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BEETLECRETE - AN ATTRACTIVE SOLUTION TO MOUNTAIN PINE BEETLE EPIDEMIC

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ABSTRACT

Moldability is a key property for making wood cement mixtures for decorative applications such as counter tops, planters, benches, floor tiles, stepping stones, statues, etc. Beetlecrete was created as a hybrid wood and cement composite material meant to be poured in forms as regular concrete but also to be machinable like other wood-based materials. The wood from Mountain pine beetle killed trees showed a decrease in extractives with time since death and consequently, an increase in the chemical compatibility with Portland cement. However, the beetle-killed wood's higher permeability affects the fluidity of the wood cement mixture by reducing its molding capability. Torrefaction is proposed as a method to reduce the water absorption capacity of the wood chips and therefore to enhance the quality of the particles used for Beetlecrete applications while also improving chemical compatibility between wood and cement.

KEYWORDS:

Beetlecrete, beetle-killed wood, Portland cement, moldability, torrefaction

INTRODUCTION

For more than a decade the mountain pine beetle (MPB) has ravaged the forests of northern British Columbia, leaving millions of hectares of dead Lodgepole pine trees in its wake. The estimates show that the amount of beetle-killed Lodgepole pine affected by the current epidemic in British Columbia is over 700 million cubic meters. The low moisture content in beetle-killed trees affects the manufacturing process of the wood products. Dry beetle-killed logs develop checks which have a negative impact on veneer and lumber recovery. Also, the size, the geometry, and the increased permeability of the strands used for manufacturing oriented strand boards (OSB) affect the gluability characteristics, in terms of both quality and consumption. The beetle-killed woodcan be essentially wasted if attention is not directed towards manufacturingof products that use smaller pieces of dead wood. In other words, the shelf life of the beetle-killed timber would be prolonged if the particle size of the wood incorporated into composite materials decreased, thus avoiding those detrimental characteristics of dead timber (Hartley and Pasca, 2006).

Increased demand for engineered systems and durability are critical issues dictating the future of building materials for the next decades (Winandy, 2002). Wood-cement composites can contribute to such development; however, the huge potential of the North American market has been modestly challenged. Only the siding and the roofing market seem to be active (Moslemi, 1999). Fire, water and fungal resistance, a decent strength, and thermal stability are among the advantages of using wood-cement boards for both interior and exterior applications within light-frame wood construction. Since numerous studies have shown that formaldehyde is susceptible of causing sickness in humans, the use of a wood-cement composite that is free of any petroleum-based binder instead of actual resin bonded wood boards, seems to be an environmentally responsible alternative welcome by the green building movement. Besides its physical and structural characteristics, the wood-cement composite material can bring aesthetic and functional attributes that make it suitable for various decorative applications such as countertops, floor tiles, benches, planters, stepping stones and patio elements, etc. Beetlecretewas developed as hybrid material that uses mountain pine beetle-killed wood chips as a substitute for mineral aggregate in concrete products. This material is highly attractive because it combines the structural strength of concrete with the aesthetic quality of the wood. Unlike many other wood-cement composites on the market, this product pours like concrete, yet it can be drilled, machined, cut or fastened with regular woodworking tools. Similar to wood, it holds nails while forming a marbled material with a unique look and feel.

In this paper, a review is presented describing some of the issues related to wood-cement chemical compatibility, while focusing on the beetle-killed pine trees sampled from sites affected by the mountain pine beetle epidemic in northern British Columbia, Canada. Then, the aspects regarding the physical compatibility between wood particles and cement paste are also investigated. It is showed how the use of mild torrefaction can contribute to improving chemical, physical and aesthetical attributes of the beetle-killed wood used for fabricating Beetlecrete, a moldable wood-cement material suitable for many household applications.

BEETLE-KILLED WOOD COMPATIBILITY WITH PORTLAND CEMENT

The quality of the wood cement material is mainly given by the quality of the cement paste. Cement hydration is an exothermic process and therefore, the strength of concrete is directly related to the amount of heat released during this reaction. Wood is an organic material that inhibits the hardening of cement, an inorganic binder. Weatherwax and Tarkow (1964) showed that sugars, tannins, starches are among those compounds having an adverse effect on cement hydration. Hachmi and Moslemi (1989) suggested that there was an indirect correlation between the amount of wood extractives and wood-cement compatibility. However, prolonged seasoning of the logs and adding various types of accelerators to wood-cement mixtures have been used in order to improve wood-cement compatibility (Lee et al., 1987). Since the amount of wood extractives in dead pines decreases with time since death, this should enhance beetle-killed wood's suitability for wood-cement composites. This unfortunate natural process is a replica of what many manufacturers use to do for increasing the wood-cement compatibility namely, storing the timber for a long period of time in their mill yard.

