How Adding Wood Dust Affects the Properties of Composite Construction Materials

N G Cherkasova

1Reshetnev Siberian State University of Science and Technology, 31, Krasnoyarsky Rabochy Av., Krasnoyarsk, 660037, Russian Federation

E-mail: 5hat@bk.ru

Abstract. Composite materials based on wood dust are promising construction materials that have recently gained traction in the market. Their success is attributable to the benefits such materials represent for construction: they are eco-friendly and resistant to atmospheric effects; they are well-disposable and easy to machine. Utilizing wood dust is essentially recycling the waste of woodworking, furniture-making, and lumbering industries, as well as the waste associated with the use of low-grade wood. The present paper covers the processes that occur in the structure of a composite materials when using abrasive wood dust as a filler. The research team has made pilot samples of various composition; analysis revealed the composition affected such properties as density, flexural strength, and water absorption. The effects were further analyzed to attribute them to specific mixture components. Refining the production technology and the recipe is one of the key objectives of producing and applying constructional composites today. Maximizing the performance while reducing the energy costs and the production costs requires a focus on rheological properties. The properties of a composites material mainly depend on the type and properties of its organic filler. Understanding that is fundamental to optimizing the composition, i.e. to finding such filler that will provide sufficient strength at a maximum fill factor. It is also known that using fillers makes the composition significantly cheaper.

1. Introduction

Primary machining of timber consists in pruning and cross-cutting; additional machining employs special tools to saw timber longitudinally e.g. sawmills, saw tapes, circular saws, woodworking equipment, choppers, etc. Whatever such machines produce, be it lumber, sleepers, box boards, or graded timber, their waste generation is unsustainable. Given how critical the problem of optimizing the use of wood is, integrated recycling of raw wood becomes imperative; as such, it is also a great contributor to environmental well-being, as this approach helps concentrate waste at production sites. A large-scale and energy-intensive facility recycles the so-called ‘soft waste’: sawdust and wood dust. It would therefore be of benefit to develop a low-cost, waste-free technology to recycle crushed wood waste.

Wood dust is a light organic filler of plant origin. Being a locally collectible and producible material, wood dust may well be termed cost-effective production waste. What makes such terming appropriate is not only the sheer volume of wood dust as such, but also that of wood waste left form sawing and wood machining, which could be crushed to generate even more waste. Another important
economic factor is the absence of environmental fees for exceeding the waste limits. Dust is cheap and highly thixotropic, making it a perfect filler for many composites.

The wood dust utilization method proposed herein will effectively free up the space that is currently used to stockpile wood waste; shall such waste be stored in open air, the method will prevent dust from wind-induced dissipation onto the adjacent territories.

A bulk of research covers the potential applications of crushed wood waste [1]. One important subfield deals with the rheological properties of wood-fiber composites, particle boards, and other types of composites that use wood flour or dust as a filler [2]. For instance, pure spruce sawdust and woodworking-generated shavings are considered the best raw materials for making wood flour that is further used as a filler in phenolic plastics, linoleum, explosives, and piezothermoplastics. Of greatest interest would be to analyze how the properties of composite components (type, humidity, particle size, and percentage in the composite mixture) could affect the composite and its properties in general.

The goal hereof was to find out ways to make new construction mixes and materials based on wood dust as a filler while also finding out the most optimal rock composition.

2. Experimentation

The basic components of the experimental composite materials were: Portland cement per GOST 31108-2003 General structural Portland clinker cements as the matrix; fly ash per GOST 25818-91 Thermal plant fly ashes; coniferous wood flour, Grade 180 per GOST 16361-87, produced by OOO KrasTaiga (WF); wood dust collected when grinding the front surfaces of birch blockboards at the carpentry shop of FSBEI HE Siberian State Technical University (GDbb) or GOST 10632–2007 particle boards at ZAO Krasnoyarsk Woodworks (Rus: Красноярский деревообрабатывающий комбинат), or GDpb. Table 1 briefly describes the mixture components.

