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STRUCTURE PROTECTION FROM WILDLAND-URBAN INTERFACE FIRES BY FIRE BLANKETS

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Background

Wildland fires often destroy homes in WUI

- Fire damages can be reduced if an initial structure ignition is prevented

2007 Santa Clarita, CA fire (Photo: *Jeff Turner*)

Current measures in practice

- Application of fire suppression foams, gels, or water
- Applied material can be evaporated or blown away before the fire front arrives.
- Access to homes and availability of water are often limited in WUI areas during wildfires.

Crew foaming college dorm during 1988 Yellowstone fire

Firefighters spraying water on Old Faithful Inn

Structure wrapping

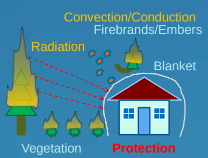
- US Forest Service used fire shelter material to protect historic buildings

Mumford Cabin near 2008 Foresthill fire (photo courtesy: *Nolan Smith*, USFS)

Objectives

Develop fire protective blanket technology

- Test thermal protective performance of fabrics in the laboratory.
- Conduct proof-of-concept field fire tests: (1) live house burn at firefighter training (2) prescribed burn in wildland
- Perform physics-based numerical modeling
- Design prototype blanket deployment device



Numerical Model

1D Transient Heat Transfer

- Governing energy equations

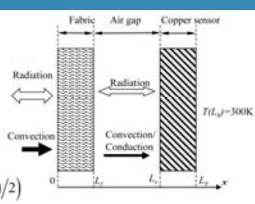
$$\rho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \gamma q''^{in}_{rad}\big|_{x=0} \cdot e^{-\gamma x}$$

- Fabric front surface

$$q''^{in}_{rad}\big|_{x=0} = (1-\rho_{refl})Q_{rad}$$

$$q''^{out}_{rad}\big|_{x=0} = -\varepsilon\sigma(T^4_{x=0} - T^4_{amb})$$

$$q_{conv} = h_{fl}(T_g - T_{x=0});\ h_{fl} \propto k_{air}\left(\left(T_g + T_{x=0}\right)/2\right)$$



- In-depth radiation absorption (Beer's law)

$$q_{rad}(x) = q''^{in}_{rad}\big|_{x=0} \cdot [1-\exp(-\gamma x)] \qquad \gamma = \frac{-\ln(\tau)}{L_p}$$

γ: extinction coeff
τ: transmissivity
L_p: penetration distance

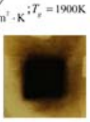
- Fabric properties used (aramid/fiberglass)

L_p=L_f (mm)	ρ (kg/m³)	k (W/m/K)	C_p (J/kg/K)		ϵ=ϵ_s	ρ_{refl}	τ
1.65	349	(23.23T + 5.7)·10⁻⁵	2000	T_{back} < 400°C	0.7	0.3	0.04
				T_{back} > 500°C	0.8	0.1	0.03

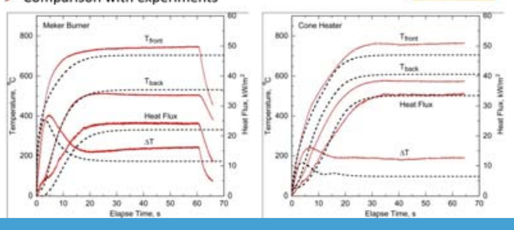
- Heat source parameters

$$\text{Convective:}\begin{cases} h_{fl} = \dfrac{k_{air}}{k_{air,1100K}} \cdot h_{fl,1100K}\ ;\ h_{fl,1100K} = \dfrac{(83\,\text{kW/m}^2)}{(1900\text{K}-300\text{K})} = 0.0519\,\text{kW/m}^2\cdot\text{K};\ T_g = 1900\text{K} \\ Q_{rad} = 0 \end{cases}$$

$$\text{Radiative:}\begin{cases} h_{fl} = 0 \\ Q_{rad} = 83\,\text{kW/m}^2 \end{cases}$$



