IRAQI Academic Scientific Journals

SAMARRA JOURNAL OF ENGINEERING SCIENCE AND RESEARCH

S.J.E.S.R

The effect of delay time in cold joints on the bonding and shear strength in concrete

Aseel Yousif Kareem[1*] and Wisam Amer Aules[1]

1- Department of Civil Engineering, College of Engineering, Tikrit University, Tikrit, Iraq

Article Information

Received: 23/12/2024

Accepted: 18/3/2025

Keywords

***Shear stress, Bonds, Cold joint, Compressive strength, and Delay* time.**

***Corresponding Author**

E-mail:
ay230002en@st.tu.edu.iq

Abstract

This study investigates the effects of delay time in cold joints on the structural behavior of reinforced concrete (RC) beams and cubes with varying compressive strengths of 30 MPa and 50 MPa. The selected delay times (0, 60, and 180 minutes) were chosen to study their effect on shear strength and bond performance in the critical regions containing a cold joint. The shear strength at the critical regions that contain a cold joint was investigated in the beam without shear reinforcement tested under a four-point load. For the cubes, the bonding strength in the cold joint was indirectly investigated using the bi-surface shear test. Experimental results detected that cold joints significantly influence shear strength and failure modes, specifically for longer delay times. Beams without stirrups dominantly failed in shear, with diagonal cracks initiating near the support, while delay times exacerbated the weakening of bonds, altering stress distribution and crack patterns. Similarly, cubes subjected to bi-shear stress demonstrated varied failure modes, transitioning from cohesive to adhesive and mixed failures depending on the delay time and compressive strength. A higher compressive strength of 50 MPa enhanced the overall shear capacity compared to 30 MPa; however, it also contributed to increased brittleness in failure modes. The findings emphasize that the interaction between delay times and compressive strength plays a crucial role in influencing the bonding characteristics and shear behavior of concrete elements containing cold joints.

1. Introduction

Cold joints in reinforced concrete occur when the pouring process is interrupted, resulting in a discontinuity between successive layers of concrete. This phenomenon can significantly impact the bond strength between the old and new layers, which is critical for reinforced concrete elements' overall integrity and durability. Investigating the bonding strength in cold joints in relation to delay time is the most important issue that needs more experimental results to evaluate this bonding between old and new concrete. Cold joints in concrete structures can significantly affect the shear behavior of reinforced concrete elements. At the microstructural level, the interface between the two layers of concrete is a critical zone where bonding issues arise. Without any surface roughness or treatment, the bond between the old and new concrete relies mainly on chemical adhesion. However, when there is a delay in casting, the hydration process in the first layer progresses, reducing the ability of the new concrete to chemically bond with it [1]. This weak interface can lead to a significant reduction in shear strength, as the connection between the two layers is not effectively integrated into the structural behavior of the beam [2].

A cold joint was identified as a construction issue resulting from delays in the concrete pouring process between two sections of reinforced concrete (RC) elements, as noted [3]. The influence of the location and type of cold joint in RC beams was investigated in studies conducted [4,5]. Research [6] demonstrated that cold joints formed at a 45° angle exert less impact on the strength behavior of concrete compared to those formed at a 90° angle due to the increased contact area between the two pourings. At the same time, the flexural strength capacity was decreased for the beams with a 45° angle of cold joint with different delay times [7]. Moreover, the testing was conducted of cold joints with different inclines (0°,20°,45°,65°, and 90°) and strengths to investigate the effecting on concrete strength [8]. The samples at a 65° angle were more influenced by compressive strength, which decreased by up to 48%, but the samples with an incline of 90° were significantly weak in terms of tensile strength. In addition, they found that the relation depends on the joint angle of the cold joint and splitting tensile strength in a new equation. The research studied the impact of cold joints on concrete strength [9]. The testing cold points were formed in different directions of concrete cylinder specimens. The horizontal trend did not affect the concrete strength. At the same time, vertical and diagonal cold joints had a significant influence, reaching up to 42% of decreased concrete strength due to the speedy setting time or long delay times. So, the weakest joint is the diagonal cold joint because the force trend of cracking is better suited to the diagonal joint. Moreover, [10] examined specimens with cold joints to study the effect of delay time at 0,60,120,180 min that impacts cold joints on the strength and durability of concrete. It decreased in all samples of concrete properties, especially when the delay times increased. Cold joints lower influence the compressive strength. Furthermore, normal and high compressive strength were used to calculate the influence of cold joints on concrete strengths [11,12]. Both types are decreased flexural and compressive strength of concrete with cold joints. More negative influence of strength concrete when increasing the time of second casting to form the cold joints. Also, the superplasticizer added high compressive strength and gained significantly weak cold joints because of the quicker setting time, but it improved the initial strength.

In this study, the effect of delay time in cold joints on the bonding strength of concrete was investigated using six reinforced beams and varied compressive strengths (30 MPa and 50 MPa), delay times (0, 60, and 180 minutes), and without shear reinforcement experimentally was tested under four points load to evaluate the effect of the cold joint on shear strength. In addition, eighteen concrete cubes were tested under Bi-surface shear. The results highlighted the significant impact of delay time and compressive strength on bonding performance, shear strength, and failure modes. This article discussed by comparing reference specimens and those with cold joints, and provided insights into the interplay between compressive strength and bonding efficiency.

2. Experimental program

2.1 Material of specimens

The six reinforcement concrete beams were designed according to (ACI 318-19) [13]. Also, six sets of concrete cubes were prepared for the indirect bonding strength, according to studying by Momayez [14]. In this test, there were two groups of beams and cube specimens. In the first group, three beams and nine cube specimens were cast with C30 (ƒć=30) concrete, and in the second group, three beams and nine cube specimens were cast with C50 (ƒć=50). The beams' dimensions were 200mm in width, 300 mm in height, and 2000 mm in length, and the cubes' dimensions were 150x150x150 mm. Fig. 1 shows the beam configuration, Fig. 2 shows the cube, and Fig. 3 illustrates the reinforcement details of each group of beams. Table 1 illustrates the reinforcement details and identification of all beams. Table 2 shows the details of each group of cubes.

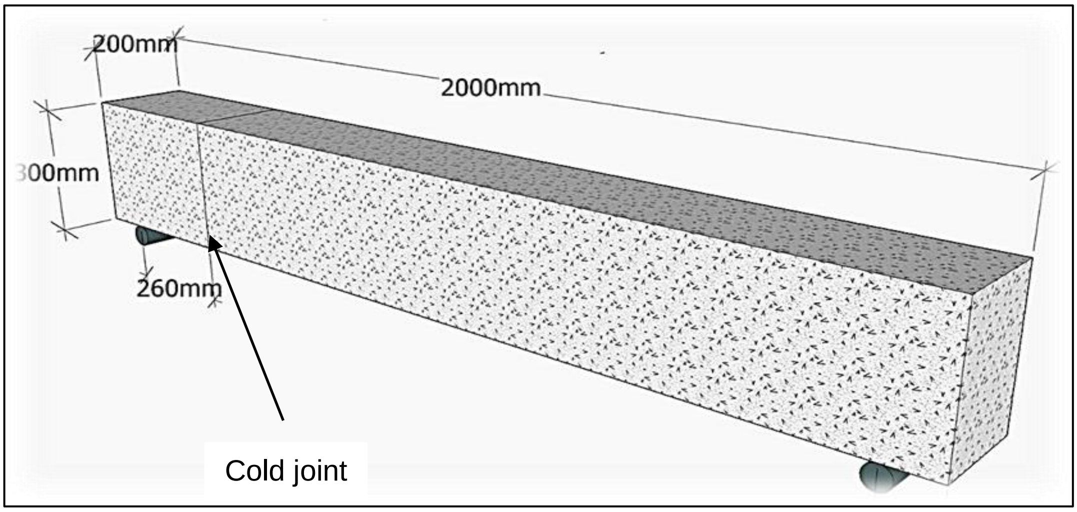


Fig. 1. Beam specimen.

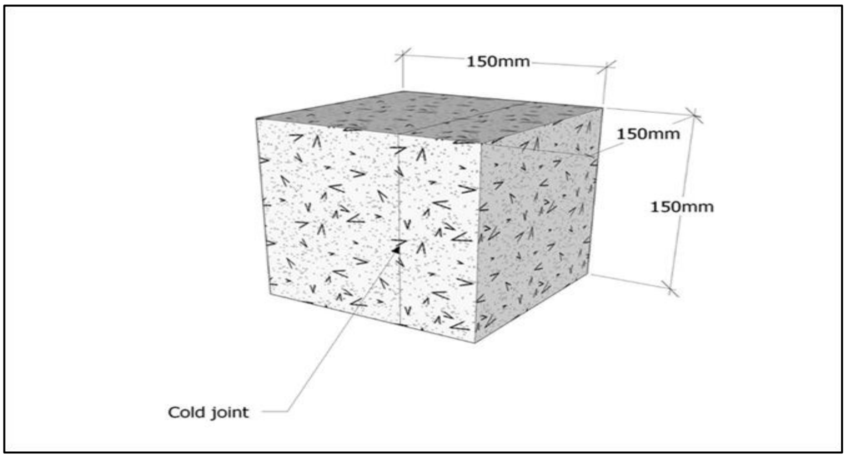
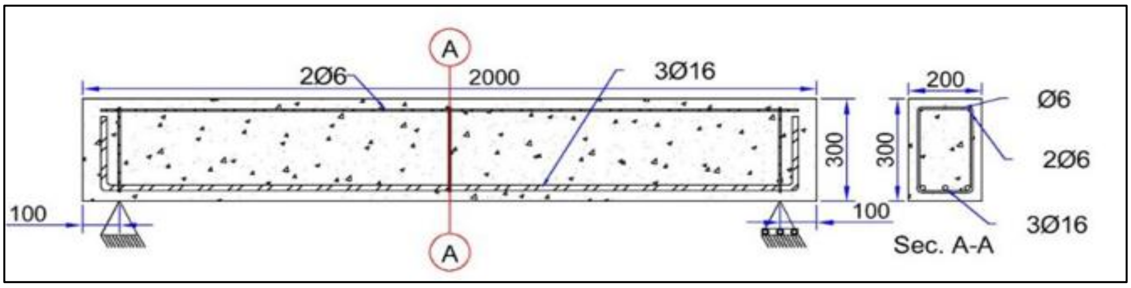
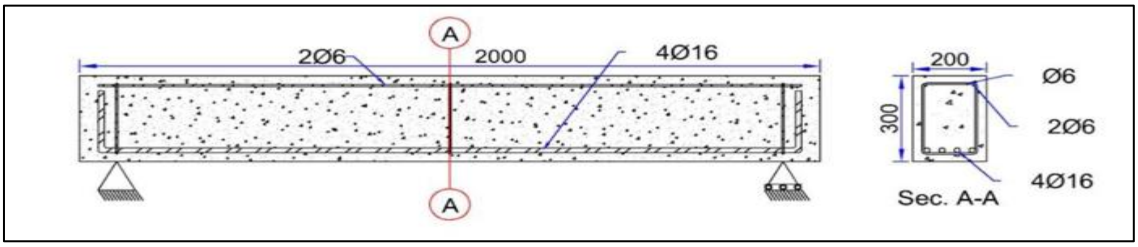


Fig. 2. Cube specimen.

The traditional materials were deformed steel bars. Steel bars 16mm in diameter were used for longitudinal reinforcement only without shear reinforcement. Additionally, ordinary Portland cement was used, sourced from local production facilities. The cement conformed to the specifications outlined in ASTM C150 / C150M-19a (Standard Specification for Portland Cement) [15]. Table 3 shows the initial and final sitting time. The fine aggregate used in the concrete mix was washed river sand, which passed through sieve #4 (4.75 mm) and had a fineness modulus of 2.37. Additionally, the coarse aggregate consisted of normal crushed stone, which passed through sieve #12 (12.5 mm). Both aggregates met the requirements specified in ASTM C33 / C33M-18 (Standard Specification for Concrete Aggregates) [16]. Additionally, all concrete mixes and curing used distilled water (drinking water). Furthermore, a superplasticizer was added to the second group mix. Table 4 presents the amount of material weights that were used.



(a) Beams with f'c=30MPa.



(**b)** Beams with f'c=50MPa.

Fig. 3. Reinforcement details of beams.

Table 1: Details of the beam and specimen identifications (Reinforcement steel diameter is Ø16, and the tinsel strength =620 MPa).

Identification	Compressive strength, f_c', MPa	Spacing between stirrups, mm	Delay time, min.	Note
R-30	30	No stirrups	0	Reference
CJ-30-60	30	No stirrups	60	With Cold Joint
CJ-30-180	30	No stirrups	180	With Cold joint
R-50	50	No stirrups	0	Reference
CJ-50-60	50	No stirrups	60	With Cold Joint
CJ-50-180	50	No stirrups	180	With Cold Joint

Table 2: Details of the six-set cube and specimen identifications.

Identification	Compressive strength, f_c', MPa	Delay time, min.	Average of specimen	Note
C 30-0	30	0		Reference
C 30-0	30	0	C 30-0	Reference
C 30-0	30	0		Reference
CJ 30-60	30	60		With Cold Joint
CJ 30-60	30	60	C 30-60	With Cold Joint
CJ 30-60	30	60		With Cold Joint
CJ 30-180	30	180		With Cold Joint
CJ 30-180	30	180	C 30-180	With Cold Joint
CJ 30-60	30	180		With Cold Joint
C 50-0	50	0		Reference
C 50-0	50	0	C 50-0	Reference
C 50-0	50	0		Reference
C 50-60	50	60		With Cold Joint
C 50-60	50	60	C 50-60	With Cold Joint
C 50-60	50	60		With Cold Joint
C 50-180	50	180		With Cold Joint
C 50-180	50	180	C 50-180	With Cold Joint
C 50-180	50	180		With Cold Joint

Table 3: Result of setting time.

Type of setting time	Test time (min)	ASTM C150/C150M – 21 time (min)
Initial time	98	Not less than 45
Final time	233	Not more than 375

Table 4: Specific material proportions used for the concrete mixes.

Compressive Strength (MPa)	Cement (kg/m³)	Sand (kg/m³)	Coarse Aggregate (kg/m³)	Water (kg/m³)	superplasticizer (kg/m³)
C30	325	725	1200	140	0
C50	450	725	1025	150	2.7

2.2 Specimens preparation

Two types of concrete mixing designs were prepared: normal-strength and high-strength concrete. After preparing the molds and concrete mixes, the six reinforced concrete beams were cast using the prepared concrete mixes. Fig. 4 illustrates the details of pouring. The casting process used a shovel and a vibrator to consolidate the concrete, casting the first part of the concrete at a distance of 260mm, where the maximum shear stress concentration was induced using a wooden plate in the vertical direction, followed by a casting interruption of 60 or 180 minutes before pouring the second part to create the cold joint. In contrast, the reference beam was cast continuously without interruption, resulting in no cold joint. Furthermore, six sete specimens (150 mm,150 mm, and 150 mm) were cast into steel oiled molds for a direct shear test with every group. The casting method of cube specimens was similar to that of beam specimens, casting the first part (150mm, 150mm, and 100mm) and then casting the second part (150 mm, 150 mm, and 50 mm) at different times. Fig. 5 shows the method. After the specimens had finished casting, they were left for 24 hours and removed from molds to be put in curing for 28 days.

(a) **(b)** **(c)**

Fig. 4. Process of casting beam (a) casting first part (b) casting the second part (c) full beam.

(a) (b) (c)

Fig. 5. Process of cube casting (a) casting first part (b) casting the second part (c) full cube.

2.3 Experimental setup

2.3.1 The beams

The experimental setup for the testing of supported beams is illustrated in Fig. 6. The tests were conducted using a Universal Testing Machine with a maximum loading capacity of 2000 kN. The load was applied through a load cell connected to a data logger system, enabling the precise recording of applied loads. Additionally, Linear Variable Differential Transformers (LVDTs) were employed to measure the deflection of the specimens during the tests.

The beams were supported on four steel shafts. The two lower cylinders, spaced 1800 mm apart, served as reaction supports, while the two upper cylinders applied concentrated loads, spaced 600 mm apart. This arrangement ensured a four-point bending test configuration, which is ideal for evaluating the shear and flexural behavior of the beams.

The tests were performed under displacement control, with a 2 mm/min displacement rate. A monotonically increasing load was applied to the specimens until failure. Deflection measurements were taken using two LVDTs placed at the mid-span on the beams' underside to ensure accurate deformation monitoring. This setup precisely determined the beams' load-deflection behavior, shear stress, and failure characteristics.

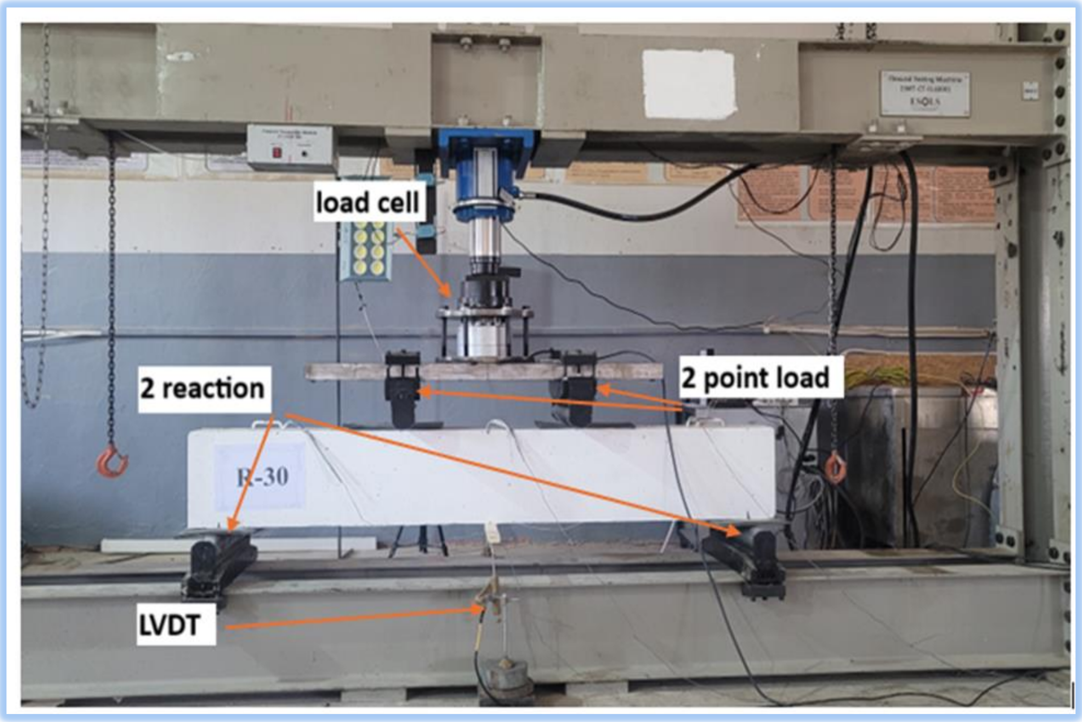


Fig.6. Setup of beam.

2.3.2 The cubes

In this study, the Bi-surface shear test, a direct shear test introduced by Momayez [14], was selected due to its simplicity and compatibility with the laboratory setup. The direct shear test indirectly evaluates the bond between the old and new layers of concrete (cold joint) by subjecting the bond surface to shear stress along with a minor bending moment. Specifically, the Bi-surface shear test, which applies pure shear forces, is widely recognized for assessing the bonding properties at the interface of cement-based materials [17].

This research employed the bi-surface shear test method to determine the bond strength of specimens with cold joints (old layer with new layer), a method that has also been validated in previous studies, such as [18]. The experimental setup involved electric material testing equipment operating at a loading rate of 1 kN/s, Fig. 7. Each specimen was supported by two plates measuring 150 × 50 × 50 mm, while a single loading plate with the same dimensions was centrally placed above the specimens.

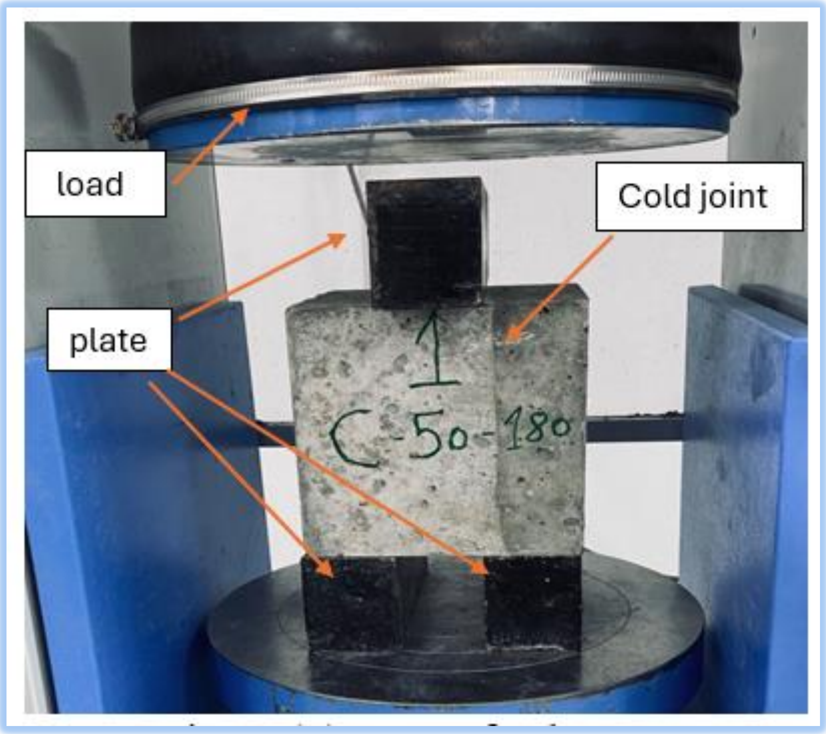


Fig. 7. Setup of cube.

3. Results and discussion

3.1 Failure mode

3.1.1 Failure mode of beams

Fig. 8 presents images of the six tested beams, all of which failed in shear, aligning with the design expectations. To illustrate the failure mode clearly, the six beams were divided into two groups: the first group was the beams with 30 MPa compressive strength, and the second group was the beams with 50 MPa compressive strength.

In the first group with (R 30, CJ 30-60, and CJ 30-180), these beams exhibited a dominant diagonal crack originating near the support and propagating toward the loading point, indicating shear failure. Minor vertical flexural cracks were visible near the midspan but did not propagate significantly, confirming that the failure mode was shear-dominated. Then, the diagonal shear crack developed because the tensile stress in the concrete in the shear span exceeded its tensile capacity. Since the beams lacked stirrups, there was no shear reinforcement to arrest crack propagation or redistribute shear stresses, leading to brittle failure.

The crack pattern suggested that the failure occurred in the critical shear span near the support, consistent with the expected behavior for beams without stirrups. The reference beam R 30 in Fig. 8a exhibited symmetrical stress distribution with failure in the expected critical span. While CJ 30-60 in Fig. 8b was similar to the reference beam, shear failure occurred in the crucial shear span but on the side opposite the cold joint. The cold joint altered the stress distribution, causing stress concentration on the opposite side. Despite the bond at the cold joint being relatively strong (due to the shorter delay), stress redistribution was sufficient to avoid joint failure. The longer delay (180 minutes) of CJ 30-180 in Fig. 8c caused a reduction in bond strength at the cold joint, leading to a more pronounced stress redistribution. So, the behavior was similar to CJ-30-60, as shown in Fig.8b, but there is more noticeable cracking near the joint due to the weaker bond. It is important to note that the failure in beams with cold joints did not occur along the joint plane but rather on the opposite side. Instead of causing a direct failure at the joint, the presence of the cold joint altered the stress distribution, leading to stress concentration on the opposite side. The redistribution of stresses away from the cold joint might be attributed to the presence of an interlocking mechanism at the interface, which prevented premature separation. Additionally, the absence of stirrups in the tested specimens meant that shear stresses had to be accommodated by the concrete alone, resulting in diagonal cracks forming in the critical shear span rather than at the cold joint itself.

When looking at pictures (d, e, and f) in Fig. 8 of group two, these beams had similar behavior to group one (R 50 as R 30, CJ 50-60 as CJ 30-60, and CJ 50-180 as CJ 30-180). Still, the higher compressive strength of 50 MPa resulted in more brittle failure than the 30 MPa group. 'Fig. 9' shows the load-deflection curves of beams with 30MPa and 50MPa to indicate the difference between beams under load.

Overall, higher compressive strength beams (50 MPa) demonstrated greater load capacities but failed more abruptly, while lower compressive strength beams (30 MPa) exhibited more gradual failure modes.

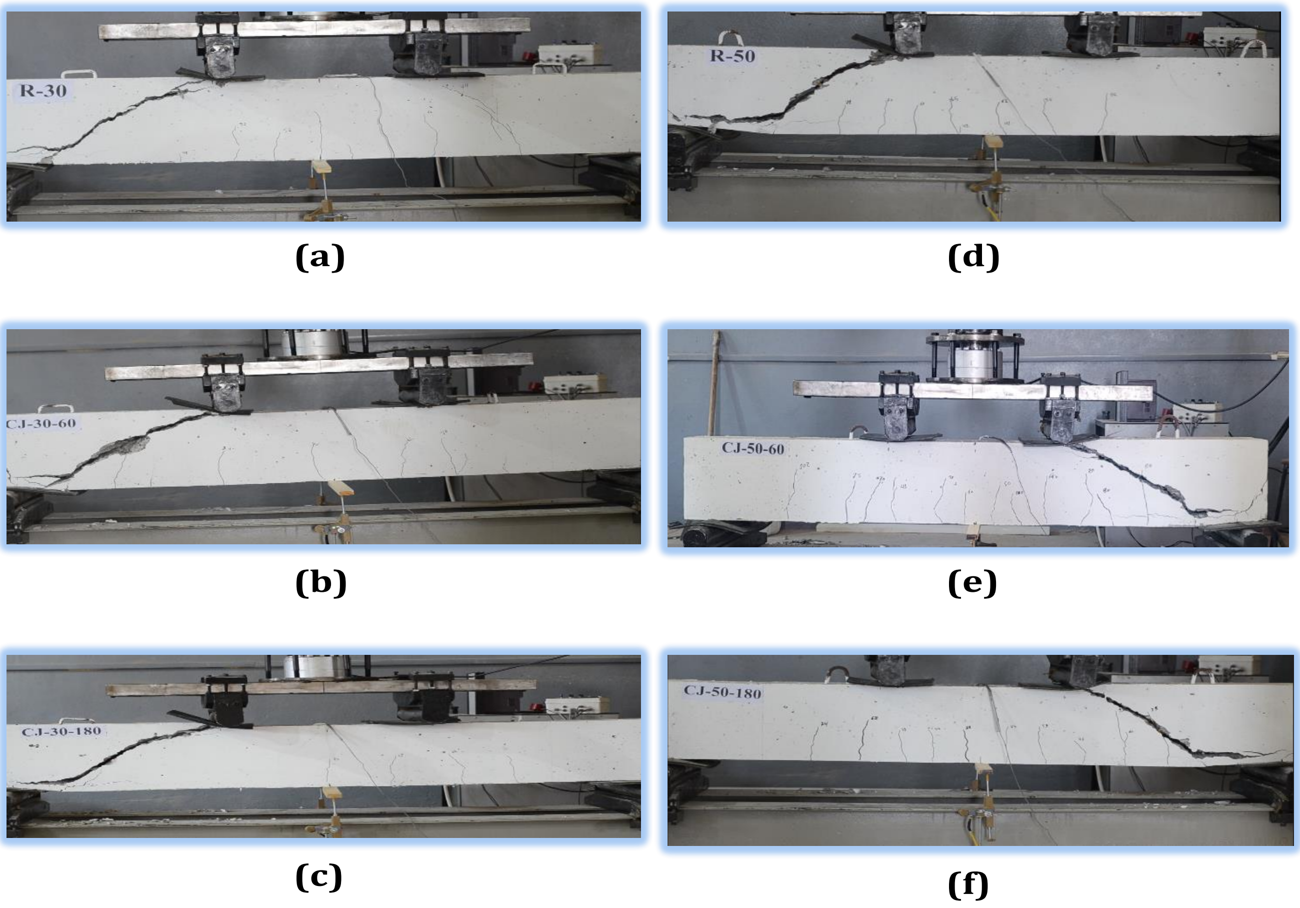
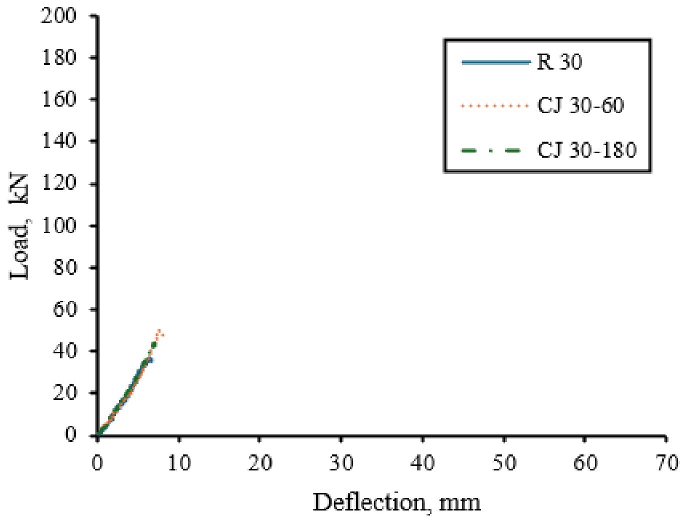
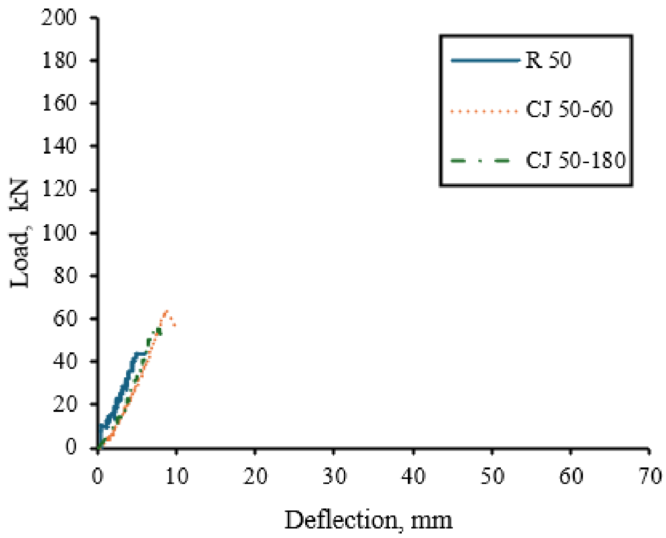


Fig. 8. Failure mode of beams (a) R-30 (b) CJ-30-60 (c) CJ-30-180 (d) R-50 (e) CJ-50-60 (f) CJ-50-180.



(a)



(b)

Fig. 9. Load-deflection of beams (a) Beams with 30 MPa (b) Beams with 50 MPa.

3.1.2 Failure mode of cubes

Fig. 10 shows the failure modes of the specimens tested under bi-surface shear loading conditions. Three failure types correspond to variations in the mechanical interlocking and adhesion between the old and new concrete layers in cold joint specimens, as well as the homogeneity of the monolithic specimens.

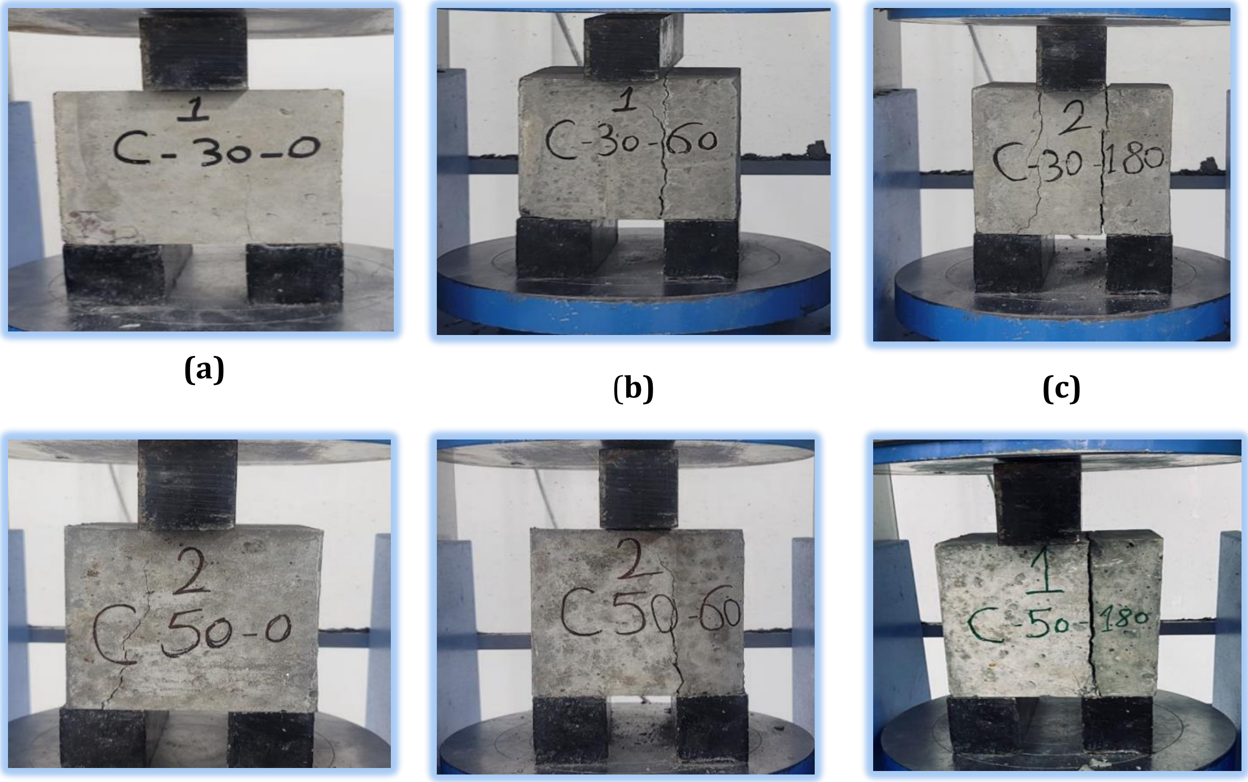
The monolithic cube (C 30-0) Fig.10a, which had no cold joint, exhibited a cohesion failure mode. This type of failure is characterized by shear damage concentrated in the cube concrete itself. The failure was initiated by small diagonal cracks propagating within the cube concrete and along the part of the shear plane. These cracks continued to grow under increasing applied load until the specimen ultimately failed. This mode of failure indicates strong internal mechanical interlocking in the concrete matrix and high cohesive strength within the material. Since no joint existed, the stress was evenly distributed across the cube, allowing for failure to occur through the shear surface in the cube concrete. The cohesive failure highlights the concrete's ability to sustain substantial loads before failure [19].

Fig. 10 b shows the second type of failure, with a delay time of 60 minutes for specimen C 30-60, which is a clear example of adhesion failure. The failure occurred along the joint interface between the old and new concrete layers, with minimal to no damage to the old layer of concrete. Cracks were observed propagating along the interface plane, leading to a sudden and brittle failure. This failure mode is attributed to the delay time, which allowed the first layer to harden before the second layer was cast fully. As a result, the bond between the two layers was weakened. Additionally, the short depth of the second layer (50 mm) limited the extent of mechanical interlocking, further weakening the joint. This adhesion failure mode indicates that the joint acted as the weakest link, unable to transfer significant shear or tensile stresses ACI 224R (1990) [20].

Fig. 10 C shows that a mixed failure mode was observed for the specimen (C 30-180) with a cold joint created with a 180-minute delay. This failure involved partial interface debonding at the joint (an adhesion failure mode) and partial shear damage in the old layer of concrete (a cohesion failure mode). The failure was initiated by small vertical cracks forming along the interface joint between the old and new concrete layers. These cracks propagated into the old layer and along the interface of the cold joint as the applied load increased, eventually leading to failure. The mixed failure suggests that the delay reduced the bonding of the first concrete layer with the second layer. However, mechanical interlocking between the two layers still provided some resistance, explaining the combination of old layer damage and interface debonding. The presence of the joint created a stress concentrator, reducing the cube's overall load-carrying capacity compared to the monolithic specimen [21].

On the other side, Fig.10d shows the cube (C 50-0), which had the 50 MPa compressive strength, and without a cold joint**,** the failure mode for this monolithic specimen was identical to that of the 30 MPa specimen. However, the cracks were finer and more well-defined in the 50 MPa cube, indicating the concrete's higher stiffness and greater cohesive strength. The higher compressive strength of 50 MPa allowed the specimen to resist a greater load before failure, but the eventual shear failure occurred within the concrete cube. The cube (C 50-60) in Fig.10 e' had a cold joint at 60 minutes; like the (C 30-60) specimen with an adhesion failure mode, the 50 MPa specimen with a 60-minute cold joint delay failed along the interface between the old and new concrete layers. Cracks propagated exclusively along the interface plane, with minimal damage observed in the old layer of concrete. The higher stiffness of the 50 MPa concrete resulted in sharper, clearer crack patterns, indicative of a brittle failure along the interface. Furthermore, the specimen (C 50-180) in Fig. 10f was unlike the (C 30-180) specimen with a mixed failure mode; the 50 MPa specimen failed predominantly along the cold joint interface, showing a clear adhesion failure. Cracks were confined to the joint, with minimal to no damage in the old layer of concrete. The delay allowed complete hydration of the first layer, then weakening bonding between the layers. The absence of mixed failure suggests that the higher stiffness of the 50 MPa concrete created a sharper stress concentration at the joint, causing a clear debonding failure along the interface.

It was clear that higher compressive strength (50 MPa) reduces crack propagation and improves the integrity of the cube. Failure modes in 50 MPa specimens are more localized than the extensive cracking in 30 MPa specimens. In both 30 MPa and 50 MPa specimens, cold joints significantly weaken the bond strength, with adhesion failure being the dominant mode for delayed casting conditions. However, higher compressive strength mitigates the extent of failure beyond the joint.



(a) (b) (c)

(d) (e) (f)

Fig. 10. Failure mode of cube specimens (a) C-30-0 (b) C-30-60 (c) C 30-180 (d) 50-0 (e) C-50-60 (f) C-50-180.

3.2 Effect of cold joint and compressive strength on the shear strength

3.2.1 Beam specimens

Fig. 11 chart compares the shear stress capacities of reinforced concrete (RC) beams with a compressive strength of 30 MPa, R X-0, a beam without a cold joint, achieving a shear stress of 0.62 MPa. CJ X-60, a beam with a cold joint formed after a delay of 60 minutes, showed an increased shear stress of 0.84 MPa. Meanwhile, CJ X-180, a beam with a cold joint formed after a delay of 180 minutes, achieved a slightly lower shear stress of 0.73 MPa compared to CJ X-60. The results indicate that introducing a cold joint at 60 minutes increases shear stress compared to the beam without a cold joint, potentially due to better bonding at the interface of the concrete layers under shear loading. This can be attributed to the bonding mechanisms at the interface and the hydration process. At 60 minutes, the initial concrete layer had not been fully set. Additionally, hydration continued at the interface, potentially leading to a denser microstructure that improved bond strength. The presence of moisture at the joint might have also contributed to better adhesion, reducing the negative impact of the cold joint. However, when the cold joint delay increases to 180 minutes, the shear stress decreases compared to the 60-minute case but remains higher than the beam without a cold joint. This finding aligns with the observation that cold joint timing significantly impacts shear strength, where prolonged delays can weaken the bond at the joint, resulting in reduced performance [22].

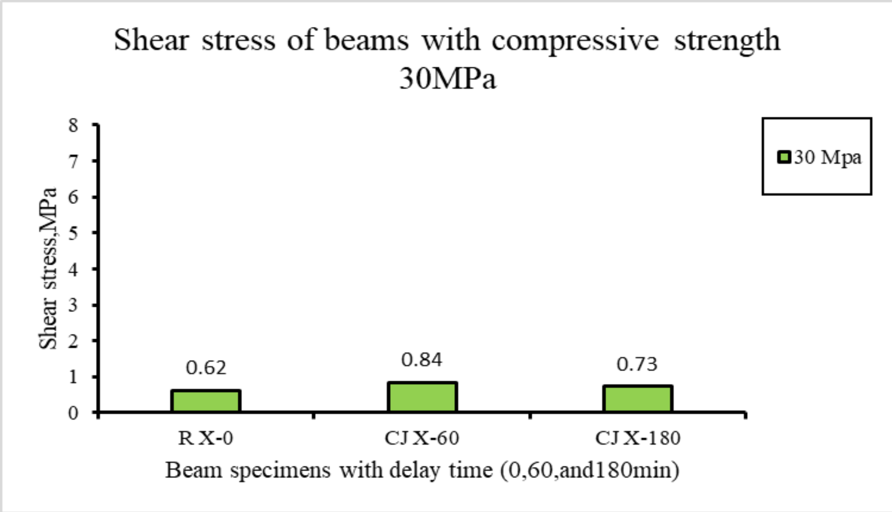


Fig. 11. Shear stress of beams with compressive strength 30 MPa.

Furthermore, the Fig. 12 chart displays the shear stress capacities of RC beams with a compressive strength of 50 MPa. R X-0, a beam without a cold joint, achieved a shear stress of 0.73 MPa. Also, CJ X-60, a beam with a cold joint formed after a delay of 60 minutes, showed the highest shear stress of 1.07 MPa. Moreover, CJ X-180, a beam with a cold joint formed after a delay of 180 minutes, achieved a shear stress of 0.93 MPa.

Compared to the 30 MPa beams, these results demonstrate an overall improvement in shear stress values due to the higher compressive strength. This enhancement is consistent with the well-documented relationship between concrete compressive strength and shear capacity ACI Committee 318 (2019) [13]. As in the 30 MPa beams, a delay of 60 minutes results in the highest shear stress, while a longer delay of 180 minutes reduces shear stress but still maintains higher values than beams without cold joints.

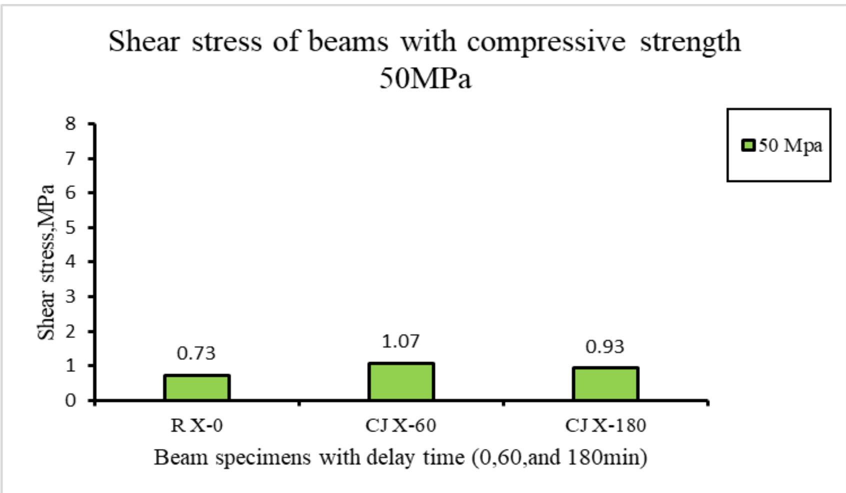


Fig. 12. Shear stress of beams with compressive strength 50 MPa.

For more explanation, Fig. 13 chart directly compares the shear stress capacities of beams with 30 MPa and 50 MPa compressive strengths. Beams R X-0 without cold joints show higher shear stress for 50 MPa (0.73 MPa) than 30 MPa (0.62 MPa). However, beams CJ X-60 with a 60-minute cold joint delay achieve the highest shear stresses for both compressive strengths, with a notable increase for 50 MPa (1.07 MPa) compared to 30 MPa (0.84 MPa). Meanwhile, beams CJ X-180 with a 180-minute cold joint delay show similar trends, with the

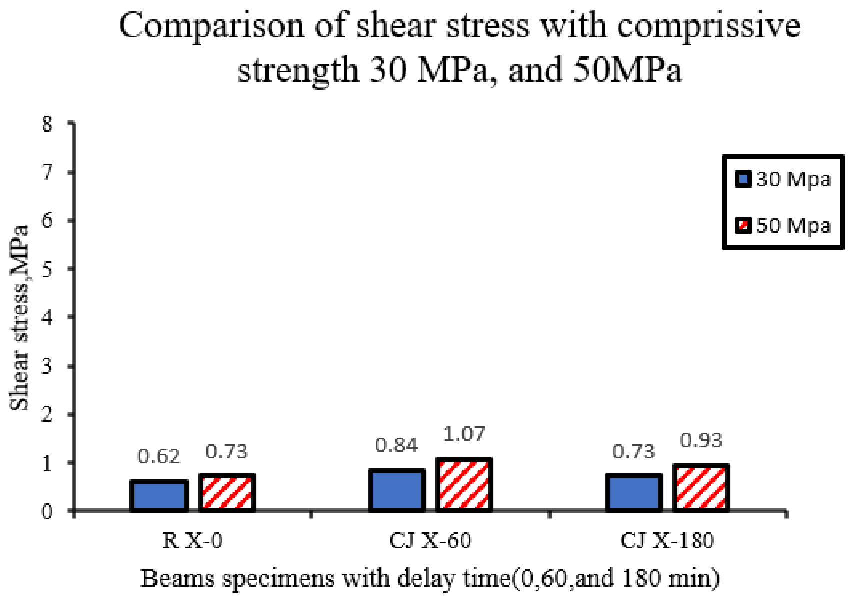


Fig. 13. Comparison of shear stress with compressive strength 30 MPa and 50 MPa.

50 MPa beams (0.93 MPa) outperforming the 30 MPa beams (0.73 MPa). Shear failure in beams with cold joints is largely influenced by the bonding quality at the interface. Since the surfaces were neither roughened nor treated before placing the second layer, the connection between the two layers depends solely on the ability of the new concrete to adhere to the hardened surface. When the delay between castings is prolonged, the hydration process in the first layer is already well-advanced, leaving a smooth, weak interface where bonding is insufficient [12]. This results in poor stress transfer across the joint, making it a vulnerable plane for shear failure. Additionally, shrinkage in the newly placed concrete can introduce microcracks at the interface, further weakening the joint and reducing the beam's overall shear resistance [23]. As a result, beams with longer delays between castings exhibit more pronounced shear failure due to the limited interaction between the two concrete layers.

Overall, higher compressive strength consistently improves shear stress capacity across all conditions, as expected from the fundamental mechanics of reinforced concrete [24]. The presence and timing of cold joints significantly influence shear stress. Beams with a 60-minute delay show improved shear stress due to enhanced interfacial bonding, while a longer delay (180 minutes) reduces the shear stress, likely due to reduced interfacial adhesion and bonding at the cold joint. For more information, 'Table 5' shows the first crack load and failure load to understand the behavior of beams under loads and how these beams had load capacity. This table shows how cold joint delay time affects the shear performance of beams. Beams with a 60-minute delay (CJ-30-60 and CJ-50-60) surprisingly carried higher loads before failure compared to the reference beams, likely due to improved bonding at this stage. However, when the delay was extended to 180 minutes (CJ-30-180 and CJ-50-180), the failure load dropped, confirming that longer delays weaken the bond and reduce shear strength.

Table 5: First crack load and failure load of beams.

Beam ID	Compressive Strength (MPa)	Delay Time (min)	First Crack Load (kN)	Failure Load (kN)
R-30	30	0	20	37
CJ-30-60	30	60	22	50
CJ-30-180	30	180	18	44
R-50	50	0	24	44
CJ-50-60	50	60	26	64
CJ-50-180	50	180	23	56

3.2.2 Cube specimens

Fig. 14 and Fig. 15 show depict the effects of compressive strength (30 MPa and 50 MPa) and the presence of cold joints (with delay times of 60 and 180 minutes) on the shear stress (shear strength) of concrete cubes subjected to bi-shear stress. For Fig. 13, the first bar shows the highest shear stress of 5.865 MPa, corresponding to a cube with no delay time,
indicating continuous and monolithic concrete. This value reflects the maximum shear strength achievable in 30 MPa concrete. The second bar illustrates a significant drop in shear stress to 3.66 MPa, showing the adverse effect of introducing a cold joint with a 60-minute delay. The discontinuity caused by the cold joint reduces the bonding between the fresh and hardened concrete. Furthermore**,** the third bar indicates a shear stress of 3.66 MPa, similar to the 60-minute delay. The lack of further reduction suggests that the initial delay has significantly weakened the bonding, and further delay (180 minutes) does not diminish the shear stress

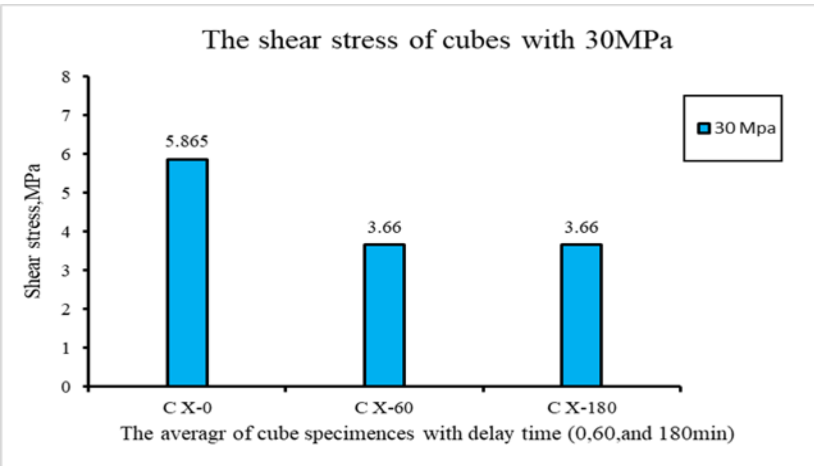


Fig. 14. Shear stress of cubes with compressive strength 30 MPa.

Looking at Fig. 15, the first bar shows the highest shear stress of 6.74 MPa, highlighting that higher compressive strength (50 MPa) results in stronger monolithic concrete than the 30

MPa specimens. This is consistent with the direct relationship between compressive strength and shear strength. Also, the second bar shows a reduced shear stress of 4.84 MPa, which is higher than the corresponding value for 30 MPa concrete with a cold joint (3.66 MPa). This demonstrates that higher compressive strength improves the resistance of concrete to the negative effects of a cold joint. The third bar shows a further decrease in shear stress to 4.36 MPa, unlike the plateau observed in 30 MPa concrete. This indicates that further delays exacerbate the weakening effects of cold joints on shear stress at higher compressive strengths.

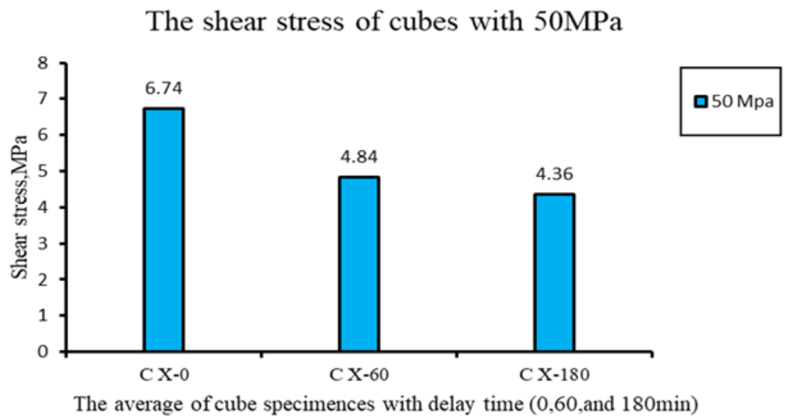


Fig. 15. Shear stress of cubes with compressive strength 50 MPa.

Fig.16 compares the shear stress for both compressive strengths (30MPa and 50MPa) under the conditions (no cold joint, 60-minute delay, and 180-minute delay).

For C X-0 bars, shear stress for 50 MPa concrete (6.74 MPa) is significantly higher than for 30 MPa concrete (5.865 MPa). This reinforces the correlation between compressive strength and shear strength. Additionally, C X-60 shear stress for 50 MPa concrete (4.84 MPa) is still higher than for 30 MPa concrete (3.66 MPa). However, the reduction in shear strength due to the cold joint is more pronounced in lower-strength concrete (30 MPa: 37.6% reduction; 50 MPa: 28.2% reduction).

Also, for C X-180 bars, the shear stress for 50 MPa concrete (4.36 MPa) remains higher than for 30 MPa concrete (3.66 MPa). The cold joint's additional weakening effect is more evident in 50 MPa concrete.

Lastly, a cold joint significantly reduces shear stress in 30 MPa and 50 MPa concrete. This reduction is primarily attributed to the weakening of the bond between the fresh and hardened concrete. Higher compressive strength mitigates the impact of the cold joint. In 30 MPa concrete, the reduction in shear strength plateaus after 60 minutes, while in 50 MPa concrete, the reduction continues with increased delay time (180 minutes). Higher compressive

strength enhances the overall shear stress and reduces the relative impact of cold joints and delay time

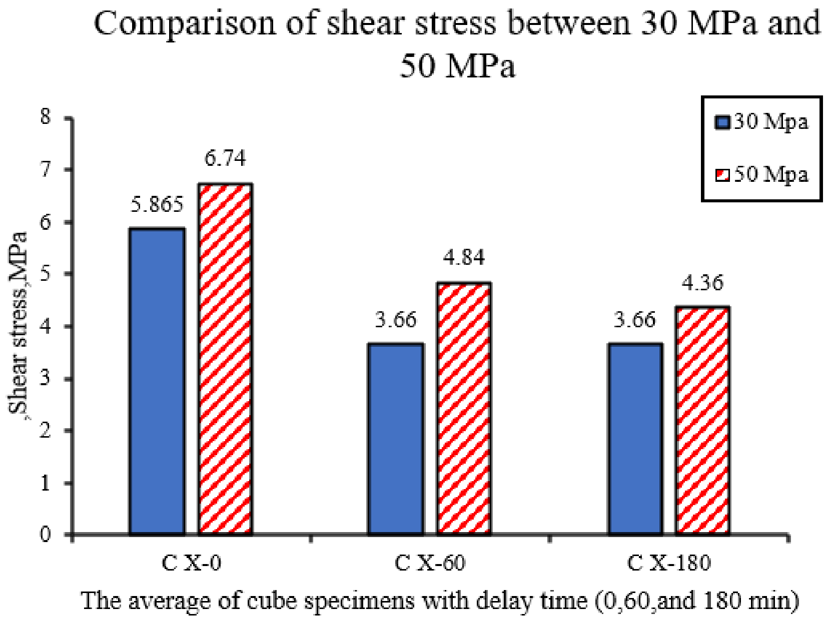


Fig. 16. Comparison of shear stress between 30 MPa and 50 MPa.

The results of this study confirm that cold joints significantly impact shear strength and failure modes, particularly as delay times increase. These findings align with the research [3] [10], which also observed a reduction in strength as delay times increased. However, our study provides more detailed insight into the specific failure modes associated with different delay times.

[6] found that cold joints with different angles affect strength differently. While their research focused on inclined joints, our study concentrates on vertical cold joints in shear-critical regions, adding a new perspective to how shear behavior is influenced by delay time.

Additionally, [9,8] demonstrated that the weakest cold joint orientation is diagonal due to stress concentration along the joint. While our research did not vary joint angles, it confirms that longer delay times increase stress redistribution, leading to weaker bonding, similar to what has been observed in angled joints.

Moreover, the results support the conclusions [11,12], who noted that cold joints decrease flexural and compressive strength, particularly when superplasticizers are used. In our study, the higher compressive strength concrete (50 MPa) showed increased brittleness, reinforcing their findings that strength enhancement does not necessarily improve bonding at cold joints.

A key difference between our results and previous research is the increase in shear strength observed in beams with a 60-minute cold joint delay. This differs from the general trend reported in earlier studies, where cold joints always led to strength reduction. This unexpected outcome can be explained by hydration processes and bonding at the interface, as discussed in the results section. Such findings highlight the importance of considering both hydration timing and mechanical interlocking in evaluating cold joint performance.

4. Conclusions

1. This study confirms that cold joints significantly impact shear strength, especially as the delay time increases. Beams and cubes with a 180-minute delay showed the weakest shear capacity, highlighting how longer casting interruptions lead to poor bonding at the interface and reduced shear performance.

2. Beams with a 60-minute cold joint delay performed better than the reference beams in terms of shear strength. This suggests that at this stage, hydration and bonding mechanisms helped improve interfacial adhesion. However, when the delay time was extended to 180 minutes, the bond weakened noticeably, leading to a clear drop in shear strength.

3. In all cases, the beams failed in shear, with diagonal cracks forming near the supports and extending toward the load points. Longer delay times altered stress distribution, leading to more severe cracking and reduced shear transfer across the section.

4. Higher compressive strength (50 MPa) helped improve shear capacity, but it also made the failure more brittle compared to 30 MPa concrete. While stronger concrete can better resist shear, the presence of cold joints still causes a significant strength reduction, showing that even high-strength mixes are vulnerable to delayed casting effects.

5. Comparing beams and cubes under shear loading, we found that the shear strength of beams is only about 10.6% of that of cubes. This highlights key differences in how shear stresses are distributed and transferred between these structural elements. Additionally, the failure patterns in cubes closely mirrored those in beams, particularly in how bonding at the cold joint influenced overall performance.

References

[1] M. Tuyan, A. Mardani-Aghabaglou, and K. Ramyar, "Freeze–thaw resistance, mechanical and transport properties of self-consolidating concrete incorporating coarse recycled concrete aggregate," Mater. Des., vol. 53, pp. 983–991, 2014.

[2] O. Davaadoij, P. M. Calvi, and J. F. Stanton, "Shear stress transfer across concrete-to-concrete interfaces: Experimental evidence and available strength models," PCI J., vol. 65, no. 4, 2020.

[3] F. H. N. Al-Mamoori and A. H. N. Al-Mamoori, "Reduce the influence of horizontal and vertical cold joints on the behavior of high strength concrete beam casting in hot weather by using sugar molasses," Int. J. Eng. Technol., vol. 7, no. 4.19, pp. 794–800, 2018.

[4] Z. W. Abbas, "Effect of construction joints on the performance of reinforced concrete beams," Al-Khwarizmi Eng. J., vol. 8, no. 1, pp. 48–64, 2012.

[5] S. K. Akın and H. Güz, "An Experimental Study on the Behavior of Reinforced Concrete Beams Having Different Angled Cold Joints in the Shear Zone under," Int. J. Eng. Res. Dev., vol. 16, no. 1, pp. 496–506, 2024.

[6] N. Kadyrov and S. Yazıcıoğlu, "Research of cold joint effects on the direct tensile and flexural strength of the concrete," J. Polytech. -Politeknik Dergisi, vol. 19, no. 3, 2016.

[7] J. Vanlalruata and C. Marthong, "Effect of cold joint on the flexural strength of RC beam," J. Struct. Integr. Maint., vol. 6, no. 1, pp. 28–36, 2021.

[8] Q. Q. Ali, B. Erdil, and T. M. Jassam, "Critical cold joint angle in concrete," Constr. Build. Mater., vol. 409, p. 133881, 2023.

[9] A. K. P. A. N. Udoh, "Mechanical behaviour of concrete cold joints," Ebonyi J. Sci., vol. 3, no. 1, pp. 59–74, 2020.

[10] İ. Bekem Kara, "Experimental investigation of the effect of cold joint on strength and durability of concrete," Arab. J. Sci. Eng., vol. 46, no. 11, pp. 10397–10408, 2021.

[11] B. C. Zega, H. Prayuda, F. Monika, F. Saleh, and D. E. Wibowo, "Effects of cold joint and its direction on the compressive and flexural strength of concrete," GEOMATE J., vol. 20, no. 82, pp. 86–92, 2021.

[12] N. Ozbakan, F. Şamdan, T. Orhan, and M. Canbaz, "An Experimental and Numerical Study on the Effects of Cold Joint Location and Angle in Concrete," J. Build. Eng., p. 111529, 2024.

[13] ACI Committee 318, Building Code Requirements for Structural Concrete (ACI 318-19). American Concrete Institute, 2019.

[14] A. Momayez, M. R. Ehsani, A. A. Ramezanianpour, and H. Rajaie, "Comparison of methods for evaluating bond strength between concrete substrate and repair materials," Cem. Concr. Res., vol. 35, no. 4, pp. 748–757, 2005.

[15] ASTM C150M-19a, Standard Specification for Portland Cement, 2019. Available: www.astm.org.

[16] ASTM C33/C33M-18, Standard Specification for Concrete Aggregates, 2018.

[17] M. A. Al-Osta, S. Ahmad, M. K. Al-Madani, H. R. Khalid, M. Al-Huri, and A. Al-Fakih, "Performance of bond strength between ultra-high-performance concrete and concrete substrates (concrete screed and self-compacted concrete): An experimental study," J. Build. Eng., vol. 51, p. 104291, 2022.

[18] H. A. Al-Azzawi, W. A. Aules, M. Alshandah, and Y. M. Saeed, "Bonding strength between ultra high-performance concrete (UHPC) and the surface of normal and high-strength concrete," J. Build. Pathol. Rehabil., vol. 10, no. 1, p. 29, 2024.

[19] A. M. Neville, Properties of Concrete, 5th ed. Pearson Education Limited, 2011.

[20] American Concrete Institute (ACI), Guide to Concrete Repair (ACI 224R), 1990.

[21] P. K. Mehta and P. J. M. Monteiro, Concrete: Microstructure, Properties, and Materials, 4th ed. McGraw-Hill Education, 2014.

[22] J. Liu, A. Wan, X. Chen, H. Zheng, X. Huang, and Q. Wu, "Effect of Fatigue Loading and Precracking on the Interface Shear Transfer of Cold Joints," KSCE J. Civ. Eng., vol. 28, no. 11, pp. 5137–5150, 2024.

[23] K. Tang, Y. Zhang, and J. Zhao, “Experimental investigation on shear behavior of the interface between new and old concrete,” Constr. Build. Mater., vol. 314, p. 125624, 2022. DOI: 10.1016/j.conbuildmat.2021.125624.

[24] R. Park and T. Paulay, “Ductile reinforced concrete frames: Some comments on the special provisions for seismic design of ACI 318-71 and on capacity design,” Bull. N. Z. Soc. Earthq. Eng., vol. 8, no. 1, pp. 70–90, 1975.