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Impact of Various Hydrophobic Treatments on the Properties of Recycled Aggregate Concrete: Literature Survey

Md. Faiyaz Alam, Onkar Yadav
Assistant Professor, Department of Civil Engineering, Sandip University, Madhubani, Bihar, India

Kanhaiya Kumar
Research Scholar, Department of Civil Engineering, Sandip University, Madhubani, Bihar, India

Abstract: The utilization of recycled aggregate in concrete production has gained significant attention due to its potential environmental and economic benefits. However, one of the major challenges associated with recycled aggregate concrete (RAC) is its susceptibility to moisture absorption, which can negatively affect its durability and mechanical properties. To address this issue, various hydrophobic treatments have been investigated to enhance the performance of RAC. This literature survey aims to provide an overview of the research conducted on the impact of different hydrophobic treatments on the properties of RAC. The survey begins by discussing the importance of hydrophobic treatments in improving the resistance of RAC to moisture ingress and the subsequent effects on its mechanical strength, durability, and dimensional stability. The survey further explores the different types of hydrophobic treatments employed, including surface coatings, impregnation with hydrophobic agents, and incorporation of hydrophobic admixtures in the concrete mix. The effectiveness of these treatments in reducing water absorption, improving compressive strength, enhancing freeze-thaw resistance, and minimizing drying shrinkage is analyzed based on the findings of various experimental studies and case studies. Additionally, the survey highlights the influence of key factors such as treatment methods, dosages, curing conditions, and aggregate characteristics on the performance of hydrophobically treated RAC. Furthermore, the limitations and challenges associated with hydrophobic treatments in RAC are discussed, along with potential avenues for future research. Overall, this literature survey provides valuable insights into the impact of different hydrophobic treatments on the properties of RAC, offering a comprehensive understanding of the current state of research in this field and paving the way for the development of more durable and sustainable concrete structures incorporating recycled aggregates.

Keywords: Recycled aggregate concrete, Hydrophobic treatments, Moisture absorption, Mechanical strength, Durability, Sustainable construction.

1. INTRODUCTION

The construction industry in India is experiencing significant growth, with a current contribution of 10 percent to the country's GDP. Over the past decade, it has been expanding at a rate of 10 percent annually, surpassing the global average of 5.5 percent. As a result, the built-up area is projected to increase nearly fivefold, reaching approximately 104 billion square feet by 2030 compared to 21 billion square feet in 2005. However, this rapid growth also leads to the generation of construction and demolition (C&D) waste. C&D waste encompasses waste generated during the construction, maintenance, and disposal phases of buildings, including demolished structures, renovations in the real estate sector, and construction and repair of infrastructure such as roads, flyovers, and bridges. Unfortunately, there is currently no systematic database on C&D waste maintained by the Union Ministry of Forests and Environment (MoEF). Estimates by the Centre for Science and Environment (CSE) suggest that India constructed an additional 5.75 billion square meters of floor space since 2005, with nearly one billion square meters in 2013 alone. Considering the average waste generation of 40-60 kg per square meter, India would have generated around 50 million tonnes of C&D waste in 2013. Over the past eight years, the cumulative waste production would amount to approximately 287 million tonnes. It is important to note that these figures only account for new construction, and additional waste is generated through demolition and renovation/repair activities. The waste generated during demolition is approximately ten times greater than that produced during construction, with estimates of 300-500 kg per square meter. Therefore, the overall volume of C&D waste in India is a significant concern, requiring effective management strategies and policies to address its environmental and economic impact.

