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Long-Term Performance of Nail-Based Connections in Attic Environments: Literature Review

Research specifically addressing the long-term connection strength performance of nails in attic environments is very limited in the public domain. However, research has been conducted on metal fastener's (nails) performance in wood when exposed to moisture and temperature changes. And another body of research exists on roof sheathing and truss temperatures in attics. Coupling these two collections of research together, one can begin to understand the dynamic environment which nail-fastened connections face in attic environments. The following is brief literature review of research on nail's performance, concluding with the recommendation that specific, focused research is needed to discover and address nail's potential reduction in holding strength and performance over time in an attic environment.

Interestingly, one of the more detailed long-term nail performance studies was completed in 1956. The author found that "plain-shank nails show considerable losses…in initial holding power during exposure of the nailed assembly" (Stern, 1956, p. 18). Stern conducted a series of comprehensive tests on numerous nail types (plain-shank common nail, fluted nail, helically threaded nail, and annularly threaded nail) and wood types under various wood moisture contents and withdrawal delay periods. Current research on nail performance usually sets the maximum delay period at six months while Stern's work implemented three, six, and twelve month delay periods before testing a nail's withdrawal strength. The author warned against using short-term delay tests to prove effectiveness since a nail's performance reduction can vary. In some cases, a small strength reduction in the first weeks of exposure could be followed by a larger loss in the following weeks (Stern, 1956). This study from 50+ years ago does indicate that nails can experience reductions in withdrawal strength, while more recent research with shorter withdrawal delays supports this same conclusion.

“After the smooth shank nail is driven, stress relaxation of the wood fibers occurs, which results in loss of withdrawal strength” (Skulteti, Bender, Winistorfer, & Pollock, 1997, p. 452). It is also predicted that “[w]ood relaxation may be compounded if lumber dries and shrinks over time as a result of changing moisture conditions” (Rammer, Winistorfer & Bender, 2001, p. 442). Further, Rammer and Zelinka (2004) conducted a thorough review of numerous research studies on nail withdrawal strength and found reductions in withdrawal strength do occur, but vary greatly depending on type of nail, moisture content and moisture cycling characteristics. However, none of the reviewed research studies had delay periods of longer than six months. Rammer and Zelinka recommended that long-term research into nail performance be conducted to better understand the degradation of nail connection strength over time.

Besides the species of wood, moisture content and moisture fluctuations also impact the withdrawal strength of nails in wood connections. Nails in wood that experience drastic swings in moisture content can see reductions in withdrawal strength by “as much as 75 percent below the values given by the general formula” (Forest Product Laboratory, 1965, p. 2). This figure of 75 percent is arrived at by comparing the <u>calculated</u> withdrawal strength to the actual withdrawal strength discovered through testing. This study is one of the few that compared testing results to industry accepted calculations; most studies just report time-delayed withdrawal strength results compared to immediate withdrawal strengths.

In an ASTM D1037 24-hour soak and 6-cycle accelerated-aging exposure test, 6-common penny nails and typical sheathing materials (OSB and plywood) experienced average reductions in the “withdrawal resistance value in roof sheathing specimens about 30 and 40 percent" (Chow, McNatt, Lambrechts, & Gertner, 1998, p. 19). The authors attributed the reductions in nail withdrawal strength to the fact that "wood fibers were separated from the…repeated shrinkage and swelling during the accelerated-aging process…..The compressive stress was drastically reduced when specimens were exposed to the 6-cycle aging condition" (p. 24). Although this research focused on non-attic environment characteristics, one can see that periods of moisture exposure have dramatic impacts on nail-wood connection strength.

Withdrawal strength reductions have been shown to be partially dependent on moisture cycles, type of wood, and metal fastener characteristics (Rammer & Zelinka, 2004). While a literature review conducted by Winistrorfer and Soltis (1993) showed that "cyclic moisture conditioning can reduce lateral and withdrawal resistance of certain types of nails" (p. 666). Further, the U.S. Forest Service's document "Nail-Withdrawal Resistance of American Woods" states:

> *"In practically all species, nails driven into green wood and pulled before any seasoning takes place will offer about the same withdrawal resistance as nails driven into seasoned wood and pulled soon after driving. However, if common smooth-shank nails are driven into green wood that is allowed to season or into seasoned wood that is subjected to cycles of wetting and drying before the nails are pulled, they lose a major part of their withdrawal resistance. In seasoned wood that is subjected only to moisture changes from normal atmospheric variations, the withdrawal resistance of smooth-shank nails also diminishes in time. On the other hand, tests indicate that, when moisture conditions cause nails to rust, withdrawal resistance is very erratic; it may be regained or even increased over the immediate withdrawal resistance." (p. 2)*

In the absence of reliable long-term nail performance research evidence, one only knows that nail-based connections of wood framing are impacted and possibly degraded due to moisture changes and time decay, but one cannot predict the potential strength reductions three or five years out.

The air in attic environments not only experiences moisture variations but also temperature variations. Research on nail connection strength related to temperatures indicates “strength increases when its [wood framing] temperature is less than normal [20°C (68°F)] and decreases when its temperature is greater than normal” (Winistorfer, 1994, p. 607). Because there is no long-term test data on nail’s performance in attic environments, research on attic temperatures needs to be analyzed to determine if potential decreases in nail strength due to elevated temperatures is a significant issue.

The USDA’s Forest Product Laboratory conducted temperature monitoring of shingles, rafters, and roof sheathing on exposure structures in Wisconsin over a two-year period. These structures were monitored and represented the temperature performance of residential vented attic assemblies in their construction. The high temperatures for the bottom layer of roof sheathing ranged from 52.7°C to 44.2°C depending on the color of the shingle. The rafter’s maximum temperature ranged from 49.1°C to 42.0°C, and attic air temperatures maxed out at 48.9°C to 42.6°C, again depending on the shingle’s color (Winandy, Grambsch, & Hatfield, 2005). Research was also conducted on similarly constructed exposure structures in Hartford, CT. This work showed that a residential roof in this region can experience 66°C (150°F) for a total of 36 hours and 82°C (180°F) for two hours over the course of a year (Winandy & Beaumont, 1995). Thus, a roof’s truss-sheathing connections can experience substantial temperatures, even in cooler climates, which exceed the temperature threshold identified in other research at which strength reductions can occur.

The residential construction industry is experiencing a trend towards building conditioned attics. This trend is driven by a few factors, including managing moisture and capturing additional living space. Models of such assemblies predict that insulation placed directly under the roof sheathing will raise the average temperature of the sheathing and its connections (Winandy & Beaumont, 1995). Research and testing on roof connection temperatures is needed for both insulated and uninsulated attics because "[l]ower shingle, sheathing, and rafter temperatures should increase structural service life" (Winandy, Barnes, & Falk, 2004, p. 33), while higher temperatures could decrease structural service life of roof assemblies.

With limited multi-year performance testing, and existing research which indicates that moisture and temperature changes in attics can degrade the strength of nail-based connections, it is evident that further research is needed on roof assemblies' long-term performance. This multi-year performance research should include a range of connection systems (i.e. nails and adhesives) to arrive at a reliable and predictable performance estimates. The development of such data will allow a more informed view of today's building code requirements and lead to the development of innovative strategies to improve roof performance in homes.

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