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# Investigating the Effect of Micro Silicon and Slag on the Mechanical Characteristics of Repaired Concretes

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**Abstract:** Due to intensive failure of concrete structures in Persian Gulf region, the cement repair and restoration operation is carried out on great number of such structures. High cost of structures repair makes it reasonable to find out ways using stable concretes with new materials as a solution for cost reduction. In the present investigation, four mix designs with 0.38 water to cement ratio considering cement material of which as 420 kg/m$^3$ is prepared in order to evaluate the effect of micro silicon, slag, and their mixture on the mechanical characteristics (compressive, bending, shearing strength and the modulus of elasticity) of repaired concretes. The results show that the micro silicon and slag mixture plays an important role in mechanical characteristics improve of the repaired concretes. In addition, applying slag improves the ductility of repaired concretes. The results also depict that all mix designs have ductility that is more proper in compare with the core concrete. The ductility feature increase would increase the repaired concrete’s strength against the fraction.

**Key words:** Repaired Concretes, Bond Strength, Modulus of elasticity, Micro silicon, Slag

## INTRODUCTION

The failure caused by concrete steel corrosion is considered as the most important factor of steel concrete structures failure in Persian Gulf region. These failures cause cracking or loss of concrete cover. In the other hand, due to such corrosion, the diameter of concrete steel is decreased and in result, the brittle fracture risk in structure elements is increased (Pargar *et al.,* 2007). According to such failures, the performance of the structure such as servicing capability and safety level is impacted and its lifetime is decreased. Through the periodical repairs in the destructed sections, the performance of the structure can be improved up to an acceptable level. Fig. 1 shows the effect of repairing on the structure servicing time increase (Trejo and Radhakrishna, 2003).

Two factors of durability and the adaptability of the repair with the core concrete of the structure are considered as the most important factors in selecting the method and materials of the repairing process (Shekarchi *et al.*, 2009; Emmons *et al.,* 1993; Morgan, D. R., 1996; Emberson and Mays 1990).

In general, the repair materials adaptability with the core concrete should guaranty the repaired system strength against the imposed stresses and should increase its protective features under particular environmental conditions and during the designing interval (Hassan *et al.,* 2000). Several factors affect the adaptability of the repair materials. The investigation results reported in (Mays and Wilkinson, 1987; Hewlett and Hurley, 1985; Emmons and Vaysbund, 1994) show that in most cases, the dimensional and mechanical adaptations and the bond maintenance between the repaired and core concretes are the most important factors among the factors impress the repair adaptation. Based on such a fact, the mechanical characteristics of the repair materials should reach to a level not result in unbalanced stiffness. In other words, the bearing share and stress distribution on the repair materials and the core concrete should fall in an acceptable range (Emberson and Mays, 1990; Marosszeky, M., 1991; Sharif *et al.,* 2006).

Applying repair materials with features similar to core concrete is an important issue in structures repair process (Wood *et al.,* 1990). The normal concrete can be utilized in a wide range of several due to its low cost. However, it shows no good performance in some cases such as in corrosive environments. Applying cement complementary materials, such as micro silicon and slag, could be important in mechanical characteristics improve and in repaired structure stability. Pozzolans affect one or more characteristics of the concrete with regard to the amount of their consumption in concrete and to the physical characteristics (silicon percentage, amorphous, particles size, and particles shape) they have (Momayez *et al.,* 2004).

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In the repaired structures, the weakest section from the viewpoint of stress bearing ability is the contact surface of repaired concrete and concrete base. Therefore, reinforcing this surface and increasing the bond strength plays an important role in structure's repaired elements bearing capability. Several techniques are reported in literatures to evaluate bond strength in the faying surface of repaired and the core concrete. Momayez et al., (2004) have reported a simple method in compare with the other approaches to obtain the bond strength of repaired and core cement, which presents results that are more acceptable from data dispersion and numerical analysis point of view in compare with the other approaches. In this paper, this technique is used to measure the shearing strength. The results of previous researches show that the micro silicon application improves the bond strength of the concrete, due to its great pozzolan activity (Momayez *et al.,* 2004). Due to this fact, adding 7% micro silicon up to the concrete increases the bond strength up to 25% while more micro silicon addition, no more affects the bond strength. Applying slag on plain concretes increases the stability of concrete structures in marine environments as well as performance increase and hydration caused heat reduction. The pozzolan characteristics of slag make it to be widely applied as a substitution for a part of normal concrete for destructed and damaged structures repair (Sisomphon, 2009). The researches well show that the permeability of the slag applied concretes is less than that of the normal ones. However, they demonstrate the slow trend of gaining compressive strength in comparing with plain concrete during early ages (Bouikni *et al.,* 2009).

