Evaluation of Glass Composite Material as Next-Generation Fire Doors

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Abstract - Statistics show that during fire incidents, the vision panels in fire doors often lose transparency when exposed to flames. This limits firefighters' capacity to evaluate conditions within enclosed spaces, heightening dangers like backdrafts and related threats. If the glass melts or breaks, the situation worsens—especially when flammable materials are stored on the opposite side. Broken glass fragments can also endanger occupants and trigger panic. Since different types of glass are used in fire-door vision panels, each must be tested for fire resistance to ensure suitability for various occupancies and safety conditions.

Key Words: Fire, compartment fire, flame, fire doors, fire-resisting glazing, fire-rated doors.

1. INTRODUCTION

FIRE: -Fire is an oxidation reaction between fuel and oxygen in the presence of heat. And the nature of the reaction is exothermic, which implies energy is released in the form of heat and light, along with byproducts such as smoke. When the combustion reaction reaches ignition temperature material will ignite and continue to burn as long as there is fuel, oxygen, and proper heat. To depict the burning process 'fire triangle' has been used for many years. The triangle's three sides denote the three essential components of fire: oxygen, heat, and combustible material. If any one side of the triangle is removed, that will result in the collapse of the entire triangle. That means by eliminating one component of fire (heat, fuel, oxygen), the fire can be suppressed. In recent years, to show the fourth element chain reaction, which provides the heat to maintain the fire 'fire tetrahedron', has been introduced. This fire tetrahedron will show the constituents of fire as well as the controlling measures. Removing any one factor from the fire tetrahedron will lead to the extinguishment of the fire effectively. For example, consider a flame of natural gas, such as from a cooking burner. The extinguishment of the fire can be possible by any one of the following:

- By turning off the gas supply (removal of fuel)
- By covering the flame completely, which smothers the flame as the combustion both uses the available oxygen in the air and displaces it from the area around the flame with carbon dioxide.
- By applying water (removal of heat)
- By applying a synthetic chemical clean agent (inhibition of chain reaction).

Fire has been used by humans for different purposes like cooking, agriculture, for cleaning land, rituals, incineration of waste, propulsion purpose etc. Therefore, proper fire prevention and fire protection measures are necessary for all buildings.

FLAME: -Flames are the visible glowing part of fire. They are made up of hot gases that emit light as fuel burns. Their color depends on fuel type, chemical reactions, and temperature. Incomplete combustion (like wood or gas) makes yellow-orange flames from soot, while complete combustion gives a blue flame [5]. Different chemicals burn in different color flames. For example, hydrogen appears light blue, and boron ignites bright green. Flame color also signifies the heat of combustion: white/yellow indicates higher warmth, orange is milder, and red is the least before burning ends, leaving dark smoke. On Earth, flames rise upward due to the convection effect, but in zero gravity, such as the environment in outer space, convection no longer occurs, and flames form blue, spherical shapes and burn more effectively. Thus, this experiment conducted by NASA indicated that diffusion flames in microgravity permit more thorough oxidation of soot after formation compared to Earth-based diffusion flames, due to various mechanisms operating differently under microgravity versus normal gravity. These observations of NASA are utilized in applied science and industry, especially for enhancing fuel economy [3].

INTRODUCTION OF COMPARTMENT FIRES: A compartment fire can be defined as a fire confined within an enclosed space, like a room or a compartment within a building. These fires can be dangerous due to the limited space and the potential for rapid fire development, including flashover, backdraft, which can cause physical damage [4].

VENTILATION FOR COMPARTMENT: -Ventilation is an essential part of structural firefighting strategies, and it can remove the heat and smoke from a burning structure, which will help the firefighters to assess the location effectively and safely to locate trapped persons and suppress the fire. If a large blaze is not adequately ventilated, not only does it become far more difficult to control, but it can also accumulate enough partially combusted smoke to trigger a smoke explosion or generate sufficient heat to cause a flashover. On the other hand, ventilation that is poorly timed or incorrectly positioned may increase the fire's oxygen supply, leading to rapid growth and spread [4].

