Commercialization Potential of Viscoelastic Thermal Compressed Wood: Insights from the US Forest Products Industry

Natalie Macias
Chris Knowles
Fred Kamke
Andreja Kutnar

Abstract

The increasing demand for forest products and restricted use of natural forests has resulted in a shortage of high-strength wood fiber. The area covered by plantation forests is steadily rising, but the fiber produced by these forests is often unsuitable for high-strength applications. One attempt to combat this problem is the viscoelastic thermal compression (VTC) process, which can dramatically increase the strength and stiffness of any wood species.

To advance VTC wood from the concept evaluation stage to the development stage, concept testing interviews were conducted with individuals in the forest products industry. Opinions, ideas, and insights were gathered from interviewees concerning potential applications for VTC wood, as well as advantages and barriers to commercialization.

As a whole, interviewees thought the most viable uses for VTC wood were laminated veneer lumber, plywood, concrete forms, transportation components, and flooring. The most frequently mentioned advantages to commercialization included increased mechanical properties and the utilization of a low-value wood species; barriers to commercialization were cost and the forest products industry's resistance to change. Overall, interviewees thought VTC wood would be successful as long as it was not markedly more expensive than similar products.

As the global population increases, the demand for forest products increases and the availability of raw materials decreases. The increased awareness and conflict regarding the environment has resulted in more stringent regulations concerning the use of natural forests. In many regions of the world, the forest industry has turned to plantations to satisfy demand (Wright et al. 2000).

The increased use of plantation fiber has stirred controversy surrounding the positives and negatives of plantations themselves. Plantations are very productive and are able to rapidly grow trees in a small land area, but they also have intensive water and pesticide use and often do not promote the local wildlife due to the use of nonnative species (Juslin and Hansen 2003, World Resources Institute 2007). Short rotation times result in low-density wood that is often weaker and less stable than naturally grown trees due to the high growth rate and a high proportion of juvenile and reaction wood (Bowyer et al. 2007).

Decreased strength values are problematic in the production of certain wood composites. Composites such as laminated veneer lumber (LVL) and glulam beams contain wood of varying strength characteristics. Oftentimes, the high-strength pieces required for production of these composite products cannot be found in plantation-grown logs. One way to increase the available volume of high-strength wood is to modify plantation fiber to increase its strength and stiffness. Wood densification is one such approach. In general, wood densification is the process by which wood density is increased by compression of the

The authors are, respectively, Graduate Fellow, Assistant Professor, and Professor, Wood Sci. and Engineering, Oregon State Univ., Corvallis (natalie.macias@oregonstate.edu, chris.knowles@oregonstate.edu, fred.kamke@oregonstate.edu); and Researcher, Primorska Inst. for Natural Sci. and Technol., Univ. of Primorska, Koper, Slovenia (andreja.kutnar@upr.si). Natalie Macias is currently International Marketing Manager, Softwood Export Council, Portland, Oregon (Natalie@softwood.org [corresponding author]). This paper was received for publication in November 2010. Article no. 10-00065.

Forest Prod. J. 61(7):500–509.

wood, impregnation of cell lumens with a fluid substance, or a combination of compression and impregnation (Kollmann et al. 1975). Densification of wood can be achieved by impregnating its void volume with polymers, molten natural resins, waxes, sulphur, and even molten metals (Kultikova 1999). Wood can also be densified by compressing it in a transverse direction under conditions that do not cause damage to the cell wall (Kollmann et al. 1975).

A variety of densification methods exist today, which achieve wood densification through compressive, thermal, and mechanical means. A new densification technology, which is still being refined on a laboratory scale at Oregon State University, has the ability to turn low-strength plantation fiber into structural material. This technology, called the viscoelastic thermal compression (VTC) process (Kamke and Sizemore 2008), can increase the density of low-density wood species by three to four times. Through the use of VTC technology, plantation fiber can be manufactured into a product possessing mechanical properties above and beyond what is necessary for structural applications in traditional wood-framed construction.

The VTC process uses heat, steam, and mechanical compression to densify wood. The process is unique in that it does not damage the microcellular structure of the wood (Kutnar et al. 2009). Kutnar et al. (2008) described the VTC process in five main steps:

1. The wood is heated and conditioned to a temperature between 150°C and 190°C and a high moisture content. This is done until the wood reaches or goes beyond its glass transition temperature.
2. The bound water is removed from the cell wall. Removal of the bound water allows the wood to be compressed without damaging the cell wall structure.
3. After the bound water is removed, the wood is compressed perpendicular to the grain. This is done while the wood is still at its glass transition temperature and results in an increase in density.
4. The wood is annealed to relax the internal stresses and to reduce the hygroscopicity.
5. The wood is cooled below its glass transition temperature and the moisture content is increased. The wood is conditioned to the ambient temperature and humidity.

From start to finish, the VTC process takes 10 to 15 minutes. The VTC process can be applied to veneer, structural lumber, or strand composites (Kamke 2006); the resulting product has increased density, strength, and stiffness values compared with those of untreated wood (Kamke and Sizemore 2008, Kutnar et al. 2008). Depending on the VTC wood's end use, the producer can customize the process to attain the required properties. The VTC process can use any wood species but was initially developed to improve the properties of low-density, structurally unsuitable species, such as those that are often grown in plantations.

Objectives

This study was intended to identify potential commercial applications and markets for VTC wood. The specific objectives were to identify potential commercial applications for VTC wood and to understand potential advantages and barriers to VTC commercialization. To achieve these objectives, personal interviews were conducted with individuals in the forest products industry. The resulting qualitative data were then analyzed.

