Evaluation of Epoxy Injection Method for Concrete Crack Repair

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***Abstract*—The use of epoxy resins for repairing concrete cracks is a common method to restore cracked concrete structures. In this paper, the effectiveness of three chosen brands of epoxy which are commonly used in industry in New Zealand to repair cracked concrete beams are investigated. Multiple unreinforced concrete beams were tested before and after epoxy repair under vertical loads (flexural load) to determine the effectiveness of the epoxy to restore the structural strength or continuity of the beams. The tests were conducted using the third-point loading method applying a constant bending moment to the middle segment of the beam span. The results showed that the performance of the repaired beams varies depending on the epoxy type and application methods. It is demonstrated that the viscosity of epoxy is critical to ensure full bonding and in turn reinstating the capacity of the cracked sections.**

***Index Terms*—Concrete crack, epoxy injection, flexural testing**

I. Introduction

Since the Canterbury earthquakes that occurred in 2011, the need for concrete crack repair has greatly increased as there were a large number of concrete structures, from commercial tilt-slab buildings to concrete bridges that were affected by the earthquakes especially, causing cracks that, in some cases required more than just surface treatment. The use of epoxy resins for repairing concrete cracks, restoring the concrete and increasing the durability is a common procedure in New Zealand and is very often the only economic option.

Cracks need to be repaired if they reduce the strength, stiffness, or durability of a structure to an acceptable level, or if the function of a structure is seriously impaired [1]. When a concrete structure is in need of repair, it is evaluated to determine suitable methods and takes into account causes of the crack as well as the width, which has a considerable influence on the materials and methods used for its repair.

The concrete crack repair can be undertaken using different methods such as the electrochemical methods [2], using polymer-based materials [3] or the epoxy resin injection methods [4]-[8].

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Epoxy resins were first recognised in 1944 by Preiswerk and Gams [9]. The properties of epoxy were then unusual and for the first time, it was possible to achieve reliable adhesive joints with structural integrity and outstanding cohesion. This discovery of the bonding function of epoxy introduced a new concept in adhesive materials [9].

Epoxy resin products were commercialised in 1946 and since then, modern adhesive technology has led to the development of many types of epoxy-based systems. Since commercial introduction, epoxy resins are being used for structural applications including laminates, moulding, casting and bonding. Epoxy resins can be combined with curing agents to meet specific requirements for use.

Quick epoxy repair is extremely important not only to improve the structural integrity, but to ensure that the reinforcement is protected from moisture and contaminants that could have an effect on the rebar and decrease the durability of a structure. For repairing concrete structures using epoxy resins, two application methods are commonly used. It includes Epoxy resin injection and gravity filling [10]. The injection method usually requires a series of entry ports at regular intervals along the crack.

The available technical data of epoxy resins provided by the manufacturers show high tensile and compressive strength of the epoxy materials. However, the actual performance or effectiveness of these epoxy resins for concrete structure repair is not well studied in the literature. The objective of this research is to investigate the performance of some samples of epoxy repaired concrete beams in terms of their flexural tensile capacity.

For this purpose, in this study, the failure load of undamaged concrete beams under flexural tensile loading is compared with the failure load of repaired concrete beams. Three types of common epoxy resin products are compared in this paper.

II. Research Methodology

In this research, the maximum failure load in flexural testing (i.e. the max load before the beam cracks in the

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flexural tensile region) is regarded as the performance indicator.

The flexural testing can be carried out by either applying a single load point or two load points to the beam. The centre-point loading method is where the entire load is applied at the centre span and the maximum stress is present only at the centre of the beam. On the other hand, the third-point loading method applies a constant bending moment to the middle segment of the beam span. In this research the flexural testing is conducted based on the standard test method as per ASTM C78/C78M-16 [11]. Six undamaged, unreinforced concrete beams are considered in this study. The beams are loaded under vertical load until the beam cracks or fractures in the tensile region. They are then repaired and re-tested under flexural loading to determine the effectiveness of the epoxy to restore the cracked/fractured beam. The maximum failure loads before and after repair are compared.

III. Test Setup

A. Test Specimens and Materials

Concrete beams were constructed with dimensions of 505mm long by 105mm high. The width of the beams was 100mm at the bottom and 105mm on the top. The slight difference in width allowed for the concrete beams to be removed easily from the moulds. The concrete beams were constructed with the same mix design and cured in water for 28 days before transporting to the testing lab. After curing, the general condition of the beams was examined to ensure there were no visible voids and defects on the concrete.

Three types of epoxy products with different properties were chosen for the experiments. Table 1 shows the technical data for each of the epoxy resins used in this experiment. As shown in this table, the Type1 epoxy has the highest viscosity. On the other hand, Type3 epoxy has low viscosity and E modulus, but high compressive and tensile strength. Type2 epoxy has the same tensile and compressive strength as Type 1; however, unfortunately the viscosity and E modulus of Type2 epoxy is unknown as they are not provided in its technical data sheet. It should be noted these data are approximate values obtained from the manufacturers' technical data sheets related to 20 ℃ application temperature.