TYPES OF VENTILATION: -There are two types of ventilation, vertical and horizontal. Their names describe the locations where the hot gases and smoke are released. Vertical ventilation is carried out through openings cut in the roof, typically by truck teams during the initial phase of a fire, an operation commonly called roof work. Horizontal ventilation, on the other hand, is done through doors and windows. The objective of both ventilation techniques is to expel heat and smoke, either to enhance the survival prospects of trapped occupants or to help firefighters move hose lines forward more efficiently. Each approach aims for the same output, and it depends on the situation; proper timing and coordination are crucial, since increasing airflow inside a burning structure can also worsen fire spread if done carelessly.

Mechanical fans can be used to create positive pressure ventilation, either with existing openings like windows, skylights, or roof vents, or by making new ones if needed. When there's no suitable outlet, firefighters may cut one using specialized saws to open a large hole in the roof. Another approach is hydraulic ventilation, where a wide-angle water stream is directed toward a doorway or window. This water spray drags smoke out with it, speeding up the removal of smoke from the area. This method is often applied when the fire is relatively small and the goal is to limit smoke damage, but it can also be used in larger fires, where thick/dense smoke blocks the nozzle operator's view of hot spots.

When windows in a burning building shatter due to heat and pressure, or when flames break through the roof, the fire is said to have self-ventilated or auto-ventilated.

HORIZONTAL VENTILATION: -Horizontal ventilation is the most commonly used ventilation because, in most circumstances, it is the most suitable technique, which can aerate the structure and is often the simplest. Furthermore, firefighters entering a structure for search and rescue or fire suppression initiate a kind of horizontal ventilation by unfastening doors or windows to gain access.

VERTICAL VENTILATION: -Vertical ventilation uses the buoyancy of heated smoke and gases to the fullest, allowing them to disperse harmlessly into the air by the most direct path available. It is particularly advantageous in potential backdraft conditions. The difference between vertical and horizontal ventilation lies in the placement of the outlet opening. In horizontal ventilation, the exhaust vent is located as high as possible on the compartment wall. In vertical ventilation, the exhaust vent is created in the compartment roof, as close to the flames as safety permits. Vertical ventilation is most efficient as an offensive tactic, applied to influence the fire directly. In defensive operations, its effectiveness relies on its nearness to the fire, and therefore on the buoyancy of the smoke and heated gases.

FORCED VENTILATION: -Ventilation efforts should align with prevailing atmospheric circumstances, utilizing natural airflow whenever feasible. Nevertheless, in certain conditions, natural ventilation may be insufficient and must be augmented or replaced with forced ventilation to provide a survivable environment and to support rescue actions. The application of fans, blowers, water streams, or other mechanical apparatus to produce or redirect airflow within the structure is forced ventilation.

FIRE DOORS: -A fire door is a door with a fire-resistance rating used in passive fire protection systems to limit the spread of flames and smoke between different compartments of a building, and helps in allowing safe exit from a structure [1], [2], [4].

1.1 Component

Fire doors can be made up of the following materials and their combinations, such as:

1. Glass sections
2. Gypsum (as an endothermic fill)
3. Steel
4. Timber
5. Vermiculite-boards
6. Aluminum

Both the door leaf and the door frame must meet the guidelines of the testing agency, which provides the product listing below. The frame of the door includes the fire or smoke seals, door hardware, and the structure that holds the fire door assembly in place. Together, these components form an assembly that is typically called a "door set" that holds a numerical rating, quantified in hours of resistance to a test fire. All of the components of the door assembly must bear an agency's label (except ball-bearing hinges, which meet the basic build requirements of ANSI 156.2 and NFPA 80) to ensure the components have been tested to meet the fire rating requirements.

1.2 Door hardware

Door hardware includes. But it is not limited to:

1. Automatic closing devices or objects, Ball-bearing hinges
2. Gas seals
3. Positive latching mechanisms
4. Smoke seals

Seals Edges of a Tire door usually need to have fire-rated seals, which can be composed of:

1. An intumescent strip, which expands when exposed to heat
2. Gaskets to prevent the passage of smoke
3. Neoprene weather-stripping

So, when intumescent seals are used in the door design, the correct seal use is crucial for the fire rating performance of the door assembly. Chemical composition of seals may vary in rate of expansion, volume of expansion, and/or charring characteristics.

1.3 Windows

Some fire doors come along with integral windows, which also have a fire rating or are tested as part of the complete door setup, meaning they are subject to the same overall certification [11]. These fire-resistant windows must withstand fire exposure; at the same time, they have to withstand hose stream impact testing. They can consist of:

1. Wire mesh glass – usually Georgian wired
2. Liquid sodium silicate fills between two window panes
3. Ceramic glasses
4. Borosilicate glass

Wired glass usually resists fire at the same time, and sodium silicate solution reduces heat transfer by absorbing the heat during the reaction.

