Fire Resistance Modeling for Nano-Particle Reinforced Composites Designed for Blast Protection

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From Quantum to Infrastructure
Outline

- Objectives
- Approach
- Experimental Data
- Fire Dynamic Simulations
- Parametric Evaluation
- Finite Element Modeling Results
- Remarks and Conclusion
objectives

- To develop representative models of low-rise, critical function buildings in Mississippi subjected to fire and smoke scenarios

- The test will be conducted by computer in high fidelity operational environment. The software used are the Fire Dynamics Simulator (FDS), the Consolidated Model of Fire and Smoke Transport (CFAST), and the Smokeview (SMV), developed and supported by BFRL/NIST

- The properties of the new materials investigated in Material Research, and the fire resistant retrofitting solutions investigated in Structural Component and System Research, will be used to investigate the improved performance of these critical function buildings
APPROACH
FDS: Fire Dynamic Simulations

RTM: Radiative Transport Modeling

FEA: Finite Element Modeling

Temperature: T(t)

Absorption Coefficient

Surface Heat Flux

Coupled Thermal-Structural
Material research

- Experimental

- Simulation

- Parametric Evaluation For The Best Performance Material
Material research

Description of Material Used

- **Epoxy** “The flexible epoxy used was made of 100phr Epon 828/50phr Jeffamine D-400/25phr Jeffamine D-2000.”

- **Polyurea** “LINE-X XS-350 is a two- component polyurea from Protective coating Inc.”

- **Polyurea POSS** “Polyhedral Oligomeric Silsesquioxane (POSS®) is a class of silicon based nanochemicals designed to fulfill various mechanical functions. Hybrid Plastics Inc”

- **Epoxy reinforced with xGnP** “(xGnP) were produced at Michigan State University. XGnP-15, made from Asbury 3772 using High Power Microwave was used. Prior to its use, xGnP platelets were kitchen-microwaved for 1 min/1 min per 10-15 g.

- **Polyurea reinforced with xGnP**
Material research

**Fire Protection Material**

- **LR** “Tyfo® LR is a liquid [ethylene propylene] rubber coating used from Fyfe Inc.”
- **LR HP** “Tyfo® HP is a two-component epoxy fire retardant-intumescent coating based on non-halogenated phosphates.”
- **LR FC F** “Tyfo* FC/F is a two-part epoxy coating system specially formulated to provide an increase in existing fire rating. Tyfo * F is a one component formulation designed to be applied over Tyfo FC. The Tyfi FC/F System will provide an increase to the fire rating of an element as per ASTM E-119 (2- hours wall rating) and provide a Class 1, ASTM E-84 flame and smoke rating.”
- **Type 4** “Tyfo® Blast-Flex Type 4 is two-component polyurea based systems with fire-resistance additive from Fyfe Inc”
EXPERIMENTAL
Calorimeter experimental setup
Time Dependent HRRs Obtained From Cone Calorimeter Measurements Epoxy Plaque

**PHRR: Peak Heat Release Rate**
Time Dependent HRRs Obtained From Cone Calorimeter

PHRR: Peak Heat Release Rate

Epoxy Brick

Time (s)
0 200 400 600 800 1000

HRR (kW/m²)
-100
0
100
200
300
400
500

Time Dependent HRRs Obtained From Cone Calorimeter Measurements Epoxy Coated Brick
Fire Experiments: HRR polymer plaques

Heat Release Rate (HRR) Measurements Polymer Plaques

Polymer Plaques

Heat Flux (kW/m$^2$)

25 30 35 40 45 50 55

PHRR (kW/m$^2$)

600 800 1000 1200 1400 1600 1800 2000 2200 2400

polyurea
polyurea + POSS
epoxy
epoxy + graphene
polyurea + phosphate

Heat Release Rate (HRR) Measurements Polymer Plaques
Fire Experiments: HRR Coated Blocks

Heat release rate (HRR) measurements Polymer Coated Blocks

Heat Flux (kW/m²)

PHRR (kW/m²)

polyurea
polyurea+POSS
polyurea+graphene
epoxy
epoxy+graphene
LR
LR HP
LR FC F
Type 4
## PHRR EXPERIMENTAL VALUES

<table>
<thead>
<tr>
<th>Material</th>
<th>Incident Flux (30 kW/m²)</th>
<th>Incident Flux (40 kW/m²)</th>
<th>Incident Flux (50 kW/m²)</th>
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<td>Type 4</td>
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FIRE SIMULATIONS
Fire simulations outline

- **Structural Component Research**
  - Concrete Column
  - Steel Column
  - Masonry Wall

- **Structural System Research**
  - Single Room
  - Multiple Room

- **Decision Support System**
Radiation field must be determined from solutions of the radiative transport equation which relates the incident flux to the spatial distribution of temperature and combustion products.

