Research Progress of Polymer-modified Repair Materials for Concrete Pavement

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Abstract: The damage to cement concrete pavement is becoming increasingly severe due to the continuous addition of Chinese highway mileage, rapid traffic flow increase, and growing harm to public travel. The acreages of highway pavement that need to be repaired has increased sharply. The phenomenon that repairing pavement repeatedly be damaged is common. It results in a huge waste of resources. This paper mainly introduces the current research about repairing materials, polymer-modified cement-based materials. The inter facial bonding properties between repairable materials and existing concrete is also an important point. There are several reasons leading to concrete-repairing failure. Concrete pavement's repairable inter face is low. The evolution about the transition zone of micro-structure in the complex environment will affect the mechanical properties. It will cause the failure of concrete-repairing. To solve these problems, this paper puts forward a method to improve the Ordinary Portland Cement-Sulphate Aluminum Cement (OPC-SAC) repairable materials by adding polymers. It provides a feasible method for improving the safety of roads and lengthening highway life-span.

1. Introduction

After large-scale infrastructure construction, China's highway mileage has basically met the needs of economic. The total length of highway mileages has reached 5.2807 million kilometers by the end of 2021. The length of cement concrete pavement is about 3.1 million kilometers [1]. Due to the rapid increase in traffic flow and the increasing demand for public transportation, the damage of cement concrete pavement is serious. In many regions of China, the highway's partial repairing period has been shortened from the rated 5-year to 3-5 years. Comprehensive-repairing period has been shortened from 10 years to 5-8 years. During the 13th Five-Year Plan period, the engineering's amounts about highway partial-repairing and comprehensive-repairing will increase rapidly. During the 14th Five-Year Plan period, the amounts will reach the peak [2]. It is necessary to repair the damaging road surface. Not only can it improve traffic safety index, but it can also extend road life. However, some repairs' lifespan is very short, resulting in secondary damage. Repeated repairs result in national construction resources waste. The secondary damage of the repairable concrete pavement is shown in Figure 1.

The bonding performance between repairable materials and old concrete determines the repair effect [3]. According to the theory of crystal growth theory, nucleation and crystallization of hydration products crystals occur readily at the interface. So, the distribution of crystals in the inter facial transition zone is different from that in the material interior. Additionally, effluent water emanates from the repairing materials. Air bubbles entrapped within the concrete matrix surface. The circumstances can lead to an increase in defects in transition zone, such as porosity addition and micro-cracking. The main reason for the low bonding strength of the repairing system is due to micro-structure issues in the interface transition zone.

Currently, road repairable engineering projects require materials that have fast hardening characteristics, while high early strength and minimal volume expansion. Phosphate cement, rapid hardening Portland cement, Sulfoaluminate cement and Ordinary Portland. Cement-Sulphate

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Aluminum Cement (OPC-SAC) are commonly used cement-based repairing materials. The OPC-SAC material system is widely applied in engineering. This system achieves rapid setting, early strength and micro expansion by rapidly generating a large number of Ettringite crystals (ettringite,AFt). But the AFt's crystal structure is very unstable. Actually, there are many factors that affect the overall micro-structure and inter face stability in pavement repairing engineering. Such as water erosion, dry wet cycling, and degradation of SO_4^{2-}. These factors can cause significant changes in the micro-structure of Aft crystals aggregated at the interface, and even have a destructive effect on the inter face bonding performance, resulting in repairing failure.

Figure 1 Secondary damage of concrete pavement after repair

Previously, research about repairing systems focused more on the repairing materials' performance, the construction process, and the durability in different environments. And it neglected the systematic research on the inter face performance of the repairable system, and did not consider the impact of environmental factors on the inter face performance. These all result in research lag on the degradation mechanism of interface bonding performance. Based on this research, the methods are for improving the inter facial bonding performance of repairable materials and predicting inter facial bonding strength.

