A REVIEW ON REPAIRING FIRE-DAMAGE GYPSUM BOARD

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Abstract- Recently, different types of gypsum board composition are being used in buildings due to their excellent thermal properties. Thus, the requirement for fire safety concerns rose. As a result, the goals of these studies are to first reduce the fire risk of gypsum board at normal temperatures, and then to increase the maximum failure time of gypsum-based boards when exposed to fire. Finally, maintenance or repair of fire-damaged gypsum-based material. Fire-resistant plasterboards were used because of their thermal, physical, and heat transfer properties. Various types of gypsum board were manufactured around the globe and studied for their chemical composition and thermal effects at high temperatures. By executing fire tests on gypsum-based boards, the results showed that gypsum board slows the process of extinguishing fire, and it performed well up to 400 °C. When the temperature was raised to 600 °C, cracking and volume shrinkage were observed. When the temperature rises by up to 1000 °C, the gypsum board crumbles. According to the findings of this study, increasing the thickness of the board, decreasing the density of the main element pure gypsum, the initial mass friction dehydration process, then hemi-deration process, air cavity filled with insulation material, and the addition of mixed proportions of PCM with gypsum all help to improve the failure time.

Keywords - Gypsum board, High Temperature, Fire Test, Shrinkage, Cracking, Falling off.

1 Introduction

Kong et al. (2022) reported that, due to its exceptional fire resistance, gypsum board (GB) is used as a fire-resistant component of walls. However, cracking and separation lead to partition failure because water leaks out at high temperatures [1]. As Feng and Jihong (2022) reported, a key factor in the accuracy of the thermal response simulation for cold-formed steel (CFS) composite buildings is the specific heat capacity at high temperatures of fire-resistant gypsum boards. However, the current standard does not provide complete and precise values for the test parameters (such as heating rate, sample quality, and sample size) that were used to determine the specific heat capacity of gypsum boards [2]. D.Norsk et al. (2022) studied that partition walls composed of gypsum plasterboard are commonly used in construction, and they provide passive fire protection as separating elements due to their significant role in determining the wall's fire resistance Thermo-mechanical characteristics [3]. In 1888, Augustine Sackett, combined layers of paper with plaster of Paris, and moulded a sample of the first gypsum board, which became "Sacket Board". In the 1950s, technology for gypsum board was developed, allowing for the invention and modification of designs of fire-rated gypsum board on peak and the manufacture of different types of gypsum board including partitions in curves, curved edges, partitions without stud and runner, special types of nails, low density plaster board, and sound-controlling systems. Gypsum board materials in that period were at their peak in commercial and residential buildings due to inventions and experimental studies [4]. Gypsum board is used in approximately 50% of new houses that were constructed in 1955. Lightweight steel-framed buildings were most compatible with lightweight gypsum assemblies, which encouraged the design of high-rise commercial and residential building construction in the 1960 to 1970 eras [4]. Nowadays, different types of gypsum products are used in interior designing, ceiling decoration, wall partitions, duct closing of HVAC, wet areas of kitchens and toilets, fire rated partitions, stairwells and lift shafts. Because of the cost-saving and fire-resistance properties of gypsum assemblies, Gypsum minerals are sedimentary rocks in crystalline form called "calcium sulphate dehydrate". Chemically combined water was found in 21 pounds of raw material. Rock is taken from mines, then big-sized rocks are turned to small aggregates by crushing. After crushing, the material is ground into powder and dried at 350 °C. Drying off 3/4 of the chemically combined water is known as calcining. This calcined powder is used in gypsum plaster and in other products [5].

Gypsum board manufacturing, additives and calcined powder mixed with water will become a paste, then using a machine put on a layer of paper. The conveyor machine moves down, then the gypsum board rehydrates and turns into its original shape. The chemical and mechanical bonds cause the paper layer to harden. Then the board moves toward and cuts into the stander length to clean the surface or remove the dampness on the surface [6]. Gypsum board is the best fire-resistant material in the construction industry. It is used in interior decoration and where fire resistance requirements as per stander are met. Because its core has chemically combined water when exposed to fire, it evaporated slowly in a form of steam, which helps to slow the heat transfer rate. Even after releasing all the water steam, it becomes a heat insulation barrier. Furthermore, tests conducted according to ASTM Standard (E 84) show that gypsum board has a low flame and smoke spreading index. Gypsum-based material is used with other materials to protect the building element effectively from fire at specified times [7]. The study's goal, it is quite difficult to simulate the fire behavior of plasterboard's cracking, falling off, and water transport caused by gypsum. The effectiveness of the wall's fire resistance is determined by carrying out fire tests. The aim of the study is to assess the fire resistance of walls lined with gypsum plasterboard and steel studs. On the gypsum plasterboard walls, a number of large, medium, and small-scale fire tests are carried out. The goal of these studies is to identify the risk of fire with gypsum board assemblies in commercial and residential buildings so that humans can be evacuated before the gypsum board assemblies fail during fire exposure.