The components were mixed at room temperature by a LERM-1 laboratory extruder. The samples thus obtained were placed in molds to make experimental specimens, each size 0.04*0.04*0.1 m. The mortar would cure over 28 days at room temperature as per GOST 31357-2007 Dry building cement binder mixes. The specimens thus made were used for physico-mechanical testing. Flexural testing was done by an RMI pull-test machine per GOST 28840 (0.1H force reading accuracy; 50 mm/min loading rate).

| Parameter                          | Portland cement | Ash (GDpb) | Ash (WF) | Ash (GDbb) |
|-----------------------------------|-----------------|------------|----------|------------|
| Mass fraction of the component    | CaO: 67;       | SiO₂: 64;  | Mixture of deciduous (100%) |
|                                  | Al₂O₃: 35;     | Al₂O₃: 29; | Pine (100%) |
|                                  | SiO₂: 22;      | Fe₂O₃: 3.5;| Birch (100%) |
|                                  | Fe₂O₃: 3;      | FeO: 0.28; |           |
|                                  | other components at 3% | CaO: 1.7; |           |
|                                  |                | MgO: 0.2;  |           |
|                                  |                | K₂O: 0.7;  |           |
|                                  |                | Na₂O: 0.3; |           |
|                                  |                | TiO₂: 0.7; |           |
| Absolute humidity, %             | 1               | 5.0        | 8.0      | 6.4        |
| Arithmetic means (n=50) of the linear particle size, microns: length | 31              | 25         | 4.1      | 4.6        |
| width                            | 35              | 27         | 6.4      | 4.6        |
| Form factor                      | 3.0             | 3.2        | 45       | 52         |

Table 1. Component properties.
The components were mixed at room temperature by a LERM-1 laboratory extruder. The samples thus obtained were placed in molds to make experimental specimens, each sized 0.04*0.04*0.1 m. The mortar would cure over 28 days at room temperature as per GOST 31357-2007 Dry building cement binder mixes. The specimens thus made were used for physico-mechanical testing. Flexural testing was done by an RMI pull-test machine per GOST 28840 (0.1H force reading accuracy; 50 mm/min loading rate).

Water absorption was measured per GOST 12730.3-78.

The morphology of the experimental specimen was analyzed by electron microscopy, see Figure 1. Linear size of the components was measured by a JSM-6390LA electron microscope (SEM).

The experiment design matrix for testing the physical and mechanical properties of composites is shown in Table 2 for wood dust (GDpb, GDbb, WF).

The most important requirements to dispersed wooden materials are: the ability to be merged with, or dispersed in, the matrix; good water affinity; lack of propensity for particle agglomeration; homogeneous particle size; low humidity.

![Figure 1. Electron microscopy of the components (*40): (a) cement; (b) fly ash; (c) wood dust.](image)

![Table 2. Experiment design matrix, % component content.](table)

| Specimen # | Normalized, % | Actual, g | Wood dust |
|------------|---------------|-----------|-----------|
|            | Cement | Ash | Wood dust | Cement | Ash | Wood dust | Water |
| 1          | 80     | 10  | 10 (WF)  | 214    | 27  | 27 (WF)  | 300   |
| 2          | 60     | 30  | 10 (GDpb)| 160    | 80  | 27 (GDpb)| 200   |
| 3          | 60     | 10  | 30 (GDbb)| 160    | 27  | 80 (GDbb)| 450   |
| 4          | 40     | 50  | 10 (GDbb)| 107    | 134 | 27 (GDbb)| 200   |
| 5          | 40     | 30  | 30 (GDpb)| 107    | 80  | 80 (GDpb)| 400   |
| 6          | 40     | 10  | 50 (WF)  | 107    | 27  | 134 (WF)| 500   |
| 7          | 55     | 22.5| 22.5 (GDpb)| 147 | 60  | 60 (GDpb)| 300   |
| 8          | 55     | 22.5| 22.5 (WF)| 147    | 60  | 60 (WF) | 300   |

When describing the interaction of dust particles, auto-adhesion is referred to as adhesiveness. It is caused by electrical, molecular, and capillary forces. The adhesiveness is usually measured by the dust-layer tensile strength, Pa. In this case, dust adhesiveness was measured by a two-piece cylinder [3].

In most wood composites based on mineral binders, Portland cement is used for binding; this is a hydraulic substance that retains its strength regardless of whether it is exposed to air or to water.
The production and chemical formulation of Portland cement make it clear that the substance contains minerals that might be involved in the synthesis of rather active ingredients; the minerals might also interact with the components of wood.

Cement curing is a complex chemical process and is a function of time $P = F(t)$, where $t$ is the duration of a multi-stage process. Cement crystallizes when exposed to water and a wood filler, which is engaged in chemical reactions.

Injecting a wood filler into the cement mixture alters the crystallization of cement grain.

