Role of Blank Moisturisation in Press Forming of Paperboard

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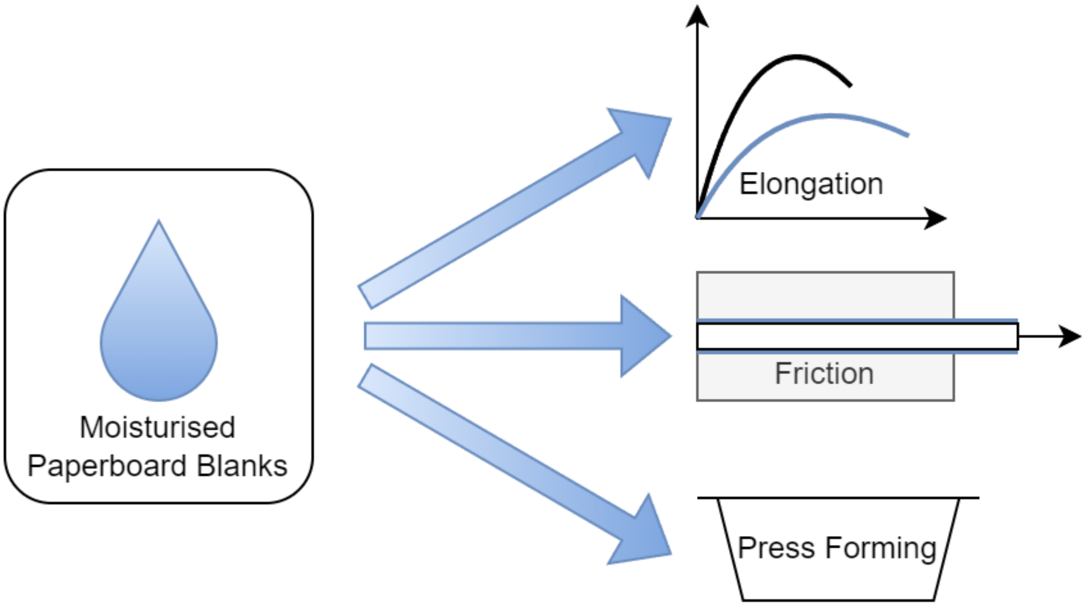
GRAPHICAL ABSTRACT



Role of Blank Moisturisation in Press Forming of Paperboard

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To investigate the influence of blank moisture on the forming of paperboard, press forming experiments were performed with fixed blank setup and sliding blank setup to produce paperboard trays. The trays were rated by their forming height. Different moisturisation procedures were established to achieve one or double-sided surface moisturisation or homogenous moisture distributions in the blanks. Additionally, basic influences of moisture to paper-to-metal friction and tensile properties of the paperboard were measured. Surface moisturisation increased the paper-to metal friction and therefore limited the achievable forming heights in sliding blank press forming. The elongation at break of paperboard increased with increased sample moisture content. In the fixed blank press forming test this increase was not apparent in the data.

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INTRODUCTION

In the packaging sector, there is an ongoing trend to limit the use of fossil resources, *e.g.*, by replacing plastic packaging with cellulosic fibre-based structures. This paper focuses on trays made of paperboard, which are widely used in food applications. Paperboard as raw material is based on renewable resources and has reached a recycling quota of over 70% in Europe since 2012 (Confederation of European Paper Industries 2023). These tendencies also reflect in legislation, with the EU single-use plastics directive as one prominent example. Compared with thermoformable plastics, paperboard has limited formability and is sensitive to moisture influences.

This study investigated the influence of moisture and surface moisturisation on the forming behaviour of paperboard regarding changes in elongation and friction properties. Focus was placed on the press forming process in fixed blank and sliding blank configuration. Press forming represents a process in which a punch pushes a flat paper blank into a cavity to create a three-dimensional shape whilst a blank holder controls the material inflow.

