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DURABILITY AND PRESSURE RESISTANCE TEST OF A SPRINKLER GLASS BULB HEAD

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The relevance of the study on the strength and pressure resistance of a glass sprinkler bulb lies in the need to ensure the safety and efficiency of fire extinguishing systems, as this allows one to assess the reliability and durability of the bulb under high internal pressure and take appropriate measures to prevent any possible accidents and damage. The purpose of this article is to conduct a study aimed at evaluating the strength and pressure resistance of a glass sprinkler bulb in order to determine its reliability and effectiveness in a fire extinguishing system. To achieve the goal of the study, a methodology was used that included performing a series of tests to study the response of a glass sprinkler bulb to various levels of pressure in order to verify its strength and stability. The result of the experiment is as follows: First, the glass bulb itself was confirmed to demonstrate a high level of strength against static external force, and breaking the glass bulb due to external impacts on the head was proven to be impossible under a general dynamic impact situation. Second, the glass bulb was confirmed to be easily damaged when a dynamic impact was applied only to the bulb. This means that after removing the glass bulb protection cover on-site, the bulb can be damaged even with a slight impact. Third, the water pressure test with the glass bulb damage demonstrated that when the bulb is damaged more than 10% of its thickness, it becomes damaged within the 1863 – 1960 kPa range. This implies that the head may be damaged over time if even light damage and a low pipe water pressure are applied to the head.

INTRODUCTION

The glass-bulb-type head of a sprinkler can be in different colours according to the registration temperature – orange for 57 °C, red for 68 °C, yellow for 79 °C, green for 93 °C, blue for 141 °C – and the glass bulb breaks when it detects the designated temperature and releases the fire extinguishing water. The domestic testing standards for sprinkler glass bulb heads are specified in the “Technical standards for formal approval and product inspection of sprinkler heads” (2022) and the test related to head breakage checks the following: water leakage after applying hydrostatic pressure of 25 MPa for 5 minutes; the frame’s strength that measures the displacement of the frame to 0.0001 mm by fixing the head to a fixture, applying a cylindrical weight over 15 g to the axial centre of the head at a 1-meter height from the centre of the deflector, and then applying a 35 kg weight to the axial centre of the head; and the glass bulb strength test to detect anomalies by externally applying a load four times the designed load to the glass bulb in the axial direction of the head.

The sprinkler systems installed per the “NFPA 13R: Standard for the Installation of sprinkler systems in low-rise residential occupancies” (2022) are specified in Chapter 5, “Sprinkler Systems” of the “NFPA 25: Standard for the inspection, testing, and maintenance of water-based fire protection systems” (2017). While the Chapter does not specify the type of heads, it does state that heads with leaks, corrosion, physical damage, liquid damage within the glass bulb, detrimental influence on sprinkler head performance, or paint stain other than that applied by the sprinkler head manufacturer require replacement. After manufacturing, sprinkler heads are transported to warehouses via vehicles, ships, and airplanes. After self-inspection by constructors, they are transported to construction sites for separate storage and installation. During this process, glass bulbs of the heads have been confirmed to receive impact and damage and to become exposed to high-temperature environments, thus much water damage will occur if damaged or abnormal heads are installed at a site with high-value equipment. However, domestic and international requirements lack standards for direct strength tests on the glass bulb of sprinkler heads and those for preventing damage to the glass bulb, as well as research on false-positive reports that may occur when damaged heads are installed.

To analyse the existing research, J. Oh et al. (2022) proved with a study on thermal fluid’s flow diffusion tendency through a live fire test with a sprinkler head that the influence of the external air should be minimised to maintain uniform thermal diffusion and accumulation in the sprinkler head. W.H. Kim et al. (2019) developed an optimal head that can protect the entire load and the front with a minimum water release rate of 115 L/min and tested it with a Stage 1 fire extinguisher under the K-115 conditions and 1 Bar of water release pressure. As a result, they discovered that the head controlled the fire without burning the entire load in the scenario. Y.S. Choi and J.C. Yoon (2016) conducted an experimental study on the behavioural characteristics of sprinkler heads in low-growth-rate fires and found that flush-type early-response sprinkler heads incompletely opened due to the cold soldering phenomenon. They suggested the need to supplement the formal approval and product inspection standards in Korea through further research.