Theoretical Background

Global demand for wood fiber

There are several factors affecting the long-term global demand for wood fiber, such as world population, gross domestic product (GDP), growth of developing economies, and environmental policies and regulations. The harvest of natural forests has decreased while harvests on plantation forests have increased; the combination of these two factors has greatly affected the global supply for wood fiber, which has indirectly affected demand (Food and Agriculture Organization of the United Nations [FAO] 2009). The world population is expected to grow from 6.7 billion in 2010 to 8.2 billion in 2030, while the global GDP is expected to increase from US$55 trillion in 2010 to US$100 trillion in 2030 (FAO 2009). Many nations throughout the world are becoming more developed, with an increased standard of living and demand for wood and paper products. The environmental policies and regulations in several countries greatly restrict the ability to use the domestic forests for wood production. Additionally, energy policies are encouraging the use of woody biomass for fuel. In 2005, the world production of wood products was approximately 417 million m^3 and the world consumption was 421 million m^3. By 2030, these numbers are expected to rise to 603 and 594 million m^3, respectively (FAO 2009). The highest growth in production is expected to occur in the Russian Federation, Eastern Europe, and South America, while increased consumption is expected to dominate in Africa, Asia, and the Pacific (FAO 2009).

The increased reliance on plantation fiber in the years to come is not a perfect solution to mounting wood demands, however. Trees in a naturally generated forest can take 50 years or more to reach a harvestable age, while those grown in a plantation can be harvested in fewer than 20 years (Taylor and Fortson 1991). The shortened time to harvest is a substantial benefit of plantations, but the demand for certain types of wood products may not be met with trees that are rapidly grown. Trees grown in short rotations have a higher percentage of juvenile wood than trees grown in longer rotations, which can result in undesirable wood properties. As of 2005, there were more than 110 million hectares of forest plantations worldwide (FAO 2006). The majority of fiber produced from plantations is suitable for papermaking and biofuel feedstock, but it is not usable in structural applications due to its low density and inadequate mechanical properties (FAO 2009). The increasing global population and resulting dependence on plantation fiber calls for some sort of solution to meet global demands for structural wood products.

One part of this solution could be the commercialization of VTC wood. Due to VTC wood's increased mechanical properties, structural wood products could be created from plantation fiber. The advantages of VTC wood are many. Since the VTC process creates a manufactured product, it is able to utilize small-diameter, low-density logs that can be grown in plantations with a short rotation time. The VTC process is also customizable; the temperature, steam, and compression can be altered to produce material with a specific density and strength. Another advantage is the ability to manufacture composite products with less material because of the increased mechanical properties of VTC wood.

New product development

New product development (NPD), or product innovation, can be defined as the creation of new products. Throughout the years, several NPD processes have been developed; all combine steps, activities, decisions, and goals in one way or another to produce new products. A basic NPD process, developed by Crawford and Di Benedetto (2008), consists of five steps: opportunity identification and selection, concept generation, concept and project evaluation, development (both technical and marketing), and launch. For the purposes of this study, concept evaluation is the focus. Concept evaluation is the evaluation of new product concepts based on technical, marketing, and financial criteria. Generally, the two or three best concepts will be carried to the next step of the NPD process, which is development (Crawford and Di Benedetto 2008).

NPD and innovation in the forest products industry.—Traditionally, the forest products industry has been more focused on production than on the customer, with a production-oriented, low-cost strategy being the norm (Juslin and Hansen 2003, Crespell et al. 2006). However, a more customer-oriented approach has begun to take precedence (Juslin and Hansen 2003). It has been found that many forest products companies are trying to move toward a market orientation (Cohen and Kozak 2001, Hansen and Juslin 2005, Hansen et al. 2007).

With respect to innovation, the industry is focused on process innovation rather than product or business systems innovation (Crespell et al. 2006, Hansen 2006). Depending on how it is marketed, VTC can be referred to as a product innovation (VTC wood), process innovation (VTC process), or both.

In addition to being more production oriented and focused on process innovation, the forest products industry is notorious for having a change-resistant culture (Hansen et al. 2007). Resistance to change is present in both the company and the marketplace, and ''the bureaucracy of building codes and standards can hamper innovation, and, in turn, the innovativeness of manufacturers'' (Hansen et al. 2007, p. 1330).

NPD processes.—There is a significant number of NPD processes used today, which are becoming more complex with time. NPD processes are important because the consistent use of a formal NPD process is often a differentiating factor between a company's success and failure (Griffin 1997). Two commonly used NPD processes are those developed by Cooper and Kleinschmidt (1986, called Stage-Gate) and Crawford and Di Benedetto (2006). In this study, the concept evaluation step (concept testing) of the NPD process was used to better understand buyer preferences and opinions regarding VTC wood.

Concept testing.—Regardless of the name it is given, concept testing has been used in one form or another for many years. Concept testing is one of many market research tools used to understand the opinions, needs, and preferences of a given population. Business-to-business firms consistently engage in concept testing activities; much time is spent talking with customers about problems, needs, suggestions, and new ideas (Crawford and Di Benedetto 2008). According to Ulrich and Eppinger (2008), the principal benefit of concept testing is the feedback received from actual customers or users of the product in question.

