



Experimental Analysis of Fire Performance of Acoustic Materials: Measured Parameters and Practical Outcomes

NAME OF PROJECT:

MYP G6006: "Acoustic Multi-Functional Composites for Environmental Risks and Health Hazards Reduction"

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Importance and Applications of Acoustic Materials

Acoustic Materials: Role and Applications

- Noise pollution as a global environmental and health issue
- Acoustic materials used for:
 - sound absorption and noise control
 - reduction of reverberation in enclosed spaces
- Main application areas:
 - buildings (offices, auditoriums, classrooms)
 - transportation (automotive, aerospace)
 - industrial environments
- Applied:
 - near sources
 - along transmission paths
 - near receivers



Structure, Mechanism and Material Types

Structure and Sound Absorption Mechanism

- Sound absorption based on:
 - viscous and thermal losses
 - interaction between air and material structure
- Dominant materials:
 - porous structures
- Main types:
 - fibrous materials
 - foam materials
 - granular materials
- Key structural features:
 - high porosity
 - low density
 - large surface area



Modern Materials and Design Trends

Modern Trends in Acoustic Materials

Shift towards:

- sustainable materials (wood composites, natural fibers)
- recycled and bio-based materials

Advanced design approaches:

- multilayer structures
- gradient materials
- composite systems

Key requirements:

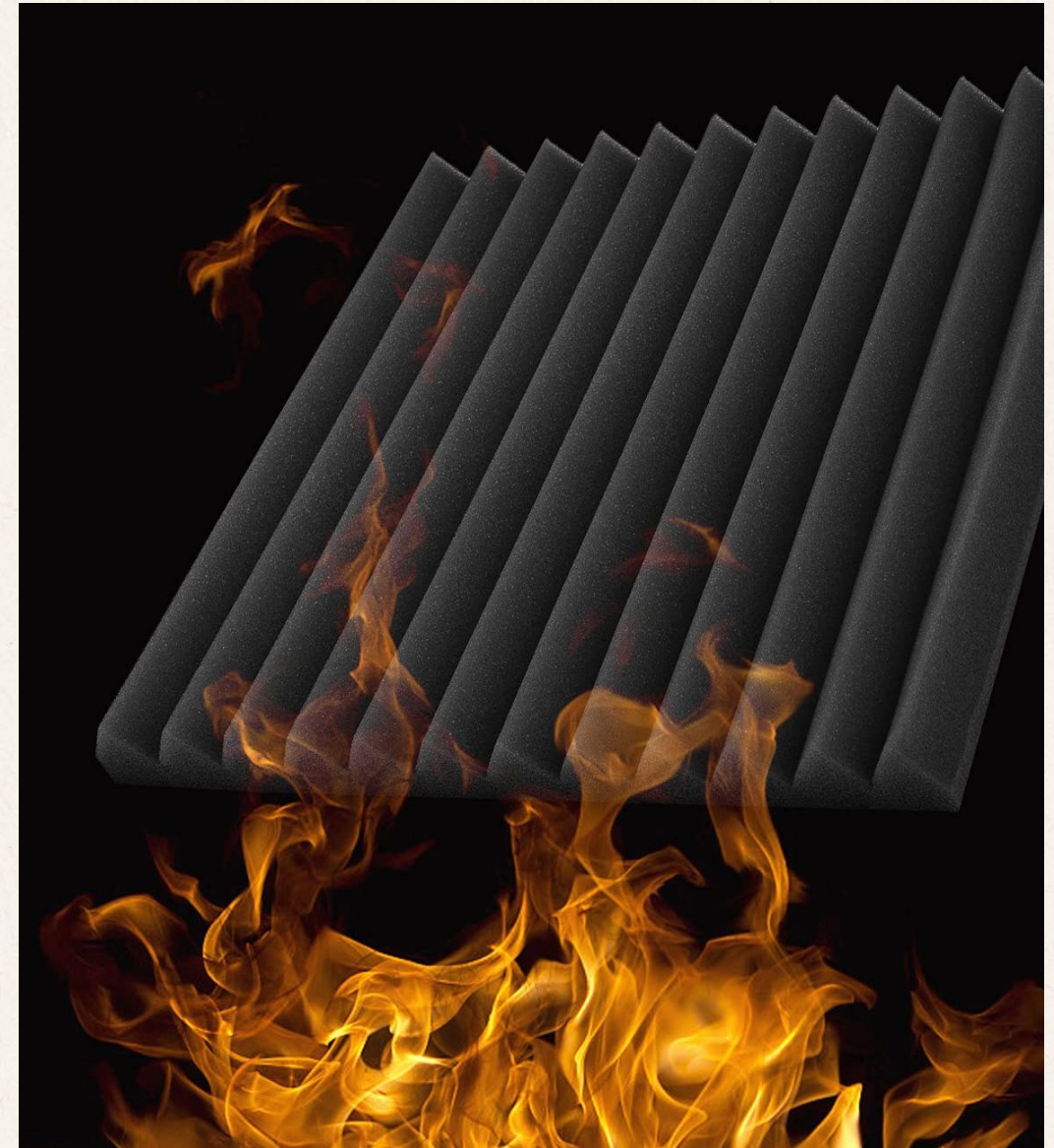
- acoustic efficiency
- lightweight design
- environmental sustainability

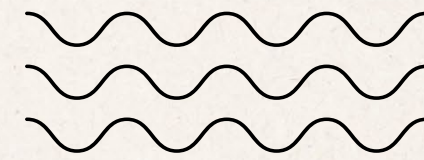


TRANSITION TO FIRE PROBLEM

From Acoustic Performance to Fire Risk

- Key acoustic properties:
 - high porosity
 - low density
 - large surface area
- also influence fire behavior:
 - rapid ignition
 - accelerated flame spread
 - high heat release rates
- Fire incidents have shown:
 - acoustic materials can significantly contribute to fire development
 - increased production of toxic gases (e.g., CO)





Problem Statement



- Acoustic materials are primarily designed for sound performance
- Fire behavior is often not a primary design criterion
- Key structural features:
 - high porosity
 - low density
 - large surface area
- may lead to:
 - rapid ignition
 - fast flame spread
 - high heat release
- Real fire incidents have shown that acoustic materials can contribute to fire development

RESEARCH GAP

- Limited data on fire performance of acoustic materials
 - Existing studies often focus on:
 - acoustic properties
 - mechanical performance
 - Lack of:
 - systematic flammability testing
 - comparative analysis across material types
 - data on gas emissions and toxicity
 - Material composition is often not fully disclosed
- limits accurate fire risk assessment



MOTIVATION

- **Need for:**

- experimental quantification of fire behavior
- identification of key flammability parameters
- comparison between different acoustic materials

- **Integration of:**

- heat release
- mass loss
- gas emissions

- **to support:**

- fire safety engineering
- material selection
- risk assessment





Research Aim



To experimentally evaluate the fire performance of selected acoustic materials



To determine key parameters of flammability:

- time to ignition
- heat release
- mass loss
- gas emissions



To compare material behavior across:

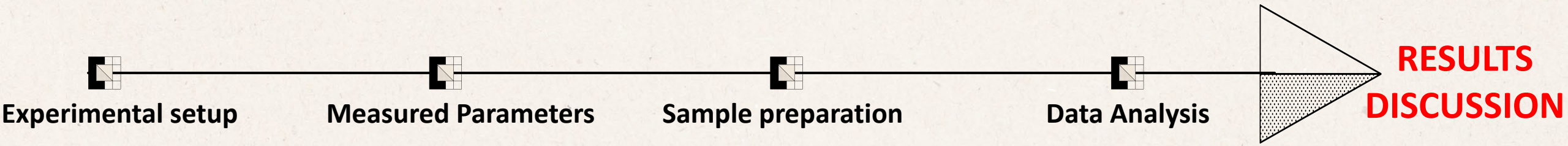
- different material types
- two experimental phases



