** (surface energy, roughness absorbency)

Fig 5.02: Paper manufacture having to meet the challenges of paper converting technologies

It is essentially impossible to fulfil at a time all the demands that are being placed on the raw materials paper and board. However, if paper manufacturers are to meet the above challenges, it is highly important for them to gain in-depth knowledge of the manifold problems of paper converting and of the particularities of the process engineering steps required to produce the various end products.

6 LITERATURE

1.01: NN; Verarbeitungstechnik; VEB Fachbuchverlag, Leipzig (1978)

1.02: TENZER H.-J; Leitfaden der Papierverarbeitung; VEB Fachbuchverlag, Leipzig (1989)

3.01: KLINGELHÖFFER, H;. Marktforschung und technische Entwicklungsarbeit; Allgemeine Papier-Rundschau -, 5 (1964)

4.1.01: KALLMES 0; Ober die Grundlagen der Formation, der Struktur und der figenschaften von Papier; Das Papier 35, V56-73 (1981) Nr. 10A

4.1.02: GROSSMANN H.

4.1.03: KLINGELHÖFFER H; Ziehender Schmitt; Allgemeine Papier-Rundschau- 12 (1962) Nr 14

4.1.04: BEIER M; Schneidkraft und Schneidarbeit beim Scherschnitt; Allgemeine Papier-Rundschau - 1190 (1962) Nr 23

4.1.05: KLINGELHÖFFER H; Spannungsverteilung und Schnittgute beim Scherschnitt; Allgemeine Papier-Rundschau - 14 (1967) Nr 15

4.1.06: HESSE F und H.-J TENZER; Grundlagen der Papierverarbeitung; VEB Verlag far Buch- und Bibliothekswesen, Leipzig (1963)

4.1.07: KLINGELHÖFFER H; Schneiddruck von Kreismessern; Allgemeine Papier-Rundschau -, 972 (1963) Nr 17

4.1.08: KLINGELHÖFFER H; Bandstahlschnitt von Wellpappe; Allgemeine Papier-Rundschau - 19-20; (1970) Nr 42

4.1.09: CUMMINGS J und A BURKART; Die Wirkung von dünnen Schneidewerkzeugen auf Herstellung und das Marketing von Wellpappe; Allgemeine Papier-Rundschau -, 804-810 (1993) Nr 31

4.1.10: LANGEMANN M; Schnelles Wasser schneidet; Papier- und Kunststoffverarbeiter -, 84-92; (1982) Nr 6

4.1.11: UMBACH M W und E.M.- VON GRAEVENITZ; Laser und Wasserstrahl; Papier- und Kunststoffverarbeiter -, 21-23; (1991) Nr 9

4.1.12: VANDELEENE J.-P; Fluid jet slitting of corrugated board; Paper, Carton et Cellulose, -, 43-48 (1980); Nr 1

4.2.01: KUBAT J; Rheologie of paper; Rheology, Theory and Applications, Vol.5; ed F.R.EIRICH; Academic Press, New York and London, 1969

4.2.02: VAN DEN AKKER J.A; Strukture and tensile characteristics of paper; TAPPI 53, 388-400 (1970) Nr 3

4.2.03: BRECHT W, L GÖTTSCHING und H L BAUMGARTEN; Beiträge zur Rheologie des Papieres; Das Papier 25,569-582 (1971); Nr 10

4.2.04: GÖTTSCHING L; Das Festigkeitsverhalten von Papier unter statischer und dynamischer Beanspruchung; Teil I: Paperi ja Puu 52, 535 - 554 (1970); Teil II: Paperi ja Puu 52, 655-669 (1970); Teil III: Paperi ja Puu 52, 781-794 (1970); Teil IV: Paperi ja Puu 53, 27-36 (1971)

4.2.05: FALTER K und G OBST: Dynamische und drucktechnische Eigenschaften von Offsetpapieren unter besonderer Berücksichtigung der Kurzzeitbelastung; FOGRA-Forschungsbericht 4.205, München (1982)