3. Experiment results and discussion

Electronic microscopy revealed a fundamental difference in the particle surface quality of the experimental specimens. Dry cement particles did not feature auto-adhesion, i.e. could not agglomerate. Fly-ash particles tended to localize due to electrostatic forces acting on them (these particles are charged when formed). Dust particles could agglomerate, but agglomerates would differ in composition. For instance, mixed grinding dust (GD) had far less particles that split into fibers than coniferous wood flour or deciduous grinding dust. This was due to the morphology of wood as well as the type of electric charge they carried [4].

Microscopy indicated a surficial difference between the particles of these two materials, which affected the ability of particles to adhere strongly.

For physical and mechanical testing of grinding dust-based composites, the research team analyzed their rheology at 150ºC loaded at 19 to 206 N, see Table 3.

**Table 3. Physical and mechanical properties of specimen.**

| Indicator                     | Experimental specimen |
|-------------------------------|-----------------------|
| Density, kg/m$^3$             | 1                     | 2                     | 3                     | 4                     | 5                     | 6                     | 7                     | 8                     |
|                               | 1,216.6               | 1,156.3               | 610.4                 | 1,101.4               | 659.7                 | 670.1                 | 874.4                 | 971.4                 |
| Ultimate flexural strength ($\sigma$), MPa | 17.67                | 16.62                 | 3.27                  | 14.05                 | 3.84                  | 4.68                  | 9.15                  | 9.72                  |
| Water absorption over 24 h, % | 6.3                   | 5.4                   | 4.1                   | 4.1                   | 5.4                   | 6.3                   | 5.4                   | 6.3                   |

As shown in Table 3, composites with GDpb were found to be no less strong than their counterparts based on a coniferous filler, which in turn was inferior to the deciduous filler in terms of water absorption.

This leads to a finding that the presence and quantity of wood dust in a composite material affects the crystallization (curing) process. If the dust is mixed, ultimate strength is equal to, or is not significantly different from that of coniferous flour-based specimens; composites based on grinding dust of decidous species are far less strong. Consider the process behind it.

In the first phase of matrix (cement) hydrolysis, alkali (Ca(OH)$_2$) are exuded. Calcium hydroxide is most aggressive to wood. It was found to wash out wood in prolonged exposure, resulting in losing up to 6% of wooden mass. Exposed to the strongly alkaline liquid phase of cement, some wood contained substances degrade, including the polysaccharides of hemicellulose.

The resulting monosaccharides are water-soluble. Researchers have found [5] that some wood cells contain resins: 6.4% in pine, 1.9% in spruce, 1.2% in birch, and 1.5% in asp (percent of absolutely dry weight). Resins are easily soluble in alcohol, acetone, and aqueous alkaline solutions. When heated, they become a plastic mass that hardens when cooled. This trait of resins makes them usable for compacting crushed wastes without adding binders. When compacting heated wood, molten resins fill the space between wood particles. Since conifers are rich in resin than deciduous trees, they are more suitable for making composites.

Analysis of the results presented herein leads to a hypothesis that xylose activates the matrix surface in these composites. Sugars injected with water into the cement undergo adsorption and are exposed to molecular cohesion force, which causes them to form a think adsorption layer on the
cement grains. Smaller portions of cement are enveloped in monosaccharides and connect bond to them; water does not bond to cement; the hydration product immobilizes. This slows down cement hydration. The quantity of solubles in water in various woods will affect the cement dough setting time, while increasing the amount of extractive substances will slow down hydration.

4. Conclusions
The research has shown that:
1. Experimentally, water-soluble components of wood interacted with Portland cement, which affecting cement hydration and curing as well as the crystallization and structuring of the composite material.
2. Composites on a cement matrix can use mixed grinding dust of multiple woods; such composites are no less strong than their well-known counterparts based on coniferous wood flour as a filler.

References
[1] Klyosov A A 2010 Wood-polymer composites. Scientific foundations and technologies (St. Petersburg) 736 p
[2] Stavrov V P, Spiglazov A V, Sviridenok A I 2007 Rheological parameters of molding thermoplastic composites high-filled with wood particles Int. J. Appl. Mech and Eng. vol 12 2 pp 527-536
[3] Kouzov P A, Scriabin L Ya 1983 Methods for determining the physicochemical properties of industrial dusts (Leningrad: Chemistry) 143 p
[4] Cherkasova N G 2002 Improving the quality of cleaning and improving the air environment by artificial ionization: the dissertation of the candidate of technical sciences: 03.00.16 (Krasnoyarsk) 286 p 61 03-5/1064
[5] Nanazashvili I Kh 2005 The study of adhesion in the structure of the conglomerate "wood-cement stone" Improving the factory technology of reinforced concrete products at agricultural enterprises (M.) 378 p