Mechanical recycling of post-consumer mattress foam

A study carried out by Bramming Plast-Industri A/S
in partnership with City of Copenhagen

15.02.2022

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foam for your purpose

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1. Introduction

This report sums up the results of a joint project between City of Copenhagen and Bramming Plast-Industri A/S concerning possibilities of mechanical recycling of postconsumer foam from mattresses to bonded foam.

City of Copenhagen has set forth a goal of recycling 70% of their waste by 2024. In connection with this they launched a project for the recycling of postconsumer mattresses and in their Call for Partners they came in contact with Bramming Plast-Industri A/S (BPI A/S) which produces bonded foam from postindustrial trimmings and foam waste. Bramming Plast-Industri A/S wishes to support circular solutions which may minimize the use of polyurethane foam made from fossil fuel based chemistry and has signed up for the project to clarify, if recycling of postconsumer polyurethane foam from mattresses into bonded foam is possible in the company`s existing production process.

At present no municipal collection schemes of postconsumer mattresses have been established in Denmark but in the Netherlands a company, RetourMatras, has specialized in the collection and dismantling of postconsumer mattresses. Learnings from RetourMatras regarding the necessary quality of the postconsumer mattress foam has been adopted by Bramming Plast-Industri A/S and as no postconsumer mattress foam collected in an established collection scheme is available in Denmark, postconsumer foam from RetourMatras has been included in this project. To be able to compare the composition of postconsumer mattress foam from Denmark with the composition of postconsumer mattress foam collected in the Netherlands, a portion of mattresses from businesses and collection schemes for bulky waste from Sjælland, was collected and dismantled by the company Marius Pedersen A/S.

2. Scope

The project aims to clarify the following topics:

1. How is the production process at BPI A/S impacted by input of postconsumer mattress foam?
2. Is the composition of the postconsumer mattress foam from DK and NL comparable?
3. Which quality requirements for the postconsumer mattress foam are necessary for the bonded foam process and product?
4. Does postconsumer mattress foam introduce hygienic issues in the handling of the foam and in the finish bonded foam?
5. Which chemical substances in 15-20 year old postconsumer mattress foam is expected to be present the finished product?
6. How are the mechanical properties in the finished product with input of postconsumer mattress foam affected in comparison to postindustrial bonded foam?
7. How are the processing and application options of bonded foam containing postconsumer mattress foam affected compared to postindustrial bonded foam? This includes evaluation of bonded foam consisting of mixtures of postconsumer mattress foam and postindustrial foam.
   How are the outlets for bonded foam containing postconsumer mattress foam assessed in comparison to postindustrial bonded foam?
8. How much postconsumer mattress waste does BPI A/S expect to be able to mechanically recycle and sell?

For the purpose of this project this report includes comparisons of bonded foam made from:

1. Post-industrial foam
2. Post-consumer mattress foam collected in an established collection scheme in the Netherlands
3. Post-consumer mattress foam collected in DK from businesses and the collection schemes for bulky waste in Sjælland
4. 50/50 mixture of postindustrial foam and postconsumer mattress foam from the Netherlands

3. Bonded foam production process

Bonded foam consists of PU-foam granulates which are glued and pressed to form a coherent foam. In the process flame retardants and colorants can be added to obtain the desired visual appearance and properties. The density of bonded foam can be varied by adjusting the density of the added foams, the size of the foam granulates, the total weight of the added foam granulates and the final block dimensions.

Foam-waste suitable for this process is the well-known PUR-types of conventional polyether and polyester types, high-resilience (HR) combustion modified (CMHR) and viscoelastic foam. Latex foam is not suitable due to very low tear strength properties.

The foam is fed into a granulator and led into a mixing tank where the foam granulates are mixed with a prepolymer (serving as a binder) and potential additives. After mixing, the foam granulates are poured into a mold where they are pressed while steam is sent through the foam to activate the prepolymer. After the foam block has cooled down it is ready for further processing.

4. Sample scheme

To distinguish between the different samples the following naming will be used:

BF xxx kg/m^3 (0%)	Standard bonded foam of xxx density produced of postindustrial waste and with 0% postconsumer waste.
BF xxx kg/m^3 (100% NL)	Bonded foam of xxx density produced of 100% postconsumer mattress foam from RetourMatras/The Netherlands.
BF xxx kg/m^3 (100% DK)	Bonded foam of xxx density produced of 100% postconsumer mattress foam from Marius Pedersen/Denmark.
BF xxx kg/m^3 (Mix 50% NL)	Bonded foam of xxx density produced with a mix of 50% postconsumer mattress foam from RetourMatras / The Netherlands and 50% postindustrial foam waste.
BF xxx kg/m^3 (Mix 50% DK)	Bonded foam of xxx density produced with a mix of 50% postconsumer mattress foam from Marius Pedersen / Denmark and 50% postindustrial foam waste.

For the trial production the following amounts of each quality of bonded foam blocks were produced using the postconsumer mattress foam:

Number of blocks produced per foam quality	Density kg/m^3		
	75	135	195
BF xxx kg/m^3 (100% NL)	3	3	3
BF xxx kg/m^3 (100% DK)		2	
BF xxx kg/m^3 (Mix 50% DK)		1	
BF xxx kg/m^3 (Mix 50% NL)	3	1	1

5. Evaluation of production process and received postconsumer mattress foam

Postconsumer mattress foam NL

BPI A/S received approximately 2.400 kg of postconsumer mattress foam from RetourMatras in the Netherlands. The foam was baled and wrapped in foil to protect the foam from moisture and dirt.

