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## METHODS AND SURFACE MATERIALS REPAIR FOR CONCRETE STRUCTURES – A REVIEW

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## 1. INTRODUCTION

Nowadays, concrete is considered to be the most used building material all over the whole world. This is due to a variety of reasons including the wide availability of concrete raw materials, low relative cost compared with other construction materials and the unique properties of concrete such as, the ability to be formed in many different shapes and its good mechanical and durability properties if proper curing is employed. However, one of the biggest and most significant problems facing the concrete structures is the occurrence of cracks (Cusson, 2009; Alexander et al., 2008). Concrete structures should be inspected periodically, with a possible repair if required, in order to avoid the propagation of cracks that may lead to structural problems and results in the failure of the structure or building (Dehn et al., 2015). These cracks may occur due to several problems ranging from inadequate design details, rebar corrosion, fatigue, chemical attack, settlements, etc... (Recommendation, 1994). Also, one of the most hazardous issues leading to the existing of cracks is the natural disasters such as earthquakes (Ma et al., 2017; Nandakumar, 2020). The presence of cracks is not always risky and adequate repair strategy can be implemented to rehabilitate the structure. In order to ensure the safety of structures and buildings, early inspection is necessary for early detection of cracks (Kannan et al., 2022; Verma et al., 2022). Despite the fact that cracks cannot be prevented completely, they can be controlled with appropriate repair techniques and materials (Yanez, 2018; Delatte, 2009; Silva et al., 2017). A good repair will avoid the risks and improves the function of the concrete structure and its performance. However, the main parameters that should be considered and studied when examining the cracks. These include the dimensions of the cracks, location and the environment surrounding the cracks. Also, the selection of the material used to repair certain crack is of high importance since each material have its unique properties and can be used in specific locations only. In addition, in recent years, concrete mixes contain cement replacement materials (ElKhatib et al. 2021, Khatib et al., 2021; Katman et al., 2022; Laidani et al., 2022; ElKhatib et al., 2022; Khatib et al., 2020;) and recycled materials (Bawab et al., 2021; Ramakrishnan et al., 2021; El Bast et al., 2021; Bawab et al., 2021; Ghanem et al., 2023). This may affect the presence of cracks and the repair strategy.

## 2. CRACKS

### 2.1 Causes of Concrete Cracks

Concrete cracks and defects have many causes. These cracks can appear due to mechanical, physical and chemical factors. They can affect only the appearance of structures and buildings or can reveal serious problems regarding the structural distress or lack of durability. They can indicate problems with large danger and may lead to a huge damage. The most common and known crack causes are listed in Table 1 (Guo et al., 2020; Verma et al., 2022; Nandakumar, 2020; Ghaffary and Moustafa, 2020; de Almeida, 2016; Jumaat et al., 2006; Lukovic et al., 2012; Issa and Debs, 2007, Larosche, 2009, Dermawan et al., 2019; Zhou and Wang, 2019; Sahafnia, 2018; MANASA, 1956):

**Table 1: Causes of Concrete Defects and Cracks (Lukovic et al., 2012)**

CONCRETE			
Mechanical	Chemical	Physical	Thermal
Abrasion	Alkali-aggregate reaction	Freeze/thaw cycles	Fire
Fatigue	Aggressive agents	Thermal effects	Explosion
Impact	Biological action	Salt Crystallization	
Overload		Shrinkage	
Movement		Erosion	
Explosion		Wear	
Vibration		Crazing	

REINFORCEMENT CORROSION		
Carbonation	Corrosive contaminants	Stray Currents
Cement type and w/c ratio	Chloride salts	
Humidity and temperature	Sea water, road salt, other contaminants	
Curing		
Rainfall		

## 2.2 Types of Concrete Cracks

Cracks can occur either before hardening of concrete or after. Fig. 1 shows the different types of cracks and their properties.

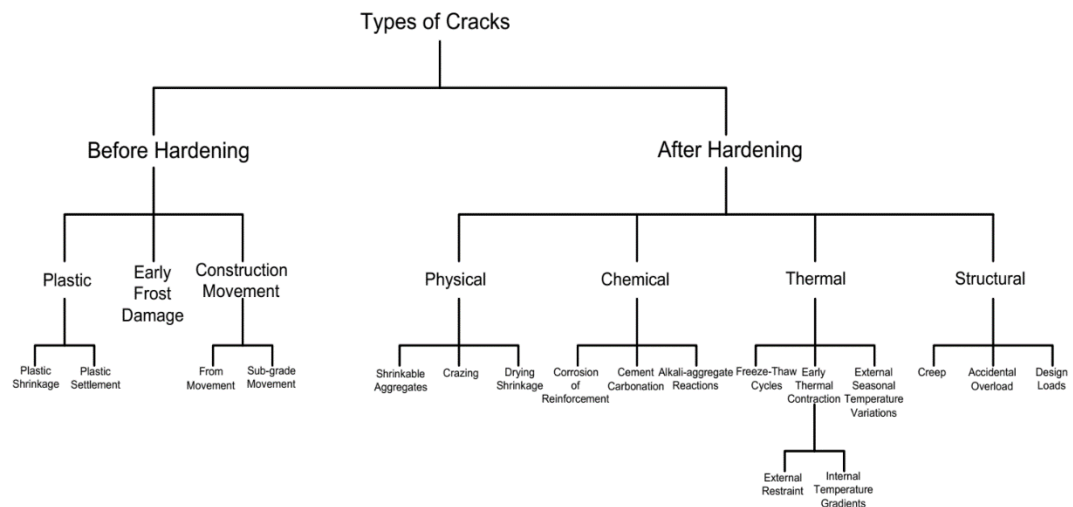


Fig. 1: Types of Cracks (Nordström et al., 2019)

The main types of cracks threatening the strength and durability of concrete are due to:

- a- **Curing Shrinkage:** This is also known as plastic shrinkage and shown in Fig. 2. After the process of concrete casting, and especially in hot weather concreting, the water starts to evaporate early in fresh concrete causing it to shrink leading to the formation and propagation of cracks. It usually occurs within the first thirty minutes after casting when concrete is still in the plastic stage.



Fig.2: Plastic Shrinkage (Ghourchian et al., 2017)

- b- Plastic Settlement: The cracks occur due to the migration of water to the exterior surface of concrete causing its volume to decrease and then settlement of fresh concrete occurs as shown in Fig. 3.