K.A.M. Moinuddin and I.R. Thomas (2014) researched the reliability of sprinkler systems in Australian high-rise buildings and compared it with United States and Australian statistical data using the Fault Tree Analysis. They found that the probability of a sprinkler system in a 60-story Australian office building failing ranged from 2.1 – 3.4 %, which is higher than the values generally accepted in Australia. H.C. Kung et al. (2012) conducted a study of glass bulb thermal response measurements in a compartmental fire test and suggested that the effectiveness of a sprinkler system in controlling or suppressing a fire depends on the actual delivery density of the sprinkler. V. Reimer et al. (2022) proposed the fibre optic monitoring of sprinkler heads as an improved fire sprinkler system and proved that the suggested concept could monitor the activation of fire sprinkler heads in real-time.

As such, previous research and domestic and international standards are focused on external defects – the head's appearance, structure, and weight measurement – and product performance – water pressure, hydraulic test, physical properties test, temperature test, fire performance test, and spray distribution. There is a lack of research on glass bulb damage that may occur during the transportation and installation of sprinkler heads and the resulting false-positive fire reports. Therefore, this study aims to verify the possibility of false-positive fire reports of damaged glass bulbs through a durability test – divided into a static load test and a dynamic load test that directly impacts the glass bulb of sprinkler head – and glass bulb pressure impact test – verifying the damage of the glass bulb head by applying internal pressure according to the degree of the glass bulb damage – and to propose management measures to minimise any head damage in the field.

EXPERIMENTAL

The internal temperature and the humidity of the experimental site was maintained at 23 – 25 °C and 39 ± 3 %, respectively. The experiment used Company A's early-response glass-bulb type sprinkler head with a temperature of 68 °C and a thickness of about 2.5 mm. Before the experiment, basic pressure, vibration, and drop tests were conducted and applied; the pressure tests included 1176 kPa for 10 min, 1569 kPa for 10 min, and 1961 kPa for 10 min; the vibration test was run at 5 mm/25 Hz/3 hours; and the drop test was conducted a cylindrical weight from a height of 1 metre. The test used five glass-bulb-type heads with a temperature of 68 °C and a thickness of about 2.5 mm from German company A. The Loa cell measured the load from 0 N to the breaking point. As shown in Figure 1, the bulbs were fixed in the compression testing machine with the specification of 5 – 250 kN and a compression speed of 80 mm·min^{-1}, which is shown in Table 1, and the moving crosshead was configured to gradually increase the load on the glass bulb at a constant speed.

Table 1. Universal tensile machine specifications.

Category	Specifications
Test load	5 – 250 kN
Device height	2340 mm
Device width	1200 mm
Compression speed	80 mm·min-1
Motor	Ac servo-motor
Input signal	Digital
Accuracy	±2 μm
Strength measurement	grade 0.5/1 see load cell, to DIN EN ISO 7500-1, ASTM E4
Power	AC 220 V

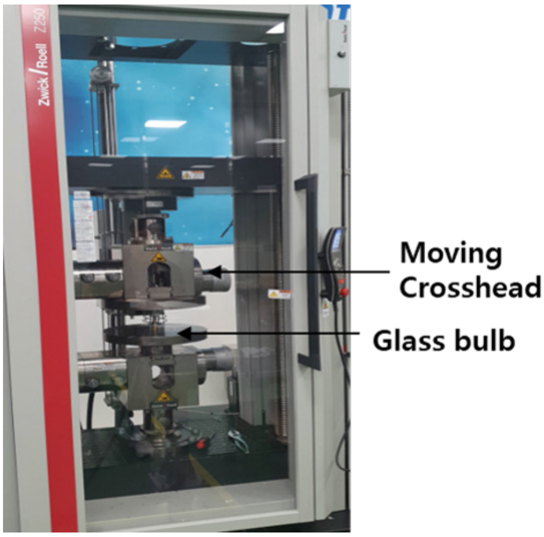


Figure 1. Static load test equipment.