Lodgepole pine is the most compatible North American wood species with Portland cement (Hofstrand et al., 1984; Hachmi et al., 1990; Defo et al., 2004), provided its very low extractives content (Woo et al., 2005) corroborated with the large percentage of sapwood of the harvested trees that have rather small diameters.Following the mountain pine beetle attack, physicochemical properties of the lodgepole pine wood changed dramatically. The blue stain fungus does not affect the strength properties of the wood, but, as a result of their presence, the amount of extractives in the sapwood substantially decreases and consequently, this increases the compatibility with cement. In early studies, wood cement products made with southern pine showed high levels of blue-stained sapwood-cement compatibility, expressed by an earlier rise in temperature (Davis, 1966) and a reduced setting time of the wood-cement mixtures (Biblis and Lo, 1968).The results were correlated with reducing-sugar means for both winter-cut blue-stained sapwood and spring-cut blue-stained sapwood obtained after extraction with hot-water. Semple and Evans (2000) found that the MOR of boards made from radiata pine blue-stained sapwood was higher, although not statistically different from the average MOR of the commercial board samples.

The CX index (Pasca et al., 2010) was developed to cover all the exothermic aspects of the cement hydration: maximum heat rate, time to reach that maximum heat rate and total heat released during the chemical process. The means of the three wood-cement compatibility indexes are presented in Table 1. Means with the same letter are not significant different at the 95% level. The results demonstrate that the levels of compatibility between beetle-killed wood and Portland cement have stayed high many years after death. Pasca et al., (2010) demonstrated that, while blue-stained sapwood has shown an outstanding compatibility with cement, incipient decay after the brown rot attack still produced cement compatible samples. However, it was the white rot attack that significantly reduced the wood-cement compatibility.

Table 1 – Beetle-killed wood compatibility with Portland cement

Group	CA		CI		CX	
Blue-stained sapwood	81.8	a	108.0	A	91.9	A
Sound wood	79.8	a	94.1	b	80.8	b
Heartwood - 1 year since death	79.4	a	88.7	b	79.2	b
Heartwood - 2-3 years since death	78.9	a	85.4	b	79.3	b
Heartwood - 4-5 years since death	79.5	a	87.9	b	79.3	b
Heartwood - +6 years since death	76.9	a	84.3	b	74.4	b
Brown rot heartwood	76.4	a	91.9	b	78.8	b
White rot heartwood	48.8	b	51.2	c	40.6	c

Note: Modified from Pasca et al., 2010

CHALLENGES IN FABRICATING BEETLECRETE

Unlike manufacturing ordinary concrete, where the mineral aggregates (i.e. sand, gravel, pebbles, or rocks) are practically impermeable, fabricating wood cement composites requires prudence in setting up the amount of water because too much water negatively affects the quality of cement paste. On the other hand, too little water is instantly absorbed by the wood making the mixture unworkable and cement lacking the minimum moisture requirement for hydration. For that reason, it seems that less permeable softwood heartwood is more suitable for manufacturing high quality cement composites. However, if chemical compatibility is the main concern, then sapwood (or even blue-stained sapwood) is the best choice. Beetlecrete is meant to be a moldable product, therefore the mixture of wood and cement paste has to be fluid enough for allowing pouring capabilities. A compromise between workability and strength is still the main concern of making any type of concrete product. Unlike the mineral aggregates, wood is hygroscopic and absorbs water intended for cement hydration. At the beginning, Beetlecrete wood-cement mixture requires more water in order to supply both the adsorptive/absorptive wood and the cement powder. The water is continually absorbed by the wood until the cement paste starts to set. A desired cement/water ratio of 0.35-0.40 is a guarantee for a superior cement paste quality. However, the water transfers between wood and cement before, during, and after cement hydration are complicated processes. Therefore, it is hard to quantify exactly the water/cement ratios during initial stages of hydration; reducing the proportion of the initial water increases the quality of concrete but diminishes its workability. The variation in wood permeability and moisture content make difficult to develop a specific formula for calculating the original volume of water needed to manufacture a product. Moreover, the differences in permeability among the species are amplified by the wood particle size. For the same amount of wood, finer particles are more adsorptive because the contact surface is larger. On the other hand, bigger particles form a coarser mixture and impede workability which also leads to adding more water.

