

BENEFITS OF FOAM FORMING TECHNOLOGY AND ITS APPLICABILITY IN HIGH MFC ADDITION STRUCTURES

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ABSTRACT

In paper and board industry there is a strong need for a radically more resource-efficient production technologies, which would also enable the manufacture of sustainable and value-added fibre products. In this paper we introduce foam forming method, where foam is used as a transporting media of furnishes. The technology enables to make structures with excellent formation in higher headbox consistencies and a very high bulk. When this is combined with the good water drainage properties, which allows the high addition levels of strengthening agents as micro fibrillar cellulose (MFC), one can make products with very big bulk and still have an adequate strength value. We studied different MFC grades and they seem to behave rather similarly in bulk vs. strength comparisons. However, some difference is obtained leaving room for optimization of best MFC grade on certain product.

INTRODUCTION

In the traditional paper making, foam is found typically to cause problems such as aggregating fine materials. Therefore, from a historical point of view, much more

attention has been given to the development and the usage of foam control agents than to foaming agents. There are a number of publications and books dealing with foam problems in processes and foam control [1]. However, in the 1970's technology based on usage of foam was demonstrated in a pilot scale based on the Radfoam process [2, 3, 4, 5]. The Radfoam process was found to enhance product properties and especially formation in non-woven and paper applications [4, 5]. In the foam-laid technology aqueous foam is used (instead of water) as a process fluid and flowing medium. This kind of foam has an air content of 60–70% and it contains small, spherical air bubbles with diameters below 100 μm . Aqueous foams are pseudoplastic, having very high viscosity at low shear conditions, but low viscosity at high shears. Due to these characteristics aqueous foams are excellent material to transport particles and fibres in a dispersed state leading to the excellent formation of the paper [5, 6]. In additions, these foams allow the use of wide variety of different raw materials, from nanoparticles up to 200 mm long fibres and also low density materials.

The foam forming technology is used in non-woven production, but after the 1970's in paper making it was forgotten due to the lack of economical drives like savings in energy and raw material consumptions. At the moment paper industry is facing such demanding, and there is a strong need for a radically more resource-efficient production technology, which would also enable the manufacture of sustainable and value-added fibre products.

In this paper we re-introduce this foam forming method, because it provides many interesting benefits for the properties of the paper, as well as for the processing phase. For the studies foam formed paper sheets were made using a laboratory scale foam handsheet mould and a semi-pilot scale dynamic former. The former was modified from a water former based on the knowledge of the Radfoam process.

In the Radfoam process a paper making furnish was mixed with prefabricated foam. The foam was generated under controlled, high shear conditions from a surfactant-water solution. On the paper machine wire, foam was broken down by physical means to form a foamy-water medium; this could be done by vacuum or by pressure in the nip of any configuration [6]. Under the influence of suction, these foam-fibre mixtures drained rapidly producing sheets of a higher uniformity than that of water slurry of the same weight consistency [5]. In our semi-pilot scale studies enchantments in formation, dewatering and headbox fibre consistencies were obtained. The paper made by the Radfoam process had high bulk and low strength characteristics in an unpressed state compared with a comparable water-laid paper, but the strength could be regained by beating or by pressing. Pressing raised the strength to the water-laid level whilst correspondingly reducing the bulk [2].

In our laboratory scale studies we show another way to increase the strength, namely a usage of micro fibrillated cellulose (MFC) as a strength additive to

enhance sheet strength to the acquired level, for example, to the level suitable for normal packaging applications. We used six different types of micro fibrillar celluloses, isolated from the wood-based fibres in our laboratory scale studies, in order to study their capability to increase strength of paper sheets made from chemical or mechanical pulp. In water forming high MFC addition is not an option, as fine material influences on dewatering, but the open structure of the foam formed sheets enables the high MFC usage. Our studies show that MFC enables the strength enhancement without a bulk lost. It also shows that the grade of MFC must be chosen based on the application and product requirements.

EXPERIMENTAL

Materials

The forming studies were carried out using a refined chemical pine pulp, chemical birch pulp and chemi thermo mechanical (CTMP) spruce pulp [7]. The average fibre length of pine pulp was 2.19 mm, coarseness was 141.7 $\mu\text{g}/\text{m}$ and shopper value was 26 °SR. The average fibre length of birch pulp was 0.91 mm, coarseness was 101.9 $\mu\text{g}/\text{m}$ and shopper value was 26 °SR. The average fibre length of spruce-CTMP pulp was 1.60 mm, coarseness was 220,3 $\mu\text{g}/\text{m}$ and Canadian Standard Freeness value was 566 ml. Tap water was used as process water. Sodium dodecyl sulphate was used as a foaming agent. Micro fibrillated cellulose was used as a strength additive. MFC is a material composed largely of nano and micro sized cellulose fibrils with a high aspect ratio (length to width ratio). Width of fibrils is typically 5–20 nanometres and length is in a wide range from 10s of nanometres to several microns. The more nano scale the material is, the more viscous and transparent it is. We used six different types of micro fibrillar celluloses isolated from the wood-based fibres in our trials. The background information of the MFCs available is the following and Figure 1 shows the light microscope images of the MFCs and Table 1 the characteristics available from the MFCs:

