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CONTENT

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TESTS OF STATIC RESISTANCE OF CUTTING WOOD WITH A NEW MODEL KNIFE DESIGNED FOR CHIPPING LOGGING RESIDUES

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ABSTRACT

In the face of technological progress with regard to harvesting of timber and shredding of logging residues (often considered silviculture waste), there have been attempts to streamline machinery operation and reduce energy consumption, while improving the quality of the end product, that is wood chips. To meet these expectations, a new knife for chippers was designed. The purpose of the current laboratory tests was to determine and compare static resistance of cutting wood with the standard chipper knife and the new model knife. Wood cutting tests were performed on an Inspekt Table 100 strength testing machine for three coniferous species (pine, spruce and larch) and three different feed rates. Samples 50 mm high and 100 mm wide were cut in the machine, with the cutting edge of the knife acting on the sample width. Depending on the measurement case, average cutting resistance was 21 to 27.5 kN for the standard knife or 24.5 to 42.6 kN for the new model knife, whereas specific energy required for wood cutting ranged 0.025–0.086 J·mm^{-2} or 0.026–0.091 J·mm^{-2}, respectively. The analysis of cutting resistance might imply that the values for the new model knife were slightly higher. However, this could be attributed to the study methodology rather than the knife design itself, as the sample thickness (cutting height) exceeded the milled section of the new model knife, and cutting resistance significantly increased at the moment its non-milled section entered wood. Regarding specific cutting energy, there is a clear negative correlation with cutting speed, while no correlation with the latter could be identified in the case of cutting resistance. Overall, based on the study results it could not be clearly and unambiguously concluded which of the tested knife designs is superior in terms of energy efficiency.

Key words: cutting resistance, chipper knife, wood cuting, cutting energy

INTRODUCTION

Wood comminution processes necessitate not only the precise adjustment of cutting machinery mechanisms to produce suitable material, but are also directly determined by the mechanical parameters of plants, particularly their cutting resistance. The latter varies depending on the wood piece inclination angle and dimensions, but also the properties of the plant material processed (Kowalski, 1993).

Heterogeneous wood structure entails high variability of properties and is often a derivative of natural processes (Tomczak et al., 2009). As an anisotropic material, wood may display different properties varying in value depending on the investigated direction or area (Wdowiak, 2017), which translates into its strength and cutting resistance. Wood much easier transfers forces applied along fibres than in the across direction (Habyk et al., 2023). Consequently, grain, anatomy, age, various defects or other potential environmental effects are all distinctly relevant (Wiemann and Williamson, 2002). In general, cutting resistance is influenced by a number of parameters, including, but not limited to, type of wood, species, moisture content, density, early to late wood ratio, hardness and density. As reported in the literature, lower cutting resistance is displayed by juvenile wood, wood of lower density and hardness, as well as timber with a higher proportion of early (coniferous) wood or sapwood (Giefing and Jablonski, 1989; Spława-Neyman et al., 1995). Conversely, resistance increases with hardness, density or a higher proportion of late wood (Ross, 2021; Wdowiak, 2017). Resistance also increases with a drop in temperature (Więsik, 1976). A major parameter affecting wood cutting resistance is humidity, which is negatively correlated with it, that is the higher moisture content, the lower cutting resistance (Bąk, 2006; Hernández et al., 2014).

Apart from wood properties, cutting resistance depends also on the chipping equipment design (Kowalski, 1993; Kuptz and Hartmann, 2021); knife parameters, namely thickness, inclination angle and dullness (Grubîi et al., 2019; Kowalski, 1993; Pszkit and Więsik, 1985; Wiklund, 1967); and cutting process parameters, such as speed (Więsik, 1981).

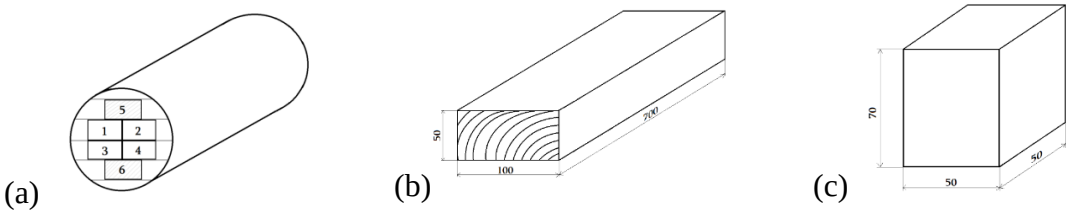
The impact of various chipping unit designs or parameters of various wood species on cutting resistance has been already presented in a number of studies. However, several issues remain to be discussed, particularly related to new knife designs for the machinery used for felling and bucking of various types of wood. As tests tend to be based on standard blades, there is no or limited data comparing various cutting elements that could indicate specific differences in cutting efficiency and resistance with reference to wood properties and cutting process parameters.

Researchers from the Technical University in Zvolen (Slovakia) developed and patented a new asymmetric knife design for use in forest machinery (Krilek et al., 2024, 2023), and subsequently determined that there are no studies on the resistance of cutting wood with such a knife or comparisons against the existing knife design solutions.

For this reason, it was reasonable to attempt a study aimed at determining the resistance of cutting wood with two types of flat knives: (i) the standard chipper knife, and (ii) the new model knife, at various cutting process parameters for coniferous species.

MATERIALS AND METHODS

In our study, we used wood of three coniferous species: the Scots pine (*Pinus sylvestris* L.), the Norway spruce (*Picea abies* L.) and the European larch (*Larix decidua* Mill.), harvested by final cutting. From the butt-end of logs, rollers of a diameter of at least 28 cm and length of approximately 140 cm were extracted. Each roller was cut into 4–6 samples of the cross-sectional dimensions of 100×50 mm, which were further divided into two sections approximetely 700 mm in length (cf. Fig. 1). In addition, a 70 mm long section was cut from each sample and divided into 50×50×70 mm samples for wood hardness testing (H_{s12}).



(a) (b) (c)

Fig. 1. Roundwood division for sampling (a); a sample for cutting resistance testing (b); a sample for wood hardness testing (c).

The external diameters of samples were measured with a digital calliper (±0.1 mm) or a tape measure (±1 mm). Next, samples were weighed on a laboratory balance. This enabled the determination of wood density in the analytical state (ρ) and, upon finding moisture content (*MC*), dry wood density (ρ_{dry}). Moisture content of wood was determined by the drying and weighing method, and samples were taken on a current basis during cutting resistance (*F*) and static hardness (H_s) tests.

Static hardness of wood (H_s) was determined using the Janka test, that is by measuring the force required to embed a 11.28 mm steel ball to half of its diameter into the wood of the analytical moisture content (*MC*), and subsequently converting the result to hardness in MPa at moisture content of 12% (H_{s12}).

The number of growth rings (*GR*) was determined on the frontal surface of samples. The procedure consisted of selecting at least ten radially-oriented sections 10 mm long, counting the number of annual growth rings, and determining the mean value (units·cm^{-1}).

Wood cutting resistance was determined using two asymmetric flat knives (standard and new model). The knives were mounted in an Inspekt Table 100 strength testing machine (from Hegewald und Peschke), which controlled the cutting process and recorded measurement data using the LabMaster control software. The same machine was used for wood hardness testing.

(a)  (b) 

Fig. 2. Wood cutting process in an Inspekt Table 100 strength testing machine with the standard knife (a) and the new model knife (b).

Wood cutting tests were performed for three coniferous species (pine, spruce and larch) and three cutting speeds (v = 2 mm·s^{-1}, v = 4 mm·s^{-1} and v = 6 mm·s^{-1}). During tests, the LabMaster software recorded force with the accuracy of ±1N and crosshead feed rate with the accuracy of ±0.001 mm. Based on the recorded data, the software computed the predefined output parameters. For the purpose of wood cutting analysis, these included: average cutting resistance (F_{avg}, kN), instantaneous maximum cutting resistance (F_{max}, kN) and specific cutting energy (E_s, J·mm^{-2}). Depending on the parameter, there were at least twelve repetitions for each measurement case.

RESULTS AND DISCUSSION

The characteristics of samples of the three species tested in the study are summarised in Table 1 below. ANOVA indicated statistically significant differences (p<0.05) between all samples in terms of moisture content (MC), growth ring number (GR) and hardness (H_{s12}). For density, a statistical analysis did not reveal significant differences between pine and larch wood samples (p>0.05), which had been expected, as these are similar species; whereas spruce wood density was statistically different from that of pine and larch (p<0.05). In connection with the differences recorded, no comparative analyses of cutting resistance between various wood species were conducted. The analysis focused on cutting resistance as a function of feed rate and the comparison thereof between knives to determine whether the new model would meet the designers' expectations.

Table 1. Characteristics of samples used for cutting resistance testing.

Species	MC [%]	GR [units·cm^{-1}]	H_{s12} [MPa]	ρ_{dry} [kg·m^{-3}]
Pine	15.7 ±1.8	5 ±2	30.2 ±6.2	602.0 ±82.1
Spruce	20.3 ±2.2	4 ±2	24.9 ±3.3	468.0 ±11.5
Larch	27.1 ±3.0	2 ±1	37.0 ±5.1	629.8 ±21.9
Note: Superscript letters at mean values indicate homogeneous groups determined using Tukey's HSD test for the significance level α=0.05. Differences are considered statistically significant for p<0.05.				

Wood cutting resistance (F_{avg}, F_{max}) for two types of chipper knives for the tested wood species as well as specific cutting energy (E_s) as a function of feed rate (v) are presented in Figure 3 below.

According to the test results for the standard flat knife, average values of wood cutting resistance (F_{avg}) slightly increased with cutting speed for both spruce and larch (cf. Fig. 3a). No such dependency could be determined for pine. During pine wood cutting with the standard knife, F_{avg} reached the peak value of 20.1 kN at v = 4 mm·s^{-1}, then fell to 17.6 kN at v = 6 mm·s^{-1}.

In the case of the new model knife, no specific patterns of F_{avg} in relation to cutting speed changes could be observed. For spruce, based on the results presented in Figure 3b it could be claimed that F_{avg} generally decreases with growing feed rate, as the peak of 19.08 kN was recorded for v = 2 mm·s^{-1}, then it fell to 15.6 kN at v = 4 mm·s^{-1} and slightly rebounded to 16.5 kN at v = 6 mm·s^{-1}. A similar trend could be observed for larch wood samples. When feed rate v was increased from 2 mm·s^{-1} to 4 mm·s^{-1}, F_{avg} fell from 19.97 kN to 16.55 kN, then rebounded to 21.91 kN at v = 6 mm·s^{-1}.

The opposite trend was observed for the new model knife when cutting pine wood. In this case, an increase in speed v from 2 mm·s^{-1} to 4 mm·s^{-1} was accompanied by an increase in F_{avg} from 19.77 kN to 25.02 kN respectively. A further increase in speed to v = 6 mm·s^{-1} resulted in F_{avg} falling to 17.92 kN, which was the lowest value for this species.

