Improvements to the Understanding of the Fire Performance of Wood over the Past 30 Years - A Tribute to Robert Hawthorne White

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Abstract

Dr. Robert Hawthorne White had a 31 year career researching the fire performance of wood and wood composites at the USDA Forest Products Laboratory. Over his career, Dr. White made substantial contributions to codes, standards, and regulations pertaining to the design of wood structures. This review article summarizes Robert's major accomplishments as a tribute to his career at the Forest Products Laboratory.

Introduction

Robert Hawthorne White began his career at the USDA Forest Service, Forest Products Laboratory (FPL) in 1972 as a summer intern while obtaining his undergraduate degree from Pennsylvania State University. He returned to FPL after completing his M.S. in Forest Products at Oregon State University. He began his formal research career at FPL in 1980, while simultaneously pursuing his Ph.D. at the University of Wisconsin, Madison, which he obtained in 1988. Over his research career, Robert published over 120 technical papers and gave 58 scientific presentations (of which 23 were invited). Additionally, he made substantial contributions to ASTM standards on the fire performance of wood materials through his work on ASTM International (formerly known as the American Society for Testing and Materials) committees E5 (fire) and D7 (wood).

Concurrent with Robert's career, our knowledge of the fire performance of wood and wood products has greatly changed in the past 30 years. This paper highlights Robert's contributions to the current understanding of fire in wood products, especially his contributions to the fundamental understanding of char formation and structural fire performance of wood. Robert's major scientific accomplishments are summarized below in roughly chronological order.

KEYWORDS : *Wood, Char, Fire Resistive Coatings, Fire Resistance*

Dr. Robert H. White

Fundamental Studies of Char in Wood

One of Robert's first and most important accomplishments was his contribution to the understanding of the development of char in wood. When wood is exposed to high temperatures, it decomposes into char. Char is thermally insulating and helps to protect the remaining wood material from damage. The rate of char formation determines how fast the wood member is consumed in a fire and how fast the load bearing capacity of the wood is reduced during a fire. Throughout his career, Robert made notable advances in how we understand the kinetics of char formation and destruction in wood under different fire exposure conditions, notably the ASTM E119 time-temperature profile (Anon 2014).

An early influence on Robert's career was Dr. Erwin (Erv) Schaffer. Robert's early work in collaboration with Erv focused on expanded charring models to include two factors; the recession of the char layer on the outer surface of the material and the role of moisture movement and vaporization in the charring process (White and Schaffer 1978; White and Schaffer 1981). Their work showed, for the first time, that the char layer receded because of shrinkage, rather than further oxidation or ablation. To study the role of moisture movement, Robert instrumented wood exposed to fire with electrical resistance moisture meter probes and developed a moisture meter temperature correction for extreme temperatures. Through this study, he was able to show that the predominant mode of moisture transport was caused by a pressure gradient in the wood caused by the vaporization of water (as opposed to a moisture gradient or temperature gradient, which are the predominant driving potentials under most conditions). This pressure gradient causes a peak moisture content to form in the wood near the char-wood interface. The peak moisture content can be as high as twice the starting moisture content of the material.

Prior to Roberts's research, a simple linear model was frequently used to describe the growth of the char layer in wood. However, his accomplishments in this area led to the development of a more accurate, non-linear char rate model for wood. Both the Eurocode and the National Design Specifications for Wood Construction (NDS) now incorporate a non-linear char rate model in their calculations of the passive fire resistance of wood members.

Fire Resistive Coatings

In the early 1980s engineered wood building products such as glue-laminated beams, trusses and wood I-joists were gaining in popularity, and a need to improve the fire resistance of these products became apparent. At that time, Robert noted that while there were many fire retardants available for wood, they were designed to limit ignition or flame spread on a wood product and offer little fire resistance in a post-flashover scenario. He instead suggested that fire resistive coatings might be better suited to improve the hourly fire ratings of engineered wood products. At that time, there were no commercial fire resistive coatings for wood, although such coatings had been developed for steel members and foam plastics. Robert designed a study that evaluated four fire retardants and four fire resistive coatings (originally developed for steel and plastic) on plywood panels and subjected them to the ASTM E119 time-temperature profile (White 1983; Anon 2014). The results of this study showed that even though the fire resistive coatings were not designed for use on wood, some added as much as 40 minutes of fire protection when compared to an unprotected plywood specimen. These early results suggested that 1-hour, or potentially 2-hour, fire rated assemblies may be possible in a fire resistive coating specially developed for engineered wood (White 1986).

