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**TGA, DSC, and FTIR Analysis of Thermal Decomposition of Different Multi-layered Gypsum Boards**

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**Abstract:**

Gypsum board, widely used in construction for its fire-resistant properties, is composed of calcium sulfate dihydrate (), with of its weight consisting of bound water. This water absorbs heat during exposure to fire, delaying fire spread and maintaining material integrity. However, variations in the material properties of different gypsum board types, such as Sound-break drywall and GlasRoc sheathing (Type X), significantly impact their performance under fire, necessitating a detailed investigation. A series of experiments were conducted to understand the calcination process and the factors limiting gypsum board performance. Thermogravimetric Analysis (TGA) was employed to study weight loss and decomposition kinetics during thermal exposure. Differential Scanning Calorimetry (DSC) analyzed heat flow at different heating rates to analyze thermal behavior. Preliminary results from TGA analysis of the Sound-break drywall and GlasRoc sheathing (Type X) under a nitrogen medium at a heating rate of reveal a significant weight loss between, corresponding to the dehydration of gypsum. The derivative weight curve exhibits a sharp peak, indicating rapid decomposition kinetics during the primary dehydration phase. Additionally, Fourier Transform Infrared Spectroscopy (FTIR) provided details on the stretching and bending vibrations of water molecules during various stages of dehydration. Unburnt samples exhibit consistent spectra with distinct peaks associated with water-related vibrations, including bending at and stretching at . Upon heating, these peaks diminish significantly, indicating dehydration and the conversion of gypsum () to hemihydrate () or anhydrite (). Additional peaks in the ranges of and reflect the presence of metal oxides and silicates, respectively, highlighting compositional shifts induced by heating. These findings enhance the understanding of the thermal behavior of different gypsum boards under different heating rates.

***Keywords: Gypsum calcination, Heat and mass transfer, Reactive porous media***

# Introduction:

Gypsum board, often referred to as plasterboard, is widely used in construction due to its excellent fire-resistant properties. This material is primarily used in walls, ceilings, and partitions in both residential and commercial buildings. The key component of gypsum board is calcium sulfate dihydrate (CaSO₄·2H₂O), which contains a significant amount of bound water. This water makes up about 21% of the gypsum board’s weight and plays a crucial role in its ability to resist fire [1]. In fire safety and fire investigation research, predicting the behavior of gypsum boards during a fire is important. The ability to understand how gypsum reacts to fire can help improve building safety and aid in reconstructing the events of a fire [2].

Calcination is the process by which gypsum loses its bound water when exposed to heat. This process occurs in two stages as shown in Equation (1) and (2) [3]. The first stage happens at temperatures between and , where calcium sulfate dihydrate loses of its water and converts into calcium sulfate hemihydrate (CaSO₄·½H₂O). The second stage happens at higher temperatures, around , where the remaining water is released, and the hemihydrate is transformed into anhydrite (CaSO₄) [4]. This entire process absorbs a significant amount of heat, which slows down the fire’s progress by keeping the material intact until the water evaporates. This heat absorption is why gypsum is so effective at preventing fire from spreading quickly.

# Gypsum Boards Under Study:

The following types of drywalls will be analyzed in the study:

1. **GlasRoc Sheathing Drywall:** This type of drywall is made with a gypsum core that is treated with mold and mildew inhibitor. The mold and mildew inhibitors are chemicals that help to prevent the growth of mold and mildew on the drywall. The most common mold and mildew inhibitors are copper-based compounds and quaternary ammonium compounds. The glass fiber facing is used on mold-resistant drywalls to avoid organic materials. This is more effective at preventing mold growth due to the lack of any organic materials. These differences could significantly alter how they respond when exposed to fire.
2. **Sound-break Drywall:** This type of drywall is made with a gypsum core that is sandwiched between two layers of sound-absorbing material. The sound-absorbing material is a material that helps to absorb sound waves, which helps to reduce noise levels in the room. The most common sound-absorbing materials are mineral wool, glass fiber, and acoustic foam. Certain fire-resistant drywalls possess sound-absorbing characteristics.