2 Fire Risk for Gypsum Board Assemblies

The fire risk in residential and commercial buildings can vary depending on the building's specific use. In residential buildings garage areas where flammable materials or vehicles were parked, kitchen areas, hearths, and electrical main boards on or inside partition walls and behind the ceiling where shortcutting chases. Commercial buildings have a higher fire risk than residential buildings because they are used more frequently than residential buildings. For those reasons, specific uses of gypsum boards, which include Type X Gypsum Board for fire-resistance-rated building systems, roof systems, interior walls, exterior walls, soffits and ceilings, vertical openings, stairs, and HVAC duct enclosure, By keeping in mind fire risk aspects, failure in gypsum-based material could be in the form of a collapsed structure due to losing thermal properties. Research restricted the focus only on the thermal failure of non-load-bearing elements, and when the temperature of the backside of the unexposed surface of a board increases beyond 700 C, it is known as the thermal failure time [8]. During the furnace test, the temperature in the beginning gradually increased until it reached a critical temperature. After that, a sudden increase in temperature was noticed and reported as failure time [9]. Furthermore, failure time analysis by considering different characteristics of gypsum components When gypsum is heated, two dehydration processes happen in the range of 80 °C to 250 °C [3]. First, it was converted to di-hydrated gypsum, then to hemi-hydrate gypsum, and finally to anhydrous gypsum. During this process, first water turns into steam and evaporates from gypsum, and then a slow reaction happens until all water evaporates from gypsum. At that stage, gypsum board loses all resistance against thermal protection. At this stage, when gypsum loses thermal resistance, it is known as failure time [10].

One of the oldest materials is gypsum board. Around the globe, use of gypsum board began around 7000 years B.C. Use of gypsum board was noticed. Nowadays, more use of gypsum-based products in building construction is due to the availability of raw materials for their manufacturing. They are easy to fabricate, environmentally friendly, and have excellent thermal insulation and fire protection qualities. Fire resistant qualities depend on the dehydration process and the low thermal conductivity of gypsum products. These properties demonstrated the ability to effectively delay or retard temperature in a fire situation environment. However, the volume shrinkage and cracks due to high temperatures lead to the gypsum product collapsing, which brings challenges to fire-resistant gypsum board members [11]. Current studies show different admixtures were used with gypsum material for different purposes, such as metakaolin, latex, expanded polystyrene, glass fiber, fly ash, furnace slag, silica fume, lime, cement, vermiculite, and perlite. In the same period, considerable attention was gained by the fire resistance requirements of buildings. Studying the behaviour of fire and understanding the philosophy of gypsum material exposed to elevated temperatures are flattering principles for safety and business motive. Studies mainly focused on the most commonly used pure gypsum board products compared with fire resistance behavior. For example, Thomas et al. studied the chemistry behind the dehydration process while increasing the temperature. Ghazi et al. and Park et al. explored the thermal properties of gypsum material exposed to fire. Nevertheless, the impact of admixtures on gypsum material properties at elevated temperatures has been investigated until now [12].

