Compression Behavior of Forest Residues from Spruce Thinnings A Pre-study for the Design of Volume-optimized Transport Solutions for Energy Wood

Gero Becker*, Florian Schnaible, Uwe Uhlich
Institute of Forest Utilization and Work Science, Faculty of Forestry and Environmental Sciences
University of Freiburg, Werthmannstraße 6, D-79098 Freiburg, Germany
gero.becker@fobawi.uni-freiburg.de

Abstract:
Energy policy aims at the substantially increased utilization of renewable energies. Forestry can provide relevant quantities of energy wood. Forest residues are a high volume and low weight product which makes long distance transport costly and environmentally problematic. There exist several technical concepts to overcome this basic problem. (1) Chipping at the place of origin, (2) bundling and (3) mechanical densification. Mechanical densification might be a an alternative which allows transporting the compacted material to a central place or even the final destination, were the chipping can be organized in a much better environment, resulting in a higher productivity and lower costs for chipping. Semi-technical and real size experiments were done to get basic knowledge about the compression behavior of forest residues. The results are showing a final volume reduction from around 70 %, a reached density between 200 and 250 kg/m³ with the same load of 1200 kg/m². There is no significant volume increase when the load is stepwise reduced. Only at end of the releasing process a certain increase of volume between 25 % to 35 % can be observed.

Keywords: compression behavior, forest residues, energy wood, transport solution

1 Introduction, background and objectives

International and national energy policy aims at the substantially increased utilization of renewable energies. Energy wood (ligno-bioenergy) is in this context of special importance. Agriculture as well as forestry can provide relevant quantities, which can be even increased on a sustainable basis (BMELV 2004, Vorher 2008). Most technologies to produce and provide energy wood for combustion are established (Neugebauer et al. 2005). Also new technologies to convert biomass into high value liquid fuels (BTL) are recent under development (FNR 2007).

In contrast to agricultural bioenergy products, the use of wood does not fuel the conflict between the need for more renewable energy and food production. The use of wood is therefore widely accepted in society and practice. Besides wood from the forest, also additional quantities of wood from landscaping and from short rotation coppices (SRC) can be used for conversion.

In contrast to classical fossil energies, bioenergy from agriculture and forest grow and have to be collected on relatively large land areas, typically in rural areas i.e. far away from any point of production, conversion or final use. This decentralized origin inevitably leads to the necessity to transport biomass over medium to long distances, if technologically and economically viable conversion with modern industrial installations is targeted (Wittkopf et al. 2003). Biomass in general and especially residues from forestry are a high volume – low weight product which makes long distance transport both costly and environmentally problematic. There exist several technical concepts to overcome this basic problem:

⇒ Chipping of the material at the place of origin. Depending on species, moisture content and the size of chips, the specific density of the chipped material can reach approximately 350 kg/m³ (Lechner et al. 2004, Spinelli 2005, Kanzian et al. 2006).

The process of decentralized chipping in the field and especially close to the forest is in many cases difficult: depending on the capacity of the chipper and the transport distance to organize the chip-transport chain smoothly is tricky (Remler et al. 1999). As time studies show, the technical capacity of the chipper is only used up to 50% in many cases because of delays in the whole chain. This increases costs (and also the fuel consumption of the chipper) (Wittkopf et al. 2003, Spinelli 2005).

⇒ Bundling: Bundling of forest residuals with special machines may lead to a density of approximately 315 kg/m³.

Bundling technology has been developed in Scandinavia for big clear cuts, employing special bundling devices mounted on a forwarder or truck chassis. Adapting the systems to the conditions of the selective harvesting of Center Europe resulted in quite high costs for the bundling process itself, because less material is available and the productivity of the bundling machine decreases rapidly (Wittkopf 2005).

⇒ The mechanical densification of the load of loose material right on a truck by appropriate technical means may be an alternative which allows transporting the compacted material to a central place or even the final destination, were the chipping can be organized in a much better environment, resulting in a higher productivity and lower costs for chipping. Furthermore this concept would make it possible to store the un-chipped material either before transport in the forest or before chipping at the place of destination which reduces the moisture content and simultaneously increases the heating value of the material. There are only few attempts until now to develop this compaction concept to a feasible solution.