Because of the exploratory and often qualitative nature of concept testing, it is essential to interview as many stakeholders as possible associated with the proposed product (Patrick 1997). Those who will be involved in the purchase or use of the product or who might know how the product could be improved must be consulted during concept testing (Crawford and Di Benedetto 2008). The vast majority of concept testing occurs through personal contact, such as direct interviewing or telephone interviews (Crawford and Di Benedetto 2008). Even though concept testing can be done over the phone, face-to-face interviews are ideal because they give the interviewee an assurance of confidentiality, the option to ask questions if something is unclear, and the ability to see a physical sample of the product (Patrick 1997, Crawford and Di Benedetto 2008). The qualitative information gathered through open-ended discussions with interviewees may be the most valuable result of concept testing (Ulrich and Eppinger 2008) since the goal is to explore what people are doing and thinking rather than to take a poll (Crawford and Di Benedetto 2008).

Prior to an interviewee being asked questions, it is important to communicate the concept. This can be done in a variety of ways, from a verbal description of the product to the presentation of a working prototype (Ulrich and Eppinger 2008). The order in which information is gathered during a concept-testing interview is important. First, the interviewer should acquire background information from the interviewee. Questions about how the interviewee currently tries to solve his or her problems, his or her openness to change, and benefits he or she seeks in current products are all examples of background information. The background information can then be used by the interviewer to assist in the interpretation of the interviewee's comments about the new product concept (Crawford and Di Benedetto 2008). To get a feel for the interviewee's take on the product concept, the interviewer might ask if the concept solves a problem, what changes could be made to the concept, what the concept would be used for and why, or what products or processes the concept would replace (Crawford and Di Benedetto 2008).

Once the concept testing interviews are complete, the results must be used with caution. The only real information acquired is an indication of likely product acceptance (Cooper 2001). If the product concept is innovative, new, or unfamiliar to the interviewee, the results may actually understate the product's acceptance (Cooper 2001). This is due to the fact that unfamiliar concepts tend to draw a negative response initially, but the response is often changed with time and exposure (Cooper 2001, Crawford and Di Benedetto 2008). The information gleaned from concept testing should be used to decide whether or not to proceed with the next step of the NPD process development (the next step toward commercialization).

Methods and Data Analysis

Data for this study were collected by personal interviews, which are commonly used in qualitative research. In personal interviews, data are collected via a face-to-face or telephone conversation between the interviewer and the interviewee. In this study the interviewer asked questions of the interviewee(s) in both face-to-face and telephone conversations, which were audio recorded. The product concept was communicated with both a verbal description and a working prototype. The recorded responses were then transcribed word for word to ensure accuracy.

Personal interviews

There are several advantages to personal interviews compared with other methods of data collection. First, the researcher has the ability to explore the interviewee's attitudes, beliefs, and motives in more depth compared with other research methods (Barriball and While 1994). Second, researchers may acquire additional information by asking follow-up questions guided by the interview or by interviewees providing additional information in response to questions the researcher did not think to ask. The primary disadvantages are cost and time.

Study design

Interview protocol development.—A semistructured interview, rather than a structured interview, was chosen for this study due to the exploratory nature of the questions. This type of interview was chosen because of the interviewer's ability to ask additional questions spurred by interviewees' responses; a structured interview only allows the interviewer to ask questions found in the interview protocol.

Prior to beginning the personal interviews, a semistructured interview protocol was developed. According to Flick (2002), a semistructured interview protocol serves three main functions in an interview: ensures answers to the main topics are gathered from all interviewees, serves as a guide to keep both the interviewer and interviewee on topic, and keeps the interview moving forward if dialogue between the interviewer and interviewee lags or stops. The complete interview protocol used in this study can be found in Table 1.

Pretesting.—Pretesting of the interview protocol consisted of open-ended, casual, face-to-face interviews with three salespeople in the forest products industry and one venture capitalist. Those interviewed were chosen by convenience sampling, which may not produce the best results but saves on time, money, and effort (Patton 1990). The interviews provided a means to generate ideas, questions, thoughts, and reactions from key individuals concerning the use and application of VTC wood. The information gathered during pretesting was utilized to fine-tune the semistructured interview protocol.

Development of interview reference materials.—An information sheet was created to provide the interviewees with materials to reference during the interview. The information sheet contained facts about the mechanical properties of VTC wood and those of commonly used wood species. Several graphs were also created to visually compare the density and mechanical properties of VTC wood and other building materials. In addition, physical samples of undensified hybrid poplar and hybrid poplar treated with the VTC process were shown to the interviewees.

Table 1.—Semistructured interview protocol for forest products industry.

Question
1. What is your job title (e.g., production, retail, wholesale, marketing)?
2. What do you see as the greatest unmet need for your customers?
3. In what applications do your customers find wood limiting because of strength or other properties? What are those limiting properties?
4. What are the greatest objections you receive concerning existing wood products for structural applications? For aesthetic applications?
5. In which existing products do you think VTC[a] wood could be used?
6. Do you have any new product ideas that could incorporate VTC wood?
7. What do you see as advantages to the commercialization and/or use of VTC wood?
8. What do you see as barriers to the commercialization and/or use of VTC wood?
9. What do you consider a ''deal breaker'' concerning your decision to use or not use VTC wood?

[a] VTC = viscoelastic thermal compressed.

Data collection and analysis

Snowball sampling.—The interviewees in this study were identified through the use of ''snowballing.'' Snowballing is the process of identifying new interviewees based on the recommendations of previous interviewees, and is ''based on the premise that members of a rare population know one another'' (Lohr 1999, p. 403). It's possible to create a large sample by snowballing; however, it is not a probability sample due to the breach of statistical assumptions (independent observations, homogeneity of variance, normality) that occur (Lohr 1999).

