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# Use of polymer modified mortar in controlling cracks in reinforced concrete beams

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ABSTRACT

This paper presents the results of an experimental investigation on the strengthening of existing cracked RC members. The proposed technique consists of applying locally available polymer modified mortar in cracked beams to increase the load carrying capacity. A total of six full scale RC beams were constructed with the same material using the same mix and water–cement ratio. Initially, beams were tested until the development of cracks with width reached a limiting value of 1 mm. The beams were then repaired with the application of polymer modified mortar technique. After 3 days of water curing the beams were tested again and loaded till the failure. An improvement in the load carrying capacity was observed in the beams after the retrofitting. Results clearly demonstrate the effectiveness of the proposed technique in repairing the RC members for strengthening the existing structures.



## 1. Introduction

Reinforced concrete (RC) is the most frequently applied structural material because of its durability, which has been used for many years to build a wide variety of structures from houses to bridges. Cracking and spalling are the most common phenomenon of deterioration of concrete. Cracks in concrete may occur in both the plastic state as well as hardened state owing to the internal stresses which arise from the response of the constituent's materials to the external excitation as well as their environment [1]. Beyond certain limit, cracks not only destroy the serviceability of the structure, but also lead to exposure of reinforcement to the environment resulting possible corrosion. Therefore, cracks may cause considerable structural distress or a deficient in durability [2–5]. Repair and rehabilitation of deteriorated concrete structures are essential not only to use them for their intended service life but also to assure the safety and serviceability of the associated components so that they meet the same requirements of the structures built today and in future. The repair of cracks depends not only on the understandings of the causes, but also on the selection of a suitable repair technique that takes the causes into account. Successful long-term repair procedure must address the causes of the cracks in addition to mitigate the cracks themselves [6,7]. Conventional upgrading techniques often lead to heavy demolition, lengthy construction time, reconstruction and relocation of inhabitant with all the related costs (direct and indirect). Huge indirect costs, the environmentally hostile approach and the hassle associated with conventional techniques are some of the major reasons that discourage owners and custodians of buildings from their any commitment regarding retrofitting.

A number of retrofitting strategies for RC structures have been implemented in the past [8–10]. Concrete or steel jacket provision to defective RC members improves the strength in addition to the stiffness enhancement. The use of a shotcrete overlay is also a common technique. This technique involves adding an extra reinforcement and a layer of new concrete around the existing ones [11–13]. Although this technique may increase the strength, stiffness and ductility several deficiencies are also encountered. Uncertainty between the bond of new and existing concrete surface is the major drawback. These are also proved to be time consuming, labour intensive and may create a disruptive situation. In order to avoid these possible situations, steel cage is used as an alternative to the complete jacketing [14–16]. Non-shrink grouts are normally filled in the available spaces between the steel cage and the existing concrete. A grout concrete or shotcrete cover may be provided to ensure resistance against corrosion and fire. An improvement in shear and flexural strength can also be achieved by the implementation of steel plate adhesion [17]. However, there is a need of sound understanding of both the short and long-term behaviour of the adhesive used in this case. In addition, reliable information concerning the adhesion to concrete and steel is still to be explored. Composite materials such as fibre reinforced plastic (FRP) can also be used to retrofit the existing structures [18]. However, it is important to note that the use of FRP is often dictated by strain limitations [19]. The large differences in strength and coefficients of thermal expansion can result in bond deterioration and splitting of concrete [20].

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Epoxy injection has also been used as repair material [6]. This is an economical method of repairing non-moving cracks in concrete structure and is capable of restoring the concrete to its pre-cracked strength but the epoxy bonded systems also exhibit some disadvantages. For example the diffusion closeness, poor thermal compatibility with base concrete, sensitive to moisture on the adherents at time for bonding, hazardous working environment for the manual worker and the problem of minimum temperature of assemble in cold climates. It is, therefore, of interest to replace the epoxy adhesive with a mineral based bonding agent. Many cementitious mortars contain cellulose ethers as an additive to improve water retention and workability. However, after setting and drying they will adhere poorly. In addition, cementitious mortars are very hard, brittle and inflexible materials, whereas for many applications flexible and deformable cementitious materials are essential. Un-modified mortar made with Portland cement is normally used as repaired material in some field applications. However, these kinds of mortars have some disadvantages due to inorganic nature of the material [21]. These disadvantages include (1) low tensile, flexural, shear, impact and bond strengths, (2) large drying shrinkage, (3) tendency to crack with changes in temperature and moisture, (4) relatively high moisture absorption and permeation, (5) low resistance to corrosive agents, and (6) rapid loss of gauging water in thin surfacing by evaporation and substrate absorption. Afridi et al. [22] examined that abundance of cracks and pores were present in electron micrograph of a hardened unmodified cement mortar.

