TECHNICAL NOTE: LIMITATIONS OF A 3-D IMAGE ANALYSIS–BASED PARTICLE SIZE MEASURING SYSTEM FOR WOOD PARTICLE DIMENSION MEASUREMENT

*Jan T. Benthien**
Research Associate
E-mail: jan.benthien@thuenen.de

Jan Lüdtke
Research Associate/Dr.
Thünen Institute of Wood Research
21031 Hamburg, Germany
E-mail: jan.luedtke@thuenen.de

Rainer Friehmelt
Research Manager/Dr.
E-mail: rainer.friehmelt@basf.com

Michael Schäfer
Research Manager/Dr.
BASF SE 67056 Ludwigshafen, Germany
E-mail: michael.schaefer@basf.com

(Received September 2017)

Abstract. Against the background of inaccurately measured wood particle dimensions, applying the three-dimensional (3-D) image analysis–based particle size characterization system Partimac 3D XL in preliminary tests, metal platelets with various aspect ratios of the three main axes are employed to understand and explain the observed limitations of the measuring principle. It was found that particle width and thickness interact increasingly with a decreasing aspect ratio and, thus, the digital replica and subsequent determination of the dimensions become incorrect. This was ascribed to the random orientation of the particles during image acquisition, which cannot be overcome with a finite number of cameras in the system.

Keywords: 3-D particle size measurement, image analysis, particleboard manufacturing.

INTRODUCTION

In the manufacturing of particleboards, the properties of the wood particles have a significant effect on panel quality. The particles also impact the cost-related optimization of quality with respect to the required amount of adhesive. In this context, the important wood particle characteristics are the distributions of particle length, width, and thickness, and the particle surface area onto which the adhesive is spread. Both determine the effectively available area for the formation of adhesive connections between the particles (Dunky and Niemz 2002).

The particle size is influenced by the wood species used for particle manufacture and the details of the chipping process. In the case of the chipping process, the geometry and the wear of the cutting tool edges are of particular interest. Because the wear of the cutting tool edges and the wood quality vary permanently during production, a detailed knowledge of the actually produced particle size distribution is required to operate in a highly optimized process and, thus, with maximal efficiency.

Commonly applied sieve analysis is inadequate as it is limited to providing only one-dimensional size information. This information cannot be clearly attributed to one of the main particle axes.

---

* Corresponding author

Wood and Fiber Science, 50(3), 2018, pp. 358-362
https://doi.org/10.22382/wfs-2018-034

Even conventional two-dimensional (2-D) image analysis–based particle size characterization (PSC) is of limited informative value. Only two of the particles' main axes (length and [usually] width) and just one of the theoretically infinite number projection areas can be thus determined (Sun et al 2014). To measure particle thickness and, consequently, obtain information on particle volume and surface area, an additional measurement (eg manual thickness gauging) is required, as stated by Plinke (1987). The dynamic development of digital image acquisition, and image and data processing techniques should make it possible to measure the thickness for a considerable number of particles, and base the result on a reasonable statistical sample size. At this time, however, such measurements are not economically viable, and applicable industrial measurement systems are not yet available.

Preliminary tests with Partimac 3D XL (BASF SE, Ludwigshafen, Germany) (BASF SE et al 2007) were used to transfer this technology from rather convex particles to biaxially stretched wooden particles for process optimization. As was to be expected from the principal limitation of 3-D size characterization of particles with arbitrary shapes (ie not simply ellipsoid-shaped or noncylindrical objects), size measurement was found to be faulty. In particular, the calculated density of sample wood particles was strongly undervalued. This leads, in consequence, to wrong conclusions through an overvaluation of the particle's volume. Satisfactory results were, in contrast, obtained at the Partimac's actual area of application. Depending on the specific material, the volume of mainly convex granulates or extrudates is measured with an error of 5-20%.

The intention of the present study was to comprehend the findings of 3-D wood PSC on the basis of reference samples (metal platelets) of defined and manually verifiable dimensions. The study shall also contribute to the ongoing effort to develop an industrial technique to measure particle dimensions, in particular, particle thickness.

MATERIALS AND METHODS

Test Specimens and Experimental Setup

Nine metal platelets with variations in length, width, and thickness were measured approximately 100 times each (by manual refeeding into the vibrating feeder inlet) applying the 3-D image analysis–based PSC system Partimac 3D XL.

To investigate the influence of particle length on the overvaluation of particle dimensions, test specimens' width (thickness) was kept constant at 5 mm (1 mm), whereas length was 10, 15, and 20 mm. The influence of particle width on the overvaluation of the particle dimensions was measured using specimens of constant length (15 mm) and thickness (1 mm) but varied width (1, 2.5, 5, and 10 mm). Particle thickness was investigated as an influencing variable by applying metal platelets of constant length (15 mm) and width (5 mm) but varied thickness (0.5, 1, 1.5, and 2 mm).