Paperboard is a hygroscopic material, which implies the absorption and desorption of water under changing climate conditions. As a consequence, water is regularly present in paperboard in the form of a liquid, as water vapour or chemical bonding of fibres. The water interacts with the other components of the paper, such as cellulose-based fibres. Therefore, with a changing moisture content, the mechanical and thermal properties of paperboard also vary. Alava and Niskanen (2006) give a comprehensive overview about paper properties, including moisture influences. Marin *et al.* (2020) express the moisture influence on mechanical properties of paperboard in a bilinear, elastic-plastic material model covering the elastic modulus, hardening modulus, yield point, and stress at break. Vishtal (2015) studied the formability of paperboard materials based on the material properties for fixed blank as well as sliding blank processes. He states that for fixed blank processes, extensibility and elastic-plastic deformation ratio are the governing mechanical properties, whereas the sliding blank process depends on paper-to metal-friction, elastic recovery, and compressive strength and strain. Conditioning paperboard at specific climate conditions can be expensive or time consuming and difficult to organize at industrial production sites. Active manipulation of water content in paperboard (and not obtaining equal moisture content nor equilibrium), such as spraying (Niini *et al.* 2022), rolling (Hauptmann *et al.* 2017), or steaming (Franke *et al.* 2018), formerly has gained interest in paperboard forming. Previous works have provided starting points for this study. Östlund *et al.* (2011) described the influence of one and double-sided moisturisation of paperboard on elongation in a hydroforming process. They found that with similar overall moisture content, one-sided moisturisation led to fewer ruptures. The investigated moisture contents were extremely high and were not replicated for this study. As another difference in the testing methods, Östlund *et al.* (2011) used heated moulds with temperatures of 130 °C to 170 °C as opposed to tools at room temperature.

The friction properties of paperboard with different material pairings, such as aluminium and cellulose film (Kawashima *et al.* 2008), metal and rubber (Deshmukh 2005), stainless steel (Ko *et al.* 2020; Lenske *et al.* 2017), or PTFE foil (Lenske *et al.* 2022) have been investigated. A direct comparison of the obtained values is not possible due to differences in measurement procedures, including normal force, and velocity. In general, higher material moisture contents result in increased paper-to-paper friction, as presented by Fellers *et al.* (1998) and increased paper-to-metal friction as presented by Kawashima *et al.* (2008) and Back (2002). Elevated moisture contents of paper result in higher surface roughness (Norgren and Höglund 2009) and could explain the moisture dependency of the friction forces.

The present study investigates the influence of surface moisturisation of paperboard with liquid water on the short timescale of 1 min of sorption time, and consequently the blank is in non-equilibrium conditions when forming occurs. Furthermore, the present study first transfers the findings of Östlund *et al.* (2011) to the fixed blank press forming operation (sometimes called pressing), which relies equally on the elongation properties as does the hydroforming. Paperboard blanks are moisturised to different moisture contents with one-sided or double-sided application procedures, but in a limited parameter range. The experiments are then extended to a sliding blank press forming process. Sliding blank conditions are usually associated with higher forming degrees. With respect to the modified process conditions, moisture influences on friction properties between the paperboard and a metal surface are also investigated. The press forming toolset used in this study was first presented by Tanninen *et al.* (2017). Their study focused on the formability of paperboard in a sliding blank press forming process with the new toolset and the increased forming degree. Nevertheless, the fixed blank press forming of a PET-coated paperboard at a homogenous moisture content of u = 0.088 in the baseboard of the blanks was also studied. The baseboard materials used by Tanninen *et al.* (2017) were identical to the materials used for this study.

This article addresses four questions: first, how moisture influences elongation in standard experiments and forming experiments. An increase in moisture content is supposed to increase the extensibility and further the formability in the fixed blank process. The surface moisturisation may still support the formability, but to a lower degree. Second, it investigates how moisture and surface moisturisation affect friction properties of paperboard and their influence on sliding blank press forming. Enhanced extensibility, reduced tensile strength, and increased friction are presumed to counteract each other. Third, the authors want to examine the hypothesis derived from literature (Östlund *et al.* 2011) that one-sided moisturisation enhances formability for fixed blank processes. Fourth, the authors question if surface moisturisation has comparable influence as homogenous moisturisation does and whether it could replace the conditioning of blanks for 3D-forming processes.

EXPERIMENTAL

Materials and Blank Preparation

All tests were performed with Stora Enso Trayforma (Trayforma; Stora Enso Oyi, Helsinki, Finland), a commercial three-ply board (SBS + CTMP + SBS) with grammage of 350 $g \cdot m^{-2}$ and a thickness of 465 µm (Stora Enso Oyi 2021). To investigate the influence of blank moisturisation, seven different blank moisture conditions were selected. Each moisture condition consisted of the overall moisture content and a descriptor of the application. The application determined the moisture distribution in the thickness direction of the paperboard. Different procedures were established to reach reproducible moisture conditions in the blanks. To achieve inhomogeneous moisture profiles over the blank thickness, liquid water was added to the blanks through contact with either a moist plastic surface or a roll with a moist cut-pile polyester sleeve (10 mm pile height).

Table 1 summarizes the moisture contents and their standard deviations using the described procedures. For the samples with homogenous moisture distributions no standard deviation was calculated, because masses were measured only once. However, the reliability was favoured by usage of larger sample weights.