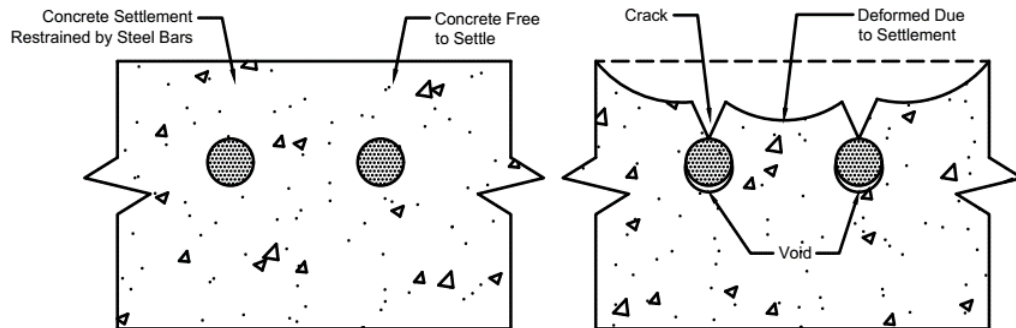


Fig.3: Plastic Settlement (Kayondo et al., 2019)

- c- Support Settlement: If the displacement of a support recorded higher value than the one in the design process as shown in Fig. 4, cracks will occur in the structure after deformation of elements.

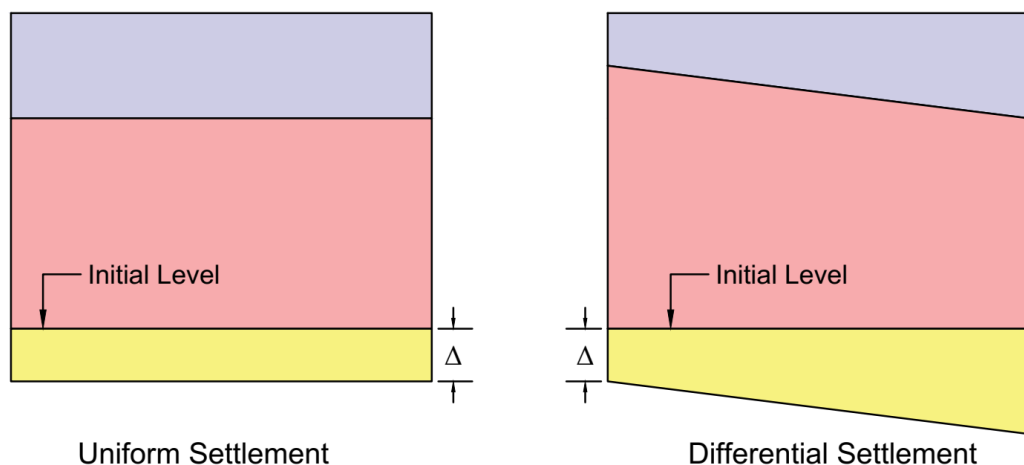


Fig.4: Support Settlement (MANASA, 1956)

- d- Temperature Change/Weathering: While mixing concrete, its temperature records very high values. When casting in a very hot or cold temperature, the difference in the temperature between the concrete and its surrounding environment causes the propagation of cracks. As the temperature increases in hot weather and decreases in cold weather, the concrete expands and cracks are formed.
- e- Creep: Cracks occurring due to creep can be caused by the simplification that many do in the design process by taking the short/intermediate and long-term deflections as an equal value without taking into consideration the time and age of concrete. It also occurs due to subjecting the element to a constant load over time increasing the deformation and causing cracks.
- f- Handling Practices: Cracks may occur due to mistakes while mixing the concrete and transporting it from the factory to the site. The size of aggregates, type of cement, the water to binder ratio may be considered as most critical issues that cause cracks. The time needed for the concrete to be transported should be taken into consideration in order to avoid the process of adding water to the mix which causes cracks to concrete structures due to the excess in water. The use of vibrators could be beneficial to avoid excess in pores in the concrete member that leads to the formation of cracks. After casting the concrete, water should be poured on its surface to avoid rapid evaporation of

water that leads to crack propagation. Also, incorrect placement of steel bars, insufficient concrete cover, incorrect construction joints, high water content, segregation, bleeding, poor compaction, etc all could be main reasons for the formation of cracks in structures and buildings.

- g- Corrosion: When steel bars rust due to the climate and environment surrounding the structure, a thin layer of the bar will be lost leading to the formation of cracks after the deterioration of concrete covering it as shown in Fig. 5.



Fig.5: Corrosion of Steel Bars (Hulimka et al., 2020)

- h- Carbonation: After carbon dioxide reacts with calcium hydroxide that is found in concrete, calcium carbonate is formed. The penetration of calcium carbonate into concrete structures through hairline cracks, honeycombs and many others will increase the deterioration of concrete leading to a large crack width.
- i- Chlorides: Chlorides can be created due to a wrong admixture used or due to the use of contaminated water in the mix. Chloride will attack the steel bars forcing them to corrode and causing cracks in the concrete.
- j- Tension Stresses: placing concrete on a poorly compacted surface or ground may cause additional in the tension stresses that was not taken into account in the design process causing the concrete to crack.
- k- Under Design: Wrong design due to errors in designing calculations or reinforcement detailing maybe one of the most critical problems causing the structure to crack and even to collapse. Poor designed structures will reflect on the performance of concrete developing cracks and causing dangers as illustrated in Fig. 6.

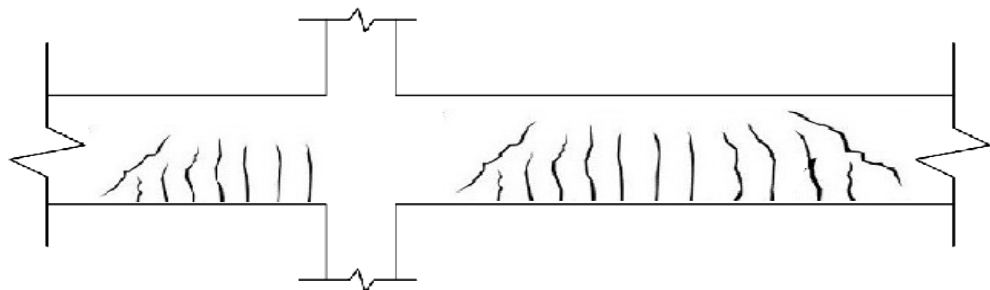


Fig.6: Under Design Cracks (Eom et al., 2015)

- l- Fatigue: Fatigue is caused by the process of repetitive loading on a structure, mainly found in bridges and parking. While designing, if fatigue was not taken into consideration, cracks will be formed as hairlines in the first stages and then propagate and elongate to form large cracks.
- m- Unforeseen Accident: Cracks can form due to accidents such as explosion or fire. Any structure subjected to fire or explosion will show cracks on its different structural members.