Sample selection.—The first group of interviewees was selected based on their attendance at the North American Wholesale Lumber Association (NAWLA) annual conference that took place in Chicago, Illinois, November 5 to 7, 2009. Each year the NAWLA conference is attended by approximately 1,500 individuals employed throughout the forest products industry. Attendees range from production personnel to sales and marketing associates. A large component of the conference is the Trader's Market, where companies set up information booths. Conference attendees have the opportunity to see what other companies are doing, learn about new products, and catch up with others in the industry. Because so many people from the forest products industry were in the same place at the same time, the NAWLA conference was an ideal opportunity for data collection.

Two weeks before arriving in Chicago for the Trader's Market, an e-mail was sent to 20 individuals in the forest products industry who planned to attend the conference. The 20 individuals contacted were identified as knowledgeable by those interviewed during pretesting and by faculty at Oregon State University. The purpose of the e-mail was to secure a few interviews prior to arriving at the conference. A total of 10 interviews were conducted at the NAWLA conference: 9 in individual interviews and 1 in a group interview. Two interviewees participated in the group interview. Interviewees were all part of the forest products industry and included three in manufacturing, two wholesalers, two manufacturer/wholesalers, two distributors (companies that sell wood products as well as other building materials), and two treaters (Table 2).

The second group of interviewees was selected based on their proximity to Corvallis, Oregon, and/or the researcher's desire to interview individuals from a wide variety of companies and backgrounds. A total of nine interviews were conducted after the NAWLA conference: three phone interviews and six face-to-face interviews (two face-to-face interviews were also group interviews). Two interviewees participated in one group interview, and three interviewees participated in the second group interview. Phone interviews were minimized because those interviewees were not able to see and touch the working prototypes. Of those interviewed

Table 2.—Forest products interviewees by position and location of interview.[a]

Interviewee category	Geographic area of interview		Total
	NAWLA	Other	
Manufacturer			
General manager	1	2[b]	3
Sales manager	2	0	2
Marketing manager	0	2[c]	2
Sales	0	1[c]	1
R&D	0	3[b]	3
Wholesaler			
Sales and marketing manager	1[d]	0	1
Sales	1[d]	0	1
Manufacturer/wholesaler			
General manager	1	0	1
Buyer	1	0	1
Distributor	2	0	2
Exporter	0	1	1
Treater	2	0	2
Trade association	0	2	2
Total	11	11	22

[a] NAWLA = North American Wholesale Lumber Association; R&D = research and development.
[b] This was a group interview consisting of three people from the same company (one manufacturer general manager and two manufacturer R&D employees).
[c] This was a group interview consisting of two people from the same company (one manufacturer marketing manager and one manufacturer sales employee).
[d] This was a group interview consisting of two people from the same company.

in the second group, eight were in manufacturing, two in trade associations, and one was an exporter (Table 3).

Data collection.—The interviews ranged from 20 minutes to 1 hour in length and were audio recorded digitally. Audio recording enabled the researcher to accurately preserve the interview data and to be more immersed in the conversation (Yin 1994). The audio recordings were then transcribed verbatim, and the resulting transcripts were used for data analysis. In total, the transcribed interviews were 74 double-spaced pages of text (Arial font, 12-point type size).

Each interviewee was placed in one of three interviewee categories: manufacturing, sales, or other. The manufacturing category included manufacturers, manufacturers/wholesalers, and treaters; the sales category included wholesalers, distributors, and exporters; and the other category included those in trade associations.

Data analysis.—After the interviews were transcribed, an exhaustive list of answers was compiled for each of the nine questions in the interview protocol. Once the list was completed, the frequency of each response was recorded every time an interviewee mentioned it. This process was completed for each of the nine questions. The end result was a list of the nine questions asked with all corresponding responses and the frequency of each response. The list was broken down by interviewee category for each question. This method of analysis was deemed appropriate due to the exploratory nature of the research as specified by the objectives.

Results and Discussion

To ensure anonymity, all interviewees are referred to by their position within the forest products industry (e.g., manufacturing manager, distributor, exporter). All results are presented regardless of the frequency of each response. Responses with a frequency of 1 are considered equally ‘‘significant’’ to those with a frequency of 10, due to the wide range of interviewee background and the potential for VTC wood to be successful in a niche market.

Greatest unmet customer needs

Twenty-two interviewees identified 10 different unmet customer needs. A few of the interviewees identified more than one unmet need facing their customers. All responses are listed from the highest to lowest frequency in Table 3.

The four most frequently reported unmet customer needs with respect to the forest products industry were product consistency, product quality, demand, and maintenance-free products. Other reported unmet customer needs were achieving increased mechanical properties, aesthetics, dimensional stability, product ability to withstand hurricanes, product meets end user's specifications, and availability of products with desired certifications (e.g., California Air Resources Board, Forest Stewardship Council).

Several interviewees reported consistency (of both the product and the supply) as their customers' greatest unmet need:

> Wood is a natural product . . . it's not a manufactured product. There's even some species of panels you're not going to get stability out of. I would say the biggest unmet need is consistency and stability for building products that are used today. *Manufacturer/Wholesaler, General Manager*
>
> I think in general I would say a guaranteed supply of consistently low-priced raw material. I really think in the marketplace, as long as what they're buying works for them, what matters the most is price and dependability of the supply. Our biggest concern is availability of the resource that will fit our product. *Manufacturer, General Manager*

In addition to consistency, product quality was reported as an unmet customer need:

> The quality of the veneer, because as the logs have gotten smaller the peels have gotten rougher, the lathes go faster. Finding good, consistent, smooth peels is definitely the hardest thing. *Manufacturer, Manager*
>
> I think there's a huge need in terms of the quality of the material we get . . . it's degraded over the last twenty years. We're trying to make high quality products with lower quality raw materials. *Manufacturer, Marketing Manager*
>
> I'm going to put the question into the sense of what I'm not getting, versus what they're [my customers] not getting . . . consistency of the quality of the product. Consistency of quality of the product within the grades is what I'm not getting. *Treater*

Applications where wood is limiting

Interviewees were asked to identify applications where wood is limiting, as well as the greatest objections concerning the use of wood in structural applications. Eight different applications were reported (Table 4). The interviewee responses are listed from the highest to lowest frequency.