- Comparison with experiments

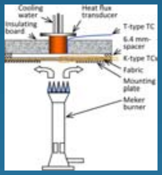


Laboratory Experiments

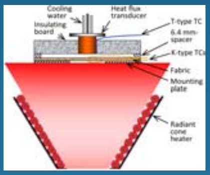
Fire Blanket Materials Characterization

- Studied the effects of **convective** and **radiative** incident heat fluxes independently up to 84 kW/m² using a Meker burner and a radiant cone heater, respectively.
- In addition to the conventional thermal protective performance (TPP), new transient and steady thermal characteristics were determined for 50+ fabrics from 4 fiber groups: aramid, fiberglass, amorphous silica and pre-oxidized carbon, under high temperatures (up to 950 °C).

Meker burner

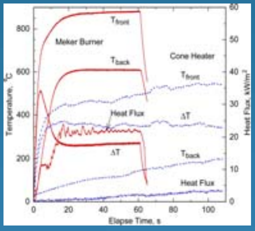


Cone heater

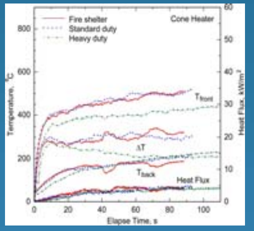


Temporal Thermal Response

Aluminized aramid/fiberglass



Fire shelter & fire wrap

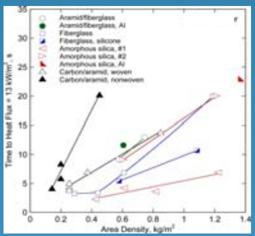


Incident heat flux: 83±2 kW/m²

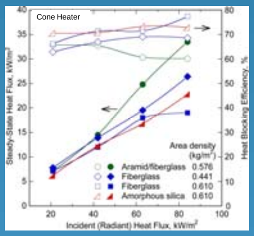
Response Time & Heat-Blocking Efficiency