The dynamic load test consisted of a fixed hollow rod through which the weight could fall freely when the weight-holding pin was removed, as shown in Figure 2.

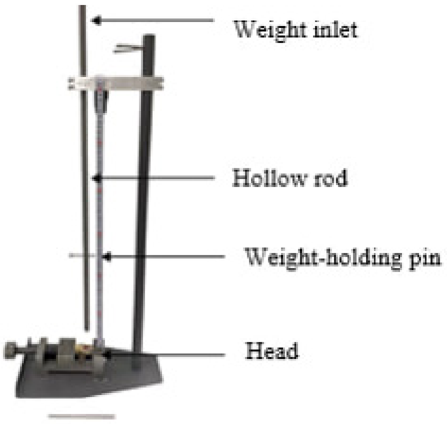


Figure 2. Dynamic load test equipment.

The test used ten early-response upright-type sprinkler heads with a temperature of 68 °C from Company T. The heads were fixed on the floor, and further weight drop tests were conducted in three cases and nine conditions for the body and the glass bulb itself. To evaluate the internal pressure impact according to the glass bulb damage, the test used an early-response upright-type sprinkler head with a temperature of 68 °C from Company T and five glass-bulb type heads with a thickness of about 2.5 mm from German Company A. Diamond grinding rods, as shown in Figure 3, were used to cause arbitrary damage at a depth exceeding 8 – 10 % of the outer diameter of the glass bulb.

Figure 3. Diamond grinding rod.

Then, the head was installed in a 25 A sprinkler pipe, and the internal pressure was gradually increased to 1960 kPa, conducting a holding test at the final pressure for over 5 minutes to verify whether the head was broken.

RESULTS

The domestic test standards for sprinkler heads are specified in the “Technical standards for formal approval and product inspection of sprinkler heads” (2022), which includes the following tests: material inspection, a head strength test, a fuse blink strength test, a glass bulb strength test, the disassembly part strength test, a vibration test, the water hammering test, a corrosion test, an operating temperature test, a jamming operation test, a reflector strength test, a long-term leakage test, a heat resistance test, a sensitivity test, a thermal reaction test, a water release amount test, and a water sprinkling distribution test. Among them, the glass bulb strength test mainly consists of tests on the temperature’s influence. However, there is a lack of test standards for the glass bulb strength that directly applies static and dynamic loads to the glass bulb and its head (Wang et al., 2021). This experiment conducted direct static and dynamic impact tests to evaluate the level of damage and strength, and randomly damaged the glass bulbs to determine the influence of the internal pressure on the glass bulbs.

Static load test

To conduct the static load test on the glass bulb, it was carefully placed inside a universal tensile machine. This machine allowed for accurate measurements and calculations to determine the bulb’s capacity to endure static loads. In this particular test, the objective was to validate whether the glass bulb could withstand a weight comparable to that of approximately 3 adult men, equivalent to around 2744 Newtons (N), under static load conditions. The test results, as presented in Table 2, demonstrated that the glass bulb exhibited an impressive level of strength when subjected to static external forces.

Table 2. Data values from the static load test.