4.2.06: CAVLIN S, C ENGMAN, C FELLERS, R LUNDBERG und A de RUVO; Viskoelastische Charakterisierung des Bruchmechanismus bei Kompression von Papier; Das Papier 29, 280-288 (1975) Nr 7

4.2.07: BRECHT W und M SCÄDLER: Über neue Messungen der Kompressibilität von Papieren; Das Papier 17, 626-634 (1963)

4.2.08: SCHAFFRATH H.-J und L GÖTTSCHING; Modellierung der Kompression von Papier in z-Richtung bei niedriger Flächenpressung; Das Papier 46, 350-355 (1992) Nr 7

4.2.09: CROTOGINO R H: Das Glätten von ungestrichenen holzhaltigen Papieren; Das Papier 38, V211-217 (1984) Nr IOA

4.2.10: KOLSETH P und A de RUVO; The Measurement of viscoelastic behaviour for the characterisation of time-, temperature-, and humidity- dependent properties, Chapter 6, in: Handbook of Physical and Mechanical Testing of Paper and Paperboard, Vol.2, E MARK (Ed.); New York und Basel, Marcel Dekker

4.2.11: SALMÉN L and E LBACK: Effects of temperature and moisture on the tensile properties of packaging papers; Paperi ja Puu 67, 477-482 (1985); Nr 9

4.2.12: LENK R S: Rheologie der Kunsstoffe; München, Carl Hanser Verlag (1971)

4.2.13: JUNGNICKEL B H u.a: Umformen von Kunststoffen im festen Zustand Ehningen; Vogel Verlag, expert Verlag (1988)

4.2.14: BACK E L, M T HTUN, M JACKSON und F JOHANNSON: Ultrasonic measurements of the thermal softening of paper products and the influence of thermal auto-crosslinking reactions; TAPPI 50, 542-547 (1967) Nr 11

4.2.15: SALMËN L und E L BACK; Simple stress-strain measurements on dry papers from -25°C to 250°C; Svensk papperstidning 78, 178-183 (1977) Nr 6

4.2.16: GOHRING, D A I: Thermal softening of lignin, hemicellulose and cellulose; Pulp and Paper Magazine of Canada 64; T517-T527 (1963) Nr 5

4.2.17: GÖTTSCHING L und W OTTO: Über das Laufverhalten von Wellenpapieren, Teil Va: Die Formbeständigkeit unter dem Einfluß von WPA-Geschwindigkeit und Feuchtigkeit der Wellenbahn; Das Papier 31, 85-93 (1977) Nr 3

4.2.18: GÖTTSCHING L und W OTTO: Über das Laufverhalten von Wellenpapieren, Teil IIa: Die Formbarkeit unter dem EinfluB von WRA-Geschwindigkeit und Feuchtigkeit der Wellenbahn; Das Papier 30, 417-425 (1976) Nr 10

4.2.19: GÖTTSCHING L und W OTTO: Über das Laufverhalten von Wellenpapieren (Teil I); Das Papier 30, 221-228 (1976) Nr 6

4.2.20: THOMAS C E: Flute formation on the singlefacer-preconditioning and alternatives; Tappi Journal 63, 67-75 (1980) Nr 6

4.3-01: KLINGELHÖFFER H: Spannungsverteilung um Drahtheftungen; Allgemeine Papier-Rundschau -,70-71 (1962) Nr 13

4.3-02: BAHMÜLLER H.-J: VerschlieBen von Verpackungen mittels Heften: Stand der Technik und Entwicklungstrends; Vortrag auf dem 11.PTS-Symposium für Papierverarbeitung und Klebetechnik "Trends bei der Herstellung, Verarbeitung und Verwendung von Wellpappe", München (1992)

4.3-03: BENDIG E, R KRUSCHWITZ, R NESTLER und F SCHUMANN: Lehrbuch der industriellen Buchbinderei; Verlag Beruf + Schule, Itzehoe (1987)

4.3-04: KLINGELHÖFFER H: Rändel-Verschluß; Allgemeine Papier-Rundschau -,72 (1964) Nr 24

