

PAPER • OPEN ACCESS

Comparison of shrinkage related properties of various patch repair materials

To cite this article: S A Kristiawan and R S Fitrianto 2017 *IOP Conf. Ser.: Mater. Sci. Eng.* **176** 012017

View the [article online](#) for updates and enhancements.

You may also like

- [Micro/nano topography with altered nanotube diameter differentially trigger endoplasmic reticulum stress to mediate bone mesenchymal stem cell osteogenic differentiation](#)
Shi Mengqi, Song Wen, Zhang Boxin et al.
- [Fatigue life analysis and damage evaluation in glass fiber reinforced composite materials based on recycled polyethylene terephthalate](#)
Ashwani Kumar Singh and Raman Bedi
- [Synthesis and Characterization of Composite UPR/ \$\text{Fe}_3\text{O}_4\$ for Its Use as Electromagnetic Wave Absorber](#)
Yusmaniar, W A Adi, Y Taryana et al.

ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Comparison of shrinkage related properties of various patch repair materials

S A Kristiawan¹ & R S Fitrianto²

¹ SMARTCrete Research Group, Civil Engineering Department, Sebelas Maret University, Jl. Ir. Sutami No. 36A Surakarta 57126, Indonesia.

² Civil Engineering Department, Sebelas Maret University, Jl. Ir. Sutami No. 36A Surakarta 57126, Indonesia.

E-mail: s.a.kristiawan@ft.uns.ac.id

Abstract. A patch repair material has been developed in the form of unsaturated polyester resin (UPR)-mortar. The performance and durability of this material are governed by its compatibility with the concrete being repaired. One of the compatibility issue that should be tackled is the dimensional compatibility as a result of differential shrinkage between the repair material and the concrete substrate. This research aims to evaluate such shrinkage related properties of UPR-mortar and to compare with those of other patch repair materials. The investigation includes the following aspects: free shrinkage, resistance to delamination and cracking. The results indicate that UPR-mortar poses a lower free shrinkage, lower risk of both delamination and cracking tendency in comparison to other repair materials.

1. Introduction

Numerous reinforced concrete (RC) structures have been built to provide a variety of infrastructures which serve human needs and support economic activities. Some of these RC structures prove to have an excellent performance spanning for a period of more than their intended service life. However, there is also evident that many of these RC structures tends to lose their serviceability after years in use and need a repair in order to meet their service life. Patching method is an appropriate technique to repair the degraded RC structure in the form of spalling and delamination. Patching method, when correctly applied, could recover the size and appearance of RC element, regain its strength and capacity, minimize the continuing corrosion of reinforcement and ultimately extend the service life of RC structure [1-3].

The expected additional service life of the repaired RC structures will be governed by the performance and durability of repair material being used. Previous study through case history by Mathew [4] demonstrated that the common forms of repair failures are cracking of repair material (32%), delamination (25%), continues corrosion of reinforcement (22%), alkali-aggregate reaction (4%) and others (17%). Cracking and delamination which count for more than 50% of repair failures could be triggered by differential shrinkage between the repair material and parent concrete. The differential shrinkage will induce tensile stress in the repair material [5]. High induced tensile stress leads to cracking when this tensile stress attains tensile capacity of repair material. In addition to tensile stress, shear and peeling stress also exist at the interface of repair material and parent concrete.

¹ To whom any correspondence should be addressed.



High induced shear and peeling stress will promote a risk of delamination when these stresses overcome the bonding capacity of repair material to parent concrete.

Curing of repair material is a good practice to improve the material's resistance against differential shrinkage cracking. Curing will delay drying and consequently reduces the rate of shrinkage. Furthermore, curing promotes strength gain with a benefit of increasing tensile capacity of repair material. Even though curing may also reduce the stress relaxation due to an increase of repair material's stiffness, the overall effect is to reduce the risk of cracking [6]. Another approach that could improve the shrinkage cracking resistance of repair material is to incorporate fibres on the mix [7], develop a high strength-high ductility of repair material [8], make a rough surface which permits a realization of monolithic behaviour of repair system instead of smooth surface which is likely to provoke debonding [9]. The bond strength has also been identified to be influenced by the type of repair material. Greater bond strength is recognized in the following order: polymer mortar, polymer cement mortar and modified polymer cement mortar [10].

In the preceding paragraphs, the key factors influencing the risk of cracking and delamination have been highlighted and a variety of examples are shown in the development of repair materials to achieve repair materials with lower tendency of cracking and delamination. Previous research by authors [11-13] proposed a repair material made from an unsaturated polyester resin (UPR)-mortar which shows an excellent mechanical performance. In this paper, UPR-mortar is further investigated to characterize its shrinkage related properties which include free shrinkage, delamination and cracking tendency. The properties of this material are compared to other repair materials which are available commercially in the market.