Before developing a technical solution to densify forest residues mechanically on a truck, basic knowledge concerning the process of densification is needed.

Systematic densification experiments were conducted on both semi-technical and real size level to learn more about forest residues densification, with the following objectives:

1. Which forces must be applied to compact forest residues significantly?
2. Is there a “Springback Effect” after release?
3. How can the compacted material be unloaded?

2 Methodology and materials

Forest residues from standard thinning operation from medium aged spruce stands were the material to be tested.

2.1 Semi-technical experiments

A wooden box was constructed with the size 1.20 x 1.00 m (identical to a euro-pallet) and 1,30 m high, resulting in volume of 1.56 m³. This box was filled with the following material: spruce and twigs and small diameter tops (4.0 – 13.0 cm with bark) with approximately 48% moisture content. The length of the material was cut to approximately 1.30 m and was filled into the box manually and loose. A tank (intermediate bulk container) with exactly the same base dimension than the box (1.20 x 1.0 m) was put on top of the filled box. The empty tank had a weight of 65 kg which creates a specific version of 54 kg/m². The densification effect of this load was measured as distance between the surface of the densified material and the edge of the box at the four corners of the box and averaged. After this the tank was filled with water, and measurements were taken after every 100 liter (equivalent to 83 kg/m²) additional load. When the tank was completely full, containing 1000 liter, a second tank was put on top and also filled in 100 liter steps. The final load totaled in 2130 kg, equivalent to 1775 kg/m². During the last steps of 100 liter loads, no significant further compression of the material could be observed.

To explore the sprinback behavior after taking off the load, the load was released stepwise using the same intervals as before.

The experiment was repeated five times, every time completely new branch material was filled into the box.

2.2 Real size experiments

A standard steel truck container with open top and two doors at the back end was used (size 1.71 x 3.20 x 2.33 m = 12.75 m³).

The container was filled with a crane with loose branch and crown material from spruce thinnings. The crown material had a maximum diameter between 8 cm and 35 cm with bark. The length of the material was between 0.5 and 3.0 m.

After filling the container, a steel plate of the same size as the container was put on top of the load with the crane, resulting in a specific load 160 kg/m².

The densification effect was measured as the average distance from the level of the compressed material to the edge of the container at four corners.

Then stepwise load was applied with the crane, using big bags with steel bullits inside. Every bag had a weight between 340 and 760 kg. In total 14 bags were loaded one by one, evenly distributed on the steel plate and the respective densification of the load was measured at all four corners. At the end approximately 8.140 kg were applied resulting in a specific load of 1800 kg/m².

To measure the springback effect the offloading of the bags followed the same steps.

3 Results

Figure 1 shows five curves representing the relative volume reduction with increasing load. Figure 2 shows the respective increase of the density of the material. The loose material showed densities between 49 and 60 kg/m³. After the maximal load was applied, a density between 200 and 215 kg/m³ was obtained. The curves are asymptotic, meaning that the first load creates the greatest densification effect, and the last loads result only in marginal additional densification.