2. RECYCLED AGGREGATES

Currently, there is a growing focus on integrating sustainable development principles into the construction industry, particularly through the use of recycled compounds in building materials. Sustainability entails evaluating and reducing the consumption of natural resources, minimizing environmental impact, ensuring human safety, and promoting sustainable systems within industrialized societies. Construction relies heavily on natural resources such as water and raw materials, making it crucial to propose building components that offer the same properties while minimizing resource consumption. The concept of sustainability also encompasses environmental impact resulting from intensive human activity. All materials and processes involved in construction must prioritize the health and safety of individuals and the environment. Recycled compounds suitable for inclusion in building materials can be sourced from building demolitions, mineral wastes, urban wastes, industrial wastes, and by-products. Public administrations in industrialized countries are actively promoting research programs on recycling as a solution for waste management, reflecting the social interest in ecological and environmental aspects. Building material producers and manufacturers are primarily interested in value-added solutions, waste management cost reduction, and economic efficiency. Researchers focus on the technological properties of new building materials and their potential applications. Therefore, ecological, environmental, economic, and technological considerations need to be addressed from the outset. The inclusion of recycled materials in mortar and concrete can be in the form of binder compounds, aggregates, or reinforcements. It is important to recognize that mortar and concrete should not be treated as mere waste disposal, but as technological materials with specific properties suitable for building purposes. The utilization of recycled materials in mortar and concrete can be applied to various building functions such as structures, joint materials, finishes, substrates, insulation layers, among others, with recycling proposals tailored to specific applications.

