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BRIEF ORIGINALS KURZORIGINALIA

Wood based bulk material in 3D printing processes for applications in construction

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Abstract Additive manufacturing of large scale solids can be achieved by using wood based bulk material (sawdust, wooden chips, etc.) in 3D printing processes. Thin layers of bulk are bonded selectively with a suitable binder thus forming layer by layer a solid of almost any desired shape. Preliminary tests were carried out using a defined assortment of wooden chips as bulk material and gypsum, cellulose, sodium silicate and cement as binder.

1 Introduction

Computer aided additive manufacturing allows the automated generation of freeform solids on the basis of a digital model without the necessity of specialized tools. It was first launched on the market in 1987 by 3D-Systems (Wohlers and Gornet 2012) and is nowadays widely used not only in the manufacturing of models and prototypes but also in the fabrication of end use products like custom prosthetics or lightweight structures for aerospace. It can be realized in many different ways, one of them being 3D printing that was developed explicitly to offer a wider variety of materials than other proposed techniques (Sachs et al. 1993). Materials common in additive manufacturing are plastics, metals, sand and gypsum; examples for the use of wood however, are scarce. Meghan Trainor, for example, experimented with 3D printing of sawdust with synthetic resin as binder in an adapted commercial machine (Open3DP 2011), and Zhao et al. (2011) did a study on the use of wood plastic composites in an extrusion process.

Additive manufacturing is competitive to conventional production especially when there are pieces of high complexity to be produced in small batches. Because of this aspect it promises to be highly suited for applications in construction where it could be put to use in the fabrication of form optimized structures or tailor-made building envelopes. First trials for the use of additive manufacturing in construction were performed by Pegna (1997) who locally yielded cement into thin layers of sand and afterwards hardened each layer by the use of steam. Another more recent research project on the subject investigates the layer-wise extrusion of cement mortar with nozzles (Lim et al. 2012). The sole use of mineral materials however, has many disadvantages (high weight, poor insulation, etc.) that could be conquered by the substitution of at least one of the ingredients with a plant based material.

This paper describes experiments using a certain type of wooden chips and several types of binding agents to define a potentially suitable combination to be used in 3D printing processes with special regard to applications in construction.

2 Materials and methods

The tests were performed with wooden chips made of spruce as they are used for the production of particle boards. They were classified on a laboratory gyratory sifter in the fraction $0.8 < x < 2$ (mm). The bulk density was 192 kg/m^3. Gypsum, methyl cellulose, sodium silicate and different tpyes of cement were tested as bonding agents.

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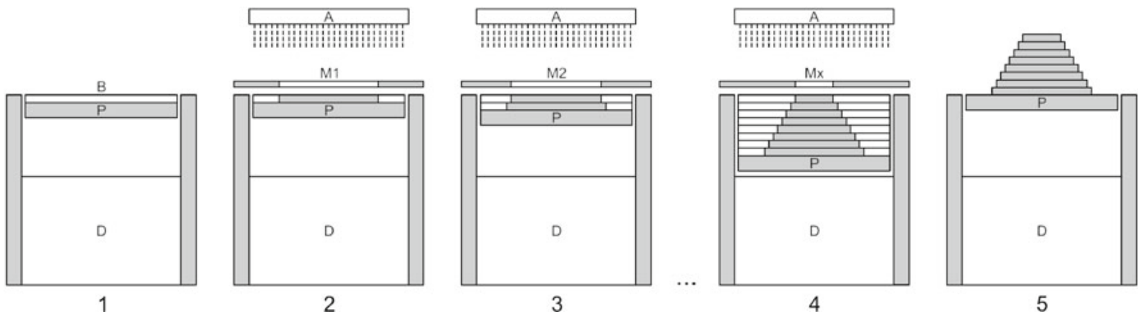

B = mixture of bulk and binder, P = platform, M1-Mx = masks, A = activator, D = drive and control