Table 3.—Greatest unmet customer needs.[a]

Response	Interviewee category: Manufacturing	Sales	Other	Total
Product consistency	3	1		**4**
Product quality	2	1		**3**
Demand		1	1	**2**
Maintenance-free products	1	1		**2**
Achieving increased mechanical props.	1			1
Aesthetics	1			1
Dimensional stability	1			1
Product ability to withstand hurricanes	1			1
Product meets end user's specifications		1		1
Products with desired certification	1			1

[a] The frequency of each response by interviewee category is provided. Bold numbers indicate the most frequently mentioned responses.

According to the interviewees, wood is most limiting in applications associated with high strength, dimensional stability, fire ratings, and long spans. In this context, ''strength'' refers to a variety of wood properties, such as modulus of rupture (MOR) in bending, compression, tension, and shear. Dimensional stability and spans are also a common issue and can be a restriction when building with wood. Additional reported limitations involve building codes, cost, contact with insects, and weathering. The majority of interviewees stated two or more applications where they find wood limiting:

> There are two limiting factors we find . . . span ratios . . . and in a groundsill application . . . strength for compression and bugs. *Exporter*

> Wood is limiting in everything we do . . . from quality, availability, the quirky aspects, how it moves, and how our customers use it. But it's also the attraction. *Manufacturer, Sales*

> One limiting area of wood would be its bending properties. Quite often we're asked to make a product conform to a curve, and the biggest limiting factor in that scenario is being able to conform wood to a small enough radius without either breaking it or having too much tension. Another problem we have with wood is dimensional stability. *Manufacturer, R&D*

> Wood is very limiting in lots of applications. Certainly we've overcome some of those in the last few years, but in some parts of the world you still can't build over two stories with wood. *Trade Association*

Table 4.—Applications where wood is limiting.[a]

Response	Interviewee category: Manufacturing	Sales	Other	Total
High strength	4	2	2	**8**
Dimensional stability	3			**3**
Fire rating	2		1	**3**
Spans	1	2		**3**
Building codes	1		1	2
Cost	2			2
Contact with insects		1		1
Weathering			1	1

[a] The frequency of each response by interviewee category is provided. Bold numbers indicate the most frequently mentioned responses.

Potential products to incorporate VTC wood

Interviewees were asked to identify products that could potentially benefit from the incorporation of VTC wood, as well as any new product ideas. Of all the questions posed to the interviewees, this question resulted in the widest array of responses. On average, each interviewee reported three products they believe could be improved by the addition of VTC wood. Table 5 lists interviewee responses from the highest to lowest frequency.

As a whole, the 22 interviewees identified 17 products that could benefit from incorporation of VTC wood. Both structural and nonstructural products were mentioned. Structural products, such as LVL, glulams, plywood, concrete forms, and components for transportation vehicles were mentioned with the highest frequency. LVL was likely mentioned most frequently due to the relative ease with which VTC veneers could be incorporated into conventional LVL. The same is true for both plywood and concrete forms. Nonstructural products mentioned were composite flooring, wood window and door frames, crates and packaging, decking, underlayment, and furniture:

Table 5.—Potential products to incorporate viscoelastic thermal compressed wood.[a]

Response	Interviewee category: Manufacturing	Sales	Other	Total
Laminated veneer lumber	5	1	2	**8**
Concrete forms	3	1	2	**6**
Flooring	4	2		**6**
Components for boat/car/train/truck interiors	3		1	**4**
Doors	3	1		**4**
Glulams	3		1	**4**
Plywood	1	3		**4**
Wood window frames	4			**4**
Commercial truck/trailer beds	3			3
Crates/pallets/packages	1	1	1	3
Decking	2			2
I-joists	1		1	2
Underlayment	1	1		2
Cabinets		1		1
Furniture			1	1
Manufactured housing	1			1
Parallel strand lumber	1			1

[a] The frequency of each response by interviewee category is provided. Bold numbers indicate the most frequently mentioned responses.

VTC wood could be used in concrete forms, and some sort of LVL application. It is also possible for wood that gets bonded with steel or something else, such as parts for rail cars. There are also parts that have a plywood core, and they put steel around it. They buy premium panels for the parts encased with steel. *Manufacturer, General Manager*

The number one place, especially in the European market, is in the wood window and door industry. In an area where you need a single piece of wood that has good tension strength, and all of the characteristics that you're trying to work with. When you're doing any engineered wood product, you need something with stability and strength. *Treater*

I would use it [VTC wood] in boats, truck bed decking, Great Dane trailers, and applications like that. *Manufacturer, Sales Manager*

You're really looking at some sort of product like a high density LVL, a modified glulam, a big I-beam, or maybe a high-strength post. That's where I see it instantly. . . . I don't see it in residential construction except for maybe in a big beam over a garage door or something similar. *Trade Association*

The specialty plywood market, with face veneers, with melamine versus compressed hardwoods versus stripped veneer, that market would definitely use something like this [VTC wood] because this would have an application where the rigidity would allow it to be used for cabinet stock, cabinet frames and things like that. Non-appearance grade where they might be interested in something this hard is a specialty poly-fill plywood that's used for concrete forms . . . it's pretty expensive, uses a petroleum-based paper, and is not environmentally friendly. Those are two areas where I could see this being used. *Exporter*

I think if some of our lower grade veneers we currently can't use in LVL were treated with the VTC process, they would become a viable product for use in LVL. *Manufacturer, R&D*

A few interviewees asked whether VTC wood could be made into three-dimensional shapes, such as those necessary for transportation vehicle components. This ''outside the box'' thinking did not occur often, however. Many interviewees only felt comfortable suggesting products that they work with on a daily basis, rather than products unfamiliar to them that could incorporate VTC wood.