Table 1. Moisture Contents of the Blanks and their Standard Deviations

	Surface Moisturisation		
Target Moisture Content u	***u* after One-sided Application**	***u* after Double-sided Application**	***u* at Homogenous Distribution**
0.08	-	-	0.08
0.12	0.12 ± 0.007	0.12 ± 0.011	0.12
0.24	0.24 ± 0.014	0.24 ± 0.016	0.24

Storing the blanks in standard climate according to ISO 187 (2022) of 23 °C and 50 % relative humidity (RH) for at least 24 h led to a moisture content u of 0.08, which is referred to as the reference moisture content. The other homogenous moisture profiles were achieved by enclosing the samples in plastic bags and letting them rest for at least 24 h. The moisture content u was measured with the oven-dry method, as presented in ISO 638-1 (2022), but in contrast to the standard, it was calculated to the basis of oven dry weight m_0 by Eq. 1,

$$u = (m_1 - m_0) / m_0 \quad (1)$$

where m_1 is the initial mass.

Tensile Tests

Elongation at break and tensile strength were measured by means of tensile tests. Parameters beside the moisture conditions were according to ISO 1924-3 (2005) (velocity: $100\ \text{mm}\cdot\text{min}^{-1}$). The investigation of three different homogenous moisture conditions and distinguishing between fibre orientations in machine direction (MD) and cross directions (CD) resulted in six experimental points ($n = 10$).

Friction Tests

The paper-to-metal friction was investigated with the friction test rig described by Lenske *et al.* (2017). A paper strip was pulled through a set of friction blocks at controlled velocity, temperature, and contact pressure. This setup is an adequate model for the conditions in a forming rig, where the blank slides under a blank holder and into a cavity. The friction blocks were made of polished stainless steel (1.4301). The friction test conditions were chosen to match the conditions in the forming rig. In a fully formed sample, the pressure under the blank holder at 4800 N blank holder force based on blank size and material infeed ranged from to 0.04 to 0.4 MPa; 0.2 MPa was chosen, because it was central in the range and led to results for most experimental points. Only the combination of double-sided moisturisation to u = 0.24 required testing at a lower pressure and was therefore tested at 0.1 MPa. The tool temperatures equalled room temperature (23 °C). The coefficient of friction (*cof*) was then calculated as the quotient of the normal force F_N and the pulling force F_p, as represented by Eq. 2:

$$cof = F_\text{N} / F_\text{p} \quad (2)$$

To avoid influences from static friction and inertia force, the region of interest was set from 5 to 50 mm sliding distance. The *cof* for each experiment was taken as the mean value of Eq. 2 within the region of interest.

Forming Tests with Fixed Blank and Sliding Blank

The forming tests were performed with a press forming machine and the “MiniMould” toolset presented by Tanninen *et al.* (2017), which was designed for trays of 90 mm × 80 mm × 35 mm (width × length × height). The “Minimould” toolset is depicted in Fig. 1. The punch (B), blank holder (C), and cavity (A) had polished steel surfaces. The increments of forming height changes were steps of 0.5 mm, and the full forming height for this toolset was 35 mm. The blanks were cut in such a way that the fibre orientation of the material was parallel to the longer side of the blank respective tool.

Although heated tools are widely used in forming of paperboard (Hauptmann 2010; Vishtal *et al.* 2014; Tanninen *et al.* 2016), the tool temperature was in all forming tests equal to room temperature (approx. 20 °C). The contact with heated surfaces after surface moisturisation partially removed applied liquid from the blank, leaving the paperboard in an unknown moisture state. Through using unheated tools, the moisture influence was separated from thermal influences and coupled hygro-thermal effects. Tanninen *et al.* (2017) introduced a geometrical relation between forming height and necessary material elongation for the same toolset and blank geometry, which was later applied to the current measurements. The application of blank holder force determined the type of the test: high blank holder forces of 4800 N resulted in no or only minor sliding of the blank. Hereinafter, this is called the fixed blank setup. The low blank holder force of 480 N allowed the blanks to slide into the cavity during the forming, which is why it is referred to as sliding blank setup. For one-sided moisturisation it is further distinguished whether the moist side of the blank faces the punch and blank holder ("p") or the cavity ("c"), whereas double-sided moisturisation ("d") and homogenous moisturisation ("h") remain.