Compatibility of the repair materials with the existing substrate and durability under various conditions in service are of much greater importance. Apart from bond and compressive strength there are some other properties such as dimensional stability (shrinkage), coefficient of thermal expansion, modulus of elasticity and permeability which should be taken care during selection of a repair material. The other factors like permeability, chemical and electrochemical compatibility should also be considered [23].

Polymer modified mortars (PMM) are considered to overcome these limitations [24]. Also from the viewpoint of sustainable development in the construction industry, environment-conscious PMM has been developed with a great interest in recent years. The PMM with high performance, multi-functionality and sustainability are expected to become the promising construction materials in Pakistan in the 21st century. Polymer modified mortars (PPMs) are related to setting shrinkage control, thermal properties and temperature dependence; lightweight or porous nature [24].

PPMs are environmentally friendly and can be classified as construction materials that support the sustainability aspects of construction. These types of cementitious materials address concerns about saving natural resources, provide longevity to infrastructures, and protect the environment. Not only it strengthens the RCC structural members but also makes a highly durable repair along with excellent adhesion characteristic even to difficult substrates [25]. The polymer films are responsible for improved mechanical and durability characteristics of such systems that results in enhanced properties compared with conventional cement mortar mixes [24]. As a consequence for almost all applications in modern construction, the modification of cementitious mortars with polymers is a must. Availability of polymers as redispersible polymer powders has helped to develop prepackaged polymer modified cementitious mixes requiring only water to be added at construction site prior to application. Prepackaged polymer modified cementitious are highly helpful in improving the handling procedures and to avoid mixing error. Even then the people in construction industry are reluctantly using this product in as such form because only very little research data is available and arguments are on cost factor.

The usage of PMM as strengthening material for pre-cracked RC members is not well documented; no sufficient research data is available on use of pre-packaged PPM except some successful case histories of repair [26]. Such current case histories and results on some of its other properties [22,27] encouraged to investigate performance behaviour of the RC beams using PMM. The research reported in this paper was aimed to develop a new retrofitting technique, especially for a developing country like Pakistan, resulting more effective and cost benefiting repair and strengthening for restoration of pre-cracked RC structures. The proposed technique consists of application of PMM in cracked beams to increase its load carrying capacity.

## 2. Experimental programme

### 2.1. Materials

#### 2.1.1. Constituents of concrete

The cement used was Ordinary Portland cement complying with ASTM type 1. Fine and coarse aggregates used were from the local sources in Pakistan. The coarse aggregates consist of crushed stones having a maximum size of 10 mm. The physical properties of aggregates used are summarised in Table 1. Tap water was used in manufacturing the concrete. Steel form-work (moulds) was used for casting beams. Deformed steel Grade 40 for # 3 bars and Grade 60 for # 4 bars were used in the test beams.

#### 2.1.2. Materials for repair

Polymer modified mortar (PMM); a commercial prepackaged formulation developed locally in Pakistan was used as repair material. This is a proportionate mix of cement, sand, an organic film-forming re-dispersive polymer powder and other related ingredients in appropriate ratios. A comparison of properties of PPM with those of normal (unmodified) mortar properties are shown in Table 2. The PMM into the crack was injected by following the procedure as laid down by the manufacturer [25].

### 2.2. Mix proportions

The proportions of the concrete mixes for preparing RC beams were 1:2.4 by mass of cement, sand and gravel respectively. The mix was designed to produce a concrete with 28 days cylindrical strength of about 30 MPa. The water–cement ratio (w/c) was kept 0.50. The workability of concrete was measured in terms of slump as per ASTM C 143 [28] and a slump of 35 mm was noted. An average cylindrical compressive strength of 30.5 MPa was achieved.

### 2.3. Preparation and curing of beams

Beams with a constant cross-section of 152.4 mm × 304.8 mm and a length of 3353 mm were prepared in two categories, namely Category HB and Category GB. There were three beams in each category, resulting altogether six full-scale beams. Category HB had flexural reinforcement only, and these beams were designated as HB-1, HB-2 and HB-3. Category GB had the flexural as well as shear reinforcement, and these beams were designated as GB-1, GB-2 and GB-3. The cross-sections of the beams for Category HB and Category GB are shown in Fig. 1a and b respectively. Two days after casting, the forms were removed and the beams were wrapped in wet hessian cloth. Curing was continued by keeping the hessian cloth wet until the testing at the age of 28 days.

### 2.4. Testing procedure

RC beams were simply supported and loaded in flexure under a two points loading conditions. The position of the loads and the set up of the machine are shown in Fig. 2. The load was applied in increments till the cracks appeared to have a width of 1 mm which is a value well beyond the allowable limits defined by ACI 318-05 [29]. The crack width was determined using a non-destructive crack inspection device (crack comparator). The load at crack width equal to 1 mm, mid-span deflections and failure loads were recorded.

**Table 1**
Physical properties of aggregates used.

| Aggregates | Relative density (SSD condition) | Water absorption (%) |
|---|---|---|
| Fine aggregate | 2.63 | 1.20 |
| Coarse aggregate | 2.60 | 0.99 |