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Review On Repairing of Cracks Using Grouting Method by Resin-Based Grout

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Abstract: Improving accessibility, mobility, and safety in developing nations like India requires the construction and upkeep of high-quality pavements. Small hairline cracks, half depth cracks, and large full-depth cracks in concrete pavements are all examined in this study, along with their sources and effects on structural integrity. With advantages including quick application, less lane closures, and increased durability, we stress the efficiency of epoxy resin and hardener as a grouting method for repairs. The goal of this study is to contribute to the longevity of roads and road user safety by examining crack behaviour and applying suitable restoration techniques. The results show that proactive crack treatment and cutting-edge materials like epoxy resin can greatly improve concrete pavement performance and lifetime.

Keywords: Concrete Pavements, Crack Repair, Epoxy Resin, Pavement Longevity

1. INTRODUCTION

Constructing and enhancing high-quality pavements is crucial in a developing country like India. The pavement structure should be able to offer a surface with low noise pollution, attractive light reflecting qualities, sufficient skid resistance, and high riding quality. A rigid pavement tends to disperse the load over a comparatively large sub-grade area due to its rigidity and high tensile strength, while the slab itself provides the majority of the structural capacity. A slab of cement concrete makes up the rigid pavement construction. Rigid pavements can be built over comparatively weak subgrade and are utilized for heavier loads [1]. By enhancing the many facets of road infrastructure, including accessibility, mobility and safety, pavements play a diverse role in social development. The pavements must be built to last a long time, just as other engineered constructions. An essential component of promoting economic growth is a functional road system. Because of their strength, longevity, and ability to support large loads, concrete pavements are an invaluable part of the country's road system. The pavement's primary purpose is to provide a smooth and efficient ride while successfully withstanding environmental factors and imposed traffic loads during severe weather. But the structural integrity of concrete pavements can be significantly impacted by the high traffic volumes, local climate, and temperature fluctuations. One common impact in concrete that cannot be avoided is cracking. The cracks may range from major-full depth cracks that may extend through the thickness of pavement, to partial depth cracks that affect the surface area and even minor hairline cracks. The strength, stiffness, and longevity of the concrete pavement are significantly reduced when cracks widen beyond what is permitted by the rules of practice, necessitating their repair. Therefore, restoration is necessary to prolong the pavement's service life, guarantee safe driving, and stop the pavement system from deteriorating [2].

To preserve structural integrity, there are various materials and techniques available. For high-traffic highways in particular, repairing concrete pavement with cast-in-place concrete can be difficult because it usually takes several days of lane closures before the repaired pavement is available for traffic. Road users experience interruptions and annoyances when lanes are closed for extended periods of time on heavily travelled highways. This is because fewer lanes mean slower traffic flow, longer travel times, and higher traffic congestion, which is especially noticeable during peak hours. To reduce the impact on commuters and ease traffic congestion, temporary detours or other routes might need to be put in place. It is crucial to understand that these methods can be costly and time-consuming [3]. So, it is very important to study, which technique is best for repairing concrete pavements to reduce the amount of time that lanes must be closed, avoid traffic jams, and produce long-lasting, sturdy pavements. One such technique is the use of resin-based grout i.e., epoxy resin and hardener while using grouting method as an effective repair solution to repair the cracks ranging from major full depth cracks to partial depth cracks. The ultimate goal of this study is to contribute to the longevity of the pavement and enhance safety for all road users, making the roads more reliable over time.

1.1 Types of Cracks in Concrete

Small Hairline Cracks: When concrete is originally placed, tiny hair cracks; also known as hairline fractures, are frequently seen. Plastic shrinkage is the main cause of these superficial cracks, which are normally 0.08 mm wide. Plastic shrinkage occurs, when moisture swiftly evaporates from the freshly poured surface of concrete before it has had time to fully cure [4]. The pace at which moisture evaporates from the concrete surface can be accelerated by elements including high temperatures, low humidity, and wind speed. Unexpected temperature variations in the air or concrete can cause stress in the material, which can lead to the production of cracks on the pavement. Even while hairline fractures might seem little, they might be an indication of more serious problems that could develop if ignored. Preventing moisture intrusion and additional degradation can be achieved through routine monitoring and prompt repair actions.

Partial Depth Cracks: Cracks of partial depth ranging from 10-13 mm in depth & 0.3-0.5 mm in width, pierce the surface of the concrete pavement but do not reach the bottom. The movement of the structure, shrinkage, or thermal expansion and contraction are frequently the causes of these cracks [5]. These cracks usually reach a depth of few inches, although they are sufficiently shallow to not jeopardize the overall thickness of pavement. These kinds of cracks can be caused by a number of variables, including shrinkage, temperature changes, and the weight of large trucks. In order to preserve the structural of pavement integrity, medium-depth cracks must be repaired. The danger that medium-depth cracks will develop into full-depth cracks, which can result in more extensive damage and expensive repairs, is reduced by routine inspections and timely repairs.