# Numerical Model:

To better understand and predict how drywalls behave during a fire, numerical models are often used. These models simulate the transfer of heat and moisture within the material as it undergoes calcination. Advanced mathematical models, such as the finite volume method, are used to simulate the movement of heat, water vapor, and mass through the gypsum board [5]. These models can help predict how fast the gypsum will calcinate, how deep into the board the calcination will go, and how long the material can resist fire before it weakens [6].

In the numerical model, the rate of dehydration () is calculated and incorporated as a source term in the species transport equation for water vapor. This rate is determined based on the total water content, the time integration of the water production rate, temperature, and two reaction-specific coefficients, as described by the equation in Figure 1. Using TGA data, the derivative of mass loss with respect to temperature is obtained. This derivative is then multiplied by the material density and the heating rate to compute the mass loss rate per unit volume of gypsum [7]. The estimated dehydration rate () for the numerical model is compared with the experimentally determined mass loss rate for the two distinct stages of the gypsum calcination process, detailed in next section. Reaction rate coefficients for each heating rate are subsequently derived from the comparison. These coefficients, which are temperature- and heating rate-dependent, are used to calculate the reaction rates in the model.

The governing equations are discretized using a finite volume method and the coefficient matrix for the system of differential equations is solved using Tridiagonal Matrix Algorithm (TDMA). A fully implicit Euler’s method is used for the time integration. Temperature-dependent thermo-physical properties are used for both the solid phase and the gas phase. A central differencing scheme is used for the conductive and diffusive terms along with an upwind scheme, sensitive to the change in velocity direction, for the convection term [8]. The rate of decomposition is obtained using the Arrhenius Equation (3) [9].

where, is the mass of the sample at the time, is the actual mass, is the pre-exponential factor, is the activation energy and is the reaction order. See Equation in [10] for more details on the reaction rate expression where the Arrhenius parameters are used.

A graph of a graph showing the temperature

Description automatically generated with medium confidenceFigure : Comparison of numerical prediction and experimental measurement of vapor production rate extrapolated from mass loss curve of TGA

# Results and Discussion:

The reaction rate parameters for the two types of boards, GlasRoc Sheathing (Type X Drywall) shown in Table 1 and that of Sound-break Drywall shown in Table 2 and, are analyzed for heating rates ranging from 10 to 100K/min. The tabulated data provides the pre-exponential factor A (1/s), activation energy B (kJ/kmol), and reaction order n, derived from Equation 3 (Arrhenius equation). Both Reaction 1 and Reaction 2 correspond to distinct chemical processes shown in Equation 1 and 2, where Reaction 1 primarily involves dehydration, and Reaction 2 includes more complex reactions such as decomposition.

**Table 1: Reaction Rate Parameters**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |
| **GlasRoc Sheating (Type X Drywall)** | | | | | | |
|  | Reaction 1 | | | Reaction 2 | | |
| Heating Rate (K/min) | Pre-exponential factor A (1/s) | Activation Energy B (kJ/kmol) | Reaction Order n | Pre-exponential factor A (1/s) | Activation Energy B (kJ/kmol) | Reaction Order n |
| 10 | 3.65E+06 | 6.37E+03 | 2.86 | 1.01E+09 | 2.30E+04 | 0.10 |
| 20 | 8.10E+05 | 5.99E+03 | 2.82 | 3.04E+08 | 2.31E+04 | 2.93 |
| 30 | 1.26E+06 | 6.48E+03 | 2.76 | 9.70E+08 | 2.48E+04 | 1.06 |
| 40 | 5.12E+05 | 6.17E+03 | 2.79 | 9.69E+08 | 2.52E+04 | 1.06 |
| 50 | 2.07E+04 | 4.91E+03 | 2.74 | 9.70E+08 | 2.56E+04 | 1.06 |
| 60 | 3.80E+04 | 5.17E+03 | 2.75 | 9.71E+08 | 2.59E+04 | 1.06 |
| 70 | 8.49E+04 | 5.50E+03 | 2.74 | 9.70E+08 | 2.62E+04 | 1.06 |
| 80 | 2.83E+04 | 5.08E+03 | 2.70 | 9.81E+08 | 2.65E+04 | 1.04 |
| 90 | 1.50E+05 | 6.01E+03 | 2.77 | 9.46E+08 | 2.70E+04 | 1.11 |
| 100 | 9.86E+03 | 4.78E+03 | 2.67 | 2.79E+08 | 2.65E+04 | 2.95 |