TABLE I. Epoxy Resins Technical Data (Approximate Values as Reported by the Manufacturers)

Epoxy Type	Viscosity (mPas)	Flexural Tensile strength (MPa)	Compressive Strength (MPa)	E modulus (MPa)
Type1	250 - 500	45	70	3900
Type2	-	45	70	-
Type3	145	65	75	3000

B. Test Method

The tests were undertaken with an Avery Universal testing Machine (UTM) at Ara's Engineering Laboratory. A view of the testing machine is shown in Fig. 1.

Figure 1. The avery machine

The experiments were conducted using the third point loading method where a constant bending moment is applied to the middle 100mm of the beam span length. Fig. 2 demonstrates one of the test beams which has been set up ready for testing.

Figure 2. Test setup

For the tests, first, the beams were placed on the two support blocks and ensured that there is an equal amount of overhang at each end as shown in Fig. 2. Next, the load-applying blocks were adjusted to be in contact with the upper surface of the beam. Then, the load was applied at a constant rate until the beam reached its tensile strength causing the breakage.

The above procedure was repeated for each beam specimen. After the first set of testing, the cracked/fractured beams were repaired using the epoxy materials. The tests were then repeated for the repaired beams with the same setup.

C. Epoxy Application Process

The cracked/fractured beams were carefully transported to the concrete lab where the repair process (epoxy injection) was carried out. A clamp system was used to hold the broken beams in position during the epoxy application process. The clamps were laid out at even spaces on a work bench and thin sheets of steel were placed between the clamps which provide a flat stable surface to rest on while the clamps were being tightened as shown in Fig. 3.

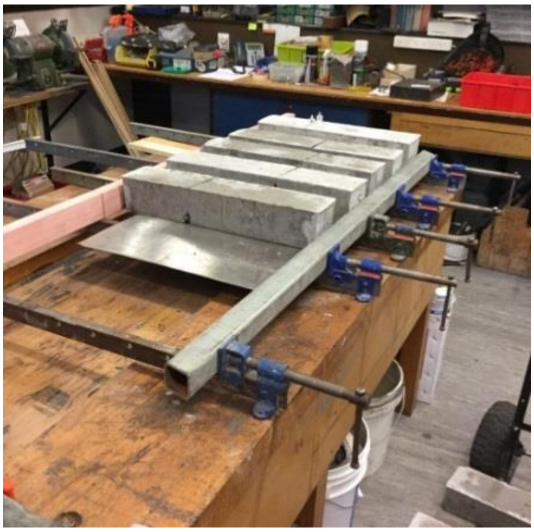

Figure 3. Clamp system

Two methods of epoxy application were used including the "gravity filling" and the "injection method" as per the epoxies' technical specifications.

Two beams were repaired using Type 3 epoxy product. For this product the gravity filling method was used. This epoxy product consists of two components which were mixed according to the required mixing ratio as per their manufacturing specifications. The liquid was then carefully poured into the visible crack on the top face of beam. To ensure that the epoxy seeped through the entire crack, pouring was continued until the liquid began to overflow out of the gap on the top surface of the beam.

Four remaining beams were repaired using Type1 and Type2 epoxy products. These products were applied using the injection method as per their standard specifications. This method is the most appropriate choice when structural repair is critical because the use of pressure allows the epoxy to reach the entire crack. These two products come in a cartridge which contains the resin and the hardener. To mix the two components, the cartridge was slowly inverted 20-30 times to mix the components. The foil on one end of the cartridge was then pierced and screwed onto the connection hose. The cartridge was placed into a standard gun. The hose was screwed onto one of the two ports and an air release pin was inserted into the other port. Pumping was then commenced slowly until the resin appeared visibly in the next port or until the port accepted no more resin. The hose was detached from the port and attached to the second port on the beam. The resin was then pumped through this port to ensure full penetration.

For epoxy Types1 and 2, each beam required two injection ports to be fitted for the epoxy to be injected into. A small amount of sealant was applied to the back of two ports which were placed over the visible crack. These are placed between 100mm and 500mm apart, depending on the size of the concrete specimen. In this case, the ports were spaced 100mm apart. Additional sealant was then applied around the sides of the ports and along the rest of the crack that was still exposed as shown in Fig. 4.

Figure 1. Injection port application

Once this process was completed, all beams were left to harden for a minimum of seven days which is the approximate length of time needed to reach full strength. The excess epoxy on the outside on the beams was removed using an electric grinder, and a chisel was used to remove the ports.

The beams were then transported to the testing lab where they were once again tested under flexural loading using the Avery machine.

IV. Test Results

All of the beams failed within the middle third (Fig. 5). This was expected due to the third point loading method which allowed for a constant bending moment in the middle segment of the beam spans.

Figure 5. Typical test beams fracture under the vertical load

Observation of the repaired beams after breakage, shows that the repaired beams performed differently depending on their epoxy type and application method.

In the specimens repaired by Type1 epoxy, the failure occurred at the original crack line where the epoxy was visible in the fractured faces as shown in Fig. 6. On the other hand, the specimens repaired by Type2 and Type3 epoxy fractured away from the original fracture line (Fig. 7). It means, the Type2 and Type3 epoxies have performed better that Type1 in bonding the fractured section.

