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Studying the Compatibility between Metakaolin Repair Materials And Concrete Substrate

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Abstract

In this study, the compatibility of Metakaolin repair mortar and substrate concrete was investigated in three stages. First: individual properties of Metakaolin as a pozzolanic material and conventional repair materials (cement mortar), and two types of concrete, such as compressive strength, split tensile strength, and flexural strength, were determined using standard ASTM test procedure. Second: the bond strength of composite cylinder for different combinations of repair materials and substrate concrete were evaluated. Third: the compatibility was investigated using a composite beam of repair material and substrate concrete under third point loading.

The experimental results indicated that repairing weak substrate concrete by Metakaolin modified repair material is not preferable du to disparity in mechanical properties and create high level of mismatch between them. Furthermore, bond strength is considered as great influence factor on the success range of repair system.

Keywords: Metakaolin, concrete repair materials, compatibility, bond test

دراسة التوافق بين مواد الاصلاح الحاوية على الميتاكاؤلين والجسم الخرساني

الخلاصة

في هذه الدراسة تم التحري عن التوافق بين مواد الاصلاح الحاوية على الميتاكاؤلين والجسم الخرساني وعلى ثلاث مراحل. الاولى: التحري عن الخواص الذاتية لكل من مواد الاصلاح الحاوية على الميتاكاؤلين والتقليدية (مونة السمنت) ولنوعين مختلفين من الجسم الخرساني، مثل مقاومة الانضغاط و مقاومة انفلاق الشد ومقاومة الانثناء. واعتمادا على المواصفة الامريكية(ASTM). الثانية: تقييم مقاومة الربط للاسطوانة المركبة والمصنوعة من انواع مختلفة من مواد الاصلاح والخرسانة. ثالثا: التحري عن التوافق باستخدام عتبة مركبة مصنوعة من الخرسانة ومواد الاصلاح وفحصها بطريقة التحميل بنقطتين.

بينت نتائج الجزء العملي انه من غير المفضل اصلاح الجسم الخرساني الضعيف بمواد اصلاح مطوره بمادة الميتاكاؤلين وذلك بسبب تباعد الصفات الميكانيكيه بينهما ويقود ذلك الى عدم التطابق. كما تعد مقاومة الربط عاملا مؤثرا قويا عن مدى نجاح نظام الاصلاح.

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Introduction

Deterioration of concrete structures is a major problem in civil engineering, which is mainly associated with contamination, cracks and spalling of the cover concrete. In many instances, the serviceability of the deteriorated structures becomes an important issue and therefore the cost-effective solution is often to use patch repair, which involves the removal of the deteriorated area and refilled with a fresh repair mortar.

A good repair enhances the performance and function of the structure, bring deteriorated area back into a condition that is as close as possible to its original strength and stiffness, improve the appearance of the concrete surface, provides water tightness, prevents the attack of aggressive solution to both concrete and embedded steel, and consequently improve its durability. It's important to say that the present study represent the 2nd part of two parts research work. While the 1st one (currently under publication) concern about using of polymer modified repair with substrate concrete, and the results is quit agreed.

Previous studies [1, 2] on repair materials have shown that some of these materials did not perform adequately on hydraulic structure when subjected to severe site and climatic conditions. For example, there is a wide variation in the coefficient of thermal expansion of the epoxy mortars compared to that of the concrete, and this may explain its bad performance in such wet condition.

Other types of repair materials use mixture of cement replacement materials (pozzolanic materials) and super plasticiser to keep low water/cement ratios. These mixes produce dense impermeable high strength repair materials. Parrot [3] found that the cementitious materials was strongly affected the long term deterioration of cement paste. Nilson et al [4] found that chloride diffusion was linked to porosity and so depended on water/ cement ratios, cracks and compaction. Hassan [5, 6] found that pozzolancs such as Metakaolin, Fly ash and Silica Fume, had beneficial effect on chloride diffusion of repair materials.pozzolans are widely used in repair materials and contribute to the low chloride diffusion coefficients of the materials [7, 8, 9].