1.4 Regulations

All parts of the door must meet the product certification standards that are accepted by the local fire authority, based on the regional building and fire code. These rules can be different in each country. For illustration, in Australia, the National Construction Code requires that all fire hatches be time-tested to certain standards to get approval and a certificate. In the UK, fire-resisting doors must be time-tested and conform to BS 476 Part 22:1987 or BS EN 1634-1:2000. The testing reports contain details about how the door was designed, any modifications in shape, and how it handles stress. The number of times the door can withstand fire is unveiled in the Building Regulations Approved Document B or in some British Standards, like FD30 for 30 minutes of protection or FD30(S) when smoke regulation is a part of the system. In the US, fire doors are tested using the ASTM E119 standard, which checks how long the door can withstand fire under diverse temperature timelines, like 20, 30, 45, 60, and 90 minutes [11]. These doors also need to be certified by an NRTL, like as Underwriters Laboratories.

While the fire door is being installed, attention should be given to the fact that, in addition to hanging the door and leveling it, all gaps between the wall and the door frame that are being filled with fire-resistant material should be sealed. Fire doors are a part of a passive fire safety system. It will resist the movement of smoke and heat. Comparable technical guidelines and building codes are enforced in other nations as well.

1.5 Combustibility: - Fire doors aren't consistently comprehensive non-combustible. Some portion might appear to burn during a fire, but as long as the whole door layout withstands fire tests, it prevents heat from passing through to the other side. This is the main job of a fire-rated door: to cease fire of disseminate between diverse zones for a certain amount of time [13]. This gives sufficient time for people to flee and for firefighters to act.

1.6 Fire door failure

Fire doors are sometimes made incapable of delivering their specified fire resistance due to a lack of awareness about their proper function, related limitations, and requirements, or through incorrect usage. For example, fire doors are occasionally blocked open, or carpets are laid across them, which allows fire to spread beyond the fire partition where the door is placed. The door's certification labels are shown on the door panels as well as on the fire door frames, and they should not be removed or painted over during the building's lifespan. Sometimes, fire doors come across unusually wide gaps at their base, an inch or two, which will allow airflow, as seen in dormitory buildings. This can make people think the door isn't as strong as it should be. NFPA 80 permits a maximum clearance of ¾ inch; at the bottom, even though fire doors are tested with tighter gaps, they comply with NFPA 252 [2]. Corridors typically have a fire rating of one hour or less, and the fire doors in them must have a fire rating of 1/2 or 1/3 hour to comply with standards. This rating primarily stops smoke from propagating.

1.7 Normal operation

Mainly, fire doors remain closed at all times. Also, there are some doors constructed to be open in normal conditions, and they will be closed automatically in the event of fire. Sometimes, electromagnets connected with a fire alarm network are used to open doors. Regardless of the design, the door's movement must never be obstructed by a doorstop or any other object. The intumescent and smoke seals on fire doors should be checked regularly, along with the proper functioning of the door closer and holder. When the alarm is triggered or there's a power cut, the magnet loses power and the door closes automatically. Wireless battery-operated fire door holders are used nowadays to open the door under normal conditions and automatically close it during a fire. Rated fire doors are tested according to the time–temperature curve of ASTM E119 standard for a specific duration of time. [1], [2]. These doors shall be certified with an approved Nationally Recognized Testing Laboratory (NRTL), such as Underwriters Laboratories. The certification will be only valid if each part of the installation is correctly specified and placed. Because using the wrong type of glazing can reduce the door's fire resistance ratings in a fire test for at least 60 minutes before its temperature rises enough to cause softening.

1.8 Installation

When placing a fire door, it is important to make sure that the g ap between the door frame and the wall is adequately sealed wit h fireproof material,
along with making sure that the door has been installed accurate ly and uniformly. Fire doors play a significant role in a

structure's passive fire protection system. Therefore, it is mandatory to install offices, residential buildings, and industries. Fire doors are normally installed by a carpenter.