Postconsumer foam received from

Baled postconsumer foam from NL

Foam from 1 bale of postconsumer mattress foam from NL after unpacking

The foam appeared clean and the foam pieces were large, resembling lengths and thicknesses of mattresses. The foam had a slightly different odor than the post-industrial foam and a theory is that the cell gasses in the post-consumer mattress foam consist of air from the surrounding environments the mattresses have been stored in and these cell gasses are released due to the pressure the foam is baled under. However, no odor was detected on the finished material after steaming.

The foam was easy to handle and not significantly different than post-industrial foam for the operator to load into the granulator.

Postconsumer mattress foam DK

BPI A/S received approximately 500 kg of postconsumer mattress foam collected by Marius Pedersen in Denmark. No return-scheme was established for the mattresses nor was a dismantling method established. The foam had not been protected from dirt or moisture which was evident on the received foam. Apart from the visual contaminations, the postconsumer mattress foam had a significant odor. This odor was not eliminated by the steaming process, though somewhat reduced.


Postconsumer mattress foam from DK containing Latex and other non-PU materials

This postconsumer mattress foam contained several other materials than PU-foam, such as metal pieces, non-woven, felt, rubbish, and wadding along with latex foam which is not a suitable foam for bonded foam.


The postconsumer mattress foam from DK contained non-PU-materials including metal parts

Hard materials such as metal will damage the granulator and pose a safety risk for the operators and soft materials such as felt and wadding as well as dirt will affect the bonding process and have a negative effect on the quality of the bonded foam.
The sorting of the foam was conducted by 3 operators during the production process however the types of foam qualities loaded into the granulator resembled the foam qualities in the postconsumer mattress foam from the Netherlands.

Learnings from the production process

- Identical production settings can be used when processing post consumer mattresses
- The Dutch mattress waste was bigger and more suitable than the Danish mattres waste, allowing better efficiency during the process.
- The relative low density of the postconsumer mattress foam have a small negative impact on efficiency on medium to high densities.
- No unwanted odor occurs after the steaming process

Learnings from the quality of postconsumer mattress foam

- Danish and Dutch collected mattress foams appears to be an identical mix of types
- Only PU-materials can be used, and a dedicated dismantling setup is required to obtain this.
- Only fairly clean and dry mattresses can be used, which further supports the need of controlled collection and dismantling


Foam granulates in the mold


Pressing of the bonded foam block


Mattress foam from DK


Mattress foam from NL

6. Hygienic risks

In order to assess the hygienic risks of handling and recycling postconsumer mattress foam samples from before (pre-) and after (post-) the steaming process of the 3 foam fractions were sent for microbial analysis and risk assessment at Eurofins. The samples were not collected aseptically and therefore may be contaminated by hands of the operators or cross-contaminated by the processing equipment. The pre-steam samples were collected in the mixer tank and the post-steaming samples were cut from the finished bonded foam blocks.

The hygienic quality of the foam samples was assessed by use of four microbial parameters recommended for this assessment by a microbiologist at Eurofins:

- **Aerobic count** is a general indicator of bacterial populations in a sample.
- **E. coli** and **Enterococcus sp.** are indicators of feacal contamination and commonly used as general hygiene indicators in food, water and environmental samples.
- **Bacillus cereus** is a bacterium commonly found in soil, vegetation and water. *Bacillus* are generally resistant to heat treatment and able to survive for longer periods under dry and unfavorable conditions, due to the ability to form endospores – a dormant, and resistant form of the bacteria. If allowed to grow to high numbers, the bacteria can produce a toxin, causing gastrointestinal illness.

Test results:

Sample description	Aerobic count (NMKL 86)	E.coli (AOAC 991.14)	Enterococcus sp. (NMKL 68)	Presumptive Bacillus cereus (ISO 7932)
Pre-BPI foam	37 000	<10	<10	<100
Pre-NL/RM foam	30 000	30	30	<100
Pre-DK/MP foam	>250 000	<10	1 600	2 400
Post-BPI foam	220	<10	<10	<100
Post-NL/RM foam	1 200	<10	<10	<100
Post-DK/MP foam	650	<10	<10	<100

The full test reports are enclosed as appendixes 1-6.

The investigation of the microbial quality is based on a selection of microbial parameters and a limited number of samples. Yet, considering that relatively low levels of potentially harmful bacteria were detected in the pre-steaming samples, and none were detected after processing, the obtained results do not indicate that the recycled foam materials are associated with a microbial safety risk. Nevertheless, Pre-DK/MP foam showed high results of Aerobic count and some level of *Enterococcus* and *Presumptive Bacillus*, which supports the recommendation of a controlled collection and dismantling setup.

The steaming process appears to effectively decrease microbial contamination in the foam, also on the contaminated Pre-DK/MP foam.

The level of Bacillus cereus detected in the pre-DK foam was below levels normally associated with food-borne infections and therefore not considered a hazard.

Previous studies have reported evidence that used mattresses can serve as environmental reservoirs of pathogenic bacteria and potential mediators of hospital acquired infections. Outbreaks and infections caused by antibiotic resistant strains of *Pseudomonas aeruginosa* and *Staphylococcus aureus* (MRSA) have been linked to hospital mattresses in which the water-resistant mattress covers were damaged and failed to prevent blood and other body fluids from entering the inside (inner core) of the mattresses.