In this research, Metakaolin is used in the formulation of repair mortars, and it is produced by heating kaolin, (i.e. natural clay) to a temperature about (700°C). This treatment, called calcinations, radically modifies the particle structure making it a highly reactive, amorphous pozzolana. A recent, independent laboratory study of mortar pastes demonstrates the ability for Metakaolin to react with the free lime resulted from the hydration process of the Portland cement to form additional C-S-H (Calcium Silicate Hydrate) material, which makes the concrete stronger and more durable. The particle size of Metakaolin is significantly smaller than cement particles, yet not as fine as silica fume. It is typically added to concrete at rates not more than 10 % by weight of cement [10].

Metakaolin is produced from a raw material available in commercial quantity in Iraq. So, the results are expected to be useful to engineers who are interested in the production of repairing materials for the markets of the Arab world.

2-Experimental Work

2.1. Substrate Concrete

Two substrate concrete mixes were used in this study. One mix considered to be low quality substrate, while the other one considered being normal quality substrate using Ordinary Portland Cement (OPC) (Type1) according to ASTM C150 produced at Al-Sharkia factory from the Kingdom of Saudia Arabia, Al- Ekadir natural sand having maximum size of 4.75 mm (zone2) according to the requirements of Iraqi specification No.45/1984,and AL-Nebai region coarse aggregate having maximum size of 10 mm according to the requirements of Iraqi specification No.45/1984.The mix proportion of the concrete is the same, (1:1.6:2.9 by wt.). The difference is only in w/c ratio, which is 0.4 for normal strength concrete and 0.6 for low strength concrete. The resulted workability were 75 mm for normal concrete, C_{25}, and 200mm for weak concrete, C_{15}. All specimens were cured in water until the age of 28 days.

2.2. Concrete repair materials

Repair material M_c (named as conventional mortar) was a blend of Portland cements with sand. The mortar was proportioned to have a cement-to-sand weight ratio of 1:2 with a water to cement ratio of 0.5. Repair material M_{MK}, pozzolanic modified mortar, was prepared according to previous investigation [5,10] by admixing Metakaolin (10 % as cement replacement by weight).The M_{MK} mortar has also cement-to-sand weight ratio of 1:2 , but w/c was 0.52 to achieve workability of (90 ± 10 mm). mixing procedures for the two types of repair materials were according to standards, and all specimens were cured in water for 28 days.

3.0 Evaluation methods

The selected evaluation methods for this research were as follows:

3.1 Compressive Strength

The compressive strength of the two mentioned mortars using 50-mm cube according to ASTM C109, and also for the two mentioned substrate concrete using 100-mm cube according to B.S - 1881; part116 standard practice were determined at 1 and 28 days. The idea behind choosing 1 day age strength value for each of the evaluation methods is to determine the influence of adding Metakaolin on the properties of repair mortars and substrate concrete compared with the conventional ones measured from and earliest starting point of age for both of them .

3.2 Split Tensile Strength

The split tensile strengths for both repair materials and substrate concrete were determined for 1 and 28 day using 100×200mm cylinders according to test procedure of ASTM C496 .

3.3 Flexural Strength

The flexural strength for both repair materials and substrate concrete were determined for 1 and 28 days using 100×100×400mm prisms and according to the third point loading beam method ASTM C78.

3.4 Bond Strength

The bond strength of the repair materials is determined according to test procedure of ASTM C882.Substrate concrete specimen on a slant elliptical plane inclined at 30° angle from vertical to form a 100×200 mm composite cylinder (see Fig 1) were casted from the same batches of substrate concrete mentioned in item **2.1,** and cured in water for 28 days. The slant surface of the substrate concrete specimen is cleaned and dried before applying the repair material between the two portions of the composite cylinder The test is performed by applying compressive load on the composite cylinder. The bond strength is the product of the [Max Load] / [Area of Slant Surface] .

Pattnaik [11] found three different modes of failures. They are (as shown in figure 2): slant surface failure, repair materials failure, and substrate concrete failure. Slant surface failure indicating of the weak bond between the repair and substrate materials. While materials failure, (either in substrate concrete or mortar), indicating weaker materials strength than the bond strength at the interface.

Figure 3: shows the observed failure in this study for composite cylinder in samples of M_{MK} specimens for Interface, Substrate, and Repair Material and the load test machine used in the experimental works.

3.5Compatibility test for composite beam.

Poston et al. 2001[12, 13], found that a repair section in concrete structures is mostly occurred at the joints or in the tension area. Tension stresses in concrete are caused by either bending force due to loading or other factors such as environment conditions. Consequently, flexure test method is thought to be an appropriate to study the compatibility between repair and substrate material. Czarneck et al. 1999[14] developed an experimental method using simple beam with third- point loading. The failure modes (compatible or incompatible) were categorized as shown in the Figure 4.