**GlasRoc Sheathing Drywall:**

 







Figure : Vapor production rate is compared for experimental TGA data and numerical predictions in two regions: the low-temperature (left) and the high-temperature (right) during gypsum dehydration under heating rates 20K/min, 40K/min, 70K/min, 80K/min

**Sound-break Drywall:**







Figure : Vapor production rate is compared for experimental TGA data and numerical predictions in two regions: the low-temperature (left) and the high-temperature (right) during gypsum dehydration under heating rates 20K/min, 40K/min, 70K/min, 80K/min

The numerical and experimental vapor production rates are compared for both drywalls in Figures 2 and 3, showing good agreement at lower temperatures and heating rates. While the alignment with the exponential relationship is reasonable, it reflects the complexity of the dehydration process associated with the release of chemically bound water. The initial range (low-temperature range) is primarily associated with vapor production. At elevated temperatures, additional reactions, such as the decomposition of calcium carbonate, may take place. Higher heating rates could also introduce more experimental noise. Nevertheless, the developed chemical model closely predicts reaction rates and mass loss rates across a broad range of heating rates.

**Table 2: Reaction Rate Parameters**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |
| **Sound-break Drywall** | | | | | | |
|  | Reaction 1 | | | Reaction 2 | | |
| Heating Rate (K/min) | Pre-exponential factor A (1/s) | Activation Energy B (kJ/kmol) | Reaction Order n | Pre-exponential factor A (1/s) | Activation Energy B (kJ/kmol) | Reaction Order n |
| 10 | 2.11E+08 | 7.86E+03 | 3.93 | 1.00E+09 | 2.35E+04 | 0.10 |
| 20 | 3.29E+06 | 6.62E+03 | 3.80 | 9.71E+08 | 2.43E+04 | 1.09 |
| 30 | 8.31E+05 | 6.00E+03 | 3.74 | 9.83E+08 | 2.47E+04 | 1.05 |
| 40 | 3.61E+05 | 5.92E+03 | 3.70 | 9.69E+08 | 2.50E+04 | 1.09 |
| 50 | 1.30E+04 | 4.50E+03 | 3.68 | 9.69E+08 | 2.58E+04 | 1.09 |
| 60 | 3.56E+04 | 5.18E+03 | 3.72 | 9.72E+08 | 2.61E+04 | 1.08 |
| 70 | 3.37E+04 | 5.03E+03 | 3.70 | 9.69E+08 | 2.63E+04 | 1.09 |
| 80 | 6.07E+04 | 5.48E+03 | 3.56 | 9.77E+08 | 2.69E+04 | 1.07 |
| 90 | 4.76E+04 | 5.26E+03 | 3.68 | 9.76E+08 | 2.71E+04 | 1.07 |
| 100 | 2.99E+04 | 5.22E+03 | 3.62 | 9.09E+08 | 1.78E+04 | 1.27 |

**Infrared Spectra Comparison (Unburnt vs. Heated Drywalls):**

The IR transmittance spectra of drywalls samples before and after heating are compared in Figure 4. Notable changes in absorption peaks reflect the chemical transformation due to heating. In the heated sample (dashed red line), these peaks are significantly diminished, indicating the loss of water due to heating.