These studies, along with results presented in this report, highlight the importance of assessing the quality of the foam material collected for recycling. Routine visual inspection of incoming material, or other preventive measures is recommended to reduce the risk of introducing highly contaminated material into the production.

The risk assessment from Eurofins in full length is enclosed as appendix 7.

Learnings of hygienic risks:

- The steaming process reduces the microbial contamination in the foam.
- The levels of potentially harmful bacteria are low in pre-steaming samples and below detection level after the steaming process leaving no cause for concern.
- Mattresses from the health sector pose a safety hazard and is not wanted for recycling at BPI.
- A controlled collection and dismantling setup is needed to avoid microbial contamination.

7. Chemical substances

Postconsumer mattress foam can be 15-20 years old and may contain hazardous chemicals which were allowed to be used in the manufacturing process at the time. To test for relevant hazardous chemicals used within the foaming industry over time, the test scheme is chosen to be according to CertiPUR US combined with relevant tests from CertiPUR – EuroPUR to cover the most relevant hazardous substances in PU-foam. CertiPUR is the foaming industry`s own HSE-certification scheme for flexible polyurethane foams. CertiPUR EuroPUR has lower limits than CertiPUR US for heavy metals and organic tin compounds. Eurofins is accredited to perform tests according to CertiPUR US and is chosen to perform the chemical analyses.

To be able to compare chemical contents in postconsumer mattress foam from DK and NL to postindustrial foam, 3 samples at density 135 kg/ m^3 were sent for chemical testing:

1. BF 135 kg/m^3 (0%)
2. BF 135 kg/m^3 (100% NL)
3. BF 135 kg/m^3 (100% DK)

The full test reports are enclosed as appendixes 8-10.

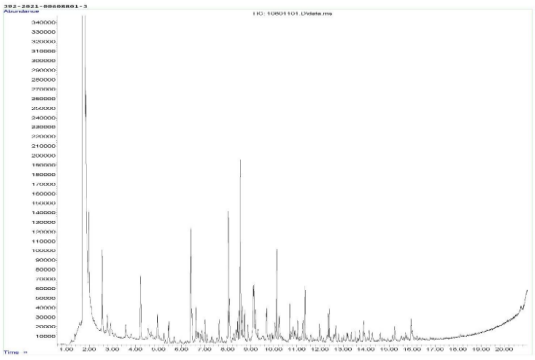
VOC emissions:

VOC Emission	CAS No.	BF 135 kg/m^3 (0%) mg/ m^3	BF 135 kg/m^3 (100% NL) mg/ m^3	BF 135 kg/m^3 (100% DK) mg/ m^3	CertiPUR US Limit value mg/ m^3	CertiPUR EuroPUR Limit value mg/ m^3	REACH Compliance Yes/No
Total TVOC (C_6 – C_{16})	-	**0.0065**	**0.0080**	**0.0058**	**< 0.5**	**0.5**	-
Benzene	71-43-2	< 0.002	< 0.002	< 0.002	< 0.5	-	Yes[1]
Toluene	108-88-3	< 0.002	< 0.002	< 0.002	< 0.5	0.1	Yes[1]
Styrene	100-42-5	< 0.002	< 0.002	< 0.002	< 0.3	0.005	Yes
Vinylcyclohexene	100-40-3	< 0.002	< 0.002	< 0.002	< LOD*	-	Yes
4-Phenylcyclohexene	4994-16-5	< 0.002	< 0.002	< 0.002	< LOD*	-	Yes
Butadiene	106-99-0	< 0.002	< 0.002	< 0.002	< LOD*	-	Yes
Vinylchloride	75-01-4	< 0.002	< 0.002	< 0.002	< LOD*	-	Yes[1]
Aromatic hydrocarbons	-	0.0029	< 0.002	< 0.0022	< 0.5	0.5	Yes
Formaldehyde	50-00-0	< 0.003	< 0.003	< 0.003	< 0.1	0.01	Yes

*Below limit of detection

[1] REACH Annex XVII (Restriction list)

Sample for emissions testing of bonded postconsumer mattress foam



Chromatogram of VOC Emissions after 3 days

Learnings from VOC emissions:

- The levels of VOC emissions are much below the limit values for CertiPUR.
- VOC emissions are not likely to pose a hazard risk in postindustrial or postconsumer mattress foam.

Extractable Compounds:

Heavy metals	**CAS No.**	**BF 135 kg/m³ (0%) ppm**	**BF 135 kg/m³ (100% NL) ppm**	**BF 135 kg/m³ (100% DK) ppm**	**CertiPUR US Limit value ppm**	**CertiPUR EUROPUR Limit value ppm**	**REACH & RoHS compliant Yes/No**
Antimony (Sb)	7440-36-0	< 0.5	0.56	0.75	60	0.5	Yes
Arsenic (As)	7440-38-2	< 0.5	< 0.5	< 0.5	25	0.2	Yes[1]
Barium (Ba)	7440-39-3	< 2	9.1	8.5	1000	-	Yes
Lead (Pb)	7439-92-1	< 1	1.1	2.4	90	0.2	Yes[1,3,4]
Cadmium (Cd)	7440-43-9	< 0.1	< 0.1	< 0.1	75	0.1	Yes[1,3,4]
Chromium total (Cr)	7440-47-3	< 1	< 1	1.5	60	1.0	Yes[4]
Mercury (Hg)	7439-97-6	< 0.2	< 0.2	< 0.2	60	0.02	Yes[1,4]
Selenium (Se)	7782-49-2	< 1	< 1	< 1	500	0.5	Yes