The Shapiro–Wilk Test was applied to check each data set for normality. As no normal distribution occurred (exclusively overvaluation of the particle dimensions because of the overlaying main axis which results in a skew distribution), the nonparametric Kruskal–Wallis test was applied to test whether all sample means are equal at the 95% significance level. The Kruskal–Wallis Test was applied as it is suitable for comparing two or more nonnormally distributed independent samples of equal or different sample sizes. If the null hypothesis (no difference between the samples' means) was rejected, the samples were compared pairwise applying the nonparametric multiple Steel–Dwass test. The Steel–Dwass test was applied to show whether sample means are equal or, respectively, not equal to each other. For this purpose, groups of statistic homogeneity (groups with the same subset are not statistically different—homogenous group) were determined afterward from the Steel–Dwass test's results and given in Table 1. Statistical analysis was performed by applying the analysis tool JMP from SAS Institute (Cary, NC).

Differences between measurements were calculated by subtracting the real specimens' dimensions (caliper measurement) from the Partimac

Table 1. Coefficient of variance (CV) and homogenous group (HG) of sample means (different letters within a column indicate statistical distinguishability) as well as differences of caliper and measuring system measurement.

	Nominal specimen size (mm)			CV and HG of measuring system measurement			Difference between caliper and measuring system measurement (%)		
Spec. no.	*l*	*w*	*t*	*l*	*w*	*t*	*l*	*w*	*t*
Influence of particle length									
1	*10*	5	1	*2.5 A*	6.8 A	31.2 A	*2*	7	120
2	*15*	5	1	*1.8 B*	5.8 A	26.4 A	*1*	8	120
3	*20*	5	1	*2.6 C*	4.3 B	23.9 A	*0*	9	121
Influence of particle width									
4	15	*1*	1	1.9 A	*28.1 A*	12.2 A	0	*52*	40
5	15	*2.5*	1	2.0 AB	*10.2 B*	19.5 B	1	*13*	61
(2)	15	*5*	1	1.8 A	*5.8 C*	26.4 C	1	*8*	120
6	15	*10*	1	1.6 B	*2.8 D*	31.9 D	0	*2*	187
Influence of particle thickness									
7	15	5	*0.5*	2.0 A	4.7 AB	*34.2 A*	0	5	*243*
(2)	15	5	*1*	1.8 A	5.8 AC	*26.4 B*	1	8	*120*
8	15	5	*1.5*	2.2 AB	5.4 BD	*18.5 C*	1	9	*66*
9	15	5	*2*	1.8 B	4.6 CD	*15.1 D*	1	11	*51*

italic: varied dimension. *l*, length; *w*, width; *t*, thickness.

measurement (mean) and expressed as percentage in respect to caliper measurement.

Although presented coefficient of variance (CV) may be misleading for skewed distributions (as the distribution is not symmetrical), they help to point out the investigation's goal in the present article.

Particle Size Measuring System

The Partimac system consists of four digital cameras, each of them opposing a light field of light emitting diodes and arranged with intermediate angles of 45° around the particles' free fall path. An overhead vibrating feeder channel for particle dosage and separation supplies the particles. They drop through the field of view of the cameras and thus fall freely during image acquisition (BASF SE et al 2007; Aßmann 2015). The Partimac was used as 3D XL variant, which means a camera resolution of 54 μm per pixel and an object field of 41.2 mm × 31.4 mm. The image information is used to build a voxel model of the particle and to derive particle length, width, and thickness approximated by the three orthogonal axes of inertia.

RESULTS AND DISCUSSION

It can be seen from the data displayed in Table 1 that the Partimac basically found the varied dimensions of the metal test specimens (italic in Table 1) to be significantly different from each other (subsets are different for the groups of varied dimension). Length measurements consistently show low CV, whereas thickness and certain width measurements consistently hold a much higher CV level. CV was found to be comparatively high for slender (thin) specimens and lower for wide (thick) specimens. It seems as if the repeatability decreased with decreasing width and thickness, respectively. No comparable relationship was observed at varied specimen length. Notwithstanding these details, measurement accuracy (difference between caliper and Partimac measurement) was unacceptable for most width, and all thickness, measurements. Although differences between caliper and Partimac length measurement was low (0-2%), width measurements differed up to 52%. Thickness measurements were found to be between 40% and 243% greater than the caliper measurement. In addition to dimension-related variability, interdependencies were observed between specimens' dimensions and the measuring accuracy. Variation of specimens' lengths showed no influence on the accuracy of width and thickness measurements. Specimens' width was overvalued on an acceptable level (7-9% difference) and thickness more than at least twice (∼120%

difference) at all tested specimen lengths. Varying the specimen's width, a high level of measuring accuracy (2% difference) was found for wide specimens (10 mm), whereas the level of measuring accuracy decreased with decreasing width. For specimens with a width of at least 1 mm, a difference of 52% was found between Partimac and caliper measurements. Thickness was determined to vary at different specimen widths. Thickness overvaluation increased from 40% (1-mm-wide specimens) to nearly 190% (10-mm-wide specimens). This means both thickness and width determination are impaired by increasing particle width. The same holds true when varying the specimen thickness: measurement accuracy improves with increasing specimen thickness at a fixed width (lowering CV). However, differences between Partimac and caliper measurement were found to be very high (243% difference) for thin (0.5 mm) and wide specimens.