Major-full Depth Cracks: The structural integrity of the pavement is seriously jeopardized by full-depth cracks that run from the surface of the pavement to its base. The depth of full depth cracks may range from 20-25 mm and the width ranges from 8-10 mm. Inadequate subgrade support, excessive traffic loads, and structural settlement are some of the common causes of these cracks. Pothole formation and hazardous driving conditions are just two of the major problems that can result from ignoring full-depth cracks [5]. More severe steps are typically required to repair full-depth cracks, such as removing the damaged concrete part and replacing it with new material and installing cutting-edge sealants to stop moisture ingress and further deterioration of the surrounding region. To find full-depth cracks early, concrete pavements must undergo routine examinations.

1.2 Grouting

Grouting is the process of adding material to cracks or fractures in concrete, rock, and masonry buildings to strengthen their ability to support loads. The substance used to accomplish this is grout. Grout is a mixture of cement, sand, water, or chemicals. It fills in tile gaps, stabilizes soil, fixes concrete cracks, and seals joints and gaps for waterproofing. Additionally, grouting is done to strengthen the ability of pavement to support weight [6-8]. Chemical grouting employs two or more chemicals (e.g., epoxy resin + hardener) to produce a gel, solid precipitate, or foam, as opposed to cement mortars, which are composed of suspensions of solid particles in a liquid. Concrete cracks between ranging from major depth to full depth will be sealed using epoxy resin. Chemical grout has several benefits, including as its ability to be used in humid environments, its wide gel time control range, and its ability to accommodate very tiny fractures.

1.3 Epoxy resin

One of the most adaptable types of thermosetting polymers, epoxy resins were first produced commercially in 1947. Epoxy groups can create a three-dimensional, densely crosslinked network by reacting with high molecular polymers that are catalytically produced or with appropriate curing agents. The cured resins are still referred to as "epoxy resins" even though all of the reactive epoxy groups have all but reacted [9]. The usefulness of epoxy resins is determined by the quantity of epoxy groups and other chemical groups present in each molecule. Epoxy resins' exceptional qualities include robustness and longevity, minimal cure shrinkage, adherence, compatibility with a wide range of substances, Insulation for electrical systems and Resistance to corrosion and chemicals [10]. Epoxy resins and its derivatives are used extensively in a variety of fields because of their exceptional qualities, which are created by various formulas using certain curing agents. More and more epoxy materials, such as epoxy concrete, epoxy asphalt, and epoxy emulsified asphalt, have been used in the pavement industry since epoxy resin was initially used in the pavement on the steel bridge deck [11].

The most used substance for fixing cracks in concrete structures is epoxy. With their exceptional adhesive properties, epoxy resins can adhere to almost any building material, but especially to concrete. Given the variety of physical and chemical characteristics of epoxy resin systems, they must be taken into account in each scenario involving concrete repair, overlay, coating, or un favorable environmental conditions. It is suitable for fixing concrete cracks because of its increased tensile strength, reduced shrinkage, and quick hardening properties. The ACI Committee 503 has established repair standards for concrete in the US. Furthermore, a lot of work has lately been done on European Standard EN 1504 for concrete structure protection and restoration [12]. The most often used recommendations for fixing concrete cracks are these standards.

Epoxy Application in Concrete Repair

However, numerous studies have been conducted to examine the performance of broken concrete following epoxy resin restoration. Hindo looked into how to repair broken concrete's strength under different concrete surface circumstances. However, based on this research, actual fracture surface restoration is more like the real case than those previously indicated. French repaired concrete cracks using two epoxy repair methods: vacuum impregnation and low-pressure injection. Both methods were successful in regaining the specimens' strength, stiffness, energy-dissipation capacity, and bond. A specimen cored from broken concrete that had been epoxy-repaired was put through a strength test. Epoxy repair on a variety of concrete face types, including smooth, wire-brushed, needle-punched, and hand-crushed surfaces, was compared by Abn-tair et al. It was determined that when epoxy is used to repair concrete surfaces, hand-crushed surfaces adhere the best, followed by needle-punched, wire-brushed, and smooth surfaces.

In order to ascertain the bond strength, Kan et al. documented the restoration effectiveness of epoxy-repaired concrete beams on actual cracked concrete faces. When used to fix concrete with flexural fractures, both epoxy mortars were more effective at restoring the damaged area than when used to fix shearing cracks. The fracture behaviour of the reconstructed concrete, however, has not been the subject of many published studies.

