EPiC Series in Built Environment
Volume 2, 2021, Pages 46–54
ASC 2021. 57th Annual Associated Schools of Construction International Conference

Assessing the Relative Performance of Three Different Fire Resistant Class A Roofing Materials in a High-Altitude Area

Brad Harris, Rodolfo Valdes-Vasquez, Ph.D. and Erin Arneson, Ph.D.
Colorado State University
Fort Collins, CO

The purpose of this study is to assess three Class A roofing materials (asphalt shingle, synthetic shake, and metal), which are typically used on residential homes in wildland-urban interface (WUI) areas. A series of tests were conducted by incorporating many aspects of the ASTM E108 burning-brand test while also analyzing the change in room temperature and carbon monoxide (CO) emissions. Since these tests were conducted at 7,500 feet in elevation, a higher elevation than all other U.S. testing facilities, results provide a unique insight into fire behavior and performance of residential roof systems built-in high elevation WUI locations. Tests included placing a burning-brand at the top of a roof deck specimen. The resistance to flame impingement of the roofing material was recorded along with temperature changes and CO emissions. Results indicated no differences in temperature and emission for all three materials. However, the area of charring on the plywood underlayment was the smallest on the metal sample. The charred plywood was approximate twice the size of the metal roofing area in the synthetic shake tests, and approximately three times the size of the metal roofing area in the asphalt shingles test. Based on these pilot results, asphalt shingle roofing on residential homes in high fire danger WUI areas should be avoided, while metal roofing should be encouraged. If noise or appearance is a key issue for a homeowner, synthetic shakes could be used. Future tests should be performed on other Class A materials at higher elevations to evaluate material costs, insulation ratings, and noise resistance of residential roofing systems installed in mountain regions of the U.S., such as the Colorado Rockies.

Key Words: Residential roofing systems, Wildfires, Asphalt shingle, Wildland-Urban Interface

Introduction

Due to the recent 2020 wildfires across the West Coast and the Rocky Mountains, wildfires have taken on a new role in the national consciousness. Wildfires are no longer a seasonal or regional problem, and their destructive force has become staggering. Year after year, records have been broken for most acres consumed, most homes destroyed, and the highest containment cost. In 2018, over 8.5 million acres burned in more than 50,000 separate incidents (NIFC, 2018). Beyond the quantitative picture of the issue, these events' human component is becoming increasingly hard to ignore. Historically, wildfires consumed remote natural areas and the occasional isolated structure. Recently, massive firestorms have obliterated entire communities in mere hours, in some cases taking hundreds of lives. For instance, Colorado's 2012 fire season saw the record for most property damage from fire in state history broken twice in one month (McGhee, 2013). The same year's statewide fires resulted in a federal disaster declaration, with similar circumstances experienced again in 2020. Considering the homes and lives lost, families forced from their homes, tourism revenues lost, and natural areas damaged, it has become evident that wildfires are deeply connected to Colorado and its citizens.

The U.S. wildland-urban interface (WUI) has overgrown due to expanding communities and the desire to live closer to natural areas. One insurance study found that 4.5 million U.S homes were in areas of high or extreme wildfire risk (Arindam, 2017). While the expansion of communities with growing populations is inevitable, it is often done irresponsibly. Homes are not maintained according to fire safety guidelines, increasing the fire risk to residential neighborhoods. Many homes are surrounded closely by trees and high grasses, have gutters filled with leaves and needles and are constructed with wooden siding and shingles. In contrast, a home with trees and grasses trimmed within an approved radius, has no natural debris on the property and is made of less combustible materials, offers significantly lower fire safety risks. Entire neighborhoods can suffer, too, whether from overgrown trees creating hazards for egress and fire crews, insufficient signage, poorly designed water distribution, or merely a dangerous location, such as within a valley or box canyon (NWCG, 2019).

