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REVIEW ARTICLE

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IMPROVING THE PROPERTIES OF CONCRETE USING ADDITIVES: REVIEW

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ABSTRACT

Concrete structures are popular in the construction industry due to their durability and strength. However, shrinkage cracking is a common issue that can negatively impact their appearance and hasten their rate of deterioration, potentially causing a significant decrease in their overall service life, which can be costly and unsafe. Fortunately, there is a solution to this problem. Shrinkage-reducing admixtures (SRAs) are chemical compounds that can be added to concrete mixes to limit the amount of shrinkage that occurs as the concrete dries. These admixtures operate by minimizing the surface tension of water molecules in the mix, which helps to prevent the concrete from cracking or shrinking excessively as it dries. This results in a more robust and long-lasting finished product. By incorporating SRAs into concrete mixes, the likelihood of shrinkage cracking can be significantly reduced. These admixtures work to minimize the volume of capillary stresses and stresses caused by shrinkage that occur when concrete loses moisture. By doing so, they help to ensure that the concrete remains strong and stable over time, reducing the need for costly repairs or replacements down the line. Comprehensive research has shown that SRAs are highly effective in reducing dryness, self-shrinkage, and plastic shrinkage in concrete, making them an essential component in many construction projects. The evidence for the benefits of SRAs is widely available in the literature, making them a dependable solution to the issue of shrinkage cracking in concrete structures.

Keywords: additives, surfactants, shrinkage reduction, self-shrinkage.

Introduction

Over time, concrete structures experience changes in volume that can result in self-induced stresses and shrinkage cracks [1]. These cracks can cause significant structural damage, compromising the durability, serviceability, and appearance of the structure. To increase the lifespan of cement concrete, it is crucial to control and minimize the occurrence of shrinkage [2]. One effective method is to use lightweight coarse or fine saturated aggregates in internal processing [3]. However, finding suitable materials for this process can be challenging. Another option for reducing shrinkage and enhancing tensile strength is to include fibers and extended agents in the mix. However, this approach is more expensive, reduces the workability of fresh concrete, and requires a more complex preparation process. A promising technique for reducing the risk of cracking is to minimize tensile stress by mitigating shrinkage development, leading to a growing interest in shrinkage-reducing admixtures[4]. These admixtures can effectively decrease concrete shrinkage and improve the quality and longevity of concrete structures.

Main molecules and additives to reduce shrinkage

Shrinkage-reducing admixtures, or SRAs, are specialized chemical compounds used in concrete mixes to help counteract the problem of shrinkage[5]. These mixtures contain a variety of surface-active agents, including non-alcoholic substances, glycols, esters of polyoxymethylene glycols, polymeric agents with surfactant properties, and amino alcohols[6]. Compared to other types of admixtures, SRAs typically require a higher dosage rate, which can be up to 10 times that of superplasticizers[7]. However, in high-performance concrete, the dosage rate is similar to that of superplasticizers.

Diluents

Shrinkage reduction additives are chemical surfactants that are specifically designed to lower the surface tension between air and water[8]. These additives are primarily used to minimize the shrinkage of materials during the drying process by altering the properties of the pore system[9]. Surfactants are a type of chemical compound that can aid in reducing the angle of contact between the meniscus and the walls of the pore system. This decrease in the angle of contact leads to the creation of tensile stresses, which can have a significant impact on various physical and chemical processes[10]. By altering the surface properties of the materials involved, surfactants can help to modify the behavior of fluids and enhance their interactions with other substances[11]. The term "hydrophobic tail" refers to a structural feature of a molecule called SRA. This molecule possesses a distinctive chemical composition that allows it to be easily incorporated into nonpolar environments[12]. As a result of this property, SRA exhibits low surface tension[13]. This is primarily due to its ability to be absorbed by interfaces that lack water-loving (hydrophilic) properties.

