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# SUSTAINED LOAD AND AGING IMPACT ON WATERPROOF MEMBRANES: A REVIEW OF CURRENT RESEARCH

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## ABSTRACT

Building leakage is a prominent quality issue today. The application of waterproof membranes is the most widespread in waterproofing projects, and these membranes must consider the influence of external and various natural factors, primarily including the effects of external forces, natural conditions, and defects in concrete structures. Only by accurately analyzing these influencing factors can scientifically grounded and operable repair solutions be proposed. This paper reviews relevant academic literature and reaches the following conclusions: (1) Studying the mechanical properties of waterproof membranes, such as tensile strength and elongation at break, under adverse or accelerated conditions is an intuitive and effective method for evaluating their performance. Under sustained loading and stress, the performance of waterproof membranes generally declines, including reduced waterproofing effectiveness and mechanical strength. (2) Although waterproof membranes demonstrate good durability, factors such as light, heat, and oxygen can still negatively impact their performance. Utilizing these factors to induce aging is a common method among researchers and is worth considering. (3) The results indicate that the durability of waterproof membranes is primarily determined by the base material. The impact of sustained loading under high-temperature conditions is more pronounced, potentially leading to accelerated material fatigue and aging. Despite the existence of numerous studies and review articles exploring various aspects of waterproofing, there remains a significant lack of in-depth reviews specifically addressing the impact of waterproof membranes under sustained loading and their aging performance. Given the increasing importance of concrete durability and water resistance in construction, it is crucial to systematically evaluate the performance of waterproof membranes. This research aims to fill this gap by examining the behavior of waterproof membranes under sustained loading conditions and assessing their effects on aging performance. Understanding these effects is vital for optimizing concrete performance and addressing long-term water resistance challenges. The necessity for this review lies in providing a comprehensive analysis of waterproof membranes, guiding researchers and engineers in selecting appropriate materials and techniques to enhance concrete protection.

**Keywords:**
*Building Leakage, Waterproof Membranes, Mechanical Performance, Aging Performance, Temperature*

## INTRODUCTION

Building waterproofing engineering is an integral component of construction projects. Waterproofing technology in construction comprises specialized measures aimed at ensuring that the structures of buildings and structures are not compromised by water intrusion, and that interior spaces remain safeguarded from water-related hazards. This also refers to a series of structural, architectural, and construction measures taken to prevent the infiltration of water, including rainwater, industrial or domestic water, groundwater, stagnant water, capillary water, and water resulting from human activities, into the interiors of buildings and structures. These measures are also adopted to prevent leakage from water storage systems (Sun, D, 2016).

The primary purpose of architectural waterproofing is to safeguard the functionality of buildings, while also serving to extend the lifespan of the structures. Until the 1990s, China did not have specialized design standards for waterproofing engineering. During the design process, aspects such as roof waterproofing, drainage measurement, water downpipe diameter and quantity, insulation layer thickness, etc., were often determined based on experience or local customary practices. This frequently resulted in poor roof drainage and significant leakage issues (Ye, L, 2013).

Currently, there are many relevant standards, specifications, and regulations such as "Technical Code for Roof Engineering" (GB50345—2012), "Quality Acceptance Specification for Roof Engineering" (GB 50207—2012), "Technical Code for Waterproofing of Underground Engineering" (GB 50108-2008), and "Quality Acceptance Specification for Waterproofing of Underground Engineering" (GB 50208-2011) that provide a certain basis for the design and construction of building waterproofing projects. However, often due to insufficient experience of the designers, unfamiliarity with building waterproofing materials and construction practices, inadequate depth of waterproofing design, inability to guide construction or ineffective guidance, leakage issues may occur in building projects caused by the design. The technical level of building waterproofing projects urgently needs to be improved.

