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MECHANICS OF CHIP COMPACTION

Zoltán Kocsis – Etele Csanády

Abstract
It is a common practice in agriculture to pelletize wood in a way that the pressure is equal to or greater than 1000 bar. During compression, the density and the elastic modulus increase rapidly. Wood and wood pellets show viscoelastic behavior and therefore the pressure-deformation relationship is dependent on time or the speed of the load. Previous research on the compaction of sawdust and chips showed that not even solid wood has the elasticity attributes of Hooke's law. There is always a certain degree of deformation left at the end of the load cycle. Most of the deformation is permanent during the offload. The stress-strain relationship depends on time and the amount of stress, so it does not show linear viscoelasticity. According to current research, we have created a dimensionless criteria equation that characterizes the pressure-density changes universally (independently of the species) in relation to the compaction work and press temperature, for different pellet diameters. The equation can also determine the specific energy as a function of to the compressional pressure.

Key words: *Compression, viscoelasticity, creep, specific work, dimensionless numbers*

INSTRODUCTION

We need to fulfill many criteria during mechanical measurements. The results we obtained are only valid under the given conditions. This is so because of the complexity of biological materials. It is often necessary to resort to empirical methods to describe these observed phenomena. Because of the many influencing factors, these purely theoretical considerations rarely give us usable results, and thus experiments have an extraordinarily important role. It is very important to know all attributes of the material (load, species, particle size, moisture, etc.). This is important to get accurate results. *Figure 1* shows the course of the compaction processes in a general case. After loading, the wood stays under a constant load (σ_0) for a shorter or longer time (t_2-t_1) and during this time creep occurs (ε_1). In this case, creep means a further compaction of the material at constant pressure. After removing of the load, the elastic deformation is suddenly recovered (t_2); afterwards the rebound of the material occurs over time. The latter reduces the tightness and with it density of the pellet. It can be concluded that the higher the pressure holding time (t^M), the more it creeps (becomes more compacted) and the less the rebound rate is that way there is more permanent deformation. (Sitkei, 1994; 2000). In order to generalize the obtained experimental results, the method of dimensional analysis was used (Sitkei, 1971). First the

University of West Hungary, Bajcsy-Zs. u. 4., 9400 Sopron, HUNGARY
e-mail: etele.csanady@skk.nyme.hu, zoltan.kocsis@skk.nyme.

variables that influence the compaction process should be selected as follows. Using the standard dimensional analysis method, the following dimensionless numbers are obtained.

$$W = f\left(p, \gamma, d, \sigma_C, \vartheta, \vartheta_0\right),\ \pi_1 = \frac{W}{p};\quad \pi_2 = \frac{\gamma \cdot d}{\sigma_C};\quad \pi_3 = \frac{\vartheta}{\vartheta_0}$$

Knowing the dimensionless numbers the similarity equation can be written in the following form.

$$\frac{W}{p} = \text{const.} \cdot \left(\frac{\gamma \cdot d}{\sigma_C}\right)^n \cdot \left(\frac{\vartheta}{\vartheta_0}\right)^m \qquad (1)$$

where:
p – is the pressure, N/m^2
W – is the specific energy, Nm/m^3
γ – is the specific weight of pellet, N/m^3
d – is the diameter of the pellet, m
σ_c– compressive strength of the wood species used, N/m^2
ϑ , ϑ_0 – are the pellet temperature and a reference temperature, here taken as ϑ_0 =25°C
n, m – are exponents.

We intend to determine the energy requirement of the compaction process and therefore, the independent variable is the specific energy (*W*). As a consequence of Eq.(1) the (*W/P*) simplex is placed as a function of independent variables containing in the other two dimensionless numbers. The total work of compaction is determined by the pure compression work and by the work done during pushing out the pellet from the processing channel. The relationship between the pressure (*p*) and strain (*ε*) can be given following form (Sitkei, 1981):

$$p = A\left(\frac{\varepsilon}{1-\varepsilon}\right)^n \qquad (2)$$

where:
A – is the material dependent constant,
n – is the exponent.