Comparisons of F_{avg} for various wood species between the standard knife and the new model knife (cf. Fig. 2a & 2b) are not sufficiently consistent to support a conclusion whether the new chipper knife meets the designers' expectations and involves lower resistance. When comparing the values of F_{avg} for the same speeds for all three species tested, the average cutting resistance for the new model knife is alternately higher or lower than or similar to that for the standard knife. The apparent randomness of results seems to require either a more detailed analysis or separate examination of each sample of particular species. Moreover, a higher number of repetitions would probably be needed.

From the point of view of the mechanics of wood cutting flat-knife machinery as well as the durability of blades and other operating elements thereof, the analysis of instantaneous maximum cutting resistance (F_{max}) for the tested knives in particular measurement cases is much relevant (cf. Fig. 2c & 2d).

For the standard chipper knife, the overall pattern of changes in F_{max} for particular species is similar to trends observed in F_{avg}. For spruce samples, an increase in speed v from 2 mm·s^{-1} to 6 mm·s^{-1} resulted in F_{max} growing from 21.66 kN to 26.85 kN. In the case of pine samples, when speed v increased from 2 mm·s^{-1} to 4 mm·s^{-1}, the maximum cutting resistance F_{max} peaked 27.55 kN, then fell to 25.24 kN at v = 6 mm·s^{-1}. The most stable values of F_{max} for the standard knife were recorded for larch samples, as they ranged 20.97–22.2 kN for all speeds.

Wood cutting with the new model knife was accompanied by a higher spread of results and lack of any evident trend in F_{max}. When cutting spruce wood (cf. Fig. 2d), an increase in speed v from 2 mm·s^{-1} to 4 mm·s^{-1} caused a major drop in F_{max}, but a further increase to v = 6 mm·s^{-1} did not substantially affect the maximum resistance.

In the case of pine wood, when speed v increased from 2 mm·s^{-1} to 4 mm·s^{-1}, the maximum resistance F_{max} surged to 42.66 kN, then fell to the lowest level of 27.76 kN at v = 6 mm·s^{-1}. The pattern of instantaneous maximum cutting resistance for larch wood was opposite to that for pine: F_{max} reached the optimum of 24.54 kN at v = 4 mm·s^{-1}, then rebounded when speed increased to v = 6 mm·s^{-1}.

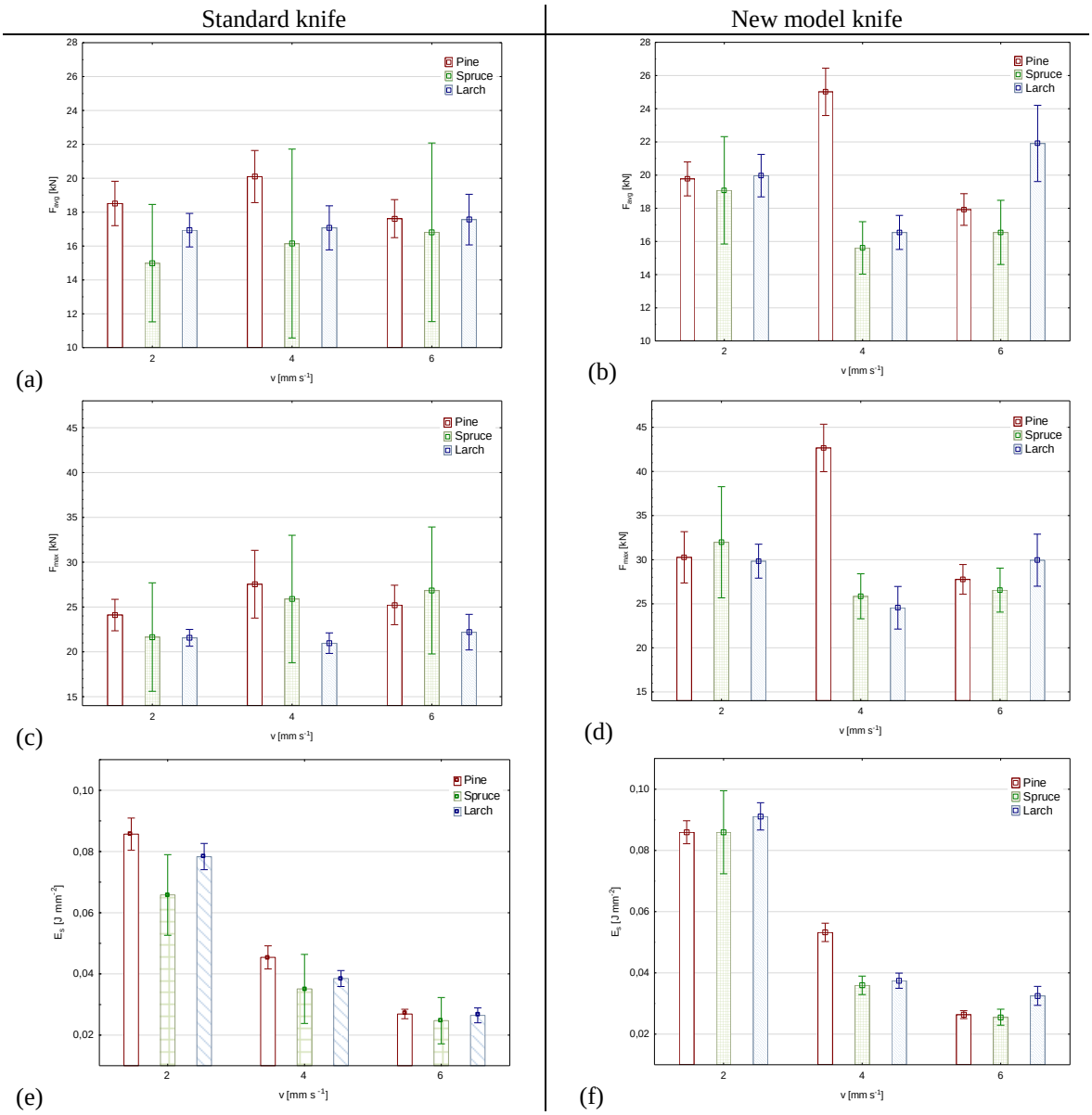


Fig. 3. Average cutting resistance (F_{avg}), instantaneous maximum cutting resistance (F_{max}) and specific cutting energy (E_s) as a function of wood cutting speed (v) for various species.

Like in the analysis of average wood cutting resistance (F_{avg}), no single evident trend in instantaneous maximum resistance (F_{max}) with changes in cutting speed could be identified.

When comparing the values of F_{max} between the standard knife and the new model knife for the same speeds (cf. Fig. 2c & 2d), in the great majority of cases (all three cases for pine and larch, and one case for spruce) the maximum cutting resistance for the new model knife is higher than for the standard knife. Lower values of F_{max} were only observed for spruce samples at speeds v = 4 mm·s^{-1} and v = 6 mm·s^{-1}.

The comparison might imply that the new model knife does not produce improvements in cutting efficiency versus the standard knife, expected by the designers. However, it should be noted that the confirmation of this conclusion could require further tests and analyses using the same or altered measurement methods. In the current study, the sample thickness (cutting height) exceeded the milled section of the new model knife, and cutting resistance significantly

increased when its non-milled section entered wood, which might have altered the ultimate results.

An important characteristic of wood cutting with a flat knife is the energy required to cut a sample. During the wood cutting process, the LabMaster software computed and recorded the total energy consumption, which was subsequently converted to the specific cutting energy (E_s) expressed in $J \cdot mm^{-2}$.

The analysis of the data presented in Figures 2e and 2f above indicates that in each case (i.e. for either chipper knife and all three feed rates) the value of E_s tends to drop with an increase in feed rate.

At cutting speed v = 2 $mm \cdot s^{-1}$, the absolute values of E_s were higher for the new model knife in the case of spruce and larch, while the same for both knives in the case of pine wood. For v = 4 $mm \cdot s^{-1}$ and v = 6 $mm \cdot s^{-1}$, in the case of all three species the absolute values of E_s were either the same or very similar for either knife. This might imply that the new design is not necessarily a superior solution.

However, when analysing a pro rata decrease in specific energy depending on cutting speed, it might be claimed that the new model knife performed better for pine and spruce samples, while it was inferior for larch wood. For the standard knife, an increase in speed v from 2 $mm \cdot s^{-1}$ to 6 $mm \cdot s^{-1}$ corresponded to a drop in the energy required for cutting (E_s) by 62% for spruce, 69% for pine and 67% for larch wood. In the case of the new model knife, with an increase in v from 2 $mm \cdot s^{-1}$ to 6 $mm \cdot s^{-1}$, E_s decreased by 70%, 70% and 64% for spruce, pine and larch wood, respectively.

Similarly, to the output of the cutting resistance analysis, also in the case of E_s it could not be clearly and unambiguously concluded which of the tested knife designs should be considered superior in terms of energy efficiency. There is a clear downward trend in specific energy as cutting speed increases, yet the absolute values are very similar or differ only slightly between both knives.

CONCLUSION

The analysis of the measurement data focused on comparing cutting resistance between two chipper knife designs (standard vs. new model), accounting for various cutting speeds (2 $mm \cdot s^{-1}$, 4 $mm \cdot s^{-1}$ and 6 $mm \cdot s^{-1}$). The outcome led to a conclusion that increasing wood cutting speed for either type of knife did not produce plain evidence whether speed influenced wood cutting resistance. The new model knife is not clearly superior to the standard knife in terms of efficiency and lower cutting resistance to consider it an evident improvement in design. In numerous cases, cutting resistance was higher for the new model versus the standard one. For either design, specific cutting energy was negatively correlated with wood cutting speed for all tested species. A pro rata drop in specific energy depending on cutting speed indicated that the new knife design was superior to the standard knife in cutting samples of spruce and pine wood, while inferior in cutting larch wood.

The data might have been influenced by the study methodology, as the sample thickness (cutting height) exceeded the milled section of the new model knife, and cutting resistance significantly increased at the moment its non-milled section entered wood. This might have altered the ultimate results.