Prior studies showed that wood particle geometry was also an important factor in affecting physical properties of the wood cement composites. In fabricating wood-cement particle boards that require pressing, slender, long particles would act as reinforcement for concrete, although the sawdust had some advantages over wood slivers as an aggregate (Prestemon, 1976). Wood particles screened through a 8-16 mesh size were considered the most suitable for optimum bending strength of the boards (Moslemi and Pfister, 1987).Poured wood-cement products were stronger when made of smaller particles (Pasca, 2007), although it is well known that the finer the particles, the greater the chemical inhibition is with cement hydration. In addition, the smaller and spherical particles always lead to a more fluid mixture suited for applications where imprinting capability is important (i.e., textured stepping stones, cast statues, and signs). Duplicating the normal practice of making ordinary concrete, it can be said that a variety of wood particle sizes is a good choice for manufacturing Beetlecrete. Nevertheless, screening the wood chips into various sizes/shapes remains an option for meeting many customers' desires - people always like to see the wood pattern in a countertop (Figure 1).

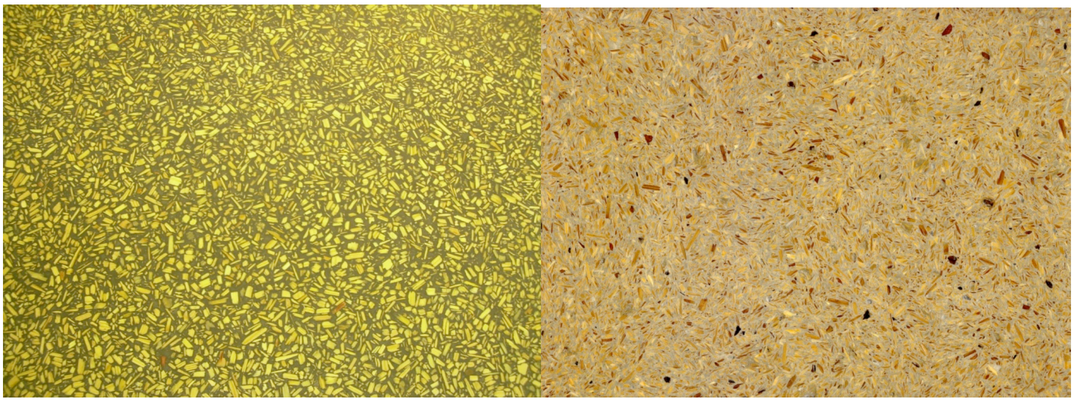

Figure 1 - Details showing the wood pattern in Beetlecrete products

In summary, the wood used for fabricating a Beetlecrete product need to meet several quality requirements: (1) an increased chemical compatibility with cement, as a guarantee for strength and durability, (2) a reduced water permeability that allows optimizing the amount of water for hydration without affecting the pouring capability of the wood-cement mixture, (3) increased grinding capacity of the wood flakes into desired shapes and sizes, and (4) colour variation as for increasing the aesthetics value of the final product. In addressing these challenges, torrefaction is proposed as a method for enhancing the chemical and physical attributes of the wood used for manufacturing Beetlecrete.

TORREFACTION – PROPOSED METHOD FOR ENHANCING WOOD'S ATTRIBUTES

Torrefaction is a process successfully used for improving the combustion properties of the biomass fuel. It can be described as a mild form of pyrolysis at temperatures ranging between 200-320 C (Bergman and Kiel, 2005). The concept of heating the lumber at high temperatures has been utilized in Europe for years (ThermoWood® Handbook, 2003). Success has been obtained with respect to an increased aging resistance by improving some of the physico-chemical properties of the wood. However, the treatment negatively affects the strength properties and reduces the suitability for many ordinary structural applications, such as dimension lumber. Yet there is little research to assess the potential suitability of the high temperature treated wood for wood-cement composites.