The exponent *n* depends on the kind and the compression rate of the material being compacted. Its value varies between 1.5 and 2.5 for wood-based chip compaction processes of particles, including the pelleting ranges. The value of the exponent is greatly depending on the strength of particles. The greater the strength of the particles (i.e. a harder wood) the less the deformation under a given pressure and thus the value of the exponent becomes smaller (Csanády et al., 2013). This was observed for samples of pine and black locust. Moisture content of the material also affects the endurance of individual particles and the value of the exponent. The particle size distribution is also an influencing factor. The smaller the particle, the faster the compaction at lower pressures, i.e. the value of the exponent becomes larger. Based on our research, in practice, durable pellets can only be made with a specific deformation ε = 0.8 to 0.85. The exponent values were n = 2 to 2.5

respectively. We found that the push-out force of the pellet decreases linearly depending from the length of the motion path (solid pellet length). Thus, the work can be easily calculated knowing the push-out force (*F*) and the displacement (*s*):

$$W_p = \frac{F \cdot s}{2} \qquad (3)$$

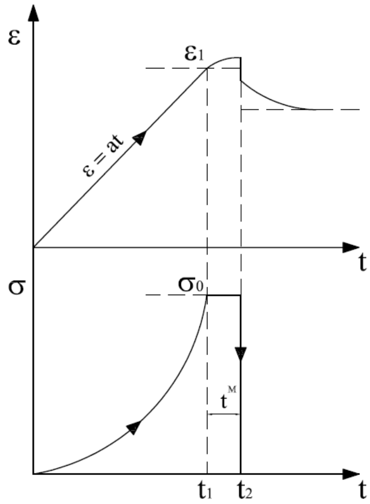

Figure 1. The time course of the compression process (Sitkei, 1994)

MATERIALS AND METHODS

Single stroke press-channels were used to make pellets with different diameters. Metal cylinders(dye) of 6, 8 and 12 mm dia. With appropriate indenters were manufactured to ensure 20-30 mm pellet length. An universal testing machine performed the measurements. (*Figure 2*). The punch had a unique thermo regulating and measurement system (*Figure 2*).

Figure 2. Press-channel (left)
Temperature control and measurement system (right)

Air-dried (10-12%) pine (*Picea abies*) and black locust (*Robinia pseudo acacia*), wood was used during the test. It was important to know the particle size because the particle size significantly influences the density of the pellet. We used pelletizer after chopper pilot to achieve this. Then electromagnetic sieve shaker was used to sort the milled particles. The samples were sieved for 10 minutes at a1.5 mm vibration amplitude. After sieving, we weighed the leftovers with digital scale. Analyses of the particles showed that 80-90% of the particles were in the range of 0.2 to 1.5 mm. Thus, these determine the changes of mechanical properties during pelleting.

RESULTS AND DISCUSSION

Figure 3 shows the total specific work for pine chips for different pellet diameters using 1400 bar pressure. With increasing diameters the relative contribution of wall friction decreases and therefore the energy requirement also decreases.