[1] REACH Annex XVII (Restriction list)
[2] REACH Annex XIV (Authorisation list)
[3] REACH Candidate List
[4] RoHS substance

Phthalates	**CAS No.**	**BF 135 kg/m³ (0%) ppm**	**BF 135 kg/m³ (100% NL) ppm**	**BF 135 kg/m³ (100% DK) ppm**	**CertiPUR US & EuroPUR Limit value ppm**	**REACH & RoHS compliant Yes/No**
Diisononyl phthalate (DINP)	28553-12-0	< 30	44	< 30	-	Yes[1]
Di-2-ethylhexyl phthalate (DEHP)	117-81-7	< 5	310	42	-	Yes[1,2,3,4]
Butylbenzyl phthalate (BBP)	85-68-7	< 5	< 5	< 5	-	Yes[1,2,3,4]
Di-butyl phthalate (DBP)	84-74-2	< 5	21	16	-	Yes[1,2,3,4]
Di-n-hexyl phthalate (DnHP)	84-75-3	< 5	< 5	< 5	-	Yes[2,3]
Diisobutyl phthalate (DIBP)	84-69-5	< 5	25	20	-	Yes[1,2,3,4]
Di-n-pentyl phthalate (DPENP)	131-18-0	< 5	< 5	< 5	-	Yes[2,3]
Dicyclohexyl phthalate (DCHP)	84-61-7	< 5	<5	< 5	-	Yes[3]
Sum of 8 phthalates	-	< 0.003 wt.%	0.04 wt. %	0.0078 wt. %	≤ 0.01 wt. %	Yes[1]

[1] REACH Annex XVII (Restriction list)
[2] REACH Annex XIV (Authorisation list)
[3] REACH Candidate List
[4] RoHS substance

TDA and MDA	**CAS No.**	**BF 135 kg/m³ (0%) ppm**	**BF 135 kg/m³ (100% NL) ppm**	**BF 135 kg/m³ (100% DK) ppm**	**CertiPUR US & EuroPUR Limit value ppm**	**REACH compliant Yes/No**
2,4-Toluenediamin (TDA)	95-80-7	0,80	0.58	0.77	≤ 5.0	Yes[3]
4,4'-Diaminodiphenyl-methane (MDA)	101-77-9	1.4	1.5	1.3	≤ 5.0	Yes[2,3]
Sum of TDA (2,4) and MDA (4,4')	-	2.2	2.1	2.1	≤ 5.0	

[1] REACH Annex XVII (Restriction list)
[2] REACH Annex XIV (Authorisation list)
[3] REACH Candidate List
[4] RoHS substance

Flame Retardants	CAS No.	BF 135 kg/m³ (0%) wt. %	BF 135 kg/m³ (100% NL) wt. %	BF 135 kg/m³ (100% DK) wt. %	CertiPUR US Limit value wt. %	CertiPUR EUROPUR Limit value ppm	REACH & RoHs compliant Yes/No
Pentabromodiphenyl ether	32534-81-9	< 0.001	< 0.001	< 0.001 (99 ppb)	≤ 0.01	Prohibited	Yes[4]
Octabromodiphenyl ether	32536-52-0	< 0.001	< 0.001	< 0.001	≤ 0.01	Prohibited	Yes[1,4]
Decabromodiphenyl ether	1163-19-5	< 0.001	< 0.001	< 0.001	≤ 0.01	-	Yes[3,4]
Tribromodiphenyl ether	49690-94-0	< 0.001	< 0.001	< 0.001	-	-	Yes
Tetrabromodiphenyl ether	-	-	-	< 0.001 (70 ppb)	-	-	Yes[4]
Hexabromodiphenyl ether	36483-60-0	< 0.001	< 0.001	< 0.001	-	-	Yes
Hepta bromodiphenyl ether	68928-80-3	< 0.001	< 0.001	< 0.001	-	-	Yes
Nonabromodiphenyl ether	63936-56-1	< 0.001	< 0.001	< 0.001	-	-	Yes

[1] REACH Annex XVII (Restriction list)
[2] REACH Annex XIV (Authorisation list)
[3] REACH Candidate List
[4] RoHS substance

Tinorganic compounds	CAS No.	BF 135 kg/m³ (0%) ppm	BF 135 kg/m³ (100% NL) ppm	BF 135 kg/m³ (100% DK) ppm	CertiPUR US Limit value ppm	CertiPUR EUROPUR Limit value ppm	REACH compliant Yes/No
Tributyltin (TBT)	688-73-3	< 0.1	< 0.1	< 0.03	0.5	< 0.05	Yes
Monobutyltin (MBT)	78763-54-9	< 0.03	0.14	0.79	-	< 0.1	Yes
Dibutyltin (DBT)	1002-53-5	< 0.03	0.027	0.083	-	< 0.1	Yes
Tetrabutyltin (TeBT)	1461-25-2	< 0.03	< 0.03	< 0.03	-	-	Yes
Monooctyltin (MOT)	15213-57-9	< 0.03	< 0.03	< 0.03	-	-	Yes
Dioctyltin (DOT)	15231-44-4	< 0.03	< 0.03	< 0.03	-	-	Yes
Tricyclohexyltin (TcyT)	6056-50-4	< 0.05	< 0.05	< 0.05	-	-	Yes
Triphenyltin (TPhT)	892-20-6	< 0.03	< 0.03	< 0.03	-	-	Yes
Sum of tinorganic compounds	-	< 0.05	0.17	0.87	-	0.5	

Postindustrial foam waste show no extractable compounds above CertiPUR US`s limits and apart from TDA and MDA the concentrations of the tested substances are below the detection limits.