Cracks also can be classified into 3 different main categories (Winterbottom and Goodwin, 2005; de Almeida, 2016):

- Active Cracks: They are cracks that change in length and width with time variation.
- Passive or Dead Cracks: They are cracks that are stabilized and do not change as time passes when its cause disappear and is not available anymore.
- Dormant Cracks: They are passive cracks that become active after the repairing process was done.

### 3. SURFACE PREPARATION

Surface preparation for concrete cracked elements is an essential step that should be done in order to get a proper bond between the concrete and the repairing materials. There are some typical steps and methods that should be applied before repairing cracks for the surface of cracked concrete element (Bissonnette et al., 2012; Courard et al., 2018).

- 1- Measuring Cracks: In order to decide what method of repair should be applied for the cracked part, the length and the width of the crack should be examined and measured as shown in Fig. 7 (Saliah et al., 2021).

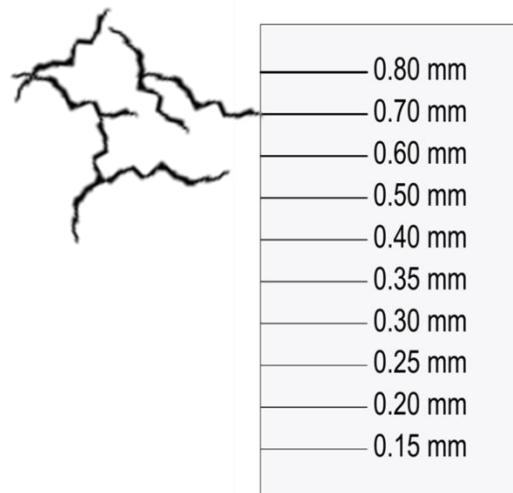


Fig.7: Crack Inspection (Bissonnette et al., 2012)

- 2- Cleaning the Crack Surface: Various methods could be applied to clean the cracks depending on the situation and shape of crack.
  - a- Sandblasting: Sandblasting is considered as the most commonly used method for cleaning the surface of cracks and reinforcing steel. The materials used in process of cleaning are sand, silica, metallic sand or slag.
  - b- Shot-blasting: Shot blasting is the process of cleaning concrete surface by projecting metal shot at a very high velocity removing finite amounts of concrete.
  - c- Water-blasting: Water blasting is the process of spraying water at pressures between 35 – 105 MPa. It is suitable and can be used for vertical and horizontal surface cleaning.
  - d- Water-blasting with Abrasive: it is the process of cleaning the surface by a stream water at high pressures with the presence of abrasive materials such as aluminum oxide or garnet. This technique is very beneficial in removing dirt and other foreign particles.
- 3- Choosing the Appropriate Method and Material for Repair: There are different methods and materials used for repairing cracks in concrete structures. Selection should be based on the dimensions, environment, and place of cracked section.

#### 4. METHODS FOR CRACK REPAIR

There are various methods used for repairing concrete structures. The selection of repair method should be based on several aspects such as the environment available, time, money, dimensions of cracks, etc in order to get the appropriate repair method that will be the most effective, long lasting, less timing and money saving method (Czarnecki et al., 2020). However, the most important and effective factor that should be taken into consideration while selecting the methods is the type of crack. Fig. 8 and 9 describes the path that must be drawn in order to select the appropriate method for repairing concrete structures based on the type of crack available.

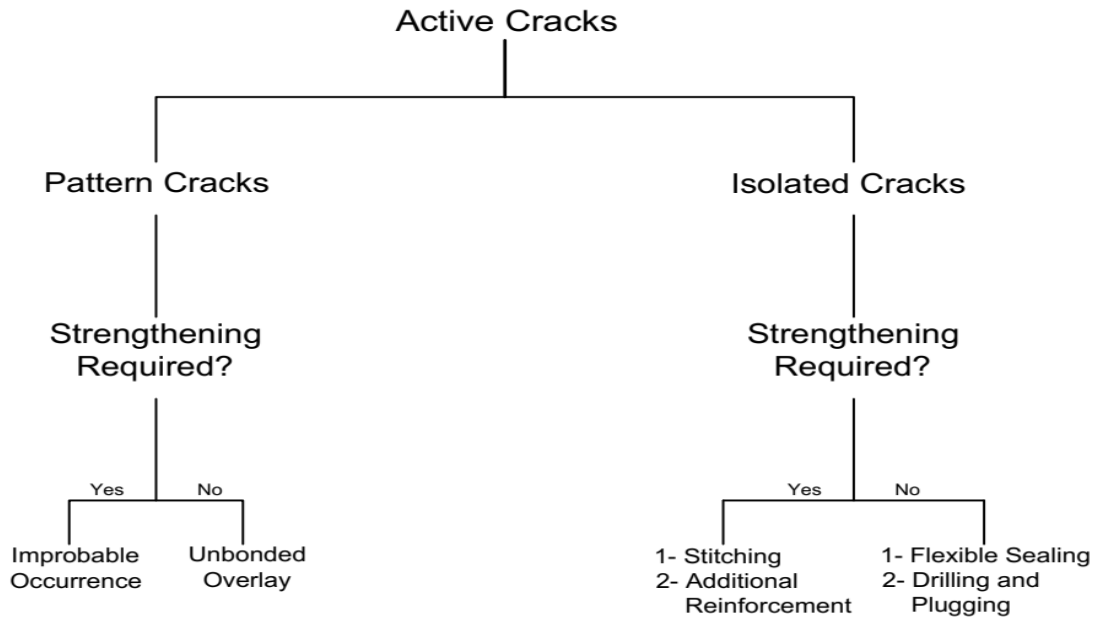


Fig. 8: Selection of Repairing Methods in Case of Active Cracks (Issa, 2009)