- MFC1, MFC2: made of bleached hardwood kraft pulp. They are ground to different coarseness levels having viscous structure higher than the other grades. These grades have also the highest transmittance levels. Material was delivered in the consistency of 3%
- MFC3: made of dissolving pulp with high cellulose content. The dissolving pulp is originally from softwood. Material was delivered in the consistency of 10%.
- MFC4: is produced via acid hydrolysis of kraft pulp cellulose polymer, and refined with varied setups. Material has relatively low viscosity.

- MFC5: micro fibrillated material that consists of wide selection of unfibrillated and fibrillated material that form medium viscosity in the scale of available grades.
- MFC6: micro fibrillated material that consists of stiff fibre fragments and fibrils that form medium viscosity in the scale of available grades

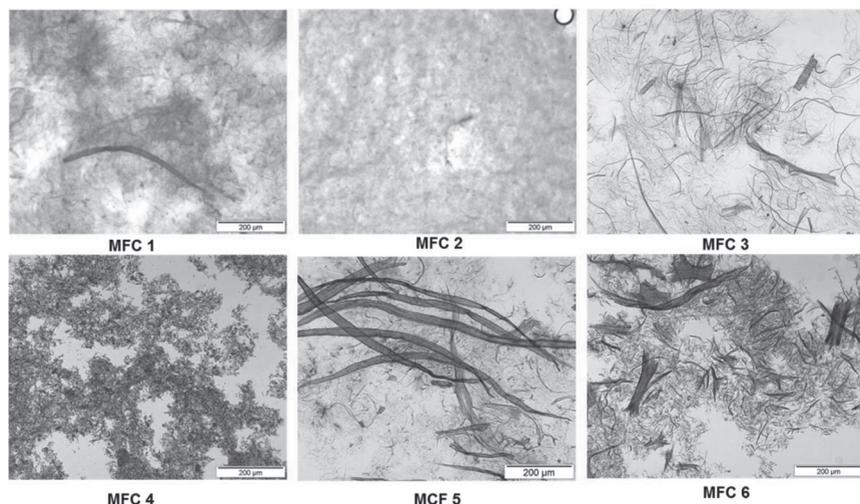


Figure 1. The light microscope images of the micro fibrillar celluloses used in the studies.

Table 1. The characteristics available from the micro fibrillar celluloses used in the studies

<i>Sample</i>	<i>Viscosity, mPas·s 10 rpm 1.5% conc.</i>	<i>Transmittance, % 800 nm 0.1% conc.</i>	<i>Sedimentation volume, mm</i>	<i>Visual appearance (optical microscopy)</i>
MFC1	23200	34.3	35	Coarse
MFC2	22500	60.2	42	Fine
MFC3	15800	8.1	16	Coarse, long fibrils
MFC4	400	0.5	32	Coarse
MFC5	3650	26.2	13	Coarse
MFC6	2780	24.9	23	Coarse

Material characterization

The pulp properties were characterised using the Fibre Quality Analyser (Fibre-Master). The Schopper-Riegler value was determined according to ISO standard 5267–1:1998 and the Canadian Standard Freeness value, in accordance with ISO standard 5267–2:2001. The grammage of the paper samples was determined according to ISO standard 536:1995. Thickness of the samples was determined according to ISO standard 534:1998. Density and bulk are based on the measured values of the grammage and sheet thickness. The tensile strength properties of paper samples were measured using a Lloyd tensile tester, in accordance with ISO standard 5270:1998. The z-strength property was measured according to ISO standard 15754:2009. Internal bonding strength, modified Scott bond was measured using Huygen Internal Bond Tester, in accordance with TAPPI T569.

Based on the β -formation measurement for the current study, a storage phosphor screen (SPS) was exposed to β -radiation through the paper sample, with Carbon-14 as the radiation force. This was done in order to evaluate the radiation absorption map. Thereafter, the screen was scanned with a Fuji BAS-1800 II SPS reader. Then, the measured values were converted into a grammage map. The size of the scanned area was 100 mm \times 100 mm and the scanning resolution was 100 μ m. Following this, the resolution was transformed to the Ambertech resolution (0.1mm). The characteristics of the micro fibrillar celluloses were delivered with the samples.

The static foam forming equipment

The static forming studies were performed using refined chemical pine pulp and chemi thermo mechanical (CTMP) spruce pulp. The foam laid handsheets were made using a method and an equipment set-up adopted from the glassfibre industry (Figure 2).