Waterproofing engineering involves three major aspects: preventing water from infiltrating the interiors of buildings, preventing water within water storage structures from leaking out, and providing mutual water resistance within buildings and structures. Building waterproofing engineering encompasses various components of buildings and structures, including basements, floors, walls, and roofs. Its primary function is to ensure that buildings or structures remain protected from erosion caused by different forms of water during their intended design lifespan (Zhu, Y., & Yuan, Y, 2021). This is achieved to guarantee that the architectural structure and interior spaces remain undamaged, providing people with a comfortable and secure environment. The requirements for waterproofing functionality differ based on the specific locations within the building, and the demands for waterproofing vary accordingly.

Waterproof membranes are flexible building materials that can be rolled up, primarily used for waterproofing in construction walls, roofs, tunnels, highways, landfills, and other areas. Their main function is to prevent the infiltration of external rainwater and underground water (Research Institute of Standard and Quota, 2022).

Waterproof membranes have a wide range of applications, including but not limited to waterproofing construction walls and roofs, as well as meeting waterproofing needs in tunnels, highways, basements, and other locations. As the first line of defence in engineering waterproofing, they are crucial for protecting building structures from moisture damage. Waterproof membranes, which were initially made from asphalt, have a long history. With advancements in technology, various types have emerged including polymer-modified asphalt membranes and synthetic polymer membranes.

At present, the usage of waterproofing materials in China's construction industry is steadily increasing. There is a continuous growth of new types of building waterproofing materials, primarily represented by modified bituminous waterproofing membranes which have taken a dominant position. The consumption of these new waterproofing materials accounts for 85.29% of the overall building waterproofing materials. Building waterproofing is still predominantly based on modified bituminous waterproofing membranes, accounting for over 60% of the total, with polymer waterproofing membranes making up 11.44%, and waterproof coatings comprising 13.07% (Liao, W, 2016). Among these, polymer waterproofing membranes have experienced rapid development over the past 20 years. They are characterized by high strength, significant elasticity and elongation, resistance to weathering and low temperatures, as well as simple construction, with PVC waterproofing membranes, in particular, being their representative (Xie, C, 2017).

During processing, storage, and utilization, polymer materials gradually deteriorate in performance due to the comprehensive effects of internal and external factors, ultimately resulting in the loss of their utility value. This phenomenon is referred to as "aging" (Eckhardt, H., & Schiller, M, 2005). Aging is an irreversible change, often characterized by irreversible chemical reactions. For instance, once "spots" appear on polyvinyl chloride film, these "spots" cannot be eliminated. The appearance of spots is a characteristic manifestation of aging in the visual aspect of polyvinyl chloride film.

Aging is a common problem for polymer materials, with almost no polymer material exempt from aging. Polymer material aging, akin to the weathering of rocks or the corrosion of steel bars, reflects a transition from quantitative to qualitative change under certain conditions. After monomers undergo polymerization or condensation to form polymers under specific conditions, aging occurs according to certain laws due to internal and external factors. Some primarily degrade into low-molecular-weight polymers or other compounds, some revert to their original monomers, and some undergo cross-linking, ultimately leading to qualitative changes (Zhao, C., et al., 2012). Polymer material aging is an objective law beyond human will. It is impossible to absolutely prevent the aging of polymer materials. However, through the study of the aging process, one can gradually understand and master the regularities of polymer material aging (Kovacs, J. Z., & Yu, Y., 2016). By utilizing these regularities and implementing appropriate anti-aging measures, it is possible to slow down the aging process, enhance the material's resistance to aging, and thereby extend its service life.

The causes of polymer material aging can generally be attributed to two aspects: internal factors and external factors (Jiang, W., & Wu, D., 2018). Internal factors refer to the structural state of the basic components of polymer materials, which include the chemical and physical structures of polymers themselves, as well as the properties and proportions of various components within the polymer material system.

External factors refer to environmental factors outside the polymer material, including physical, chemical, and biological factors. These factors mainly include sunlight, oxygen, ozone, heat, moisture, mechanical stress, high-energy radiation, electricity, industrial gases (such as sulfur dioxide, ammonia, hydrogen chloride, etc.), seawater, salt spray, molds, bacteria, insects, etc. Among these external factors, sunlight, oxygen, and heat are particularly important causes of aging in various polymer materials. If sunlight, oxygen, and heat can be isolated, many polymer materials can remain stable for long periods without aging.