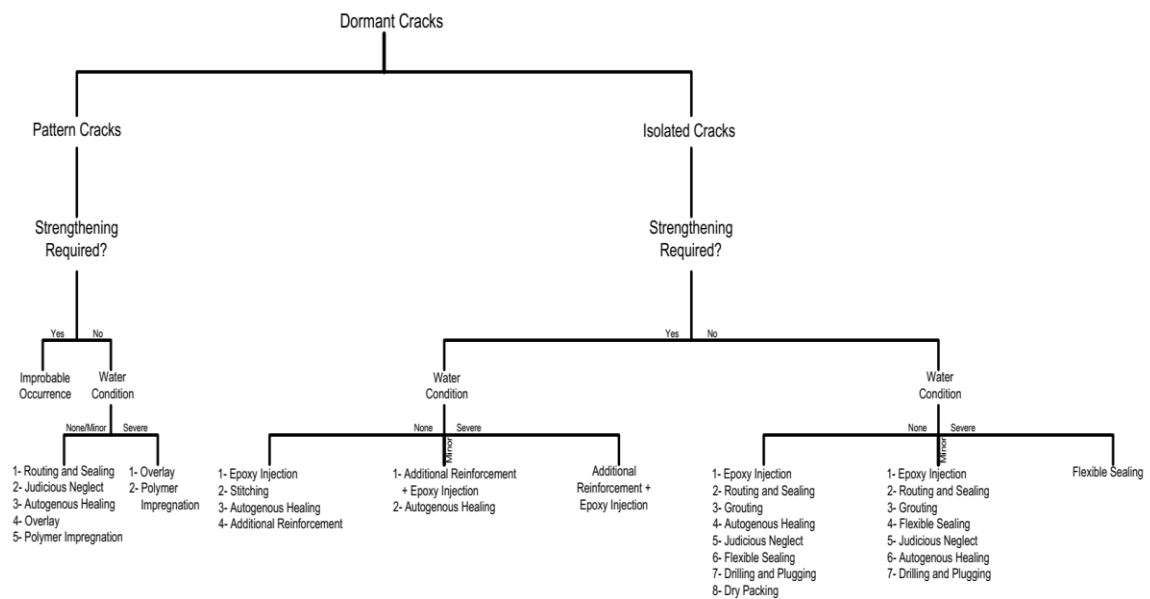


Fig. 9: Selection of Repairing Methods in Case of Dormant Cracks (Issa, 2009)



#### 4.1 Concrete Crack Repair Through Epoxy Injection

The epoxy injection method is suitable to be used for cracks that are narrow with openings equal to 0.05 mm. For the crack widths that are so narrow, the epoxy should be with low viscosity in order to be able to flow through the hairline cracks and bond them. This method is applied by establishing entry and venting ports along the cracks at close intervals (Shao et al., 2020; Griffin et al., 2017). Then, the cracks will be sealed on the exposed surface and the epoxy will be injected under high pressure (Yeon et al., 2019; Doshi et al., 2018). However, this technique cannot be used for active cracks unless the cause of cracks is removed and the crack becomes dead. Also, this technique is not applicable to be used in wet environments and when cracks are leaking and cannot be controlled or dried out (Modesti et al., 2020). Several steps should be applied in a high degree of skill in order to get a successful crack repair by epoxy injection. The first step to be applied is to clean well the cracks from contaminants such as grease, oil, fine particles, dirt, etc since such materials blocks the epoxy penetration, decrease the bonding strength and lessen the effectiveness of the repair applied. Contamination can be removed by flushing or vacuuming the crack surface. The second step will be sealing the surface in order to prevent the leakage of the epoxy out before being gelled (Kan et al., 2021). The third step will be applying or installing the entry and venting ports that can be applied using three different ways or methods. The first way is established by inserting fittings into drilled holes. It can be applied in V-grooved sections by drilling a hole in the crack with a diameter of approximately 20 mm and 13 to 25 mm under the apex of the V grooved part. The other way is used when the cracks are not V-grooved. It is applied by providing an entry port to bond the fitting flush with the concrete crack surface. The last way can be used when special gasket devices are available where injection can be applied directly into the crack without leaking out through the crack. After applying one of these ways, the epoxy should be mixed and then injected to the crack. For vertical and inclined cracks, the epoxy injection process should begin by injecting epoxy through the entry port at the lowest point or elevation and then stay injecting until the level reaches the highest level of the entry port. Regarding the horizontal cracks, the process of injecting epoxy should start from one end to the other at the same manner, mainly from the wide side to the narrow one (Pattanaik et al., 2021). After the epoxy has been cured and hardened, the seal must be removed by grinding. All steps are illustrated in Fig. 10 (Nandakumar, 2020).

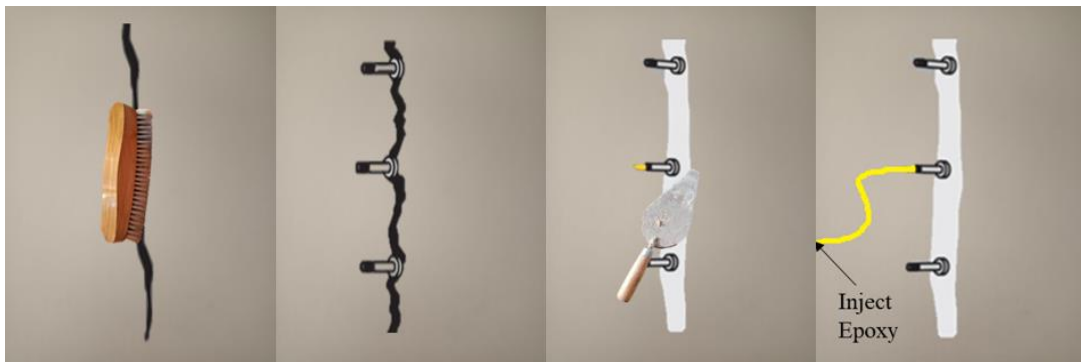


Fig.10: Epoxy Injection (Nandakumar, 2020)

#### 4.2 Routing and Sealing of Cracks

Routing and sealing of cracks is considered to be the most common and simplest method used for repairing concrete cracks (Venkateela et al., 2017). It can only be used where remedial repair is required and where structural repair is not obligatory. This technique requires the enlargement of cracks along the exposed face and then filling and sealing the cracks with an appropriate joint sealant (Mazumder, 2019). This technique is commonly used for surfaces that are flat and horizontal like floors and concrete pavements. However, it can also be used for vertical surface as well as curved and oblique ones with the help of non-sag sealant. Routing and sealing technique can be applied on both thin and large cracks. Also, this method can be very essential in places where water is present and can



play a significant role in blocking the path preventing water from reaching the steel reinforcing bars. There are several steps that should be applied while using this technique in repairing concrete cracks. The first step is to prepare a groove at the surface that ranges between 6 to 25 mm in depth. After preparing the groove, it should be cleaned well using any method of cleaning concrete surface such as blasting, sandblasting or water blasting. After the groove is cleaned and dried, a sealant is injected into the groove and cured. A bond breaker could be helpful in allowing the sealant to change in shape while filling the crack. Fig. 11 and 12 illustrates the routing and sealing concrete and the use of bond breaker to maintain the required shape for the repaired part (Issa, 2009).