2. Experimental

2.1. Materials

UPR-mortar has been developed using an unsaturated orthophthalic type resin made from the polymerization of di-carboxylic acids with glycols as the main binder. The thermo-setting of this material is initiated by curing agent (hardener). The amount of hardener was proportioned at 3% by weight of the UPR. Aggregate used for the production of UPR-mortar was sand having a bulk specific gravity of 2.51 and fineness modulus of 3.77. Fillers were also incorporated in the development of UPR-mortar. The fillers were cement and fly ash. The final composition of UPR-mortar per m³ volume was as follows: 860.7 kg of sand, 430.4 kg of UPR, 731.6 kg of cement, and 129.1 kg of fly ash. For the purpose of comparison, three other repair materials were investigated namely normal mortar (NM), SIKA repair mortar and BASF Nanocrete. The last two materials are commercially available in the market. The proportion of NM per m³ volume was as follows: 891.6 kg of sand, 757.9 kg of cement, 133.7 kg of fly ash and 285.3 kg of water. While the commercial repair mortars were mixed with water at amount specified by the respective manufacture.

2.2. Method

Free shrinkage of repair materials were measured on cylinder specimens with diameter of 76 mm and height of 276 mm following RILEM recommendation [14]. Each repair material was represented by two specimens. For each specimen, four pairs of demec points were attached on the surface of specimen at equidistant of 90°. The gauge length of this pair of demec points was 200 mm. The deformation of each specimen due to shrinkage was taken as an average of four changes of the distance between each pair of demec points. These changes in distance were measured using demountable mechanical strain gauge with a resolution of 1 micron. Figure 1 (a) illustrates the free shrinkage specimen.

The delamination of repair materials were investigated by monitoring the tendency of the materials to detach from the SPS Plate (see Figure 1 (b)). After repair material which has been cast on top of the SPS Plate reached a hardened state (in this study 1 day after casting), one of the edge of the repair beam was clamped. The other edge was left without any sorts of clamping and so, this edge would be

allowed to curl freely when the repair material exhibited shrinkage. The curling of the repair layer at this location was measured using dial gauge.

The German angle test method was adopted to measure the cracking tendency of repair materials (see Figure 1 (c)). The repair material was cast into V channel. On the following day, any visible cracks that may occur on the surface of repair materials were recorded. The observation of cracks covered the following aspects: time of initial crack, width of crack, length of crack, period of crack and propagation. Microcrack meter was used to measure the width of crack.

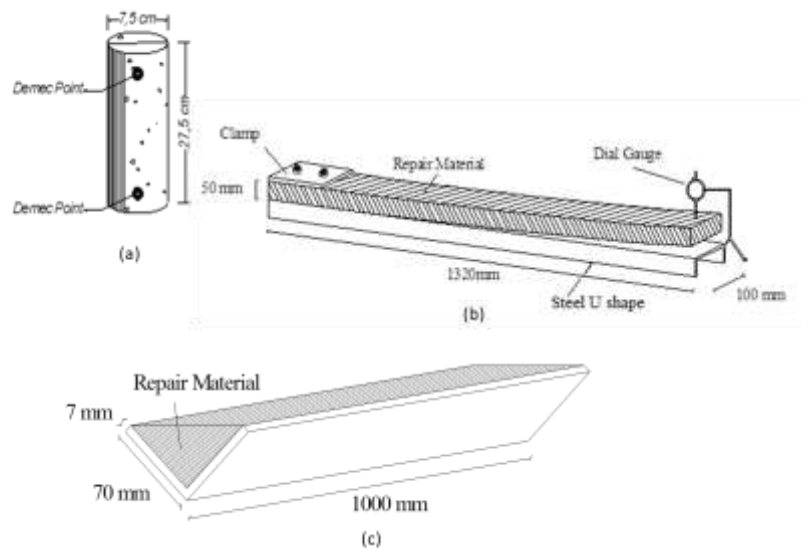


Figure 1. Specimen types for measurement of shrinkage related properties of repair material: (a) free shrinkage; (b) delamination tendency; (c) cracking tendency

3. Results and discussion

3.1. Free shrinkage

The free shrinkage of various repair materials measured for period of 30 days is presented in Figure 2. The temperature and relative humidity of the environment during test period are also presented in the figure. The fluctuation of shrinkage values is associated with the fluctuation of the environment condition especially the relative humidity. The relative humidity controls the drying process in which moisture within the pores of material evaporate to the surrounding environment. The drop of moisture in the pores induces surface tension with a consequence of shrinkage. Therefore, a fluctuation of relative humidity of the environment will create a fluctuation of drying and its subsequent shrinkage.