Based on high-strength epoxy resins, Issa C. A. used Sikadur-52, a two-component, solvent-free liquid with a low viscosity. It conforms to Grade 1 Class B + C of ASTM C 881-78 Type I. Bridges, industrial structures, columns, beams, foundations, walls, floor slabs, and water-retaining structures are among the structural elements that can have cavities and fractures filled and sealed with Sikadur-52. It not only creates a strong barrier that prevents water from penetrating and causing corrosion, but it also binds the concrete portions together structurally.
It offers the following benefits;
Free of solvents.
It works well in both dry and wet environments.
Suitable for low temperatures.
There are two classifications (normal and long pot life) for various climates.
Hardening without shrinkage.
Strong adhesive and mechanical properties.
Not brittle, but hard.
Extremely low viscosity.
Table 1.1 displays the attributes of the epoxy adhesive. The evolution over time in compressive, tensile, and shear strengths of the epoxy, Sikadur-52 is shown in Figs. 1.1-1.3.

Table 1.1 Attributes of Epoxy Resin

Characteristics	Guide Values
Pot life (2 kg) 5ºC 10ºC 20ºC 30ºC 40ºC	Long pot life type - - 60 min 30 min 15 min
Viscosity 10ºC 20ºC 30ºC	 - 29 cPa s 13 cPa s
Compressive strength (at 20ºC) after 10 days	53 N/mm^2
Flexural strength (at 20ºC) after 10 days	50 N/mm^2
Tensile strength (at 20ºC) after 10 days	25 N/mm^2
Bond strength to concrete (at 20ºC) after 10 days	4 N/mm^2 (concrete fail)
Shear strength (at 20ºC)	15-20 N/mm^2
Modulus of elasticity (static)	1060 N/mm^2
Coefficient of thermal expansion (from 20 to +60ºC)	89 x 10^6 per ºC
Heat deflection temperature	50-70ºC

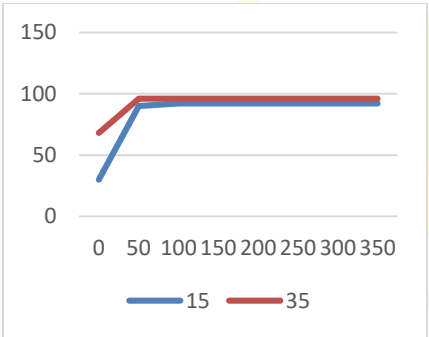

Fig. 1.1 Development of compressive strength of Sikadur-52 [13]

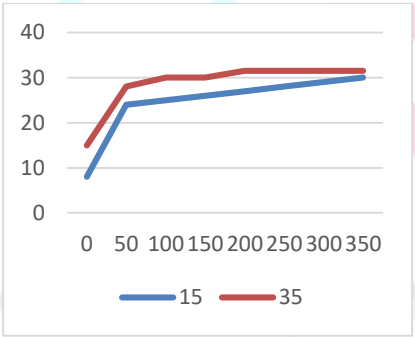

Fig. 1.2 Development of tensile strength of Sikadur-52 [13]

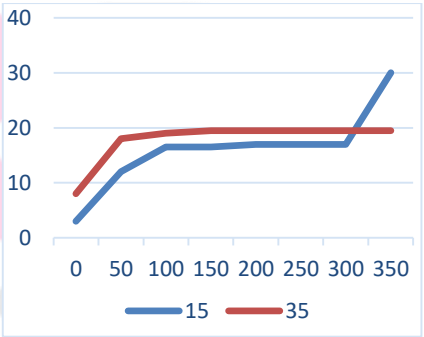

Fig. 1.3 Development of shear strength of Sikadur-52 [13]

2. LITERATURE REVIEW

Effective repair of concrete structures requires determining the root causes of cracks, and the selection of restoration methods should take into account whether the cracks are active or dormant. To reduce fracture formation, a variety of techniques are advised, including visual inspection, ultrasonic testing, and epoxy injection for small cracks. Preventive building techniques are also advised. Furthermore, Tetteh A. R., Liang Y. (2020), investigated in their study that the use of pre-stressing steel in bridge girders and stitching for large fractures can improve structural integrity, and photographic inspection helps assess material-related cracking