Mechanism of action of additives

SRA is a type of organic compound that is categorized as a surfactant. The chemical composition being referred to comprises of a primary component known as the head, which is chemically bonded through a sharing of electrons with another atom, and a secondary component called the tail, which exhibits a strong aversion to water due to its hydrophobic nature[14]. Due to its unique chemical structure, SRA can be absorbed into nonpolar interfaces, which results in its low surface tension[15]. The reason behind the phenomenon is the occurrence of electrostatic repulsion between the opposite poles of neighboring SRA molecules[16]. This force of repulsion creates a state of energy imbalance, which leads to a separation between the molecules and causes them to move away from each other.[17] When present in lower concentrations, the SRA molecules exist as individual units which are dispersed in water, commonly referred to as monomers. As the concentration of SRA (Surface-active agent) increases, the hydrophobic tails of the SRA molecules start experiencing an unfavorable interaction with the surrounding water molecules. In order to minimize this interaction, the SRA molecules tend to group together and form micelles. These micelles are clusters of SRA molecules that are arranged in a way that the hydrophobic tails are shielded from the water molecules, which creates a more stable and energetically favorable configuration .Some SRA (Shrinkage-Reducing Admixture) molecules serve as non-ionic surfactants that get absorbed on the interface of water and solid[18]. This results in a reduction in the interlayer energy of cement particles and wetting agents, which alters the polarity of the surface of the molecules. In simpler terms, SRA molecules can act as a barrier between the water and cement particles, reducing the shrinkage of concrete and improving its strength. The hydrogen bond interactions between the polar units of SRA play a significant role in enhancing the dispersion of molecules[19]. This happens because the polar units of SRA attract and bind to other polar molecules, resulting in a more even distribution of molecules throughout the solution . SRA, which stands for Shrinkage-Reducing Admixture, is a substance that has a number of unique properties that make it highly effective in reducing the amount of shrinkage that occurs in concrete[20]. Specifically, SRA is able to mitigate the surface tension of the pore solution and the interfacial energy, which in turn helps to reduce the overall amount of cracking and shrinkage that takes place within the concrete structure. By using SRA in concrete construction, builders can create stronger, more durable structures that are less prone to cracking and other forms of damage over time[1][21]. As a result of this, SRA considerably impedes water absorption and lessens the shrinkage process.