Subject	Maximum breaking load [N]
Bulb No. 1	1930.548
Bulb No. 2	2707.293
Bulb No. 3	1773.768
Bulb No. 4	1693.552
Bulb No. 5	1698.381
Average	1960.708

It successfully withstood the applied weight without breaking or experiencing any significant damage. This outcome confirms that the glass bulb possesses the necessary structural integrity and resilience to withstand static loads effectively. By passing the static load test, the glass bulb proves its suitability for functioning in scenarios where it may be subjected to sustained pressure or static loads. These findings contribute to ensuring the reliability and performance of the glass bulb, further reinforcing its effectiveness in the intended applications. According to the data from the Table 2, it is evident that the maximum load applied before the glass bulb reached its breaking point fell within a range of 1693.552 N to 2707.293 N. This range represents the diverse capacities of the tested glass bulbs and their ability to withstand external forces. To obtain a more comprehensive understanding, Figure 4 provides a graphical representation of the data. It illustrates the distribution of the maximum breaking loads observed during the tests. The average value of the maximum breaking load, calculated based on the data presented in Figure 4, was approximately 1960 N.

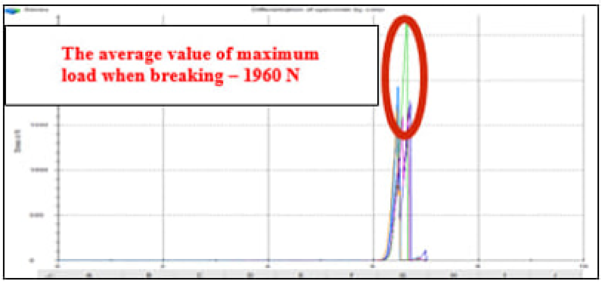


Figure 4. Values from the static load test.

These findings highlight the variability in the strength of the tested glass bulbs. While some bulbs demonstrated higher resistance to external forces, reaching closer to the upper limit of 2707.293 N, others had a lower breaking point, closer to the lower limit of 1693.552 N. The average breaking load of 1960 N provides a useful reference point for assessing the typical performance of the glass bulbs during the test. Understanding the maximum breaking load and its distribution is crucial for evaluating the safety and reliability of the glass bulbs in real-world scenarios (Sinha et al., 2021). By determining the range and average breaking load, manufacturers and users can make informed decisions regarding the appropriate applications and limitations of the glass bulbs based on their specific requirements and the expected forces they may encounter.

Dynamic load experiment

The velocity of the falling weight according to the height can be solved with the formula:

$$V = \sqrt{2gh} \tag{1}$$

where: V – falling velocity (m·s^{-1}); g – the gravitational acceleration (9.8 m·s^{-2}); h – falling height (m).

Cases 1 and 2 were conducted to assess the bulb's performance under dynamic load conditions. The test aimed to determine whether the bulb could withstand extreme impacts on the side outside the head. The results confirmed that the bulb remained intact even when subjected to an impact of 90 g (equivalent to one computer bolt) at a velocity of 4.5 m·s^{-1}. Therefore, it was concluded that the bulb was not susceptible to breakage from external impacts on the head under normal dynamic impact conditions. Moving on to Case 3, the test focused on evaluating the bulb's resilience under the condition of 7 g (equivalent to one bolt) at a velocity of 2 m·s^{-1}. The normalisation rate of 90 % was observed, indicating that the majority of the bulbs remained unbroken under this specific condition. However, it is worth noting that although the bulb itself demonstrated resistance to impact, the test revealed that it could be easily damaged when subjected to a direct dynamic impact, such as objects falling during construction activities (Wang et al., 2022). Table 3 provides the test results for Case 1, which involved conducting heavy-weight drop tests under nine different conditions.

Table 3. Dynamic load of the Case 1 drop on the frame wing.

Falling height	1000 mm	500 mm	200 mm
Weight	Number of unbroken bulbs		
90 g	10	10	10
40 g	10	10	10
7 g	10	10	10

Weights measuring 90 g, 40 g, and 7 g were dropped from heights of 1000 mm, 500 mm, and 200 mm on the deflector wing, as illustrated in Figure 5.

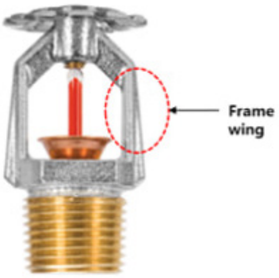


Figure 5. Drop on the deflector wing.