The procedure of the foam laid handsheets is as follows:

Aqueous fibre suspension is mixed with the prefabricated foam, which was produced by stirring water and surface active agent (sodium dodecyl sulphate, SDS) at 3500 rpm. The ratio of SDS should be 0.15–0.2 g/L for 60–70% air content of the foam. When the fibre foam state is stabilized, it is decanted into the handsheet mould using tilted plate as shown in Figure 3 (centre). There is a one centimetre slit between the plate end and the mould wall. This restricts the spreading speed to the wire and also forced the foam to spread from one end of the mould to another end of it. This movement is enough to orient fibres in a flow direction. After foam is settled it is filtered through a wire using a vacuum chamber. In the filtration we use same wire material as used in paper machines. The sheet filtrated is detached with the transferring wire from the mould and

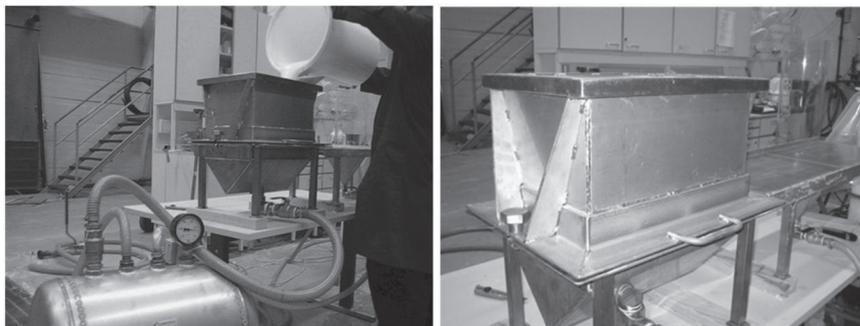


Figure 2. The foam forming handsheet mould and the equipment set-up.



Figure 3. The procedure of the foam laid handsheet making. (1) An aqueous fibre suspension is mixed with a prefabricated foam produced from water and sodium dodecyl sulphate (SDS) in ratio 0.15–0.20g/L. (2) The fibre foam is decanted into the handsheet mould and filtrated through a wire using a vacuum chamber. (3) The sheet is pre-dried on a suction table (0.2 bar vacuum).

pre-dried on a special suction table. The suction table has a 5-mm-wide suction slit that sucks air through the sheet with a 0.2 bar vacuum. The picture series below show the working procedure (Figure 3). The sheets formed were fixed between a metal plate and a fabric to be dried in an air tunnel for one night, stored and analysed in a standard conditioned room at RH 50% and 23°C.

The dynamic foam forming equipment

The dynamic forming studies were performed using refined chemical pine pulp, chemical birch pulp and chemi thermo mechanical (CTMP) spruce pulp. The average process temperature in the foam forming studies was around 27 °C. The water-laid fibre webs from the pulps were produced using the semi-pilot scale former. The foam forming studies were performed using the same former modified to a foam forming mode [7]. The schematic picture of the modified water-laid

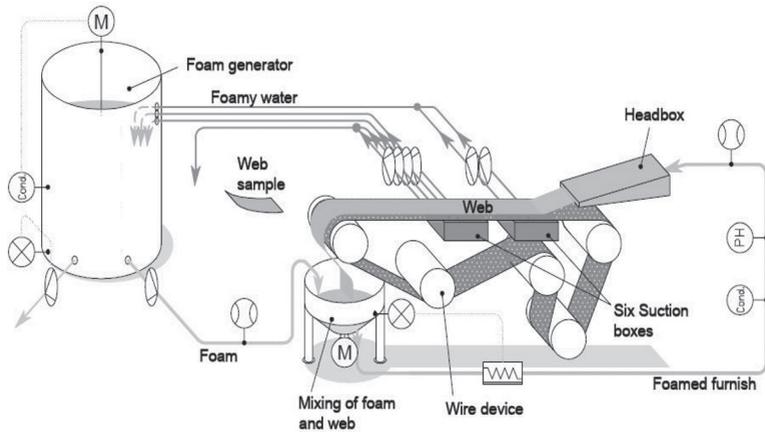


Figure 4. Schematic picture of the water-laid process research environment.

semi-pilot scale former is presented in Figure 4. The main principle of the foam-laid process is that the process foam recirculates in the flow loop and raw materials are mixed with the process foam in a machine chest.

RESULTS

Dynamic forming studies

One of the major benefits of using the foam forming technology is the excellent formation of products formed. The formation potential of the foam-laid forming technology for different kinds of wood-fibres has been studied in the case of chemical pine pulp, chemical birch pulp and spruce-CTMP pulp. Paper samples were formed using selected web-forming conditions [7]. The average grammage of spruce-CTMP pulp was 108 g/m^2 for foam and 107 g/m^2 for water, forming consistencies were 1.45% for foam and 1.15% for water, crowding numbers [9] were 88 for foam and 70 for water, for pine pulp respectively grammages 82 g/m^2 and 84 g/m^2 , consistencies 1.30% and 0.67%, crowding numbers 230 and 119, and for birch 84 g/m^2 and 83 g/m^2 , consistency 1.38% and 0.72%, crowding numbers 59 and 31.