Postconsumer foam from both DK and NL show contents of various heavy metals below CertiPUR US limits but the levels of antimony and lead are above CertiPUR EuroPUR`s limits. However, the levels of lead are well below RoHS and REACH limits of 0,1% and in compliance with REACH Annex XVII.

Both postconsumer foam from DK and NL show contents of phthalates and for the postconsumer mattress foam from NL, the sum of the 8 measured phthalates is above CertiPUR US limits. Several of the phthalates are listed on the REACH Candidate List, but with levels below 0,1% the postconsumer foam is in compliance with both RoHS and REACH limits.

Both postconsumer foam from DK and NL show contents of the organic tin compound MBT above CertiPUR EuroPUR`s limits, with the postconsumer foam from DK well above the limit. This was expected, as organic tin compounds were used in PU-production in the past.

Heavy metals, phthalates and organic tin are present in various concentrations in postconsumer mattress foam from both NL and DK, however, tests shows compliance to REACH and RoHs legislations, even to the REACH Annex XVII children`s articles. This should be monitored over a longer period to prove continuous compliance, due to expected content variations over time.

Learnings from extractable compunds:

- Postindustrial bonded foam complies with both CertiPUR US and Europe, as well as REACH & RoHS
- Postconsumer bonded foam complies with CertiPUR US and Europe except:
  - NL version has too high phthalates value
  - DK version has too high heavy metals
  - Both DK and NL has too high organic tin (only EuroPUR)
  - All non-conformities are expected due to the nature of substances used in PU-production in the past
- Both NL and DK bonded foams are REACH and RoHS compliant.
- Tests show a snap shot of the contents of hazardous substances, and should be monitored over a longer period to prove continuous compliance, especially to particular sensitive applications (e.g. children's articles).

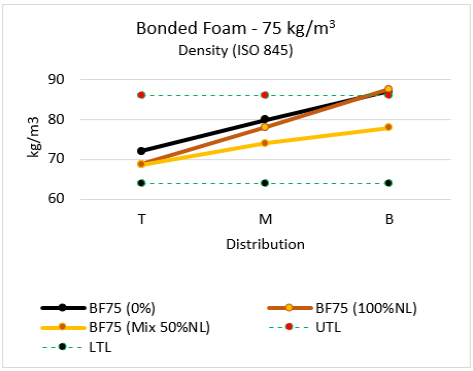
8. Mechanical testing

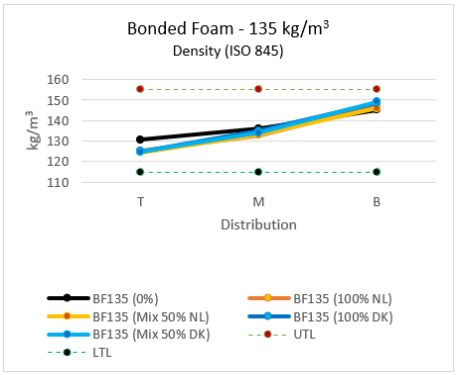
Density:

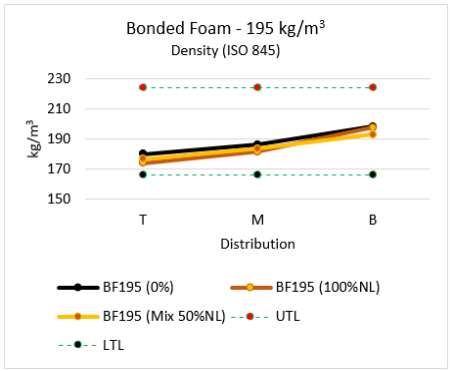
As bonded foam consists of foam granulates of different weights being pressed together, it is well known that varieties in density from top to bottom of a bonded foam block occurs. To be able to determine if postconsumer mattress foam follows the same pattern as postindustrial foam, the densities of bonded foam made from postconsumer mattress foam are measured at top, middle and bottom of the blocks and compared to bonded foam made from postindustrial waste. This is done at three different densities:

Density target +/-15%	75 kg/m³ (64 – 86)	135 kg/m³ (115-155)	195 kg/m³ (166-224)
BF (0%)	80	137	188
BF (Mix 50% NL)	74	134	184
BF (Mix 50% DK)	-	136	-
BF (100% NL)	78	135	184
BF (100% DK)	-	136	-

Samples for mechanical testing







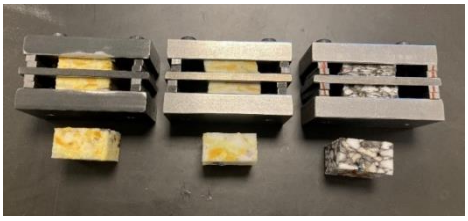
Learnings from density:

- Average density of all samples are within tolerance.
- The distribution of density within blocks is similar for postindustrial and postconsumer mattress foam.