The raw material of waterproofing materials is polymer. Therefore, the essence of waterproofing material aging is essentially the aging reaction process of polymer. Polymers are exposed to natural environments during transportation and use. Under the influence of natural environmental factors such as sunlight, water, oxygen, and heat, they undergo "aging," which is the chemical degradation process of polymers (Kreilgaard, L. F., & Madsen, J. S. 2020).

When waterproofing membranes are used as roofing materials without protective layers, they undergo aging under the influence of light, heat, oxygen, etc., resulting in phenomena such as discoloration and cracking, leading to the failure of the waterproofing layer. Therefore, studying the aging durability of waterproof membranes is of significant importance for predicting the degree of degradation and service life of the waterproofing membranes. Experimental research is a common method for studying material properties. For example, Khir Johari et al. (2022), Che Mat et al. (2023), and Miasin and Chuan (2020) all employed this approach.

## PROBLEM STATEMENT

Building leakage is a prominent quality issue at present, and the causes are diverse. Waterproofing projects must take into account the influence of external factors and various natural elements. Generally, the main considerations include the impact of external forces, the influence of natural conditions, and defects in concrete structures (Wang, Y., 2019). In other words, waterproofing membranes typically operate under complex factors such as loads, deformation, temperature, and exposure to ultraviolet radiation, and cannot be simply assessed based on a single factor.

In actual engineering practice, the most common cause of leakage is damage to the waterproofing membranes. Merely studying the performance of waterproofing membranes, themselves or qualitatively explaining the deterioration mechanism of the waterproofing membranes does not provide guidance for the construction of waterproofing membranes in real construction environments ( Hu, J., & Qu, P., 2023).

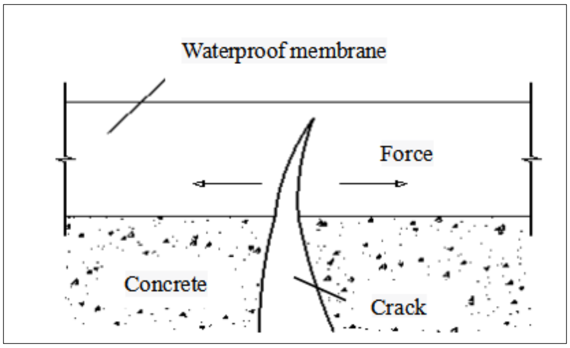
Despite significant advancements in the development and application of waterproof membranes for concrete protection over the past few decades, there remains a critical gap in our comprehensive understanding of these membranes. Although numerous studies and review articles have explored various aspects of waterproofing, there is a notable absence of in-depth reviews specifically addressing the impact of waterproof membranes on sustained loading and their aging performance.

Given the increasing importance of concrete durability and water resistance in construction, it is essential to evaluate the performance of waterproof membranes systematically. This research aims to fill this gap by reviewing waterproof membranes in the context of sustained loading and assessing their effects on aging performance. Understanding these effects is crucial for optimizing concrete performance and addressing challenges associated with long-term water resistance.

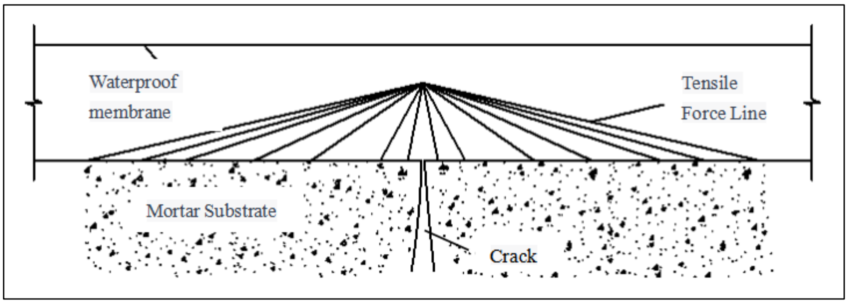
The need for this review arises from the necessity to provide a comprehensive analysis of waterproof membranes, which can guide researchers and engineers in selecting appropriate materials and techniques for enhanced concrete protection.