The effect of admixtures on concrete shrinkage

Surface-reducing agents (SRAs) are an essential component in the field of concrete construction. They are used to reduce the risk of shrinkage and cracking that can occur in concrete elements due to various factors such as temperature changes and moisture conditions[22]. These agents work by minimizing the surface tension of the concrete, which allows for the displacement of water and air within the material. This displacement results in a more uniform and stable concrete structure that is less prone to damage and deterioration over time[23]. Overall, the use of SRAs is crucial for ensuring the long-term durability and integrity of concrete structures. These agents are widely used due to their ability to reduce the drying shrinkage in concrete by slowing down the evaporation of water from the surface, making it possible for the concrete to cure uniformly[24]. This helps to improve the overall durability and longevity of the concrete structures, making them more resistant to environmental factors such as temperature fluctuations, moisture, and other external stresses. Surface-Reactive Agents (SRAs) are chemical compounds that can be used to modify the properties of concrete. They work by altering the surface tension of the pores in concrete, which in turn can significantly reduce the amount of shrinkage that occurs during the drying process[25]. This can result in a reduction of concrete shrinkage by up to 50%, making SRAs a highly effective solution for preventing cracking and other forms of damage that can occur as a result of shrinkage. In addition, SRAs have been shown to reduce capillary stresses that are created by self-origin shrinkage. This is particularly useful in conventional and high-strength concrete, where shrinkage cracking is a common problem that can lead to structural damage. Several studies have been conducted to investigate the effectiveness of SRAs in reducing concrete shrinkage and cracking. These studies have shown that the addition of SRAs, such as xylene glycol and propylene glycol, can significantly reduce free dry shrinkage by up to 44% and restrict drying shrinkage by up to 17%. Studies have demonstrated that the use of Butoxyethanol and alkyl ether can significantly decrease drying shrinkage by up to 42% in cement materials[26]. Additionally, the magnitude of the reduction in shrinkage has been found to be directly proportional to the amount of Shrinkage-Reducing Admixture (SRA) added to the cement composition. To put it simply, when a higher dose of Shrinkage-Reducing Admixture (SRA) is used, the shrinkage of cement materials is reduced to a greater extent[27]. However, it is worth noting that the effectiveness of SRA in reducing dehydration shrinkage may vary depending on the type of cement material and the processing conditions used. One of the major issues that limit the application of concrete is cracking. This problem is often caused by excessive plastic shrinkage, and can significantly impact the durability and functionality of concrete structures. To address this issue, engineers and construction professionals widely use Shrinkage-Reducing Admixtures (SRAs), The use of specific materials has been proven to greatly decrease the likelihood of concrete shrinkage and the subsequent formation of cracks in concrete structures[28]. These materials are known for their exceptional effectiveness in minimizing the risk of shrinkage cracking in various concrete elements. SRAs are commonly employed in construction projects to ensure the durability and longevity of concrete structures, as well as to enhance their overall safety and performance. In order to tackle the issue of plastic shrinkage in concrete, a number of researchers have undertaken extensive investigations into the use of Shrinkage Reducing Admixtures (SRA). These admixtures are added to the concrete mix in order to mitigate shrinkage and reduce the likelihood of cracking and other forms of damage occurring over time[29]. Through their research efforts, these experts aim to identify the most effective ways of using SRA to improve the durability and longevity of concrete structures, helping to ensure their safety and reliability for many years to come. SRA (Shrinkage Reducing Admixture) is a popular method used in the construction industry to reduce the shrinkage stress in concrete. Shrinkage stress is a major concern as it can lead to cracking and other structural issues. SRA admixtures have proven to be effective in reducing the risk of restricted shrinkage cracking, making them a preferred choice in construction projects[30]. One of the significant benefits of using SRA is the reduction of plastic shrinkage in both conventional and high-strength concrete. The results have demonstrated remarkable improvements in the plastic shrinkage of concrete that contribute to the durability and longevity of concrete structures. The reason behind the reduction in the rate of evaporation and peak capillary pressure can be attributed to the growth and formation of articular cartilage in the pores and lower levels. This phenomenon has been proven in various studies. Additionally, the inclusion of polypropylene glycol, a type of non-ionic surfactant, and a waxy-non-ionic surfactant, have been found to be effective in significantly decreasing shrinkage deformation and crack width. During the cement-wetting reaction, moisture is consumed by the cement material to dry the inside of the capillary pores[31]. As a result, the cement material undergoes self-shrinkage. It has been observed that the addition of SRA (Shrinkage-Reducing Admixture) leads to a significant improvement in the self-shrinkage of the cement material. However, this improvement is not linear as the reduction in self-shrinkage gradually decreases with an increase in the SRA content. It has been discovered that incorporating low molecular polyether and high molecular polymer can effectively reduce self-shrinkage[32]. Upon adding low molecular polyether type SRA, a significant decrease of 55% in self-shrinkage has been observed. Similarly, by adding high molecular polymer type SRA, a reduction of 34% in self-shrinkage has been achieved. This indicates that both low and high molecular weight additives can play a vital role in decreasing self-shrinkage, thereby improving the overall quality of the product . According to the research carried out, the use of a new mixture to reduce shrinkage has demonstrated a substantial decrease in self-shrinkage ranging from 15.3% to 48.1%. This novel mixture contains 2-butoxyethanol, ethylene oxide, propylene oxides, potassium hydroxide, and an expanded mixture of ternate. The study highlights the effectiveness of this shrinkage reduction mixture in reducing self-shrinkage[33]. By incorporating Supplementary Cementitious Materials (SCMs) such as Silica Fume (SF), Fly Ash (FA) or Metakaolin (MK) to concrete, we can effectively reduce the shrinkage that occurs during the curing process. This leads to a more durable and long-lasting concrete structure that can resist the effects of environmental factors such as moisture, temperature changes, and cracking[34]. In addition to reducing shrinkage, the use of these materials can also enhance the mechanical and chemical properties of concrete, making it more resistant to corrosion and improving its overall strength.