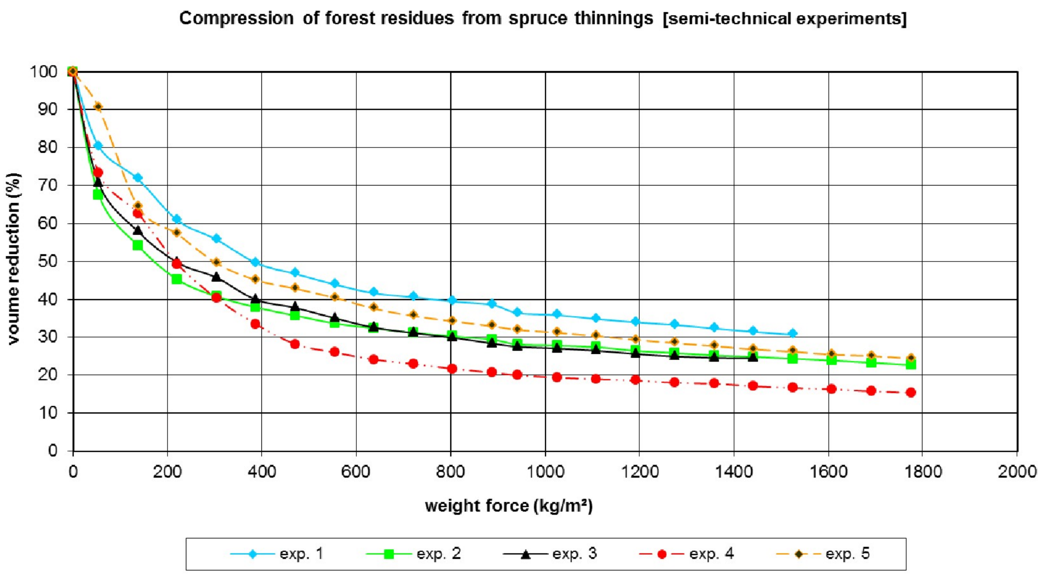

Figure 1: Curves of volume reduction over the increasing weight force during the semi-technical experiments

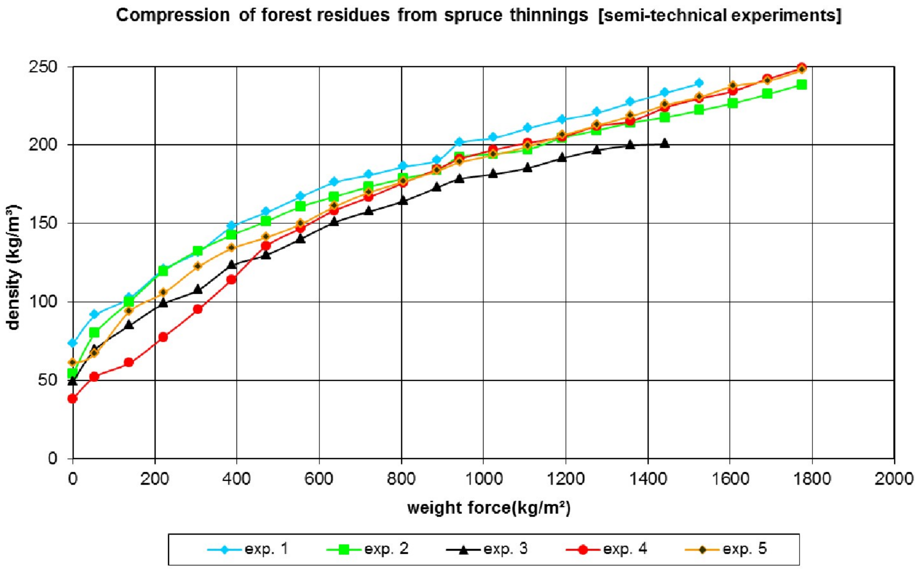

Figure 2: Curves of density over the increasing weight force during the semi-technical experiments

The curves are normally parallel. Only experiment No. 3 starts with a lower initial density, but the curve runs at a load level of approximately 400 kg/m² parallel to the other curves.

Summarizing the result can be said, that volume reduction of approximately 70% can be reached if a load of approximately 1000 to 1200 kg/m² is almost applied.

Figure 3 shows the springback effect of the five experiments.

There is no significant volume increase when the load is stepwise reduced. Only at end of the releasing process (below approximately 300 kg/m²) a certain increase of volume between 25 % to 35 % can be observed.