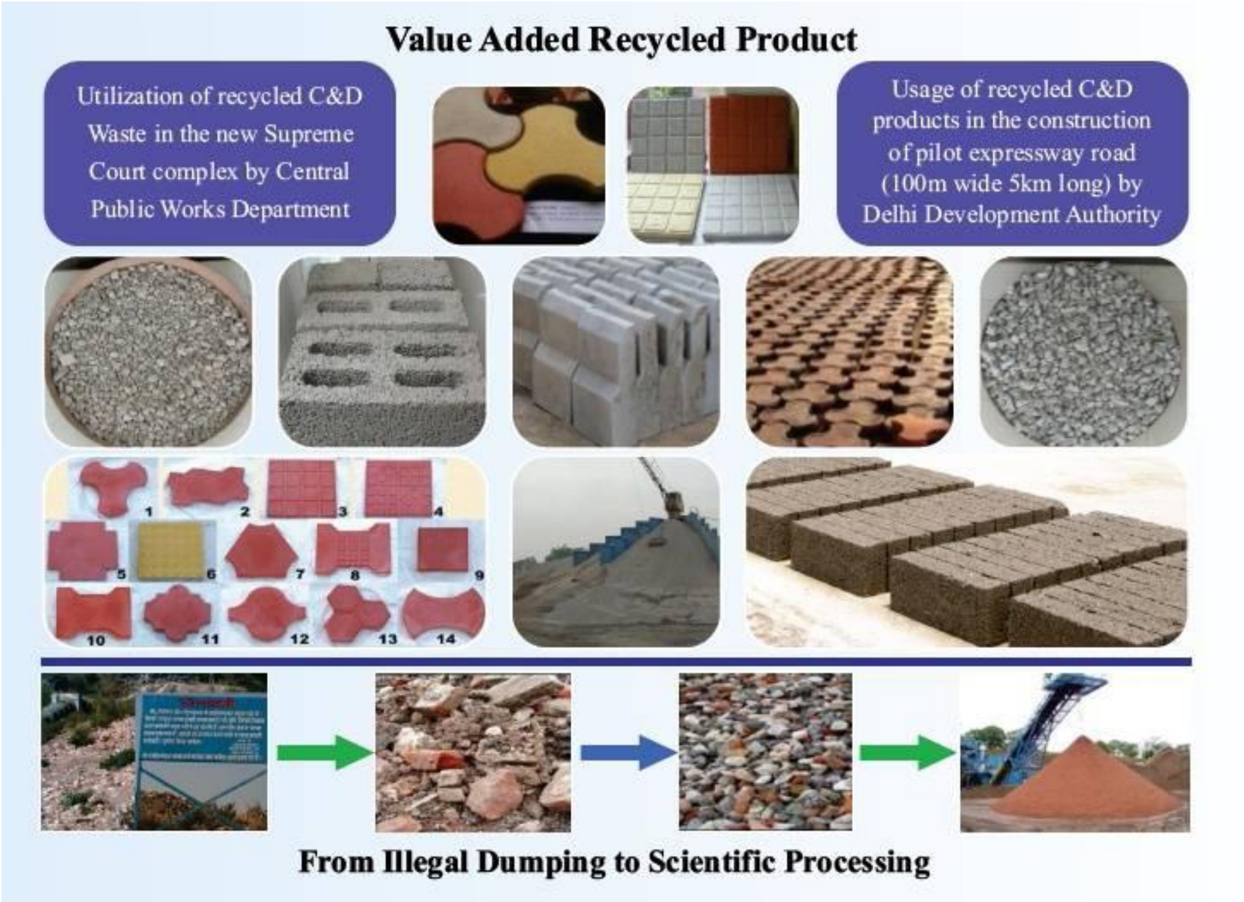

Figure 1: Concrete Recycling Plant and Products (Source-Google image)

3. SMALL STEPS TO MAKE RESOURCE FROM WASTE IN INDIA

An initiative undertaken by MCD-ILFS-IEISL in Delhi involves the recycling of construction and demolition (C&D) waste. This initiative focuses on converting the waste into aggregates, which are then used in the production of Ready Mix Concrete, pavement blocks, kerb stones, and concrete bricks. The aim is to reduce the environmental impact associated with C&D waste by promoting its reuse in various construction applications.

In a similar vein, the YUVA and CIDCO initiative in Navi Mumbai successfully recycled 1500 tonnes of C&D waste between 2002 and 2006. However, the initiative had to cease operations due to the lack of supportive policies and market demand. Despite their efforts to recycle C&D waste, the absence of a conducive policy framework and sufficient market support posed significant challenges, ultimately leading to the discontinuation of the initiative.

4. LITERATURE SURVEY

The survey further explores the different types of hydrophobic treatments employed, including surface coatings, impregnation with hydrophobic agents, and incorporation of hydrophobic admixtures in the concrete mix. The effectiveness of these treatments in reducing water absorption, improving compressive strength, enhancing freeze-thaw resistance, and minimizing drying shrinkage is analyzed based on the findings of various experimental studies and case studies. Additionally, the survey highlights the influence of key factors such as treatment methods, dosages, curing conditions, and aggregate characteristics on the performance of hydrophobically treated RAC. Furthermore, the limitations and challenges associated with hydrophobic treatments in RAC are discussed, along with potential avenues for future research.

Farid Debieb et al. (2010) According to the study, it was found that recycled aggregates exhibit certain physical properties such as increased water absorption, lighter weight, and a higher quantity of residual mortar compared to natural aggregates. These properties can have an impact on the durability of recycled aggregate concrete (RAC). The increased water absorption capacity and higher porosity of recycled aggregates can potentially reduce the durability of RAC. However, it was also observed that recycled aggregates with higher levels of porosity, particularly those contaminated with higher levels of porosity-inducing substances, demonstrated an increased resistance to freeze-thaw cycles. This suggests that the presence of higher levels of pores in contaminated recycled aggregates can contribute to their ability to withstand the damaging effects of repeated freeze-thaw cycles. Overall, the study highlights the potential trade-offs between the physical properties of recycled aggregates and the durability of RAC. While the increased water absorption and porosity may pose challenges to durability, certain types of recycled aggregates with higher porosity levels can exhibit improved resistance to freeze-thaw cycles. These findings underscore the importance of considering the specific characteristics of recycled aggregates and their potential impact on the performance of RAC.