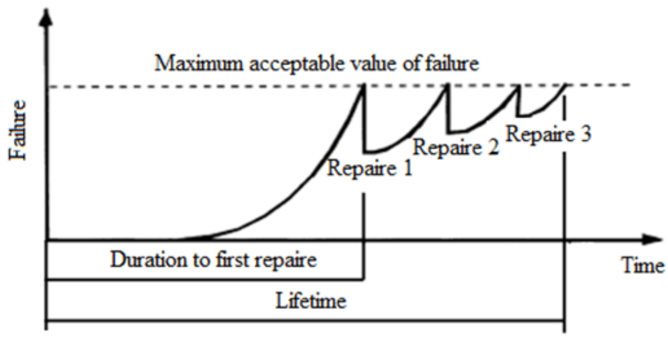


**Fig. 1:** The lifetime presentation of structures considering the structure condition improve after repair

In this paper, the effect of micro silicon, slag, and the mixture of these pozzolan materials on the mechanical characteristics (compressive, bending, shearing strength and the modulus of elasticity) of the repaired concrete is investigated.

***Laboratory Program:***

In this paper, four mix designs with 0.38 water to cement ratio, considering cement material of which as 420 $kg/m^3$ is prepared in order to evaluate the effect of micro silicon, slag, and their mixture on the mechanical characteristics (compressive, inflective, incisive strength and the modulus of elasticity) of repaired concretes. For the core concrete, the water to cement ratio and cement materials alloy are considered 0.34 and 440 $kg/m^3$, respectively. Table 1 shows the materials specifications applied in the mixtures. The cement used here for repair concretes is Hormozgan type 2 concrete, and slag Portland cement of Isfahan Sepahan concrete firm. For the core concrete, the type 1 concrete of Tehran concrete firm is used. The pozzolans used in the mixtures for repair concretes quality improve is micro silicon and slag. Slag well exists in the mixture form in the Isfahan slag cement. Table 2 shows the chemical analysis of the micro silicon and Isfahan slag Portland cement. The mix designs specifications are well depicted in Table 3.

**Table 1:** The specifications of the materials used in the mix designs

| | Materials Type | | Characteristics |
|---|---|---|---|
| 1 | Stone materials | Granular | sand |
| | | Coarse | Gravel with 16 mm nominal size |
| 2 | Cement | | Portland Type 1 |
| | | | Portland Type 1 |
| | | | Slag Portland (25% Slag) |
| 3 | Super lubricant | Gelenium 51 | PoliKarboksilat |

**Table 2:** The chemical characteristics of the Isfahan slag Portland cement and the micro silicon

| Cement Type | Chemical analysis based on percentage | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | $SO_3$ | L.O.I |
| Slag Portland Cement | 25.41 | 8 | 2.30 | 56.5 | 3.3 | 0.4 | 0.6 | 1.86 | 1 |
| Micro cilicon | 93.16 | 1.13 | 0.72 | 0 | 1.6 | 0 | 0 | 0.05 | 1.58 |

The compressive strength test is accomplished on the 3, 7, 28, and 90 days old concrete samples corresponding to the ASTM C39 standard in the cylindrical 15*30 testers. The bending strength test is accomplished on the 28 and 90 days old prismatic samples corresponding to the ASTM C78 standard. In this test, the middle one third is under loading. The bond strength test is carried out on the cubical 15*15 samples applying two-level technique. In order to prepare the test samples, two third of the form is filled by concrete initially. Next day, the samples layers are **s**errated and are cured in water for 28 days. After the production period, the samples are left in the air to achieve the structure's core concrete characteristics. The core concretes are placed in the templates again and the repair concrete is added to the empty one third of the templates. The laboratory samples are provided as table 3 and are maintained in 23°C according to ASTM C192 standard.

**Table 3:** The specifications of the mix designs

| Mix design code | Cement Material ($Kg/m^3$) | | | | | Water to cement material ratio | Aggregate ($Kg/m^3$) | | Super lubricant ($Kg/m^3$) | Slump (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cement Type | Cement Value | Cement replaced materials | | Total | | | | | |
| | | | Micro silicon | Slag | | | sand | Gravel | | |
| R-SF | Hormozgan Type2 | 390.5 | 29.5 | - | 420 | 0.38 | 992 | 793 | 2.5 | 155 |
| R | Hormozgan Type2 | 420 | - | - | 420 | 0.38 | 1000 | 793 | 2.1 | 140 |
| R-SFS | Slag of Esfahan | 285.5 | 29.5 | 105 | 420 | 0.38 | 973 | 793 | 2.1 | 150 |
| R-S | Slag of Esfahan | 315 | - | 105 | 420 | 0.38 | 980 | 793 | 2.1 | 180 |
| BASE-C | Tehran Type 1 | 440 | - | - | 420 | 0.34 | 1161 | 720 | 3.2 | 140 |

