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ANALYSIS OF INTENSITY OF CHANGES IN THE MOISTURE CONTENT OF WOOD CHIPS IN THE PRODUCTION OF WOOD POLYMER COMPOSITES DURING DRYING AND STORAGE PROCESSES

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ABSTRACT

The article presents the results of research on changes in humidity of wood chips intended for the of wood-polymer composites (WPC) manufacture. In the studies were used wood chips of various origin (coniferous and deciduous wood) and the various forms (from dust-meal, through small chips on big chips). Measured moisture content of chips during drying in the dryer and after that, during the natural return to hygroscopic equilibrium with the atmosphere of the storage space. After drying, the samples were stored in open and closed containers.

KEYWORDS: Wood-polymer composites, wood chips, moisture content, drying, hygroscopic, equilibrium.

INTRODUCTION

Wood polymer composites (WPC), almost imperceptibly but rapidly, gain space in our environment, for example as decking board, fence boards, elements of park benches, and elevation panels etc. (Schneider and Witt 2004; Kaczmar et al. 2006; Rowell 2006; Oksman-Niska and Sain 2007; Weinfurter and Eder 2009; Zajchowski and Ryszkowska 2009; Kuciel et al. 2010). Despite many obvious advantages such as resistance against weather, mildew and fungi, mechanical treatment capability of wood components, WPC are characterized by a very important feature they are regarded as organic materials. A number of reasons argue for that, and one of them is the content of wood fraction. The wood fraction may be composed of uniquely manufactured wood-like materials with different form and background, and various size of chips and wood flour produced from the proper wood (deciduous or coniferous) and also be can shredded wastes from widely understood timber industry (sawmills, floorboards or furniture factories), sorted according to granulometric distribution. Bio-plastics materials are more often considered as materials containing natural polymers occurring in the environment (e.g., cellulose, starch), and polymers resulting from processing of synthesis gas (biogas) (Thakur et al. 2012; 2013). These polymers do not represent products of petroleum, but demonstrate typical functional properties. Thus, the warp material and the filling used for WPC composites may represent biomaterials.

The fraction of WPC affects the properties of the obtained products, and acts as filler. The resulting material is stronger, stiffer, and lighter compared to the solid material by containing less than 50 % of wood content. However, after exceeding this percentage, the material becomes stiff and brittle, including the propensity for chipping and disintegration. The presence of wood in WPC composites brings other serious problems. Wood during the storage in warehouse conditions may be microbiologically contaminated and that may lead to the development of mold and fungi in the finished product. However, application of some processing operations (high temperature and sufficient pressure) leads both to the sterilization (Michalska-Pożoga and Czerwińska 2015) of the wood fraction and microbiologically stable material. However, with increasing content of the wood fraction in the mixture, the likelihood of a lack of continuity of the matrix increases. This results from a small contribution of material regarding the wood, which may lead to a situation in which the wood fraction will be exposed to weather, and then contact between wood particles contained in the composite will occur. In such a situation, fast moisture of the surface followed by microbial contamination of the composite, will happen and will lead to its progressive degradation and destruction. One of the most troublesome characteristics in the processing of wood and other natural fillers is its high hygroscopicity or the ability to collect or donate moisture from the environment. The degree of hygroscopicity of wood depends mainly on the wood species, temperature and relative air humidity (Zajchowski et al. 2009; Celino et al. 2014; Kotwica 2004; Neuhaus 2004). During storage, wood tends to achieve so-called hygroscopic equilibrium. Each temperature and air humidity corresponds to a predetermined equivalent moisture content of wood, and therefore chips and wood flour unprotected against dampness quickly absorb moisture from the environment. During processing and plasticization, the water contained in dank or non-dried wood fraction, under the influence of high temperature, evaporates leading to foaming of the material. However, this may also lead to decrease in the mass of the resulting material, but at the same time (when the porosity is large) may adversely affect the strength properties of the products. Therefore, wood fraction requires drying prior to processing. One of the leading manufacturers of wood-like materials in Europe (Rettenmaier and Söhne GmbH+Co.KG) recommended drying the wood fraction at a temperature of about 105°C for 5 hours, directly prior processing. After drying and during the processing, moisture content of wood material should not exceed 0.5 %. After drying, the wood fraction should be used immediately; otherwise, it will acquire moisture again.