CAI Ning et al. (2010) In their research, the investigators examined the effectiveness of silane hydrophobic agents in protecting concrete. They conducted experiments using various concentrations of these agents and different types of silanes through surface treatments. One of the key parameters they studied was the water absorption capacity of the treated concrete. The results revealed that as the concentration of the hydrophobic agents increased, the water absorption capacity of the concrete decreased. This indicates that higher concentrations of hydrophobic agents can significantly reduce the amount of water absorbed by the concrete. Additionally, the researchers measured the contact angle of the treated concrete surface, which is an indicator of its hydrophobicity. They observed that as the concentration of the hydrophobic agents increased, the contact angle also increased, indicating a higher degree of water repellency. Furthermore, the researchers investigated the penetration depth of the hydrophobic agents into the concrete. They found that highly concentrated agents were able to penetrate deeper into the concrete compared to lower concentrated agents. This suggests that increasing the concentration of hydrophobic agents enhances their ability to penetrate the concrete matrix and provide effective protection against water infiltration. In summary, the study demonstrated that higher concentrations of silane hydrophobic agents in surface treatments can reduce the water absorption capacity of concrete and increase its hydrophobicity. Moreover, the penetration depth of these agents is influenced by their concentration, with highly concentrated agents exhibiting greater penetration. These findings emphasize the importance of carefully selecting and applying hydrophobic agents to enhance the water resistance and durability of concrete structures.

Claudio Javier Zega and Ángel Antonio Di Maio (2011) The researchers conducted a study in which they investigated the mechanical properties of concrete containing fine recycled aggregates. They examined the effects of replacing 20% and 30% of natural fine aggregates with recycled aggregates and compared them to concrete made with natural fine aggregates alone. The results of the study indicated that the concrete samples containing 20% and 30% replacement of natural fine aggregates with recycled aggregates exhibited similar mechanical properties to the concrete made solely with natural fine aggregates. This suggests that incorporating a portion of fine recycled aggregates in the concrete mixture did not significantly affect its mechanical performance. Additionally, the researchers explored the use of a pasticizer or admixture in the concrete mix. By incorporating this additive, they were able to achieve improved durability behavior in the concrete specimens. The pasticizer/admixture facilitated a reduction in the water-cement ratio, which is known to enhance the durability and strength of concrete. By optimizing the water-cement ratio through the use of a pasticizer/admixture, the concrete with recycled aggregates demonstrated improved durability characteristics. Overall, the study demonstrated that incorporating fine recycled aggregates in concrete at 20% and 30% replacement levels did not adversely affect the mechanical properties of the concrete. Furthermore, the use of a pasticizer/admixture allowed for better control of the water-cement ratio and improved durability behavior in the concrete specimens containing recycled aggregates. These findings highlight the potential of using recycled aggregates as a sustainable alternative in concrete production while maintaining satisfactory mechanical properties and enhancing durability.

Ya-Guang Zhu et al. (2012) In their study, the researchers observed a reduction in both mechanical and physical properties when replacing natural aggregates with recycled aggregates. The incorporation of recycled aggregates led to a decrease in the overall performance of the concrete. To address this issue, the researchers explored the use of surface-based treatments to improve the properties of the recycled aggregate concrete. They found that treating the surface of the recycled aggregates with water repellent agents, such as silane, resulted in a reduction in water absorption. The effectiveness of these treatments varied based on the number of coats applied and their concentrations. However, the researchers also noted that the use of surface-based treatments had an impact on the compressive strength of the concrete. They observed a decrease in compressive strength as the dose of silane increased in the mixing process for the treated recycled concrete. These findings indicate that while surface-based treatments can help reduce water absorption in recycled aggregate concrete, they may have a negative effect on compressive strength. Therefore, a balance needs to be struck when considering the application of surface treatments in recycled aggregate concrete to ensure that the desired improvements in water absorption are achieved without compromising the overall strength of the concrete.

D. Matias et al. (2013) In their study, the researchers found that the porosity of recycled aggregate concrete increased when a higher water-cement ratio was used. This increase in porosity was accompanied by a reduction in the quantity of mortar present in the concrete. As a result, the workability of the concrete decreased while water absorption increased. The findings suggest that the water-cement ratio plays a significant role in the porosity and overall characteristics of recycled aggregate concrete. A higher water-cement ratio leads to increased porosity, which can negatively impact the workability of the concrete and result in higher water absorption. Therefore, careful consideration of the water-cement ratio is necessary when working with recycled aggregate concrete to maintain desirable properties and optimize the performance of the material.