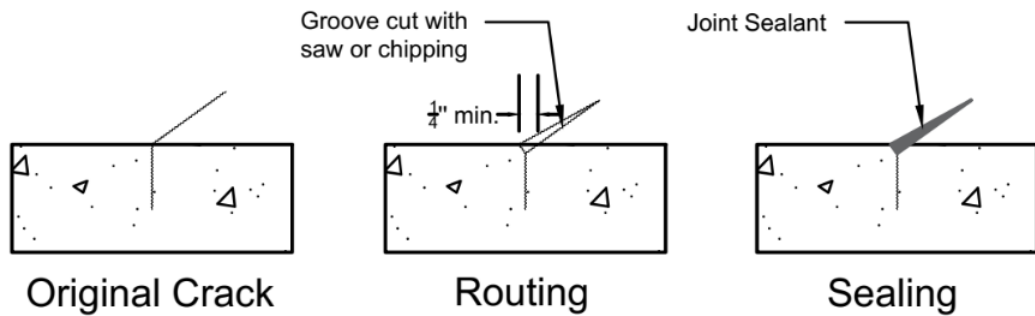


Fig.11: Routing and Sealing of Crack (Issa, 2009)

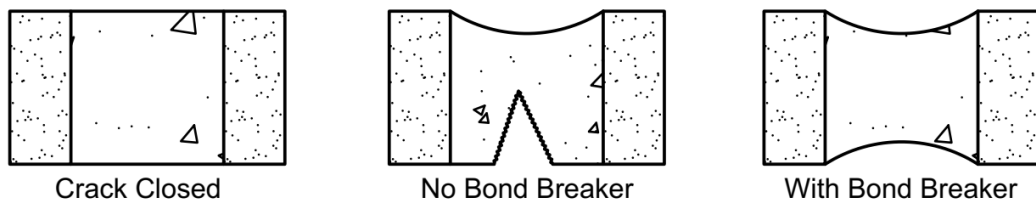


Fig.12: Bond Breaker Concrete Crack (Issa, 2009)

### 4.3 Concrete Crack Repair Using Stitching

Stitching method is known to be the easiest and long lasting technique used in the process of repairing concrete structures. This kind of repair includes the process of drilling holes on both sides of the cracked section (Aksoylu et al., 2022; Hamoush and Ahmad, 1997; Karvekar et al., 2021). Then, a metallic U-shaped bar or wire, with two small legs, is attached to the drilled holes, anchored in a strong way and grouted as shown in Fig. 13. Stitching method is commonly used when the tensile strength in a certain concrete element should be reestablished (Uddin et al., 2017). The U-shaped metallic bars should vary in length and orientation according to the width of the crack and its inclination (Hove et al., 2018; Ponnada et al., 2019). Also, diagonal stitching bars should be used in order to resist the shear along the crack. Another way of stitching is by applying post tension on two external strands inserted at a 45 degree in the cracked section as shown in Fig. 14 (Sabra et al., 2018). Two opposite holes were drilled in the concrete element and strands were inserted in an inclined way. Then, post tension is applied either on both ends of the strands or only at one edge and after that strands will be anchored. Fig. 15 illustrates the steps done for stitching a concrete member with post tension (Sabra et al., 2018).

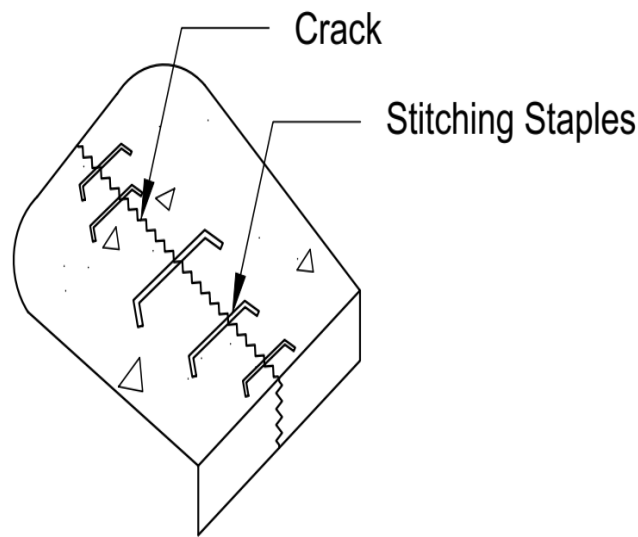


Fig.13: Stitching Concrete Crack (Issa, 2009)

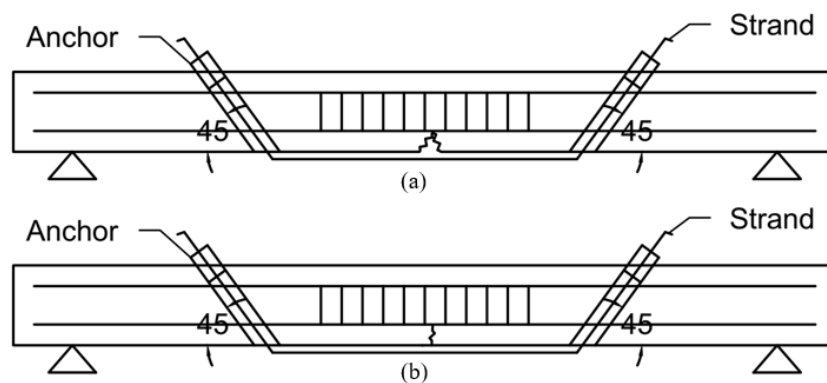


Fig.14: Section Layout (a) Before Prestressing, (b) After Prestressing (Sabra et al., 2018)

#### 4.4 Addition of Reinforcement

This technique can be applied using either conventional reinforcements or using prestressing steel bars. The selection between these two methods depend on the case, the crack properties and dimensions and the structural member that needs repair. Some critical cracked structural members need prestressing steel in order to withstand the loads and proceed in its role in the structural system (Woodson, 2009; Tadros et al., 2010; Issa, 2009).

a- Conventional Reinforcements: Many cracked reinforced concrete sections especially bridge girders were repaired using this method. It consists of inserting steel reinforcing bars in the girder and bonding them in the appropriate place with epoxy. However, first, the crack should be sealed, holes should be drilled in a way that intercepts the crack in around 90 degrees as shown in Fig. 15. Then, the holes and the cracks should be injected by epoxy and the steel reinforcing bars will be then placed in the drilled holes (Chen et al., 2018). The epoxy injected shall be of low viscosity in order to have the ability to flow and bond the steel bars into the cracked concrete in a strong way. Mainly the bars used in this method are of diameter 10 mm and 15 mm. The bars shall be extended for 0.5 m at least from each side of the crack. The space between the steel reinforcing bars shall be studied well in a way that suits the needs of the repaired crack.

b- Prestressing Steel: In severe cracked sections where strengthening is a need and the cracked part formed shall be closed completely, post-tensioning must be a very desirable and useful technique. In this technique, either prestressing strands or bars are used where a compressive force is applied. Care and adequate anchorage shall be applied for the prestressing steel bars or strands in order to have a successful repair and to avoid the migration of the crack into another part in the structure. Fig. 16 shows a side view for the cracked slab that needs prestressing to be repaired. However, Fig. 17 shows a three dimensional view that illustrates the anchorage and bolts used with the strand.