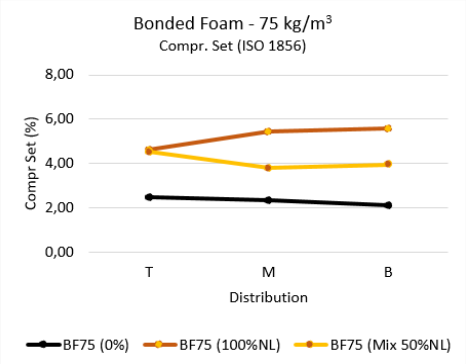
Compression set:

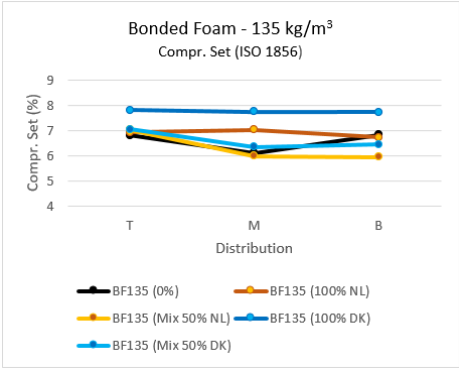
Compression set describes the foams ability to recover to full thickness after being pressed to 50% thickness for 72 hours in 23°C. The result is shown as the percentage of height loss from the original height. The density of the foam affects the compression set making differences in test results from top to bottom of the bonded foam block expected.

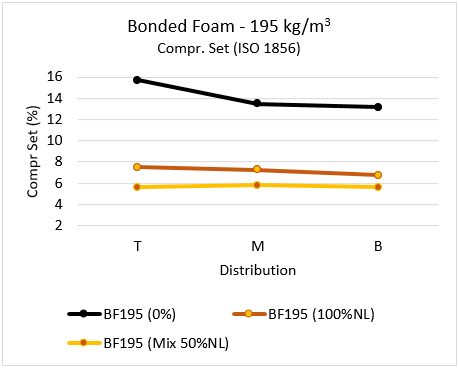
Compression set	75 kg/m³ (%)	135 kg/m³ (%)	195 kg/m³ (%)
BF (0%)	2,3	6,6	14,1
BF (Mix 50% NL)	4,1	6,3	5,7
BF (Mix 50%DK)	-	6,5	-
BF (100% NL)	5,2	6,9	7,2
BF (100% DK)	-	7,8	-



Compression set testing







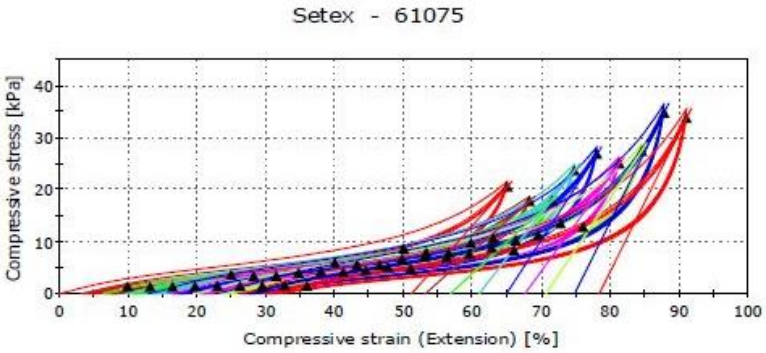
Learnings from Compression Set:

- At the lowest density of 75 kg/m³ samples containing postconsumer mattress foam have a slightly higher compression set than postindustrial foam samples.
- At density 135 kg/ m³ the compression set values are all comparable.
- At density 195 kg/ m³ postindustrial foam has a significant higher compression set compared to the samples containing postconsumer mattress foam

Compression Load Deflection 40%:

Compression load deflection 40% (CLD 40%) describes the foam´s load-bearing capacity at an indentation of 40% of a standard thickness of the foam. The results are expressed as the force needed to achieve a compression of 40% in kPa and is an expression of the foam`s hardness.

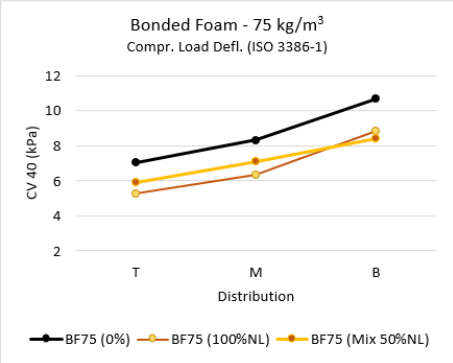
Compression load deflection testing

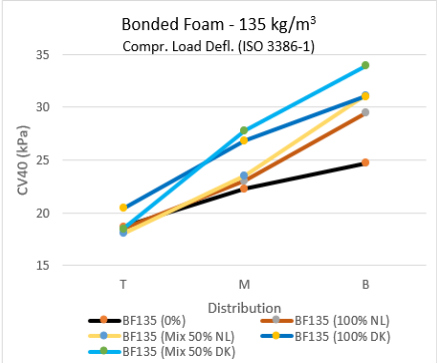


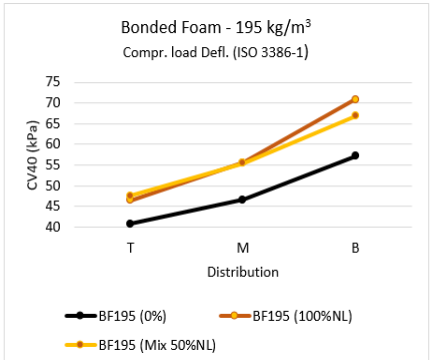
CLD example

Again the density affects the test results, as can be seen in the graphs of top, middle and bottom test results of the foam blocks.