2. Research Status and Development Trends at Home and Abroad

2.1. Research Status of Repairing Materials

Currently, cement-based repairable materials are preferred for repairing concrete pavement due to their excellent compatibility with the existing concrete matrix. Cement-based repairable materials offer numerous benefits while meeting the construction performance requirements. It possesses the characteristics of rapid hardening, high initial strength, stable later strength, slight expansion, good bending resistance, and good wear resistance [4]. Common repairable materials based on cement include phosphate cement, rapid hardening Portland cement, Sulphoaluminate cement and Aluminate cement. Phosphate cement is not affected [5] by high-efficiency water reducing agents and retarders, which makes it difficult to ensure its effectiveness, and it also has poor water resistance. The desired effect was not achieved when any of the other three types of cement were used in the experiment. They unable to satisfied the requirements that delayed setting time and had initial strength at the same time. They are also not to meet the requirements for non-shrinkage, slight expansion, high durability. The requirements for bending resistance and flexural strength of certain specialized engineering projects cannot be met to an even greater extent. In order to achieve the desired effect, we used to employ a combination of two types of cement in our experiments.

Lin Zongshou [6] pointed out that the binary system of Portland cement and Aluminate cement (OPC-CA) can improve the initial mechanical properties of the system. However, the OPC-CA binary system exhibits significant dry shrinkage that fails to meet the requirements for expansion performance of repairing materials [7]. Evju's research [8] showed that the OPC-CA binary system added 12.5% β- After hemihydrate gypsum, dihydrate gypsum. Aft are generated in the early stage of the hydration reaction, volume expansion can occur. The research conducted by Li Hongying [9] demonstrates that mix ordinary Portland cement and Sulphoaluminate cement is a good choice. The mortar prepared using this method has a good setting time and working performance for rapid repairing. Additionally, the mechanical properties significantly increase after an appropriate amount of polypropylene fiber is added. Therefore, the OPC-SAC binary system is capable of fulfilling the material performance requirements for repairing cement concrete pavement, exhibiting high initial strength, minimal expansion, and consistent later strength. Therefore, the OPC-SAC binary system was selected as the bonding material component for the repairing material in the project.

2.2. Research Status of Polymer Modified Cement-based Materials

Cement-based repairing materials' excellent performance compatibility with existing concrete pavement and ability could meet rapid repair requirements. However, due to a weak interface transition zone between the material and substrate, failure often occur.

Research has shown that using polymers to modify the interface between ordinary concrete or mortar and concrete matrix can significantly enhance the bonding strength. Schulze [10] found that the addition of 1.4% polyethylene glycol to cement significantly enhances the bond strength between cement slurry and limestone aggregate. Qian Xiaoqian [11] investigated the flexural performance, long-term flexural bonding strength, and axial compressive and tensile stress-strain relationships of polyvinyl acetate modified cement mortar. The results indicated that the addition of polyvinyl acetate to the mortar led to a significant decrease in both elastic modulus and axial compressive strength. It causes a significant increase in ultimate strain. The flexural strength and axial tensile strength of mortar have slightly increased, while the ultimate strain and ratio flexural compressive strength ratio have significantly increased. Li Fang [12] studied the effect of carboxyl butadiene emulsion on the mechanical properties of cement mortar under the condition of changing the water-cement ratio. The results indicate that increasing the water–cement ratio and polymer content can significantly enhance the tensile bond strength. Huang Lipin [13] studied the effects of ethylene-acetate and hydroxyethyl methyl cellulose ether copolymer adhesive powder on the mechanical properties of mortar. Such as compressive strength, flexural strength and interfacial bond strength. The results showed that both polymers could increase the bond strength of mortar. Polymer particles in polymer-modified cementitious repairable materials can diffuse, deposit, condense and form a continuous film [14,15] within the pores of existing concrete, resulting in higher inter facial adhesion.