1.9 IMPORTANCE

All of us who use or occupy any building have a right to expect that we all be safely protected should a fire break out. Sadly, this does not always happen; something may fail within the fabric of the building, or with the fire safety devices, and tragedy occurs, causing death or serious injury. Since no one can predict the outbreak of fire, unlike any normal door, the fire door must carry out its main purpose to save lives and limit the spread of fire to the other parts of the building. They are also a requirement in certain domestic situations, depending on the country's local regulations, for example.

1. In flats,
2. Other situations, for example, where a door leads into an integral garage,
3. In dwellings where there is a second-floor 'habitable' room, such as houses with loft conversions or a 'room in the roof.

All rooms are separated from each other, forming a compartment.

1. Keep any fire in the compartment in which it starts
2. Protect the occupants (and contents) of other compartments
3. Provide a safe, protected route to allow the occupants to escape.

Walls, ceilings, exits, and entrances are designed as fire-retardant to withstand the conditions.

The simple purpose of a fire door in everyday use is just of any other door. Fire can break out at any time, so the primary purpose of this is to withstand the fire and prevent it from spreading.

1.10 Types of Fire Doors with Different Occupancies

Buildings are divided into different compartments to slow the spread of fire from one section to another. The doors are connected to the compartment; thus, safe movement of people is possible. Fire doors serve two main purposes. In the event of a fire, if the fire door is closed, it acts as a barrier to prevent flames and smoke from spreading. Meanwhile, when it is open, it provides an escape route.

A well-designed timber fire door can retard fire and smoke spread for a certain duration of time, which allows the easy evacuation of people. The door's level of resistance depends upon its location in the building and the potential fire risks present. FD30 & FD60 are the common classifications of fire doors. These doors will provide resistance against fire for 30 and 60 minutes, respectively.

1.11 Fire-Resisting Glazing

Glazing is different for a small viewing panel in a door and full full-glazed screen. This provides maximum light and safety. Regular glass tends to crack when exposed to heat and may fall out quite early during a fire [6]. Fire-resistant glass, however, can withstand the heat conditions of a fire test for at least 60 minutes before its temperature rises enough to cause softening [12]. This is mainly because, with clear FR glazing, nearly 50 % of the incident heat is transmitted through the glass by radiation [7]. To delay the ignition of beading to 30 minutes, it is necessary either to provide protection by impregnation of a surface coating or a surface covering of non-combustible material, or to fit a fire-resistant glass secured using a fire-resistant glazing system [8], [11]. This will hold the glass firmly in place during normal use, but in the event of fire, it allows the intumescent material to expand, thereby securing and insulating the glass and protecting the surrounding timber.

For longer periods of fire protection, an improved retention system for the glazing is required. The glass panel should be small, and the method of fixing must ensure that no direct path can be created for the transference of hot gases.

1.12 Significance of Vision Glass in Fire Doors

Fire-rated door glazing

All fire-rated doors that contain glass panels must use fire-rated glass. This is a specialist type of glass which has been specifically designed to provide protection against fire. The glass in fire-rated doors will act as a barrier against flames, stopping their spread, and will also stop smoke from spreading throughout the rest of the building [10]. Depending on the type of glass, the glazed panel will also act as an insulator, protecting the rest of the site against the heat of the fire. All rated fire doors that contain glass must use fire-rated glass according to building regulations.

Testing for quality

All types of fire-resistant glass used in fireproofed doors have been thoroughly checked by outside firms under strict circumstances to guarantee their safety. Typically, this involves placing the glass and frame inside a testing oven, which is then lit to mimic a real fire. The temperatures on the surface of the glass are the glass recorded, and a rating is given based on the temperatures and the length of time it remains structurally integral. Normal glass can withstand approximately 120 ºC, usually for only a few minutes in a real fire [7]. Good quality fire-rated glass can withstand high heat at 900 ºC, which is more than seven times hotter than regular glass [8]. In addition, it protects against high temperatures for over an hour, stopping the fire from spreading and giving firefighters ample time for evacuation and responding [9]. A vision panel must be both fire-resistant and impact safe to exceed 100 square inches in size [1], [2]. Having sprinklers does not mean you can create bigger screens now. Creating safe learning environments costs less than what? Saves money by making them more secure. Add glass now. Finding glass that offers maximum benefits and complies with regulations. Daylighting methods like window taps, skylights, and door panel visions enhance both student security and energy conservation. Natural light boosts academic success in studies. The 2012 IBC rules state that, for safety, vision panels in certain doors must have small, fire-resistant glass, like wired glass or ceramics, which cannot exceed 100 square inches, even if there's no sprinkler system [12]. Any vision panel should be no more than 43 inches above the ground to meet ADA requirements.