Following these promising early results, the National Fire Protection Association (NFPA) suggested that the FPL hold a workshop on the future of fire resistive coatings. This workshop was held in the spring of 1988 and included representatives from the wood products industry, coating manufactures, test laboratories and insurance companies (White 1989). This workshop along with Robert's earlier work on fire resistive coatings for wood sparked a new area of research. Today, there are several commercial fire resistive coatings formulated especially for engineered wood that can reach 1-hour or 2-hour fire ratings.

Structural Fire Resistance

As a graduate student, Robert started his scientific career researching char rates among various species of wood and what caused differences in those char rates. He then built upon this research to develop a model for calculating the fire resistance rating of solid-sawn structural members as a function of char rate. This research directly impacted the code acceptance of fire-resistance calculation procedures for determining fire resistance of structural wood members. His extensive knowledge in structural fire resistance of wood products led to many collaborations and several studies including, but not limited to, the fire resistance of both composite materials and trusses.

In the 1970s, composite lumber products began with the creation of laminated veneer lumber (LVL) which continued with parallel strand lumber (PSL) in the 1980s and laminated strand lumber (LSL) in the 1990s

(Yeh 2003). When composite lumber was first considered for use in buildings, questions regarding fire resistance and structural performance after exposure to a fire were raised, specifically due to the performance of the adhesives at high temperatures. Robert conducted several tests on LVL, LSL and PSL to determine the char rate and their performance when loaded in tension while subjected to the ASTM E 119 fire exposure in an intermediate-scale horizontal furnace (Anon 2014). His findings showed that the char rates for composite lumber products were comparable to those of solid-sawn lumber, resulting in the use of the fire-resistance calculation procedures for solid-sawn lumber to estimate the ratings of composite lumber products. Today, the National Design Specification/Technical Report 10 includes procedures for calculating fire resistance ratings of structural composite lumber.

In the early 1990s, Robert collaborated with Dr. Steven M. Cramer (University of Wisconsin, Madison) to evaluate and develop a numerical model that could be used in understanding and evaluating the fire endurance of truss assemblies. The developed fire endurance model can be used to predict the failure time of metal-plate-connected wood trusses exposed to a design fire. The model also calculates deflection, forces within the members, and mode of failure which allows designers in the truss industry to examine the predicted performance of a truss design at high temperatures before proceeding with an ASTM E 119 test (White et al. 1993; Shrestha et al. 1995).

Development of the Room Corner Fire Test in the United States

In the 1980's room corner fire testing was in its infancy and there was no formal ASTM standard. The FPL room corner fire test using the oxygen consumption method to measure the heat release rate was developed by Dr. William Parker from the National Institute of Standards and Technology (NIST), Dr. Marc Janssens from the American Wood Council, and FPL employees John Brendan, Dr. Hao Tran and Sue LeVan. In 1991, Robert began work on the room corner fire test and collaborated with Dr. Mark Dietenberger, Dr. Marc Janssens and Dr. Ondrej Grexa to examine the European version of the room corner fire test, ISO 9705 (Anon 1993).

Robert and his cooperators showed that, in certain cases, the ISO 9705 method could be used to assess the flame spread index of certain materials such as wood, wood-based materials, Type X gypsum board, and fire retardant treated polyurethane foam and give results consistent with the ASTM method for determining the flame spread index, ASTM E84 (White et al. 1999; Anon 2015). However, for other materials and other test configurations allowable under the ISO 9705 method, the ISO method did not correlate with the ASTM flame spread index. In further testing on matched samples, they were able to develop fire growth models to predict time to flashover and ASTM E84 flame spread index data from cone calorimeter data (Dietenberger et al. 2012; Grexa et al. 2012). Additionally, Robert helped in the development of creating an ASTM analog for the ISO 9705 method through his work with the ASTM E05 task groups.