The interviewees' hesitation to suggest products unfamiliar to them was not surprising because it is a common occurrence with radical innovations. Oftentimes the interviewees did not completely understand the innovation, and therefore held back suggestions that might not make sense. Other times, they had trouble thinking about the product in an actual application since they were limited to the interviewer's explanation and a few small samples.

Advantages to the commercialization and use of VTC wood

Interviewees were asked what advantages might occur from the commercialization and/or use of VTC wood. Table 6 lists interviewee responses from the highest to lowest frequency.

The two most commonly mentioned advantages to the commercialization of VTC wood were increased mechanical properties and the utilization of low-value wood species, which are also the most apparent. Interviewees seemed intrigued and excited by the possibility of a wood product with the properties attainable through the VTC process. In addition, the possibility of turning a structurally unusable wood species, such as hybrid poplar, into a structural element piqued the interest of several interviewees. Due to the mechanical properties made possible by the VTC process, capturing part of the steel market seemed viable to some. A few of those interviewed stressed that the ''ultimate goal'' of new forest products is to take as much market share away from steel and concrete as possible. Since the strength to weight ratio of VTC wood is greater than that of steel, this goal could be attainable. The following quotes illustrate what some of the interviewees consider advantages to the commercialization/use of VTC wood:

The MOR boost is the key. It really buys us a whole heck of a lot, because it allows us to do so much more with our regular stock. We wouldn't have to use a ton of VTC wood; it would just be to supplement our product. *Manufacturer, Sales Manager*

For some applications you might want either LVL or plywood to span a little longer, and for the concrete form you might want a denser surface. *Trade Association*

The possibility of creating wood that's smaller in dimension than what you're currently using that achieves the same or better properties. *Manufacturer, General Manager*

Taking lower density species and making high quality, strong products. *Wholesaler, Sales and Marketing Manager*

You can take twelve year old plantation poplar and make structural components from it . . . that's valuable. *Manufacturer, General Manager*

It opens up a pool of raw material that currently isn't usable for various applications. You could take a fiber resource base that prior to this process would never have the value or the ability to go into a given application. A lot of these species you're dealing with here, they're a fiber that has very limited application. *Manufacturer, R&D*

In addition, interviewees considered the time necessary for commercialization as an advantage with respect to nonstructural products. Several of those interviewed believe that a nonstructural product with VTC wood would take significantly less time and scrutiny to commercialize than a structural product with VTC wood. A structural product would take a considerable amount of testing and time to be approved for use in building applications. A nonstructural product would not require extensive testing, and would be available for use earlier than a structural product.

Barriers to the commercialization and use of VTC wood

Interviewees were asked to identify barriers that might hinder the commercialization and/or use of VTC wood. Barriers are important to understand because they can be improved upon or eradicated before VTC wood proceeds to

Table 6.—Advantages to the commercialization/use of viscoelastic thermal compressed (VTC) wood.[a]

Response	Interviewee category			Total
	Manufacturing	Sales	Other	
Increased mechanical properties	7	3	2	**12**
Add value to low strength species	4	3		**7**
Create thinner/lighter products	5	1	1	**7**
Potential to capture some of steel market	2	1	2	**5**
Create products with longer spans		2	1	3
Utilize rapidly grown species	3			3
Increase product density		1	1	2
Open up a new resource pool	2			2
Color change as result of VTC process		1		1
Consistency/uniformity of end product	1			1
Use of local product/resource			1	1

[a] The frequency of each response by interviewee category is provided. Bold numbers indicate the most frequently mentioned responses.

the development step of the NPD process. Table 7 lists interviewee responses from the highest to lowest frequency.

The following quotes illustrate what some of the interviewees consider barriers to the commercialization/use of VTC wood:

> Cost would be the first hurdle, and the second would be getting market acceptance. Whether it's the builders, or lumbermen, or whatever, they don't care whether the wood cells collapsed or not. They don't care about any of that ... they just want to know if the product will perform, or if there's some sort of marketing advantage, whether it's price, installation, whatever it may be. Market acceptance and cost seem like a challenge. *Distributor*

> Number one, probably that it's a new product. This is a very old school industry; everything is grandfathered in. *Treater*

> People in this industry are slow to change to new ideas. Getting people comfortable with it is tough ... but on the other hand they did make the move from plywood to OSB. To find people that are willing to take those initial risks ... you're going to have to go to some really major starting points in the construction industry. *Manufacturer, R&D*

> Number one barrier [to commercialization] is cost ... that's what anybody will tell you and it's probably true. *Trade Association*

> If you compress wood, your yield is maybe half of what your supply was. Plus manufacturing costs, it seems very expensive. From that standpoint, you'd have to have a very special and niche market. *Manufacturer, Sales*

Interviewees had the most similar answers to potential barriers of the commercialization of VTC wood than they did to any other question. More than half of those interviewed mentioned the industry's cost focus and/or the cost of production as a significant barrier to commercialization. In addition to cost, the majority of interviewees believed the industry's resistance to change will be a barrier to both the commercialization and use of VTC wood. Several individuals made reference to the products and methods of doing things in the forest products industry as being ''grandfathered in.'' In other words, people continue to do things a certain way because that's how they've always been done, rather than because their way is the most efficient or effective. Even though this way of thinking continues to prevail in the forest products industry, some new products have managed to become successful. Oriented strand board, LVL, composite flooring products, I-beams, medium-density fiberboard, and composite decking are a few examples of products that were successfully commercialized and are now widely used. Their success can be attributed, in part, to superior performance and/or cost compared with similar products on the market.