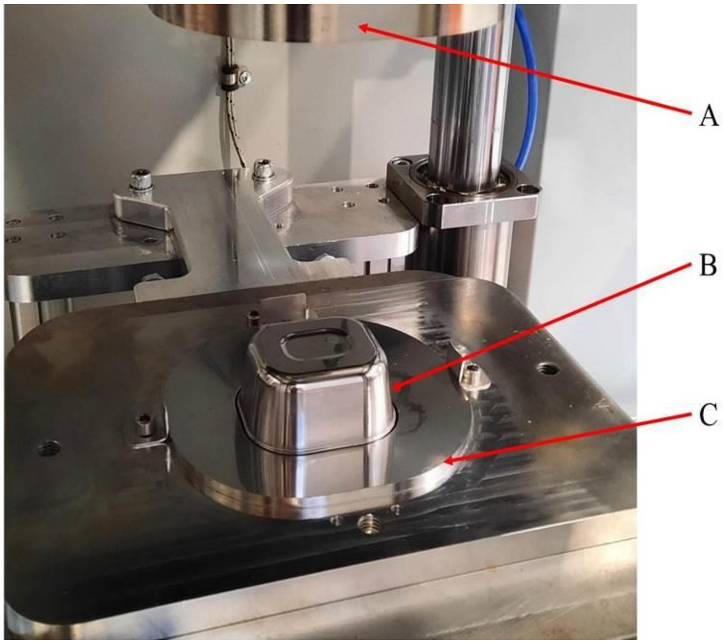

Fig. 1. Forming cavity (A), punch (B), and blank holder (C) of the Minimould toolset

A visual defect rating with the three classes *intact*, *minor defects*, and *major defects* was established and later applied to all formed parts. In the case of *intact* samples, no rupture was visible, and the surface was fully intact. Ruptures in the corners of the formed parts, mainly on the outer material layer and only in places through the full material thickness and in total on less than one quarter of the circumference of the samples were rated as *minor defects*. *Major defects* were visible ruptures on more than one quarter of the circumference of the samples and often through the full material thickness. The forming was considered successful if not more than one out of three samples had more than a minor defect. Figure 2 shows an example for each class.

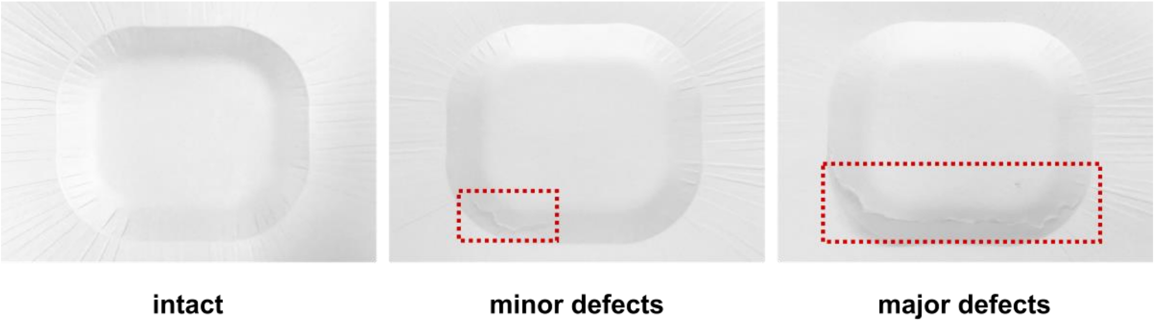

Fig. 2. Examples for defect rating of formed paperboard shapes with boxes highlighting visible defects

RESULTS

Tensile Strength

Table 2 presents the results of the tensile tests and shows the elongation at break and the tensile strength. As expected, in all cases the stretch was higher in CD than in MD direction. The tensile strength behaved contrarily, being higher in MD than in CD. An increase in moisture content from 0.08 to 0.24 increased ε_t by 22% (MD). The loss in tensile strength was much more pronounced. The tensile strength F_B of paperboard with $u = 0.24$ dropped 58% in MD and 56% in CD.

Table 2. Results of Tensile Tests and their Standard Deviations

u	**Orientation**	**ε_t (%)**	**F_T (N)**
0.08	MD	2.6 ± 0.15	455 ± 15
0.08	CD	5.5 ± 0.19	200 ± 4
0.12	MD	2.9 ± 0.14*	373 ± 11*
0.12	CD	6.3 ± 0.46	171 ± 6
0.24	MD	3.2 ± 0.13	191 ± 15
0.24	CD	6.6 ± 0.38	88 ± 7
Number of experiments n = 10 with exception of * where n = 9			

Forming Heights

The results of the forming tests with a fixed blank press forming setup are illustrated in Fig. 3a. Forming heights between 8 and 9.5 mm were achieved. The difference between homogenous moisturisation and surface moisturisation was clearly apparent, as blanks with homogenous moisture content reached the largest forming height at any moisture level. The differences between the types of surface moisturisation (cavity side / punch side / double-sided) were in the range of the smallest height increment. Figure 3b provides a close-up of a ruptured section at a formed sample.