This study focuses on roofing materials used in residential construction to assess and reduce the fire risk of homes in the state of Colorado. While the entire shell of the structure and the surrounding property's condition are important considerations when assessing fire risk, roofing systems introduce a crucial vulnerability to a structure. The roof's sizeable horizontal plane can collect embers as a fire approaches, meaning that roofing materials are exposed to fire for much longer than the rest of the structure. While many homeowners may not be aware, a home's roof is an essential component of preventing fire damage and is highly scrutinized by insurance companies (Bates, 2017). Given the importance of a home roof when considering fire vulnerability and insurance costs, the tests in this study aim to evaluate the most effective roofing materials for use in WUI areas.

Background

Given the average 20-year life span for asphalt shingle roofing and the increased fire resistance requirements for homes in WUI areas, roofing materials provide a realistic opportunity for homeowners to improve their homes' fire resistance without undue expense or effort (Seiders et al., 2007). When replacing existing roofing or building new construction, homeowners and contractors must understand the fire rating system for roofing materials and how selecting the wrong material could have disastrous consequences during a wildfire.

Residential roofing materials are given a classification based upon their fire resistance. Roofing materials are assigned a rating of Class A, B, C, or unrated. Each material classification is based on flame penetration, flame spread, time until ignition, and embers' generation (Quarles, 2019). For example, untreated wood shakes are rated as Class C and are not recommended for use in residential projects. Wood shakes which are pressure treated or impregnated with fire-resistant chemicals qualify as Class B, and can be effective against moderate fire exposure. Class A materials include clay tiles, slate, asphalt shingles, sheet metal, and concrete tiles. Class A materials have proven to be more resistant to fire conditions and are therefore recommended, and often required by building code, for homes in areas with high fire danger. The classification process also considers roofing underlayment materials to provide an aggregate rating for an entire roofing assembly. For instance, Class C materials like wood shakes can be upgraded to a Class A rating as part of a roofing assembly with the proper chemical additives and a suitable underlayment material.

Homeowners must balance the initial expense, maintenance time and costs, performance under fire conditions, and aesthetics when choosing a roof covering in high fire risk areas. While asphalt shingles (Class A) are a common choice for homeowners, recent firestorms have experts questioning if the material is sufficiently fire-resistant for use in WUIs (FEMA, 2008). Given the fierce onslaught of embers and heat seen in recent wildfires, many homeowners are seeing the advantages of building with non-combustible building materials such as masonry claddings and sheet metal roofing (Russell, 2019). The roofing market is also witnessing the emergence of new synthetic roofing materials, which can have a wooden shake's natural appearance without low fire resistance.

This study aims to provide an assessment of Class A residential roofing materials' fire resistance by testing three roofing types (asphalt shingles, sheet metal, and synthetic roofing). When homeowners and contractors learn the advantages and limitations of potential roofing materials, they will be more capable of responsibly building and maintaining fire-resistant homes and communities.

Research Approach

This study aims to assess the performance of three roofing materials under fire conditions.
The American Society for Testing and Materials (ASTM) Standard E108 is used to test fire-resistant roof coverings in the U.S., and testing may be carried out at any certified testing facility (Fricklas, 2013). The facility used in the study was the burn room of a fire-training center in Estes Park, Colorado, at an elevation of approximately 7,500 feet above sea level, with an approximate 16% effective oxygen level (CWS, 2019). This high elevation is a unique aspect of this study, and likely led to different fire behavior and roofing performance than found at other testing facilities. For example, the UL Building Envelope Performance Testing facility in Northbrook, Illinois, is at an elevation of 643 feet and has an effective oxygen level of 20%, which will impact fire burn rates (CWS, 2019). By testing roofing materials in an environment more closely resembling a Colorado WUI wildfire-prone climate in terms of elevation, temperature, and humidity, this study provided a new approach to roofing resistance testing.