Hongsong Wang et al. (2013) According to the study, significant improvements were observed by applying a deep impregnation technique using a water-resistant silane material. The effectiveness of the treatment was attributed to the reaction between SiOH groups in the silane and water, resulting in the formation of highly water-repellent Si-O-Si groups. As a result, a protective layer was created on the surface of the concrete, leading to a decrease in sorptivity. The use of silane-based materials for waterproofing purposes was found to be beneficial. These materials are non-harmful to the ecosystem and human health. By forming a protective layer, they effectively reduce the water absorption of concrete and enhance its resistance to moisture ingress. This not only improves the durability of the concrete but also helps preserve its structural integrity over time. The findings highlight the potential of silane-based treatments as a sustainable and effective approach for enhancing the water repellency of concrete surfaces. By minimizing water penetration, these treatments contribute to the long-term performance and longevity of concrete structures while posing no harm to the environment or human well-being.

F. Tittarelli et al. (2014) In their investigation, it was found that the addition of a hydrophobic admixture to no fines concrete resulted in a reduction in its capillary water absorption capacity. This reduction in water absorption was attributed to the presence of the hydrophobic admixture, which created a barrier against water penetration. However, the increased availability of micro voids in the concrete led to an increase in carbonation depth. Regarding the mechanical performance of the concrete, the addition of the hydrophobic admixture at doses of 0.5% and 1.0% by weight of cement had a slight effect. The impact on mechanical properties was minimal, suggesting that the hydrophobic admixture did not significantly compromise the overall strength and performance of the concrete. These findings indicate that the use of a hydrophobic admixture can effectively reduce the water absorption capacity of no fines concrete and enhance its resistance to water ingress. However, it is important to consider the potential increase in carbonation depth when using such admixtures. Additionally, the slight effect on mechanical performance suggests that the hydrophobic admixture can be used without significantly compromising the structural integrity of the concrete.

Luc Courard and Annelise Cousture (2014) The study focused on heritage buildings, which are subject to deterioration caused by natural climate conditions. The research aimed to investigate whether the application of hydrophobic surface-based treatments could help protect the concrete from these detrimental effects. It was observed that factors such as thermal shocks and ultraviolet rays played a significant role in breaking down the Si-O-Si solvent bond molecules present on the surface of the concrete. As a result, the untreated concrete exhibited high moisture absorption and water absorption capacities. However, when the concrete was treated with a hydrophobic surface treatment, the water absorption capacity was reduced. This indicated that the treatment created a protective barrier that limited the ingress of moisture into the concrete. Consequently, the durability of the concrete was improved. It should be noted that for long-term protection, repeated treatments were necessary. The research concluded that the application of solvent-based hydrophobic treatments could effectively enhance the durability and moisture resistance of the concrete in heritage buildings, thereby safeguarding them against the detrimental effects of natural climate conditions.

Valerie Spaeth and Assia DjerbiTegguer (2014) In their study, it was found that the physical properties of recycled aggregates could be significantly enhanced by utilizing siloxane/silane polymerization. The researchers specifically focused on treatments for recycled aggregates, where the aggregates were immersed in various agents and combinations of agents to assess their effects. Through the dip treatment, a microfilm was formed on the surface of the recycled aggregates. This microfilm played a crucial role in reducing the water absorption capacity of the aggregates. By decreasing water absorption, the overall durability and performance of the recycled aggregates were improved. Additionally, the researchers investigated the impact of combining different agents for the treatment. It was observed that the combination of different agents resulted in a more efficient enhancement of the physical properties of the recycled aggregates. This finding suggests that utilizing a synergistic approach by combining specific agents can lead to superior outcomes in terms of improving the properties of recycled aggregates. Overall, the study highlights the potential of siloxane/silane polymerization treatments for enhancing the physical properties of recycled aggregates. The development of a protective microfilm and the synergistic effects of combined treatments offer promising opportunities for optimizing the performance and sustainability of recycled aggregate materials in various construction applications.