3 Post Fire Assessment

According to laboratory fire test evidence from US gypsum companies, fire resistance characteristics may vary from company to company manufacturing. Gypsum board is well known due to its characteristics of fire resistance. Yanqiu Chen's research found that gypsum board structure performing well to resist heat, flame, and smoke due to slow dehydration process, evacuation time will increase if escape ways are available and clear, and gypsum board thickness is greater than fire resistance time will also increase. These were the board thickness, the di-hydration process of gypsum, and the hemi-hydration process of gypsum. When those were increased to 5%, the increase in failure time was noticed from 8 % to 12% [13]. Zhong Taoa performed tests for pure gypsum board with formable phase change material [table 01]. For economic analysis, a ceiling model for FSPCM-gypsum board was created and tested in normal environmental conditions. Results discussed 16% cooling load saved while using FSPCM with a gypsum board ceiling [14] [Table 1]. Lenka Scheinherrová investigated the changes in properties of different gypsum materials at elevated temperatures. Three gypsum board samples, one pure gypsum, one gypsum-lime binder, and one gypsum-lime-silica fume binder, were prepaired and exposed to 1000 C temperature. Only the gypsum-lime binder did not perform well at 400 C temperatures. Pure gypsum binder performed best at high temperatures [15]. C.N. Ang and Y.C. Wang concluded that additional specific heat value is affected by the heating rate of natural fires and the permeability of gypsum plasterboard [16].

Table 1- Gypsum Board and PCM GB Mix Design proportions

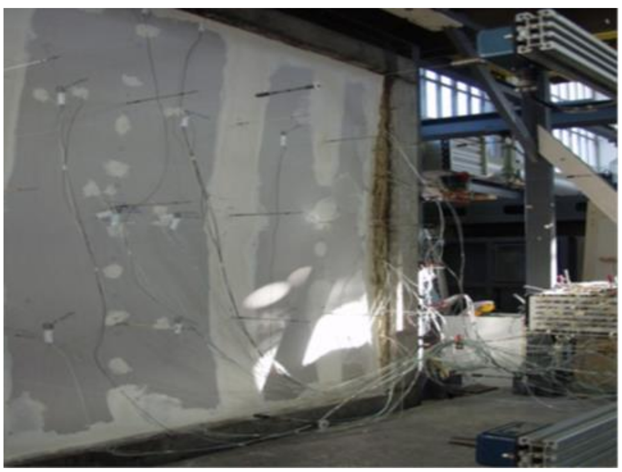
Specimen	**Pure gypsum (g)**	**PCM (g)**	**Gauge water**	**Foam water**	**Potassium sulphate**	**Glass fibres**	**Polyacrylic acid**	**Alkyl sulphate oligomers**
GB	715		257	358	1.61	4.6	0.11	0.46
PCM GB	511	204	184	256	1.15	3.3	0.08	0.33

Xianyong Li conducted fire resistance tests, preparing a steel column covered by gypsum board and then analysing it at various temperatures. SAFIR standard was compared with test results, steel temperature histories were used to obtain fire exposed results, and fire results were used to develop a formula for predicting test model critical temperature less than 1,000 °F (538 °C) [17]. Rene Prieler and companions performed fire resistance tests to determine the heat transfer rate and water vapour transformation. The results show that at 65 °C, thermal heat conduction was the primary cause of heating in thin gypsum assemblies up to 2.5 cm thick. When the temperature was raised to 100 °C, more water vapour condensed. Furthermore, during fire exposure, a sudden decrease of water vapours recorded in mineral wool from 33.3 mm2/s to 26.7 mm2/s was determined. Finally, the result shows that the water vapour mean velocity was determined to be between 1 and 3 mm/s [18]. Jae D and companions investigated the characteristics of functional gypsum board (FGB) with expanded vermiculite (EV), expanded perlite (EP), nano carbon material (C300), and noctadecane (PCM) were analysed by Fourier transform infrared (FTIR) spectroscopy for structural stability. As a result, FGB's thermal conductivities decreased by 15% when compared to conventional gypsum board. In the case of moisture properties, the water vapour resistance and water content of FGB were increased, compared with the conventional gypsum board (SR). However, the simulation results showed that there were no moisture problems, such as condensation, mould growth, or structural damage [19].