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CHARACTERISTICS OF INDUSTRIAL WASTE PELLETS FROM THE COFFEE BEAN ROASTING PROCESS

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ABSTRACT

Worldwide, coffee husks constitute significant waste from the coffee bean roasting process in roasteries. There are industrial methods to recover husks for further processing and utilisation (e.g. for energy generation). Pelletisation is a technology applied for further processing of coffee husks. One of the reasons for the low utilisation of agglomerated coffee husks as a fuel is lack of sufficient information on their combustion characteristics and how these are affected by pellet properties. The aim of the present study was to identify the physical-mechanical-chemical characteristics of fuel in the form of coffee husk pellets and refer these characteristics to transport, storage and energy properties. Moisture content, which evolves over time and is more intensive in the initial days after production, affects the physical and mechanical properties of pellets. Pellets produced from wet husks obtained immediately after coffee bean burning required over two weeks to achieve solid physical and mechanical properties. Over that period, with natural loss of moisture (to <10%) occurring in pellets, their bulk and unit density increased (to >850 $kg \cdot m^{-3}$) and radial compressive strength improved (to >2.4 MPa). Intermolecular bonds became stronger rendering pellets harder and more resistant to external factors. The mechanical durability of pellets at >96.5% was achieved. Both coffee husks and pellets made from them had net calorific value of 18.5 $MJ \cdot kg^{-1}$, with relatively high ash content of 6.6%. Based on the study results and analyses, it was concluded that industrial waste in the form of husks from the coffee bean roasting process can be a potential substrate for the production of solid fuels, but the produced pellets require more than two weeks for moisture loss and the resulting improvement in their physical and mechanical parameters. Husks can be also utilised for production of other fuels, such as biodiesel, biogas, bioethanol or hydrogen.

Key words: coffee roasting, bulk density, mechanical durability, compressive stress, calorific value

INTRODUCTION

In 2022, Poland ranked tenth among the European Union member states in the coffee bean roasting industry, with the production volume of 38,000 tons. This corresponds to approximately 2.1% of the total volume of the European Union's production. Re-exports to Ukraine and Slovakia account for 1.1% of Poland's coffee imports. The vast majority of imported green coffee beans stay in Poland, which implies that Poland has a substantial and important industry potential in the coffee roasting market. About 80% of adult Poles consume coffee daily, and the annual consumption ranges between 0.7 kg and 2.5 kg per capita. Such quantities of coffee generate significant volumes of waste both during roasting and from brewing and consumption. It is estimated that processing of one ton of green coffee beans produces approximately 650 kg of spent coffee grounds (Campos-Vega et al., 2015; Tokimoto et al., 2005), which worldwide translates to over 6.5 megatons of waste annually.

The by-product of spent coffee grounds and potential uses thereof have been discussed by a number of authors. Spent coffee grounds were pelletised and combusted (Malaťák et al., 2020), torrefied (Jeníček et al., 2022), converted to biodiesel fuel, or used as a mineral-rich fertiliser. Less attention has been paid to husks, which constitute industrial waste generated at the stage of coffee roasting. Like spent coffee grounds, husks, which account for about 12% of coffee beans by weight, may be either burnt (Manrique et al., 2019) or pressure-agglomerated to produce pellets or briquettes (Felfli et al., 2011; Lubwama and Yiga, 2018). However, due to high moisture content and low bulk density, coffee husks need to be pre-processed and converted to denser fuels.

Seaenger et al. suggested that one of the factors contributing to the low utilisation of coffee husks, either raw or agglomerated, as a fuel, was lack of sufficient information on their combustion characteristics (Saenger et al., 2001). Although some studies in this regard can be found in the literature (Bekalo and Reinhardt, 2010; Saenger et al., 2001; Tadesse et al., 2023), the available data concern mainly biomass materials mixed with various coffee additives in order to improve durability and strength of solid fuels, while there have been few studies on the utilisation of pure biomaterials composed of coffee husks alone. Therefore, the authors undertook research on pellets produced from husks in one of roasteries in Poland. The aim of the present study was to determine the physical, mechanical and energy parameters of fuel in the form of coffee husk pellets and refer their characteristics to transport and storage properties.

MATERIALS AND METHODS

Both bulk coffee husks and the pelletised material were obtained directly from a coffee roasting and production facility in southern Poland. The study materials were examined for physical parameters (moisture content, bulk and unit density of pellets), mechanical characteristics (radial and axial compressive strength, modulus of elasticity and mechanical durability of pellets) and energy properties (ash content, elemental composition, oxygen content, gross and net calorific value).

The physical and mechanical characteristics of pellets were determined on days 3, 10, 17, 23, 52 and 78 after production, while energy properties were tested thirty days after production.

The measurement procedures, tools, equipment and accuracies applied were described by the authors in a number of their earlier studies (Gendek et al., 2023; Piętka et al., 2019; Aniszewska et al., 2020; Tamelová et al., 2021; Aniszewska et al., 2024). Furthermore, the procedures described in the standards ISO 18134-1:2022, ISO 18134-2:2017, ISO 18134-3:2015, ISO 17828:2015, ISO 17831-1:2015, ISO 18122:2022, ISO 16993:2016, ISO 1928:2010 and 18125:2017 as well as the general relationships mentioned in other scientific publications (Borowski, 2012; Lisowski et al., 2019b; Matkowski et al., 2020) were used in the study.

Statistical analyses were performed using Statistica v. 13 software (TIBCO, 2017). Basic statistics, analysis of variance (ANOVA), and post-hoc tests were conducted with the significance level of $\alpha = 0.05$. Differences between mean values were deemed significant at $p < 0.05$.

RESULTS AND DISCUSSION

The relative moisture content (MC) of the input material, that is coffee husks, evolved over time. *MC* was 26% at baseline. Next, it decreased to 11% between day 10 and day 23, and reached 8% on day 78 (cf. Fig. 1a). For the pelletised material, the relative moisture content was 38.6% at baseline, then decreased to 19.8% and 10.5% after 10 days and 17 days of storage, respectively. Subsequent storage of pellets resulted in a minor improvement in MC to 9.7% by day 23 and 7.5–7.8% by day 52 after production (cf. Fig. 1b). The latter value was similar to *MC* of husks.

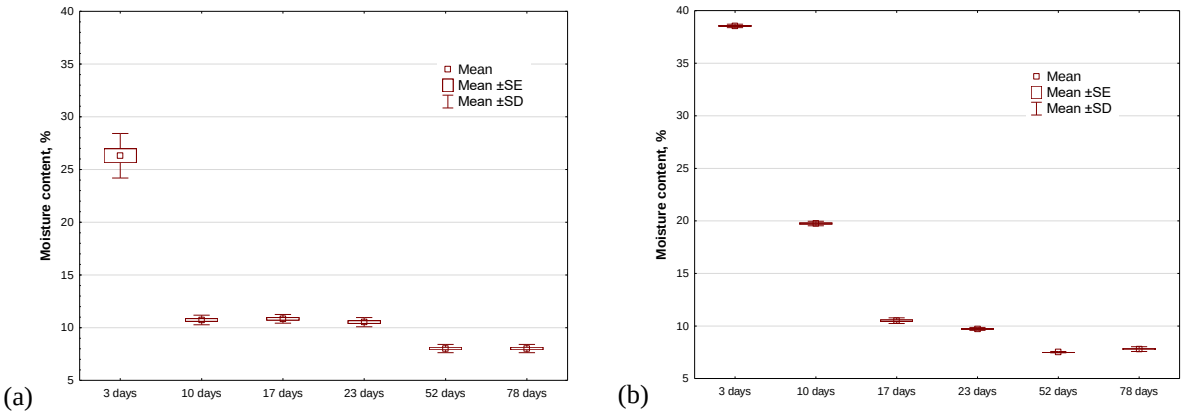

Fig. 1. Evolution of moisture content of husks (a) and pellets (b) during storage.

The pellets used in the study had the mean length of 9.83 mm and mean diameter of 10.02 mm. It was demonstrated that both unit and bulk density of pellets increased with falling moisture content during storage (cf. Fig. 2a). Dry bulk density (BD_{dry}) was 367.2 kg·m^{-3} three days after production, then increased to 497.3 kg·m^{-3} on days 52 and 78 of the study; while unit density of dry pellets (UD_{dry}) evolved between 678.6 kg·m^{-3} on day 3 and 874.6 kg·m^{-3} on day 52 after production. Unit density reported by Lisowski et al. was almost two-fold higher (1,149

kg·m^{-3}), but they studied pellets from ground coffee waste at moisture content of 6.2% (Lisowski et al., 2019a).

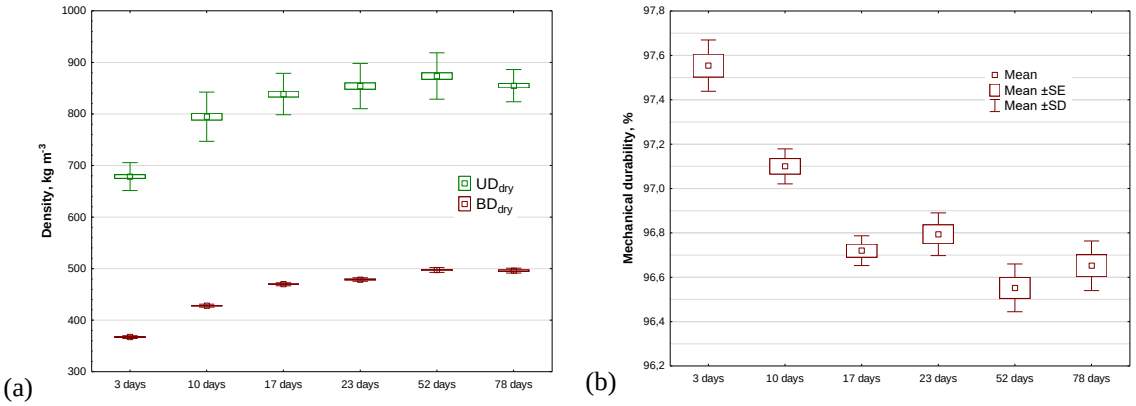

Fig. 2. Evolution of unit and bulk density of dry pellets (a) and mechanical durability of pellets (b) with reference to storage time.

The mean mechanical durability of pellets determined on subsequent measurement days ranged from 96.6 ± 0.1% to 97.6 ± 0.1% (cf. Fig. 2b). Overall, mechanical durability decreased by one percentage point throughout the study period, and statistical analysis confirmed that this parameter was influenced by the storage time, especially in the initial period (p<0.05). After day 17 of the study, subsequent storage did not significantly affected the durability of pellets. Furthermore, another relationship was demonstrated: a decrease in moisture content was accompanied by linear reduction in durability of pellets, which may be related to the chemical composition of coffee husks. Namely, a 10% decrease in moisture content resulted in a 0.3% decrease in durability.

Mechanical properties of pellets in the axial and radial direction were determined using a strength testing machine with force sensors (cf. Fig. 3).