Immediately following the heat treatment hemicellulose is degraded leading to increased dimensional stability of the wood under changes in moisture. The wood becomes more rot resistant, lighter in weight, darker in color and with better thermal insulation properties. The extractives degrade more easily and some of them are volatilized during the heating process. Water permeability is reduced significantly (Metsa-Kortelainen et al., 2006). The wood is more brittle that leads to a greater grinding capability. It seems that almost every chemical and physical change wood suffers works in favour of meeting most the quality requirements needed for fabricating Beetlecrete products.

A simple trial was set in order to evaluate how the heat treatment affected the wood particles with respect to reducing the water sorption and increasing the wood-cement compatibility. Two types of wood were used in this experiment: shavings from heartwood of beetle-killed lodgepole pine trees (MPB heartwood) and sawdust, as ordinary sawmill waste material. Beetle-killed pine represents a high fraction of sawmill waste mixture, but spruce and fir may also be part of the species assortment (SPF sawdust). The wood was ground and screened through a system of three sieves (4, 8, and 16 mesh size) in order to obtain two particle sizes: 4-8 and 8-16. Besides two control groups, one comprising wood conditioned into the lab at 21 °C and 35% RH and the second obtained by oven drying the wood for 24 hrs at 103 °C, another three groups were heated for 1 hr at temperatures of 180, 200, and 220°C after being oven dried at 103 °C. The water sorption test was conducted by water soaking the wood particles for 3 minutes and then by extracting the water with a centrifuge. Three minutes was determined as the average time for mixing and pouring the mixture. The water sorption coefficient was calculated as the ratio between the mass of water retained by the wood particles and the mass of the dry wood (conditioned at 21 °C and 35% RH) (Figure 2).

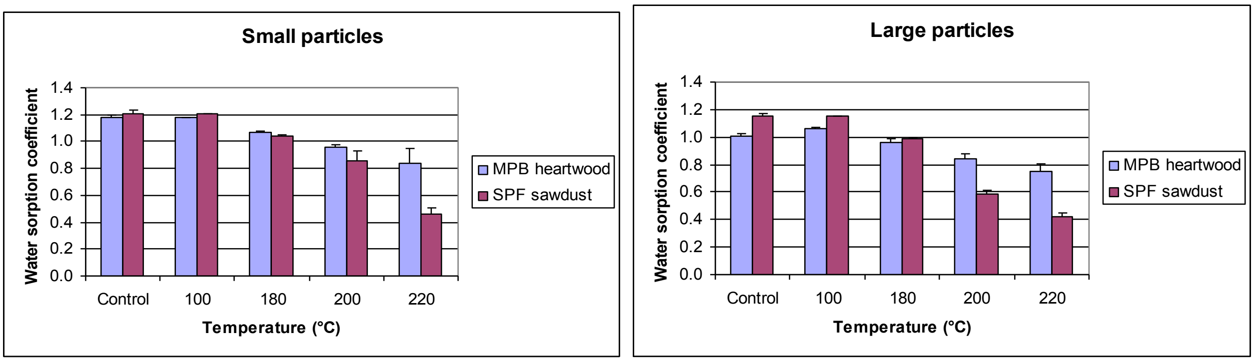

Figure 2 - Water sorption vs. heat treatment

For the wood-cement compatibility assessment an inhibitory index was calculated as the ratio between the maximum temperature of wood-cement mixtures and the maximum temperature reached by neat cement paste (the differences between the actual recorded maximum temperatures and the room temperatures were used)(Figure 3). The wood was prepared as for the CX calculations.