All repair materials show similar trend of free shrinkage behaviour i.e. shrinkage is generally increased with time at diminishing rate. The shrinkage is relatively faster at the beginning of drying and proportional to the lost of water during evaporation. The shrinkage will be restrained by the bulk material. At the beginning of hardening process, the restraint provided by the bulk material is small. In the progress of hardening, the restraint will gradually increase. Hence, both reduction of rate of water lost due to evaporation and increase of restraint provided by material in the progress of hardening could explain the observed shrinkage behaviour.

The magnitude of free shrinkage of the repair materials after 30 days of drying is in the range of 1500-3000 microstrain. This amount of shrinkage is considered to be high in comparison to the concrete. Thus, the free shrinkage of repair materials could potentially create high differential shrinkage which gives a risk of cracking and delamination. It is clearly seen in Figure 2 that UPR-

mortar exhibits the lowest magnitude and rate of shrinkage. Having the lowest shrinkage property, UPR-mortar is expected to undergo the least differential shrinkage induced stresses in comparison to other repair materials.

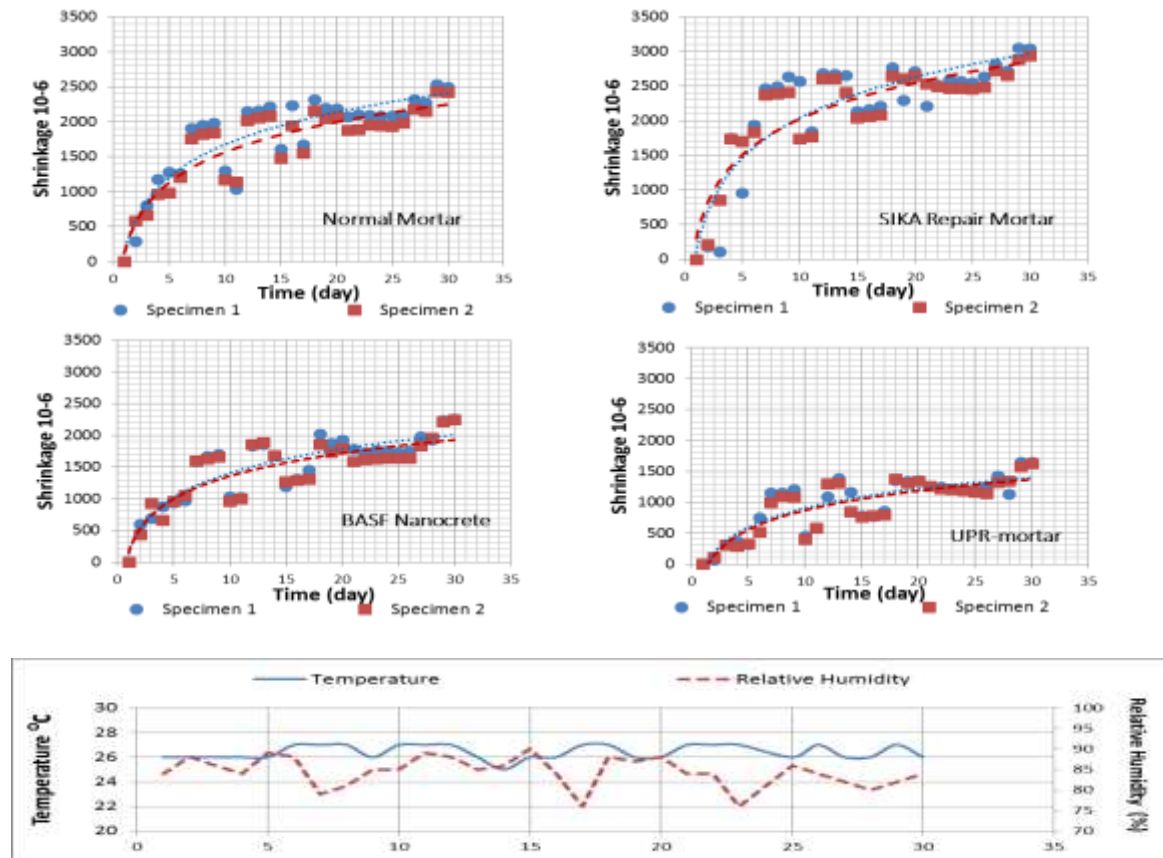


Figure 2. Free shrinkage of various repair materials and their corresponding environment condition during period of testing