## Mechanical Performance Analysis of Waterproofing Membranes

When the waterproofing membranes are fully adhered to the substrate, it is subjected to continuous stress due to deformation of the substrate, changes in environmental temperature, or loads on the waterproofing membranes. When cracks occur in the substrate, because the waterproofing membranes on both sides of the crack are firmly bonded to the substrate and the crack width is usually small, the change in crack width will have two effects on the waterproofing membranes at the crack site as shown in Figure 1(a) & (b) (Wang, T., 1997):




(a) The strain generated by the waterproofing membranes at the crack site is much greater than that of the waterproofing membranes on both sides of the crack (Wang, T., 1998)




(b) The waterproofing membranes at the crack site are subjected to additional load after sustained loading.

Figure 1: Change in crack effects on the waterproofing membranes (Wang, T., 1998)

As a result, the waterproofing membranes at the crack site are more prone to failure. Its performance evaluation should take into account the influence of sustained loading, especially the tensile properties of the material after sustained loading.

Zhang, S. et al. (2022) conducted mechanical performance experiments and analyzed the microscopic failure mechanisms of internally reinforced thermoplastic polyolefin (TPO), homogeneous ethylene propylene diene monomer (EPDM) waterproof membranes, and related supporting materials for pressure-sensitive, self-sulfurized expansion joints. Xie Xiong and other scholars used polyethylene-polypropylene composite waterproof membranes as the research object, conducted aging tests, and accelerated aging through artificial corrosion methods. They investigated the influence of aging on mechanical properties such as fracture strength and elongation at break through tensile tests. Zhang, G. et al. (2022) also studied three types of homogeneous TPO waterproof membranes and investigated the effects of thermal aging temperature and time on their tensile strength, elongation at break, tear strength, mass loss, and melt mass flow rate.

This indicates that studying the mechanical properties of waterproof membranes, such as tensile strength and elongation at break, under adverse or accelerated conditions is a very intuitive and effective way to evaluate the performance of waterproof membranes.

Han, Q. et al. (2019) pre-applied a 100% strain to materials and investigated the aging performance of thermoplastic polyolefin (TPO) membranes and polyvinyl chloride (PVC) membranes in different environments. This was done to reflect the durability of waterproof materials under stress (strain) conditions. Their research found that under 100% strain, PVC membranes were prone to notch fracture in strain environments. Compared to PVC membranes, TPO membranes exhibited superior resistance to heat aging and boil aging.

Figure 3.2 shows the mechanical performance test results of TPO and PVC membrane specimens before and after 7 days of thermal treatment at 115°C under 100% strain. As illustrated in Figure 2, the tensile strength at break of the PVC membrane specimens was 0 (specimens failed prematurely) after 7 days of thermal aging at 115°C under 100% strain, whereas the tensile strength at break of the TPO membrane specimens also showed a significant decrease following thermal aging treatment.

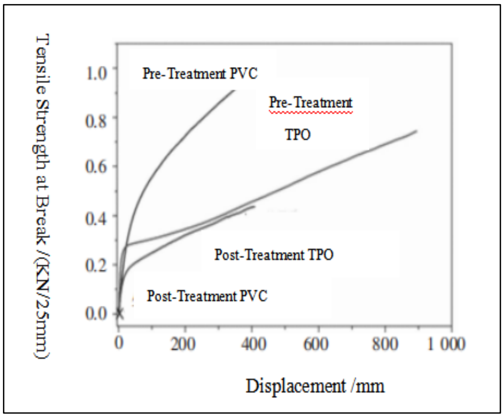



Figure 2: Mechanical Performance of Specimens Before and After Thermal Aging Under 100% Strain

Wang, X. et al. (2020) found that the performance of waterproof membranes significantly deteriorates under sustained loading, especially at high temperatures. Long-term loading leads to material fatigue and stress concentration, which in turn reduces their waterproofing effectiveness and mechanical strength. Chen, L. et al. (2019) showed that waterproof membranes exhibit different stress-strain behaviors under various stress conditions. Sustained loading causes plastic deformation and performance degradation of the material, while proper load management can significantly improve long-term stability.