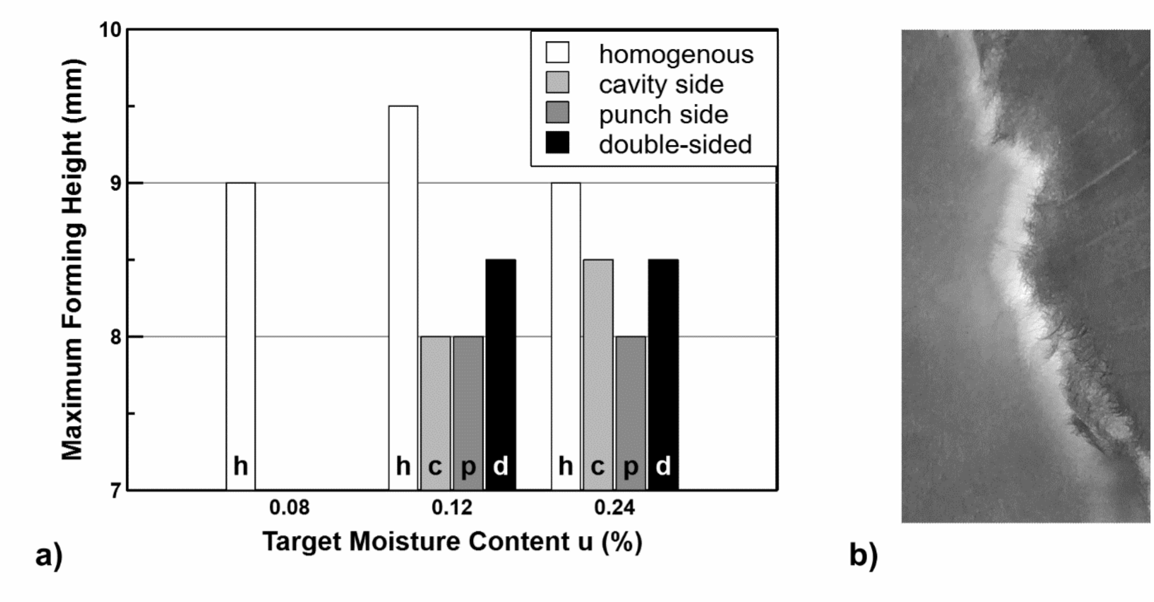

Fig. 3. a) Results of forming tests at fixed blank conditions (h: homogenous, c: cavity side, p: punch side, d: double-sided), and b) close-up of rupture in the board

Dynamic Friction

The coefficients of dynamic friction (*cof*) for moisturised paperboard samples are presented in Fig. 4 (left). At any moisture level, the homogenously distributed moisture resulted in the lowest friction values. The increase in friction between moisture content 0.12 and 0.24 is obvious. For example, the friction value after one-sided moisturisation increased 113%. It was surprising that the *cof* values of samples with a homogenous moisture content of 0.08 and 0.12 were similar to each other. Overall, the lowest friction value 0.18 was measured for samples with a homogenously distributed moisture content of 0.12 and the highest friction value 0.54 was measured for double-sided moisturisation to moisture content 0.24. Figure 4 (right) displays the achieved forming heights of moisturised blanks at a sliding blank setup. Note that the axis displaying the forming height on Fig. 4 was different in comparison to Fig. 3a. The maximum forming height of 35 mm, which corresponds to the full forming height of the MiniMould-toolset, was achieved with homogenously moisturised and cavity side moisturised blanks with moisture contents of 0.12 (converted to dry base: u = 0.14). Overall, the lowest forming heights of 16 mm were reached with blanks after punch-sided or double-sided moisturisation. The data depicted no general correlation between blank moisture content and the forming height.