The selected forming points were formed with optimal forming conditions determined to reach the appropriate formation level and the tensile-strength ratio approximately to the same level in both cases, e.g. in the case of pine pulp a jet-to-wire ratio of 1.1 for the water-laid paper and with 2.2 for the foam-laid

paper, the formation 1.9 for water-laid paper and 0.7 for foam-laid paper and the tensile-strength ratio approximately 2.2 in both cases.

In the case of foam-laid forming studies an electromagnetic flow sensor for measuring a volume flow rate cannot be used, because of high amount of dispersed air involved in. For the reason, the volume flow rate for foam suspension was determined using a scale and by defining the amount of foam suspension as a function of time. The average flow rate was 2.5 l/s for foam-laid forming studies.

In the water forming method the formation is dependent on fibre length; good formation can be achieved with short fibres like birch, but when the fibre length and fibre coarseness increase the formation start to deteriorate [9]. In the foam forming the formation is much less dependent of fibre properties, and a significantly better formation was achieved with all pulps than in the case of water-laid paper (Figure 5). However formation is still poorer than for random networks [9] as shown in Figure 5. When fibres are mixed to the foam, the foam bubbles attached to the fibre surface thus forming a bubble layer. This layer prevents fibres touching each other before dewatering phase, thus preventing flocculation. The formation difference was greatest in the case of spruce-CTMP, due to relatively stiff fibre compared to chemical pine and birch pulps.

Given that the headbox consistencies in the foam forming trials were higher compared to the water forming trials, the formation results are even more impressive. The consistencies are shown in Figure 6. In all cases there is a significant increase in the headbox consistencies. The limitations to the consistencies in the foam forming in our dynamic former come from the mixing procedure of fibres to the foam. In the Wiggins Teape Radfoam process even higher headbox consistencies were used. They managed to raise it up to 3–5% [4].

In foam forming, the dewatering in a wire section is more effective than in the case of water forming. With foam forming we have been able to ad as high as 30%

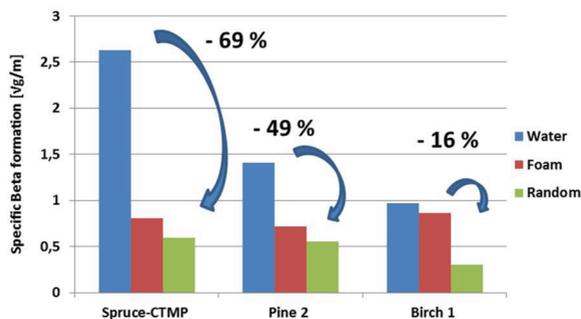


Figure 5. Comparison of specific formation number of water formed samples (left bar), foam formed samples (middle bar) and random network (right bar) using spruce-CTMP, pine and birch.

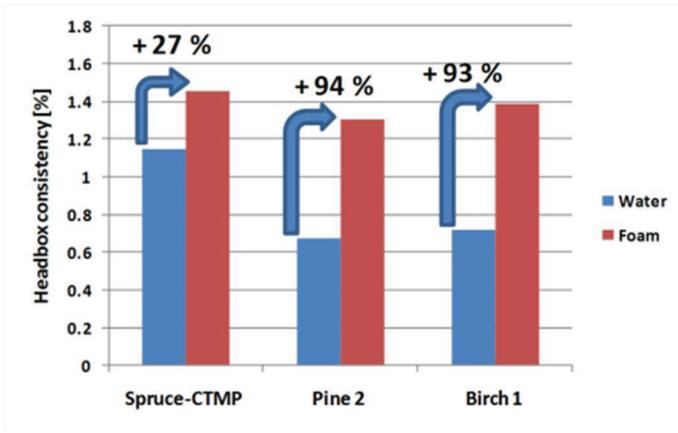


Figure 6. Comparison of headbox consistency of the water formed samples (left bar) and the foam formed samples (right bar) using spruce-CTMP, and chemical pine and birch pulps.