Fire Performance of Wood-plastic Composites

Robert began a long collaboration with Dr. Nicole Stark, Research Chemical Engineer at FPL to investigate the fire behavior of wood-plastic composites. Early work was motivated by the desire to increase markets for recycled plastic by mixing with wood products and focused on effects of different amounts of plastic (Stark et al. 1997). The methods and research tools used to characterize fire behavior were still in flux at that time, so the first tests were done with the Ohio State University rate of heat release apparatus. Small samples were exposed to a steady heat flux and source of flame until they ignited. The rate of heat release (HRR) was determined by the newly developed method of oxygen consumption and plotted over time. In general, composites with higher plastic content had higher HRR and, hence, reduced fire performance compared to wood.

Later work on wood-plastic composites used the cone calorimeter; a standard tool and set of methods for investigating the fire behavior of materials using a small (10 cm x 10 cm) sample. Many different studies were carried out, eventually producing a dataset of the test results for a variety of materials. Typical of these results was work done on wood-based decking material (White et al. 2007). Motivated by the desire to address fire concerns in the wildland-urban interface a series of cone tests evaluated three different classes of material: southern pine lumber, naturally durable species, such as redwood, and wood-plastic composites. Results included not only the HRR, but also time to sustained ignition, and total heat released, which help to further characterize the fire behavior. These data were used to try to predict the flame spread index that determines the fire class.

Given the generally reduced fire performance of wood-plastic composites there has been on-going interest in use of fire retardant additives. Robert and Nicole published results characterizing five different additives mixed into wood flour-polyethylene composites (Stark et al. 2010). This represents one of Robert's most cited papers. Magnesium hydroxide increased ignition time, while ammonium polyphosphate resulted in reduced heat release rates.

Broader Impact and Concluding Remarks

Robert was internationally-recognized by colleagues and mentored numerous scientists and students from all over the world. His research has had a major impact on establishing safety standards of building materials used in construction. He often mentioned that one of the best parts about working at FPL was that, as a federal researcher, all of his data and publications were in the public domain and freely available to other scientists and the public. Both Chapter 18: Fire Safety of Wood Construction from the Wood Handbook and Analytical Methods for Determining Fire Resistance of Timber Members from the SFPE Handbook of Fire Protection Engineering are just two examples of Robert's impact on a wide variety of audiences (White 1995; White and Dietenberger 2010). His papers have been cited over 1,500 times. Additionally, Robert worked with the American Wood Council to develop the cone calorimeter database. The database, created in 2010 to increase the availability of cone calorimeter test data files to the public, has been downloaded more than 150,000 times to date.

Throughout his career, Robert had considerable involvement with ASTM International, chairing and serving on numerous committees that establish building code standards. Robert served as chairman of Subcommittee E05.21 on Smoke & Combustion Products and also of Subcommittee E05.22 on Surface Burning. In 2007, he received the L.J. Markwardt Award for his notable contributions to the knowledge of wood as an engineering material. In 2009, Robert was presented with an Award of Merit and an honorary title of Fellow for recognition of his outstanding contributions to the development of ASTM standards. Robert was also a member of the Forest Products Society, the National Fire Protection Association, the International Association for Fire Safety Science and the International Union of Forest Research Organizations, where he served as deputy coordinator for the wood protection research group. He was a university lecturer, graduate student advisor, counselor to local fire departments, host to international visiting scientists, advisor to Underwriters Laboratories (UL), and served as an expert witness. He will always be remembered for his unparalleled integrity, dedication to the Forest Products Laboratory and the wood products industry as a whole, and his contributions in advancing the fundamental understanding of the fire performance of wood products.

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