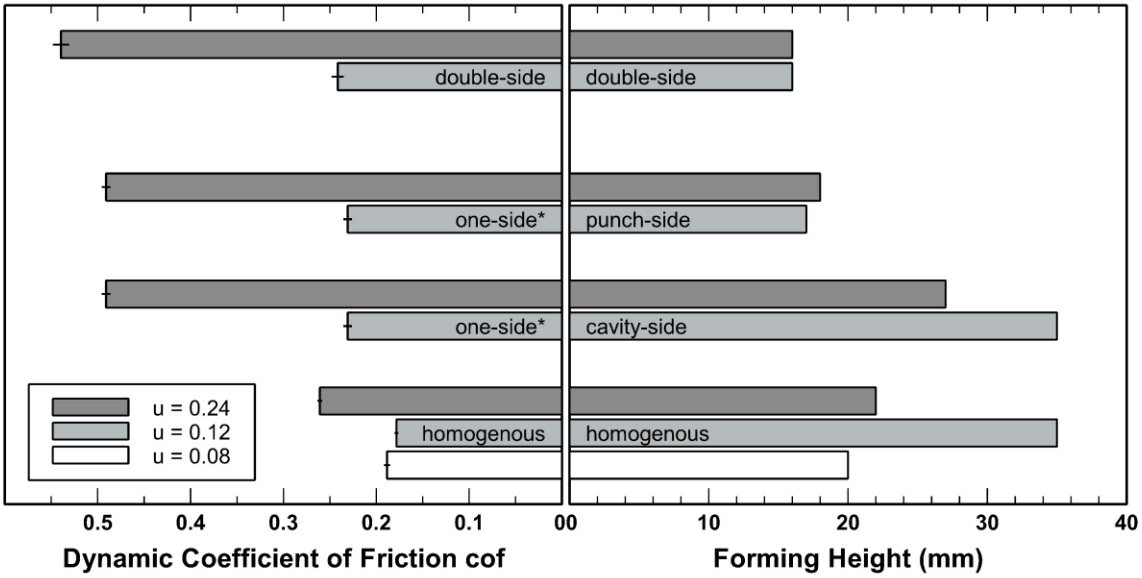

Fig. 4. Dynamic coefficient of friction (left) and forming heights of forming tests (right) of moisturised paperboard samples; each moisturisation method for two respective three moisture levels

DISCUSSION

Tensile Tests

In tensile testing, the material performed like a classic paperboard material with high strength but low elongation at break in MD, and the opposite for CD. The measured values of 0.08 moisture content at standard conditions are well within the specifications of the manufacturer (Stora Enso Oyi 2021). Stretch was slightly reduced at standard conditions because only 5.5% stretch was measured, in contrast to 6.0% given in the data sheet.

Vishtal and Retulainen (2014) name three structural factors that affect the extensibility of paperboard: the properties of the single fibres, interfibre bondings, and the structure of the fibre network. External factors, such as relative humidity, temperature, or strain rate, may influence them. From the structural factors, five general deformation mechanisms of the fibre network structure of the paperboard emerge (Vishtal and Retulainen 2012). These are fibre straightening, shift of bonding angles (shear), changes in fibre-to-fibre bond positions (slip), and finally individual fibre stretching. Each of these may contribute to the observed material elongation. Similarly, the rupture mechanisms subdivide in breaks of the fibre and separation of interfibre bondings. For the presented experiments, the rupture lines tend to be fringy with individual fibres sticking out, as illustrated in Fig. 3b. Bonding failure appears to be the dominant rupture mechanism. The loosening of fibre bonds and the slip between fibres can contribute to the observed extensibility of the paperboard. Still, the breakage of many bonds will result in loss of structural integrity of the samples.

Fixed Blank Press Forming

Fixed blank forming processes heavily rely on the elongation of the material. The material reacts to the motion of the punch with elongation. Ruptures occur when the bearable stretch is exceeded. Therefore, elongation at break ε_t becomes the limitation in paperboard forming with a fixed blank setup. In general, the lowest elongation capacity of a conventionally produced sheet occurs in MD, wherefore it determines the formability in a fixed blank setup.

The authors hence expected that an elevated moisture content will be beneficial for fixed blank forming processes, because it increases the elongation at break in MD. The increase in elongation at break with higher uniform moisture content was clearly confirmed by the data from Table 2 and in accordance with literature (Rhim 2010). In contrast, the findings did not transfer to the fixed blank press forming experiments with homogenous moisturised samples, even though the moisture conditions of the blanks have been equivalent to those of the tensile tests. Homogeneous distribution of moisture in the specimens was not necessarily equivalent to the equilibrium moisture with the surrounding climate conditions at the test setups. For specimens with a homogenous moisture content, the achieved forming heights with fixed blanks were 9 mm or 9.5 mm for all moisture levels (see Fig. 3 a). Considering that 0.5 mm was the smallest increment in forming height, no effect can be associated with the data. The measured forming heights for these experiments were in good alignment with similar experiments conducted by Tanninen *et al.* (2017), who reported forming heights between 7 mm and 10 mm.