1.13 TYPES OF GLASSES USED IN FIRE DOORS

A variety of fire-rated systems allow for both fire protection and unobstructed pathways and visibility. Fire-rated rooms and stairwells don't have to be solid walls and dark; architects can use glazed systems or protective glass openings to fill them with light. The items mentioned in the list of glazing systems and specialty glasses are considerably pricier than ordinary safety glasses, such as those made from laminated or tempered glass. We have an additional article that discusses regular glass varieties. Architects need to think about how much it will cost to use fire glass in big spaces first. Then they should decide what kind of building they want to make.

Fire-Protective vs. Fire-Resistive

When you want to use rated glass, you need to think about what you want to keep safe. There is an important difference between fire protective glass and fire-resistive glass, and the building codes are very specific about where each is to be used. Architects need to know the difference between the two types of documents and write them down clearly. Fire-protective glass prevents the spread of fire and smoke. Radiant heat transfer can still happen even if you use this material. When one side of the glass gets hot from the fire, the other side of the glass will also get hot. There are three types of glass that can protect tires from damage: wired glass, tempered glass, and glass-ceramics. These types of glass are allowed in places where the building code requires them to be used for safety reasons. Fire-resistive glass stops fire and smoke from moving from one place to another. It also stops heat from reaching objects on the other side of the glass. This way, the objects do not get too hot and catch fire by themselves. This is generally achieved by creating a laminated assembly that is composed of a number of layers of glass separated by heat-resistant interlayers. Fire-resistant glass is a type of glass that can stop or slow down the spread of fire. It is used in places where the rules say that the building needs to have a fire-resistant part, which also means that the side of the building that is protected from fire cannot get too hot. The temperature rise on the protected side should not be more than 250 ºC higher than the normal temperature.

Fire-Rated Glazing Labels

The code says that glass that stops fire has to have a label that shows how it does that. The label also tells you how long the rating is, in minutes. This is important because the building codes only allow certain types of glazing depending on the type of wall, the size of the opening. And the type of opening. The label must always be on and visible.

Wire Glass

For a long time, the only kind of glass that could be used for windows that could break was wire mesh glass. It is made from a sheet of glass that has a wire grid mesh incorporated into it [6]. The glass stays in the wire when the wire gets very hot from a fire. The wire makes the glass weaker and easier to break when it hits something. It also makes the breakage look sharper and riskier. - Some places where people go to learn or exercise have rules that do not let them use wired glass indoors or windows. This is because wired glass can break easily and hurt people if it falls. Safety wired glass has the same fire-resistant properties as normal wire glass, but it also has film that allows it to meet safety requirements ¾, so it can be used in doors and sidelights [12]. The film stops the glass from falling if it breaks. This way, the glass does not hurt anyone with the sharp edges. Wire glass is cheaper than other kinds of glass. Other choices are getting closer to the best ones.

Specially Tempered Fire-Rated Glass

A cost-effective alternative to wired glass is tempered glass that has been tested and has a fire-rated label. However, there are two main drawbacks. First, it will usually not be able to survive the hose stream test. Second, since it can't pass the hose test, tempered fire glass carries a maximum rating of 20 minutes, so it has limited use [7], [9].

Ceramic Glass (Glass-Ceramics)

Ceramic glass, also known as glass ceramic which can sustain higher heat when the equipment is exposed. It can hold against 800 degrees Fahrenheit, which is why it is used as a cooktop as well as in fire doors [8]. Due to its fire-retardant (fire rating 3 hours) property, it is also employed for glass glazing [11]. It is fabricated from several sheets of glass in a systematic way. The glass process through controlled heating that causes it to crystallize. This process must be done conscientiously, and it makes the glass more robust and steadier when it is exposed to heat.

Acquiescent glass is a sort of fire-rated double glazing made with atomic layer deposition of glass and transparent material [13]. The fire approval rating can be up to three hours, based on how many atomic layer deposition cycles are required. When fire knocks, the exterior glass disrupts, but the acquiescent atomic layer deposition accelerates to shape a safeguard fence. This ceases the dissemination of fire and smoke, and likewise cluster heat from moving amongst. The main advantage of acquiescent glass is that it ceases heat from dispersing. It can be used in fire-heat resistant structures as elongated as it has been time-tested and is tagged for that objective.