In addition, humidity in the storage rooms is around 50 %, thus secondary moisturizing of wood particles is happening. Drying is a time-consuming and expensive process therefore it is important to understand the dynamics of drying. Also, it is very valid to understand the process of spontaneous return to hygroscopic equilibrium of wood particles, to design such conditions, in which, the wood after drying will be able to be stored so long as possible, without the need for drying shortly before processing.

In the available literature, there are reports describing various properties of WPC composites, including their water absorption; however, there is no analysis of the capacity for drying and returning to hygroscopic balance of wood chips themselves (Zajchowski et al. 2009; Shi and Gardner 2006; Adhikary et al. 2008).

The aim of this paper is to present the results of studies involving changes in moisture content during drying process and then natural moisturizing of five forms of wood chips – flour and chips of various shapes and sizes.

MATERIAL AND METHODS

Material

The material used in the study included five types of wood chips supplied by Rettenmaier and Söhne GmbH + Co. KG: chips type 1 – small wood chips of coniferous wood (Lignocel BK 8/14), chips type 2 – typical wood chips of coniferous wood (Lignocel 3–4), chips type 3 – wood chips of deciduous wood (Raucher Gold KL 1–4), chips type 4 – small wood chips of coniferous wood (Lignocel HBS 150–500) and chips type 5 - dust – conifer wood flour (Lignocel LC 120) (Fig. 1). In further analyses, the sample will be marked with numbers from 1 to 5 in such an order as ranked above. A graph presenting their granulometric distribution is shown in Fig. 2.

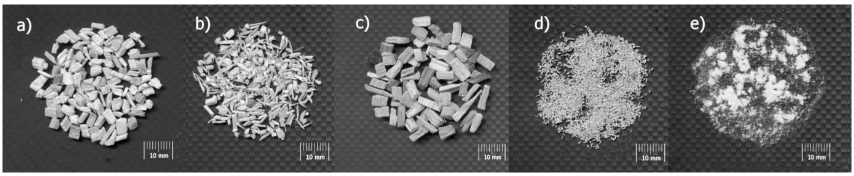

Fig. 1: The test samples of wood chips: a) small coniferous wood chips Lignocel BK 8/15 (chips type 1), b) average shavings of coniferous wood chips 3-4 (chips type 2), c) deciduous wood chips RaucherGold KL 1-4 (chips type 3), d) fine deciduous wood chips Lignocel HBS 150-500 (chips type 4), e) dust - meal coniferous wood Lignocel LC-120 (chips type 5).

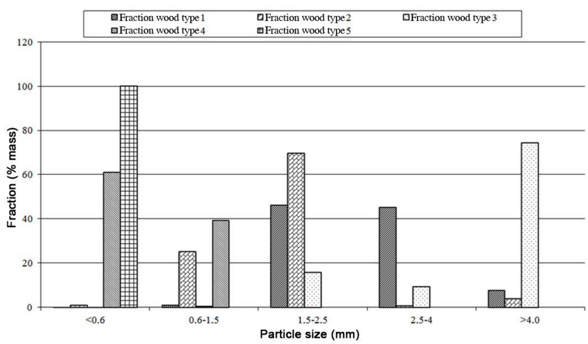

Fig. 2: Graph showing the size distribution of the respondents wood chips.

The timber material was stored in open 25 kg bags (400 x 700 mm): A bag with a thick PE foil (chips type 1, 3, 4), the multiwall paper bag (wood flour type 5) and a PP woven bag (chips type 2) under typical storage conditions. Such type of storage was used to provide real storage conditions of wood waste. Air humidity in the warehouse ranged from 39 to 51 % and the temperature was maintained at 27–28.5°C. The highest initial moisture content was observed for large chips (type 3, about 10.5 %), and the lowest – for the typical coniferous wood chips (type 2, about 1.85 %).

Drying process

Wood material, according to the manufacturer's instructions, was dried at 105°C for 5 hours. The chips were sprinkled on a layer of a thickness of about 4 cm on steel plates and placed inside the lab dryer with forced convection. To prevent chips from blowing away with the circulating air, light airflow was provided in the drying chamber. To homogenize the mixture and simultaneously increase the drying capacity, the material was stirred every 30 min. Samples were collected every 60 minutes. After moisture content determination, the samples were discarded (did not return to the dried weight) to prevent from affecting the overall moisture content of the probe.