To identify relationships between material structure and fire behavior



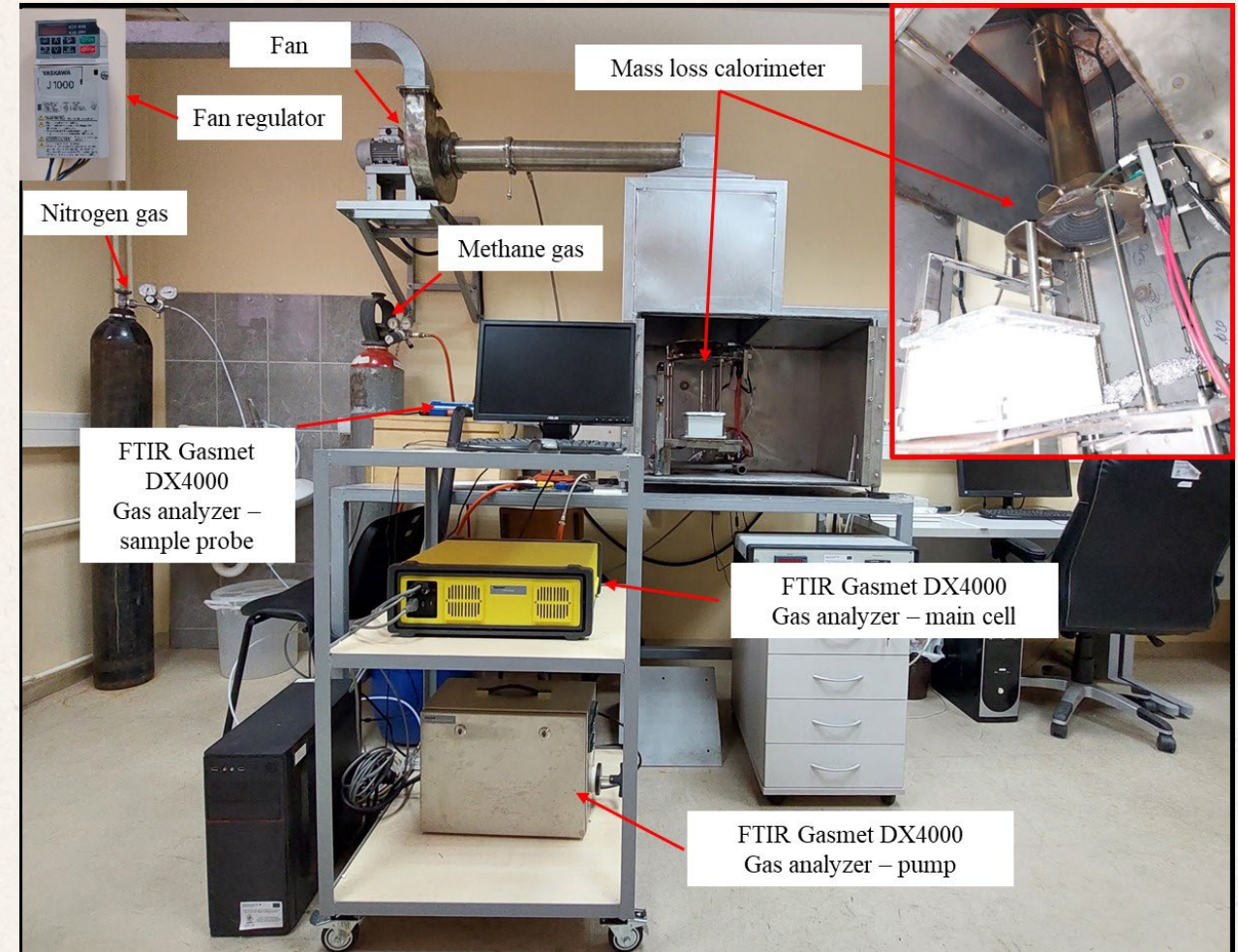
Material and methods



Material and methods

Experimental Setup

- **Mass Loss Calorimeter** (MLC, FTT, UK)
 - controlled external heat flux
 - external heat flux: 50 kW/m^2
 - measurement of mass loss and heat release
- Modified configuration:
 - integrated chimney with thermocouples
 - calibrated using methane burner
- **Coupled with FTIR gas analyzer** (Gasmeter DX-4000)
 - real-time analysis of combustion gases
- Simultaneous measurement of:
 - flammability parameters
 - combustion products
- Ensures:
 - controlled conditions
 - reliable and comparable results

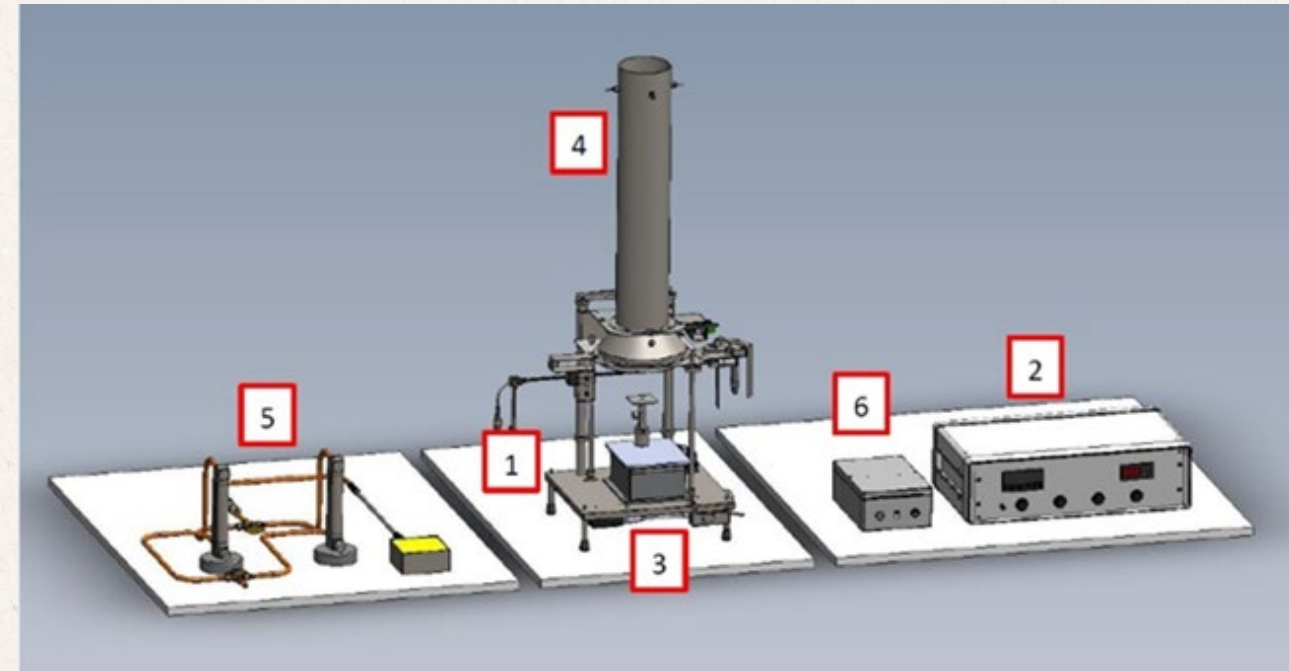


Material and methods

Experimental Setup

Mass Loss Calorimeter configuration

- Fire simulation module, including:
 - cone heater
 - heater cover
 - spark igniter
 - thermocouples for heater control
- Control unit
- Load cell for mass loss measurement
- Exhaust duct (chimney) with thermocouples
 - for measuring combustion gas temperature
- Calibration system, including:
 - methane burner
 - gas flow meter
- Signal conditioning and data acquisition system