Fire-Rated Framing Systems

It's significant to recall that both the glass and the structure work concurrently to provide a fire approval rating. That's why we frequently utilize the term "assembly" in this article. [11]. Both the structure and the glass should possess the identical approval rating; nevertheless, building codes do allow for exceptions where a higher approval rating than mandatory is adequate (invariably conform to local codes when designing a network).

When utilizing a network made of diverse portions, each section should be clearly tagged so the approval ratings are easy to comprehend and correspond to the location.

Fire-Rated Glass Testing

Fire-rated networks are significant for protection and must be cautious retrospect during both the intend and construction stages to ensure they meet the incumbent standards. Fire-rated glass is time-tested in the same way as diverse fire-rated materials.

A barrier is built following a blast furnace, and the glass network is placed in the barrier just as it would be in an authentic context. Then, a fire is commenced in the blast furnace at the needed temperature and burned for the defined moment. The glass network must remain intact as a contour in the experimental conditions. In the United States, another experiment is conducted where water is sprayed on the hot glass to determine how well it can grip. For further details about this experiment, notice the Hose Stream experiment beneath. In a different homeland, a weight is dropped on the glass to test impact resistance.

2. Methodology

As per the strategy's objective, various sorts of glass, LPG cylinders, temperature sensing laser guns, and other testing apparatus were preferred broadly, based on what was available in the market. The glasses were purchased from companies that make glass and fire doors, while the LPG cylinder and other apparatus were bought from the local market. These items were then time-tested in the institution's laboratory. Testing of four glasses was done-

1) Clear glass

2) Wired mesh Glass

3) Inter-layered Glass

4) Gel-filled Glass

1) Clear Glass: Dimensions: -
Area (100 mm by 100 mm)
Thickness: - 6 mm

Fig. 1. Experimental arrangement of clear glass

The testing of clear glass was accomplished successfully by appropriately setting up the gear. The glass was located on a stand as a display in the picture. The igniter is switched ON, and the premixed flame comes in contact with the glass exterior. The flame temperature was 1100 ºC. There was continuous contact of flame with the glass for a 90-second approval rating, withstanding 104 seconds at 719 ºC. The affability of the glass vanishes at 692 ºC.
The readings for the clear glass, as per the time and temperature, visibility point, and breaking point, are given below.

TABLE I. Time–temperature observations of clear glass under direct flame exposure

Time(sec)	Temperature(ºC)
0	36.6
30	500
60	613
90	643
120	712
150	730
180	745

Fire rating of glass: 90 seconds
Breaking point: 104 seconds, 719 ºC
Visibility point: 692 ºC

2) Wire mesh glass: Dimensions:
Area (285 mm by 300 mm)
Thickness: 6 mm

Fig. 2. Experimental arrangement of wire mesh glass

The wire mesh glass was sandwiched between two layers of glass, and a grill of horizontal and vertical wires was meshed between the two layers of glass [3], [6]. This alloy was kept in contact with the flame for 30 seconds at 370 ºC, and the inner layer, which was exposed directly to the flame, got cracked.

At this time and temperature, the inner layer of the glass, which was facing the flame, broke, and the visibility of the glass went to zero at 714 ºC, after 180 seconds. After 240 seconds at 895 ºC outer layer of the glass, which was not facing the flame, broke. The readings with respect to time and temperature are given below:

TABLE II. Time–temperature observations of wire mesh glass under direct flame exposure

Time(sec)	Temperature(ºC)
0	36.6
30	370
60	430
90	537
120	607
150	692
180	714
210	861
240	895

Breaking point (inner layer): 370 ºC, 30 seconds
Breaking point (outer layer): 895 ºC, 240 seconds
Visibility point: 714 ºC, 180 seconds

3.) Interlayered Glass: Dimensions: -
Area (100 mm by 100 mm)
Thickness: - 5 mm

Fig. 3. Experimental arrangement of interlayered glass

The interlayer was transparent glass, consisting of the attachment of two layers of glass to each other. This glass was kept in contact with a flame for 120 seconds at 712 ºC and was cracked at this time and temperature. After 150 seconds at 730 ºC, the visibility of the glass went to zero. The readings during the test with respect to time and temperature are given below:

TABLE III. Time–temperature observations of inter-layered glass under direct flame exposure