The process of returning to hygroscopic equilibrium with the environment (spontaneous moisture)

After completion of sample drying, the samples were divided into two groups and placed inside polypropylene boxes. The first group was closed tightly with sealed PP lids, the second was left open. Both batches were placed under the same conditions in the storage room and stored for four days. The air humidity in the storage room ranged from 39 to 51 %, and the temperature was maintained at 27–28.5°C. Measurement of moisture content and air temperature was conducted with Air Flow Meter 9871 anemometer. During the storage, twice a day, at an interval of 8 hours, moisture content measurements of wood fraction, were carried out.

Measurements

Moisture content (wetness) measurement of wood fraction was carried out using rapid technical method with Radwag WPS 110S moisture balance. Parameters: Drying temperature T = 105°C, drying time T = 15 min, sample weight m_p = 3 g, sampling time β = 3 s, accuracy of the measurement d_w = 0.01 %. Each measurement was done in triplicate. These calculations were carried out according to ISO 13061: 2014 and the Eq.:

$$W = \frac{(M_P - M_K)}{M_K} \cdot 100\,\% \qquad (\%\,mass)$$

where: W - wetness (% mass),
M_P - initial mass (weight) of the sample (g),
M_K - the final sample mass (weight) (g).

RESULTS AND DISCUSION

Analyzing the results of the measurement of moisture content during drying of chips (Fig. 3) demonstrates that the most intensive drying process proceeded with chips 1 and the slowest with chips 2 it resulted from lower initial moisture content (less than 2 %) of chips 2.

Chips 1 and 2 are made of coniferous wood, have large and extensive surface, and are light, soft and porous, which facilitates and accelerates the mass transfer during drying. Other chips lost 7 % of moisture on average during 3 hours of drying.

The slowest drying was reported for chips 5 (wood flour) that results from small size of particles. Heaped mass is compacted and of little porosity, which makes the conditions for mass transfer less effective. Furthermore, it can be observed that regardless of the initial level of moisture content and the type of chips, after 3 hours, all the probes showed less than 1 % of moisture. Further drying did not affect significantly the change in the level of moisture content of wood. After five hours of drying all the samples exhibited moisture content in the range from

0.4 to 0.7 %. In order to accomplish lower values of moisture content, one should apply modern, more efficient and thus more expensive dryers. In this case, the process would be longer, more expensive and by that unprofitable.

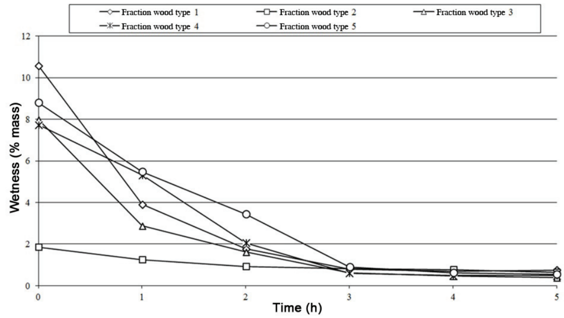

Fig. 3: Changes in moisture content during drying of wood chips as a function of time.

Because of the porosity of products induced by a fraction of wood added, of a very extensive surface area, the presence of additional few bubbles filled with water steam derived from evaporated water of chips during heat treatment (plasticization, homogenization and dosing) are not significantly important for the properties of the product. Additionally, they may reduce mass of the products, which is a positive phenomenon in some applications. Mixing the chips and the presence of voids in the WPC composites involving various types of wood were reported in the monograph by Rydzkowski (2012).

The results of the determination of changes in moisture content of chips stored in closed (Fig. 4) and open (Fig. 5) containers demonstrate that an increase in the moisture content of chips should be expected, which is caused by the trend of wood fraction to accomplish hygroscopic equilibrium with the environment, whose measure is the balance moisture content.