To circumvent the industry's cost focus, VTC wood might have to enter the market as a specialty product that

Table 7.—Barriers to the commercialization/use of viscoelastic thermal compressed (VTC) wood.[a]

Response	Interviewee category			Total
	Manufacturing	Sales	Other	
Cost focus of industry/cost of production	10	2	2	**14**
Industry's resistance to change	8	2	2	**12**
Raw material supply	3	1	1	5
Dimensional stability	1	2		3
Energy consumption of process	3			3
Volume loss from input to output	2		1	3
Interaction between VTC wood and undensified wood in a composite	1	1		2
Introduction of VTC wood could slow down production process	2			2
Someone could buy VTC technology and shelve it	1	1		2
Brittleness	1			1
Color change as a result of the VTC process	1			1

[a] The frequency of each response by interviewee category is provided. Bold numbers indicate the most frequently mentioned responses.

Table 8.—Deal breaker to use viscoelastic thermal compressed wood.[a]

Response	Interviewee category			Total
	Manufacturing	Sales	Other	
Cost	5	3	1	**9**
Market acceptance of product	7			**7**
Raw material supply	1	3	1	**5**
Exclusivity/licensing of technology	3	1		4
Product appearance/color	3			3
Environmental certification	2			2
Environmental impact of process	1			1
Fire rating	1			1
Glue bonds	1			1

[a] The frequency of each response by interviewee category is provided. Bold numbers indicate the most frequently mentioned responses.

doesn't compete primarily on price. This may be the only way to get VTC wood into the hands of design professionals and those in the forest products industry toward the beginning of its commercialization.

Deal breaker to use VTC wood

Interviewees were asked to identify a ''deal breaker'' as to whether they would use VTC wood if it were available in the marketplace. Although similar to barriers, deal breakers differ in that they often cannot be overcome. Table 8 lists interviewee responses from the highest to lowest frequency.

The deal breakers reported by interviewees with the greatest frequency were identical to those mentioned in barriers to commercialization: cost and market acceptance. Since deal breakers often cannot be overcome, extra effort must be expended to minimize the cost of VTC wood and how it is introduced in the market. If the cost of VTC wood products cannot compete with that of similar products, it may be forced to compete in a niche market that is less cost-focused. Unfortunately, cost is still the primary focus for commodity products in the forest products industry. Other commonly mentioned deal breakers were raw material supply and how the VTC technology is going to be licensed. A few interviewees stated they would only consider purchasing the VTC technology if they were guaranteed some level of exclusivity. If the technology was available to all interested companies, it could become a commodity and the original investing company(ies) would not have an advantage in the marketplace. Some interviewees were also concerned with the raw material supply. If VTC wood were to take off, is there enough low-value wood to support demand? Poplar may be inexpensive now, but what if it becomes expensive in the future? These are both questions that need to be carefully considered. The following quotes illustrate what some of the interviewees consider deal breakers:

> On a purchasing side, or distribution/marketing side, it would be how it would be licensed. How much control can I have over my own destiny, are you going to go sell this to everybody, so that it becomes a commodity and isn't viewed as a value product anymore. So, that's a deal breaker to me. *Manufacturer, Sales Manager*

> The only thing that would make us use it is if it performed and met our customers' specs, and did so in a fashion where we could buy the material and our customers were willing to pay the extra costs to get better performance. *Manufacturer, General Manager*

> One is the discoloration . . . that's a definite drawback. I would have a problem because it wouldn't match my other components. *Manufacturer, Marketing Manager*

> And then again, the visual side of things . . . for us, it would be used as a visual member. The darker color could be desirable, depending on what the customer asks for . . . but the biggest deal with color is consistency. As long as the color is consistent, I could see it being used for products like we're using right now. *Manufacturer, R&D*

Conclusions

VTC wood can both fulfill the needs satisfied by current products and go beyond what's currently available in wood products. Interviewees thought VTC wood could most likely be used in LVL, plywood, concrete forms, transportation components, and flooring. Advantages to commercialization included increased mechanical properties and the utilization of a low-value wood species; barriers to commercialization were the forest products industry's resistance to change and cost focus. Overall, interviewees seemed to think VTC wood would be successful as long as it was not markedly more expensive than similar products.

Before VTC wood's ideal location in the market can be determined, cost of production must be known. If VTC wood is going to cost significantly more than high-grade veneer, for example, it may not be able to compete. If this is the case, VTC wood may be better suited to a specialty product in a niche market. The forest product industry's cost focus will be a significant factor in the success or failure of VTC wood.

In the future, it would be beneficial to conduct additional interviews in which the interviewer is equipped with cost information for VTC wood. Samples produced from a continuous process, rather than a batch process, would present a more accurate representation of the final product's appearance and properties. Prototypes could help interviewees visualize the product and respond to it in a less abstract fashion. It might also be advantageous to have completed all testing on VTC wood prior to conducting more interviews.