To achieve the aim of the research through evaluating the compatibility between Metakaolin repair material and concrete substrate, 100×100×400mm prism were casted according to ASTM C78 standard test procedure as the control prisms mentioned in item **3.3** but having wide-mouthed notch 200mm (length)×100mm(width)×10mm (thick) was cast into the bottom of the composite prism (see Figure 5). After de-moulding, the prisms were moist cured until the age of 28 days, and then the wide-mouthed notch areas were textured using dry brushing. The rough surface textured substrate specimens were air-dry cured for 7 days before filling the notched area with the repair materials. The composite sections were de-moulded next day and cured in water for 28 days. the cured composite prisms were tested according the third point loading beam test procedures ASTM C78.

Figure 6: shows compatibility test samples for composite beam of the research and some of the observed failure in samples of Substrate concrete and repair material also shows the third point load test

machine used in the experimental works.

4.0 Results and analysis.

The results and analysis of this research will be discussed through the mechanical properties and compatibility results of repair materials and substrate concrete

4.1 Mechanical properties

Table 1 shows the compressive strength, split tensile strength, and flexure strength of the repair material and substrate concrete. These values are the average of strengths of three samples. All the strengths found increasing from 1day to 28 days. Both repair materials have approximately equal compressive strength at 1 day which is intended to be in equal starting point, while the developed strength at age of 28 days indicates the influence of the modified repair material and its compatibility.

The mix proportion of both concrete substrates is the same with the exception of w/c ratio. As a result two types of concrete have been made to simulate the real condition of weak and normal strength substrate concrete C_{15} and C_{25}.

The degree of improvement in compressive strength from 1 to 28 days was found to be 78.5% and 80% for substrate concrete C_{15} and C_{25} respectively. Since the proportion of both C_{15} and C_{25} are the same with the exception of w/c ratio, then differences in compressive strength is related to the differences in w/c ratio. In contrast, test specimens of both repair materials (M_c and M_{MK}) exhibited a same level in 1-day age compressive strength, while the gain in strength was found 86.9% and 89.2% for M_c and M_{MK} respectively. Probable explanation for this behavior is that the Metakaolin as a pozzolanic material react later with cement hydration products leads to pores refinement and improve the microstructure of cement past. Figure 7: shows the development in compressive, split tensile, and Flexural strength of the substrates concrete and the two repair materials considered in this study.

It is apparent from observing the data in Figures 7 a, b, and c that depending on the specific repair material, significant difference exists between such mechanical properties of the repair material and the substrate at any given age. This disparity in mechanical properties can be expected to influence the failure mode and the bond strength determined in the composite cylinder. And also influences the load carrying capacity of the composite beams.

4.2 Compatibility results

Table 2: shows the bond strength, and third point strength of composite beams. These values are the average of strengths of three samples.

The test values listed in Table2: for the composite beam indicate the following :

a. The bond strength values of substrate concrete C_{25} with M_c and M_{MK} is greater than the corresponding values of C_{15} .
b. The bond strength values of substrate concrete C_{25} with M_{MK} is greater than with M_c while the bond strength value of substrate concrete C_{15} with M_{MK} is less than that of M_c

c. The flexural strength substrate concrete C_{25} with M_c and M_{MK} is greater than the corresponding values of C_{15}.

d. The flexural strength substrate concrete C_{25} with M_{MK} is greater than that with M_c while The flexural strength value of substrate concrete C_{15} with M_{MK} is less than that of M_c

e. Flexure ratio explains the compatibility level between types of substrate concrete and repair material. The greatest flexure ratio correspond to the lowest flexural strength of C_{15} with M_{MK}.

5.0 Conclusions

The following are the main conclusions that can be drawn from the experimental work to evaluate the compatibility of Metakaolin repair materials with substrate concrete.

1. Using Metakaolin as a pozzolanic repair material will improve the mechanical properties of repair materials compared with conventional material.
2. It is not recommended to repair weak substrate concrete by very strong repair materials which may leads to disparity in mechanical properties and create high level of mismatch between them.
3. Bond strength can be considered as priority one measure to assess the feasibility of the repair system. Once an interface bond failure occur therefore it's not recommended and not feasible to improve any further mechanical properties

Further researches are recommended to investigate the effect of curing conditions, surface texture and roughness on bond strength.