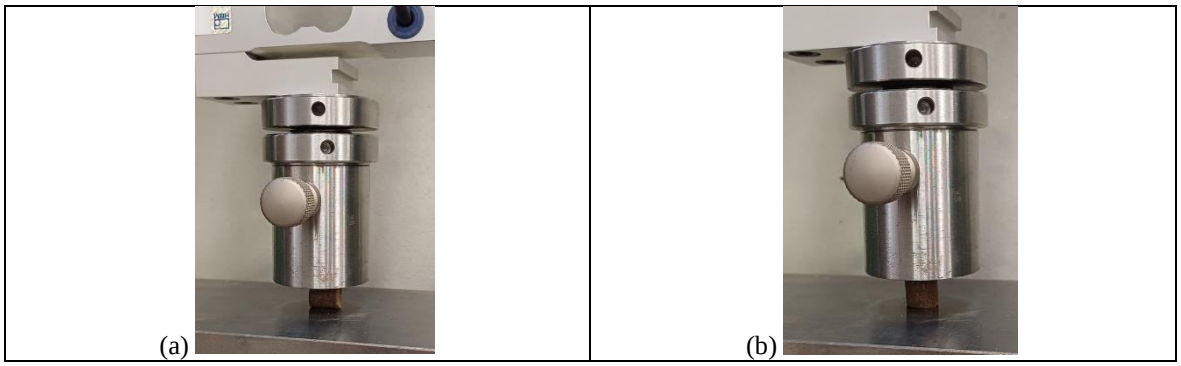

Fig. 3. Measurement of compressive strength of pellets, radial (a) and axial (b), in an Inspekt Table 100 strength testing machine with force sensors of up to 1kN (from Hegewald & Peschke).

The maximum compressive stress in the axial direction (σ_{ca}) ranged between 5.8 and 7.5 MPa, decreasing from day 10 of storage (cf. Table 1). On day 3, pellets softened sufficiently to enable the identification of the yield point on the stress-strain curve, which was found to be linear. The value of σ_{ca} peaked on day 10 after production, and ANOVA confirmed a statistically significant difference versus mean values on subsequent days (p<0.05). Between

day 17 and day 78, σ_{ca} slightly decreased (by 1.0 MPa), but ANOVA revealed no significant difference between the mean values (p>0.05). Consequently, it may be argued that storage time from day 17 to 78 did not materially affect the axial compressive strength of pellets. Nguyen et al. reported in their study that moisture content was an important factor affecting the compressive strength of pellets, as axial compressive stress increased with moisture content (Nguyen et al., 2015). In our study, an increase in moisture content of coffee husk pellets led to an increase in σ_{ca} from 5.8 to 7.5 MPa.

An upward trend in mean values of the modulus of elasticity in axial compression (E_c) was observed throughout storage of pellets (cf. Table 1). The lowest value of E_c (16.2 MPa) was recorded on day 10, and the difference versus values on subsequent measurement days was statistically significant (p<0,05). After three weeks from baseline, E_c oscillated between 28.2 and 32.6 MPa, reaching the peak value on day 52 after production of pellets. ANOVA confirmed no statistically significant differences in mean values in this period (p>0.05). Overall, it was determined that modulus of elasticity decreased with growing moisture content of pellets.

In the study, specific energy required to destroy pellets in the axial direction (E_{sa}) decreased with storage time (cf. Table 1). From day 10, E_{sa} fell from 15.6 to 7.0 mJ×mm^{-2}. The mean value peaked on day 10 after production and, together with the mean value on day 17 of the study, differed significantly from the values on subsequent days (p<0.05). Contrary to E_c, specific energy of axial compression decreased throughout the storage period with a decrease in moisture content of pellets.

The maximum compressive stress in the radial direction (σ_{cr}) ranged between 0.4 and 2.7 MPa (cf. Table 1), increasing on subsequent measurement days with falling moisture content of pellets. The lowest value of σ_{cr} was recorded on day 3, while the highest value was observed on day 52 after production. The mean values of σ_{cr} on day 3 and day 10 differed significantly from values on all other days (p<0.05). From day 17 day of storage, ANOVA did not reveal any significant differences between the mean values of σ_{cr} (p>0.05). Based on these results, it can be concluded that the radial compressive strength of pellets stabilised and remained almost constant between days 17 and 78 of storage. Pellets of the lowest moisture content had the highest radial compressive strength.

Table 1. Mechanical properties of coffee husk pellets during storage, with changes in moisture content

Day	σ_{ca} MPa	σ_{cr} MPa	E_c MPa	E_r MPa	E_{sa} mJ×mm^{-2}	E_{sr} mJ×mm^{-2}
3	-	0.4 ±0.1	-	5.4 ±1.6	-	0.4 ±0.1
10	7.5 ±2.7	1.4 ±0.5	16.2 ±5.0	26.5 ±10.3	15.6 ±7.4	0.9 ±0.4
17	6.8 ±2.2	2.4 ±0.6	24.9 ±10.1	62.5 ±16.8	10.1 ±4.4	0.8 ±0.3
23	6.2 ±2.5	2.5 ±0.8	28.8 ±14.5	61.4 ±17.3	8.1 ±4.0	0.8 ±0.3
52	6.0 ±2.3	2.7 ±0.7	32.6 ±18.1	67.6 ±18.3	7.1 ±3.6	0.8 ±0.3
78	5.8 ±1.9	2.4 ±0.8	28.2 ±13.0	57.8 ±18.4	7.0 ±3.2	0.8 ±0.3

The modulus of elasticity in radial compression (E_r) had the mean value of 5.4 MPa in the initial period of storage of pellets (cf. Table 1). Then, it increased almost five-fold from the initial value (to 26.5 MPa) after 10 days and almost twelve-fold (to 62.5 MPa) after 17 days of storage. From day 17 after production, the mean value of E_r stabilised between 57.8 and 67.6 MPa. These changes may be attributed to loss of moisture and strengthened intermolecular bonds, which result in increased hardness of pellets.

Finally, specific energy required to destroy pellets by axial compression (E_{sr}) reached the lowest value of 0.4 mJ·mm^{-2} on day 3 after production. On day 10, E_{sr} more than doubled; then, it stabilised at 0.8–0.9 mJ·mm^{-2}. Based on ANOVA (p>0.05), it may be concluded that the storage time of more than 10 days did not affect E_{sr} in the period covered by the study. Specific energy remained almost constant and did not evolve significantly with changes in moisture content.

The statistical analyses of energy parameters did not reveal any significant differences between the mean values for husks (as the raw material for pellet production) and pellets (as the end product). The results were characterised by small standard deviations, which indicates the homogeneity of the study material. Sulphur content was not considered in the analysis, because the results of less than 0.02% were within the range of the measurement error of the test equipment. Ash content averaged 6.6% and was two- or even three-fold higher then reported by Manrique et al. or Tadesse et al. in their studies (Manrique et al., 2019; Tadesse et al., 2023). Carbon content (48.38%) was within the range reported by other researchers. Hydrogen content of coffee husk pellets (5.9%) was similar to that reported by Marrugo et al. (Marrugo et al., 2019), while nitrogen content (2.9%) was two-fold higher than reported by Saenger et al. (Saenger et al., 2001). Finally, oxygen content (36.2%) was lower than reported by other authors and similar to that of rice husks.

As reported by various authors in their studies, net calorific value (NCV) of coffee husks ranges 15–18.5 MJ·kg^{-1}. Felfli et al. determined this NCV at 18.5 MJ·kg^{-1} (Felfli et al., 2011), Tadesse et al. reported 18.23 MJ·kg^{-1} (Tadesse et al., 2023), and a study by Marrugo et al. indicated that NCV of coffee husks was 15 MJ·kg^{-1} (Marrugo et al., 2019). The gross calorific value of coffee husks measured in the study was 19.8 MJ×kg^{-1}, while the computed net calorific value on a dry basis was 18.6 MJ·kg^{-1}. Thus, it is a similar figure to those reported in the literature. The obtained net calorific value may be compared to the values determined for pellets and briquettes produced from other plants. With NCV of 18.6 MJ·kg^{-1}, coffee husk pellets are suitable for energy generation and combustion in boilers.

CONCLUSION

The aim of the present study was to determine the changes of the physico-mechanical and energy parameters of pellets produced from coffee husks (as industrial waste from coffee roasting) during short-term storage with evolving moisture content of the product.

It was determined that changes in moisture content, more intensive in the initial period after production, affected the physical and mechanical properties of pellets. Both unit and bulk density of pellets increased over time, while intermolecular bonds became stronger rendering pellets harder and more resistant to external factors. Solid radial compressive strength (≥1.4 MPa) was achieved by pellets already on day 10, while moisture content of <10% and mechanical durability of ≥96.7% were achieved on day 17 after production. The above-mentioned characteristics indicate that about two weeks after production, coffee husk pellets can be transported and stored in typical household conditions without compromising their physical or mechanical properties.

The net calorific value of coffee husk pellets assayed at 18.57 $MJ \cdot kg^{-1}$, mainly due to low carbon content in the elementary composition, is slightly lower than NCV of dried coffee grounds, but can be deemed sufficient for combustion of this type of pellets in boilers.

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RESEARCH ON INCREASING THE EFFICIENCY OF ALUMINUM WASTE PROCESSING THROUGH SMART INDUSTRY METHODS

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ABSTRACT

Smart Industry (Industry 4.0) brings the requirement for comprehensive digitalization of business processes, which must respond all manufacturers who want to keep pace with modern practices. The topic of the article is the proposal to increase the efficiency of production processes through Smart Industry methods. The research was conducted in a company engaged in the processing of aluminium waste, on a separation line for aluminium granules. After an initial analysis of the line, a simulation model reflecting all the equipment and procedures involved in the sorting process was created based on real data. The simulation model was created using Siemens Tecnomatix Plant Simulation software. To better illustrate the processes, statistical charts of the efficiency of the sorting line equipment were created. In the next step, a structural modification was proposed in the simulation model of the original line, with the assumption of increasing the capacity of the vibrating sorter. After evaluating the statistics from the upgraded line model, an 8% increase in production volume was found. The research carried out with the help of creating simulation models and testing the simulation results on a real and upgraded model represents one of the approaches to digitalizing production processes in the context of Smart Industry. The subject of further research will be the creation of a digital twin of the analysed line, which will create a real information link between the real devices – components of the separation line and its simulation model, with the aim of monitoring and subsequently managing it.

Key words: Simulation model, Separation line, Aluminium waste, Efficiency of production processes

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PYROLYSIS OF WASTE SLUDGE FROM THE AUTOMOTIVE INDUSTRY

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ABSTRACT

The possibilities of energy recovery of waste sludge by pyrolysis process were solved for the area of waste sludge from the automotive industry, specifically for the area of car body production. In general, this sludge is classified as hazardous waste, mainly due to their chemical composition, and this determines the methods and possibilities for their subsequent handling and disposal. In order to carry out the research, the sludge samples were taken directly at the place of their origin, in the Volkswagen Bratislava. Samples were subjected to initial analysis, during which they were evaluated: moisture content, calorific value and chemical composition. When evaluating the chemical composition, the contents of chemical compounds and individual chemical elements were evaluated. Chemical analysis pointed out, for example, the content of heavy metals in the samples, which causes complications in conventional energy recovery, for example by incineration. The results pointed to the suitability or unsuitability of sludge samples for further energy recovery through the pyrolysis process. The two most perspective samples with the highest calorific value were used in the laboratory experimental pyrolysis, resulting in the obtaining of synthesis gas, condensate and solid residue. The condensate, which should have the highest energy potential, contained pyrolysis oil, but it was contaminated with condensed moisture from the sample and other leached substances. By subsequent separation of the pyrolysis oil, the proportions of the pyrolysis processing products were evaluated. Analysis of the calorific value of the obtained pyrolysis oils confirmed the assumption of a significant energy content of these samples. Chemical analysis of the solid residue confirmed that heavy metals and other hazardous substances from the original sample remained in the solid residue and were not released into other pyrolysis products.

