Construction and Building Materials 101 (2015) 80–90

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Review

# Waterproof performance of concrete: A critical review on implemented approaches

Nasiru Zakari Muhammad, Ali Keyvanfar *, Muhd Zaimi Abd. Majid *, Arezou Shafaghat, Jahangir Mirza

*UTM Construction Research Centre (UTM CRC), Institute for Smart Infrastructure and Innovative Construction, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia*

## HIGHLIGHTS

- Taxonomy and construct of research in waterproof, test method and additive agents.
- Performance of waterproof agents' efficiency in aggressive environment.
- Frequency aggregation of waterproof agents applied in different subject area.
- Waterproof agents' classifications based on material structures.
- Waterproof agents' classifications based on function and application methods.

## ARTICLE INFO

*Article history:*
Received 31 August 2015
Received in revised form 7 October 2015
Accepted 15 October 2015

*Keywords:*
Waterproof concrete
Concrete water absorption
Waterproof additive agents

## ABSTRACT

Permeation of water and other fluids in concrete can result in degradation and other aesthetic problems which shorten concrete structures' life. Several studies have been undertaken to produce waterproofing additives that extend the service life of concrete elements. Consequently, a great deal of repair and maintenance costs could be avoided. This paper aims to review the studies which have used various agents and tests to evaluate the waterproofing efficiency of concrete. The study establishes the taxonomy and construct of research in concrete waterproofing research. Study established frequency aggregation of different additive used and tests applied. The technique adopted by majority of the researchers was the use of surface coating. Water absorption was found to be the most common test in this research area. Study delineated that most researchers focused on the use of polymer-based materials, silicates containing compound, silanes, siloxanes, cementing materials and some nano materials. Finally, study established three classification of additives based on material structure, method of application and additives functions.



**Contents**



* Corresponding authors.
*E-mail addresses:* akeyvanfar@utm.my (A. Keyvanfar), mzaimi@utm.my (M.Z. Abd. Majid).

http://dx.doi.org/10.1016/j.conbuildmat.2015.10.048

## 1. Introduction

A waterproof material is the one that prevents passage of water from one plane to another [1]. Or preferably, a substrate which absorbs not more than 2.5% of moisture when compared to the control specimen [2]. Although concrete is basically water-resistant, variations in ingredients mixed to prepare concrete can affect the degree of water-resistance and porosity of concrete. It happens because a network of pores and capillaries exist in concrete which allows the ingress of potentially dangerous substances leading to deterioration. Hence, the association between the environment and the concrete elements determines its long-term performance durability [3].

In general, water permeability of exposed concrete structures such as pavement and bridge deck affect the durability and corrosion of the reinforcing steel in the structure [4]. Water-related problems such as freezing and thawing also cause serious degradation in reinforced concrete [3]. Permeability is known to be influenced by the quantity, kind, and spread of the pores present in a substrate [3]. Therefore, infrastructures need to be inspected and maintained over time.

The inspection and maintenance techniques used for infrastructures are increasingly drawing attention. The critical examination and subsequent maintenance of not so readily accessible infrastructures proved difficult due to the lack of funds required to cover the phenomenal costs. For example, epoxy-coal tar was used for waterproofing to eliminate seepage through the foundation of Nurek hydroelectric dam station with a maximum cost reduction [5].

Ingress of water and other aggressive materials in marine structures affect their service life [6]. Structures situated close to a water table or exposed to an environment with relatively high humidity are prone to water ingress [7]. Traditional detection and control methods are time-consuming and consequences of seepage remain unresolved. However, Rayleigh's wave detection technique combined with polymer grouting technology resolved the problem completely. Variation of temperature and moisture of the exposed environment coupled with other factors are known to cause cracks in the road pavement and bridge deck [8]. A survey revealed the presence of visible moisture, mould growth, and odour in the interior part of several built infrastructures in Finland [9]. The same study depicts that crystallization of salt due to water permeation in underground structures led to degradation of such infrastructures.