Tanninen *et al*. (2017) further suggested calculating the required elongation for a specific forming height using the geometry of the toolset (Tanninen *et al.* 2017). Figure 5 illustrates that relation. Because the same toolset was used, it is valid to apply this method to the forming heights measured here: forming heights of 8.0 mm to 9.5 mm required material elongations from 6.9% to 9.1%. These were substantially higher than the reported material parameters (see Table 2), where $\varepsilon_t \leq 3.2\%$ in MD direction. The different load velocities of 100 mm/min in tensile testing and 40 mm/s (2400 mm/min) in the press forming setup do not explain the differences, because the velocity influence inversely impacts the material's tensile behaviour. Paperboard shows viscoelastic behaviour, and under constant load it will creep, over time. Increasing strain rates often result in reduced breaking strain (Östlund and Niskanen 2021). The authors conclude that because of the three-dimensional forming process, multiaxial loads occur, and the uniaxial tensile test is not sufficiently describing the forming behaviour of the material. Hofmann *et al.* (2019) observed similar behaviour, when at a deep drawing process in high moisture conditions the measured elongation of the cup wall exceeded the elongation at break from the uniaxial tensile test. In that case, they suggested material displacement and multiaxial stress conditions as an explanation. It shall be mentioned that the clamping of the blank under the blank holder was not constantly monitored during the measurements, which set limitations to the findings of this study. A minor infeed, with 0.1 mm reduction of width and length of the blank per millimetre forming height (10% infeed), would already result in remarkably reduced elongation requirements. For illustration, see the dotted line in Fig. 5.

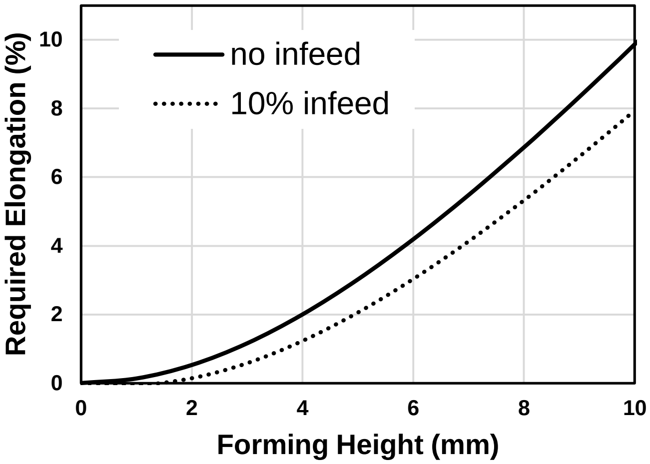

Fig. 5. Required elongation in fixed blank forming (solid line) with the MiniMould-toolset; replicated from Tanninen *et al.* (2017), dotted line added for a linear increasing blank infeed of 0.1 mm per mm forming height

The data for the fixed blank press forming process revealed a correlation between achievable forming height and moisture condition. Samples with surface moisturisation showed reduced formability compared to homogenous moisturised samples, regardless of if the moisturisation occurred on punch side, cavity side, or both. The uneven moisture distribution throughout the material thickness may be considered as an explanation: As model representation, paperboard samples with a homogenous moisture content have the same tensile properties at each point in thickness direction. In contrast, the one-sided moisturisation will lead to a layered structure with a moist and subsequently extensible top layer and a still dry and therefore rigid baselayer underneath. Double-sided moisturisation would analogously result in a three-layered structure with moist and extensible outer layers and a rigid core. Östlund *et al.* (2011) claimed that the forming benefits from these dry layers because they bear the tensile forces and thus prevent ruptures. For the experiments presented here on fixed blank press forming, the layered moisture distributions after surface moisturisation provoked earlier ruptures than in homogenously moisturised samples. It seems likely that the ruptures were initiated in the dry layers and caused by their limited extensibility. Consequently, the uneven moisture distribution was disadvantageous for the forming. The differences in forming height between punch-sided, cavity-sided, and double-sided moisturisation were within range of the smallest increment of 0.5 mm, and further differentiation of the results is not appropriate. The earlier findings from (Östlund *et al.* 2011) showed that in hydroforming, one-sided moisturisation is superior to two-sided moisturisation, yet these earlier findings did not translate to the fixed blank press forming process considering the data in this study. A comparison of unevenly moisturised samples with homogenously moisturised paperboard blanks reveals that in fixed blank press forming with unheated tools, moisturisation is not beneficial. Coupled hygro-thermal effects are not covered in this study and should be included in further research activities.

Friction Tests

The results of the friction tests in general showed an increase in friction with increased material moisture content and are thus aligned with the literature (Borch 2002; Fellers *et al.* 1998; Kawashima *et al.* 2008). At the same overall moisture contents, recently moisturised samples have at their surface locally even higher moisture contents but drier midlayers. Because dynamic friction is a phenomenon between moving surfaces, the moisture content at the surface greatly affects friction properties. Lenske *et al.* (2022) suggest that in metal-to-paper friction, the water in the contact zone induces open hydrogen bonds in the paper that are then attracted to a hydrophilic metal surface. This attraction may as part of the adhesion forces contribute to the measured friction forces. In contrast, steel-to-steel friction was found to decrease at higher humidity (Chen *et al.* 2018).