3.2. Delamination tendency

Measurement of delamination tendency was carried out for period of 90 days and the results are presented in Figure 2. The delamination is represented in the form of curling of the repair material detected at the free-clamped edge. The curling is indicated by the change in elevation of surface repair material at this edge. The general trend of the delamination could be identified as follows: initially a very fast rate of curling is observed up to 10 days of drying where the curling reaches its peak value. After this period, there is a tendency of reduction in the curling. As the time is progressing, the curling continues to decrease at diminishing rate. The curling seems to attain steady condition after 40 days of drying.

The curling behaviour of repair material tested in SPS Plate is associated with restrained shrinkage action. The restraint is provided by the bond between repair material and SPS Plate. As a result of this restraint of shrinkage, there exists shear and peeling stress at the interface where the highest stresses occur at the edge. In addition to the shear and peeling stress which are the source of separation between repair material and SPS Plate, the restrained shrinkage also induces tensile stress in the repair material. This stress will trigger creep which offsets deformation of shrinkage. Recalling that shrinkage is increased at diminishing rate, the increase of creep will finally surpass the deformation of

shrinkage. Consequently, the curling will drop. For the repair materials investigated in this study, this behaviour seems to occur at 10 days of drying.

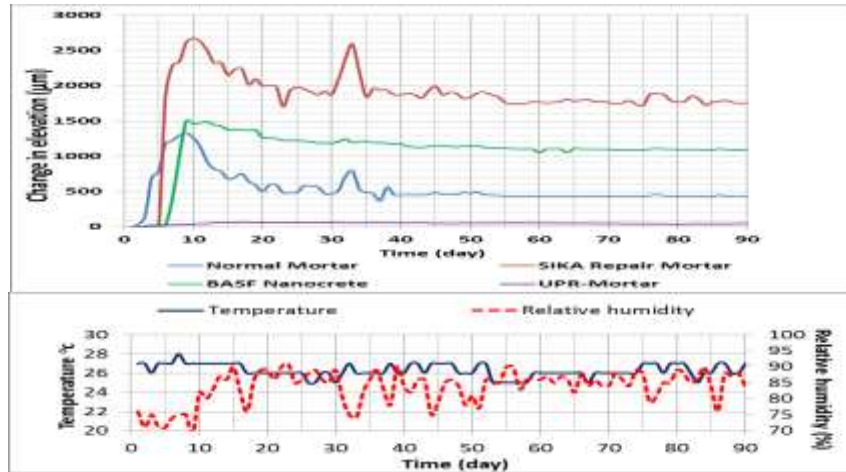
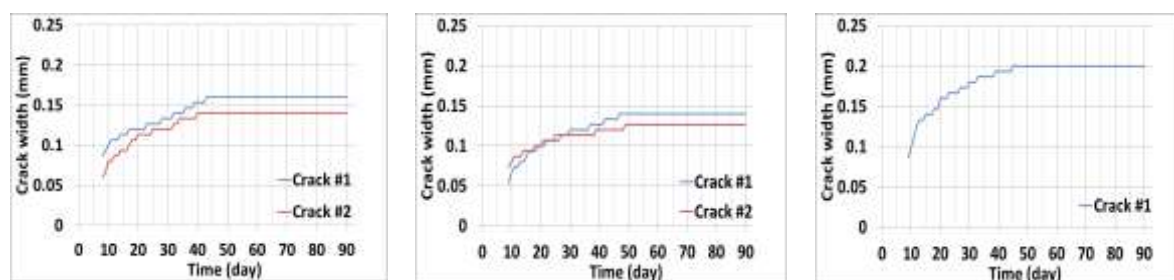


Figure 3. Delamination tendency of various repair materials due to restrained shrinkage (indicated by change in elevation) and the corresponding environment during period of testing

Repair material with higher free shrinkage will exhibit higher curling and vice versa. This is confirmed by the results of this study (see Figure 2). The low curling behaviour of UPR-mortar may also be supported by the low stiffness and high bond strength of this material [11,12]. With low stiffness, this material is able to provide high relaxation and accordingly relieve stresses that provoke separation. As for the high bond strength, this property will determine the level of accumulated stresses which are required to separate the repair material from the SPS Plate. With high bond strength, UPR-mortar could resist the stresses that may trigger separation.