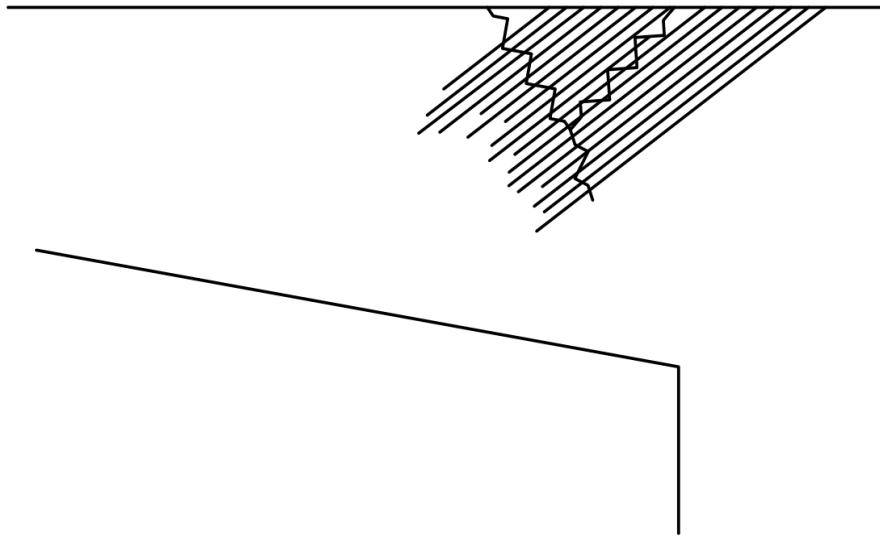


Fig.15: Conventional Reinforcement (Woodson, 2009)

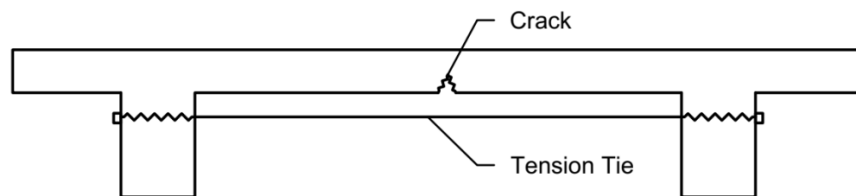


Fig.16: Side View of Prestressing Steel Repair Technique (Woodson, 2009)

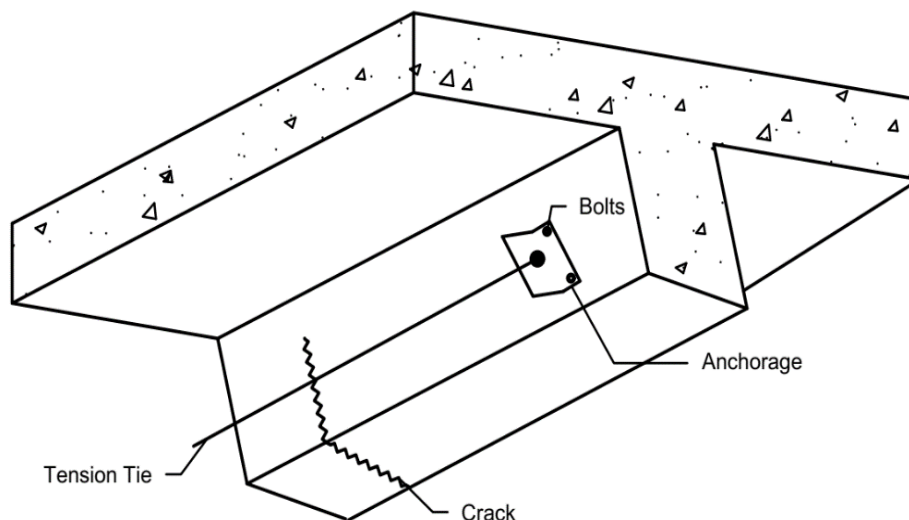


Fig.17: Three Dimensional View of Prestressing Steel Repair Method (Woodson, 2009)

#### 4.5 Drilling and Plugging

Drilling and plugging technique is applied by drilling the length of the available crack and then grouting it in a form of a key as mentioned in Fig. 18 (Issa, 2009). In order to be able to use this method, the cracks formed should be running approximately in straight lines and can be accessible from one end. Mainly, drilling and plugging method is most applicable and commonly used for vertical cracks in retaining walls. First of all, a hole with a diameter ranging between 50 mm and 75 mm should be drilled. This hole must be centered and follow the cracks. A main aspect that should be taken into consideration is that the hole drilled must be as large as needed to intersect the full length of the crack in order to provide enough material for repair and structurally support the loads exerted on the key inserted. After that, the drilled hole shall be cleaned well, tightened and filled properly with the grout.

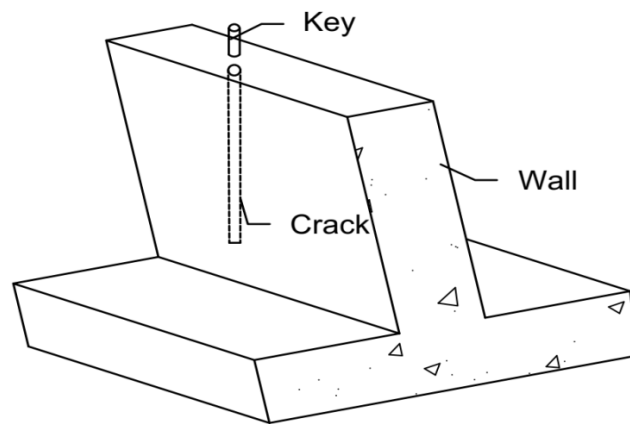


Fig.18: Drilling and Plugging Repair Method (Issa, 2009)

#### 4.6 Gravity Filling

This technique can be only applied when the cracks formed are of sizes ranging between 0.03 mm to 2 mm (Nama et al., 2015). Cracks will be sealed by the use of low viscosity resins or monomers (Joshi et al., 2017; Teixeira et al., 2019). As the viscosity of these materials is low, very fine cracks can be filled and repaired. The main steps that should be done to apply gravity filling method is first to clean the surface either by air blasting or by water blasting. However, if there is a wet surface, it should be dried in order to be able to apply this method and get the best crack binding. Then monomers and resins can be applied and all cracks can be filled (Sprinkel, 2018).