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Table (1) Strength results of repair materials and substrate concrete.

Materials type	Compressive strength MPa		Split tensile strength MPa		Flexural strength MPa	
	1-day	28-day	1-day	28-day	1-day	28-day
Substrate concrete 0.6 C_{15}	4.3	20.0	0.41	1.7	0.7	3.2
Substrate concrete 0.4 C_{25}	6.0	30.0	0.52	2.3	1.33	5.92
Conventional repair material M_c	3.0	23.0	0.35	1.7	1.47	3.6
	2.9	26.9	1.50	4.55	1.50	6.42

Table (2) Compatibility test results of repair materials and substrate concrete

Materials type	Bond strength (MPa)		Third point composite beam (MPa)	
	M_c	M_{MK}	M_c (flexure ratio)*	M_{MK} (flexure ratio)*
Substrate concrete 0.6 C_{15}	7.5	6.6	4.1 (1.12)	2.9 (2.0)
Substrate concrete 0.4 C_{25}	8.8	11.2	5.2 (0.60)	5.98 (1.08)

*flexure strength of repair material divided by flexure strength of substrate concrete

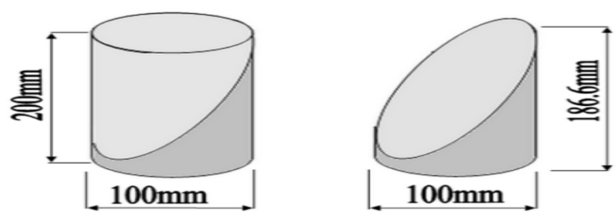


Figure (1) Substrate and composite section for slant shear bond-strength test

Figure (2) Failures of the composite slant sections [11].

(a) Interface failure

(b) Substrate failure

(c) Repair material failure

(d) Loading test machine

Figure (3) Failures of the composite slant sections of the research

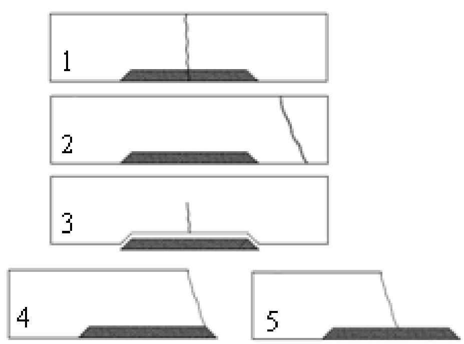


Figure (4) Probable failures of the composite beam; 1,2 – compatible; 3, 4 and 5- incompatible [14]

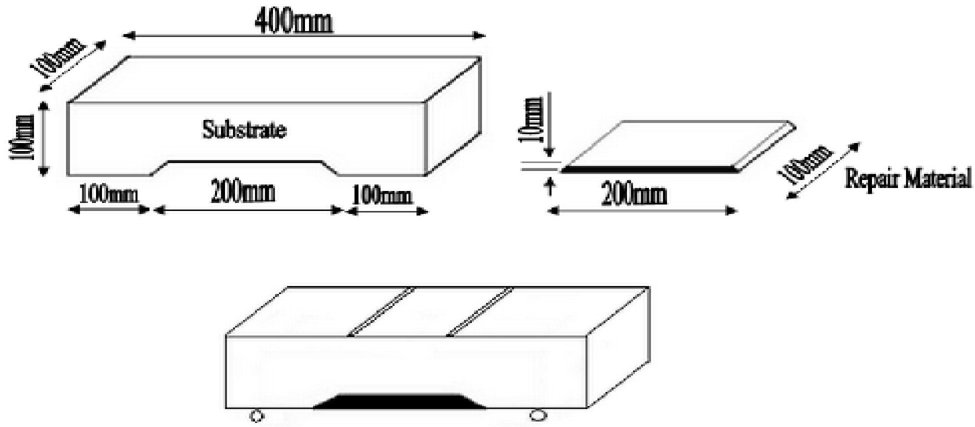
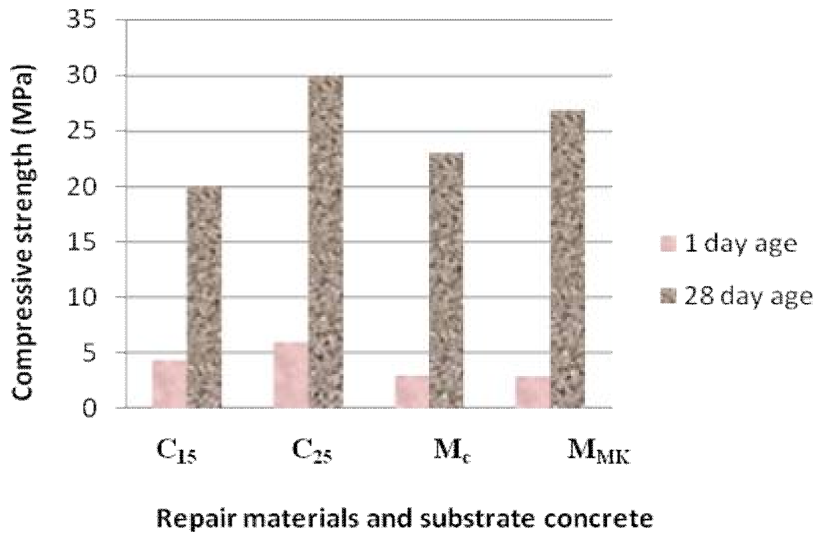