### *The laboratory Results Evaluation:*

### *The Compressive Strength:*

The compressive strength is considered as one of the most important features of concrete and is generally the major quality control index of the concrete. Several factors affect the compressive strength. In this paper, it is tried to investigate just the effect of micro silicon and slag on the repaired concretes. According to the fact that the repaired part of the concrete structure bears the dead load, it is better if the repaired concrete reaches to an acceptable strength during the early ages to minimize the undesirable effects of loading which might result in discontinuity in repaired and core concrete connection region. In the latter ages, or during the servicing time, it is necessary to have repaired concrete similar with the core concrete from strength point of view in order to have coordinated performance between two concretes. The laboratory results well show that the most and the least compressive strength in three days and seven days old concretes are related to the R-SF and R-S mix designs, respectively. According to Fig. 3, the most compressive strength increase until 28 days and 90 days old relates to the R-SFS and R-S mix designs in a way that the most compressive strength in 90 days old is of slag mixture.

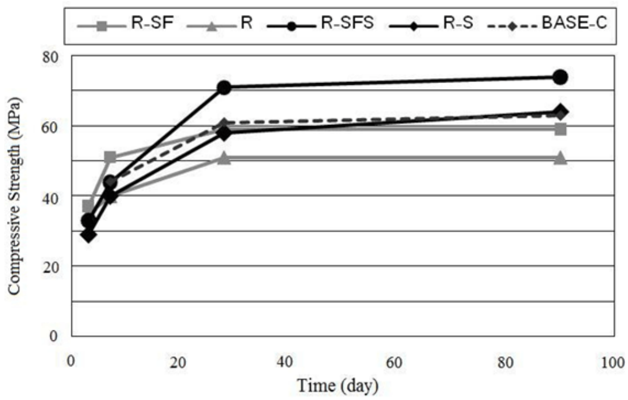


**Fig. 2:** The compressive strength gaining process in terms of time in several mixtures

In concretes which a combination of micro silicon and slag is used, the compressive strength gaining starts from the first ages and continues for long time. The compressive strength gaining process of R-S is better than that of the R-SF and R mix designs. According to Fig. 2, the R-S mix design seems to be more appropriate for concrete structures repair holding BASE-C characteristics.

***2.2. Bending Strength:***

The Bending strength of the repaired concretes depends on the type of structure must be repaired. For example, in beam elements, the composite mast behavior state should be evaluated initially and the repair concretes with proper bending stiffness should be utilized then according to the accomplished calculations. The results well depict that the R-SF mix design holds more bending strength in compare with R mix design in 28 days and 90 days old. In addition, the bending strength of R-SFS is more than that of R-S. The maximum bending persistent is of R-SFS mix design. In this experiment, the positive effects of micro silicon and slag mixture on the bending strength improve is not deniable as well as compressive strength increase.

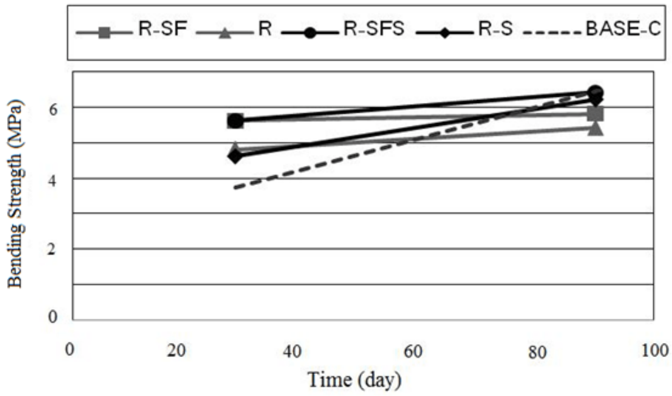


**Fig. 3:** The bending strength gaining process in terms of time in several mix designs

***2.3. The shearing Strength:***

The bond strength exists between the repair and the core concretes, is distinctively important in repaired structure bearing from between two layers power transmission viewpoint. The most important factors affect the bond strength of a repaired system are the roughness created on the core concrete and the type of repair materials. In the conducted experience, the roughness level of core concrete samples (BASE-C) fall in a mean level (4-5 mm) and it is tried (ocular) in all samples to keep this roughness constant. Therefore, the cement material type is the most effective factor affects the bond strength of a repaired system with constant roughness.

A two-layer shearing experiment is conducted on the unified cubical samples made of BASE-C mixture. The bond strength is obtained as 3.33 MPa for the unified samples.

The bond strength value obtained from two-layer shearing experiment is the combination of shearing and bending strength. Due to deep beam theory, the effect of bending strength on the bond strength is low and can easily be neglected. Therefore, the shearing strength of the samples can show the bond strength exists between core and repair concretes.