4.3-05: NN; DIN 16 920, Klebstoffe; Klebstoffverarbeitung, Begrille; Beuth-Verlag, Berlin (1977)

4.3-06: GOOD R J: Intermolecular and interatomic forces; In - R L Patrick (Ed.), Treatise on adhesion and adhesives, vol.1, Marcel Dekker, New York (1966)

4.3-07: BARROW G M: Physikalische Chemie; Fr. Vieweg + Sohn, 3. Aufl, Braunschweig (1977)

4.3-08: HABENICHT G: Kleben: Grundlagen, Technologie, Anwendungen Springer Verlag, 2. Aufl; Berlin, Heidelberg, New York (1990)

4.3-9: SPASOVA J. u. O.CADA: Erkenntnisse über die Bewertung der Benetzungsfähigkeit von Kunststoffoberflächen; Adhäsion 22, 374-379 (1978) Nr 11

4.3-10: RABEL W: Einige Aspekte der Benetzungstheorie und ihre Anwendung auf die Untersuchung und Veründerung der Oberflächeneigenschaften von Polymeren; Farbe und Lack 77, 997-1006 (1971) Nr 10

4.3-11: BARTUSCH W: Kritische Betrachtungen zur Benetzbarkeitsprüfung von Polyethylen-Oberflächen; Verpackungs-Rundschau 18, 89-96 (1967) Nr 12

4.3-12: WAKEW C: Synthetic Adhesives and Sealants; John Wiley & Sons, New York (1987)

4.3-13: ZORLL U: Bedeutung und Problematik der kritischen Oberflächenspannung; Adhäsion 18, 262-270 (1974) Nr 9

4.3-14: HUNTSBERGER J R: The mechanism of adhesion: In: R L Patrick (Ed), Treatise on adhesion and adhesives, vol.1, Marcel Dekker, New York (1966)

4.3-15: WILKEN R und H L BAUMGARTEN: Zum EinfluB des Strichs auf die Veredelung von Bogen-Offset-Drucken; Wochenblatt für Papierfabrikation -, 677-681 (1989) Nr 3

4.3-16: WESER C: Die Messung der Grenz- und Oberflächenspannung von Flüssigkeiten: eien Gesamtdarstellung - für den Praktiker; GIT Fachzeitschrift für das Laboratorium 24, 642-648, 734-742 (1980)

4.3-17: KÄSTNER H -U und R TRAUZEDDEL: Möglichkeiten zur Bestimmung der Oberflächenspannung von Festkörpern; Papier und Druck 27, 74-80 (1978) Nr 5

4.3-18: WOLF K L: Physik und Chemie der Grenzfläche; Springer Verlag, Berlin, Göttingen, Heidelberg (1975)

4.3-19: VOYUTSKII S: Autoadhesion and the adhesion of high polymers; Wiley Interscience, New York (1963)

4.3-20: WAKE W C: Adhesion and the formulation of adhesives; Applied Science Publishers, London, New York, 2nd ed. (1982)

4.3-21: CRAMM R H and D V BIBEE: The theory and practice of coronna treatment for improving adhesion; Tappi Journal 65, 75-78 (1982) Nr 8

4.3-22: WILKEN, R und H L BAUMGARTEN: Die Bedeutung geometrischer und mechanischer Eigenschaften der Klebefuge auf die Festigkeit von Faltschachtelkdebungen; Das Papier -41, V87-V90 (1987) Nr IOA

4.3-23: BRISTOW J A; The absorption of water by sized paper; Svensk Papperstidning 71, 33-39 (1968) Nr 2

4.3-24: DAUB E und LGÖTTSCHING: Verkleben und Verklebbarkeit von Wellpappepapieren; Das Papier 44, 45-54 (1990) Nr 2

4.3-25: KLINGELHÖFFER H: Chromatographische Untersuchung des Verklebungsvorganges bei Papieren; Zeitschrift für angew. Physik 8, 171-175 (1956) Nr 4

4.3-26: WILKEN R und H L BAUMGARTEN: Die Bedeutung der Fließeigenschaften von Dispersionsklebstoffen für die Herstellung von Faltschachteln; Das Papier 46, V81-V87 (1992) Nr 10A.