Figure (5) Third point loading composite beam

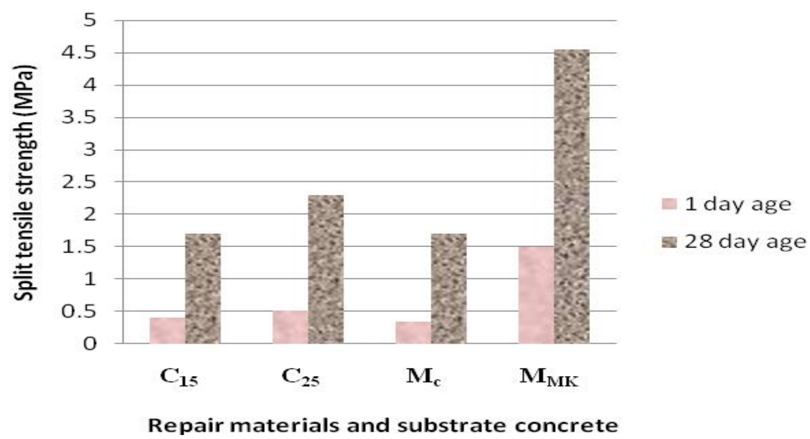
(a) Control prisms (b) Notched prisms (d) Third point load test

(e) Substrate failure (f) Repair material failure

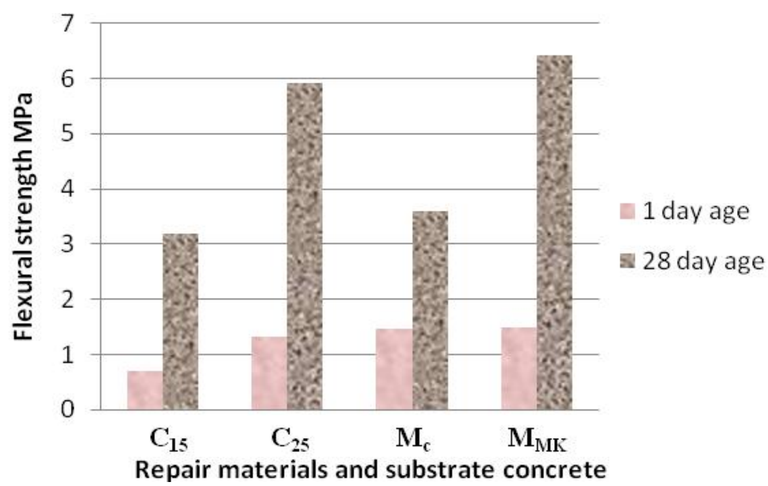
Figure (6) Compatibility test samples for composite beam of the research



a) Compressive strength development of repair materials with age



b) it tensile strength development of repair materials with age



c) **Flexural strength development of repair materials with age**

Figure (7) Strength developments of repair materials relative to substrate concrete

Notation

C_{15} = Normal substrate concrete of w/c 0.6
C_{25} = Weak substrate concrete of w/c 0.4
M_c = Conventional repair materials
M_{MK} = Metakaolin repair materials