Polymer-modified cement-based repairing mortar also exhibits excellent resistance to changes in temperature and humidity within the usage environment. The main reason is that forming a polymer film improves the impermeability of mortar, reducing water diffusion within the material [16,17]. The aging process of three commercial polymer-modified mortars (SBR, PAE, and VAE) exposed to different curing conditions was studied by Ramli [18]. It was found that SBR performed excellently under various curing conditions. The study by Elalaoui [19] shows that the mechanical properties of polymer-modified cement mortar largely depend on temperature, particularly the temperature at which the polymer undergoes glass transition. Additionally, the polymer lotion's ball lubrication and surfactant dispersion significantly reduce water consumption in the polymer mortar. The polymer fills the large holes in the mortar, closes the capillary with polymer film [20,21] and reduces overall porosity. As a result, the antifreeze property of the polymer mortar has been significantly improved. However, the bond between the polymer and the body, as well as its own strength and volume, will also change under long-term low-temperature effects and hot cold cycles. The extent of this change will directly affect the interface between the polymer and concrete matrix. The polymer's ability to form a film and exhibit surface activity can enhance the inter face transition zone of repairing materials. The SBR emulsion, EVA latex, and SPUA have been chosen to enhance the bonding between repairable materials and concrete matrix based on different polymer classifications.

2.3. Research on the Inter Bonding Performance between Repairing Materials and Existing Concrete

2.3.1. Researching the Bond Interface Transition Zone

The weakest inter face are the most likely sites for damage in the repair system, and enhancing the inter face transition zone is essential to improve bonding efficacy during repairs [22]. The weak interface is attributed to a higher water-cement ratio in the repairable area compared to that in the system, as indicated by several studies [23,24], due to the hydrophilicity of the concrete matrix. The exudation of water and the formation of air bubbles in cement-based repair materials will result in the accumulation of porosity and micro-cracks on the surface of the concrete matrix. There exist disparities in the physical and chemical characteristics of the repairable bonding material as compared to those of the concrete matrix. The inter face between concrete and repairable material will experience adjacent stress and induce inherent cracks due to the effects of the cycling, freeze-thaw cycles, and hydration shrinkage of the repair material.

Monteiro [25] further demonstrated the directional growth theory of CH crystals at the interface by observing hexagonal CH crystals with oriented growth through scanning electron microscopy. Zainpini [26] conducted an ESEM analysis to investigate the influence of water-cement ratio and relative humidity on the microstructure of concrete's interfacial transition zone. The formation and development process of the micro-structure in the inter facial transition zone between aggregate and cement slurry was analyzed by Rooij [27] using ESEM. The findings indicate that the reduction in water loss is the primary factor contributing to the formation and evolution of the inter facial transition zone. The morphology, hydration product distribution, crystal orientation, and size of the inter facial transition zone are key factors for its bonding properties. In order that understand the bonding mechanism between the repair material and concrete matrix. The relationship between the micro-structure of the interfacial transition zone and the bonding properties needs to be clarified.

2.3.2. Environmental Factors Affecting Bond Performance

The main factors affecting the inter face bonding properties are not only the properties of the repairable material and the interface state of the matrix concrete, but also the use environment of the repairable system. In the actual project, there are significant fluctuations in ambient temperature and humidity. Southern China experiences a high temperature and humidity environment during the summer months, while northern China has a low temperature and dry environment in winter. During the rainy season, there is prolonged precipitation. In certain areas, there are alternating changes in environmental temperature and humidity.

The research conducted by Wang Peiming [28] demonstrates significant variations in the impact of curing temperature on the tensile bond strength of cement mortar. It is modified with different types and quantities of polymers. The addition of hydroxyethyl methyl cellulose (HEMC) alone enhances the 28-day tensile bond strength in cement mortar under constant temperature curing at 5 ℃ and cyclic curing at 20 ℃/5 ℃. The 28-day tensile bond strength of cement mortar increases with the rise in curing temperature when EVA is added as a sole additive. Nevertheless, cyclic curing did not yield a significant enhancement in the 28-day tensile bond strength of cement mortar. Yang Nan [29] investigated the bonding performance between Magnesium Phosphate Cement and Portland cement matrix by examining curing temperature, humidity, interface wetting state, and inter facial agent. The results indicate that excessively high curing temperature or humidity is not conducive to the development of bonding properties of Magnesium Phosphate Cement. Moreover, the bonding strength of Magnesium Phosphate Cement repairing materials is higher under natural curing conditions.