Zhang, Y. et al. (2018) found that polymer-modified waterproof membranes exhibit better durability under long-term stress. However, excessive loading can lead to an increase in microcracks within the material, affecting its overall waterproofing performance. While Yang, H. et al. (2017) discovered that sustained loading significantly impacts the mechanical properties and waterproofing performance of membranes. Stress concentration points under prolonged loading can lead to a severe decline in waterproofing performance. Huang, X. et al. (2016) indicated that mechanical stress has a significant effect on the long-term performance of waterproof membranes. Stress concentration and sustained mechanical loading accelerate the aging process of the material and reduce its waterproofing effectiveness.

The studies mentioned above indicate that waterproof membranes generally experience performance degradation under sustained loading and stress, including a reduction in waterproofing effectiveness and mechanical strength. The impact of sustained loading is more pronounced under high-temperature conditions, potentially leading to accelerated material fatigue and aging. Polymer-modified waterproof membranes exhibit better durability, but long-term loading still negatively affects their performance. Stress concentration and prolonged mechanical loading may lead to the formation of microcracks, thereby affecting the waterproofing performance. Sustained loading or a certain level of strain is detrimental to waterproof membranes.

## Aging Performance of Waterproofing Membranes

When waterproofing membranes are used as roofing materials without protective layers, they undergo aging under the influence of light, heat, oxygen, etc., resulting in phenomena such as discoloration and cracking, leading to the failure of the waterproofing membranes. Therefore, studying the aging durability of waterproof membranes is of significant importance for predicting the degree of degradation and service life of the waterproofing membranes.

Ge, Y. et al. (2020) conducted a study on Styrene-Butadiene-Styrene (SBS modified asphalt waterproof membranes used in waterproofing projects for 12 and 20 years. They found that although the performance of SBS modified asphalt waterproof membranes had deteriorated to varying degrees, they still maintained good waterproofing capabilities and did not reach the failure standard of waterproof membranes. Zhang, G. et al. (2007) conducted natural exposure aging and immersion treatments on SBS modified asphalt waterproof membranes and rubber powder modified asphalt waterproof membranes. The results showed that the durability of SBS modified asphalt waterproof membranes was significantly better than that of rubber powder modified asphalt waterproof membranes

Ge, B. et al. (2017) studied the various properties of SBS modified asphalt waterproof membranes of the same specification produced by different manufacturers after natural aging. They found that under natural exposure conditions, the polyethylene (PE) film on the surface of the waterproof membrane gradually disappeared, and the asphalt coating layer gradually hardened, became powdery, and developed cracks. Although natural exposure aging tests provide more realistic and credible data, they have long test cycles, complex environments, and many variables. It is also difficult to conduct single-factor studies in such tests. In order to improve testing efficiency, artificial accelerated aging methods are often used.

Ge, Y. et al. (2020) studied the durability of SBS modified asphalt waterproof membranes and found that the effects of UV aging and xenon lamp aging were similar. The aging efficiency of these two methods was greater than that of thermal aging at 70°C. Zhu, M. et al. (2017) studied the influence of organic montmorillonite on the anti-UV aging performance of asphalt using infrared spectroscopy. They found that the combination of organic montmorillonite and SBS improved the anti-UV aging performance of SBS-modified asphalt waterproof membranes