#### 4.7 Grouting

This method can be done either using Portland cement grout or using chemical grouting (Archibong et al., 2020). Regarding the Portland cement grouting, it can be very efficient in wide cracks such as in dams and thick concrete walls (Li et al., 2021; DA SILVA, 2019). Also, this method has a high efficiency in blocking the water leakage, however, it cannot be used to bond cracked sections structurally. The procedure starts by cleaning the concrete surface along the whole crack. Then, built up seats are installed at intervals to provide an adequate pressure tight connection. The crack shall be sealed between the seats using cement paint, sealant or grout. Then the crack is flushed, cleaned, and the whole area is then grouted. Grout can be as a paste with only cement and water or as a mortar with cement, sand and water depending on the width of the crack in the structural member. As for the water to cement ratio, it shall be as low as possible in order to get large strength with less shrinkage. The use of water reducers and admixtures could be a great idea to improve the properties of the chosen grout. After filling the crack, pressure shall be maintained to get good penetration. Concerning the chemical grouting method, it can be applied on narrow cracks with size of 0.05 mm. it consists of two or more chemical solutions that shall be combined together in order to get a gel or a foam. Some of the advantages of this technique is that it can be applied in very fine cracks, its applicability in

moist environments, and the wide limits to control gel time (Jiang et al., 2019). Despite all these advantages, this method needs a high degree of skill in order to be successful (Woodson, 2009).

#### 4.8 Dry Packing

This method is considered to be a hand placement of a mortar with low water content followed by applying tamping or ramming in order to produce a good bond between the existing concrete and the mortar used for repair. Since the water to cement ratio is very low, little shrinkage is gained with a good quality in respect to strength, durability and water tightness. One of the disadvantages of the dry packing method is that it is not advisable for repairing and filling active cracks. It can be used only to repair narrow and dormant cracks. Before using this technique, the surface of crack should be widened to 25 mm wide and 25 mm deep. Then it should be cleaned, dried and bond coated with paste or mortar. Mortar must be placed in 10 mm thick layers and each layer shall be compacted using a hammer as displayed in Fig. 19.

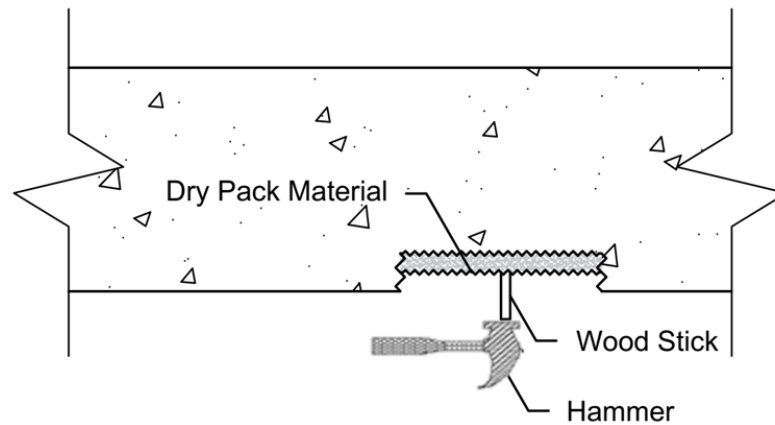


Fig.19: Dry Packing Method (Issa, 2009)

#### 4.9 Crack Arrest

While constructing massive concrete structures such as dams and retaining walls, cracks may propagate due to surface cooling or any other cause. This types of cracks can be arrested and crack may be blocked by using a piece of bond breaking membrane or a kind of a grid of steel mat that should be placed on the crack or by installing a semicircular pipe over the cracks as illustrated in Fig. 20 (Böhme, 2016; Makabe et al., 2014).

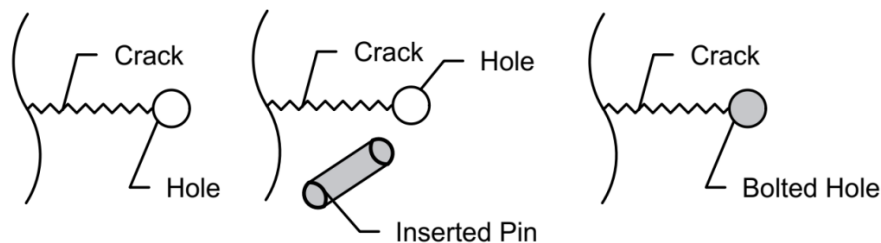


Fig.20: Crack Arrested (Makabe et al., 2014)

#### 4.10 Surface Treatments and Overlays

Surface treatments are low solids and low viscosity resins that are used to treat fine cracks. However, overlays are sufficient and successful in repairing fine dormant cracks (Issa, 2009).

#### 4.11 Autogenous Crack Healing

It is a beneficial method in closing dormant cracks found in mass concrete structures and in the presence of moist environments (Lang et al., 2019; Isaa, 2009; Van et al., 2012). The steps of this method are explained in Fig. 21 (Algaifi et al., 2018).

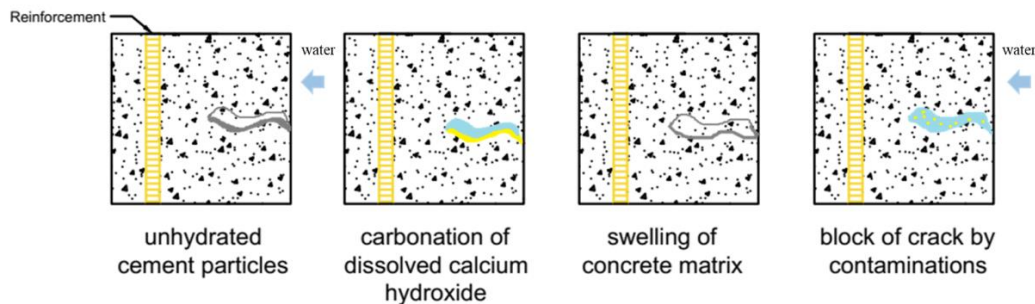


Fig.21: Autogenous Crack Healing Method (Algaifi et al., 2018)

### 5. MATERIALS USED FOR REPAIRING CONCRETE STRUCTURES

There are several materials that can be used for repairing structures. The selection between these materials is an important issue that should be studied in a well way and depends on different factors such as the cost, environmental exposure, availability of such materials, type and location of distress, bond with the concrete surface and many other factors (Fowler, 2009; Modi and Patel, 2015; ICRI, 1996).