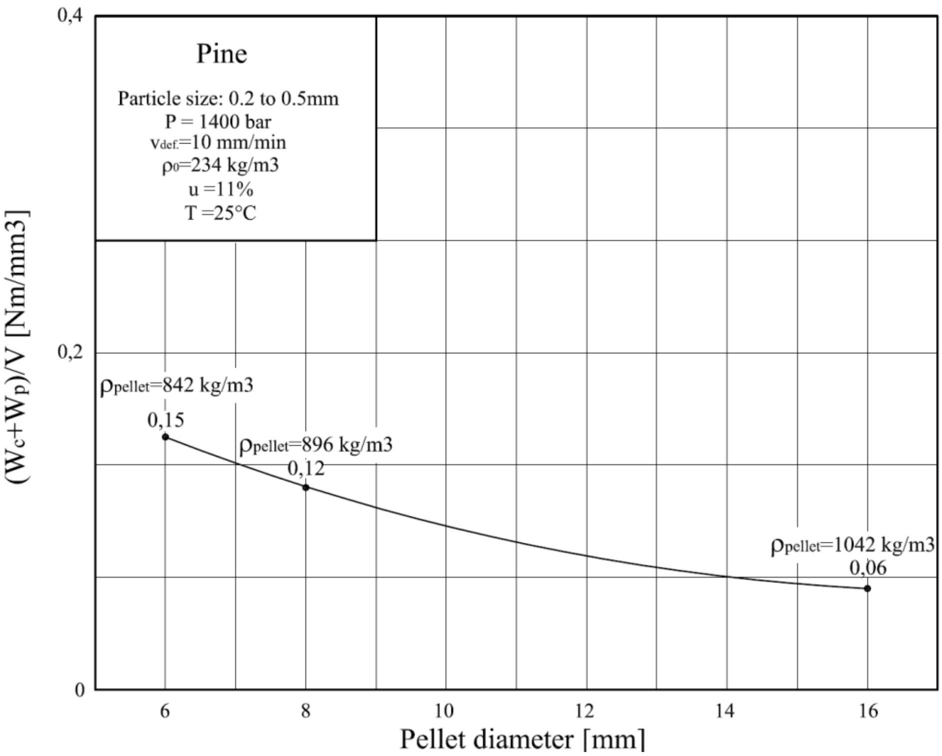

Figure 3. The change in specific work depending on the diameter of pine pellets at ambient temperature

Using pellet heating with different temperatures the viscoelastic properties of wood materials considerably changes. *Figure 4* shows the effect of pellet temperature on the total specific compaction energy.

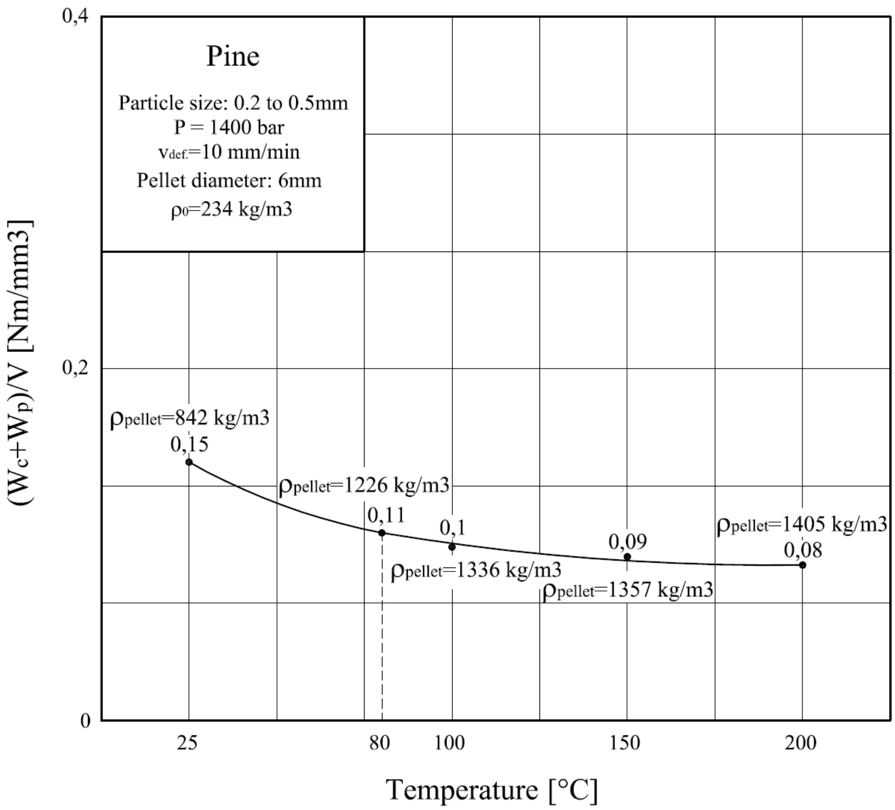

Figure 4. The change of total specific work depending on pellet temperature using pine chips

It should be noted that also in the case of black locust the curves are similar. Also specific values are nearly identical (slightly higher at black locust). The reason is that we could compress better the pine with less work than black locust.