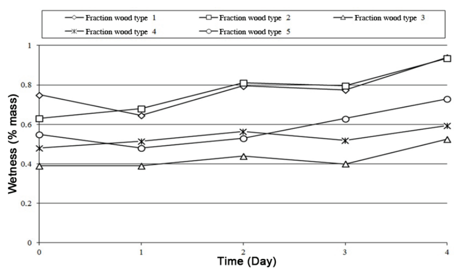

Fig. 4: The change of wetness of the dried wood chips during storage in the closed containers.

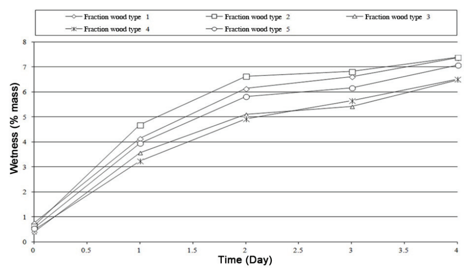

Fig. 5: The change of wetness of the dried wood chips during storage in the open containers.

It should be noted that after the first day of storage, a clear differentiation of moisture content in samples from open and closed containers is observed. The samples stored in the open containers increased their moisture from 0.5 to 8 % on average (moisture content increased by approximately 16 times). Samples kept in closed containers maintained or slightly increased their moisture content. The observed differences are less than 0.1 %. After four days of storage, all closed samples still have moisture content less than 1 %. The highest moisture content at the level of 0.94 % was observed for chips 1 and 2, the lowest (0.53 %) was reported for chips 3.

The chips stored in open containers, after the first day were losing the dynamics of moisture content changes, and after the second day, the moisture content of chips increased only 1.5-fold. In the third day, an increase in the moisture content by only 0.5 % was found. On the fourth day, the moisture content increased by 1 % on average. After the fourth day, average moisture content of chips was about 7 %. Further measurements were not conducted, however by extrapolating the results it can be assumed, that on the sixth and seventh day, probably chips' moisture stored in open containers would have returned to the initial values prior drying (8–9 % on average). That would confirm the ability of wood to reach hygroscopic equilibrium with the atmosphere of the storage space, as in the case of relative humidity of air estimated at 50 % and a temperature in the range of 20–30°C, the balance moisture content is estimated between 8 and 9 % (Kotwica 2004; Neuhaus 2004).

The analysis of the results of spontaneous, natural moisturizing indicates that in both, open and closed containers, higher moisture was observed in chips 1 and 2. Less moisture was absorbed also in chips 3 and 4. The intermediate ability to absorb moisture is exhibited by chips 5, also regardless of closure of container.

In all cases, chips 1 and 2 that represent small Lignocel BK 8/14 wood chips of coniferous wood and medium size Lignocel 3–4 chips of coniferous wood, respectively, absorbed moisture with the highest velocity.

Coniferous wood is characterized by lower density and more extensive (higher) chip surface, which promotes absorption of moisture. Chips 3 and 4 represented by RaucherGold KL 1–4 eciduous wood and small Lignocel HBS 150-500 chips of deciduous wood, respectively, absorbed the least moisture. In the case of chips of deciduous wood, we have a higher density, less extensive surface, more compact structure, which is reflected in reduced and slower water absorption capacity. Intermediate values were obtained by wood flour 5 - dust – flour from Lignocel LC-120 coniferous wood. This probably results from the small size of the chips. These are very small, dusty particles and thus they form themselves in the form of compact layer, to which the moisture is difficult to access. Such a state may be the reason for accomplishing lower moisture content of the wood flour compared to chips (type 1, 2) of coniferous wood, however higher than a wood fraction from the deciduous wood (type 3, 4).

CONCLUSIONS

1. Obtaining a very low moisture content (*wetness*) of wood chips requires longer and more expensive drying.
2. After drying, the storage in tight containers is necessary, otherwise, after a few hours, effect of drying will be diminish by natural absorption of moisture from the environment.
3. The dynamics of drying and moisture absorption is affected by both the type of wood of which the chips are made, and the size of their particles.
4. Chips from coniferous wood exhibit greater drying dynamics, unfortunately also during the storage in a storage room they return to hygroscopic equilibrium more quickly.
5. Lower moisture content growth is observed for chips of deciduous wood, thus it can be stored a bit longer without any necessity of re-drying.
6. Fraction made of coniferous wood absorbs moisture very quickly, and therefore requires more attention and care during the storage compared to deciduous wood.

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