Fig. 1 Process of the selective activation of thin layers consisting of mixtures of bulk-material and binding agents **Abb. 1** Prozess der selektiven Aktivierung dünner Schichten aus Mischungen von Schüttgut und Bindemittel

Fig. 2 Truncated cone generated by 3D printing with chips of spruce and gypsum as binder, cut open to show the inner texture (*top*); inner structure of a test specimen bonded with cement (*down left*); inner structure of a test specimen bonded with gypsum (*down right*) **Abb. 2** Im 3D-Druckverfahren hergestellter und nachträglich angeschnittener Kegelstumpf aus Fichtenspänen mit Gips als Bindemittel (oben); innere Struktur eines Testkörpers mit Zement als Bindemittel (unten links); innere Struktur eines Testkörpers mit Gips als Bindemittel (unten rechts)

The whole laboratory process of 3D printing with wooden chips is shown in Fig. 1. In the case of gypsum, methyl cellulose and cement the wooden chips were first mixed with the dry binding agents as a powder in a certain ratio. The mixing ratio was varied to fill the grain boundary voids in an ideal way. Afterwards the dry mixture of bulk and binder (B) was brought out on the platform (P) of the test device in a thin layer with a maximum height of 2.5 mm (Fig. 1, step 1). A mask (M1) was used to get the aerolised water that was used as activator (A), locally on the layer (Fig. 1, step 2). The mass of the activator needed for each layer depending on the area of activation was controlled by a scale. In the case of sodium silicate, only the chips were brought out in thin layers and the sodium silicate itself was applied locally into the chips. When the first layer was bonded the platform was moved down by the thickness of one layer and the procedure was repeated with a mask (M2) representing the outline of the second layer (Fig. 1, step 3). Further layers were generated in the same way.

When the final layer was bonded (Fig. 1, step 4) the plattform was brought back into the starting position and the solid body could be dismantled easily by removing the unconsolidated chips (Fig. 1, step 5).

With the process described different geometries, e.g. bars and truncated cones (Fig. 2) oriented in different directions, were produced and mechanical characteristics as well as dimensional accuracy were assessed.

3 Results

Tests with methyl cellulose led to poor mechanical behavior. Likewise bad results were achieved in first trials with sodium silicate as it turned out to be difficult to fill the grain boundary voids of the chips adequately. Good results were achieved with gypsum. A chips/gypsum ratio of 0.33 and water/gypsum ratio of 0.75 led to a good contour accuracy and good consolidation of the chips.

The best results were observed with cement wherefore more test runs with different types of cement and a broader range of mixing ratio between cement, water and chips were performed. On the basis of these tests a chips/cement ratio of 0.15 and a water/cement ratio of 0.80 were identified to deliver the best results. The relatively high amount of water that is needed can be explained by the water demand and water buffering capacity of the wooden chips.

With these specifications a raw density of the layer-wise composed solid bodies of 0.7–0.8 g/cm^3 was achieved. The bending strength measured on layer-wise composed bars reached values of 0.5–0.95 N/mm^2 and can be compared with wood wool lightweight building boards.

4 Outlook

The results show the feasibility in principal of the use of wood based bulk material in 3D printing processes. The mechanical strengths obtained until now would be appropriate for the use in non-structural applications only. To make the technology suitable for a broader range of applications, more optimization of the raw material used and the 3D printing process itself needs to be performed.

In this regard different wood chip geometries (pin and plane morphology) in a certain size scale are to be probed as well as different types of cement optimized for fast hardening. Special test geometries are to be developed for the evaluation of certain aspects like geometric resolution, dimensional accuracy and mechanical characteristics according to the orientation of the layers. With the growing knowledge about the material behavior, more optimization can be done on behalf of speeding up the process through adapting the thickness of the layers or the way of bringing out the activator. For an industrial application, also reproducible ways of dispersing the bulk material in thin layers are to be developed.

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