Friction occurs between the two solid bodies of paper and metal. On a microscale, rough surfaces result in asperity contacts with a smaller real contact area. When the surfaces are fully separated by a liquid film, the friction forces drop, because the shear plane moves into the liquid layer (Bhushan 2013). In contrast, the measured friction increased from moisturisation and therefore it can be assumed that the moisture did not fully separate the paper and metal surfaces. The increase in friction with surface moisturisation may instead be explained by surface energy effects and wetting characteristics. Water menisci with curved shapes form at the asperity contacts between the surfaces. The pressure inside the curved water reservoirs creates additional attractive forces and pulls the two bodies together. As a result of capillary forces, overall friction is increased.

Sliding Blank Press Forming

For paperboard forming in a sliding blank setup, the tensile strength sets limitations on the formability, and elongation is considered subordinate. The material must withstand tensile forces from the punch and the friction between blank, cavity, and blank holder. When the forces needed for the blank to slide into the cavity exceed the tensile strength of the paperboard, ruptures occur. Because the material is weaker in CD (see Table 2), the tensile strength in CD is the value of interest. When considering the tensile strength during the forming process, moisturisation appears disadvantageous to paperboard forming in a sliding blank setup. An increased moisture content reduces the tensile strength. It is emphasised that moisturisation will also affect multiple other material properties, such as bending stiffness, in-plane rigidity, and friction values.

In the sliding blank setup, the orientation of the moisturised paperboard is important, as one-sided moisturisation at the punch side or the cavity side lead to different results. Cavity-side moisturisation had comparable effects on the forming height (sliding blank) as the homogenous moisturisation, but punch side moisturisation was disadvantageous. The authors relate these observations to material dislocation and differing friction properties. The free material length that is available for elongation is in theory situated only between the edge of the punch and the infeed edge of the cavity. However, material dislocation may appear during fixed blank forming. Similarly, Tanninen *et al.*

(2017) showed for sliding blank press forming that the parts of paperboard under the blankholder and at the punch participate to a certain extent in the elongation. Consequently, the contact area of punch and blank becomes affected by dynamic friction properties of the surface pairing. A drier paper surface with smaller friction coefficients facilitates a higher material flow, whereas the friction of moist paper surfaces hinders it. In the collected data, two results are related to this phenomenon: first, the material dislocation increased the amount of material participating at elongation at the free span and can therefore partly explain why the observed required elongation exceeds the measured material properties. Second, the additional area of friction at the punch likely caused the differences between punch-side moisturisation and cavity-side moisturisation. The elevated friction after punch-side moisturisation inhibited the above-mentioned material flow and therefore limited the achievable forming heights. Additionally, Lindberg and Kulachenko (2022) found that ply-wise differences in a three-layer paper model affect the formability of the paperboard. Further, they deduced from a simulation model that the highest strain in a press forming operation appears in the outer layer facing the cavity and consequently recommend protecting this layer by bearing the forming forces in a strong layer on the opposite (punch facing) side of the board. A paper blank with a moisturised surface will have ply-wise differences in moisture content and hence ply-wise differences in tensile behaviour. The data from the sliding blank press forming tests showed superior forming results after cavity-side moisturisation opposed to punch side moisturisation. This supports the findings from Lindberg and Kulachenko (2022) that a dry and therefore strong layer at the punch-side is favourable.

The disadvantages of high moisture contents at the punch side of the blank also affect the results in forming test with double-sided moisturised blanks. For sliding blank press forming operations, a cavity-side surface moisturisation performed as well as homogenous moisturised samples that were stored in a conditioned environment. Further research is suggested to verify whether surface moisturisation could replace the material conditioning.

CONCLUSIONS

To explore the role of blank moisturisation in press forming of paperboard, paperboard specimens were moisturised to achieve homogenous or uneven moisture distributions in thickness direction. In addition, friction and tensile properties of the specimens were tested. Press forming experiments related the blank moisturisation with the achievable forming height as a measure of performance. The following conclusions were obtained:

1. All findings were found to be valid under the researched conditions of forming with tools at room temperature and blank moisture contents in the range from 0.08 to 0.24.
2. The increase in elongation at break with higher moisture contents did not affect the forming heights in the fixed blank press forming process.
3. At room temperature (20 °C to 23 °C), increased moisture content resulted in increased paper to metal friction. After surface moisturisation, the increase in friction was more pronounced due to locally even higher moisture contents.

4. Fixed blank press forming did not benefit from an elevated blank moisture content and surface moisturisation can increase defect formation.
5. For sliding blank press forming of paperboard, cavity-side moisturisation of the blanks is preferred over punch-side moisturisation. Double-sided moisturisation is affected by the negative influences of a moisturised punch side.

CONFLICT OF INTEREST / ACKNOWLEDGEMENT

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