The scattering zone of measurement points is fully acceptable and it corresponds to a good engineering accuracy. The calculated correlation coefficient is around 0.96. In the following the effect of particle size on the compression work was examined at different temperatures. For these experiments we have used three fractions of chips for both pine and black locust. The fractions have the following particle size ranges: 0.063 to 0.2 mm, 0.2 to 0.5 mm and 0.8 to 1.0 mm. Using measurement points, the similarity relationship is plotted in Fig.5.

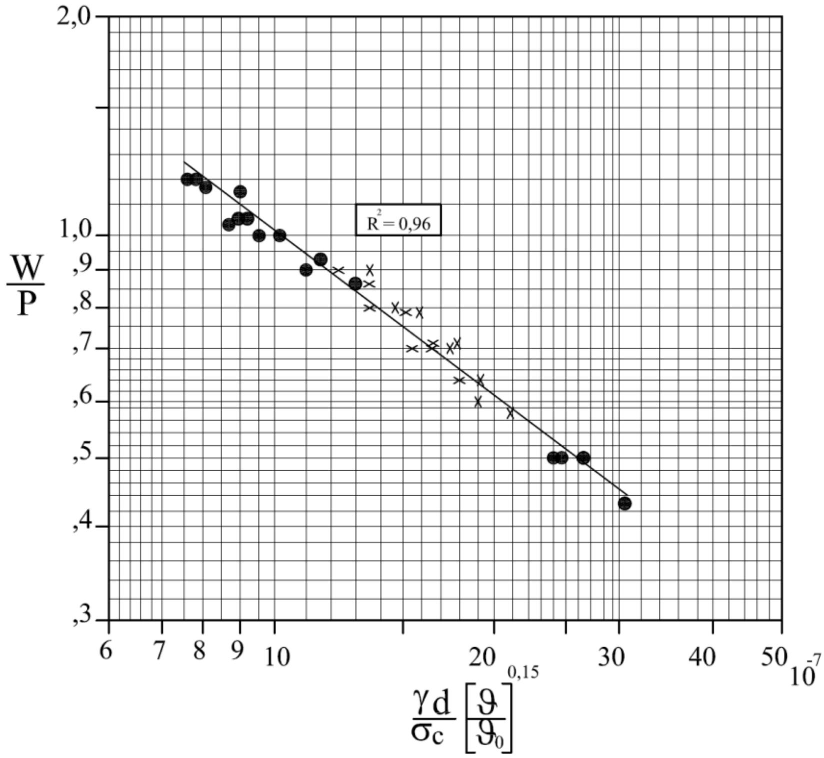

Figure 5. The final similarity plot of all measurement results

It should finally be noted that in these experiments a plunger with bottom face was used. In practice, however, due to the continuous operation requirement, the chips material will be pressed into the boreholes of a die ring and the counter-force is assured by friction forces. Therefore the push-out force is more or less the same as the maximum compression force. This means that under real conditions somewhat higher specific energy is required, especially for bigger Pellet diameters.
The final similarity equation is given in the following form:

$$\frac{W}{p} = C \cdot \left(\frac{\gamma \cdot d}{\sigma_C}\right)^{-0,75} \cdot \left(\frac{\vartheta}{\vartheta_0}\right)^{0,15} \qquad (4)$$

Where the constant *C* has the value of $3.12 \cdot 10^{-5}$

CONCLUSIONS

In this research work the effects of different influencing factors such as pressure, pellet diameter, heating, wood species and particle size on the energy requirement were examined. Determining the energy requirements, the pure compression work and the push-out work of the pellet were determined separately. The effect of heating up to 200°C was evaluated. Two wood species were used in three different chip size fractions. In order to generalize the obtained experimental results the dimensional analysis method was applied which has been shown very powerful also for wood chip compaction.

Based on theoretical and experimental investigations the following main conclusions may be drawn:

- The main influencing factor is the pellet diameter which fundamentally determines the role of wall friction forces in the total energy requirement,
- The heating of chips during pellet formation seems to be advisable up to 100°C. Above this temperature limit its effect continuously decreases,
- The chip size distribution has some effects on the energy requirement but, disregarding its effect, it does not cause significant error,
- Using similarity equation is a powerful method to generalize experimental results also for compaction processes. In this way a simple and quick estimation of energy requirement is possible.

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