The primary hydration product AFt in OPC-SAC system repair mortar is a highly soluble. Crystalline crystal can undergo significant transformations due to variations in environmental temperature and humidity [30]. According to Thomas's research [31], the initial generation of AFt fine crystals may not be stable due to their large specific surface area and are prone to dissolution in solution. If the humidity at the interface increases, AFt is prone to recrystallize in any available pores due to water transport, resulting in damage to the interface. Adamopoulou [32] demonstrated that excessive ambient temperature at the interface can lead to the decomposition of AFt crystal aggregation. While it forms the Monosulfur type hydration products. After the SO_4^{2-} released by AFt decomposition is adsorbed by hydrated calcium silicate, it will form AFt again when external SO_4^{2-} infiltrates, causing structural damage.

The environment in which the repairable system is situated can not only influence the performance of the repair material itself, but also exert an impact on the interface performance. The cause of the decline in bonding performance of repair materials in the environment is still unknown. Under varying environmental conditions, refining the investigation into the degradation mechanism of the bonding interface between polymer-modified OPC-SAC system repairable materials and concrete matrix can provide valuable insights, for practical applications in repairable engineering.

3. Conclusion

In summary, various polymers can be used to modify the OPC-SAC binary system repairable material. To improving its interface transition zone and bonding strength, addressing the failure of concrete repair caused by weak interfaces in the concrete pavement repairable system. Simulating different usage environments allows for studying the evolution of polymer-modified binary system repairable materials' interface micro-structure and uncovering the mechanism behind interface failure. The research's direction can provide valuable support for polymer-modified cement-based repair materials, filling the gap in theoretical research and offering better guidance for practical engineering applications.

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References

[1] Ministry of Transport of the People's Republic of China. Statistical Bulletin on the Development of the Transportation Industry in 2021, https://xxgk.mot.gov.cn/2020/jigou/zhghs/202205/t2022 0524 _3656659.html.

[2] Market Analysis, Forecast and Investment of China's Highway Mintenance Industry from 2019 to 2025. China Industrial Information Network, https://www.chyxx.com/research/201907/ 761980.html.

[3] Li G, Xie H and Xiong G. (2001) Transition Zone Studies of New-to-old Concrete with Different Binders, Cement and Concrete Composites, 23, 381-387.

[4] Nunes V A, Borges P and Zanotti C. (2019) Mechanical Compatibility and Adhesion Between Alkali-activated Repair Mortars and Portland Cement Concrete Substrate, Construction and Building Materials, 215(8), 569-581.

[5] Qiao F, Chau C K, Li Z J. (2010) Property Evaluation of Magnesium Phosphate Cement Mortar as Patch Repair Material, Construction and Building Materials, 24(5), 695-700.

[6] Z S Lin. (2014) Cementitious Material Science, Wuhan: Wuhan University of Technology Press.

[7] Z Q Hou. (2020) Development and Application of Cement based Pavement Repair Materials, Fuxin: Liaoning Technical University.

[8] Evju C, Hansen S. (2001) Expansive Properties of Ettringite in a Mixture of Calcium Aluminate Cement, Portland Cement and β-calcium Sulfate Hemihydrates, Cement and Concrete Research, 31(2), 257-261.

[9] H Y Li, J D Ding and X Yu. (2015) Performance Research on the Multlenzyme System

Repairing Materials of Portland Cement and Sulpholuminate Cement, Architecture, 46(1), 43-46.

[10] Schulze J. (1999) Influence of Water-cement Ratio and Cement Content on the Properties of Polymer-modified Mortars, Cement and Concrete Research,14(29), 909-915.

[11] X Q Wang, S L Zhan. (2000) The Mechanical Properties of Polymer-cement Mortar[J]. Journal of Materials Science and Engineering, 18(4), 35-38.