CLD 40%	75 kg/m³ (kPa)	135 kg/m³ (kPa)	195 kg/m³ (kPa)
BF (0%)	8,7	21,9	48,2
BF (Mix 50% NL)	7,1	24,2	56,6
BF (Mix 50%DK)	-	26,7	-
BF (100% NL)	6,8	23,7	57,7
BF (100% DK)	-	26,1	-







Learnings from CLD 40%:

- At density 75 kg/m^3 samples containing postconsumer mattress foam is softer than postindustrial foam samples.
- At density 135 kg/ m^3 all tested grades are reasonably comparable
- At density 195 kg/ m^3 the postindustrial bonded foam has lower CLD values than the postconsumer bonded foam.

Tensile strength:

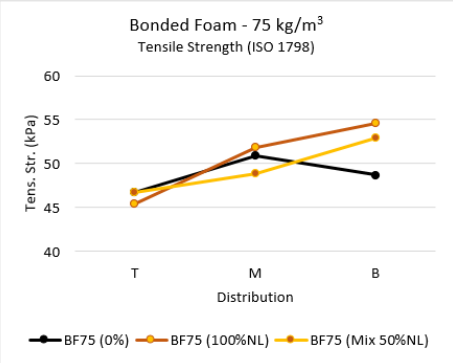
Tensile strength describes the required strength in kPa to break the foam when extended at a constant rate. For bonded foam this also describes the quality of the bonding process as the break can either happen in the foam itself or in the glued sections. The elongation of break of the foam describes the extension of the foam in % until the point where it breaks.

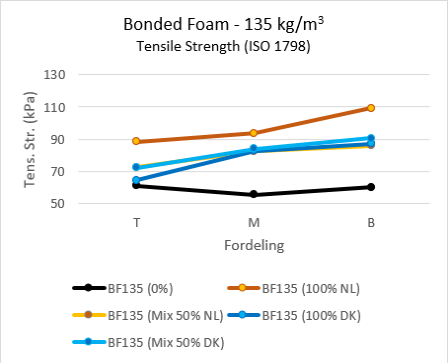
Testing of tensile strength

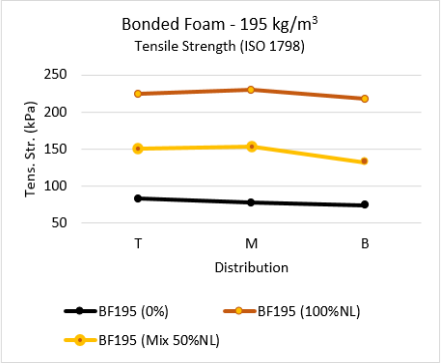
Samples before and after testing of tensile strength

Tensile strength kPa	75 kg/m^3 (kPa)	135 kg/m^3 (kPa)	195 kg/m^3 (kPa)
BF (0%)	48,7	59,0	78,3
BF (Mix 50% NL)	49,5	80,4	145,5
BF (Mix 50%DK)	-	82,4	-
BF (100% NL)	50,6	97,3	223,9
BF (100% DK)	-	78,2	-

Elongation to break %	75 kg/m^3 (kPa)	135 kg/m^3 (kPa)	195 kg/m^3 (kPa)
BF (0%)	61,6	65,1	42,4
BF (Mix 50% NL)	70,3	61,0	63,1
BF (Mix 50%DK)	-	60,8	-
BF (100% NL)	65,1	67,9	70,0
BF (100% DK)	-	49,3	-







Learnings from Tensile Strength:

- The tensile strength is significantly improved for samples containing postconsumer foam from NL compared to postindustrial foam, both in a 50/50% mixture and in 100% postconsumer bonded foam
- The results for the postconsumer mattress foam from DK shows the same trends, however, both strength and elongation is slightly lower than the bonded foam based on NL waste.

Thermal conductivity:

Thermal conductivity is the ability of a material to conduct heat. A value for thermal conductivity l is determined by measuring the rate at which heat can pass through a material. The samples were measured according to EN 12667 where the thermal conductivity is measured by means of a guarded hot plate and a heat flow meter. Lower value means better ability to insulate.

Thermal conductivity l	75 kg/m^3 W/(m*K)	135 kg/m^3 W/(m*K)	195 kg/m^3 W/(m*K)
BF (0%)	0,036	0,0393	0,0429
BF (Mix 50% NL)	0,035	0,0380	0,0419
BF (Mix 50%DK)	-	0,0380	-
BF (100% NL)	0,036	0,0387	0,0417
BF (100% DK)	-	0,0387	-

Learnings from Thermal Conductivity:

- As expected the thermal conductivity is very density dependent, higher density means higher conductivity.
- No major deviations are observed between post-industrial and post-consumer bonded foam mattress foam from both DK and NL compared to postindustrial foam. The difference between lambda values for postindustrial foam and postconsumer mattress foam increases with the density.

9. Outlet opportunities for postconsumer bonded foam

Based on all above testing we have assessed that post-consumer based bonded foam can be used as a good substitute/alternative for post-industrial bonded foam. All processing and converting technology used for post-industrial foam is fully applicable for post-consumer bonded foam.