The difference between caliper and Partimac width and thickness measurements is obviously caused by the mechanical transport configuration of the Partimac 3D XL system. This system is not adapted for measuring flat particles (length > width >> thickness), particularly if the two smaller dimensions are considerably different. During image acquisition, the particles rotate freely and their main axes are most often unaligned to one of the optical camera axes. Each camera captures the projected area of the particles in relation to the camera axis. The projection area is most often a superposition of all particle main axes. An evaluation algorithm can only correct this geometrical effect if the projected dimensions of an axis are seen in different pictures. For flat particles, the projection of the longest axis is seen in nearly every image. The reconstruction algorithm can thus correctly evaluate particle length. The projection of width and thickness nearly always superpose, and cannot be detected separately. This is why especially thickness, but also width, is too highly estimated. As a consequence, volume and surface area are also mostly overvalued. Figure 1 shows that overvaluation of thickness is a linear function of the relation of width to thickness.

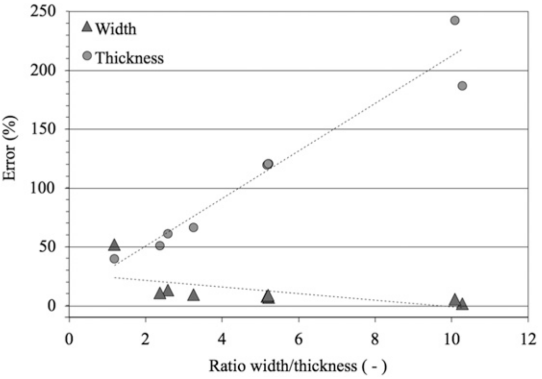

Figure 1. Measurement error in relation to width-to-thickness ratio.

CONCLUSIONS

Metal platelets with various aspect ratios in length-to-width, width-to-thickness, and length-to-thickness were employed as placeholders of wood particles. The platelets had defined and manually verifiable dimensions. They help to understand and explain limitations in the measurement accuracy of 3-D wood PSC with image acquisition on free-falling sample material. It was found that measurement inaccuracies are not an individual shortcoming of any one instrument, but rather more of the measuring principle itself. Thus, they will likewise affect 2-D PSC systems with image acquisition on free-falling sample material as well. It was found that particle length was measured with sufficient accuracy, whereas thickness measurement becomes increasingly inaccurate with increasing relation of width-to-thickness. From these findings, the limitations for wood particles can be anticipated. When measuring wood particles, length measurement will be minimally affected as the ends of the particles taper to nearly a point (when wood particles are imagined to be an ellipsoid) so that almost no superposition will occur with the particle width or thickness.

Possible actions to reduce the effect of aspect ratios and, thus, increase the accuracy of measurement would be to increase the number of cameras during image acquisition in an airborne state or possibly to employ a transport unit based on particle alignment to a plane surface. As soon as these improvements are implemented, 3-D PSC will become of increasing interest because further processing and, thus, cost optimization require a detailed knowledge of the distribution of all particle dimensions.

REFERENCES

Aßmann J (2015) Kostendruck macht erfinderisch: Innovationen für die Holzwerkstoffindustrie [Cost pressure is the mother of invention: Innovations for the wood-based panel industry]. Pages 26-34 *in* Anonymous, eds, Proc. 11th Holzwerkstoffkolloquium, 10-12 December 2015, Dresden, Germany. Institut für Holztechnologie Dresden gemeinnützige GmbH (IHD), Dresden, Germany (In German).

BASF SE, Schäfer M, Ettmüller J, Ziegler S, Reindel K (2007) Device and method for automatically determining the individual three-dimensional shape of particles. World Intellectual Property Organization (WIPO), Publication number WO/2007/060127.

Dunky M, Niemz P (2002) Holzwerkstoffe und leime—Technologie und einflussfaktoren [Wood-based panels and adhesives—Technology and influencing factors]. Springer-Verlag, Berlin/Heidelberg. 954 pp (In German).

Plinke B (1987) Rechnergestützte partikelmessung an materialien der holzwerkstoffindustrie [Computer-aided particle size measurement on materials of the wood-based panel industry]. Holz Roh Werkst 54:315-318 (In German with summary in English).

Sun Y, Indraratna B, Nimbalkar S (2014) Three-dimensional characterisation of particle size and shape for ballast. Géotech. Lett. 4(3):197-202.