It was observed that the glass bulb remained unbroken in all test conditions, further affirming its ability to withstand dynamic impacts without sustaining damage. Hence, based on the test results, it was confirmed that the glass bulb could withstand external impacts on the head under normal dynamic impact conditions without breaking. Table 4 provides the detailed test results for Case 2.

Table 4. Dynamic load of the Case 2 drop on the body.

Falling height	1000 mm	500 mm	200 mm
Weight	Number of unbroken bulbs		
90 g	10	10	10
40 g	10	10	10
7 g	10	10	10

Weight drop tests were conducted under nine different conditions, involving the dropping of weights measuring 90 g, 40 g, and 7 g from heights of 1000 mm, 500 mm, and 200 mm on the deflector body, as depicted in Figure 6.

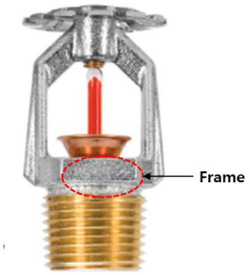


Figure 6. Drop on the deflector body.

It was observed that the glass bulb remained intact in all test conditions. The test results also supported the conclusion that the glass bulb can withstand external impacts to the head without breaking under normal dynamic impact conditions (Wang et al., 2020). Table 5 presents the detailed test results for Case 3.

Table 5. Dynamic load of the Case 3 direct drop on the glass bulb.

Falling height	1000 mm	500 mm	200 mm
Weight	Number of unbroken bulbs		
90 g	0	0	0
40 g	0	0	0
7 g	0	0	0

The weight drop tests were conducted under nine different conditions, involving the dropping of weights measuring 90 g, 40 g, and 7 g from heights of 1000 mm, 500 mm, and 200 mm on the side of the glass bulb, as depicted in Figure 7.

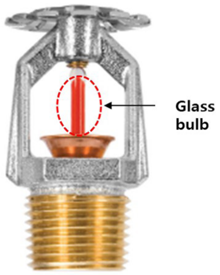
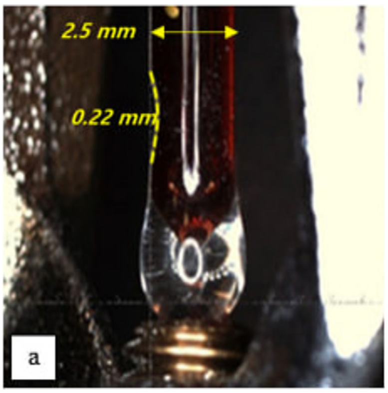


Figure 7. Drop on the side of the glass bulb.

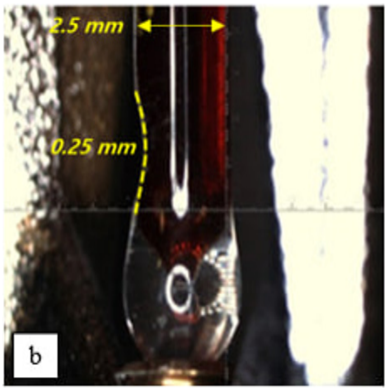
The results indicated that 90 % of the bulbs remained intact only when a weight of 7 g (equivalent to one bolt) was dropped from a height of 2 m·s^{-1}, while all the other test conditions resulted in the bulbs breaking. The test results confirmed that if the dynamic impact is applied only to the glass bulb, it can be easily broken.