#### 5.1 Cement Mortar or Concrete

One of the most important factors Portland cement have is being widely available all over the whole world. Also, it is considered to be a cheap material compared to other repair materials that can be used. Portland cement can be easily placed, finalized and cured (Bissonnette et al., 2011). It acts in a good manner in case of the stiffness and thermal expansion (Goushis and Mini, 2022). However, Portland cement have problems related to shrinkage especially plastic shrinkage and drying shrinkage. Also, it has a relatively high modulus and may react with the chemicals around in the environment where different conflicts may occur. Regarding applications where concrete is exposed to sulfates, a special type of Portland cement which is sulfate resisting cement type shall be used to avoid deterioration problems. Regarding Portland cement concrete mixes, such type cannot be placed in thin cracks, mainly it is used for both partial depth and full depth repairs satisfying that the minimum thickness that should be available for repair is around 100 mm. Conventional Portland cement concrete good be beneficial and a good choice to be used for repairing in marine environments since the very high humidity can be used to minimize and lessen the shrinkage that may occur. Concerning Portland cement mortar that can also be used as a repairing material for concrete structures, it can be placed in very thin cracks. However, it may increase the drying shrinkage that is resulted from the high water content, high cement content, and/or high pate to aggregate ratio.

Another cement based materials that can be also used are sulphoaluminate cement and magnesium phosphate cement. Sulphoaluminate cement is considered to be a fast hardening binder that shortens the setting time. Also, it so effective in reducing the shrinkage. Regarding magnesium phosphate cement, it can record a high early strength and a shorter setting time with a very good performance in bonding the crack (Li et al., 2017; Xing et al., 2018). In addition, it helps in lowering the shrinkage and can be used in several environments (Tonelli et al., 2021; Song et al., 2022).

## 5.2 Dry Pack Mortar

Dry pack mortar mainly consists of one part of cement and two and a half or three parts of sand. The water shall be added in a way to make the mix sufficient to stick all together. It may be as latex modified mortar or preshrunk mortar. This kind of material shall be placed in layers of 10 mm thick and then tamped into the right place (Von Fay, 2015). Since the water used in this mix is too low, a very little amount of shrinkage is found. By this, the mix remains in a good quality in relation to durability, strength and water tightness. Dry pack can be a sufficient choice to be used for filling both small and large cavities, for dormant cracks, and also for cracks with different propagations in vertical way and overhead surfaces. A main disadvantage of this material is that it cannot be used to fill areas located behind steel reinforcing bars (Modi and Patel, 2015).

## 5.3 Shotcrete

Shotcrete consists of two different mixes that can be applied for repairing concrete structures. These mixes are dry mix shotcrete and wet mix shotcrete. For dry mix shotcrete, water is added while poring the mix in a way that suffice the requirements. However, for wet mix shotcrete, water is mixed directly with the cement, sand and coarse aggregates. This material shall be pumped with pressure while being used for repairing concrete members. However, these mixes are sufficient to fill vertical cracks such as columns and walls, and horizontal cracks such as bottom beams and ceilings. Also, it can be beneficial when there is issues in the structure integrity and where reinforcement need a concrete layer to be added in order to be covered, while it needs a skilled labor and a lot of training to be applied in a correct way where it will be successful (Smoak, 1997).

## 5.4 Polymer Modified Concrete

Also referred as latex modified concrete and is widely and commonly used for repairing concrete structures. One of the most important advantages of this material is that it is less expensive than other materials used. Moreover, it accomplishes improvements in the adhesion of concrete, improves the resistance to water intrusion, durability properties and strength properties (Issa and Joseph, 2017). It can be the right choice to be used in applications where protection from corrosion is needed, acids and salt attacks are found, a strong bond between old and new concrete is a must (Allen et al., 1992).

## 5.5 Epoxy Resin

Epoxy resins are considered to be the most commonly used materials for repairing concrete structures and members. They recorded a high improvement with respect to concrete properties such as mechanical and physical ones (Kim and Park, 2021; Guo et al., 2020). A significant enhancement in compressive strength, tensile strength, shear strength and flexural strength was achieved when using epoxy resins. Also, chloride ion penetration length is decreased when epoxy resins are applied. Despite the fact that the epoxy resins are so expensive, in some locations and places, it is a must to use them since there are some conditions where other materials cannot be used for repairing concrete structure. In this case, the only choice that remains available is using epoxy resins to bind the cracks and have a successful repair for concrete structures (Wang et al., 2022; Rahman and Islam, 2022).

## 5.6 Alkali Activated Materials or Geopolymer Mortar

Several studies were done on using geopolymer as a repair material for cracks (Provis, 2018; Huseien et al., 2022; Pacheco et al., 2012). Geopolymer is considered to be an inorganic polymer that contains alumina and silica as main components (Tahri et al., 2018). It can be activated using alkali solutions such as sodium hydroxide and sodium silicate (Ding et al., 2017; Huseien et al., 2020). Results show a high improvement in the bond strength in comparison to Portland cement based repair materials and epoxies (Wang et al., 2019; Nunes et al., 2019). In addition to that, geopolymeric binders recorded high value of bond at early ages and can be used in place exposed to severe environments (Chindaprasirt et al., 2020, Sánchez et al., 2018). Also, it can be beneficial in places



exposed to water (Dassekpo et al., 2021). Moreover, the cost of the geopolymer material was reported to be cheaper than that of cement based repair materials. Several materials can be used as geopolymers such as wastes and bio-ashes. These two includes a wide list of materials like fly ash, rice husk ash, wheat straw ash, palm ash, pine ash, and many others (Ahmadi et al., 2021; Warid et al., 2016; Wazien et al., 2016). The bond strength between concrete and the geopolymer material used for repairing a concrete element is higher than that containing ordinary Portland cement (Asayesh et al., 2021). The compressive strength recorded higher values for geopolymer mixes than that of traditional mix (Gomaa et al., 2020; Huseien et al., 2017). There is a slight enhancement when using geopolymer material to repair concrete in some mixtures for stress test (Gomaa et al., 2020). Fan and Zhang (2021) evaluated the splitting tensile strength of concrete repaired by OPC and geopolymer mixes where higher values were recorded for geopolymer mixes.

## 6. CONCLUSION

As a conclusion, concrete cracks shall be detected and checked periodically to avoid severe problems. Each type of crack can be repaired using a specific method depending on its characteristics and properties. Some methods cannot be applied everywhere and for any type of crack. There are several materials used for repairing cracks in concrete structures. The selection of these materials depends highly on the surrounding environment and the type of crack. There is a big potential to use geopolymer mixes as a replacement of cementitious mixes in repairing concrete. This will decrease the carbon dioxide emissions in the atmosphere and lessen the cost.

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