The established ASTM areas of testing (e.g., fire spread, flame penetration, ember production, and resistance to flame impingement) and additional analysis of the contaminants produced by the burning materials are considered within this study. Overall, the ASTM burning brand test is conducted by placing a burning brand onto a roof assembly with a slope and composition specified in ASTM E108. The Class A rating classification is achieved by the roof resisting flame impingement when a 12 inch by 12 inches, 2000-gram wooden brand that is fully involved in fire is placed onto the test roof deck (ASTM, 2017). ASTM E108 dictates that a roofing assembly measuring 40" by 40" should be constructed with a 5/12 slope. A burning brand should be constructed of (36) 1" x 1" x 12" Douglas Fir strips. The brand should measure 12" x 12" x 2¼", and it should be placed on the roofing assembly after being exposed to flame for five minutes. An airflow of 12 ± 0.5 miles per hour should be directed to flow up and over the assembly. The wooden brand should be allowed to burn thoroughly until no flame, smoke, or glow can be detected.

Selection of Roofing Materials

Roofing materials included in this study were carefully selected. Asphalt shingles were chosen because of their perceived fire resistance and their widespread use. Sheet metal roofing was selected because of its assumedly high levels of fire resistance. CeDUR synthetic shake roofing was picked because of its new emergence in the industry, and its manufacturer's locality to the area being studied. To include considerations of multiple testing procedures in one test session, field tests based most similarly on the ASTM burning brand test were adapted in this study.

Asphalt shingle roofing is best utilized in locations where slope is sufficient to ensure drainage (Simmons, 2011). Underlayment should be No. 15 asphalt saturated felt, with not less than No. 55 smooth roll roofing being installed at the eaves. Underlayment should be placed as soon as possible after sheathing is erected. Shingles should be applied with proper overlapping after underlayment, drip edge, and flashing have been applied to ensure a water-tight barrier. Nails for attaching asphalt shingles should have flat heads and be made of corrosion-resistant metal. The asphalt shingles tested in this study were manufactured by Owens Corning and were the Driftwood color option within the Oakridge line. The shingles were installed over Grip-Rite Asphalt Saturated Organic Felt Paper 30 lb.

Metal roofing is manufactured in preformed panels made of a variety of materials ranging from aluminum to zinc and can have insulation incorporated into the panel (Simmons, 2011). The metal must be resistant to corrosion and the assembly must resist water penetration and air leakage. An underlayment of roofing felt of at least No. 15 in size should be used. Fasteners should be used according to the manufacturer's recommendations and should be of the same material and thickness as the metal panel. Metal Sales Manufacturing Company manufactured the metal roofing used in this study. This material was made of 29-gauge corrugated steel coated in Galvalume. The metal roofing was installed over Grip-Rite Asphalt Saturated Organic Felt Paper 30 lb.

Synthetic roofing materials are a relatively recent development within the construction industry. These materials were produced to utilize recycled materials and create better roofing system performance. Multiple companies are producing synthetic roofs with colors and textures that can be adapted for many architectural considerations. The synthetic roofing used in this study was manufactured by CeDUR Roofing Shakes, which were installed over Grip-Rite Asphalt Saturated Organic Felt Paper 30 lb. CeDUR imitates the appearance of cedar shake roofing but is a lightweight and fire-resistant alternative. CeDUR is primarily polyurethane and uses graphite entrainment in their product to obtain a high degree of fire resistance. CeDUR is a Class A-rated material without the inclusion of any underlayment material.

Data Collection

For this study, roofing assemblies were constructed to 24" by 24" compared to the ASTM 40" by 40" assembly. This reduced size was chosen for the ease of construction and handling, and the consumption of less material in each test session. The assemblies were constructed of standard ½" plywood (identify as OSB in the rest of the paper) covered with 30 lb. felt paper. Each of the three roofing materials was then attached as recommended by the manufacturer to the standardized testing roof deck. Wooden brands were constructed of (2) pieces of ½" OSB cut to 7" by 7", which were attached to both faces of (2) 1½ inch by ¾ wooden stakes. Therefore, the brands used in this study measured 7" x 7" x 1¾" (as compared to the ASTM 12" x 12" x 2¼" brand). The size of these brands accounted for the comparatively reduced roofing assembly size. It ensured that the roofing assembly area, which the brand covered, was equal in proportion to the ASTM test guidelines (approximately 9% of the roofing assembly's surface area).