Internal pressure impact test

During the experiment, the outer diameter of the sprinkler's glass bulb head was intentionally damaged to a depth exceeding 8 – 10 % of its thickness and 1960 kPa of hydrostatic pressure was applied for a duration of 5 minutes. As the internal pressure increased to 1765 kPa, the sprinkler head triggered a false-positive fire alarm, indicating the breaking of the glass bulb. This outcome led to the conclusion that significant damage to the surface of the glass bulb could result in the occurrence of false-positive alarms. Figure 8 displays a microscopic view of the glass bulb, illustrating 0.22 mm damage on one side (a single defect) of the approximately 2.5 mm diameter glass bulb, as well as 0.25 mm damage on one side.



a) 0.22 mm damage

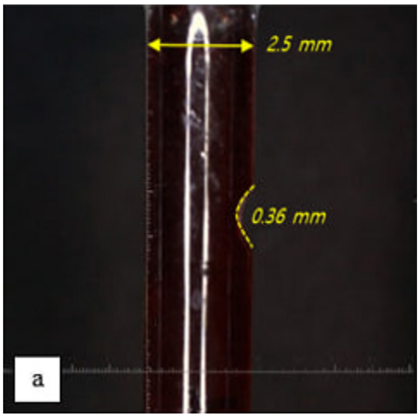


b) 0.25 mm damage

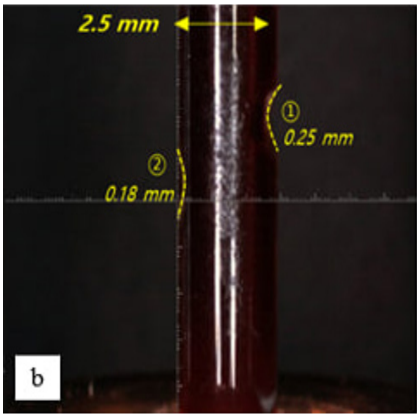
Figure 8. Single defect.

Figure 9 illustrates the condition subsequent to inducing 0.36 mm single-sided damage (a single defect), surpassing 10 % of the thickness.

Additionally, it showcases the state following the creation of 0.25 mm and 0.18 mm damage on both sides (double defects), respectively, resulting in a combined depth exceeding 10 % of the thickness. Figure 10 shows the 0.33 mm and 0.25 mm damage on both sides (double defects), respectively, so that the combined depth is greater than 10 % of the thickness.



a) single defect of 0.36 mm damage



b) double defects of 0.25 mm and 0.18 mm damage

Figure 9. Single and double defect.

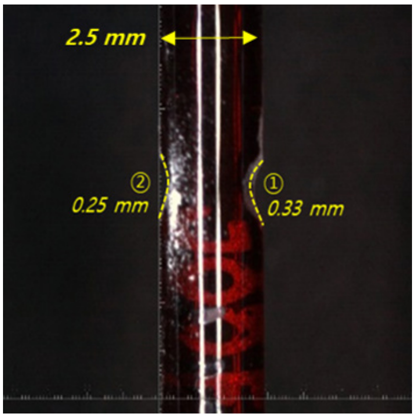


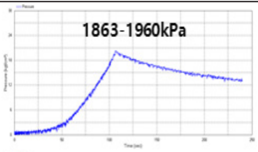
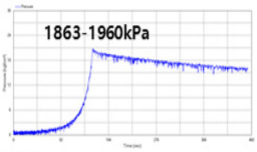
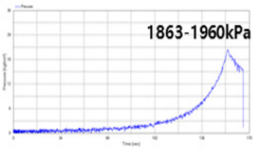
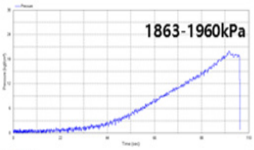
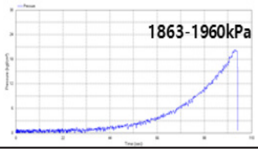
Figure 10. Double defects of 0.33 mm and 0.25 mm damage.

Additionally, it showcases the state following the creation of 0.25 mm and 0.18 mm damage on both sides (double defects), respectively, resulting in a combined depth exceeding 10 % of the thickness. Figure 10 shows the 0.33 mm and 0.25 mm damage on both sides (double defects), respectively, so that the combined depth is greater than 10 % of the thickness.

Table 6 shows the internal pressure resistance evaluation results according to the depth of the damage on the five glass bulb specimens deliberately damaged with tools.