Key words: pyrolysis, waste sludge, pyrolysis oil, waste to energy

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USE OF WASTE HEAT TO INCREASE THE EFFICIENCY OF THE HEAT SOURCE

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ABSTRACT

The biggest heat loss during the energy recovery of fuels in heat sources is the loss due to the sensible heat of flue gases. This is waste heat removed in the flue gas, which reduces the efficiency of the heat source by 20-40%. Solutions to problems with increasing the efficiency of heat sources bring energy savings to the operator, reducing emissions and saving energy sources, which ultimately has an impact on less waste generation. The standard way to increase the efficiency of heat sources is to preheat the primary air by electric heating or by applying a heat exchanger to the flue gas pipe with a controlled circulation of the heat carrier, which results in an increase in energy consumption and an increase in energy costs. This article deals with the application of a gravity loop heat pipe in a fireplace insert, which uses the waste heat of the flue gas to preheat the primary combustion air. The result of such an application is a simultaneous increase in the temperature of the supplied air and a decrease in the chimney temperature, which results in an increase in the efficiency of the heat source without the use of additional energy. According to the obtained results, such a solution can increase the efficiency of the heat source by 2 to 10% and contribute to the reduction of waste generation during the energy recovery of fuels.

Key words: waste reduction, heat recovery, increasing efficiency sustainability, emission reduction, heat source.

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THERMAL CHARACTERIZATION OF PARTICLEBOARD FOR GREEN ENERGY PRACTICES

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ABSTRACT

In the era of rising global temperatures, there is the need to develop innovative and sustainable building materials with energy-efficient thermophysical properties to reduce the energy consumption in household buildings and industries. The investigation contributes to this initiative by examining the thermal behavior of particleboard panels made of orange and oak in a percentage ratio of 80% and 20%, respectively bonded with urea-formaldehyde. The study successfully utilized non – stationary, Transient Plance Source (TPS) technique under room conditions. Recording the thermal response from the sensor, thermal conductivity (λ), and thermal diffusivity (κ) were derived in both axial and radial direction of measurement using high density particleboard (HDPB) – medium density particleboard (MDPB) samples. The relative percent change in thermal conductivity (λ) was 0.89%, and thermal diffusivity (κ) 0.908% in radial direction between MDPB, HDPB. The obtained data was perhaps considered to be less sensitive to the density change across the radial direction for the particleboards. Whereas, in the axial direction, the percent difference in thermal conductivity was 3.11 % and thermal diffusivity was 3.184%. Unlike the structure of HD and MD particleboards in axial directions shows a significant influence of heat transfer phenomena exhibiting anisotropic behavior. These results highlight the anisotropic nature of the particleboard and allow wood designers and researcher to develop the heat transfer models for better results of thermophysical analysis and better energy-efficient design with negative carbon footprint for certain types of particleboards.

Key words: Sustainable building practices, Thermophysical properties, non-stationary techniques, Anisotropic characteristic, density

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TECHNICAL DESIGN FOR THE USE OF RECYCLED MATERIAL FROM THE AUTOMOTIVE INDUSTRY IN THE PRODUCTION OF SINGLE-LAYER PARTICLEBOARDS

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ABSTRACT

The paper's goal is to develop a method that will enable recycled rubber or plastic material from used automobile parts, such as tires, carpets, hoses, cuffs, bumpers, fuel tanks, lights, or covers, to be used in the particleboard manufacturing process. A conveyor will be used to apply recycled material in the form of granulates to the particleboard production process as part of the technology's design. Two kinds of conveyors that are appropriate for moving bulk materials are covered in this study. Technical designs of screw and spiral conveyor were made using the Creo Parametric application. The required parameters of each conveyor were resolved inside the design. The required performance, the amount of recycled granulate per particleboard based on weight ratio, the diameter of the screw/spiral and the necessary engine power were estimated. It makes sense from the perspective that the spiral lacks a central shaft across from the screw when calculations revealed that the required spiral diameter for each performance is lower and the engine power is higher. Ultimately, a Visio program was used to create a schematic of the technological process, which is divided into four primary phases for the production of particleboards. The first part is the preparation of each material. The second part is material mixing and forming the mat. The third part is composite pressing and the fourth part is the final processing of the composite.

Key words: screw conveyor, spiral conveyor, recycled material, composite, technology

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

COMPREHENSIVE MODEL FOR ASSESSING ECONOMIC DEMANDS IN THE PRODUCTION OF INNOVATIVE PRODUCTS BASED ON CIRCULAR ECONOMY PRINCIPLES

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ABSTRACT

The transition from a linear to a circular economy is crucial for achieving sustainable development, maximizing resource efficiency, protecting the environment, and fostering innovation and economic growth. This paper focuses on designing a comprehensive model for assessing the economic demands of producing an innovative wood-plastic product from recycled materials, in line with circular economy principles. The subject of the study is a three-layer wood-plastic board with added plastic, whose prototype was created in the laboratory conditions of the Technical University in Zvolen. Empirical research has shown that the use of waste wood and plastic is an effective way to recycle materials into an innovative product. The results present the concept of an investment project aimed at expanding production this product, including a methodology for evaluating its efficiency using dynamic methods such as net present value, internal rate of return, profitability index, and discounted payback period. Traditional and alternative pricing methodologies for the innovative product without VAT were compared with the price of the basic product. The application of traditional markup calculation showed a material cost saving of €3.99/m³, representing more than a 5% saving, when using 10% plastic granulate in the middle layer. Increasing the proportion of plastic is expected to further increase cost savings. The work also proposes and verifies an alternative calculation using machine hour rates, which more accurately allocates overhead costs to the product price. The proposed model partially utilizes software support created in the MS Excel platform, allowing for flexible application when changing input conditions.

Key words: circular economy; economic demands; recycling, investvent project

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

AN ENVIRONMENTAL PERSPECTIVE OF THE USE OF WASTE FROM THE AUTOMOTIVE INDUSTRY IN CHIPBOARDS

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ABSTRACT

Plastic waste from the automotive industry has found use as part of the material composition of chipboards. The article is aimed at assessing the impact of three-layer chipboards made with granules from waste tires, gaskets and carpets, painted and unpainted bumpers, non-flammable and combustible cables, graphite, or waste from fuel tanks. The impact on the aquatic and terrestrial environment was evaluated using bioassays with the test organisms *Lemna minor, Sinapis alba, Daphnia magna* and *Allium cepa*. A chipboard without waste was used as a control sample. The values of pH and COD (chemical oxygen consumption) were determined as the sum of organic substances leached into the water. From the results, we can conclude that water extracts from chipboards containing waste compared to the control sample had a smaller inhibitory effect on the test organisms, but it is necessary to define and specify the appropriate types of waste for their use in terms of their effects on the environment.

Key words*:* aquatic environment, plastics, automotive industry, waste, chipboards, bioassays

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

FIRE PROPERTIES OF PARTICLEBOARDS CONTAINING PLASTIC FILLER

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ABSTRACT

Particleboards (PBs) are widely used mainly in the construction industry. Currently, a significant trend is the modification of building materials through the incorporation of waste, or recycled plastic-based materials. PBs modified by adding 10% recycled plastic (fuel tanks, painted bumpers and unpainted bumpers) was evaluated in terms of change in flammability, through the flame ignition temperature (FIT) in accordance with STN ISO 871. Based on the results, the ignition temperature was 325.15 °C for particleboard without plastic filler (PB), 326.39 °C for PBs with an admixture of 10% painted bumpers (PB10), 327.35 °C for a PBS with an admixture of 10% fuel tanks (FT10) and 327.55 °C for PBs with an admixture of 10% unpainted bumpers (UB10). The average time to reach the ignition temperature ranged from 521.4 s to 567.4 s. Considering the differences in determining the ignition temperature (2.4 °C), it can be assumed that by adding 10% of selected recycled plastics from the automotive industry to the structure of PBs, it is possible to assume their comparable fire properties.

Key words: flame ignition temperature, automobile plastics, time to ignition, wooden composites

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REFERENCE

STN ISO 871. Plastics. Determination of ignition temperature using a hot-air oven, 2010.

XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

ALTERNATIVE METHODS OF QUANTIFICATION OF POROSITY OF PARTICLEBOARDS BY OPTICAL METHOD

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ABSTRACT

In the system of evaluating the density of particleboards as a physical property of wood, porosity plays a significant role. Its quantification helps to gain a deeper understanding of the processes in the production of boards as well as related technological operations. From the point of view of wood science, there are several methods by which porosity is evaluated. An alternative method may be the use of an optical digital microscope with the ability to accurately measure the volume of pores in individual parts of a three-layer particleboard with plastic and rubber waste. In addition to measuring the volume of pores, the microscope also has the possibility of surface roughness measurement (especially areal surface texture parameters). With the parameters Sa and Sz, it is then possible to analyze the depressions (dales) at the edge of the samples, which represent the analyzed porosity inside the sample. Manipulated samples from selected types of three-layer particleboards were scanned and measured in individual parts. The experiment revealed different values of pore volume in the scans performed, which were defined by surface roughness parameters. This confirmed the changing porosity despite the same pressing conditions. The lowest values of the selected parameters were found in the FT10 and PB samples, in which the highest density was also determined by density measurement. On the other side, samples whose Sa and Sz parameters were higher in the monitored layers also had a lower density (SC10G10, T10, T10G10). The measurements show that there is a correlation between the method of pore quantification by optical methods and the measured density of the samples. The alternative methodology used can thus quickly and directly obtain digital information from the examined surface, which brings results not only for scientific activities, but also for retrospective control of technological parameters of pressing and individual production operations in the production of three-layer boards with plastic and rubber waste.

Key words: wood-plastic composites, porosity, digital microscope, volume measuring, gaps

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

DESIGN SOLUTION OF THE CUTTING MECHANISM OF THE PLASTIC CRUSHER

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ABSTRACT

Material recycling is a long-term end-of-life management concept with significant economic and environmental benefits. Plastics generally offer a high strength-to-weight ratio, relatively low production costs, and high selectivity of material properties, making them advantageous in many applications compared to metal, glass, and paper. This contribution presents a design solution for a cutting mechanism with four carbon steel knives with known physical and mechanical properties. Based on the strength of the selected plastics, the cutting force acting on the tool of the plastic shredder's cutting mechanism was calculated. The cutting force is necessary for other parameters that are necessary for the design and construction of the given device, such as power, which is directly related to the choice of a suitable electric motor. The cutting mechanism is modeled in the Creo Parametric program. The shaft analysis was processed using Creo simulate.