Figure 6. Failure through the epoxied section (original fracture line) – Typical scenario for beams repaired by Type1 epoxy

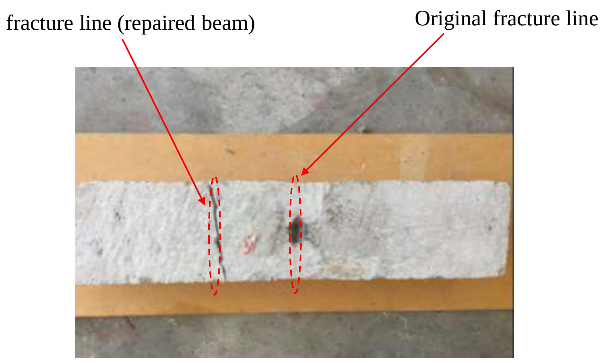

Figure 7. Failure away from the original fracture line (away from the epoxied sections) - Typical scenario for beams repaired by Type2 and Type3 epoxies

The failure loads from the flexural tests are presented in Figure8. In this figure the failure loads for beams before and after repair are compared. It can be seen that the two beams repaired with Type2 and Type3 epoxies were able to withstand loads greater than those repaired by Type1 epoxy.

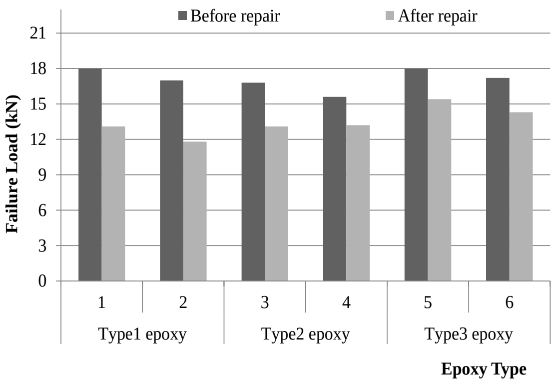

Figure 8. Flexural test results (maximum failure loads) for tested beams

As shown in Fig. 8, for the initial tests (before repair), the failure loads ranged between 15.6kN and 18kN. For the second set of testing (after repair), the failure loads at repaired beams ranged between 11.8kN and 15.4kN.

To better compare the performance of the beams before and after the repair, the "average failure load ratios" are calculated and plotted in Fig. 9. The "failure load ratio" is considered as the beam failure load after repair divided by the failure load before repair.

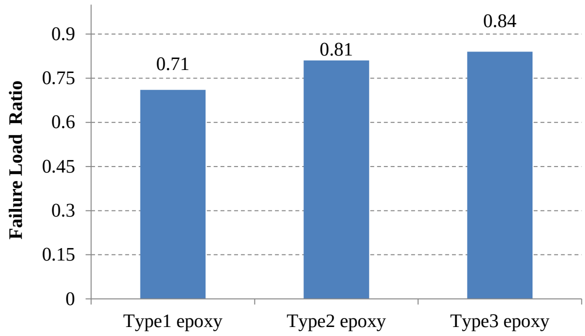

Figure 9. Average failure load ratios for beams repaired using the three epoxy products.

Comparing the performance of three epoxy types, it can be seen that Type2 and Type3 epoxies have performed much better than the Type1. The average failure load ratio for beams repaired by Type2 and Type3 epoxies are calculated as 0.81 and 0.84. However, it should be considered that the specimens repaired by these epoxies cracked in a different place (away from the epoxied section); this shows that the Type2 and Type3 epoxies can be fully effective in restoring the structural continuity of the beam.

The average failure load ratio for beams repaired by Type1 is calculated as 0.71. In these beams, the fracture of the repaired beams occurred along the original fracture line which means the epoxy failed to resist the flexural tensile stresses generated in the epoxied sections.

One reason for better performance of Type3 epoxy relative to Type1 could be its lower viscosity. As shown in Table I, Type3 epoxy has lower viscosity allowing it to seep into the entire crack whereas the Type1 epoxy did not fully penetrate the crack even though they were applied using the injection method.

The superior performance of Type2 epoxy compared to Type1 shows that the performance of an epoxy repair does not necessarily correlate to its tensile and compressive strength.

V. Conclusions

Lab experiments were undertaken to determine whether common proprietary epoxy resins reinstate the equivalent tensile capacity of concrete. This was done by comparing the failure load of undamaged concrete beams with the failure load of crack repaired concrete beams under flexural tensile loading.

The results showed that the performance of the repaired beams varies depending on the epoxy type and application methods. If suitable epoxy resin is used and applied properly, the structural strength and continuity of the concrete beams can be fully reinstated.

It was also found that most likely the viscosity of epoxy is more important than its tensile or compressive strength. In other words, even though the epoxy material may have a greater tensile strength than concrete, they cannot reinstate the full capacity of cracked concrete if full bonding or penetration is not achieved due to high viscosity or improper application.

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Dr Hossein Askarinejad has experience in research, teaching and consulting in civil and structural engineering in the Middle East, Australia and recently in New Zealand.
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