H. B. E. = [1 – (S.-S. Heat Flux) / (Incident Heat Flux)] x 100 (%)

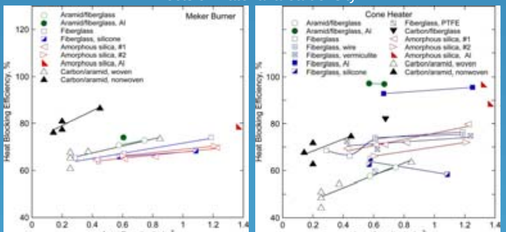
Transient Characteristics



Effect of incident heat flux



Effects of material area density



Incident heat flux: 83±2 kW/m²

Table 1: Fabrics evaluated

Fabric Description	Continuous operating temp., °C	Area density kg/m² (oz/yd²)	Thickness mm	Measured TPP rating[a] cal/cm²	Conv. HBE %	Radiant HBE %
Materials currently in use						
USFS old-style fire shelter (aluminized fiberglass)		0.214 (6.3)[f]	0.16[f]	9.3		94.8
Standard structure wrap (aluminized fiberglass)		0.207 (6.1)[f]	0.15[f]	14.8		94.8
Heavy-duty structure wrap (aluminized fiberglass)		0.441 (13)[f]	0.40[f]	13.9		95.1
Aramid/Fiberglass and Aramid/Fiberglass/Carbon (partially oxidized acrylic fiber) Fabrics						
Aramid/fiberglass	320	0.576 (17)	1.65	23.2	70.7	60.2
Aramid/fiberglass	320	0.745 (22)	2.03	27.1	72.8	63.6
Aramid/fiberglass/carbon	320	0.509 (15)	1.70[f]	33.0	81.8	78.4
Aramid/fiberglass (woven)/carbon (nonwoven)	320	1.017 (30)	2.78[f]	57.9	87.1	81.5
Aramid/fiberglass, aluminized	150	0.670 (19)	1.32	21.3	73.8	96.1
Aramid/fiberglass/carbon, aluminized	150	0.570 (17)	1.78	21.2	77.8	97.7
Aramid/fiberglass, aluminized	205	0.606 (17.8)[f]	1.30[f]	20.9	74.0	89.2
Fiberglass and Fiberglass/Carbon (partially oxidized acrylic fiber) Fabrics						
100 % fiberglass	540	0.610 (18)	0.91	18.2	67.1	75.1
100 % fiberglass	540	1.187 (35)	2.03	37.9	74.0	81.3
Fiberglass, aluminized	150	0.666 (21.5)	0.79	24.0	60.6	93.8
Fiberglass, aluminized	150	1.251 (38.5)	2.06			95.7
100% fiberglass (woven) core/100% carbon (nonwoven)	260	0.678 (20)	2.31[f]	49.4	86.8	82.3
Amorphous Silica Fabrics						
96 % amorphous silica, #1, commercial grade	980	0.424 (12.5)	0.71	13.1	65.0	70.4
96 % amorphous silica, #1	980	0.610 (18)	0.76	12.1	64.9	72.0
96 % amorphous silica, metalized polyester	150	1.321 (22)	0.91			97.0
96 % amorphous silica, aluminized	982[b]	1.366 (22.7)[f]	1.25[f]	12.4	65.6	93.7

[a] Measured with the Meker burner (incident heat flux: 83±2 kW/m²) and a calorimeter with a 6.4 mm-thick air gap.
[b] Base material.

Proof-of-Concept Field Fire Tests

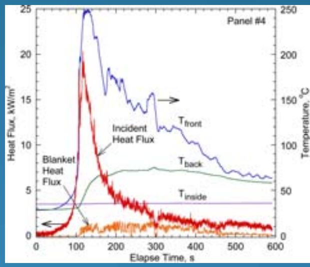
Prescribed Burn

Pine Barrens in New Jersey (April 2010)

- Live burn was conducted by the State of New Jersey Forest Fire Service.
- Placed a 2.4 m x 3.1 m blanketed cabin with instrumentation (heat flux transducers and thermocouples) in a pine forest section .
- The crown fire, initially developed, turned to the ground fire due to moisture and a low fuel density along the fire pass.
- Intend to repeat the experiment in the near future.

Near Santa Clarita, California (July 2010)

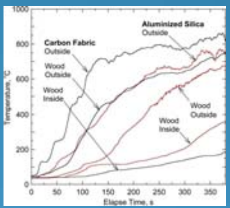
- Participated in a douser live-burn project, hosted by the U.S. Forest Service (SDTDC) in cooperation with the Los Angeles County Fire Department.
- Four instrumented wall-and-roof wooden structures (1.2 m x 1.8 m), wrapped with different materials (aramid, fiberglass, or amorphous silica) ,were placed on a slope .
- All structures with blankets survived in the prescribed fire in two separate burns, in contrast to an unprotected structure, which ignited and burned down (photo below).

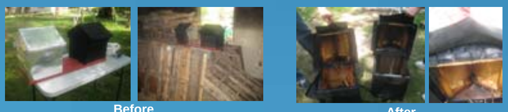


Live House Burn

Avon Lake, OH (June 2009)

- Despite substantial wood charring, structure ignition was prevented.





Before After

Conclusions

- Transient thermal response times (1) to reach T_{back}=300 °C and (2) q = 13 kW/m² , defined in consideration of material pyrolysis and ignition thresholds, increase with the material area density (or thickness).
- Steady-state heat-blocking efficiency can reach ≈90 % (against convective heat flux) to 97 % (radiation sources).
- For convective heat sources, surface radiation emission coupled with a low material conductivity and, for radiation, surface reflection play key roles in the heat blocking mechanism through the blanket.
- The live burn experiments have demonstrated the effective protection performance of fire blankets in more realistic fire scenarios.

Acknowledgments

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