Time(sec)	Temperature(ºC)
0	36.6
30	500
60	613
90	643
120	712
150	730
180	745

Breaking point: 712 ºC, 120 seconds
Visibility point: 730 ºC, 150 seconds

4.) Gel-filled Glass: Dimensions: -
Area (350 mm by 350 mm)
Thickness: - 14 mm


Fig. 9 Experimental arrangement of gel-filled glass

The gel-filled glass is sandwiched between two different layers of glass, and is fire-resistant in between the two layers of glass [13]. This glass was kept in direct Contact with flame for 30 seconds at 145 ºC, and the inner layer of the glass started forming cracks on its surface. The gel inside the glasses started Sacrificial protection and didn't allow the heat to pass to the upper layer [7], [9]. After 60 seconds of time at 300 ºC, the visibility of the glass went to zero.

TABLE IV. Time–temperature observations of gel-filled glass under direct flame exposure

Time(sec)	Temperature(ºC)
0	36.6
30	145
60	300
90	429
120	478
150	565
180	702

Breaking point (inner layer): 30 seconds, 145 ºC
Visibility point: 60 seconds, 300 ºC
The same apparatus and measurements were employed in testing the four types of glass.

3. RESULT AND DISCUSSION

As our project aims to test different types of glasses used in fire doors, we tested four types of glasses that are used in fire doors, which are:

1) Clear Glass
2) Wire mesh Glass
3) Interlayered Glass
4) Gel-filled Glass

Hence, we tested these glasses with proper apparatus and the safety equipment required for the conduction of the tests, and successfully obtained the proper readings and observations during the tests.

4. CONCLUSIONS

In this project, we tested four different types of glasses that are used in fire doors for vision purposes and showed various properties after exposure to fire. The conclusion for the four types of glasses used in the test is:

1) **Clear glass:** - The clear glass, when exposed to open flame, we observed that it didn't change its original property until it reached the time of its fire rating of 90 seconds. After 90 seconds, the cracks started developing on the surface of the glass, and it broke down into pieces.

2) Wire mesh glass: When the wire meshed glass was exposed to open flame, the first layer, which was exposed to the flame directly, developed cracks in the first 30 seconds. Later on, the glass started losing its visibility at 714 ºC, and then the upper layer also got cracked.

3) Interlayered glass: - As the interlayered glass was exposed to the flame, the glass resisted the flame up to 120 seconds and started forming cracks on its surface, and subsequently it broke into pieces

4)Gel-filled glass: - As the gel-filled glass was exposed to the open flame, the inner layer of the glass started forming cracks after 30 seconds. The gel inside acted as sacrificial protection and didn't allow the heat to penetrate the upper layer.

Know that different After the testing of four types of glasses in the project, we found that two types of glasses have different types of properties. When the clear glass was tested sustained the temperature in accordance with its fire rating (90 minutes). Thus, inference is drawn from the above observation that these types of glasses are used in the laboratories where chance of a temperature rise. Due to a chemical reaction and thereby causes fire, which is apprehended. During the test of the wire meshed glass, we observed that its major drawback is that it loses its visibility at 714 ºC, so it should be used in domestic areas such as hostels, hospitals, theatres, etc. When the interlayered glass was tested, as it broke into small pieces at 712 ºC, it should not be used in domestic areas where the pieces can cause harm to people; it should be used in warehouses or storage sections. During the test of the gel-filled glass, as the flame was exposed to the Surface of the glass, the inner layer of the glass got cracked within 30 seconds, and the gel between the two layers of the glass started covering the surface and did not allow the heat to penetrate the upper layer of glass. As such, we suggest this type of glass can be used in such areas where storage of highly flammable materials is done on both sides of the fire door.

When the temperature was lifted gradually to rest at approximately 1100 °C for 90 seconds, the clear glass broke, the double-coated glass was interlayered for 120 seconds, the wire mesh glass for 240 seconds, and the rest was frozen for 180 seconds. Therefore, in comparison to clear glass, the unique varieties of glass survived much longer, with gel-filled glass performing most satisfactorily. It should also be noted that in normal fire ratings, regular fire-resistant glass is typically designed to withstand up to 90 minutes. But in this experiment under direct flame temperature (~1100 °C), ordinary clear glass shattered within 90 seconds, whereas the specialty glasses demonstrated much greater resistance.

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