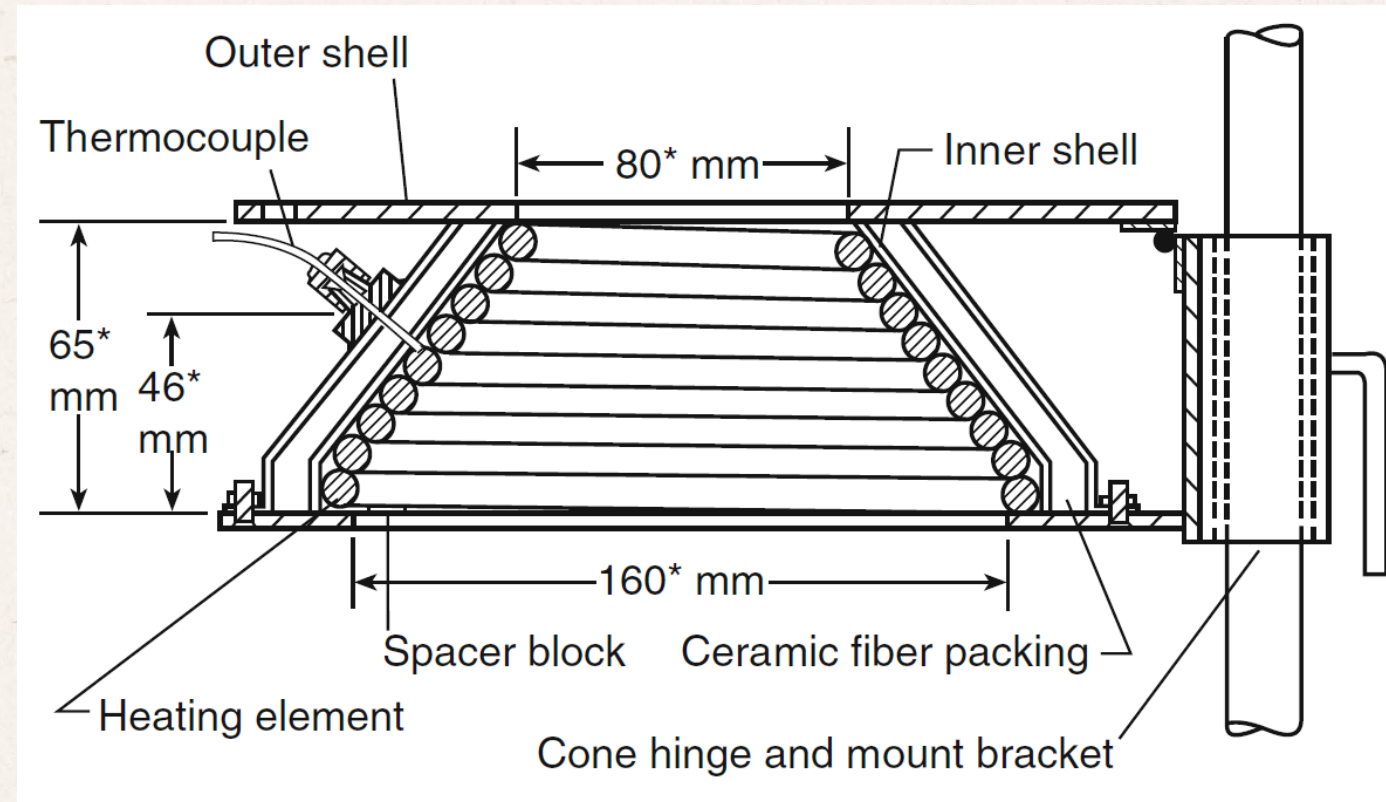


Material and methods

Experimental Setup

Cone Heater

- Based on ISO 5660 cone calorimeter design
- Provides:
 - uniform heat flux distribution
 - minimized convective effects
- Prevents:
 - localized overheating of the sample
 - direct flame contact with heating element
- Heat flux range:
 - 10–100 kW/m²
- → Enables simulation of different fire scenarios



Material and methods

Experimental Setup

Load Cell – Mass Loss Measurement

- Measures sample mass loss in real time
 - Data acquisition:
 - recorded via MLCCalc software
 - displayed on control unit
 - Capacity and precision:
 - up to 500 g
 - resolution: 0.1 g
 - Fast response:
 - 90% of mass change detected within < 3 s
- Enables accurate tracking of material degradation

Sample Preparation

- Samples prepared using a standard sample holder
 - Ensures:
 - consistent positioning
 - uniform exposure to heat flux
 - reproducible test conditions
 - Suitable for homogeneous materials
 - Provides stable support during combustion
- Minimizes experimental variability



Material and methods

Experimental Setup

Calibration Procedures

The calorimeter was calibrated through three steps:

1. Cone heater calibration

- Correlation between heater temperature and heat flux
- Performed using Schmidt–Boelter water-cooled heat flux sensor

2. Thermocouple calibration

- Conducted using methane burner (0.5–5 kW)
- Establishes relation between temperature and heat release

3. Load cell calibration

- Adjusted according to sample mass
- Ensures accurate mass loss measurement

→ Additional verification at 3 kW prior to testing

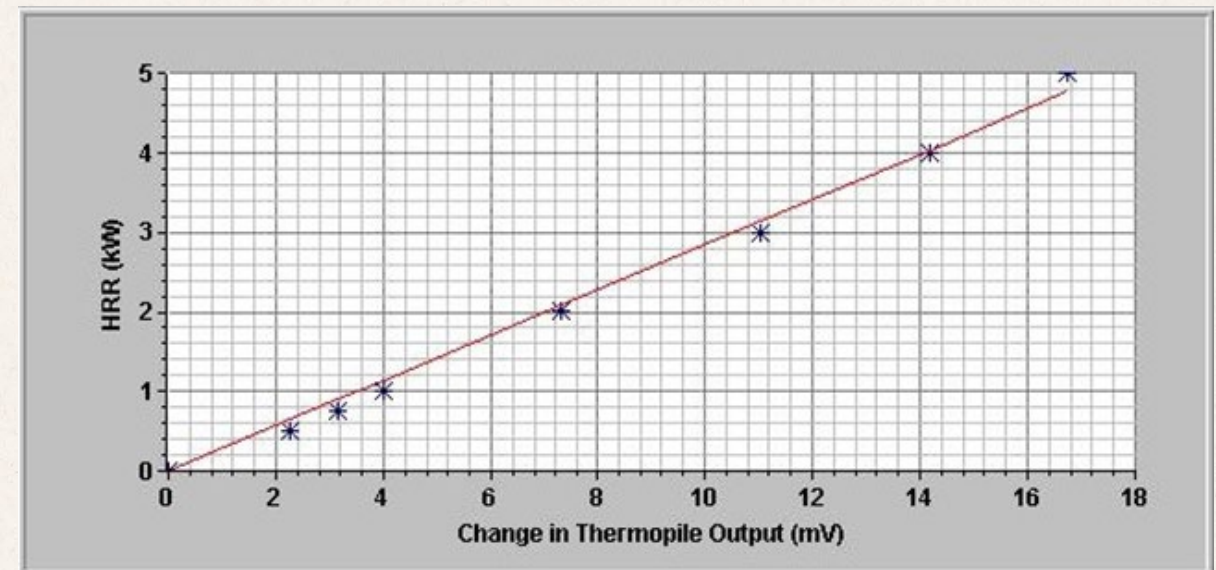
Comparative display of cone heater temperatures for certain heat flux values

Heat flux [kW/m ²]	Heater temperature on the device within the Fire Safety Laboratory [°C]	Heater temperature on a cone calorimeter developed by Babrauskas [°C]
10	416	422
20	557	547
25	609	592
30	649	628
40	720	689
50	778	744
60	835	783
70	883	825

Methane flow required for thermocouple calibration

Heat release rate [kW]	Methane flow [l/min]
0,5	0,83
0,75	1,26
1	1,68
2	3,35
3	5,03
4	6,7
5	8,38

Example of thermocouple calibration curve for a heat flux of 50 kW/m²





Material and methods

Measured Parameters

- Time to ignition (TTI)
 - indicates ignition sensitivity
- Heat release rate (HRR)
 - describes fire intensity
- Peak heat release rate (PHRR)
 - maximum fire development potential
- Total heat release (THR)
 - overall fire load contribution
- Mass loss rate (MLR)
 - material degradation rate
- Gas emissions (CO, CO₂, etc.)
 - indicators of toxicity