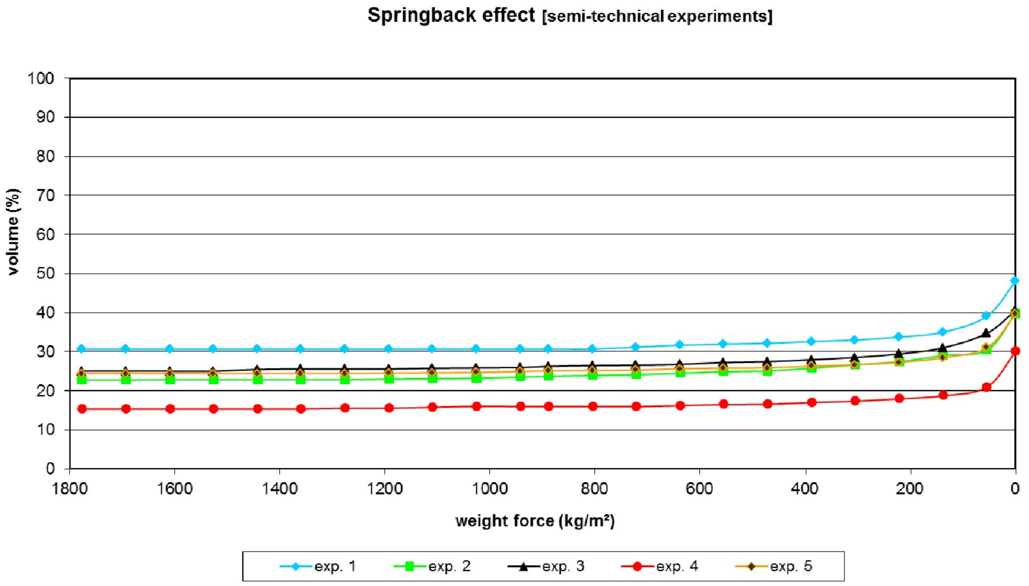

Figure 3: Curves of volume over decreasing weight force during the semi-technical experiments

The results of the semi-technical experiments are in principal confirmed in the real size experiment (Fig. 4 and 5). The starting density of the loose filled container is identical. The compression behavior follows the same pattern. With the same load, (1200 kg/m²) the final volume reduction (70%) and the reached density (200 kg/m³) is a bit lower, but in the same magnitude.

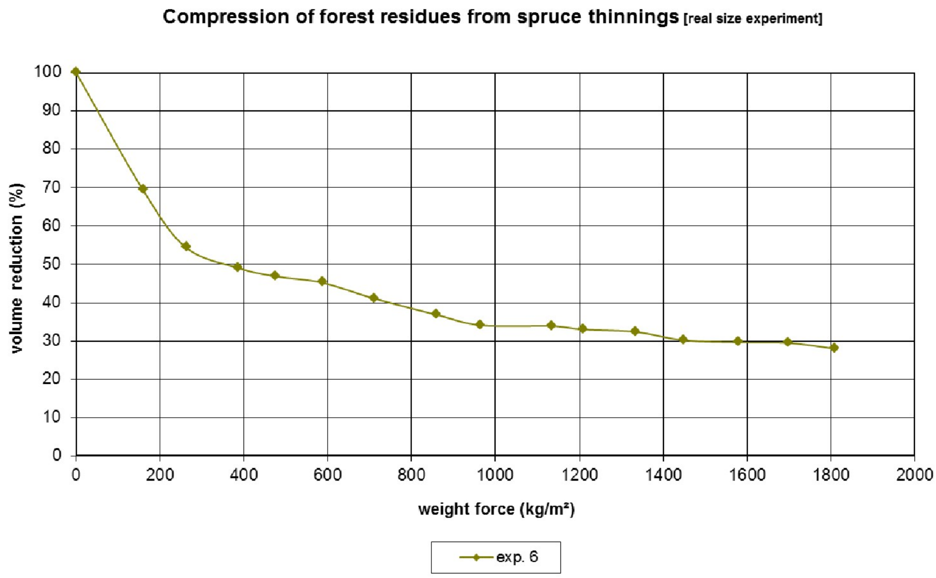

Figure 4: Curve of volume reduction over the increasing weight force during the real size experiment