Some film-formed surface coatings can be used for waterproofing leading to controlling water ingress [10]. They can be used for new or old concrete for repairing purposes [11]. In addition, a layer made of polymer can be inserted between the concrete deck and the asphaltic concrete covering to reduce water penetration [12]. In addition, cement can be modified with supplementary materials for surface treatment to improve the water-resistance property of concrete [13,14]. Service environment, the type of concrete (substrate in question), economy and long- term efficiency are important factors of high consideration in choosing an appropriate product to be used as a surface impregnation material.

Concrete structures and other infrastructures suffer degradation during their service life usually due to water ingress. This is manifested in the corrosion of reinforcements followed by chloride permeability, acidic and other chemical attack, and gaseous permeability. Moreover, water permeation affects the aesthetic appearance of an infrastructure.

In general, a lot of resources have been employed in the rehabilitation of infrastructures due to durability problems. For example in Europe and particularly in Italy, the total cost of rehabilitation work amounted to half of the total expenditure invested in construction [15]. Algiers Airport repair cost was estimated about 3Million USD [16]. In UK, corrosion-related cost in building and construction industry was estimated to be 250 million GBP [17]. Moisture-related failures in building facades of high-rise buildings constructed within five years were reported [18]. The cost of repair of moisture-related problems in building façade was found to be 55.6% of the total construction cost [19]. Thus, degradation problem of buildings and other infrastructures, particularly facade walls' fouling aesthetic problems, need to be addressed using the most suitable and economical construction materials.

The literature database includes peer-reviewed papers and patents available and accessible online. The research aims to identify and depict the taxonomy and construct of different additives, tests, and techniques of concrete waterproofing (presented in Section 2). Further, it is to establish a classification of various additives based on the material structure, functions, and method of application (presented in Section 3).

## 2. Taxonomy and construct of research on waterproof concrete

Various researchers have studied the use of waterproof membrane, surface coating, and waterproofing agents such as polymers, polymer modified concrete/mortar, pore blocker, silicones, and pore liner penetrants to enhance the service life of infrastructures.

The effects of environment on the adhesive strength of waterproofing materials used in asphalt concrete overlay studied by Xu et al. [8]revealed that the bonding strength decreases at a compaction temperature higher than 160 °C. A more favourable compaction temperature up to 170 °C and a maximum suitable layer thickness up to 1.2 $kg/m^2$ were also reported [12]. Another investigation reported the quantity of materials up to 1.3 $L/m^2$ without adversely affecting the adhesive strength [20]. He further reported that as the environmental temperatures increased from 3 °C to 40 °C, failure was more likely to occur at the point of interaction [20]. Thus, it is critically imperative to consider increasing the strength of the waterproof adhesive layer at a relatively elevated temperature. Poor on-site workmanship has undermined the efficiency of the membrane [21]. This indicates that a maximum interval of 30 min between preparation and applying the material has the best result [21]. It was known that shear strength could be improved at the moisture content of at last 1% [22]. However, the maximum adhesion quality of waterproof membrane was achieved at the moisture content of zero percent (0%). Therefore, the adhesion quality was found to decrease as moisture content increased [21]. Many other studies consolidated the previous reports results on the use of membrane for the protection of concrete structures and other infrastructures against aggressive environments [22–24]. The reports further showed that ceramic coated with aluminium stearate in a volatile solvent repels water, but it tends to lose the waterproofing property over a short period of time [25]. To offset this limitation, a silicon containing compounds was used to prolong the service life [2].

A concrete surface treated with fly-ash cement base materials improved water tightness up to 50% [14]. This finding was supported by Teng [26]. Silicates containing compounds could improve water-resistance ([27,28]). Samples treated with silanes and siloxane separately demonstrated similar efficiency in both cyclic wetting and drying condition [29]. Samples treated with solutions from four different generic groups were not shown to be completely waterproof over a long period of time [30,31]. This was corroborated by Christodoulou et al. [32]. Mortars treated with siloxane showed improved resistance to water capillary. However, water vapour permeability was not largely influenced by the treatment [33]. Waterproofing characteristics of a concrete bridge deck