Material and methods

Gas Analysis – FTIR System

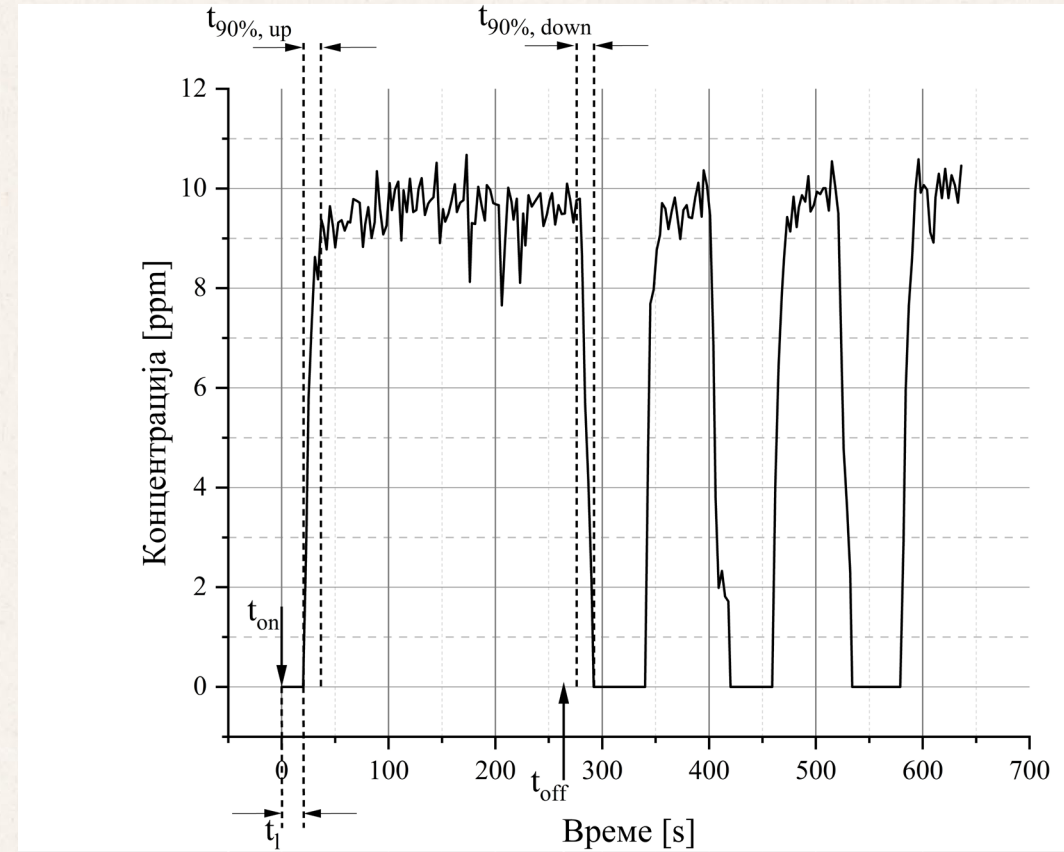
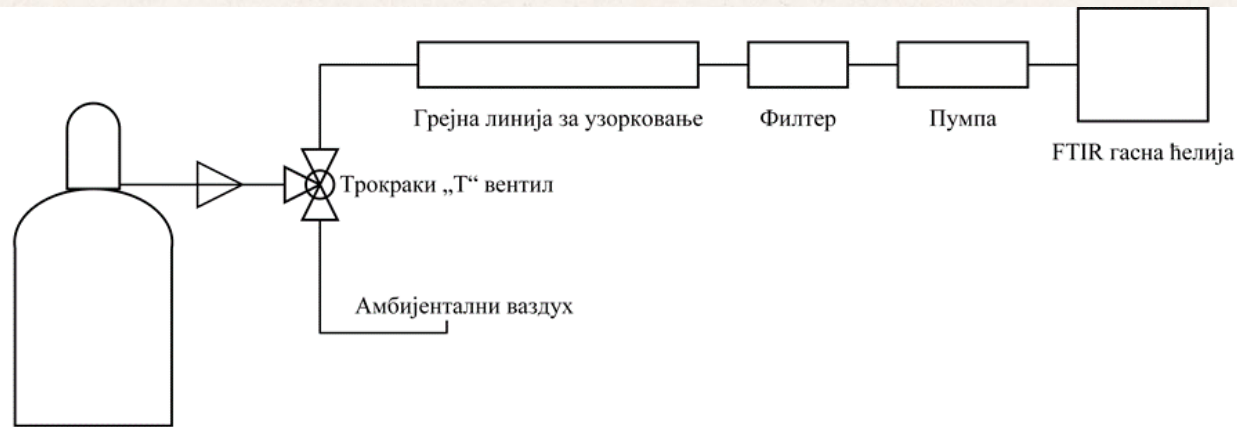
- Real-time analysis of combustion gases
- Instrument:
 - GASMET DX-4000 FTIR analyzer
- Principle:
 - Fourier Transform Infrared (FTIR) spectroscopy
 - qualitative and quantitative gas identification
- Measured gases:
 - CO₂, CO, H₂O
 - NO, NO₂, N₂O
 - SO₂, NH₃
 - HCl, HF
 - hydrocarbons (CH₄, C₂H₄, C₂H₆, etc.)
- Sampling system:
 - heated probe and PTFE line (180 °C)
 - prevents condensation
- → Enables comprehensive evaluation of fire effluents



Material and methods

Gas Analysis – FTIR Response Time

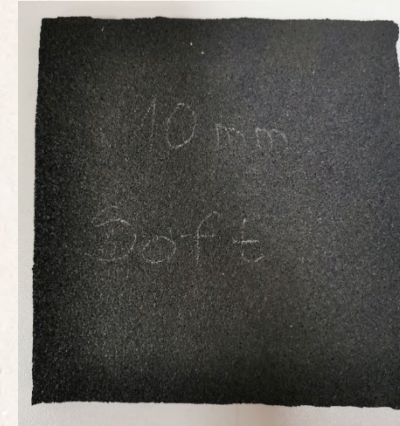
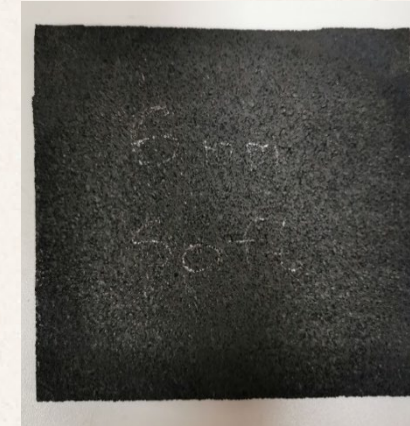
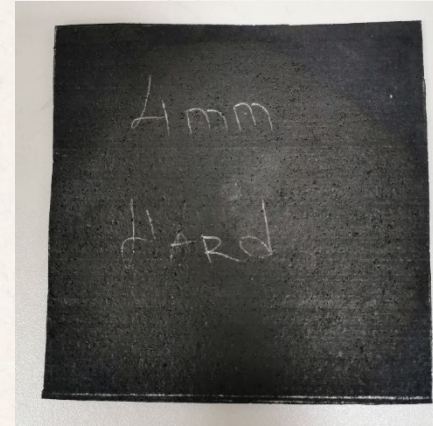
- Determined according to ISO 19702 (Annex D)
- Measured response time:
 - ≈ 14 s
- Purpose:
 - ensures accurate time alignment
 - enables reliable interpretation of gas evolution
- \rightarrow Critical for correlating gas data with fire development



Material and methods

Sample Preparation

- Acoustic materials selected from commercially available products
- Samples prepared for laboratory testing under controlled conditions
- Experimental work conducted in two phases:
 - Phase 1: 6 samples
 - Phase 2: 8 samples
- Allows:
 - broader material representation
 - comparative analysis across sample groups
- Representative samples shown in the figure





Material and methods

Experimental Design and Statistical Analysis

- Comparative analysis of fire performance across samples
 - Statistical evaluation using:
 - one-way ANOVA
 - Tukey post hoc test
 - Purpose:
 - identify significant differences between materials
 - support interpretation of experimental results
 - Applied to key parameters:
 - HRR, PHRR, THR
 - MLR
 - gas emissions
-



RESULTS

Heat Release Rate (HRR) – General Observation

All samples ignited rapidly after exposure to heat flux (50 kW/m²)

Significant variability in fire behavior observed across materials

Peak HRR values indicate:

- low-intensity combustion
- high-intensity, rapid fire growth

→ **Fire performance strongly depends on material properties**

RESULTS

HRR – Part 1

Significant variation in Peak HRR between samples

Highest fire intensity:

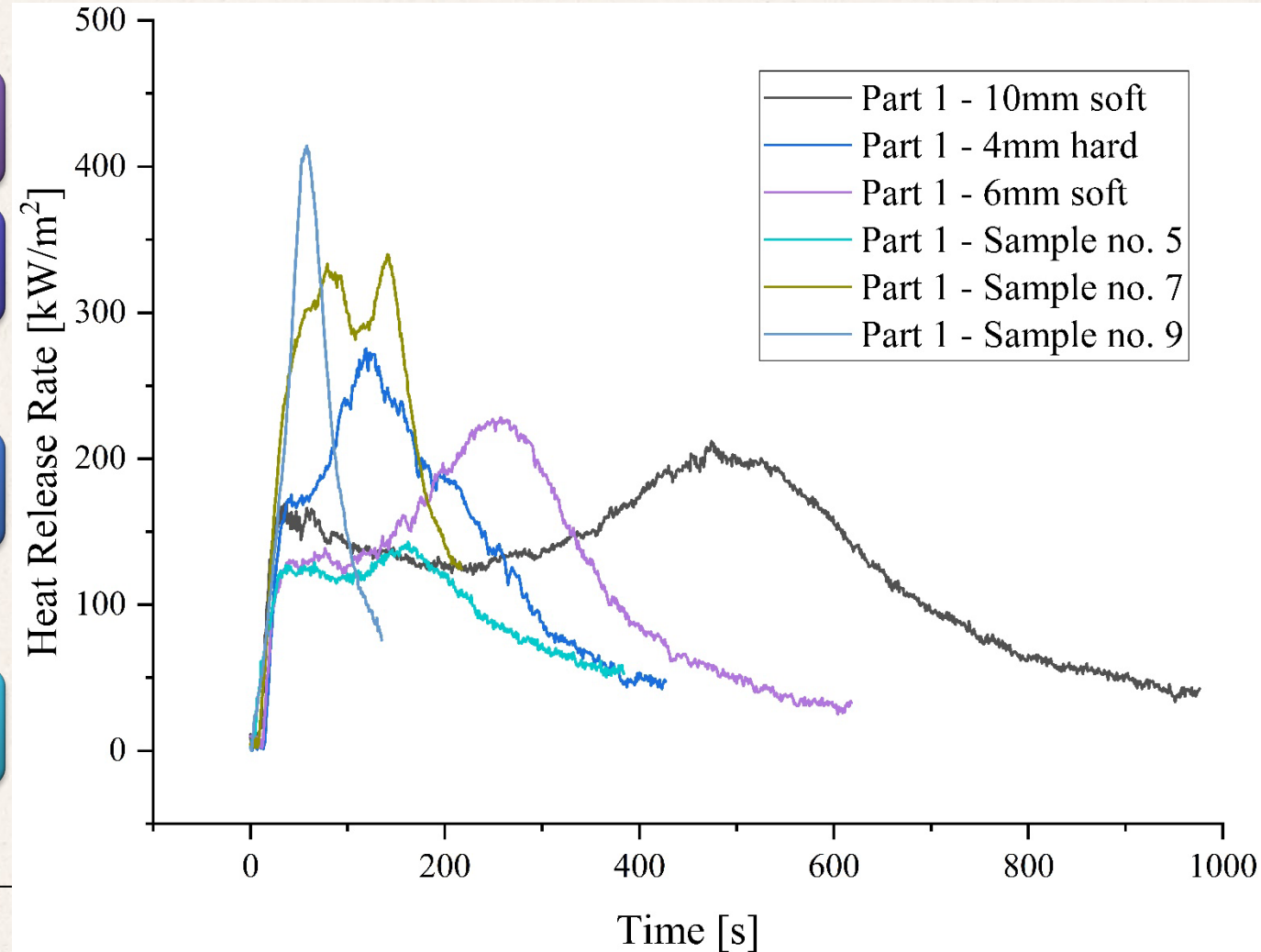
- Sample 9 → 414.4 kW/m² (≈ 58 s)

Moderate fire intensity:

- Sample 7 → 339.9 kW/m²
- Sample 4 → 275.6 kW/m²

Lowest fire intensity:

- Sample 5 → 142.9 kW/m²



RESULTS

HRR – Part 2

Wide range of Peak HRR values:

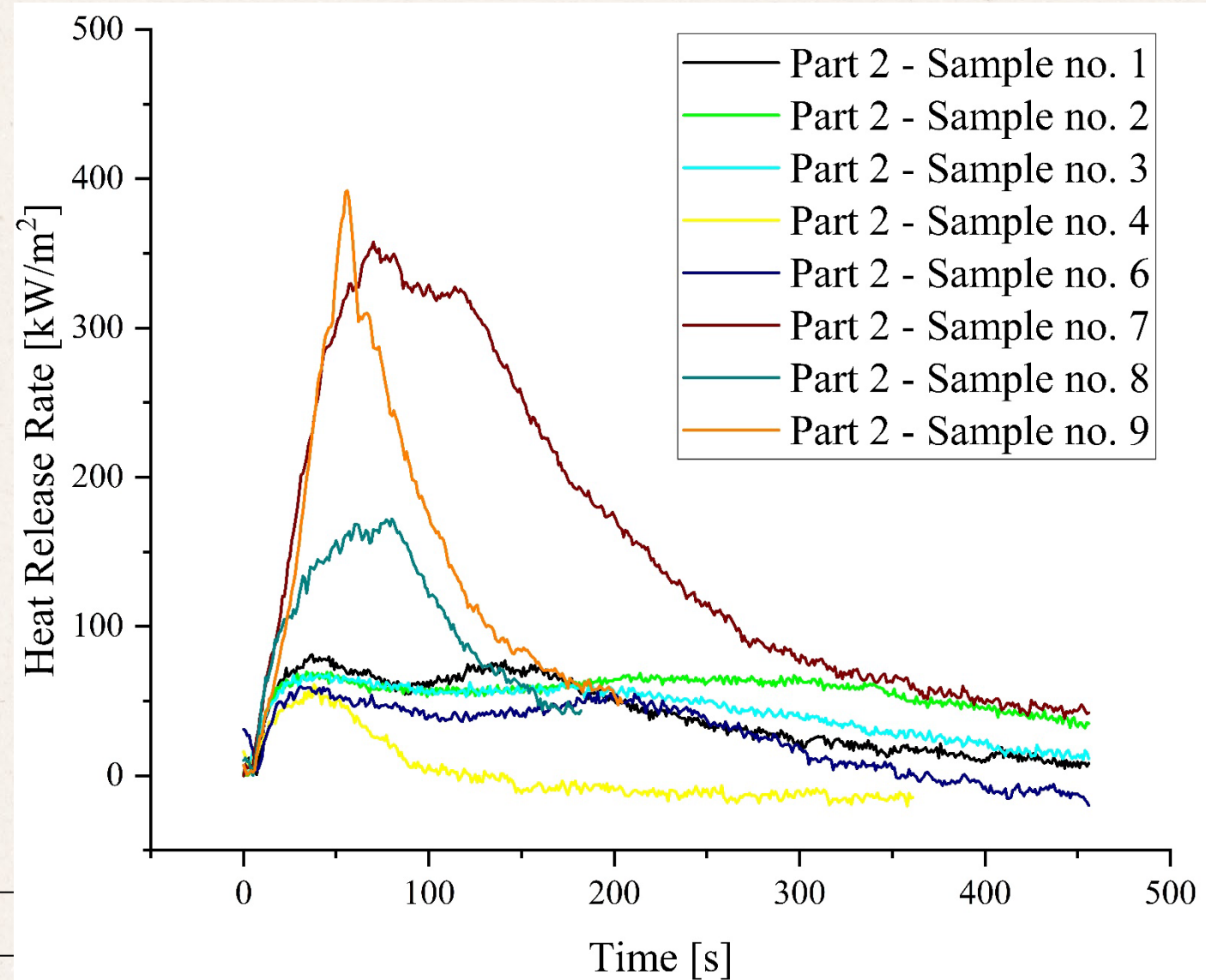
- 59.8 kW/m² (Sample 6) → 392.1 kW/m² (Sample 9)

Low fire intensity materials:

- Samples 1–6 (PHRR < 100 kW/m²)
- slower and controlled combustion

High fire intensity materials:

- Samples 7–9
- Sample 7 → 357.6 kW/m²
- Sample 9 → 392.1 kW/m² (≈ 56 s)
- rapid and intense energy release





RESULTS

Mass Loss Rate (MLR) – General Observation

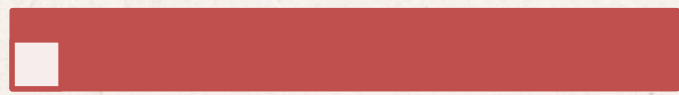
- MLR indicates the rate of material degradation during combustion
 - Strong correlation with HRR observed
 - faster mass loss → higher fire intensity
 - Significant variability between materials
 - → **Material structure influences combustion rate**
-



RESULTS

MLR – Part 1

Highest degradation rate:



Sample 9 → very rapid combustion

Elevated values:



Sample 7

Moderate degradation:



Sample 5

10 mm soft

→ Faster mass loss corresponds to higher fire intensity

MLR – Part 2

Clear separation between materials



Low degradation rate:



Samples 1–6

slower and controlled burning

High degradation rate:



Samples 7–9

rapid material consumption

→ Consistent with HRR classification

→ Indicates different combustion profiles



RESULTS

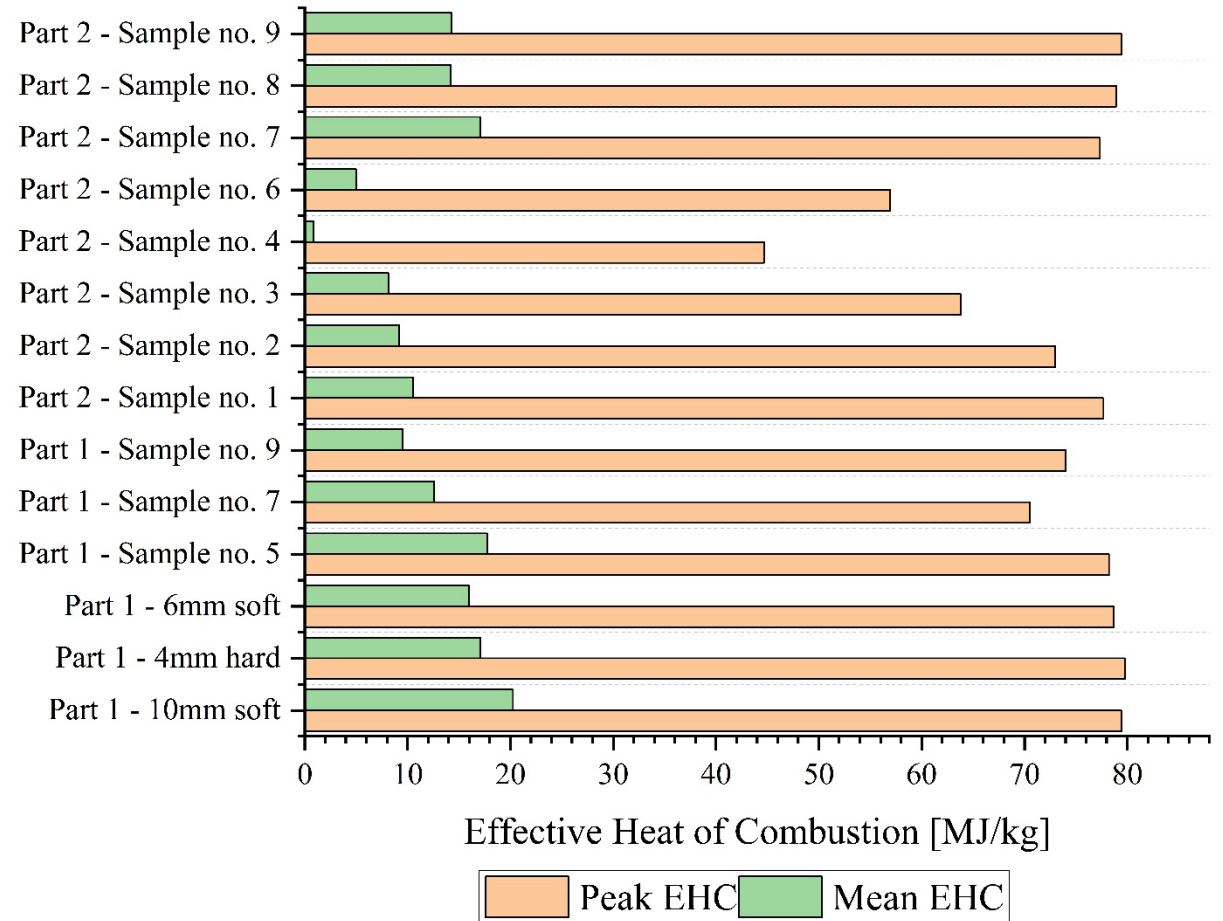
Effective Heat of Combustion (EHC) – General Observation

- EHC represents the energy released per unit mass
 - Indicates intrinsic energy potential of materials
 - Variability observed across samples
 - → Complements HRR and MLR analysis
 - → Not only how fast materials burn, but how much energy they release
-

RESULTS

Effective Heat of Combustion

- Differences observed in energy release per unit mass
- Higher EHC values:
 - Indicate greater energy potential
- Lower EHC values:
 - indicate less energetic combustion
- → Not all materials with high HRR have high EHC
- → Combines with MLR to explain fire behavior





RESULTS

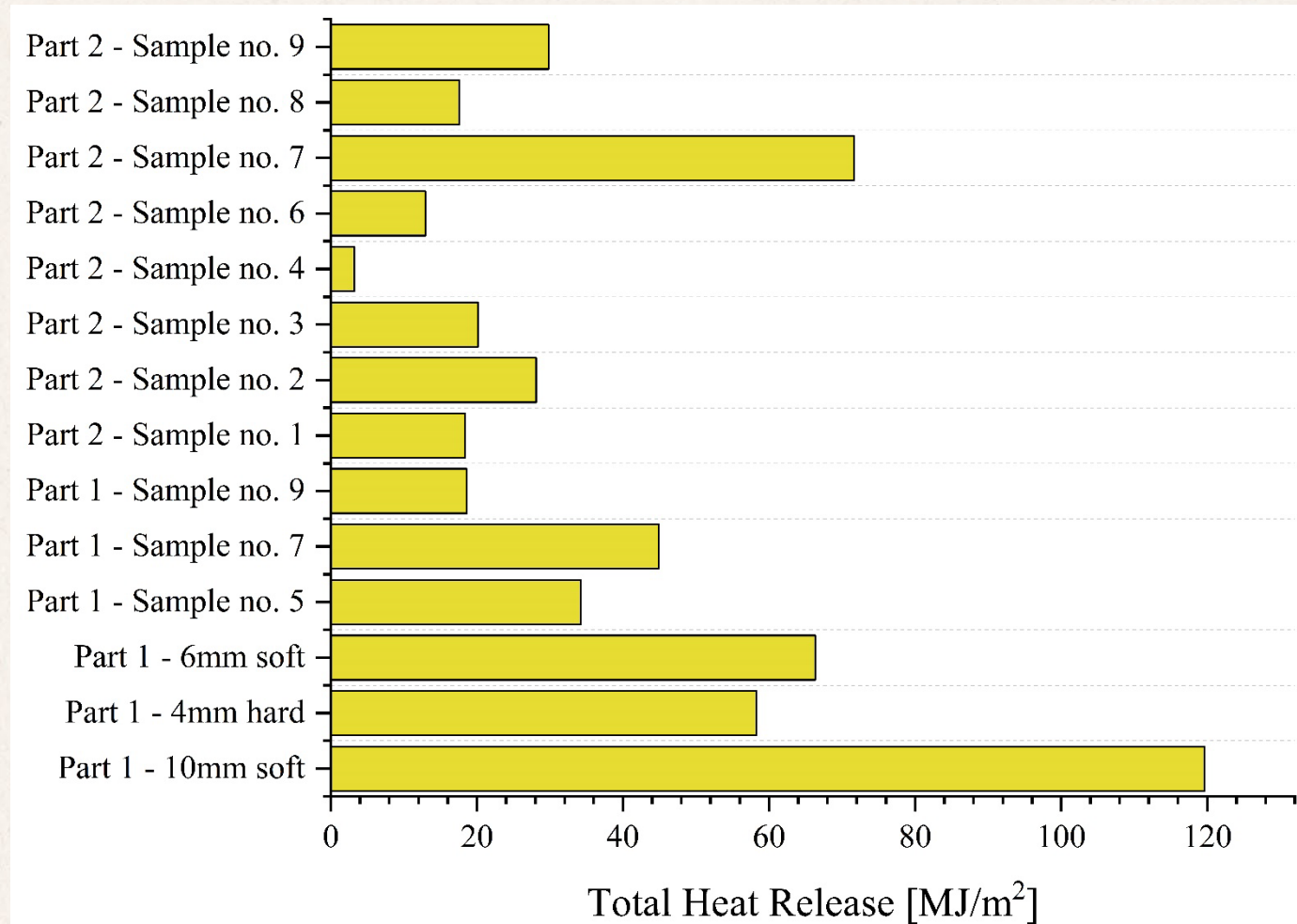
Total Heat Release (THR) – General Observation

- THR represents total energy released during combustion
 - Indicates overall fire load contribution of materials
 - Depends on:
 - amount of material burned
 - effective heat of combustion (EHC)
 - → **Complements HRR and EHC**
 - → **Provides overall assessment of fire impact**
-
-

RESULTS

Total Heat Release (THR)

- Differences observed in total energy release
- Higher THR:
 - indicates greater fire load contribution
- Lower THR:
 - indicates limited overall energy release
- → **Materials differ not only in intensity, but in total energy output**
- Clear differences in total energy release
- THR results consistent with:
 - HRR trends
 - EHC values
- → **Confirms differences in overall fire impact**





RESULTS

Comparative Observations and Safety Implications

Clear differences in fire performance across materials



Materials can be classified into:



low hazard

moderate hazard

high hazard

Key influencing parameters:



HRR

MLR

THR

EHC

→ Fire behavior strongly depends on material structure and composition



RESULTS

Comparative Observations and Safety Implications

Part 1 – Safety Interpretation

- High hazard materials:
 - Sample 9 → highest HRR and MLR
 - Sample 7 → elevated fire intensity
 - Moderate hazard:
 - Sample 4
 - Lower hazard materials:
 - Sample 5
 - 10 mm soft
 - → Faster burning and higher energy release increase fire risk
-



RESULTS

Comparative Observations and Safety Implications

Phase 2 – Safety Interpretation

- High hazard materials:
 - Samples 7 and 9 → highest HRR and THR
 - rapid and intense fire development
 - Moderate hazard materials:
 - Samples 1, 2, 3 and 8
 - Low hazard materials:
 - Samples 4 and 6
 - lower heat release and slower burning
 - → Clear ranking of materials based on fire performance
-



RESULTS

Characterization of gases evolved during flammability testing

- High fire intensity → increased gas production
 - Two hazard types identified:
 - thermal hazard (high HRR materials)
 - chemical hazard (toxic gas emissions)
 - Representative samples selected:
 - high hazard
 - chemically active
 - low hazard
-



RESULTS

Characterization of gases evolved during flammability testing

Fire Effluents – Part 1

- Main gases:
 - CO₂ and H₂O (dominant combustion products)
 - CO (indicator of incomplete combustion)
 - High emission material:
 - Sample 9 → highest gas output (CO₂, CO)
 - Specific behavior:
 - Sample 7 → presence of SO₂
 - Lower emission materials:
 - Sample 5
 - 10 mm soft
 - → Significant variability in gas generation between materials
-



RESULTS

Characterization of gases evolved during flammability testing

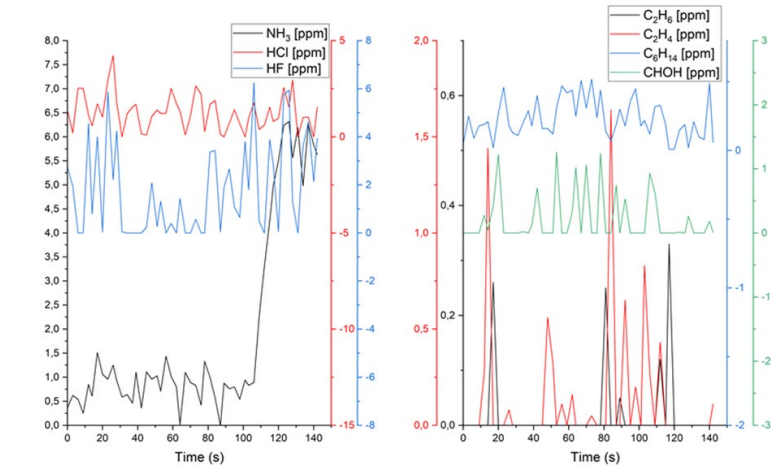
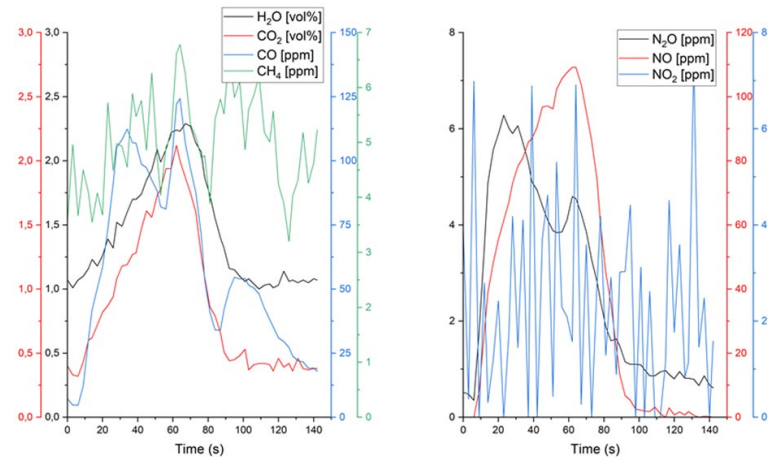
Fire Effluents – Part 2

- Main gases:
 - CO₂, H₂O, CO (dominant combustion products)
- Clear differences between materials
- Thermal hazard materials:
 - Samples 7, 8, 9
 - higher fire intensity
 - relatively cleaner combustion
- Chemical hazard materials:
 - Samples 2, 3, 4
 - elevated emissions of HCl, HF, Nox
- Low hazard materials:
 - Sample 6
 - lower gas production and stable combustion
- → Fire hazard depends on both heat release and gas composition

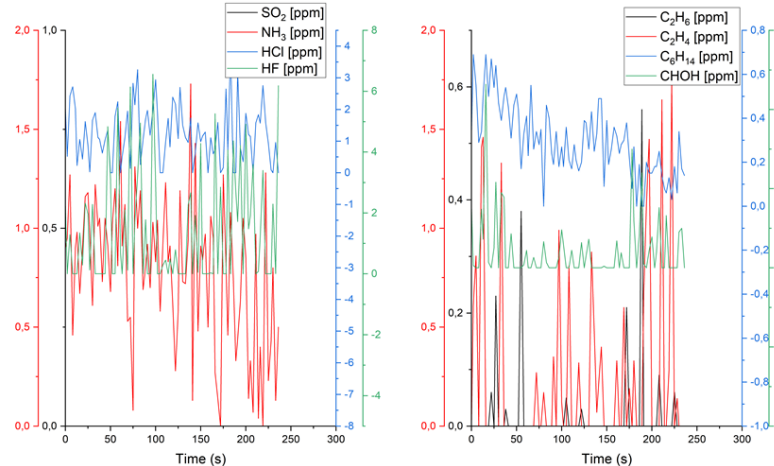
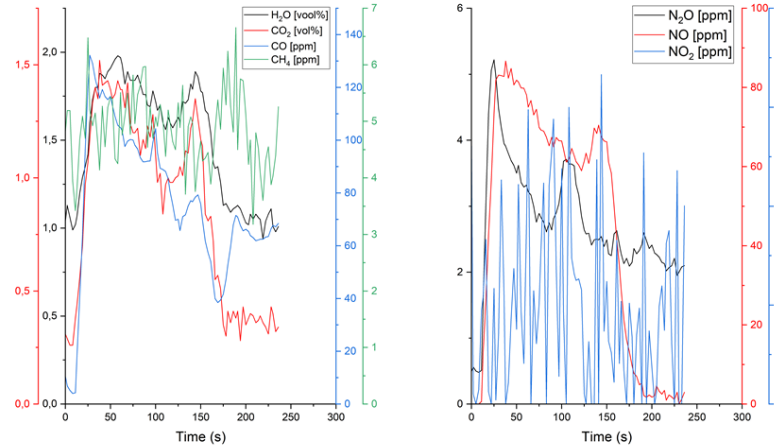
RESULTS

Characterization of gases evolved during flammability testing

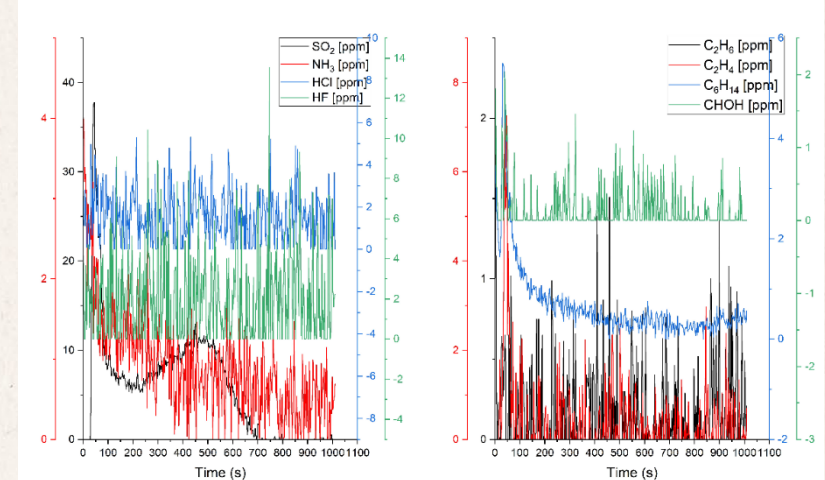
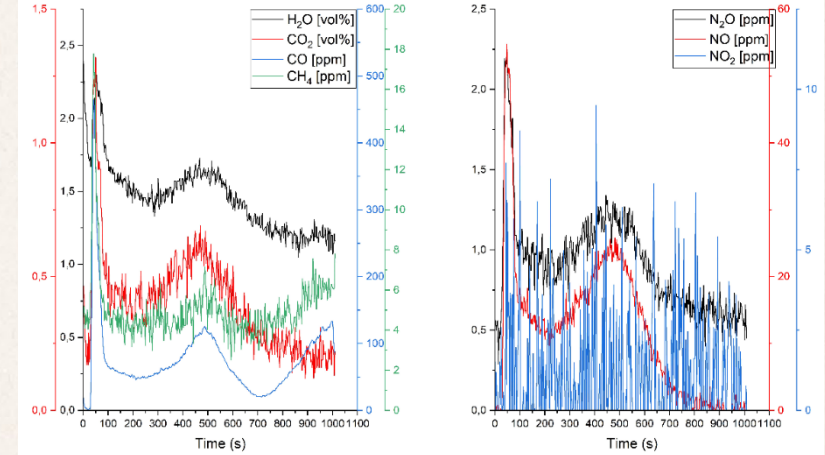
Sample No. 9