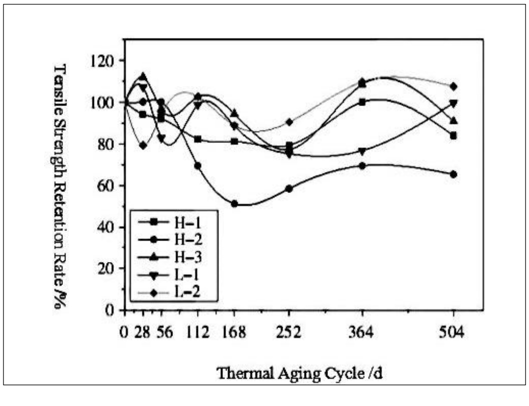
Che, J. et al. (2006) conducted durability studies on SBS modified asphalt waterproof membranes using xenon lamp aging and immersion experiments. The results showed that SBS modified asphalt waterproof membranes with polyester felt and alkali-free glass fibre felt as the substrate had better water resistance compared to those with polyester non-woven fabric and high-alkali glass fibre mesh fabric as the substrate. Wei, G. et al. (2018) compared the performance of SBS modified asphalt waterproof membranes and polyester glass fibre fabric asphalt membranes under different conditions of UV heating aging. They found that the aging resistance of the polyester glass fibre fabric asphalt membranes was superior

Kováč, J. et al. (2022) deal with the laboratory testing of a waterproofing membrane based on PVC-P in terms of its degradation from UV radiation, humidity, and temperature. They found that the experimental measurements point to a qualitative diversity of materials, and degradation takes place on both sides of the surfaces. Degradation due to the temperature also occurs on the side that is not exposed to UV radiation

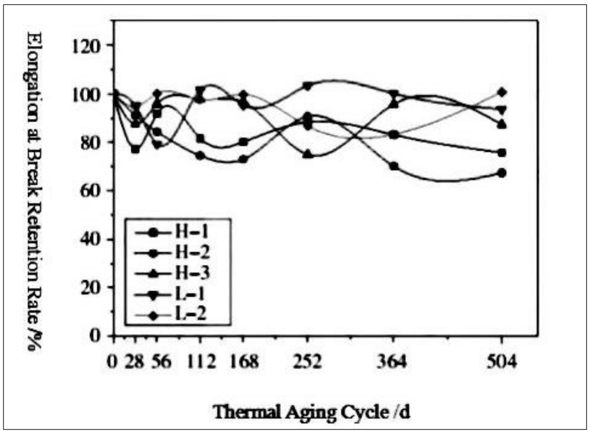
In a study by Li, Q. et al. (2022), the aging performance of high viscosity modified asphalt was evaluated based on the simulated heat-light-water coupled conditions, in which different aging effects and degrees were considered. They found that the coupled aging effects should be considered during the service period since acid rain solution and UV light also led to significant influences on the viscoelastic properties, high and low-temperature performance, and fatigue performance as similar to high temperature.

Zagorodnikova, M. A. et al. (2019) examined physical and mechanical properties taking into account the influence of typical aggressive impacts and evaluation of the durability of PVC membranes used as roofing materials. They found that the structure of the material and the effect of external factors had a direct effect on the thermal extension of PVC membrane samples. They also found that the waterproof film developed by the combination of polyurethane (PU) and industrial grade asphalt has excellent performance. It mainly has a high elongation range and has the allowable requirements of tensile strength, tear value, puncture resistance and shore hardness specified in the corresponding ASTM specification. Xiong, Y. et al. (2023) subjected five types of polymer self-adhesive waterproof membranes and their bonding with cast-in-place concrete to thermal aging treatment. They then conducted durability-related performance tests at different observation time points.

Tensile performance tests were conducted on the polymer self-adhesive waterproof membrane specimens under various thermal aging cycles, with the results shown in Figure 3. As seen in the figure, during the 90°C thermal aging test, the tensile strength and elongation at break of the five types of polymer self-adhesive waterproof membranes mainly exhibited fluctuations over 364 days. A decay trend only became apparent after continuing aging for 504 days, with the rate of decay in elongation at break being greater than that of tensile strength (Xiong, Y., et al., 2023)




(a)Tensile Strength Retention Rate of Membranes Under Different Thermal Aging Cycles




（b）Elongation at Break Retention Rate of Membranes Under Different Thermal Aging Cycles

Figure 3: Tensile Properties of Membranes Under Different Aging Cycles (Xiong, Y., et al., 2023)

The results indicate that the durability of the membrane itself is primarily determined by the base material. Tensile strength and elongation at break are the most commonly used evaluation parameters for plastic aging.

Ge, Y. et al. (2020) studied the aging rates of three artificial accelerated aging methods: UV aging, xenon arc aging, and thermal aging. The results are shown in Figure 4. For SBS-modified asphalt membranes, the actual aging effects of xenon arc aging and UV aging are similar, with both aging rates being higher than that of thermal aging at 70°C.

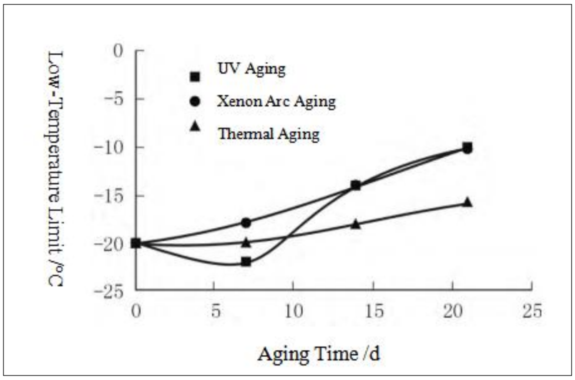



Figure 4: Comparison of Aging Rates for Three Types of Artificial Accelerated Aging Methods (Ge, Y, et al., 2020)

It is found that in natural exposure aging as well as artificial accelerated aging, the method of using factors like light, heat, and oxygen to induce aging is commonly employed by researchers and is worth considering. The aging effects of xenon arc aging and UV aging are superior to those of thermal aging at 70°C.

In summary, the literature indicates that many scholars have used factors such as light, heat, and oxygen to induce accelerated or natural aging in their studies of the mechanical and aging performance of waterproof membranes. The advantage of this method is that it provides a thorough investigation of the material properties of waterproof membranes. However, it also has a drawback: it neglects the actual working conditions of the waterproof membranes, which are primarily subjected to sustained loading or a certain level of strain for most of the time.

## CONCLUSION

Based on the summary of the above research, the following conclusions can be drawn:

（1）Studying the mechanical properties of waterproof membranes, such as tensile strength and elongation at break, under adverse or accelerated conditions is a highly intuitive and effective method for evaluating their performance. Under sustained loading and stress, waterproof membranes generally exhibit a decline in performance, including reduced waterproofing effectiveness and mechanical strength.

（2）While waterproof membranes demonstrate good durability, factors such as light, heat, and oxygen still negatively impact their performance. The use of these factors to induce aging is a common method among researchers and is worth considering.

（3）The results indicate that the durability of the membrane is primarily determined by the base material. The impact of sustained loading under high-temperature conditions is more pronounced, potentially leading to accelerated material fatigue and aging.

Waterproof membranes are widely used waterproof materials in building waterproofing projects. The influence of external and various natural factors on waterproof membranes must be considered. Only by accurately analyzing these influencing factors can scientifically grounded and operable repair solutions be proposed.

By integrating the research factors and methodologies of various scholars, studying the effects of sustained loads or stress under conditions of light, oxygen, heat, and others on the mechanical properties and aging performance of waterproof membranes can systematically evaluate their performance. Additionally, by examining the behavior of waterproof membranes under sustained loading conditions, we can assess their impact on aging performance. Understanding these effects is crucial for optimizing concrete performance and addressing long-term water resistance challenges.

Through a comprehensive analysis of waterproof membranes, this research aims to guide researchers and engineers in selecting appropriate materials and techniques to enhance concrete protection.

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