1. **1600-1800 cm⁻¹ Peak:** In the unburnt sample (solid blue line), this peak is associated with bending vibrations of water molecules, which are part of the gypsum's crystalline structure.
2. **3100-3600 cm⁻¹ Peak:** This peak corresponds to the stretching vibrations of water molecules in the gypsum's crystalline structure.

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Figure : Comparative analysis of FTIR-Transmittance Spectrum of burnt and unburnt samples of GlassRoc Sheating (Left) and Sound break Drywall (Right)

**Conclusion:**

This study investigates the thermal decomposition of Sound-break Drywall and GlasRoc Sheathing (Type X) and offers valuable insights into the fire-resistant properties of gypsum boards. Through a combination of thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), and Fourier-transform infrared spectroscopy (FTIR), the study effectively characterizes the thermal behavior and reaction kinetics of these materials across a range of heating rates. The results demonstrate that the calcination process, primarily involving dehydration and subsequent decomposition, is significantly influenced by the composition and structure of the boards.

Sound-break Drywall exhibits higher reaction orders and pre-exponential factors in its dehydration reactions, indicating a more intricate thermal response compared to GlasRoc Sheathing. Both numerical and experimental analyses reveal good agreement in reaction rates at lower temperatures and heating rates, underscoring the validity of the developed chemical model. The FTIR results further highlight the chemical transformations associated with the loss of water, as evidenced by the diminishing peaks in the spectra of heated samples. Despite challenges such as experimental noise at higher heating rates and the complexity of the dehydration process, the findings emphasize the robust predictive capability of the numerical model. This work provides a comprehensive understanding of the thermal performance of gypsum boards, aiding the design and application of more effective fire-resistant materials.

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# References:

[1] Komang N, Agustini A, Triwiyono A, Sulistyo D, Suyitno D. Konferensi Nasional Teknik Sipil 12 A REVIEW ON FIRE INSULATION TECHNOLOGIES OF STEEL STRUCTURE. n.d.

[2] Fowlie EA. Encompass Encompass Experimental and Numerical Investigation of Gypsum Calcination Experimental and Numerical Investigation of Gypsum Calcination under Fire Exposure under Fire Exposure. n.d.

[3] Hasnain M, Sezer H, Kozhumal SP. Predicting Thermal Response of Gypsum Board Under Various Heat Flux Configurations: A Three-Dimensional Mathematical Model. n.d.

[4] Sezer H, Gorbett GE, Fowlie EA, Kozhumal SP. Numerical Investigation of Heat Transfer and Gypsum Calcination under Fire Exposure. n.d.

[5] Hasnain M, Paye R, Casa J, Gorbett GE, Borth T, Kozhumal SP, et al. 3D Mathematical Model for Heat and Mass Transfer Mechanisms in Gypsum Board Exposed to Fire. n.d.

[6] Fierro V, Miranda JL, Romero C, Andrés JM, Arriaga A, Schmal D, et al. Prevention of spontaneous combustion in coal stockpiles. Experimental results in coal storage yard. Fuel Processing Technology 1999;59:23–34. https://doi.org/10.1016/S0378-3820(99)00005-3.

[7] Kozhumal SP, Sezer H. Spring Technical Meeting Eastern States Section of the Combustion Institute March 6-9. 2022.

[8] Kozhumal SP, Sezer H. Numerical Investigation of Gypsum Board Calcination under Uniform Heat Flux. n.d.

[9] Prasad K, Kramer R, Marsh N, Nyden M, Ohlemiller T, Zammarano M. NUMERICAL SIMULATION OF FIRE SPREAD ON POLYURETHANE FOAM SLABS. n.d.

[10] McGrattan KB, Hostikka S, Floyd JE, Baum HR, Rehm RG. Fire dynamics simulator (version 5) : Gaithersburg, MD: 2007. https://doi.org/10.6028/NIST.SP.1018-5.