Sample No. 7

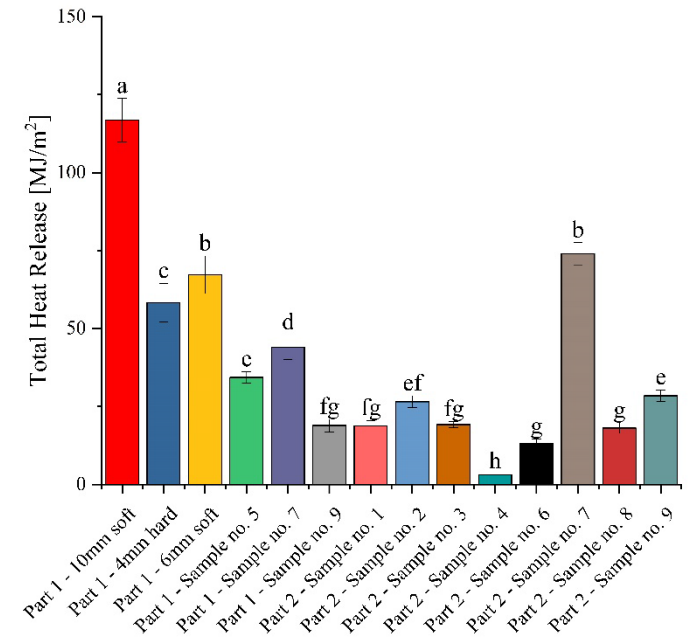
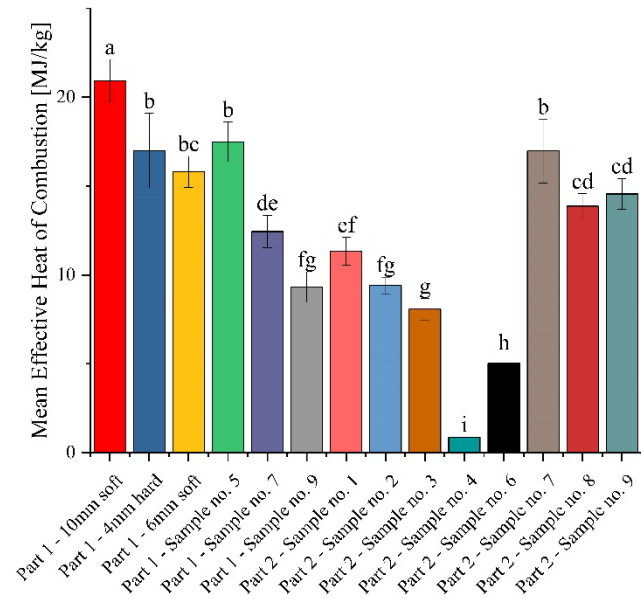
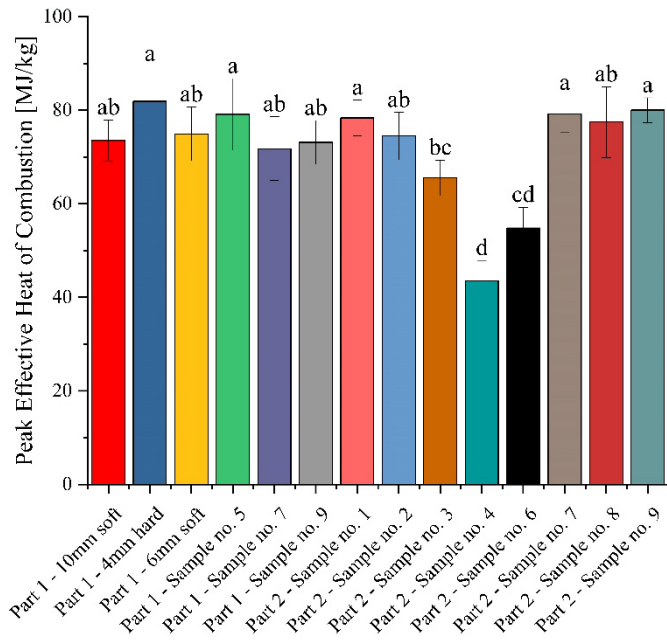
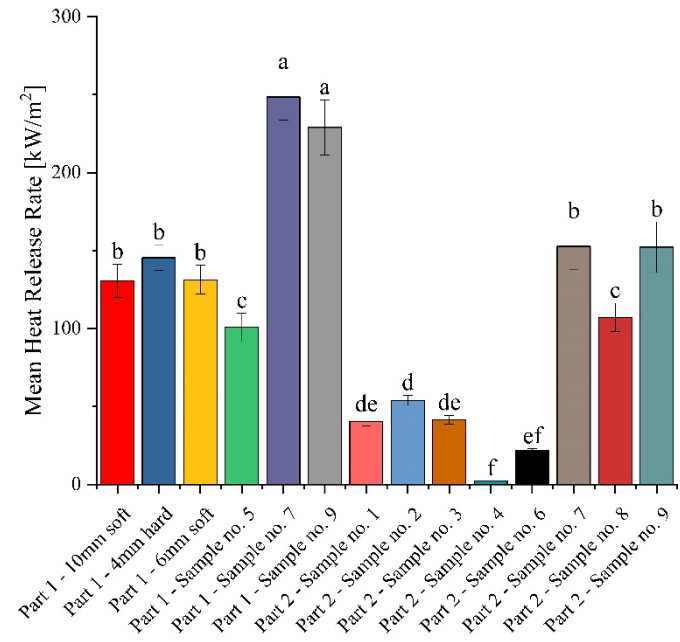
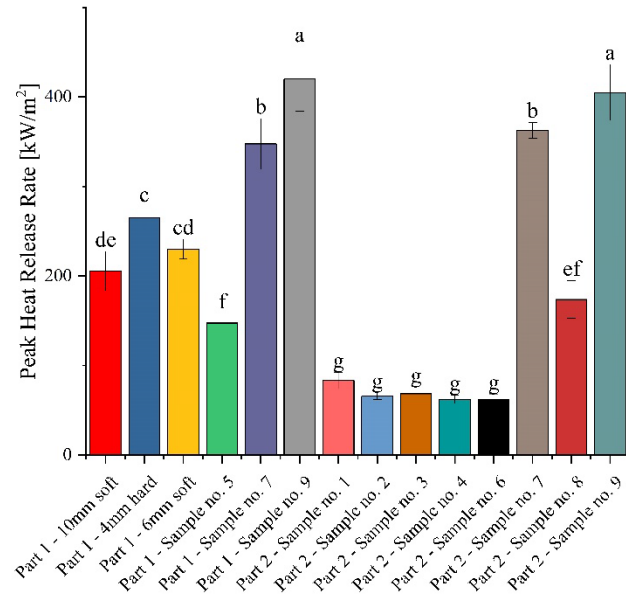


10 mm soft



RESULTS

Data Analysis





FINAL CONCLUSIONS

- All tested acoustic materials ignited rapidly under 50 kW/m² heat flux
- Significant differences observed in fire performance:
 - peak and mean heat release (HRR)
 - mass loss rate (MLR)
 - total heat release (THR)
- Materials classified into:
 - low, moderate, and high fire hazard groups
- Statistical analysis confirmed:
 - clear separation for HRR-related parameters
 - limited differentiation for EHC
- Two types of hazard identified:
 - thermal hazard (high HRR and THR)
 - chemical hazard (toxic gas emissions)
- Results highlight the need to integrate fire performance into acoustic material selection

Thank you

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