Research Article
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# Shear strength at the interface of old and new concrete: Foaming agent content and freeze-thaw cycles impact

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**Keywords:**

Freeze-thaw cycles; Old-new concrete joints; Cement grade effects; Frost resistance; Shear strength degradation

**Abstract:**

This comprehensive study investigates the relationship between the number of foaming agents and the increase in shear strength of concrete under various parameters, including cement grades (C300, C350, C400), water-to-cement ratios (0.4, 0.45, 0.5), and curing times (3, 7, 14, 21, and 28 days), and the shear strength at the interface of old and new concrete under successive freeze-thaw cycles. This research analyzes how increasing the concentration of foaming agent (0 to 0.45 wt%) affects the mechanical properties of concrete, with special emphasis on the trend of decreasing shear strength. After 3, 7, 14, 21 and 28 days of curing, 300 consecutive freeze-thaw cycles were used in this study to investigate the effect of these cycles. The temperature of the samples decreased from 4 to -18°C and increased from -18 to 4°C during the freeze-thaw cycles. This was done alternately and at a 4-hour interval for each cycle. After three hours of freezing, the samples were immersed in water for one hour to defrost. The results show that with increasing foaming agent content, a continuous decrease in shear strength occurs, and the rate of decrease is significantly affected by cement grade, water-to-cement ratio, and curing time. The shear stress increases with increasing weight percentage of foaming agents and decreases with increasing melting and freezing cycles. Higher grade cement (C400) shows greater resistance to strength loss compared to lower grades (C300), especially at longer curing periods. The water-cement ratio plays an important role, with higher ratios (0.5) accelerating strength loss due to increased porosity. The study shows that early stages of curing (3–7 days) experience the most rapid strength loss, while longer curing (28 days) partially mitigates this effect through continued hydration. A nonlinear relationship is observed between foaming agent content and strength loss, with critical thresholds identified at 0.25–0.35% foaming agent, beyond which the strength loss becomes greater. In the concrete sample with a curing period of 7 days and a foam consumption of 0.45 and zero, the shear strength after applying the temperature cycle decreased by 81.63% and 1.36% for different water-cement ratios and cement grades, respectively. In the concrete sample with a curing period of 28 days and a foam consumption of 0.45 and zero, the shear strength after applying the temperature cycle decreased by 82.48% and 7.09% for different water-cement ratios and cement grades, respectively. Water-cement ratios of 0.45 and 0.5 are associated with the highest and lowest percentage reduction in shear strength per weight percent of foaming agent, respectively. These findings provide valuable insights for optimizing foam concrete mixtures in applications that require a balance between lightweight properties and structural integrity. Practical implications for mix design, durability considerations, and performance-based specifications are discussed, which will help improve material selection for insulation, non-load-bearing foam concrete, and semi-structural foam concrete applications.

# 1 Introduction

In recent decades, strengthening and repairing existing concrete structures using fresh concrete has become a necessity in structural engineering. This process is of particular importance, especially in countries with old infrastructures such as Iran. In the meantime, the performance of the connection between old and new concrete plays a decisive role in the overall behavior of the structure. Studies show that more than 60% of failures in reinforced structures are due to rupture in the connection area [1]. Key Challenges: Freeze-thaw cycles are known to be one of the most destructive environmental factors for concrete structures. This phenomenon causes severe internal stresses in concrete in areas with annual cold weather. Laboratory studies have shown that after 50 freeze-thaw cycles, the compressive strength of concrete can decrease by up to 40% [2]. In the case of the connection of old and new concrete, these destructive effects can be up to twice as severe, since the connection area acts as a weak point of the structure. Research Background: Several studies have investigated the bond behavior of old and new concrete. Almusallam et al. [3] showed that different surface preparation methods can affect the shear strength of the bond by up to 35%. On the other hand, the use of polymeric adhesives such as epoxies can increase the bond strength by up to 50% [4]. However, most of these studies were conducted under standard environmental conditions, and there is limited information on the bond behavior under freeze-thaw cycles. Destruction of concrete is mostly caused by the action of deicing chemicals in concrete. Sometimes, in winter and in freezing weather, salt is poured on the surface of the roads to melt the ice and snow. The property of salt is that it can quickly melt ice and make the structure quickly usable. This technique is used a lot in airport runways. If the floor of the road or the airport runway is concrete, the salt has a bad and unfavorable effect on the concrete, and it gradually layers the concrete. Therefore, concretes that are exposed to deicing substances (salts) usually have their surface erode faster, especially since these concretes are mostly used in traffic, and naturally, they must be resistant to wear [5,6]. Oxygenated concrete will be far more resistant to delamination and spalling, according to experience. Even with enough strength in both the old and new concrete layers, the connecting surface is nevertheless susceptible to failure during the repair or retrofitting of old concrete with new concrete, making it the most vulnerable component of this system [7]. Two layers have different modulus of elasticity, so even though the applied stress is the same, they will have different strains. The connection surface must be able to tolerate this difference. This issue also includes the difference in strains related to temperature. On the other hand, if fresh concrete is added, this concrete also shrinks, which is another weakness of the connection surface [8]. The materials that make up concrete are very diverse, and it is difficult to estimate its strength and create a model that can express the behavior of concrete [9]. The main components of concrete are hydrated cement paste, aggregate, water, and air. Hydrated cement paste is a complex material consisting of several phases. Aggregates are composite and porous materials and are very different from the surrounding cement paste. The relationship between cement pastes and aggregate is also a complex issue [10]. Sabagh et al. [11] in 2019 prepared concrete samples with different mixing plans while investigating the effect of mixing ratios on concrete strength, taking into account the ratio of water to cement and the ratio of fine to coarse aggregate, and provided comprehensive interfaces for estimating strength. In most cases, the process of freezing and melting is considered a natural phenomenon, and preventing it is beyond human control. Therefore, the only way to prevent the destruction of concrete is to reduce the absorption of water by concrete and possible complications due to excessive water absorption and its saturation [12]. In 2002, Kearsley and Wainwright [13] investigated the effect of porosity on the strength of aerated concrete, and the results of this research showed that the porosity of concrete is highly dependent on its dry density, and the compressive strength of concrete is a function of porosity and concrete age. And with increasing porosity, dry density and compressive strength decrease. Shin et al. [14] in 2010, during research, investigated the connection interface between new and old concrete surfaces. The results of the shear test show that silica fume in new concrete increases not only the compressive strength of new concrete but also the shear bond strength of the interface. Also, for all concretes, it was found that saturated dry surface conditions lead to bond strength. Neshvadian [15] in 2010, during research focusing on the bond between the layer and the sub-layer, investigated the strength of the bond between the repair material and the substrate at the interface level. The results of this research showed that many factors, such as surface roughness, the presence of small cracks, compaction, processing, etc., affect the strength of the bond, and according to the loading methods, the strength of the bond is determined [16]. Wan [17] in 2011 investigated the shear bond between old and new concrete, and the results showed that silica fume significantly increases the compressive strength of new concrete and shear bond strength, and new concrete with a weight ratio of 0.45 leads to higher compressive strength and lower shear bond strength [18]. