Different Concrete Types Affecting the Bond Strength and Interfacial Joints between New and Old Concrete

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Abstract. The connections between concrete layers of different ages may occur in a wide range of situations, from structures rehabilitation and repairs to the construction of new buildings. This research represented an experimental study of shear forces across the joint between different concretes forming a composite action. To better understand the bond mechanism at the interface between different concrete types and old and new concrete surfaces. Overlaid specimens were fabricated to measure shear bond strength at different ages. Different parameters and a significant influence on the bond strength will be presented to evaluate the shear capacity at the interface including (the shear force for three types of the concrete cast at the same time, the shear force for three types of the concrete cast at a different time and study the effect of steel fiber on bonding mechanism). The experimental work was verified with numerical analysis carried out using ANSYS software. The general behavior of the finite element models shows a proved compatibility with the experimental test results.

1. Introduction

The interface is a separating of the two concretes in composite construction. The highly stressed interface is a potential failure plane, through which shear stress is transferred, and direct shear failure may occur [1, 2]. When two concrete members cast at different times, an interface will be formed between the contact surfaces of the two members. To entirely comprehend the mechanism of bonding at the interface within old and new surfaces of concrete, it is necessary to estimate bond strength at the interfacial layer and to examine affecting parameters of its characteristics [3,4]. Numerous investigations have concentrated on the bond mechanism. In certain applications, the characteristics of the interfacial bond essentially relay on the cohesion in the repair concrete and substrate concrete, adhesion within the concrete substrate at the interface and the repair concrete, aggregate interlock, friction and other time-dependent factors which in turn, depend on other variables. The determined bond strength is extremely conditioned on the test design employed. Numerous examinations are prepared to measure bond strength [5, 6]. Despite, insufficient knowledge is available on the identification of these different test methods and the resulting bond strength values. Based on the constituent material, mix design, construction method, and application area, different types of concrete are produced with different properties and applications. Due to the weak performance of concrete in tension, additive materials like steel fiber with different amounts and different shapes added to the concrete mixture causing qualitative changes in the physical property of concrete, resistance to cracking, fatigue, impact, flexural, durability, and other properties [7-11].

2. Literature review

Ju’lio et al. (2005) [12] evaluate the bond strength with Pull-off tests within two concrete layers, utilizing various procedures for developing the roughness. Pedro et al. (2006) [13] investigate the bond strength with pull-off tests and slant shear with different roughness. Eduardo et al. (2006) [14] studied concrete different mixtures, different ages, and strengths for the bond strength within two concrete layers. Mukhallad A Z (2007) [15] proposed a modified push-out analysis to investigate the load-slip relationship in steel-concrete-steel sandwich beams. Al-Sulayvani B J, and Al-Feel J R (2008) [16]
utilized a push-off and modified push-off type to study the shear transfer of uncracked fibrous concrete. Result revealed fiber increased stiffness, ductility, and strain capacity. Beushausen H, and Alexander M G (2008) [1] introduced interface shear strength with two new experimental methods, which have proved to be practical in bond mechanisms. Muhaned A S and Sallal R (2008) [4] studied the shear transfer strength experimentally and numerically with a finite element model of concrete with the influence of steel depending on Push-off tests. Husain et al. (2009) [17] studied different concretes with eight tests in which in-plane shear forces are applied across the composite action. Shin and Wan Z (2010) [2] fabricated overlaid specimens to study the interface bonding mechanism within old and new concrete surfaces, with different materials and additives. Aseel S M (2010) [5] introduced three test methods; (slant shear, splitting prism and Bi-Surface shear) with conventional and two polymer modified repair mortars to evaluate the bond strength for various models of repair substances. Pedro M D and Eduardo N B (2011) [18] performed an experimental investigation managed to evaluate the impact of stiffness and shrinkage of old and new concrete interfaces bond strength. Janan R A and Ragad S (2011) [19] investigated the shear transfer between self-compacting concrete and precast normal concrete by utilizing different techniques for surface processing like steel bars, and sand-blast. Amar et al. (2012) [20] analyzed modified push-out experiments managed for the purpose of high strength steel shear strength and stiffness. Magda I M (2015) [6] direct shear, flexural and splitting tests, were managed on substrate-repairing concrete composite units with different bonding elements and interface roughness. Hakim S M (2015) [21] simulates the shear strength with a mathematical-statistical trial and experimental work including a series of push-off tests. Vandhiyan R, and Kathiravan M (2017) [22] investigation was conducted to estimate the bond strength among old and new concrete layers, applying various tests for adding an epoxy-based bonding agent.

3. Details of Experimental Work
An experimental program is conducted to find between different types of concrete the bond strength. Mixes were divided into four different types with different concrete properties [3]. Different engineering properties were performed including (compressive strength, tensile splitting strength, flexural strength, weight change and density). For compressive strength 3 cylinders (100x200mm) and 3 cube (100x100x100mm), splitting tensile strength 3 cylinders (100x200mm), density and weight change 3 cubes (100x100x100mm) and flexural strength 3 prism (100*100*400mm) were prepared for each mix. All work was investigated for over 28 days. Table 1 displays the details of various types of mixes used in the current examination work. Plywood molds were prefabricated to cast the specimens. It consists of three (100*150*200mm) as shown in Figure 1 size prisms separated by thin plywood sheets. For the same concrete the mold full of concrete without separation. While for the different mixes mold the edge prisms were cast first, while the middle prism cast later or for the old connection it was cast at after 28 days. Surface treatments of the interface were done on the edge prisms, before casting the middle prism. The experimental program includes testing 16 specimens with different concrete types tested under shear, as shown in Table 2.

| Concrete type                  | Cement kg/m³ | Sand kg/m³ | aggregate kg/m³ | w/c | Superplasticizer (%) by weight of cement | Silica Fume (%) | Steel fiber (%) |
|-------------------------------|---------------|------------|-----------------|-----|----------------------------------------|----------------|----------------|
| Normal Concrete               | 420           | 650        | 1000            | 0.45| --                                     | --             | --             |
| High Strength concrete        | 560           | 635        | 1085            | 0.27| 1.5                                    | --             | --             |
| Ultra-high strength concrete  | 1000          | 1000       | ---             | 0.2 | 6.8                                    | 25             | --             |
| Ultra-high strength concrete  | 1000          | 1000       | ---             | 0.2 | 6.8                                    | 25             | 1.0            |
Figure 1. Shape of mold used.

Table 2. Experimental program specimens with different concrete type.

| Molds       | Concrete position and type | Molds       | Concrete position and type | Molds       | Concrete position and type |
|-------------|---------------------------|-------------|---------------------------|-------------|---------------------------|
| Mold 1      | All Normal concrete       | Mold 2      | All high strength concrete | Mold 3      | All ultra-high strength concrete |
|             | Cast together at the same time |             | Cast together at the same time |             | Cast together at the same time |
| Mold 4      | Normal concrete           | Mold 5      | Normal concrete            | Mold 6      | high strength concrete      |
|             | and high strength concrete Cast together at the same time |             | and ultra-high strength concrete Cast together at the same time |             | and ultra-high strength concrete Cast together at the same time |
| Mold 7      | Normal concrete           | Mold 8      | Normal concrete            | Mold 9      | high strength concrete      |
|             | and high strength concrete Cast at different time |             | and ultra-high strength concrete Cast at different time |             | and ultra-high strength concrete Cast at different time |
| Mold 10     | Normal concrete           | Mold 11     | Normal concrete            | Mold 12     | high strength concrete      |
|             | and high strength concrete Cast at the same time with fiber |             | and ultra-high strength concrete Cast at the same time with fiber |             | and ultra-high strength concrete Cast at the same time with fiber |
| Mold 13     | Normal concrete           | Mold 14     | Normal concrete            | Mold 15     | high strength concrete      |
|             | and high strength concrete Cast at different time with fiber |             | and ultra-high strength concrete Cast at different time with fiber |             | and ultra-high strength concrete Cast at different time with fiber |
| Mold 16     | All ultra-high strength concrete Cast together at the same time with fiber | |

4. Mixing procedure of Specimens

In the case of regular or high-performance mixtures are poured normally where dry materials are initially mixed from cement, sand, and gravel for a certain period and then added the water to obtain a homogeneous mixture. As for ultra-high-strength concrete mixes, dry materials are mixed together including of cement, sand and gray silica fume from (BASF company) to obtain high density and high compressive strength, then water with the superior plasticizer of (Sika ViscoCrete-PC5390) add to the mixture to get a homogeneous mixture and for the mixture containing fiber, the fiber is added finally by hand to distribute evenly. After finishing the casting process, the homogeneous mixture is distributed to the molds where it is filled with three layers and shaken using shakers to remove the air.
from the concrete to obtain a homogeneous casting. The surface of the molds shall be modified and coated with plastic to block the evaporation of water from the concrete by air for a whole day and then taken out of the molds and placed in water containers for 28 days after which they are taken out in preparation for the examination day. Figure 2 shows the materials used and experimental work test.
5. Concrete fresh and hardened properties

Several types of examinations for hardened concrete were formed which are cylinders and cubes examined in compression and cylinders tested in tension, prisms for flexure and cube for density and weight change. Results were analyzed and discussed in tables and figures forms of mechanical properties of all mixtures for different mixes specimens. Five main properties of hardened concrete are considered. They are the compressive strength, splitting and flexural tensile strength, weight change and density. For each of these properties, the average value of three specimens was obtained. Table 3 and Figures 3-8 show the concrete fresh and hardening characteristics for different concrete type.

Table 3. Concrete fresh and hardening properties.

| Test         | Compressive strength (MPa) | Density (kg/m³) | Splitting tensile strength (MPa) | Flexural tensile strength (MPa) | Weight change (%) |
|--------------|-----------------------------|-----------------|---------------------------------|-------------------------------|------------------|
| Mix          | cylinder 100*200mm (%)      | cube 100*100mm  | %                               | cylinder 100*200mm %          | Prism 100*100*400 mm | %                     | cube 100*100mm %      | %                     |
| Normal concrete | 26 0 31 0 2369 0 3.0 0 3.0 0 2.3 0 | 46 76.9 53 71 2450 3.4 4.2 40 4.4 46.6 1.8 - 21.7 | 61 134.6 67 116 2543 7.3 5.1 70 5.1 70 0.9 - 60.8 |
| High Strength concrete | 46 76.9 53 71 2450 3.4 4.2 40 4.4 46.6 1.8 - 21.7 | 61 134.6 67 116 2543 7.3 5.1 70 5.1 70 0.9 - 60.8 |
| Ultra-high strength concrete | 61 134.6 67 116 2543 7.3 5.1 70 5.1 70 0.9 - 60.8 |

1- When concrete changed from N to H and UH, the compressive strength for cylinder (100*200mm) increased by (76.9 and 134.6%) and the splitting tensile strength increased by (40 and 70%). For cube (100*100mm) the compressive strength increased by (71 and 116%), density increased by (3.4 and 7.3%) and weight changed decreased by (21.7 and 60.8%). For prism (100*100*400mm) the flexural strength increased by (46.6 and 70%)
6. Results of bond strength and Discussion

The purposes of the experimental program are conducted to find the relation between different types of concrete. These mixes were divided into four different mixes with different concrete properties. All work was investigated for over 28 days.

1-When all normal (N-N-N) concrete cast together at the same time changed to all high (H-H-H) or ultra-high-strength concrete (UH-UH-UH) with or without fiber cast together at the same time an increase of about (26.83, 48.78 and 73.17%) as shown in Table 4 and Figure 9.

Table 4. Shear test results of (normal-high and ultra-high strength concrete).

| Mold | Details | Left side | middle | Right side | shear stress (MPa) | Increasing (%) |
|------|---------|-----------|--------|------------|-------------------|---------------|
| 1    | All Normal concrete Cast together at the same time | new | N   | N   | N   | 4.10             | 0.00          |
| 2    | All high strength concrete Cast together at the same time | new | H   | H   | H   | 5.20             | 26.83         |
| 3    | All ultra-high strength concrete Cast together at the same time | new | UH  | UH  | UH  | 6.10             | 48.78         |
| 16   | All ultra-high strength concrete Cast together at the same time with fiber | new | UHF | UHF | UHF | 7.10             | 73.17         |

Figure 9. Shear stress and increasing percentage for normal, high and ultra-high strength concreted.

2-When all normal (N-N-N) concrete cast together at the same time changed to (N-H-N), (N-UH-N) and (H-UH-H) cast together at the same time an increase of about (7.31, 26.8 and 41.4%) as shown in Table 5 and Figure 10.

Table 5. Shear test results of (normal-high and ultra-high strength concrete) casting at the same time.

| Mold | Details | Left side | middle | Right side | shear stress (MPa) | Increasing (%) |
|------|---------|-----------|--------|------------|-------------------|---------------|
| 1    | All Normal concrete Cast together at the same time | new | N | N | N | 4.10 | 0.00 |
| 4    | Normal concrete and high strength concrete Cast together at the same time | new | N | H | N | 4.40 | 7.31 |
| 5    | Normal concrete and ultra-high strength concrete Cast together at the same time | new | N | UH | N | 5.20 | 26.8 |
| 6    | high strength concrete and ultra-high strength concrete Cast together at the same time | new | H | UH | H | 5.80 | 41.4 |
3-When all normal (N-N-N) concrete cast together at the same time changed to (N-H-N), (N-UH-N) and (H-UH-H) cast at a different time a decreasing of about (23.65, 12.19 and 2.44%) as shown in Table 6 and Figure 11.

Table 6. Shear test results of (normal-high and ultra-high strength concrete) casting at different time.

| Mold | Details | Left side | middle | Right side | shear stress (MPa) | Increasing (%) |
|------|---------|-----------|--------|------------|-------------------|----------------|
| 1    | All Normal concrete Cast together at the same time | new | N      | N          | N                 | 4.10           | 0.0            |
| 7    | Normal concrete and high strength concrete Cast at different time | old | N      | H          | N                 | 3.13           | -23.65         |
| 8    | Normal concrete and ultra-high strength concrete Cast at different time | old | N      | UH         | N                 | 3.60           | -12.19         |
| 9    | High strength concrete and ultra-high strength concrete Cast at different time | old | H      | UH         | H                 | 4.00           | -2.44          |

4-When all normal (N-N-N) concrete cast together at the same time changed to (NF-HF-NF), (NF-UHF-NF), (HF-UHF-HF) and (UHF-UHF-UHF) cast together at the same time but with fiber addition an increase of about (18.3, 43.9, 64.63 and 73.17%) as shown in Table 7 and Figure 12.

Table 7. Shear test results of (normal-high and ultra-high strength concrete) casting at the same time with fiber.

| Mold | Details | Left side | middle | Right side | shear stress (MPa) | Increasing (%) |
|------|---------|-----------|--------|------------|-------------------|----------------|
| 1    | All Normal concrete Cast together at the same time | new | N      | N          | N                 | 4.10           | 0.0            |
| 10   | Normal concrete and high strength concrete Cast together at the same time with fiber | new | F      | NF         | HF               | 4.85           | 18.3           |
| 11   | Normal concrete and ultra-high strength concrete Cast together at the same time with fiber | new | F      | NF         | UHF              | 5.9            | 43.9           |
| 12   | High strength concrete and ultra-high strength concrete Cast together at the same time with fiber | new | F      | HF         | UHF              | 6.75           | 64.63          |
| 16   | All ultra-high strength concrete Cast together at the same time with fiber | new | UHF    | UHF        | UHF              | 7.10           | 73.17          |
5-When all normal (N-N-N) concrete cast together at the same time changed to (NF-HF-NF) and (NF-UHF-NF) cast different time but with fiber addition a decreasing of about (18.29 and 3.658%) and when it changed to (HF-UHF-HF) cast at different time but with fiber addition an increase of about (9.75%) as shown in Table 8 and Figure 13.

Table 8. Shear test results of (normal-high and ultra-high strength concrete) casting at different time with fiber.

| Mold | Details | Left side | middle | Right side | shear stress (MPa) | Increasing (%) |
|------|---------|-----------|--------|------------|-------------------|----------------|
| 1    | All Normal concrete Cast together at the same time | new | N | N | N | 4.10 | 0.00 |
| 13   | Normal concrete and high strength concrete Cast at different time with fiber | old | HF | NF | NF | 3.35 | -18.29 |
| 14   | Normal concrete and ultra-high strength concrete Cast at different time with fiber | old | NF | UHF | NF | 3.95 | -3.658 |
| 15   | High strength concrete and ultra-high strength concrete Cast at different time with fiber | old | HF | UHF | HF | 4.5 | 9.75 |

6-The effect of fiber increased the shear stress of about (10.23, 13.46 and 16.38%) when (N-H-N), (N-UH-N) and (H-UH-H) cast together at the same time changed to (NF-HF-NF), (NF-UHF-NF) and (HF-UHF-HF) cast together at the same time but with fiber as shown in Table 9 and Figure 14.

Table 9. Shear test results of (normal-high and ultra-high strength concrete) casting at the same time compared to fiber mix.

| Mold | Details | Left side | middle | Right side | shear stress (MPa) | Increasing (%) |
|------|---------|-----------|--------|------------|-------------------|----------------|
| 4    | Normal concrete and high strength concrete Cast together at the same time | new | N | H | N | 4.40 | 0 |
| 5    | Normal concrete and ultra-high strength concrete Cast together at the same time | new | N | UH | N | 5.20 | 0 |
| 6    | High strength concrete and ultra-high strength concrete Cast together at the same time | new | H | UH | H | 5.80 | 0 |
| 10   | Normal concrete and high strength concrete Cast together at the same time with fiber | new | F | NF | HF | 4.85 | 10.23 |
| 11   | Normal concrete and ultra-high strength concrete Cast together at the same time with fiber | new | F | NF | UHF | 5.9 | 13.46 |
high strength concrete and ultra-high strength concrete Cast together at the same time with fiber

| Mold | Details                                                                 | Left side | middle | Right side | shear stress (MPa) | Increasing (%) |
|------|-------------------------------------------------------------------------|-----------|--------|------------|--------------------|----------------|
| 7    | Normal concrete and high strength concrete Cast at different time       | old       | N      | H          | N                  | 3.13           | 0              |
| 8    | Normal concrete and ultra-high strength concrete Cast at different time | old       | N      | UH         | N                  | 3.60           | 0              |
| 9    | high strength concrete and ultra-high strength concrete Cast at different time | old | H      | UH        | H                  | 4.00           | 0              |
| 13   | Normal concrete and high strength concrete Cast at different time with fiber | old       | NF     | HF         | NF                 | 3.35           | 7.03           |
| 14   | Normal concrete and ultra-high strength concrete Cast at different time with fiber | old       | NF     | UHF        | NF                 | 3.95           | 9.72           |
| 15   | high strength concrete and ultra-high strength concrete Cast at different time with fiber | old | HF     | UHF       | HF                 | 4.5            | 12.50          |

Figure 14. Shear stress for normal, high and ultra-high strength concrete casting at the same time compared to fiber mix.

The effect of fiber increased the shear stress of about (7.03, 9.72 and 12.5%) when (N-H-N), (N-UH-N) and (H-UH-H) cast at different time changed to (NF-HF-NF), (NF-UHF-NF) and (HF-UHF-HF) cast at different time but with fiber as shown in Table 10 and Figure 15.

Table 10. Shear test results of (normal-high and ultra-high strength concrete) casting at different time compared to fiber mix.

| Mold | Details                                                                 | Left side | middle | Right side | shear stress (MPa) | Increasing (%) |
|------|-------------------------------------------------------------------------|-----------|--------|------------|--------------------|----------------|
| 7    | Normal concrete and high strength concrete Cast at different time       | old       | N      | H          | N                  | 3.13           | 0              |
| 8    | Normal concrete and ultra-high strength concrete Cast at different time | old       | N      | UH         | N                  | 3.60           | 0              |
| 9    | high strength concrete and ultra-high strength concrete Cast at different time | old | H      | UH        | H                  | 4.00           | 0              |
| 13   | Normal concrete and high strength concrete Cast at different time with fiber | old       | NF     | HF         | NF                 | 3.35           | 7.03           |
| 14   | Normal concrete and ultra-high strength concrete Cast at different time with fiber | old       | NF     | UHF        | NF                 | 3.95           | 9.72           |
| 15   | high strength concrete and ultra-high strength concrete Cast at different time with fiber | old | HF     | UHF       | HF                 | 4.5            | 12.50          |

Figure 15. Shear stress for normal, high and ultra-high strength concrete casting at different time compared to fiber mix.

The effect of casting time reduce the shear stress of about (28.98, 30.77 and 31.03%) when (N-H-N), (N-UH-N) and (H-UH-H) cast together at the same time changed to (N-H-N), (N-UH-N) and (H-UH-H) cast at different time as shown in Table 11 and Figure 16.
Figure 16. Shear stress for normal, high and ultra-high strength concreted casting at the same time compared to casting at different time.

Table 11. Shear test results of (normal-high and ultra-high strength concrete) casting at the same time compared to casting at different time.

| Mold | Details                                           | Left side | middle | Right side | shear stress (MPa) | Decreasing (%) |
|------|---------------------------------------------------|-----------|--------|------------|--------------------|----------------|
| 4    | Normal concrete and high strength concrete        | new       | N      | H          | 4.40               | 0              |
|      | Cast together at the same time                    |           |        |            |                    |                |
| 5    | Normal concrete and ultra-high strength concrete  | new       | N      | UH         | 5.20               | 0              |
|      | Cast together at the same time                    |           |        |            |                    |                |
| 6    | High strength concrete and ultra-high strength    | new       | H      | UH         | 5.80               | 0              |
|      | concrete Cast together at the same time           |           |        |            |                    |                |
| 7    | Normal concrete and high strength concrete        | old       | N      | H          | 3.13               | -28.98         |
|      | Cast at different time                            |           |        |            |                    |                |
| 8    | Normal concrete and ultra-high strength concrete  | old       | N      | UH         | 3.60               | -30.77         |
|      | Cast at different time                            |           |        |            |                    |                |
| 9    | High strength concrete and ultra-high strength    | old       | H      | UH         | 4.00               | -31.03         |
|      | concrete Cast at different time                    |           |        |            |                    |                |

9-The effect of casting time reduce the shear stress of about (30.93, 33.05 and 33.33%) when (NF-HF-NF), (NF-UHF-NF) and (HF-UHF-HF) cast together at the same time with fiber effect changed to (NF-HF-NF), (NF-UHF-NF) and (HF-UHF-HF) cast at different time with fiber effect as shown in Table 12 and Figure 17.

Table 12. Shear test results of (normal-high and ultra-high strength concrete) casting at the same time compared to casting at different time with fiber.

| Mold | Details                                           | Left side | middle | Right side | shear stress (MPa) | Decreasing (%) |
|------|---------------------------------------------------|-----------|--------|------------|--------------------|----------------|
| 10   | Normal concrete and high strength concrete        | new F     | NF     | HF         | 4.85               | 0.00           |
|      | Cast together at the same time with fiber         |           |        |            |                    |                |
| 11   | Normal concrete and ultra-high strength concrete  | new F     | NF     | UHF        | 5.9                | 0.00           |
|      | Cast together at the same time with fiber         |           |        |            |                    |                |
| 12   | High strength concrete and ultra-high strength    | new F     | HF     | UHF        | 6.75               | 0.00           |
|      | concrete Cast together at the same time with fiber|           |        |            |                    |                |
| 13   | Normal concrete and high strength concrete        | old F     | NF     | HF         | 3.35               | -30.93         |
|      | Cast at different time                            |           |        |            |                    |                |
| 14   | Normal concrete and ultra-high strength concrete  | old F     | NF     | UHF        | 3.95               | -33.05         |
|      | Cast at different time                            |           |        |            |                    |                |
| 15   | High strength concrete and ultra-high strength    | old F     | HF     | UHF        | 4.5                | -33.33         |
|      | concrete Cast at different time with fiber         |           |        |            |                    |                |
Figure 17. Shear stress for normal, high and ultra-high strength concreted casting at the same time compared to casting at different time with fiber.

Tables 13 and Figure 18-20 show the comparison between all shear stress for all specimens. The experimental conclusions from the table are:

1. Compare the results to the normal shear stress it can be seen that all models can overcome the shear stress of normal concrete except models (7, 8, 9, 13 and 14) were these models are cast in a different time.

2. Compare the results to the high strength shear stress it can be seen that many models can overcome the shear stress of high strength except models (1, 4, 7, 8, 9, 10, 13, 14 and 15) were these models are cast in different time or cast from normal concrete having strength less than high strength.

3. Compare the results to the ultra-high-strength shear stress it can be seen that just three models can overcome the shear stress of ultra-high-strength because (1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14 and 15) models were cast in different time or cast from normal concrete or high strength concrete even specimens contains fiber having strength less than ultra-high strength.

Table 13. Comparison between all shear stress for all specimens.

| Mold | Details | Left side | Right side | shear stress (MPa) | % shear stress to N | % shear stress to H | % shear stress to UH |
|------|---------|-----------|------------|-------------------|-------------------|-------------------|-------------------|
| 1    | All Normal concrete Cast together at the same time | new | N | N | N | 4.10 | 0.00 | -21.15 | -32.79 |
| 2    | All high strength concrete Cast together at the same time | new | H | H | H | 5.20 | 26.83 | 0.00 | -14.75 |
| 3    | All ultra-high strength concrete Cast together at the same time | new | UH | UH | UH | 6.10 | 48.78 | 17.31 | 0.00 |
| 4    | Normal concrete and high strength concrete Cast together at the same time | new | N | H | N | 4.40 | 7.32 | -15.38 | -27.87 |
| 5    | Normal concrete and ultra-high strength concrete Cast together at the same time | new | N | UH | N | 5.20 | 26.83 | 0.00 | -14.75 |
| 6    | Normal concrete and ultra-high strength concrete Cast together at the same time | new | H | UH | H | 5.80 | 41.46 | 11.54 | -4.92 |
| 7    | Normal concrete and high strength concrete Cast at different time | OLD | N | H | N | 3.13 | -23.66 | -39.81 | -48.69 |
| 8    | Normal concrete and ultra-high strength concrete Cast at different time | OLD | N | UH | N | 3.60 | -12.20 | -30.77 | -40.98 |
| 9    | Normal concrete and high strength concrete Cast at different time | OLD | H | UH | H | 4.00 | -2.44 | -23.08 | -34.43 |
| 10   | Normal concrete and high strength concrete Cast at different time | new | F | NF | HF | 4.85 | 18.29 | -6.73 | -20.49 |
| 11   | Normal concrete and ultra-high strength concrete Cast at the same time | new | F | NF | UHF | NF | 5.9 | 43.90 | 13.46 | -3.28 |
| 12   | Normal concrete and high strength concrete Cast at the same time | new | F | HF | UHF | HF | 6.75 | 64.63 | 29.81 | 10.66 |
| 13   | Normal concrete and high strength concrete Cast at different time with fiber | OLD | F | NF | HF | NF | 3.35 | -18.29 | -35.58 | -45.08 |
| 14   | Normal concrete and ultra-high strength concrete Cast at different time with fiber | OLD | F | NF | UHF | NF | 3.95 | -3.66 | -24.04 | -35.25 |
| 15   | Normal concrete and ultra-high strength concrete Cast at different time with fiber | OLD | F | HF | UHF | HF | 4.5 | 9.76 | -13.46 | -26.23 |
| 16   | All ultra-high strength concrete Cast together at the same time with fiber | new | UHF | UHF | UHF | 7.10 | 73.17 | 36.54 | 16.39 |
7. Finite Element Modeling of Test Specimens

Finite element analysis has been improved due to the development of concrete technology and structures and the simplicity of using computer software. An acceptable concordance was found between the experimental test conclusions and the finite element program by using the Ansys program [23-27]. The FEA study includes the modeling of normal, high and ultra-high-strength molds, with the dimensions and properties corresponding to the actual experimental data. After collecting all the data required to be entered into the program in terms of physical properties and engineering division and the size, dimensions and concrete properties, then divided into small cube elements to give and simulate the original shape. All the data entered into the program correctly makes the program work and simulates the theoretically in terms of the loads that can be applied. Before the implementation of the analysis by the program, some requirements must be met to ensure that the model works, these are the locations of loading and places of support. Where all movement in the bottom of the mold held to...
zero in the outer prisms ($\delta x, y, z = 0$). From the top, loads were placed, similar to loads carried from the device, but were divided and distributed on the nodes.

8. **Comparison between experimental and analytical work**

Table 14 shows the comparison between the experimental and analytical bond stress. The theoretical work is applied to verify the finite element programs can examine many structural elements. The programs able to show the failure ultimate loads, deformations, mode of failure and stresses contour diagram, all these parameters work as ensuring factors for the accuracy of the finite element models compared to the laboratory results. It was concluded that the general behavior of the finite element models shows a proved compatibility with the experimental test results. From the stresses contour, the plot shows that the concentration of higher stress presented within the two faces of prisms and under the load. Figure 21 shows the dimensions of the molds. Figure 22 and 23 shows stress distribution and deflected shape of mold 1 (normal concrete). Figure 24 and 25 reveals stress distribution and deflected shape of mold 2 (High strength concrete). Figure 26 shows the stress distribution of mold 3 (Ultra High strength concrete). Figure 27 displays the stress distribution of mold 4 (normal and Ultra High strength concrete).

| Mold | Details | Experimental shear stress (MPa) | Analytical shear stress (MPa) | Exp/Analytical  |
|------|---------|--------------------------------|-----------------------------|-----------------|
| 1    | All Normal concrete Cast together at the same time | New N-N-N | 4.10 | 4.64 | 88.36 |
| 2    | All high strength concrete Cast together at the same time | New H-H-H | 5.20 | 5.75 | 90.43 |
| 3    | All ultra-high strength concrete Cast together at the same time | New UH-UH-Uh | 6.10 | 6.65 | 91.73 |
| 4    | Normal concrete and high strength concrete Cast together at the same time | New N-H-N | 4.40 | 4.9 | 89.80 |
| 5    | Normal concrete and ultra-high strength concrete Cast together at the same time | New N-UH-N | 5.20 | 5.89 | 88.20 |
| 6    | High strength concrete and ultra-high strength concrete Cast together at the same time | New H-UH-H | 5.80 | 6.58 | 88.1 |

**Figure 21.** Dimensions of the molds, meshing, loading and support position in the mold.

**Figure 22.** Stress distribution of mold 1 (normal concrete).

**Figure 23.** Deflected shape of mold 1 (normal concrete).

**Figure 24.** Stress distribution of mold 2 (High strength concrete).
9. Conclusions

1. Three types of concrete were studied here these are (normal, high and ultra-high-strength concrete with or without steel fiber. This research represented an experimental study of shear forces across the joint between different concretes forming a composite action and old and new concrete surfaces, to find the best hybrid concrete specimens and increase the load-carrying capacity for the member with minimum cost.

2. When concrete changed from N to H and UH, the compressive strength for cylinder and cube increased by (76.9 and 134.6%) and (71 and 116%), the splitting tensile strength increased by (40 and 70%) and weight changed decreased by (21.7 and 60.8%). The flexural strength increased by (46.6 and 70%).

3. For normal concrete, the maximum shear stress can be obtained with all ultra-high-strength concrete cast together at the same time with fiber were the increasing percentage is (73.17%) compared to all normal concrete cast together at the same time.

4. For high strength concrete, the maximum shear stress can be obtained with all ultra-high-strength concrete cast together at the same time with fiber were the increasing percentage is (36.54%) compared to all high strength concrete cast together at the same time.

5. For ultra-high-strength concrete, the maximum shear stress can be obtained with all ultra-high-strength concrete cast together at the same time with fiber were the increasing percentage is (16.39%) compared to all ultra-high-strength concrete cast together at the same time.

6. Compare the results to the normal shear stress, from 16 models about (11) model can overcome the shear stress of normal concrete were these models are cast in a different time.

7. Compare the results to the high strength shear stress, from 16 models about (7) model can overcome the shear stress of high strength concrete were these models are cast in a different times or cast from normal concrete having strength less than high strength.

8. Compare the results to the ultra-high-strength shear stress, from 16 models about (3) model can overcome the shear stress of ultra-high-strength concrete models were cast in a different time or cast from normal concrete or high strength concrete even specimens contains fiber having strength less than ultra-high strength.

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