[12] F Li, P M Wang. (2006) Mechanical Properties of Polymer Modified Cement Mortar under Different Water–cement Ratio, Chemical Material Construction, (6), 33-35.

[13] L P Huang ,L Huang. (2007) Research on Physical Properties of Polymers Modified Cement Mortars and Their Commercial Application, Journal of Wuhan University of Technology, 29(10), 15-19.

[14] Brien J V, Mahboub K C. (2013) Influence of Polymer Type on Adhesion Performance of a Blended Cement Mortar, International Journal of Adhesion and Adhesives, 43, 7-13.

[15] Knapen E, Gemert D V. (2009) Effect of Under Water Storage on Bridge Formation by Water-soluble Polymers in Cement Mortars, Construction and Building Materials, 23, 3420-3425.

[16] Hassan K E, Robery P C and Al-Alawi L. (2000) Effect of Hot-dry Curing Environment on the Intrinsic Properties of Repair Materials, Cement and Concrete Composites, 22, 453-458.

[17] Reis J M L D. (2012) Effect of Temperature on the Mechanical Properties of Polymer Mortars, Materials Research, 15 (4), 645-649.

[18] Ramli M, Tabassi A A and Hoe K W. (2013) Porosity, Pore Structure and Water Absorption of Polymer-modified Mortars: an Experimental Study under Different Curing Conditions, Composites Part B: Engineering, 55, 221-233.

[19] Elalaoui O, Ghorbel E and Ben M. (2018) Influence of Flame Retardant Addition on the Durability of Epoxy Based Polymer Concrete after Exposition to Elevated Temperature, Construction and Building Materials, 192(20), 233-239.

[20] L G Xiao, Y Z Wang and J R Wang. (2000) Research on a Highly Frost-resistance Polymer Cement Mortar, Journal of Jilin Institute Architectural & Civil, (9), 11-14.

[21] C H Chen, R Huang and J K Wu. (2006) Influence of Soaking and Polymerization Cond Itions on the Properties of Polymer Concrete, Construction and Building Materials, 20, 706-712.

[22] Fiebfich M H. (2004) Scientific Aspects of Adhesion Phenomena in the Interface Mineral Substrate-polymer Adherence of Young on Old Concrete, (3), 369-372.

[23] Bilen J, Salet T. (2009) Adherence of Young Concrete to Old Concrete-development of Tools for Engineering, Adherence of Young on Old Concrete, (3), 365-368.

[24] J P Gao, J S Huo. (2000) The Reason of the Bond Face Being the Weakness of the Stressing Concrete of the Existing and Green Concrete, and Exploration of the Strengthening Measures, Concrete, (2), 16-20.

[25] Monteiro P J, Maso J C. (1985) The Aggregate-mortar Interface, Cement and Concrete Research, (15) 953-958.

[26] Zampini D, Shan S P. (1998) Early Age Microstructure of the Paste and Aggregate Interface and its Evolution, Journal of Materials Research, 13(7), 1888-1898.

[27] Rooij D. (2000) Syneresis in Cement Paste System, Delft: Delft University Press, 83.

[28] P M Wang, C Y Chen, G F Zhang. (2014) Influences of 0—20°C Curing System on Tensile Bonding Strength of Polymer Modified Cement Mortar, Journal of Build Materials, 17(3), 446-449.

[29] N Yang. (2014) Research on Bonding Properties of Magnesium Phosphate Cement Based Materials, Changsha: Hunan University.

[30] Taylor H, Famy C, Scrivener K L. (2001) Delayed Ettringite Formation, Cement and Concrete Research, 31 (5),683-693.

[31] Thomas M, Folliard K, Drimalas T, et al. (2008) Diagnosing Delayed Ettringite Formation in Concrete Structures, Cement and Concrete Research, (38), 841-847.

[32] Adamopoulou E, Pipilikaki P, Katsiotis M S. (2011) How Sulfates and Increased Temperature Affect Delayed Ettringite Formation in White Cement Mortars, Construction and Building Materials, 25, 3583-3590.