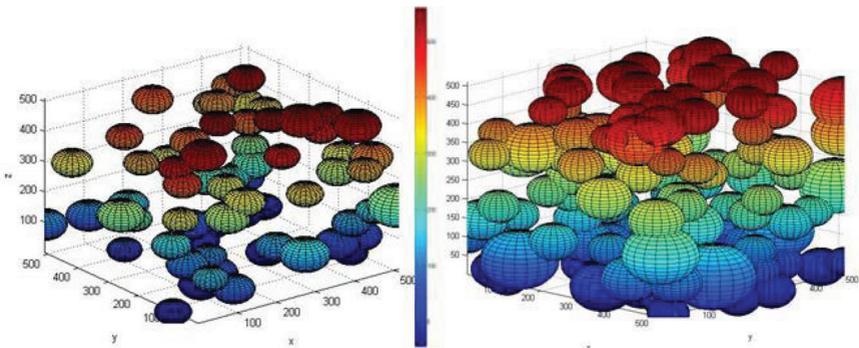


Figure 7. Characterisation of the pore network by balls of radius larger than $52 \mu\text{m}$. The figure on the left-hand side is a water-formed sample and on the right-hand side a foam-formed sample. The red colour indicates that pores are at the top of the paper and blue that pores are at the bottom [10].

of MFC without problem with the dewatering time, with water forming there start to be problem after adding 10% of MFC.

The reason for improved dewatering properties is due to the difference in pore size distribution in the paper structures as shown in Figure 7. In that figure is shown the analysis of the x-ray microtomography images of water and foam formed samples [10]. The apparent density for water formed sample is 200 g/m^3 and for foam formed sample 120 g/m^3 . To characterise the pore network of the samples,

we applied a distance transform to a binary sample image. Each local maximum in the distance transform is represented as a sphere of corresponding radius. The pores are not actually spheres [11], but the main idea of this analysis is to visually illustrate the differences in pore space. In Figure 7, all spheres of a radius larger than $52\ \mu\text{m}$ are plotted. The sphere colour indicates the z-directional position of the sphere in the structure, with red being top and blue bottom. In the foam-formed sample, big pores construct channels through the structure in the z-direction, whereas in the water-formed sample, large pores are almost isolated. The channels in the foam-formed samples are very beneficial for drainage properties.

Application of high amount of nano fibrillated cellulose

The paper made by the foam forming process has high bulk and low strength characteristics in an unpressed state compared with a comparable water-laid paper. The strength lost is possible to regain by beating or by pressing [2], in latter case at the expense of the bulk. In paper physics it is well known fact that there is strong correlation with porosity of a structure and strength of a structure [9]. In normal water forming method strong wet pressing improves the strength. The example of this behaviour is shown in Figure 8. The triangles are shown the typical values for the current CTMP pulp obtained from the KCL pilot paper machine trials. In the same figure the squares are the results of the water formed

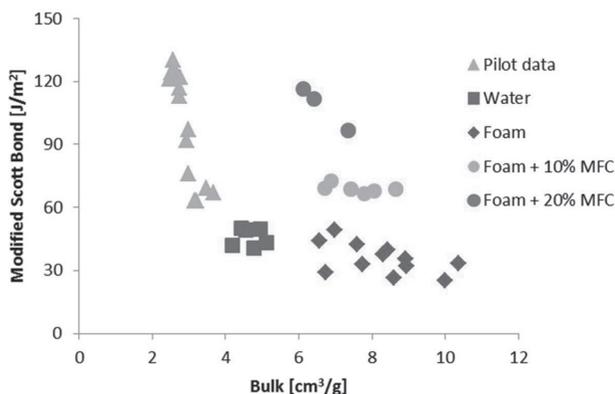


Figure 8. Scott bond values CTMP sheets as a function of bulk. The triangles are the typical values for the sheets made from typical CTMP pulp obtained from the KCL pilot plant tests. The squares and diamonds are values from water-formed and foam-formed laboratory handsheets, respectively. The circles show the values of the foam-formed samples with different micro fibrillar cellulose contents.

sheets and the diamonds the results of the foam formed sheets, both sheet forming done in the laboratory scale.

In the first experiments we used the same CTMP as in the dynamic trials. The water formed handsheets were wet pressed according to ISO 5269-1 (2005-02-01), which says that the pressing is 400 kPa \pm 10 kPa. The sheet size was 16.5 cm \times 16.5 cm. The foam formed sheets were wet pressed using a couch roll 1 time or 10 times. The method is rather crude, but enables sheets with different bulk values. Part of the foam formed sheet was left unpressed in order to see the bulk potential. The couch roll used in wet pressing has a mass 13.0 kg, length 178 mm, diameter 102 mm as said in the standard ISO 5269-1 (2005-02-01).

The results clearly show that the foam forming enables much higher bulk values compared to the water forming. The Scott bond values of the laboratory scale water and foam formed samples go into the same curve than the pilot scale results showing that by reducing the bulk in the foam formed sheets to the level 2–3 cm³/g with wet pressing, the rapid increase in the Scott bond is obtained leading to the acquired level in z-directional strength.