Assumption used in Thermal analysis in structures, is that the radiant heat flux \( q \) incident upon surface of the element is related to gas temperature.

The temperature and stress distribution in the structural elements can be calculated, given a spatially uniform enclosure temperature and a “time-temperature curve”.
Structural Component Research

- Concrete Column
- Masonry Wall
## Structural Component Research

<table>
<thead>
<tr>
<th>Column</th>
<th>Wall</th>
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<tbody>
<tr>
<td>Concrete 18”*18”</td>
<td>Concrete Wall “9’*9’*8”</td>
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</tbody>
</table>

### Diagrams

- **a)**
  - Column: Concrete block with dimensions 18”*18”

- **b)**
  - Wall: Concrete wall block with dimensions 9’*9’*8”

- Additional diagrams showing internal structure and placement of components.
PART1: FIRE DYNAMIC SIMULATION (FDS)
FDS: Concrete columns

<table>
<thead>
<tr>
<th>Concrete</th>
<th>Polyurea</th>
<th>Polyurea POSS</th>
<th>Epoxy</th>
<th>Epoxy Graphene</th>
<th>Gypsum</th>
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</thead>
</table>

HRRPUV For Coated Concrete Columns FDS Snap Shots
Heat Flux Time Evolution Plots For The Concrete Columns
FDS: Concrete columns

HRRPUV For PP Coated Concrete Columns FDS
# FDS: Masonry Walls

<table>
<thead>
<tr>
<th>Polyurea Graphene</th>
<th>Polyurea</th>
<th>Polyurea POSS</th>
<th>Epoxy</th>
<th>Epoxy Graphene</th>
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<td><strong>LR</strong></td>
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<td><img src="image8" alt="Image" /></td>
<td><img src="image9" alt="Image" /></td>
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HRRPUV For Coated Walls In A Single Room Model Snap Shots
Maximum Heat Flux At (0.5m) For Coated Blocks
Maximum Heat Flux At (0.5m) For Coated Blocks
Max Heat Release Rate At Different Heat Fluxes For Polyurea POSS Coating
Fds: Masonry Walls

Max Temperature Profiles Varying The Coating Thickness For Polyurea And POSS
PART2: FINITE ELEMENT ANALYSIS (FEA)
**FEA: Concrete Columns**

<table>
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<tr>
<th>Concrete</th>
<th>Polyurea POSS</th>
<th>Epoxy</th>
<th>Gypsum</th>
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</thead>
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Von Mises Stress Nodal Distribution In Concrete Coated Columns
# FEA: Concrete Columns

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<td>Baseline</td>
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<tr>
<td>Max Stress (GPa)</td>
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<td>0.07</td>
<td>0.11</td>
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<tr>
<td>Min Stress (GPa)</td>
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<td>-1.13</td>
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<tr>
<td>Max Strain</td>
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<td>0.027</td>
<td>0.033</td>
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<td>Min Strain</td>
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<td>-0.005</td>
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### FEA: Masonry walls

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<th>Epoxy</th>
<th>Polyurea POSS</th>
<th>LR HP</th>
<th>LR</th>
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![Von Mises Stress Nodal Distribution In Concrete Coated Walls](image)

**Von Mises Stress Nodal Distribution In Concrete Coated Walls**
## FEA: Masonry walls

<table>
<thead>
<tr>
<th>Concrete Wall</th>
<th>Epoxy</th>
<th>Polyurea POSS</th>
<th>LR HP</th>
<th>LR</th>
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<tbody>
<tr>
<td><strong>Max Stress (GPa)</strong></td>
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<td><strong>Min Stress (GPa)</strong></td>
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<td><strong>Max Strain</strong></td>
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<td>-0.02</td>
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<td><strong>Min Strain</strong></td>
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<td>-14.14</td>
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**Concrete Wall Maximum And Minimum StrainX, StressX**
Conclusion & Remarks

- Different heat fluxes did not have a major effect on HRRPA for polymeric materials studied.
- It is shown that addition of POSS and graphene has reduced the HRR for the polyurea by 2.5%.
- Graphene platelets addition to epoxy based polymer coatings has a counter effect on the HRR, maximum heat flux, and maximum surface temperatures.
Conclusion & Remarks

- Concrete wall coated with .003m LR performed the best in terms of least HRR, and minimal resulted structural stress/strain
- The addition of fire retardant filler such as LRFCF and LR for polyurea has reduced significantly the HRR peak value by 29%
- No effect for thickness variation of polyurea POSS
Acknowledgement

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THANK YOU

ANY QUESTIONS?