Transcription of Discussion

CONVERTING CHALLENGES TO PAPER AND BOARD

H L Baumgarten, **R Wilken** & B Hartman (Review Paper)

P R McKinlay, Amcor Research & Technology Centre, Australia
Thank you for an interesting presentation. I look forward to publication in Volume III, particularly in relation to the number of references to work done in this field. I suspect that there is not as much work done on converting processes as in the attention to the paper structure itself - do you have any comments?

R Wilken
That is true but every product has its own problems so it is very difficult to find areas of research for a lot of different products. I think this may be an important reason for this lack.

Prof D Wahren, Stora Teknik AB, Sweden
Congratulations - it is a very interesting paper. It is a new way as far as I am concerned of looking at the converting processes. We are really getting the systematics in there and I am looking forward to the publication. There are some things, however, which might be remedied before publication. Paper in bending buckles on the inside of the fold and does not strain too much on the outside. That makes a big difference in respect to how you should specify board products.

R Wilken
This has only been dealt with briefly in my presentation. It is a very important point because the folding of the board works only when the delamination allows well defined deformation of the delaminated

layers inside of the folding line.

D Wahren

That is correct. However, on one of your slides you had high extensibility as one of the main requirements - that need not be so.

Dr V Padányi, Amcor Research & Technology Centre, Australia

With reference to the importance of the glass transition, I think we are increasingly recognising the importance of this. The problem I see in the converting side is that the glass transition is highly strain rate dependent and we are having a lot of difficulty measuring the glass transition even under static conditions or thermally. But at the very high strain rates that are involved in these converting processes, I am not sure if any one has any information. Do you have any information on these glass transitions at high strain rates?

R Wilken

No I haven't. My idea is that it is possible to make corrugated medium which is so composed that on the outer surfaces of the paper, we have a lot of material with Tg as low as possible.

We can then deform the paper very economically and it is not interesting what happens inside the paper, it is only interesting what happens outside. By cooling down we fix this new situation without knowing exactly what happens in the inside of the paper.

Dr L Salmén, STFI, Sweden

My question relates to that of Dr Padanyi. When you referred to the glass transition in the corrugating process your figures were quite different from those that have been discussed earlier this week. I wonder if your figures were frequency corrected to the high frequencies of the corrugating operation?

R Wilken
No. It is not corrected. This figure should only give you an idea of the glass transition temperature and the impossibility that, from this point of view, I told here that the cellulosic material exceeds over the glass transition temperature. It is not possible in the corrugating process. From this comes the idea to make this approach.

Dr J L Brander, Arjo Wiggins R&D Limited, UK
The low values that you have for hemicelluloses and lignin glass transition temperature suggest that in webs that are going to have a lot of deformation induced we ought to have lots of hemicelluloses and lignin, would you agree with that?

R Wilken
It is a question I cannot answer because I have never worked in the field of glass transition temperatures. I use it only as a model for understanding of the things happening in the corrugating process. I use it as a step to try to optimise the corrugating process. When go the next step and try to optimise this process we have to learn more about the Tg than we know today.

Dr K Ebeling, Kymmene Corporation, Finland
I would like to go back to your Figure 1.04 where you showed that in the paper converting the actual product needs to be in balance between the final application ability, the environment and profit making. In trying to determine the optimum technology in converting I would like to emphasise the importance of how to characterise the

ecology. It is a big issue even when life cycle analysis is used. How should one do it? It will always be a question of values for people being involved in the evaluation. How do you get the right values into your LCA?

R Wilken

I think this is quite a political question. From my point of view I think the ecological aspects are important but not the most important. The most important aspect for me is the performance of the paper product in respect to the usage of the material. It makes no sense to produce a packaging material eg. which is perfect in ecological respects, but it cannot protect the food inside.