As mentioned in a previous section, the facility used in the study was the burn room of a fire-training center in Estes Park, Colorado, at an elevation of 7,500 feet above sea level. This high elevation is a unique aspect of this study, and likely led to different fire behavior and roofing performance than found at other testing facilities. The testing room dimensions were 19' by 6' 8" with 7' in height. This location was chosen because of the non-combustible nature of all surfaces surrounding the test area, the layout of the existing flow paths, the inclusion of structurally integrated thermometers, and the ease of measuring exhaust gases' composition (see Figure 1).

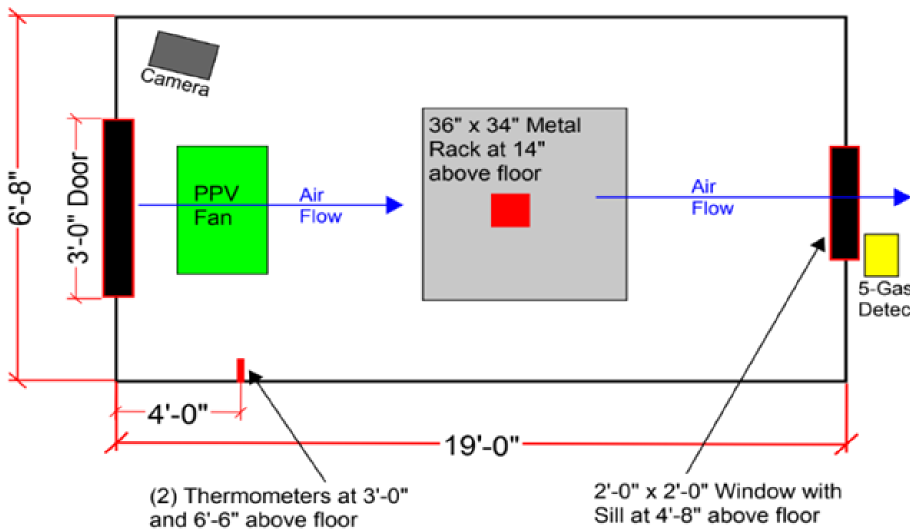


Figure 1. Burning Brand Testing Room Layout

The burning room was laid out with video cameras and a large fire service positive pressure ventilation fan at the room entrance. Midway between the entrance and the far end of the room was placed a metal frame used to hold burning materials during live-fire training evolutions. The metal frame measured 36" by 34", and the platform was 14" above the room floor. This frame was ideal because it was non-combustible, and the desired slope of the testing assembly could be attained. Beyond this frame, and opposite the room's entrance side, was a wall containing a 2' by 2' window with a sill 4' 8" above the room floor. This window was designed to allow smoke from burning materials in live-fire training evolutions to be ventilated out of the structure.

With this window opened, air could flow through the room entrance with the assistance of the fan, flow over the test assembly, and exhaust out through the concentrated window area. On the outside of the structure, an MSA Altair 5X Multigas Detector, was placed so that its air inlet lay directly within the exhaust path of the burn room, and that the display screen was easily recorded from the outside. The 5X Detector measures concentrations of oxygen, hydrogen cyanide, hydrogen sulfide, carbon monoxide, and the lower explosive limit of a variety of other gases. Integrated into the burn room structure were two thermometers, both located 4" away from the wall with the entrance door. One thermometer, with a reading designated as waist temperature, was 3 feet above the room floor. The other thermometer was designated ceiling temperature and was located 6 foot 6 inches above the room floor. The data from these thermometers was fed to an external display screen, where data was recorded during the tests. Each test was carried out following a standard procedure. A 24" x 24" roofing assembly was placed on the metal rack so that the slope of the deck was 5/12. A 7" x 7" constructed wooden brand was then doused in approximately one fluid ounce of charcoal lighter fluid. The brand was then exposed to a propane torch's flame until all sides of the brand were involved in fire. The brand was then placed in the middle of the roofing assembly. The positive pressure fan was then turned on, and air was directed at the roofing assembly at a speed of approximately 12 miles per hour. The brand was allowed to burn freely until flames were no longer seen, or a total testing time of 25 minutes had been reached. The brand was then removed and extinguished, and the roofing assembly was disassembled. Video recording of the entire roofing assembly and of the 5-gas detector was carried out for each test. Floor and ceiling temperature readings for the burn roof were recorded at five-minute intervals. Gas monitor readings were filmed continuously, and values were recorded at 30 second intervals. Photos of each roof deck were taken before and after each test, after removing the roofing material, and after removing the felt paper underlayment. The multi-gas detector was utilized to ensure the room had been flushed of contaminants from the past testing session as much as possible before starting a new one.