Maintaining the bulk, and increasing the Scott bond values to the acquired level suitable for normal packaging applications, is possible to do using some strength additives. The amounts used can be reasonable high due to the open structure of the foam formed samples explained earlier. This is not an option in the water forming, because the water drainage properties would be compromised too much. In our foam forming studies the addition amounts of MFC, 10% and 20%, did not effect on water drainage times on a static foam former. Figure 8 shows the bulk and Scott bond values of the samples containing 10% (lighter circles) or 20% of MFC (darker circles). These results show that structures with extremely high bulk and acquired strength properties are possible to produce by foam forming. This is very advantageous especially in board applications. The ability to use reasonable high amount of MFC addition opens up a wide window of different kind of optimization of the end properties. It also makes the selection of the suitable MFC grade very important, because the price of the MFC varies quite a lot. In these first tests we used MFC3.

As a consequence of this next test series were run in a laboratory scale using six different grades of micro fibrillated celluloses in order to see their effect on both z-directional and plane strength properties. The pulps used in the study were the pine kraft pulp and the mechanical spruce CTMP pulp and addition amounts of MFCs 0% (a reference), 5% and 15%. The sheets prepared were dried after forming without any wet pressing. The results from CTMP series are shown in Figure 9.

We measured both z-strength and modified Scott bond, because the latter is dependent on the formation. The similar results indicate good formation. The general trend of effects of different MFC on strength properties is rather similar. The results show that MFC made the sheet structure denser leading to the bulk lost from bulk value of 10 cm³/g (a reference, no MFC) to values of 6.5–9 cm³/g.

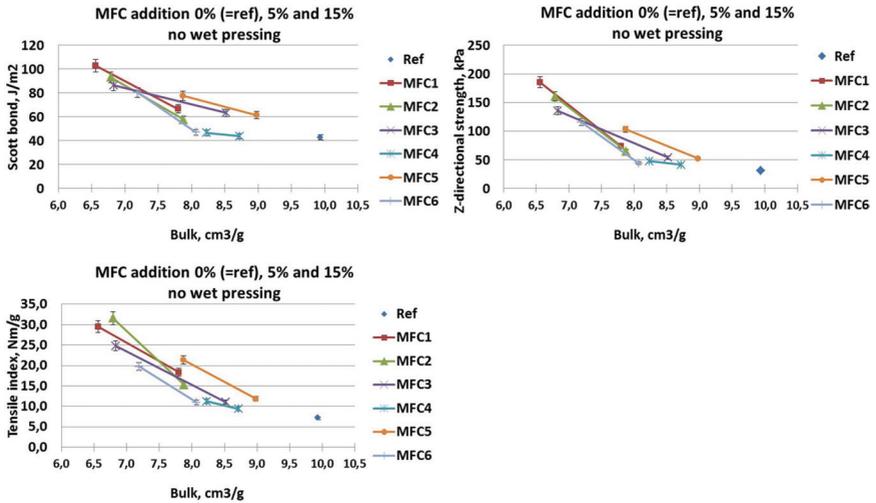


Figure 9. Effects of addition of six different MFC grades to the spruce-CTMP pulp. Above left: Modified Scott bond as function of bulk. Above right: Z-strength as function of bulk. Below: Tensile index as a function of bulk. The right edge of the line equates the 5% addition amount and the left edge 15% addition amount.

However, the acquired z-directional strengths were reached in unpressed samples with MFC addition in high bulk levels of ca. 6 cm³/g, by wet pressing the target was possible to reach in bulk levels of 2–3 cm³/g. Remarkable in these results compared with the results showed in Figure 8 is that excluding MFC4 all others in the bulk values above 6 cm³/g have Scott bond values above 50 J/m², whereas in the wet pressing case all Scott bond values were below 50 J/m². Another interesting result is to compare MFC1 and MFC2. Especially, in the case of the z-directional strength comparison MFC1 gives the highest Scott bond, even though it is more coarse (and cheaper) than MFC2. This shows that by choosing the most suitable MFC for certain application one can save substantial amount of money. The addition of MFC increases also plane strength of CTMP sheets significantly. However, in this comparison MFC2 gave highest tensile index value showing that the selection of MFC depends on needed property.

The same study was done using the pine kraft pulp. The results are shown Figure 10. The general trend of effects of different MFC on z-directional strength properties is rather similar that in CTMP series, except the behaviour of MFC5. With chemical pulp the influence of MFC5 is extremely interesting; the z-directional strengths were doubled without any bulk lost likewise the stretch. The mechanism behind this behaviour is unclear to us and needs more investigations.