Key words: shredder of plastics, cutting force, cutting mechanism

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

A MEASURING STATION TO DETERMINE THE SUITABILITY FOR STORAGE AND TRANSPORT OF BULK BIOFUELS

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ABSTRACT

A measuring station for determining the suitability for storage and transport of bulk biofuels was built and launched. Torque measurement is performed in a cylindrical chamber with a rotor inside. There are blades on the inside walls in the lower part of the tank. After pouring and pneumatic compaction of the biofuel sample, the rotor rotates. Torque at the moment of shearing is a parameter describing the strength of the sample. The material sample is loaded with a rubber bellows, through a yoke and a cover. The measurement of the actual height of the bed, necessary to determine the density, is defined as laser sensors. The mass is determined using force transducers between the stator and the cylindrical tank of the apparatus. Shearing torque measurements were performed for 4 values of the rotor rotational speed in the tank: 3, 6, 9, 13 rpm and four consolidation lines simulating the height of the loose biomass column in the tank: 5, 10, 20 and 30 kPa. The experiments were carried out on a wide range of loose biomass and, for comparison, on model materials. The test results were compared with those obtained in the rotating ring and direct shear apparatus.

XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

THE POSSIBILITIES OF WASTE WOOD UTILIZATION

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ABSTRACT

The life cycle of wood can be effectively extended by secondary processing of used wood products to produce materials for the construction and furniture industries. The chemical composition of waste wood is crucial for recycling options. Contamination of wood waste by coating and impregnating substances or adhesives limits the possibilities for recycling. From this point of view, recycling of thermally modified or steamed wood is advantageous. Research is currently focusing not only on the changes in wood constituents and properties induced by the treatment conditions, but also on the monitoring of these changes after the subsequent ageing of the modified materials. During the modification of wood by the above methods, mainly hemicelluloses are degraded, both lignin degradation and condensation reactions occur, the lignin content increases, some groups of extractives are degraded, and at the same time degradation products of the main wood components are formed. The intensity of mentioned changes depends on the type and properties of the wood, as well as on the technological conditions of treatment (temperature, duration, atmosphere). The literature reports an improvement in moisture properties and biological resistance to certain forms of rot, but also a degradation in the mechanical properties of particleboards with added thermally modified wood particles compared to particleboards produced without their addition. Currently, there is a growing interest in the study of innovative ways of using waste wood in the construction process.

Key words: waste wood, thermally modified wood, recycling, particleboards

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

UTILIZATION OF AUTOMOTIVE TEXTILE AS THERMAL INSULATION MATERIAL

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ABSTRACT

In today's dynamic automotive industry, there is an increasing emphasis on innovation and technological advancements aimed at improving vehicle energy efficiency and sustainability. One of the key factors influencing these aspects is the thermal insulation of materials, which plays a crucial role not only in ensuring passenger comfort but also in minimizing fuel consumption and greenhouse gas emissions. The aim of this paper is to explore and analyze the thermal insulation properties of various materials used in automobiles and their impact on energy efficiency, driving comfort, and sustainability. The paper focuses on both traditional thermal insulation materials and innovative materials such as advanced textile materials, which open new possibilities in the field of vehicle thermal insulation as well as other products. In addition to the theoretical perspective on thermal insulation, the authors will also engage in experimental activities, measuring and evaluating the thermal insulation properties of materials and exploring potential applications in real-world conditions. The goal of this paper is to provide a comprehensive overview of the issue of thermal insulation in automobiles and identify potential innovations and improvements that could lead to better results in the areas of energy efficiency and sustainability. This topic is highly relevant in the context of the development of electromobility and the European Union's priorities in this area.

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

NEW WOOD-PLASTIC COMPOSITES: MECHANICAL PROPERTIES

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ABSTRACT

In this paper, three-layer particleboards (PBs) with 10% of recycled plastic granulate from automotive parts (fuel tanks (FT10), painted (PB10) and unpainted bumpers (UB10)) in the middle layer of the particleboards and a reference particleboard without added plastic filler (PB) were produced. Bending strength of these wood-plastic composites was determined according to STN EN 310 (1998) and the tensile strength according to STN EN 319 (1995) standard. The average MOE (Modulus of Elasticity) was 2203.88 MPa for FT10, 2088.01 MPa for PB10, 2056.28 MPa for UB10 and 2239.91 MPa for PB. The statistical evaluation for MOE showed that the differences between PBs with different plastics and the reference group are not statistically significant, and the results show that the PBs met the requirements of STN EN 312 (2011), where the minimum and standard value for MOE is 1,600 MPa. The tensile strength perpendicular to the plate plane was 0.42 MPa for FT10, 0.40 MPa for PB10, 0.49 MPa for UB10 and 0.52 MPa for PB. Statistically significant differences were observed when comparing the reference (PB) with the FT10 and PB10 groups, however, the minimum value of the tensile strength perpendicular to the board plane is set at 0.35 MPa for (PB) with a thickness of 18 mm in the STN EN 312 (2011) standard, which was for all tested samples.

Key words: three-layer particleboards, plastics recycling, painted bumpers, unpainted bumpers, fuel tanks, mechanical properties

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

THE EFFECT OF VARIOUS ADMIXTURES ON THE SOUND ABSORPTION COEFFICIENT OF PARTICLEBOARDS

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ABSTRACT

The automotive industry produces a large amount of waste from the textile parts used in the interiors of cars. At present, this waste can be reused after recycling. Our research is focused on investigating the acoustic (but also other) properties of materials that include waste products from the automobile industry. The properties of textile materials have been investigated in the most detail so far. The input material consisted of certified synthetic textiles used in the production of textile components in the automotive industry. The material may also include fibers made from recycled tires. The recycled automotive technical textiles have a high sound absorption ability. The sound absorption above the frequency of 500 Hz is maximum in a wide range of frequencies. According to noise reduction coefficient (NRC = 0.45 - 0.8) this material can be rated as C and D sound absorption classes.

In the second phase of testing, the chips from fresh spruce were prepared. The mixture of waste rubber (carpets, isolators) and the mixture of waste tires were used as an additive. Our results showed that the admixture of rubber in particleboards increases of a sound absorption. The NRC ranges from 0.2 to 0.3. The improvement in sound insulation properties is more significant with increasing rubber content (ranging from 10 to 20%). After adding waste tires to the particleboard, there is again a slight increase in sound absorption coefficient (SAC). In this case, the content of waste tires (in the range of 10 to 20%) has no significant effect on the SAC values. The NRC value was in all cases 0.25.

Key words*:* Noise reduction coefficient, Sound absorption coefficient, waste from the automotive industry, particle board, recycled textiles

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

UTILIZATION OF BIOMASS FROM WOOD PROCESSING INDUSTRY FOR CHEMICAL APPLICATIONS

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ABSTRACT

European forests, which cover approximately 1,040 million hectares, are crucial sources of renewable biomass. In the Slovak Republic, where forests constitute 41.3% of the land area, broadleaf forests dominate; however, the processing of coniferous wood, particularly spruce (*Picea abies*), is highly prevalent. Spruce wood is extensively used in the paper and construction industries due to its rapid growth and increased wood mass production. This study aims to extract phenolic compounds from spruce bark, a by-product of the wood industry, using supercritical CO_2 extraction—a method known for its environmental safety and efficiency. The bark was manually collected, air-dried, and ground to a fraction size of 1-1.5 mm. To enhance the extraction of phenolic compounds, ethanol and ethyl acetate (1:1) were used as cosolvents. A designed experiment optimized the extraction conditions, varying temperatures from 40°C to 140°C and pressures from 80 to 480 bars. The results indicate that temperature has a significant impact on the extraction yield, with an inverse relationship observed. The optimal extraction conditions were identified at a temperature of 47.7°C and a pressure of 80 bars, achieving the highest yield. Future work will involve analyzing the extracts using gas chromatography-mass spectrometry (GC-MS), assessing antioxidant activity via the DPPH method, and determining the total phenolic content (TPC) using the Folin-Ciocalteu method. This research highlights the untapped potential of spruce bark as a sustainable source of bioactive phenolic compounds with valuable applications in the pharmaceutical, cosmetic, and food industries.

Key words: bark, extraction, phenolic compounds, supercritical extraction, industry utilization

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

EFFECT OF PRECIPITATION CONDITIONS ON LIGNIN PROPERTIES AND ITS APPLICATION IN ACRYLONITRILE BUTADIENE RUBBER COMPOSITES

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ABSTRACT

The transition from petroleum-based materials to renewable sources is essential due to climate change. Lignin, a complex aromatic polymer derived from lignocellulosic biomass, offers a promising alternative. This study focuses on optimizing lignin recovery from black liquor using the LignoBoost™ process and evaluating its application in acrylonitrile butadiene rubber (NBR). The optimized conditions (80 °C, pH 2.0) yielded lignin with significantly lower phenolic hydroxyl group concentrations compared to DOE lignins. Surface property analysis revealed a high surface free energy of 55.3 mJ/m², indicating potential for interaction with various substances. The study employed a design of experiment (DOE) approach to investigate the influence of precipitation conditions on lignin properties. NIR spectroscopy and surface property measurements were used for lignin characterization. The results demonstrated that the preparation method significantly affects hydroxyl group concentrations, influenced by factors such as black liquor freshness and filtration temperature. Notably, the application of pilot lignin in NBR composites resulted in a more than twofold increase in tensile strength and elongation at break compared to NBR without additives or with commercial lignin. These findings suggest that lignin recovered through optimized processes can enhance the mechanical properties of NBR, offering a sustainable alternative to traditional additives. This research provides valuable insights for further exploration of lignin's potential in industrial applications, particularly in the context of lignin recovery and utilization in pulp mills.

Key words: Lignin recovery; Acrylonitrile butadiene rubber (NBR); Design of experiment (DOE); Kraft lignin; Renewable resources

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

PROCESSING OF GASTRO-WASTE FOR THE PRODUCTION OF BIOMASS FOR ENERGY USE IN BIOMASS BOILER PLANTS

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Now disposal with biologically degradable waste presents one of the most severe problems in waste management. This situation is given partly because of the lagislation, which is getting constantly harder in this sphere and partly because of changing ways citizens live in their style of life. Arguments shown above essential impact on constantly increasing content of biologically degradable waste, which is need to disposal according to the legislative. The most of this waste is bound to material or energy usage. The waste contains plant nutrients and an organic matter, which can be stabilized and profitably returned back to the natural cycle as an organic fertilizer – compost.

XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

THERMAL STABILITY AND APPLICATION POTENTIAL OF WASTE MATERIALS FROM THE AUTOMOTIVE INDUSTRY FOR USE IN WOOD-BASED COMPOSITES

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ABSTRACT

In this work, initial analyses were carried out to evaluate the thermal stability of various materials intended for the production of wood composites. Materials tested included particleboard, plastic bumpers, cables, tyres, graphite composites and other components. Thermogravimetric analysis (TGA) was used to determine key thermal parameters, such as onset temperatures of decomposition, rate of decomposition, and total weight loss in different atmospheres (N_2, air). The results of the analysis suggest that by proper combination of materials, the thermal stability and mechanical properties of wood composites can be improved. These composites have a wide range of applications in the construction, automotive, energy, furniture and packaging industries. The research results represent a contribution to the development of sustainable and durable materials suitable for applications requiring high thermal and mechanical resistance.

Key words: thermal analysis, stability, composites, decomposition

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

RESEARCH OF TECHNOLOGY FOR PRODUCTION OF SHAPED PARTS FROM RECYCLED POLYURETHANE FOAM

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ABSTRACT

Waste polyurethane (PUR) foams represent a significant problem in waste management. Attention is drawn to this waste of large volume and low density mainly because of the rapidly increasing amounts and simultaneously tightening legal regulations. Paper is devoted in detail to the material recovery technology of waste polyurethane foams. The aim of the research is the mechanical recycling of this waste into the form of shaped parts by dry molding under pressure with or without a binder. The experiments carried out examine the influence of individual technological parameters, such as pressing pressure, temperature, heating time and bonding additive, on the resulting quality of shaped parts. The achieved results demonstrated the possibilities and conditions of the technology for the production of shaped parts without the addition of a binder, as well as an increase in quality properties with a binder. The investigated technology can be successfully produced parts from 100% recycled PUR foam for the automotive industry, the construction industry, or as acoustic and thermal insulation of pipe systems and air conditioning.

Key words: polyurethane foam, recycling, PUR, shaped parts

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

DESIGN OF MOBILE TECHNOLOGY FOR THE TREATMENT OF WASTE BIOMASS

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ABSTRACT

Currently, almost exclusively wood is used for the production of fuel pellets. However, limited sources of wood raw material prevent the development of the production of solid biofuels as a renewable energy source. The cost of transporting this raw material to the place of treatment is also a limiting factor for biofuel production. The presented design of mobile technology is based precisely on the effective treatment of new, so far unused sources of raw materials from various types and forms of biomass and organic waste, which are suitable for energy recovery in the form of biofuel. The paper deals in detail with the design of mobile and modular technology line suitable for different biomass sources, like materials in bales, bulk materials and piece materials. This original line enables size reduction and homogenization of the raw material before densification directly at the place of its origin, what significantly reduces the cost of transporting raw materials. It will make it possible to treat locally smaller quantities of different raw materials that are not efficient to transport to a large producer.

Key words: biomass, biomass treatment, mobile technology

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

ANALYTICAL DETERMINATION OF TOOL SURFACE TREATMENT FOR RECYCLING A GLASS

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ABSTRACT

Currently, laminated glass is used, e.g. in the automotive, construction and other industries. In cars it is all glass, in the construction industry it is basically safety glass used for various stair railings, window production and other decorative elements. The requirement for such glass is sufficient resistance against mechanical damage and adverse weather conditions. Glass recycling is of great importance from an ecological, energy, and technical point of view, as glass can represent an important secondary raw material. The present contribution is focused on the analytical determination of a suitable surface treatment of the wiper plate for a specific application of wiping bonded foil glass. In order to set up the analytical tests appropriately, it was also necessary to forge a series of theoretical analyses that form a solid foundation for laying a suitably chosen experimental investigation. The main part of the presented article consists of theoretical analyses. The result of the analyses is the determination of the appropriate surface treatment of the plates. In the next phase of the research, we will focus on experimental investigation in a real experiment.

Key words: bonded glass, wear, wiper plate, electro-plasma surface treatment, cutting material

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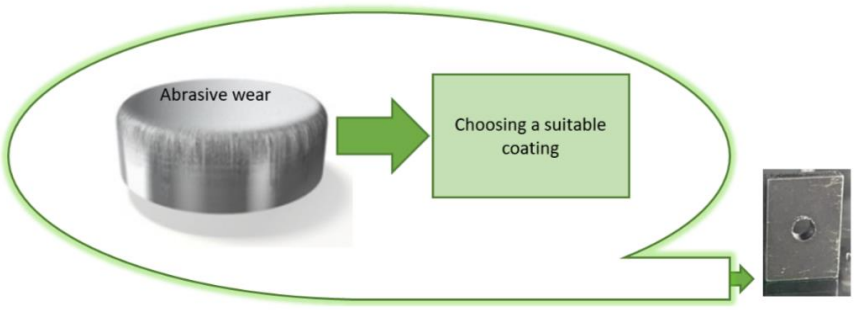

XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

ANALYSIS OF THE POSSIBILITIES OF DECOMPOSITION OF PHOTOVOLTAIC CELL FRAMES

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ABSTRACT

An important operation in the recycling process of solid photovoltaic panels is the dismantling of metal frames. Frames are usually made of aluminum alloy profiles (Table. 1). In order to effectively recycle photovoltaic panels, it is necessary to remove components that could contaminate the process of further recycling steps. The main challenge of new recycling processes is to maximize the degree of silicon recovery. At the end of the day, you need to get silicon that will not be contaminated with other chemical elements. As part of the analysis, available information on solutions protected as intellectual property was collected (Fig.1). Information was collected from available websites of machine manufacturers and recycling companies as well as databases of scientific articles. For us, a qualified analysis of the available technical solutions is the basis of the search for improved or new construction concepts that can be applied in a wider cross-section of solved research tasks at STU.

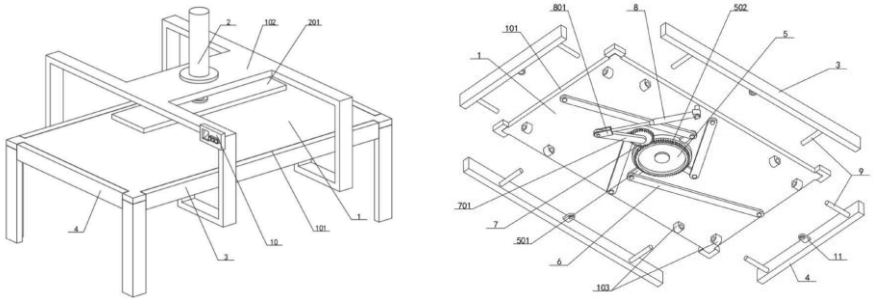

Fig. 1: Aluminum alloy frame dismantling device for recycling retired photovoltaic module, CN218874354U

Key words: decomposition, frames, photovoltaic cell

ACKNOWLEDGEMENT:

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

POSSIBILITIES OF THERMAL PROCESSING OF PHOTOVOLTAIC PANELS

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ABSTRACT

The issue of recycling photovoltaic (PV) panels after their lifespan or period of effective use has expired is a highly topical subject, addressed within several European-scale projects. There are currently various methods and technologies employed for recycling PV panels, utilizing different physical principles. These methods include both those already implemented in real-world operations and those still being tested under laboratory conditions or in experimental trials. Essentially, three fundamental principles are applied in the recycling process: mechanical, chemical, and thermal methods. In many cases, all three methods are combined to achieve the highest possible recycling rate and maximize the recovery of various valuable materials contained within the panels.

This article focuses on presenting potential methods for thermal processing of PV panels in the context of their recycling. It discusses different process combinations, with at least one method involving thermal treatment. The primary goal of PV panel recycling in this study is the recovery of silicon, which can be further processed and reused, for instance, in the electronics industry. Other material components recovered during the recycling process include aluminum, glass, copper, and others. The information provided in this article aims to support the decision-making process in the design of comprehensive recycling systems.

This abstract presents a detailed examination of thermal recycling methods and their integration with other techniques to optimize material recovery from end-of-life PV panels. It offers valuable insights for researchers and engineers involved in developing efficient and sustainable recycling processes for photovoltaic materials, particularly focusing on the recovery of high-purity silicon and other key materials for future applications.

Key words: photovoiltaic panels, thermal processing, recycling.

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

EXAMINATION OF THE POSSIBILITY OF USING RECYCLED POLYETHYLENE IN ASPHALT MIXTURES

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ABSTRACT

In the above study, the research team addresses the fundamental question, which is: is it possible to reuse at least part of the plastic waste in asphalt mixtures? The team of authors, consisting of the research part and the asphalt mix manufacturer itself, provides a realistic basis for answering this question. Plastics and plastic products have become part of our lives extremely quickly. Although, they make our lives easier in many aspects, on the other hand, at the end of their useful life - often through the thoughtless actions of people - they have become a serious environmental problem. In study, recycled plastic granulate was used, originally from films and various packaging materials. Subsequently, this recycled material was blended into the asphalt mixture under appropriately selected reaction conditions. A commercially available polymer of similar chemical composition to the recycled material was used as a comparison sample. After the successful preparation in laboratory conditions, the application was continued directly in the asphalt mixing plant and the subsequent implementation of the verification section. The results of the research with subsequent implementation in practical application show that a polyethylene-based plastic recycle, under suitably selected reaction conditions, can be effectively incorporated into an asphalt mixture without negatively altering its final properties.

Key words: low-density polyethylene; asphalt binder; asphalt mix; asphalt mix plant; verification section.

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

FINITE ELEMENT ANALYSIS OF STRESS-STRAIN BETWEEN HUMAN HEAD AND HEADREST OF OFFICE CHAIR

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ABSTRACT

The size, shape, material, and form of an office chair's headrest all have an impact on how comfortable the sitter's head and neck are. More research is necessary because the headrest's ergonomic parameter range is unclear. Nonetheless, there has been little information published regarding the impact of headrest curvature and arc depth on support performance. This study is to evaluate the influence of the headrest's curvature and inclination angle on stress-strain between human head-headrest of office chair by finite element method. The bending mode of the office chair headrest model was built with three headrest size parameters in SolidWorks based on headrest data gathered from the office chair market. Ogden Foam constitutive model was used to define the soft part of the headrest. The simulation results showed that the von Mises stress of the headrest was changed with inclination angle of the headrest. The von Mises stress on the head decreased with the increase of the long side curvature of the headrest. The headrest's curvature and inclination angle have less of an impact on the overall deformation, according to the strain values of the headrest obtained from the finite element simulation. The headrest's inclination angle has a significant impact on the maximum stress placed on the head.

The headrest's inclination angle can provide the head and neck with additional supporting force within a specific range of angles.