Evgeniya V. Tkach et al. (2015) The study presented the impact of modified complex hydrophobization and hydrophobic tragers on high-performance modified concretes. The researchers explored the feasibility of these treatments for hydro-engineering concrete, aiming to reduce water penetration in the treated concrete. The application of these treatments showed promising results in enhancing the water resistance of the concrete. By reducing water penetration, the treated concretes exhibited improved durability and resistance to water-related damage. This makes them suitable for various applications in reinforced concrete structures, such as roads, foundations, and drainage systems, where protection against water ingress is crucial. The findings suggest that the use of modified complex hydrophobization and hydrophobic tragers can offer viable solutions for enhancing the performance of concrete in hydro-engineering projects. The treated concretes provide increased reliability and longevity, making them well-suited for their intended purposes in water-intensive environments. Overall, this research highlights the potential of these treatments to improve the quality and functionality of high-performance modified concretes in hydro-engineering applications. The implementation of such treatments can contribute to the development of more durable and resilient infrastructure systems that effectively withstand water-related challenges.

Sandro Weisheit et al. (2015) In their study, the researchers reported that surface-based treated high-performance concrete exhibited improved performance in terms of DIN permeability compared to untreated concrete. The untreated concrete surface was found to be more porous, whereas the application of surface-based coatings resulted in the filling of these pores with the coated agents, creating a uniform film on the surface. The presence of roughness and inhomogeneity in the untreated concrete surface contributed to a reduction in water repellency. To evaluate the effectiveness of the treatment, three types of concrete samples were used: untreated, treated, and weathered surfaces. The contact angle between water droplets and the surfaces was measured, and it was observed that the treated surface demonstrated a higher contact angle compared to the others, indicating enhanced water repellency. The high-performance concrete exhibited a slow water penetration rate due to its dense nature, further highlighting its superior performance in terms of water resistance. Overall, the results indicate that surface-based treatments can significantly improve the water repellency and performance of high-performance concrete. By filling the pores and creating a uniform film on the surface, these treatments enhance the durability and resistance of the concrete to water penetration. This research contributes to the understanding of the factors influencing water repellency in concrete and provides valuable insights for the development of more effective surface treatments for high-performance concrete.

Tkach Evgeniya (2016) In their investigation, the researchers focused on developing a methodology to enhance the hydrophobic properties of industrial waste materials incorporated into concrete. They proposed the use of a hydrophobic traeger, which was created by combining melted bitumen and fly ash in a ratio of 1 part fly ash to 2 parts melted bitumen. The application of this hydrophobic traeger showed effective results in terms of both mechanical performance and durability.The modified concrete with the hydrophobic traeger exhibited a microstructure characterized by a uniform and porous structure. This unique microstructure played a significant role in reducing the porosity of the concrete. As a result, the concrete demonstrated improved hydrophobic properties, making it more resistant to water penetration. By combining melted bitumen and fly ash in the specified ratio, the researchers were able to create a hydrophobic traeger that effectively enhanced the performance of the concrete. The modified concrete exhibited improved mechanical strength and durability, along with a reduced porosity. This methodology provides a promising approach for utilizing industrial waste materials in concrete production while simultaneously improving its hydrophobic properties.

Zhichao Liu and Will Hansen (2016) In their study, it was reported that the freeze-thaw durability of concrete was significantly improved when treated with a silane-based surface treatment. This treatment proved to be effective, particularly in concrete with a high water-cement ratio. However, it should be noted that the silane treatment was unable to prevent bulk moisture absorption by the treated surfaces. As a result, the concrete exhibited the formation of micro bulk cracking due to a poor air void system. The application of a silane-based surface treatment showed promising results in enhancing the freeze-thaw durability of the concrete. Despite the improvements, it was observed that the treatment did not completely prevent the absorption of moisture into the bulk of the concrete. Consequently, this led to the development of micro bulk cracks, primarily attributed to the inadequate air void system within the treated concrete.