Ahmed Allam investigated: mathematical equations were developed to predict the behaviour of gypsum board during fires, which were calibrated during fire tests. A gypsum board wall test was built with C-section studs and gypsum fixed on both sides of the studs. Rockwool insulation was used to fill the cavity between the two layers of gypsum board. The sample was subjected to a standard fire test. During exposure to fire, the wall was found damaged and changed in physical, thermal, and chemical behaviour. The prediction of the equation for maximum thermal bowing of walls was quite close to the maximum values collected during the fire test. He proposed adopting the equation for structural fire engineers and fire laboratories as tools to solve the exercise [20]. She investigated the deformation, mechanical, and thermal properties of foamed gypsum at high temperatures. Two samples were prepared; one was pure gypsum (800 kg/m3), the second was foamed gypsum (650 kg/m3), and the third was fibre glass or vermiculite with foamed gypsum. They were tested under temperatures from 25 °C to 800 °C. Test results showed the first sample had more cracks than the second sample when exposed to high temperatures. Furthermore, adding fibre glass could increase thermal cracks and shrinkage of gypsum board when fibre glass melts during fire exposure, but use of vermiculite enhanced the properties of shrinkage, reducing the cracking in gypsum board and reducing the loss of strength while exposed to fire [21].

4 Repairing of Gypsum Board Assemblies

Raffaele Landolfo investigated the fire side of gypsum board, which lost strength due to dehydration, loss of physical properties, and also in vertical direction, bowing is found during fire tests [22]. Sajith Wijesuriya investigated many factors effecting the failure time while exposed to fire. One was the density of board; the second was the thickness of board; the third was the mass fraction in the initial phase of di-hydrate of gypsum content; the fourth was the di-hydration process; and the fifth was the hemi-hydration process. Sixth, the time of failure could be increased if highly reflective paper were used. The seventh was that failure time was extended when the air cavity of gypsum board could be filled with insulation, and also that melting of insulation and heat transfer ratio were impacting the failure time. In the thickness of board, di-hydration and hemi-hydration were increased by 5%. Then, the extension of failure time increased from 8% to 12% [23]. Gypsum board assemblies can be repaired if the fire exposure temperature is not more than 400 °C. Otherwise, when exposed to high temperatures, gypsum-based assemblies fully fall off or partially fall off. In this condition, fire damaged gypsum board residual material is used in its initial processing phase to make new gypsum board. According to studies, there is no evidence for fire damaged gypsum board repair. Damaged portions could be identified by physical appearance and replaced with new gypsum board [24].



a) Bowing in test wall (one hour exposure)

b) Post fire inspection of test wall

5 Conclusion

Gypsum board is the best fire-resistant material in the construction industry. It is used in interior decoration and where fire resistance requirements as per standard are met. Because its core has chemically combined water when exposed to fire, it evaporated slowly in a form of steam, which helps to slow the heat transfer rate. Even after releasing all the water steam, it becomes a heat insulation barrier. It is quite difficult to simulate the fire behaviour of plasterboard's cracking, falling off, and water transport caused by gypsum. The effectiveness of the wall's fire resistance is determined by carrying out fire tests. The aim of the study is to assess the fire resistance of walls lined with gypsum plasterboard and steel studs. On the gypsum plasterboard walls, a number of large, medium, and small-scale fire tests are carried out. The below outcome is favourable indicating the fire damaged gypsum board at safe fire temperature could be repaired but if exposed to high temperature gypsum board shrinks, cracked and fall of due to chemically and physically change in gypsum board. Fire damaged gypsum board residual material could be used with raw material to gypsum board to make new gypsum boards. Following conclusions can be drawn from the conducted study:

- The fire resistance ratings of single layer loadbearing assemblies were enhanced by the addition of glass fibre to standard lightweight gypsum board cores.
- Gypsum board type X, Type C could be used for fire resistance because they have contain shrinkage-compensating additive
- Gypsum board slows the process of fire expending due to Gypsum dehydration processes cause water vapour to be produced and then dispersed in the fire compartment when gypsum plasterboard wall assemblies are subjected to a high temperature environment. These phenomena are frequently disregarded in pertinent Computational Fluid Dynamics (CFD) simulation.
- Thermal variation causes volume shrinkage, crack formation, and strength loss. As a result, high-temperature fire-exposed gypsum board was damaged partially or fully. It will then need to replace the affected area of gypsum board with new GB.

Recommendations

- Future research requirements are defined in the context of current performance-based fire safety engineering ideas.
- The essay ends with a list of important study areas that will increase our understanding of how gypsum boards perform on wood during a fire.
- Future experiments and numerical studies will focus on combined heat and mass transmission in multilayered buildings.
- This work unequivocally shows that it is crucial to include gypsum board contraction and crack formation in future models in order to model the failure of partition assemblies.
- Gypsum boards tend to disintegrate after being exposed to moisture. It needs potential research on water resistance as well

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