There are no emission problems, no hygiene problems and mechanical properties are mostly in line or even better than post-industrial foam. As expected some low levels of hazardous substances can be detected, but all measurements are in line with current REACH and RoHS legislation, meaning no significant obstacle for outlets.

The elasticity and durability allows packaging applications with repeatable loads, and the mechanical properties sets no limitation within sound and vibration applications, which is a well-known application for bonded foam. Furthermore the thermal insulation properties are in line with other insulation materials such as EPS, mineral wool etc.

The homogenous waste fraction deriving from a comfort product as a mattress also results in a softer hardness/density ratio, and this can further promote the use of bonded foam in comfort applications such as selected components for furniture and mattresses.

Learnings on outlet opportunities:

- Main recommended applications:
  - Packaging / shock absorption (protection of e.g. hifi-equipment, sensitive devices etc.)
  - Sound and vibration insulation (industrial machine encapsulation, DIY-market etc.)
  - Comfort products (selected parts for furniture, mattresses etc.)
  - Carpet underlay and other floor underlay applications
  - Thermal insulation when respecting fire requirements

10. Capacity and market assumptions

A rough estimate is that DK discards 500.000 mattresses with an average of 7 kg. of PUR-foam per mattress, so a total of approx. 3.500 tonnes.

BPI total 2022 capacity is >3000 tonnes, and this is extended to be >6.000 tonnes by 2023. Available capacity will exceed the total DK volume of 3.500 tonnes, by far leaving available capacity for the Danish volume.

It is difficult to predict the potential bonded foam sales growth, but the market demand for sustainable products are growing rapidly year by year, and the potential introduction of post-consumer bonded foam is expected to be well received. BPI estimates a sell of >300 tonnes by 2023 growing to >1000 tonnes by 2026.

Learnings on capacity and market assumptions:

- Danish total volume of PUR waste from mattresses is estimated to be approx. 3.500 tonnes
- BPI extends its production capacity from 2023 to be >6.000 tonnes leaving enough for DK volume
- BPI sales prediction on post-consumer bonded foam is >300 tonnes by 2023 and >1.000 tonnes by 2026

11. Conclusion

1. Bonded foam containing postconsumer mattress foam can be produced in BPI`s existing production process without major changes, if the postconsumer mattress foam fulfils the quality requirements stated by BPI

2. The composition of the types of PU-foam in the postconsumer mattress foam from NL and DK is evaluated to be similar

3. The main quality requirements of the postconsumer mattress foam are:
    - The foam must be unsoiled and dry.
    - No other materials than PU-foam are accepted.

4. Learnings of hygienic risks:
    - The steaming process reduces the microbial contamination in the foam.
    - The levels of potentially harmful bacteria are low in pre-steaming samples and below detection level after the steaming process leaving no cause for concern.
    - Mattresses from the health sector pose a safety hazard and is not wanted for recycling at BPI
    - A controlled collection and dismantling setup is needed to avoid microbial contamination

5. Postindustrial bonded foam complies with both CertiPUR US and Europe, as well as REACH & RoHS.
   Postconsumer bonded foam complies with CertiPUR US and Europe except:
    - NL version has too high phthalates value
    - DK version has too high heavy metals
    - Both DK and NL has too high organic tin (only EuroPUR)

   All non-conformities are expected due to the nature of substances used in PU-production in the past.

   Both NL and DK Postconsumer bonded foams are REACH and RoHS compliant, even to the REACH Annex XVII children`s articles. Tests show a snap shot of the contents of hazardous substances, and should be monitored over a longer period to prove continuous compliance, especially to particular sensitive applications (e.g. children's articles).

6. The mechanical properties of bonded foam containing postconsumer mattress foam are primarily in line with or better than post-industrial bonded foam, and no results are causing concerns to normal bonded foam applications

7. Main recommended applications / outlets:
    - Packaging / shock absorption (protection of e.g. hifi-equipment, sensitive devices etc.)
    - Sound and vibration insulation (industrial machine encapsulation, DIY-market etc.)
    - Carpet underlay and other floor underlay applications
    - Comfort products (selected parts for furniture, mattresses etc.)
    - Thermal insulation when respecting fire requirements

   There are no application limitations for post-consumer vs. post-industrial bonded foam, except for children's articles.

8. Danish total volume of PUR waste from mattresses is estimated to be approx. 3.500 tonnes
   BPI extends its production capacity from 2023 to be >6.000 tonnes leaving enough for DK volume
   BPI sales prediction on post-consumer bonded foam is >300 tonnes by 2023 and >1.000 tonnes by 2026

12. Appendix list

Appendix 1: Eurofins bacteriological test report, Pre-BPI foam
Appendix 2: Eurofins bacteriological test report, Pre-NL/RM foam
Appendix 3: Eurofins bacteriological test report, Pre-DK/MP foam
Appendix 4: Eurofins bacteriological test report, Post-BPI foam
Appendix 5: Eurofins bacteriological test report, Post-NL/RM foam
Appendix 6: Eurofins bacteriological test report, Post-DK/MP foam
Appendix 7: Microbial risk assessment of recycled foam material, Eurofins
Appendix 8: Eurofins VOC and extractable compounds test report, BF 135 kg/m^3 (0%)
Appendix 9: Eurofins VOC and extractable compounds test report, BF 135 kg/m^3 (100% NL)
Appendix 10: Eurofins VOC and extractable compounds test report, BF 135 kg/m^3 (100% DK)