Key words: Inclination angle, FEA, Ogden Foam, Maximum von Mises stress,

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

INNOVATIVE APPLICATIONS OF EARTH-AIR HEAT EXCHANGERS FOR SUSTAINABLE SPACE HEATING AND COOLING: A REVIEW

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ABSTRACT

Energy needs and alarming CO_2 emissions across the globe have brought considerable attention to the development and implementation of renewable energy and energy-saving systems. An important aspect of the earth's thermodynamics is that its temperature remains low and constant throughout the year in comparison to outdoor air temperatures. In recent years, Earth Air Heat Exchanger (EAHE) systems have garnered substantial interest as a high energy-efficient alternative for space heating and cooling. The ground temperature is used in these systems to pre-condition air before it enters a building, effectively reducing the energy consumption of traditional heating, ventilation, and air conditioning (HVAC) systems. This paper provides a concise review of EAHE technology application in space heating and cooling. The write-up also emphasizing the potential of the technology to enhance indoor comfort while lowering energy consumption and greenhouse gas emissions.

Key words: soil temperature, EAHE system, Renewable energy, thermal comfort, heating and cooling systems

XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

COMPARATIVE STUDY OF THE CARBON FOOTPRINT OF AGRICULTURAL LAND USE TECHNOLOGIES

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ABSTRACT

Agricultural activities have a considerable impact on the environment. In Hungary, crop production covers nearly half of the country's land, approximately 5.1 million hectares as of 2022. Sustainable agricultural competitiveness hinges on two key pillars: maintaining environmental balance and mitigating the damages from climate change anomalies. Our research focuses on a time series analysis of the environmental and climate change impacts of large-scale agricultural practices in the study area, using the Environmental Life Cycle Assessment (LCA) method. The investigation spans two decades and includes calculations based on an average cultivation model for all crops, with reference data per 1 hectare and per 1 year. We compared the annual time series values per hectare with the average annual values for cultivated crops. This comparison allowed us to identify years with above-average emissions and those with lower environmental stress, offering insights into changes in the local flora and fauna over time. The study's main results include carbon footprint values for each crop, which are presented on intensity maps projected onto plots for the entire cultivation period. The results obtained enhance the ability to assess environmental impacts, climate risks, and the effects of climate change related to arable crop production technologies. This, in turn, aids in selecting the most suitable technologies that are adapted to environmental sensitivities.

Key words: agricultural land uses, carbon footprint, ranking, comparison, life cycle analysis

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

CIRCULAR ECONOMY STRATEGY FOR END-OF-LIFE PV PANELS

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ABSTRACT

Today, waste management decisions must take into account the different waste streams, collection, transport, and treatment technologies in order to ensure a balance between collection and treatment technologies in terms of environmental sustainability, cost-effectiveness and social acceptability. Circular economy strategies aim to maintain the value of products and materials as long as possible, reduce environmental impacts, and deliver customer value. Implementing a circular economy with efficient use of natural resources means that waste management is becoming part of a broader resource management system and waste is a significant source of strategic raw materials. This can also be applied to photovoltaic (PV) panels whose lifetime is expected to be at least 30 to 40 years. As a result, PV waste will accumulate only in the coming years. From a circularity perspective, PV repair and reuse to extend its lifetime is preferred over the recycling pathway. However, it is necessary to pay attention to recycling technologies, as PV panels are not only a rich source of glass but also of raw materials such as silicon, silver, and copper. Silicon is a critical raw material due to its high supply risk and economic importance because it is used in most of renewable energy applications and is of core importance for the e-mobility sector. The circularity potential of the PV value chain can be improved by producing new solar cells using up-cycled silicon from end-of-life PV modules.

Key words: circular economy, photovoltaic panel, end-of-life, repair, re-use, recovery

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

VOLATILE ORGANIC COMPOUNDS EMITTED FROM PARTICLE BOARD CONTAINING RUBBER FILLER

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ABSTRACT

This paper deals with volatile organic compounds (VOCs) that can be emitted to the indoor environment of buildings or to the exterior from new composite materials. Two types of composites were prepared. Three-layer particleboards with 10% granulate from waste tires and three-layer particleboards containing 10% granulate from waste tires and 10% expandable graphite (flame retardant). For comparison, particle boards without the addition of granulate and graphite were also prepared as a reference sample. VOCs emitted at a temperature of 35°C (temperature in summer) and 50°C (temperature that can be reached by material surfaces in summer) were analyzed using the HS-GC-MS (Head Space-Gas Chromatography-Mass Spectrometry) method. The composition of VOCs emitted from composite materials was compared with the VOC emissions of individual components from which the composites were made. The dominant VOC emitted from both the reference sample and the composites was α-pinene at both temperatures. Methyl isobutyl ketone, cyclohexanone and xylene were emitted from waste tire granulate already at 35°C. No VOCs were released from graphite at temperatures of 35°C and 50°C. The results of the analysis of VOCs emitted from wood-rubber and wood-rubber-graphite composites indicate that the combination of these materials leads to partial or complete elimination of some VOCs. At temperatures of 35°C and 50°C, VOCs typical for rubber were not emitted from the composites. Waste rubber and used tires are, like plastic waste, a global problem. Our results point to the possibility of their use as a filler for the preparation of particleboards.

Key words: wood-rubber composites, tire-wastes, volatile organic compounds, HS-GC-MS

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

LEGISLATIVE CHALLENGES OF CIRCULAR ECONOMY

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ABSTRACT

This article examines the legislative challenges of implementing the circular economy within the legal boundaries set by the European Union´s Waste Directive, with a specific focus on its transposition into Slovak national law. The current waste hierarchy, as outlined by the EU, prioritizes waste management strategies that do not fully integrate the comprehensive "R strategy" elements such as refusing, rethinking, reducing, reusing, repairing, refurbishing, remanufacturing, and repurposing. This oversight perpetuates a linear economy model, inadvertently encouraging waste generation rather than promoting circular models that extend the life cycle of products and materials and significantly contribute to greenhouse gas emissions reduction. Through a detailed analysis of Slovak legislative measures and their alignment with the Waste directive, this paper highlights the gaps and inconsistencies that hinder the transition to a circular economy. The findings suggest that a re-evaluation of the waste hierarchy is essential to incorporate comprehensive R strategies elements effectively, thereby fostering a more sustainable and circular economic model. Recommendations for policy adjustments are proposed to better support the circular economy principles and reduce waste generation at its source.

Key words: circular economy, circularity, waste hierarchy, legal instruments, European green deal

XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

COMPARISON OF LINEAR AND CIRCULAR ECONOMY AND THEIR IMPACT ON THE PRODUCT LIFE CYCLE

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ABSTRACT

This article analyzes the differences between the linear and circular economy, with a focus on their impact on the product life cycle. It explores how each of these economic models affects the environmental and economic aspects of the product cycle. The article examines the individual stages of the life cycle in both types of economies and compares them in terms of their impact on the environment and economic sustainability. The goal is to identify the advantages and disadvantages of the circular model compared to the traditional linear approach.

Key words: linear economy, circular economy, product life cycle, sustainability, environmental impact

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

FINANCIAL TOOLS FOR ELECTROMOBILITY IN THE EUROPEAN UNION

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ABSTRACT

As statistical data reveal, e-mobility is gaining pace in the world. But while sales of electric cars are increasing globally, they remain significantly concentrated in just a few major markets. In 2023, just under 60% of new electric car registrations were in the People's Republic of China, just under 25% in Europe, and 10% in the United States – corresponding to nearly 95% of global electric car sales combined. In Europe, EV sales are stagnating, following the exceptional growth of 2020 and 2021. This follows many European countries reducing or removing purchase subsidies. The growth in electric car sales in Europe is expected to be the lowest of the three largest markets in 2024. The importance of electric car purchase incentives is starting to be questioned, also in the academic empirical studies. Nowadays, according to ACEA – European Automobile Manufacturers' Association 2024, all EU member states offer some form of tax benefit (either acquisition or ownership) for electric vehicles, although there is significant disparity and fragmentation between the schemes in each country. Tax benefits for electric company cars are less widespread with only 17 member states offering them. There are no purchase incentives available in six member states: Belgium, Bulgaria, Denmark, Finland, Latvia, Slovakia. Only five member states offer incentives for charging infrastructure. According to the conclusions from the research (Ochotnický, Sivák, Belanová, Hocman; 2023) the main driving forces for the penetration of electromobility are the standard of living and the "power" of supporting tax and subsidy schemes in individual EU countries. These conclusions are in line with another studies, ex. Gomez and Thiel (2019). The simulations suggest that, in the short-run, the electric car market share is higher when the subsidies remain in place. The use of electric car purchase subsidies is an effective policy measure to support electro-mobility in the next years.

Key words: electic cars, purchase subsidies, sales, car registration

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XXVIII International Scientific Conference

Engineering of Environment Protection
TOP 2024
October 28 - 30, 2024
Technical University in Zvolen

FORECASTS OF SALES OF ECVs IN SLOVAKIA AND THE EU

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ABSTRACT

The development of the sale of passenger electric vehicles (ECVs) and their share in the total sale of passenger vehicles is one of the key indicators for assessing: (a) the success of EU strategies for the penetration of electromobility, (b) the acceptance of this strategy by the residents of EU countries. The results and conclusions of the research (Ochotnický, Sivák, Belanová, Hocman; 2023) defined and empirically confirmed the key determinants (economic factors, network density, behavioural factors) that influence the penetration of electromobility through changes in the sale of ECVs. Based on this study, the paper presents an basic econometric model approach for forecasting ECV sales scenarios in Europe and the Slovak Republic.

Key words: electrically chargeable vehicles, new car registration, factors of sales.

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RESEARCH OF PROGRESSIVE TECHNOLOGY OF DECOMPOSITION OF GLUED LAYERED MATERIALS

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ABSTRAKT

With the development of new advanced technologies and machine designs, the requirements for new types of composite materials are also increasing. Among such "composite" materials we can include multilayer laminated bonded materials. These include, for example, automotive glass, technical building glass but also photovoltaic panels.
Commonly used materials for the manufacture of laminated products are glass, foil, silicon, non-ferrous metals, rubber or plastics. The quantities of such multi-species layered materials used in industry are growing exponentially. If recycled effectively, these wastes can be an important source of secondary raw materials for the production of new products. The condition for their reuse is the purity of the secondary raw materials obtained. Logically, therefore, there is increasing pressure to develop technologies for the decomposition of the individual fractions of laminated wastes. In the world, chemical, thermodynamic and mechanical decomposition technologies are known. The problem with the first two technologies is the high cost. On the contrary, mechanical disintegration technologies are highly dusty, noisy with low efficiency of separated raw materials.
The ambition of the presented project is to implement a new patent-protected technology for decomposition of individual fractions of laminated bonded waste. This original mechanical technology does not consider the crushing of multi-layered materials. The basic principle of the presented technology is the breaking of the processed waste, while maintaining the integrity of the supporting layers, and the subsequent wiping of the cracked layers on the supporting layers - films. It is a realistic assumption that this method in combination with the end washing module will achieve a cleanliness of more than 90 %, as confirmed by the first experimental tests.

Key words: multi-layer products, decomposition, new principle, progressive technology, high efficiency

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