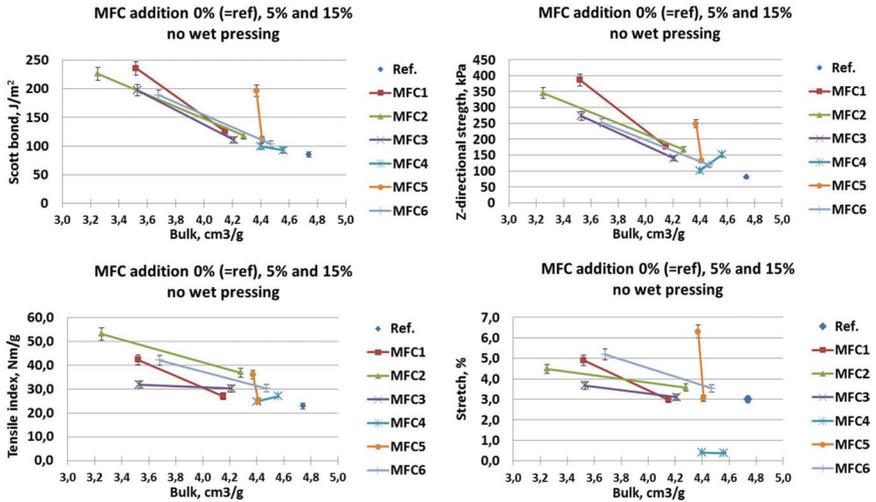


Figure 10. Effect of addition of six different grades of MFC to the kraft pine pulp. Above left: Modified Scott bond as function of bulk. Above right: Z-directional strength as function of bulk. Below left: Tensile index as a function of bulk. Below right: Stretch as function of bulk. The right edge of the line equates the 5% addition amount and the left edge 15% addition amount.

CONCLUSION

In this paper we have introduced the main benefits of the foam-laid technology. The main focus of the paper is in packaging applications, but also other application areas benefits from the process and paper properties improvements the foam-laid technology offers.

Good formation is needed in many paper and board application. Using the foam-laid technology the formation is only weakly dependent of fibre properties or head box consistency. In all cases studied we obtained improvement in beta formation. Even using coarse fibre such as spruce-CTMP we obtained slightly better formation than in the water formation using birch kraft. In addition, the headbox consistency was increased at the same time.

When water removal properties before wet pressing were compared, the foam-laid technology gave higher dryness levels. Because vacuum levels used were not exactly same, the direct comparison is not exact. However, the results from the pore size distribution of the paper samples show clear difference. In the foam-laid samples there are much more big pores that are beneficial in a water removal process. That makes it possible to use high addition levels of strengthening agents.

With the foam-laid technology one is able to make structures with very high bulk. When this is combined with the good water drainage properties, which allows the high addition levels of strengthening agents such as MFC, one can make products with very big bulk and still have an adequate strength value. That can be utilized in the savings on raw material especially in packaging applications.

There exists a lot of different kind of MFC grades that one can choose from. We compared the performance of some of them. Different MFC grades seem to behave rather similarly in bulk vs. strength comparisons. However, in case of modified Scott bond the coarser and cheaper MFC gave slightly higher value compared to more refined and expensive MFC. On the other hand more refined MFC gave higher tensile index value. This example illustrates that MFC used have to be chosen depending of paper properties needed.

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Transcription of Discussion

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Bob Pelton McMaster University (from the chair)

I noticed in the printed version that you are using SDS, sodium dodecyl sulphate as the foam forming agent. That surprised me a bit, because it is a sort of classical surfactant, and if it ends up in your fibre-fibre bonds it will act as a debonding agent. So my question is, have you tried proteins or other types of foam stabilizing agents that won't hurt and possibly might help the fibre-fibre bonding.

Tuomo Hjelt

Yes, we have tried also other types of surfactant. But actually we have made strength comparisons using SDS. We have made samples with water forming and foam forming and then wet pressed them to the same bulk and then compared strength values. The strength values were the same. So I do not know the reason, but it seems that SDS does not behave as a debonder in foam forming.

Bob Pelton

So it is not adsorbing on the fibres?

Discussion

Tuomo Hjelt

It looks like that. Yes, we have used these proteins, but we are still in a learning phase, trying to run our processes correctly. SDS is cheap and it foams really easily, whereas most of these proteins are really difficult to get to foam properly, especially because they require a reasonably high amount of energy to foam. So SDS is easier to use, and also when we have compared results obtained from foam physics, they usually use SDS, so we know that using SDS we have similar kind of system and we can compare the results.

Jim De Witt Sappi Fine Paper

Very interesting paper, thank you. You mentioned that you wet pressed the sheet after you had made it which should, in principle, consolidate the surface a bit. Did you do any sort of testing of the type that might indicate how well it might accept printing ink or might accept coating, for example?

Tuomo Hjelt

We have done only a few of that kind of test. The thing is that if you make a very bulky structure it is very porous, and then you cannot coat or print it. So in this kind of board application, we think that we should make the middle layer using foam forming and then use water forming for the top layers, and so the printability comes from the top layers. Another solution would be that, as I mentioned here, the foam forming is really easy to apply as a layered structure. With foam forming we can put on a thin layer of MFC and we can seal the surface; after this you can coat or print it.