As a result of conducting the test with the five cases, conclusive evidence was obtained confirming that all three glass bulbs, which triggered false-positive fire alarms, shattered when the depth of damage surpassed

Table 6. Analysis results of the glass bulb defect simulation

Category	Damage Depth		Test Result
Figure 8a	0.22 mm		Normal
Figure 8b	0.25 mm		Normal
Figure 9a	0.36 mm		Broken
Figure 9b	0.25 mm/0.18 mm		Broken
Figure 10	0.33 mm/0.25 mm		Broken

10 % of the outer diameter of the 2.5 mm glass bulb. This phenomenon can be attributed to the glass bulb experiencing an initial external impact that causes damage without immediate rupture, followed by the gradual breakage of the glass bulb over time due to the continuous flow of water through the piping system.

DISCUSSIONS

The process of manufacturing, installing, and maintaining glass-bulb-type sprinkler heads involves several stages, each with its own set of environmental factors that can potentially damage the heads. These stages include glass bulb manufacturing, sprinkler head manufacturing, overseas import, domestic warehousing and inspection, domestic delivery, contractor warehousing, contractor inspection, transportation to the construction site, storage at the construction site, head installation, and existing water pressure completion inspection.

Tests have confirmed that damaged glass bulb heads can break and cause water damage when installed. Even when the temperature is below the registration temperature of the thermal detector, the sprinkler head may experience a creep phenomenon and weaken when exposed to high temperatures for an extended period, particularly during the summer season (Baek and Park, 2016). To mitigate these risks, it is crucial to store the sprinkler heads in a temperature-controlled area before installation, ensuring that the temperature is kept below 30 °C. Additionally, the storage area should be inaccessible to individuals to prevent accidental contact with the bulbs. During transportation, glass bulb-type heads should be handled in a manner that allows temperature control and prevents any shock or impact. It is recommended to transport them inside a vehicle or through a box car, rather than in an open compartment during the summer months.

Upon arrival at the construction site, it is essential to store the sprinkler glass bulb heads separately in cabinets and avoid stacking the head boxes in multiple layers. During installation, it is advised not to use electric power tools, but to use a dedicated wrench recommended by the manufacturer. To facilitate easy maintenance, the head protection net should be promptly installed after removing the protective cover from the bulb. Excessive tightening of the head should be avoided to prevent deformation and leakage. Instead, wrapping Teflon tape around the head seven to eight times and tightening the remaining screw moderately is recommended. After installation, it is crucial to manage the sprinkler heads to prevent damage from other construction processes. Care must be taken to ensure that work lines and other items are not installed too close to the heads, minimising the risk of accidental damage. By following these guidelines and best practices, the durability and functionality of glass-bulb-type sprinkler heads can be maintained throughout the manufacturing, transportation, and installation processes, reducing the risk of water damage and ensuring their effectiveness in fire protection.

According to the latest research of C. Yang (2023), strength testing of a glass sprinkler bulb head is a critical step in determining its ability to withstand external forces and provide reliable performance over time. This test not only emphasises the importance of ensuring the durability and reliability of sprinkler systems, but also makes it possible to take measures to improve their design and functionality. The significance of such testing is helping to raise awareness of the importance of testing and the development of more efficient and reliable sprinkler systems that can effectively respond to fire situations and protect lives and property.

Referring to definition by L. Zheng et al. (2022), examining the specific methods and parameters used in durability and pressure testing is an integral part of a rigorous performance evaluation process for a glass sprinkler bulb head. These tests provide a detailed understanding of bulb behaviour and performance under various operating conditions. One of the key aspects is the durability test method, which allows for determining how long the head of a glass bulb can function without degradation of its properties. This may include static load testing to assess the strength of the bulb when subjected to external forces, and dynamic testing to determine its ability to withstand shock and vibration in service. Pressure resistance test parameters are of particular importance for the head of the glass bulb, as it must withstand a certain pressure in the system. This may include testing the bulb for strength at certain pressure levels to ensure it does not burst or fail under extreme conditions. Studying these specific methods and parameters helps not only to understand how the head of a glass bulb behaves in different situations, but also helps to determine its limits and limitations. This allows sprinkler system designers to select the appropriate components and optimise their design for maximum reliability and efficiency.