Results and Discussion

The multi-gas detector was run continuously during all tests, and oxygen stayed constant at 20.8% for all tests. There were no changes in hydrogen cyanide, hydrogen sulfide, or lower explosive limits. The only change noted was that of carbon monoxide (CO), which fluctuated rapidly as the tests were carried out. The CO readings were compiled, and the maximum and average readings for each burn were recorded. The waist and ceiling temperatures were recorded every five minutes during the tests. The maximum temperatures and average temperatures for each test were recorded. The burned OSB area was measured after each test, and the approximate surface area affected (in square inches) was recorded. Tables 1, 2, and 3 below show the data compiled for each test.

Table 1

Asphalt Shingles Results

	Total Time (minutes)	Max. Waist Temp. (˚C/˚F)	Max. Ceiling Temp. (˚C/˚F)	Max/ (Avg.) CO Reading (ppm)	OSB Burned Surface Area (sq. inches)
Test #1	25	17.6/63.7	17.8/64	91/ (54)	88
Test #2	25	19.2/66.6	19.5/67.1	79/ (39)	105
Averages	25	18.4/65.1	18.7/65.6	85/ (46.5)	96.5

Table 2

CeDUR Synthetic Wood Shakes Results

	Total Time (minutes)	Max. Waist Temp. (˚C/˚F)	Max. Ceiling Temp. (˚C/˚F)	Max/ (Avg.) CO Reading (ppm)	OSB Burned Surface Area (sq. inches)
Test #1	25	23.2/73.8	23.7/74.7	91/ (30)	56.75
Test #2	25	25.3/77.5	26.9/80.4	113/ (54)	45.75
Averages	25	24.3/75.7	25.3/77.5	102/ (42)	51.25

Table 3

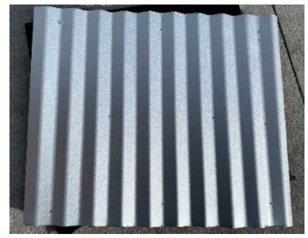
Corrugated Sheet Metal Roofing Results

	Total Time (minutes)	Max. Waist Temp. (˚C/˚F)	Max. Ceiling Temp. (˚C/˚F)	Max/ (Avg.) CO Reading (ppm)	OSB Burned Surface Area (sq. inches)
Test #1	21	22.1/71.8	23.2/73.7	80/ (32)	42
Test #2	17	23.3/73.9	25.6/78	122/ (49)	21
Averages	19	22.7/72.8	24.4/75.9	101/ (40.5)	31.5

Due to time constraints at the testing facility, this study limited each test session to 25 minutes after the burning brand was placed on the roofing assembly. Table 4 shows examples of the asphalt shingle, synthetic shake, and metal roofing assemblies during testing.