Limitations

The three major limitations of this study were the interview locations, the interviewees themselves, and the interviewees' lack of understanding of the VTC process. The interviews were limited to Chicago, Illinois, and Portland, Oregon. Most of the interviewees interviewed in Chicago were not from the Pacific Northwest, but all of those interviewed in Portland lived there as well. Only one interviewee lived and worked outside of the United States. The interviewees could also be considered a limitation because of the way they were identified. Snowball sampling was used to identify interviewees, but oftentimes the individuals solicited by the interviewer were unresponsive and an interview did not occur. As a result, interviewees with a particular personality or greater interest in VTC wood may have been the ones to consent to an interview. The third limitation was the interviewee's lack of understanding of the VTC process. The VTC process was explained to each interviewee prior to beginning the interview, but some interviewees may have not completely understood and answered based on some level of confusion.

Literature Cited

Barriball, K. L. and A. While. 1994. Collecting data using a semi-structured interview: A discussion paper. *J. Adv. Nurs*. 19(2):328–335.

Bowyer, J. L., R. Shmulsky, and J. G. Haygreen. 2007. Forest Products and Wood Science: An Introduction. Blackwell Publishing, Ames, Iowa. 558 pp.

Cohen, D. H. and R. A. Kozak. 2001. Research and technology: Market-driven innovation in the twenty-first century. *Forestry Chron*. 78: 108–111.

Cooper, R. G. 2001. Winning at New Products: Accelerating the Process from Idea to Launch. Perseus Books Group, New York. 425 pp.

Cooper, R. G. and E. J. Kleinschmidt. 1986. An investigation into the new product process: Steps, deficiencies, and impact. *J. Prod. Innov. Manag*. 3(2):71–85.

Crawford, M. and A. Di Benedetto. 2006. New Products Management. 7th ed. McGraw-Hill/Irwin, New York. 540 pp.

Crawford, M. and A. Di Benedetto. 2008. New Products Management. 9th ed. McGraw-Hill, New York. 558 pp.

Crespell, P., C. Knowles, and E. Hansen. 2006. Innovativeness in the North American softwood sawmilling industry. *Forest Sci*. 52(5): 568–578.

Flick, U. 2002. An Introduction to Qualitative Research. Sage Publications, Thousand Oaks, California. 310 pp.

Food and Agriculture Organization of the United Nations (FAO). 2006. Global forest resources assessment 2005. FAO, Rome. 320 pp.

Food and Agriculture Organization of the United Nations (FAO). 2009. State of the world's forests. FAO, Rome. 145 pp.

Griffin, A. 1997. PDMA research on new product development practices: Updating trends and benchmarking best practices. *J. Prod. Innov. Manag*. 14(6):429–458.

Hansen, E. N. 2006. The state of innovation and new product development in the North American lumber and panel industry. *Wood Fiber Sci*. 38(2):325–333.

Hansen, E. N. and H. Juslin. 2005. Marketing of forest products in a changing world. *N. Z. J. Forest Sci*. 35:190–204.

Hansen, E. N., H. Juslin, and C. Knowles. 2007. Innovativeness in the global forest products industry: Exploring new insights. *Can. J. Forest Res*. 37:1324–1335.

Juslin, H. and E. N. Hansen. 2003. Strategic Marketing in the Global Forest Industries: 2003 Update. Authors Academic Press, Corvallis, Oregon. 609 pp.

Kamke, F. 2006. Densified radiata pine for structural composites. *Maderas Cienc. Tecnol.* 8(2):83–92.

Kamke, F. A. and H. Sizemore III. 2008. Viscoelastic thermal compression of wood. US patent 7,404,422 B2.

Kollmann, F. P., E. W. Kuenzi, and A. J. Stamm. 1975. Principles of Wood Science and Technology. Vol. II: Wood Based Materials. Springer-Verlag, New York. pp. 139–149.

Kultikova, E. V. 1999. Structure and properties relationships of densified wood. Master's thesis. Virginia Tech, Blacksburg. 136 pp.

Kutnar, A., F. A. Kamke, and M. Sernek. 2008. The mechanical properties of densified VTC wood relevant for structural composites. *Holz Roh- Werkst*. 66(6):439–446.

Kutnar, A., F. A. Kamke, and M. Sernek. 2009. Density profile and morphology of viscoelastic thermal compressed wood. *Wood Sci. Technol*. 43(1):57–68.

Lohr, S. L. 1999. Sampling: Design and Analysis. Duxbury Press, Pacific Grove, California. 494 pp.

Patrick, J. 1997. How to Develop Successful New Products. NTC Business Books, Chicago. 214 pp.

Patton, M. Q. 1990. Qualitative Evaluation and Research Methods. Sage Publications, Newbury Park, California. 532 pp.

Taylor, R. G. and J. C. Fortson. 1991. Optimum plantation planting density and rotation age based on financial risk and return. *Forest Sci*. 37(3):886–902.

Ulrich, K. T. and S. D. Eppinger. 2008. Product Design and Development. McGraw-Hill, New York. 368 pp.

World Resources Institute. 2007. Sustainable procurement of wood and paper-based products: Plantations. http://www.sustainableforestprods.org/node/24. Accessed February 25, 2010.

Wright, J. A., A. DiNicola, and E. Gaitain. 2000. Latin American forest plantations: Opportunities for carbon sequestration, economic development, and financial returns. *J. Forestry* 98(9):20–23.

Yin, R. 1994. Case Study Research: Design and Methods. Sage Publications, Thousand Oaks, California. 171 pp.