causes. Because structural cracking is frequent, engineers must look into its origins in order to make successful repairs. This entails examining the features of the cracks and gathering pertinent construction data. Determining preventative and treatment strategies requires knowing whether the cracks are structural or non-structural, as well as the factors that led to their formation. The study of Sreenivasulu A., Sairam V., Anjaneya Babu P.S.S. (2020), looks at different kinds of cracks, their causes in reinforced concrete structures, and the available treatment techniques and preventive measures. According to the study Xiao Zhang, Kaixiang Liu, Jiacheng Zhang, Jiahang Hao, Shujie Han, Xiaolong Wang, Yijun Peng (2024), uniform fracture spacing can be achieved by varying the length of partial continuous reinforcement and using active crack management techniques, which improves the early performance of partial continuous reinforced concrete pavements (PCRCP). Temperature changes were found to have an inverse relationship with crack width movements, with the least crack widths produced by the ideal reinforcing length of 1.4 m. Furthermore, a novel crack width prediction model was created, which outperformed previous models in PCRCP design and showed good agreement with field data. Concrete cracking weakens the structure; longer fractures result in higher stress concentrations and possible failure; D1 cracks weaken the structure by 40.93%, while D2 cracks weaken it by 32.71%. Epoxy is frequently used in repair because it greatly improves strength loss, lowering it to 8.23% for D2 cracks and 11.25% for D1 cracks. Effective bonding, however, requires careful surface preparation, and for serious damage, extra techniques like reinforcing could be required [13]. By making sure site staff are aware of the building phases, problems like uncontrolled full-depth cracks and plastic shrinkage fissures that have been encountered in recent concrete road projects can be avoided. Full-depth repairs are frequently required when cracks larger than 1.5 mm are discovered close to joints. Techniques such as cross-bar stitching and staple pins can assist stop the propagation of cracks by letting the slab "hinge." Maintaining appropriate subgrade thickness and compaction requirements is also essential. Any PQC cracks should be sealed right away to stop additional damage, and if necessary, complete repairs should be handled later. Qian Xiang, Feipeng Xiao, (2020) have proved in their study that, because of its superior mechanical qualities, chemical resistance, and thermal stability, epoxy resin is frequently used in concrete and is perfect for bonding and repairing pavement. Durability against a range of environmental pressures is improved by its capacity to self-repair when cured with calcium hydroxide. However, issues including low-temperature brittleness, the requirement for bio-based substitutes, and recovery and regeneration techniques continue to be crucial research topics. In order to decrease cohesion and adhesion failures in epoxy resin, this study successfully incorporated a toughening agent and diluent into SCECS, an optimized asphalt pavement grouting material.

The results from the study conducted by Yun-feng Fang, Biao Ma, Kun Wei, Lin Wang, Xing-xiang Kang, Xiang-guo Chang (2021), shows the viscosity, tensile bond strength, and elongation at failure are all strongly impacted by stirring duration, toughening agent dosage, and water intake, according to an orthogonal experiment that determined the main elements influencing the material's performance. 40% toughening agent, 15% diluent, 20% PCA, and 30% water, at 60°C, with a 5-minute stirring period and 600 r/min speed, was found to be the ideal formulation. In order to demonstrate how epoxy strengthens deficiencies such low fracture resistance and brittleness, Yu-Cheng Kan, Ming-Gin Lee, Hung-Wei Lee, (2021), used Mode I fracture testing to analyse the fracture behaviour of concrete repaired using epoxy resin or mortar. Compared to the original concrete, epoxy resin repair of a 1-mm-wide crack with low-pressure injection greatly increases fracture toughness and energy by 122% and 228%, respectively. Three different crack routes were noted: cohesive fractures in the concrete, interface fractures, and fractures through both concrete and epoxy mortar. The addition of sand to the epoxy changes the failure mode and improves the fracture parameters. Yun-feng Fang, Biao Ma, Kun Wei, Xiao-qing Wang, Xing-xiang Kang, Fang-shu Liu, (2021) used encapsulated accelerator capsules, this study created a one-component epoxy resin grouting material (OEPM) and showed that it is stable at temperatures below 35°C for more than 60 days. While a 3% dosage of the accelerator increased tensile strength and toughness at low temperatures, achieving over 100% elongation at break at -20°C, the curing behavior showed that the encapsulated accelerator did not appreciably increase the activation energy. Furthermore, in hot weather, all OEPM versions successfully resisted foreign body penetration and demonstrated great resilience at increased temperatures. The recycling of epoxy resin waste liquid produced by electrophoretic deposition repair was examined in this work, along with the impact of amination rate and neutralization degree on the efficacy of cationic epoxy resin repair. Higher amination and neutralization rates were shown to improve compactness and enhance the mass and thickness of the epoxy coating; however, excessive levels had a detrimental effect on waterproof performance. Furthermore, the study found that increased amination and neutralization rates speed up the deposition rate of the resin and curing agents, enhancing overall specimen quality, and that the water absorption of the cured epoxy coating has a substantial impact on waterproofing.

3. CONCLUSION

This study emphasizes how crucial it is to find and fix concrete pavement cracks in order to preserve both structural integrity and user safety. Road users will experience fewer disruptions if epoxy resin-based grouting techniques are used to maximize durability and minimize repair times. We can guarantee that pavements not only satisfy short-term performance requirements but also maintain their dependability over time by putting proactive monitoring and efficient repair techniques into place. This strategy supports a robust and effective road infrastructure that can handle growing traffic demands and environmental issues, which greatly aids in achieving larger goals for economic growth and development. The superior pavement restoration methods will promote safer and more effective transit networks.

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