Mandoliaet al.(2020) The objective of this study was to assess the impact of three different hydrophobic treatments on the mechanical and durability properties of recycled aggregate concrete. The experimental setup involved replacing natural coarse aggregate with 10%, 20%, and 30% of coarse recycled aggregate in the concrete mix. The hydrophobic treatments employed included mixing-based treatment, aggregate-based treatment, and surface-based treatment. The results of the study revealed that both mixing-based and surface-based treatments had a positive influence on the mechanical properties, such as compressive and flexural strength, of the recycled aggregate concrete. These treatments contributed to improved strength characteristics compared to untreated concrete. Additionally, the durability of the concrete was significantly enhanced as evidenced by its resistance to acid attack, sulphate attack, chloride attack, and DIN permeability.

Zhong et al.(2022) The experimental findings indicate that soaking recycled coarse aggregate in a polyvinyl alcohol solution leads to a substantial decrease in water absorption, with a reduction of up to 64.56%. Notably, a combination of sodium silicate and silane impregnation demonstrates a synergistic effect, resulting in a significant increase in the apparent density and a notable reduction in the crushing index of the recycled coarse aggregate.

Furthermore, compared to untreated concrete, recycled aggregate concrete treated with a composite impregnation of sodium silicate and silane exhibits improvements in various mechanical properties. Specifically, there is a 9.8% increase in slump, a 26.53% increase in compressive strength, a 21.70% increase in splitting tensile strength, and a 14.72% increase in flexural strength.

Kaura et al.(2023) In current research, we focused on two types of coarse recycled concrete aggregates. One was sourced from a C&D waste processing plant located in Burari, New Delhi, while the other was developed in the NCB Ballabgarh laboratory and underwent mechanical treatment. We conducted evaluations and comparisons of the physical properties of both treated and untreated aggregates.Furthermore, we compared the fresh properties, such as workability, air content, and bleed percentage, as well as the hardened properties, including compressive strength and modulus of elasticity, of concrete made with and without treated coarse recycled concrete aggregate.The introduction of IS 383, an Indian specification, was also discussed. This specification outlines the requirements for coarse and fine aggregates used in concrete production. It permits the use of C&D waste-based recycled concrete aggregate in both plain and RCC concrete. However, it imposes limitations on the utilization of C&D waste-based coarse recycled concrete aggregate, allowing a maximum of 20% usage in RCC for M25 grade concrete. For non-structural applications, such as plain cement concrete, it permits up to 25% replacement of natural aggregates with recycled concrete aggregate.

5. SUMMARY

The utilization of recycled aggregate in concrete production has gained significant attention due to its potential environmental and economic benefits. However, one of the major challenges associated with recycled aggregate concrete (RAC) is its susceptibility to moisture absorption, which can negatively affect its durability and mechanical properties. To address this issue, various hydrophobic treatments have been investigated to enhance the performance of RAC. This literature survey provides an overview of the research conducted on the impact of different hydrophobic treatments on the properties of RAC. The survey highlights the importance of hydrophobic treatments in improving the resistance of RAC to moisture ingress and its subsequent effects on mechanical strength, durability, and dimensional stability. Different types of hydrophobic treatments, such as surface coatings, impregnation with hydrophobic agents, and incorporation of hydrophobic admixtures, are explored. Based on the findings of various experimental studies and case studies, the effectiveness of these treatments in reducing water absorption, improving compressive strength, enhancing freeze-thaw resistance, and minimizing drying shrinkage is analyzed. The survey also considers key factors such as treatment methods, dosages, curing conditions, and aggregate characteristics that influence the performance of hydrophobically treated RAC. While hydrophobic treatments show promise in enhancing the properties of RAC, the survey acknowledges the limitations and challenges associated with these treatments. It also highlights the need for further research to optimize treatment methods and develop more durable and sustainable concrete structures incorporating recycled aggregates.

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