Andreas Kornherr Mondi

Interesting topic. What I would like to know is whether you can incorporate some filler, using this approach. For example can you disperse PCC in the foam and combine with your pulp stock?

Tuomo Hjelt

In the case of fillers we need to use a retention aid. When the retention aid is the same as in the case of normal water forming, we get about the same level of retention. So we can make paper with fillers up to around 40%.

Tetsu Uesaka Mid Sweden University

Could you make a comment on the dispersion of, for example, MFC or filler in the foam forming system. You have already shown that, in the case of fibres, they disperse well and make very good formation. In the case of fibre, obviously length is much-much larger than the size of the foam bubbles, but on the other hand, the MFC particle or the filler particle is much smaller. In this case, how does dispersion happen in this system?

Tuomo Hjelt

In the case of fillers, we just take the filler suspension and pour it into the foam generator and we do not have to do any other dispersion and it seems to work fine. In the case of MFC, we usually dilute it to something like 1% solids content, we mix it with a kitchen mixer and then we pour it in the foam generator. The results show that we do not have to use any kind of tricks to get either of them dispersed. It might be because there are surfactants in the foam. There are actually some methods where they get dispersion by adding surfactants and then mixing, which seems to improve the dispersion quite nicely and it also seems to work here. It also appears that there is also enough shear force in the foam generator.

Hannes Vomhoff Innventia

Two questions: at what speed did you run the trials? And, the second one, when you calculate the crowding number, do you only base it on the water and fibre material or do you use a modified crowding number also including the air as a fluid?

Tuomo Hjelt

First, the highest speed that has been tested is 700 metres per minute. Then this other question, I did not take into account air, I only took into account the water fraction, because, after all, even though there are these bubbles, the fibres live in the water phase.

Harshad Pande Domtar

What is the maximum level of MFC you have used, or the range?

Discussion

Tuomo Hjelt

It depends on the pulp. What we have found out is that when we start to increase the MFC level, we get very good retention up to a certain point, and then after that everything goes through. What we believe is that after that we have covered more or less all the fibre surface, and MFC cannot adsorb anymore. Maximum adsorption really depends on the pulp. In the case of CTMP, it is somewhere between 50% and 60%; in the case of kraft pulp, it is something like 30%.

Wolfgang Bauer Graz University of Technology

As these sheets are very porous and open, how do they behave in drying?

Tuomo Hjelt

This is something that we have just started to study, so I do not know yet. After wet pressing, we get a similar level of solids content as for water forming. If we make laboratory sheets and put them to dry in the evening, they are dry in the morning. So that is our knowledge level at this point. A bit low, but we hope within a couple of years we will know a lot more.

Paul Krochak Innventia

I am wondering how stable these foams are that you used. I mean, 700 m/min is quite respectable, but if you start running at 1200 m/min, and if we have to run foam through pressure screens or use twin wire forming (I assume you did Fourdrinier forming), can you give any idea whether this stuff will start to break down at some point?

Tuomo Hjelt

I know from the literature that, in Wiggins Teape, they made trials at 1500 m/min, and they did not find that kind of problem. They did find other kinds of problems but the foam was stable enough. Actually when it is pumped to the wire, it is drained as fast as possible. So there is no time for foam bubbles to start to grow, and it seems that they do not collapse because of the pressure difference. The other thing is that this choice of surfactant is, according to the literature, almost limitless. You can increase the strength of foam bubbles quite a lot by choosing the right kind of surfactant. So I think that it can be handled.

Bob Pelton McMaster University (from the chair)

So what does the white water system look like? Do you pump the foam around? Do you re-inject air into the white water? Or do you have an equivalent of a thick stock with new air?

Tuomo Hjelt

Here the idea is that when you suck the foam, it actually remains as foam. When it is sucked, the air content drops from 65% to 50%, and then it is pumped again to the foam generator where it is foamed to 65% again, and so it continues.

Steve Keller Miami University

For the low viscosity of these foam bubbles, I would think it would be more subject to the jet-to-wire speed differential which would increase fibre orientation more than you would find in a typical water based stock. Have you looked at all at how susceptible it is to the jet-to-wire ratio?

Tuomo Hjelt

Yes it is, and the challenge is that it quite easily gets highly oriented. On the other hand, you can quite easily manipulate the foam. Actually I have been told that you can make the head box so that you can get almost isotropic forming just by manipulating the foam. Foam shears, more or less, as layers, and then if you manipulate these layers, they actually turn fibres towards the cross direction. That kind of application is known to exist, so it is possible to play with this orientation quite a lot.

Hannes Vomhoff Innventia

Have you estimated the specific things like specific energy consumption for making the foam?

Tuomo Hjelt

Not yet. We are doing it currently.