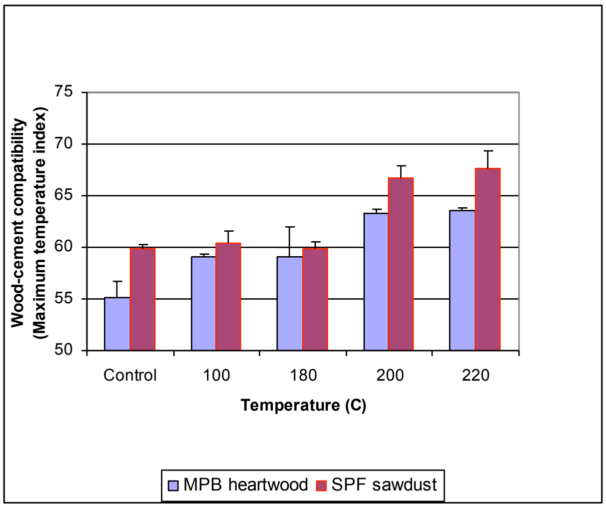

Figure 3 - Wood-cement compatibility vs. heat treatment

The results represent averages of three replication; the error bars represent standard deviations. As shown in Figure 2, the decrease in water sorption with the increase in the heating temperature is significant. At the same heating temperature, the water sorption is larger for small particles; the finer particles are more adsorptive because the contact surface per unit of volume is larger. Also, wood cement compatibility increases as the heating temperature increases too (Figure 3). As expected, heartwood shows a poorer compatibility with cement compared to ordinary sawdust which may comprise a significant amount of sapwood. The assumption that the water sorption of the heartwood is less than that of ordinary sawdust is not confirmed at the two control groups, but it is supported by this small study. It may be assumed that, in a very short time interval of only 3 minutes, most of the sorption is caused by adsorption and not by absorption. However, with respect to reducing the sorption capacity of the particles, the heat treatment affects ordinary sawdust at more extent than it affects heartwood.

APPLICATIONS AND OTHER ECO-MARKETING CONSIDERATIONS

Over the past years, several high-profile building projects in British Columbia, Canada have incorporated Beetlecrete into their design. In the capital city of BC, Victoria, the Union of BC Municipalities built a new headquarters and incorporated a countertop made of Beetlecrete (Figure 4). In addition, the Ramada Hotel Downtown in Prince George chose to use Beetlecrete for the countertop of their reception and lobby area (Figure 5). Beetlecrete benches (Figure 6), planters (Figure 7) and tiles are exposed at various locations within UNBC campus. The use of Beetlecrete in structural applications is currently being under consideration.

Figure 4 - Beetlecrete front desk countertop – BC Municipalities House, Victoria, BC

Figure 5 - Beetlecrete reception countertop – Ramada Hotel, Prince George, BC

Figure 6 - Beetlecrete bench – Botanical Garden, UNBC campus, Prince George, BC

Figure 7 - Beetlecrete planter – UNBC campus, Prince George, BC

A recent marketing study (Choi et al., 2011) examined the consumer and industry acceptance of MPBWC material towards five important attributes (price level, colour, wood chips size, green certification, and location of production) for three decorative applications: countertops, floor tiles, and garden blocks. The results showed that locally sourced materials and production seemed to be the most attractive characteristic of the product that contributed to the purchase decision. In addition, green certification and colour were more important than price or particles' size.

Moreover, Beetlecrete is suitable for do-it-yourself and in-situ projects, mostly because it's outstanding workability and molding capability. In-situ techniques are more labour intensive and time consuming, but the raw materials are cheaper because they are local and so they carry minimum delivery costs. The in-situ projects are also more versatile, adaptable and with a lesser impact on the environment, therefore suited to natural building movement. Do-it-yourself capability of wood cement material opens opportunities for niche manufacturing which is one the main topics related to rural development. The new trend in rural development is to replace traditional land use through extensive exploitation of natural resources with tourism, recreation and niche manufactures (North and Smallbone, 1996). It also focuses on locally produced economic strategies because rural areas are very distinctive from one another. A product such as Beetlecrete, with so many potential applications, can satisfy this need for diversity and adaptability within rural areas, including eco-villages or aboriginal communities.

CONCLUSION

The quality of the wood chips is critical for obtaining Beetlecrete products. Beetle-killed pine wood has proved to be highly compatible with cement for long periods of time after the death of the attacked trees. Torrefaction has been proposed as a solution for enhancing the chemical and physical characteristics of the beetle-killed wood. The wood compatibility with Portland cement increased significantly as the temperature of the heating treatment surpassed 200 °C. Also, the wood sorption decreased with more than 50% for samples of sawdust pre-heated at 220 °C. In manufacturing Beetlecrete, good results have been obtained after setting the amount of water as low as possible although that requires the ability to work with the mixture as quick as possible too. The Beetlecrete technology requires basic, inexpensive equipment used in wood or concrete manufacturing therefore, it can be easily implemented in a small shop setting, as well as by big enterprises.

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