3.3. Cracking tendency

Cracking tendency of various repair materials is evaluated using the German angle test method. Cracking of repair material in this test is a result of tensile stress development which surpasses the tensile capacity of repair material. The build up of tensile stress is induced by restrained shrinkage in which restraint is provided by the bonding of repair material with the surface of V channel. Crack is certain when the build up of tensile stress can not be resisted by the tensile capacity of repair material. Once the repair material cracks, a portion of the induced tensile stress will be relieved. However, as long as shrinkage of repair material is still progressing, the effect is to enlarge the existing crack. The propagation of crack width follows the rate of shrinkage progress. It is why the trend of crack width propagation is similar to the rate of shrinkage progress i.e. the crack width increase at a diminishing rate (see Figure 4). For the current study, the increase of crack width vanishes after 40-50 days of drying.



a. Sika Repair mortar (specimen 1)

b. Sika Repair mortar (specimen 2)

c. BASF Nanocrete (specimen 1)

Figure 4. Cracking evolution observed in Sika Repair Mortar and BASF Nanocrete

Table 1. Cracking of various repair materials due to restrained shrinkage

Repair material		Initial crack width (mm)	Maximum crack width (mm)	Crack length (mm)	Crack area (mm ²)	Total crack area (mm ²)
Normal Mortar	Specimen 1	NA	NA	NA	NA	NA
	Specimen 2	NA	NA	NA	NA	NA
SIKA Repair Mortar	Specimen 1	0.09	0.16	108.4	17.34	32.02
		0.05	0.14	104.8	14.67	
	Specimen 2	0.06	0.14	104.8	14.67	27.53
		0.07	0.13	101.5	12.86	
BASF Nanocrete	Specimen 1	0.09	0.20	102.5	20.50	20.50
	Specimen 2	NA	NA	NA	NA	NA
UPR-Mortar	Specimen 1	NA	NA	NA	NA	NA
	Specimen 2	NA	NA	NA	NA	NA

The results of cracking observation of the current test are presented in Table 1 and Figure 4. This test shows that cracks are only observed on the SIKA Repair Mortar and BASF Nanocrete. The maximum crack width is achieved after about 40-50 days of drying. The maximum crack width of BASF Nanocrete specimen is higher than those of SIKA Repair Mortar specimens. It is common to obtain a single crack with a higher crack width while a lower crack width is usually accompanied by more cracks. Comparison of cracking performance of the repair materials shows that UPR-mortar has an excellent performance than the commercial repair materials. With no appearance of crack, the build up tensile stress in this material did not exceed the tensile capacity of UPR-mortar.

4. Conclusions

Out of four repair materials investigated in this study, UPR-mortar exhibit the lowest magnitude and rate of shrinkage. UPR-mortar shows the lowest curling behaviour indicating that this material has the lowest risk of delamination compared to other repair materials. UPR-mortar also shows a superior cracking resistance than the commercial repair materials. The relatively low shrinkage, low stiffness and high tensile strength of UPR-mortar could ensure that the induced tensile stress due to restrained shrinkage is always kept below the strength of the UPR-mortar.

References

- [1] Rio O, Andrade C, Izquierdo D and Alonso C 2005 *J. Mat. Civ. Eng.* **17** 12 168
- [2] Sahamitmongkol R, Suwathanangkul S, Phoothong P and Kato Y 2008 *J. Adv. Con. Tech.* **6** 2 317
- [3] Supriyadi A, Kristiawan SA and Raditya S 2015 *Appl. Mech. Mat.* **754-755** 457
- [4] Matthews S 2007 *J. Build Appr.* **3** 2 6
- [5] Kristiawan SA 2012 *Int. J. Con. Struct. Mat.* **6** 4 221
- [6] Beushausen H and Bester N 2016 *Cem. Con. Res.* **87** 87
- [7] Briffaut M, Benboudjema F and D'Aloia L 2016 *Tunnel. Under. Space Tech.* **59** 215
- [8] Li M and Li VC 2009 *ACI Mat. J.* **106** 5 419
- [9] Perez F, Morency M, Bissonnette B and Courard L 2009 *Con. Rep. Rehab. Retrof.* **II** 347
- [10] Czarnecki L 2009 *Con. Rep. Rehab. Retrof.* **II** 343
- [11] Kristiawan SA and Prakoso AB 2016 *Mat. Sci. Forum.* **857** 426
- [12] Kristiawan SA and Prakoso AB 2015 *Appl. Mech. Mat.* **754-755** 442
- [13] Kristiawan SA, Supriyadi A and Muktamirin MK 2016 *Adv. Civ. Arch. Struct. Constr. Eng.* 225
- [14] RILEM TC107-CSP 1998 *Mat. Struct.* **31** 507