The effect of admixtures on other concrete properties

When we add SRAs to concrete, we not only reduce shrinkage but also bring about a wide range of changes and behaviors, some of which can be beneficial, while others may not be desirable. The inclusion of SRA in concrete mixtures influences various aspects of the slurry, including reaction rate, interfacial bond strength, and pore size distribution[35]. The incorporation of Supplementary Cementitious Materials (SCMs) or Supplementary Cementitious Admixtures (SCAs) such as Silica Fume, Fly Ash, GGBS, Metakaolin, or Rice Husk Ash into cement concrete can significantly enhance its durability and resistance to chloride ion penetration, sulfate attack, and alkali-silica reaction. These materials act as pozzolanic materials, reacting with calcium hydroxide and other alkalis in the presence of water to form additional calcium silicate hydrate (C-S-H) gel, which fills the voids in the cement paste and reduces its porosity, permeability, and susceptibility to cracking. Additionally, the use of SCMs and SCAs can also reduce the heat of hydration, improve workability, and reduce the risk of thermal cracking[36]. These additives make the porous solution less absorbent and more viscous, resulting in a decreased rate of propagation of aggressive ions. This property can be highly beneficial in improving corrosion resistance and the performance of concrete during freezing and thawing cycles, especially when considering sustainability and environmental research. The higher viscosity of certain materials can improve the ability of concrete to retain water, reducing the amount of evaporation that occurs and helping to maintain a consistent level of humidity within the concrete[37]. This can help to stabilize the overall volume of the concrete and prevent premature changes in its size or shape. Additionally, substances known as SRAs tend to have slower rates of hydration during the early stages of concrete formation, but can contribute to a modest improvement in the long-term hydration of the material[38]. Overall, incorporating SRA in concrete mixtures results in higher maximum degrees of hydration.

Applications on shrinkage reducing additives

Shrinkage is a common issue in concrete structures that can lead to durability problems and unsightly shrinkage joints[39]. Fortunately, shrink reduction additives can be incorporated into concrete mixtures to mitigate shrinkage and minimize the likelihood of cracking. In scenarios where new concrete is being employed to either fortify or fix existing structures, the mixtures described here can prove to be exceptionally beneficial[40]. This is because the conditions in such environments can further intensify the negative impact of shrinkage. By using shrink reduction additives, builders and engineers can ensure that their concrete structures remain strong[41], durable, and aesthetically pleasing.

Disadvantages of shrinkage reducing additives

It's worth noting that certain chemical admixtures that are commonly added to concrete can actually be incompatible with shrinkage-reducing additives[42]. This means that if you're working with concrete and you're using both types of additives, you need to be careful about which ones you choose and how you combine them. It's important to ensure that all of the additives you're using will work together effectively and not interfere with one another, as this can cause significant issues with the final product. Researchers often face significant challenges when integrating mixtures that are based on Polycarboxylate Ether (PCE) and Superplasticizer Retarding Admixture (SRA)[43]. One of the most pressing issues is the need to ensure that the SRA is compatible with the various types of cement that are commonly used in the production of concrete. Additionally, determining the appropriate dosage of SRA can be a complex and time-consuming process[44]. Despite these challenges, the use of PCE-SRA mixtures in concrete is an important area of research that holds great promise for improving the strength, durability, and overall quality of concrete structures. The incorporation of shrinkage-reducing agents in concrete mixtures has been found to be highly effective in minimizing shrinkage, drying, and self-shrinkage. These agents are used in high doses as compared to other concrete mixtures. Additionally, they have been observed to significantly reduce crack width and delay the initiation of cracks[45]. Overall, the utilization of shrinkage-reducing agents in concrete is an important strategy for ensuring the long-term durability and stability of concrete structures.

Conclusion

Shrinkage cracking in cementitious materials is a common issue that affects the durability and lifespan of concrete structures. The incorporation of shrinkage-reducing admixtures has been found to be an effective solution to this problem. Recent research has shown that the use of Shrinkage Reducing Admixtures (SRAs) in concrete can lead to a significant reduction in shrinkage caused by drying and self-shrinkage. By minimizing shrinkage, these additives not only improve the overall durability and lifespan of concrete structures but also reduce the occurrence of cracks and deformations caused by shrinkage. Compared to other concrete mixtures, SRAs are used in high doses. The addition of these shrinkage-reducing additives has also been found to result in a reduction in crack width and delay in the initiation of cracks. Surface-reducing admixtures (SRAs) are commonly used in concrete applications to minimize shrinkage. However, it should be noted that the use of SRAs can have a significant impact on various other properties and behaviors of concrete, which can be either advantageous or disadvantageous. Therefore, it is essential to carefully evaluate the benefits and drawbacks of using SRAs in any concrete application.

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