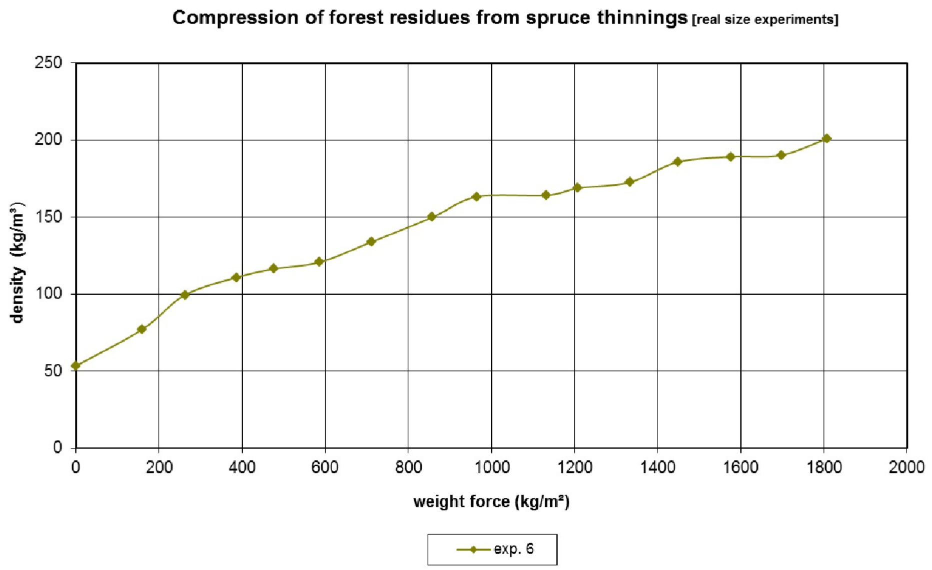

Figure 5: Curve of density over the increasing weight force during the real size experiment

This also true for the springback effect (see Fig. 6)

The off-loading of the compressed material from the container after opening the back doors was easy. It could be pulled out with the help of a forklift or tipped by lifting the front of the container, and the load remained nearly “solid” after offloading.

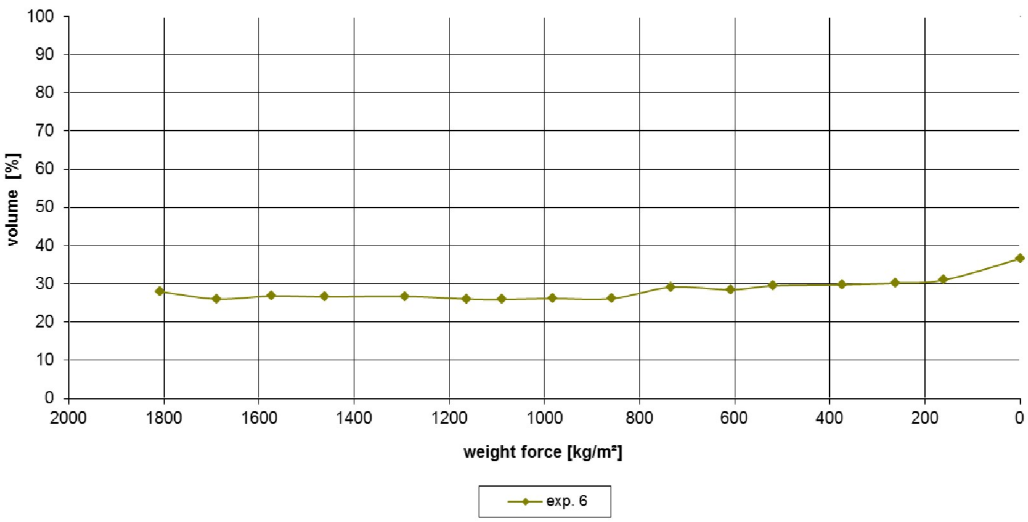

Figure 6: Curve of volume over decreasing weight force during the real size experiment

4 Discussion and outlook

The results of both the semi-technical and the real size experiments show, that mechanical densification of ordinary spruce logging residuals is possible and a significant densification (from 50 kg/m² to 200 kg/m²) with a specific pressure of approximately 1500 kg/m² can be reached. This result gives technical indications to construct a device to compress the material on a truck. The favoured solution would be using a modified loading crane, which is a normal equipment of container trucks. This would allow filling the container with a first load and compressing this load, which would result in a reduced volume of the load so that the second layer of residuals could be loaded on top of the first load and being compressed again.

The second layer of the load would be heavy enough to counteract the springback effect of the first load. This would result in a total load density close to 200 to 220 kg/m³ which would allow to make full use of the pay load (approximately 20.000 kg) and load volume capacity (80 m³) of a container truck and lorry system, a moisture content of 50% of the material provided.

This result would substantially increase both the energy efficiency and the economy of transporting loose biomass eliminating one of the biggest drawbacks of centralized processing and converting of woody biomass.

Further experiments are planned with material of different moisture content and with residues of broadleaves harvesting operations as well as with material from short rotation coppice.

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