Table 4

Roofing assemblies during the testing process

	Asphalt Shingles	CeDUR Synthetic Wood	Corrugated Sheet Metal
Before /beginning of the Test			
After Test			
Uncovered plywood			

When burning the asphalt shingles, they produced heavy smoke and a noticeable smell of melting asphalt. The OSB underlayment with asphalt shingle assemblies showed the most flame spread out of all roofing materials. When the burning-brand was removed from the assembly, the asphalt shingles smoldered and smoked for an extended period. The burned asphalt shingles melted and joined with other areas of the roof. The asphalt shingles had the lowest overall CO emission readings and the lowest waist and ceiling temperatures; however, they were the test day's first tests. Lower ambient temperatures and the absence of residual radiant heat may have played a role.

The synthetic roofing shakes were lightweight and had a realistic wood shake appearance. While burning, the synthetic shakes produced significant smoke and an acrid, burning plastic odor. The performance of these shakes resulted in a less burned OSB than the asphalt shingles. When the brand was removed from the assembly, the shakes appeared to be mostly free from smoldering. The burned shakes resulted in a fragile, chalky residue that was easily detached from the roof. The CO levels and room temperatures were comparable to those of sheet metal roofing. The preceding tests of asphalt shingles may have contributed to higher CO levels and increased temperatures from residual heat. The corrugated metal roofing assemblies were also lightweight. The metal samples produced comparatively little smoke or odor, as the metal surface was not ignited. The metal roofing test resulted in the least area of OSB being burned. Noticeable charring patterns followed the rib lines of the metal roofing, indicating that a significant amount of charring was due to radiant heat and contact with the lower ribs of the corrugation. When the brand was removed, there was no sign of flame or smoke from the metal roofing. The only sign of fire was discoloration of the surface, and no structural defects were noted. While the multi-gas detector was placed outside of the facility and within the burn room's exhaust path, the authors acknowledge that not having another sensor inside the burn room may have contributed to higher CO levels. Increased temperatures from the residual heat in the test room when conducting the preceding tests of asphalt shingles and synthetic shakes may have been present during later tests. The metal roofing tests were significantly shorter than either the asphalt or synthetic shingles, with the metal roof tests lasting 21 and 17 minutes compared to the 25 minutes for all other tests. The tests were terminated when the brands were no longer actively flaming.

Conclusion

This study aimed to assess the best roofing material for increasing the likelihood of a home surviving a wildfire. Therefore, the most significant indicator must be the flame spread on the OSB beneath the roof covering. Asphalt shingle roofing performed the best in terms of burning temperatures and levels of CO emissions released but did the worst in terms of flame spread. Synthetic roofing and metal roofing performed similarly in terms of temperature and CO emissions, but metal roofing led to a significantly smaller OSB area being burned. The metal roofing test was also the shortest and resulted in the least amount of roofing material being damaged or displaced. These results further support the Federal Emergency Management Agency's recommendations that some roofing materials, such as asphalt shingles, are less fire-resistant than others, such as metal roofing. However, many factors must be considered when deciding upon the best overall roofing option that was not sufficiently incorporated into this study, such as initial purchase and lifetime maintenance costs, durability, noise resistance, insulation ratings, and assembly weight.

This study's significance stems from the fact that the tests were conducted at high elevations and may have led to different fire behavior and roofing material performance than found at other testing facilities with varying levels of oxygen. This study is expected to further inform the ASTM classification system by ranking several materials within the Class A roofing material category. In addition, while this study conveyed a recommendation purely in terms of fire resistance, future studies should include other homeowner roofing considerations to provide a more well-rounded and useful recommendation for WUI homeowners and contractors. For a more thorough overview of the Class A roofing material category, further testing should also include other Class A materials such as slate, clay tile, and concrete roofing. Future testing assemblies should also incorporate interruptions in the roofing material, such as connections and penetrations, into the roofing deck to include a more realistic recreation of a residential roof.

Acknowledgements

The authors would like to thank the following individuals for their invaluable assistance, knowledge, and donations: Scott Kawulok of B&M Roofing, Chief Paul Capo of the Estes Valley Fire Protection District (EVFPD), Dave Dalton of CeDUR Roofing, Lieutenants William Harkins and Jason Hennig of the EVFPD, and Firefighters Nick Hernandez and Ryan Franklin of the EVFPD.

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