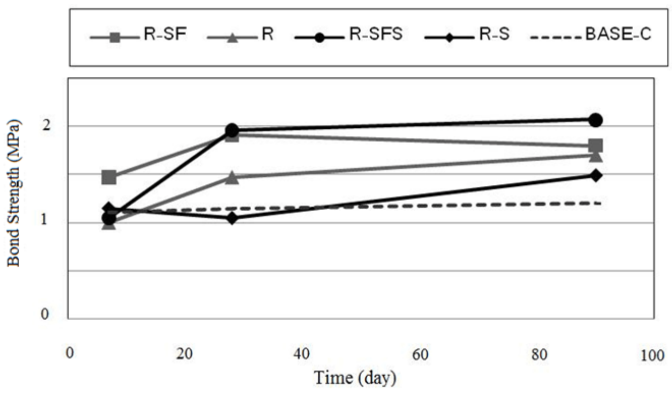


**Fig. 4:** The bond strength gaining process in terms of time

Fig. 4 shows the results of two-layer experiment. As it is obvious, the R-SF repair concrete mix design shows the most bond strength during the early ages due to micro silicon existence. The bond strength of other mixtures is almost the same in 7 days old. Bond strength increase of 28 days old R-SFS mix design is more than that of other mix designs and the maximum bond strength in 90 days old is related to the R-SFS mix design, which shows the positive influence of slag on the concrete performance in longer time. The least bond strength is of the BASE-C mixture. The results well show that the micro silicon and slag mixture can desirably affect the bearing feature of repaired system in both early and later ages.

Fig. 5 shows the loading and fracture mode of the shearing samples. For micro silicon added mixtures, the dominant mode of fracture is as Fig. 5-b, which shows an appropriate bond of core and the repaired concretes. For slag mix designs, the dominant fracture mode is as Fig. 5-c for the early ages and is as Fig. 5-b for the later ages.


Fig. 5. the loading condition and mode of fracture: a. loading, b. two-layer mode fracture, c. single-layer mode of fracture

### *2.4. Modulus of Elasticity:*

Elasticity is one of the most important and effective parameters influence a repaired system. The stress distribution between core and repaired concretes would not be uniform if the modulus of elasticity is not the same. It is critical if the repaired concrete is stiffer than the core concrete. Here, the repaired concrete bears more load and stress concentration increases in faying surface. This can lead to sudden fracture of the connection. The repaired system shows more unified performance against the imposed pressures as much as the differences between two core and repaired parts are less. In this paper, the ratio of repaired concrete's elasticity to that of the core concrete is considered as a standard to calculate the stress distribution. As this ratio tends to unit (1), the elasticity feature of repaired concrete more closes to that of core concrete and consequently, more uniform stress distribution will be applied on the repaired structure. Table IV, shows the results obtained from experiments conducted for modulus of elasticity and depicts the modulus of elasticity ratio of core and repaired concretes. Based on the results, the modulus of elasticity of the repair mixture is more than that of the core concrete. The least modulus of elasticity level belongs to the R-S mix design, which well shows that the ductility feature of slag concretes is more than the other mixtures. The results depict that all mixtures hold generally proper ductility feature.

**Table 4:** The results of modulus of elasticity and modulus of elasticity ratio of core and repaired concretes

| Mix design code | R-SF | R | R-S | BASE-C |
|---|---|---|---|---|
| elasticity modulus (GPa) | 38 | 40 | 37 | 36 |
| Modulus Ratio ($E_{Repair-C}/E_{BASE-C}$) | 1.06 | 1.11 | 1.03 | 1.00 |

### *Conclusion:*

The repaired and core concretes should fall in similar strength class in order to perform coordinative. The repaired concretes in which slag is applied, show less compressive strength during the early ages and show more in the later ages. The maximum compressive strength during the early ages and in long time relates to R-SF and R-SFS mix designs, respectively.

The maximum compressive strength is of the R-SFS mix design, which shows the positive influence of micro silicon and slag mixture on bending strength of the repaired structure.

The maximum bond strength, in early ages and in later ages, is of R-SF and R-SFS mix designs, respectively. The slag and micro silicon mixture in R-SFS increases bond strength in early ages due to micro silicon existence and in later ages due to slag existence.

The repaired concrete ratio to core concrete is one of the most important factors in repairing concrete selection. The repairing concretes with more close to unit (1) modulus of elasticity more perform similar to the core concrete from stress distribution in repair system viewpoint.

The slag made repair concretes possess less modulus of elasticity in compare with the plain concretes and the ones possessing micro silicon. Therefore, applying slag to repair the concrete structures core concrete which hold low amount of module is recommended.

Due to the obtained results, the micro silicon and slag mixture can maintain its pozzolan activity as a pozzolan mixture either in early ages or later in long term. Therefore, the mixture of these pozzolans can improve the mechanical characteristics of the repaired concretes. This scheme possesses a proper elasticity module (close to the core concrete) in addition to holding adequate compressive strength close to the core concrete.

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