J. Ivvala et al. (2022) determined that analysis of the static load test results provides valuable information about the reliability and durability of the glass bulb in sprinkler systems. This type of test evaluates the bulb's ability to withstand the static pressure that can develop in a system for a long time. The results of the analysis confirm that the glass bulb has sufficient strength and stability, which is a critical factor for ensuring the safety and efficiency of the sprinkler system. This provides confidence in the use of the glass bulb and confirms its ability to perform its functions for a long period of time, which is important to ensure continuous protection against possible fires.

M. Asad et al. (2022) showed, in their work, that the study of pressure test results is an important step in evaluating the ability of a glass bulb head to withstand pressure in sprinkler systems. These tests measure how well the bulb head can withstand the high internal pressure that can occur when the system is activated in the event of a fire. The pressure test results help to determine the limits at which the head of a glass bulb remains intact and retains its functionality. This allows sprinkler system designers and engineers to consider these parameters when selecting and installing glass bulb heads to ensure their reliability and performance under extreme conditions. Additionally, by examining the results of pressure tests, it is possible to determine the possible limitations and risks associated with the use of glass bulb heads in various conditions. This helps designers and manufacturers take appropriate steps to improve the design and construction of bulb heads to increase their pressure resistance and prevent potential damage or breakage.

Researchers K.V. Cashman et al. (2022) determined that studying the results of tests for dynamic impacts makes it possible to assess the vulnerability of the head of a glass bulb to external influences. These tests help determine how the sprinkler head responds to various dynamic impacts such as falling objects or violent impacts. The results of the study confirm that under normal dynamic influences, such as ordinary movements or vibrations, the head of the glass bulb remains intact and does not break. However, they also indicate the vulnerability of the glass bulb to direct dynamic impacts, especially after the protective cap has been removed. Even minor impacts can damage the bulb. Therefore, it is essential to take precautions and use protective mechanisms to prevent damage and maintain the integrity of the glass bulb head. These results substantiate the need for care and installation of sprinkler systems with glass bulb heads, as well as efforts to ensure safety and prevent possible damage during operation.

As C. Hopkin and M. Spearpoint (2021) point out, studying the effects of glass bulb testing on sprinkler systems is critical to the design and maintenance of these systems. The test results provide valuable information about the performance and reliability of glass bulbs that can be used to optimise the design process and select suitable components for sprinkler systems. Discussing how test results can affect design choices and maintenance practices helps develop guidelines and best practices for system installation and maintenance.

CONCLUSIONS

This study aimed to verify the self-strength level of the early-response type 68 °C sprinkler glass bulb head and the false-positive fire alarm due to bulb damage. The static and dynamic impact tests on the glass bulb and the pressure test of deliberate damage to the bulb resulted in the following conclusion: the glass bulb itself has strong resistance against static external forces, and breaking the glass bulb due to an external head impact is impossible under normal dynamic impact conditions; the glass bulb can be easily broken when subjected to dynamic impacts, such as falling. This means that even a small impact after removing the protective cover of the glass bulb in the field can result in damage; the water pressure test for glass bulb damage demonstrated that the glass bulb breaks at 1863 kPa when the damage exceeds 10 % of the glass bulb's thickness. This indicates that even at low pressure, a head that is damaged, will continue to be damaged over time if pipe water pressure is applied. The conducted study may be used to establish a standard for maintaining glass-bulb sprinkler heads. This study subjected the heads to extreme conditions of high pressure over a short period and predicted false-positive reports based on the results. However, the pipe pressure used in the field varies, so future research should conduct more calibration tests to reduce the error rate of the pressure that may damage the head.

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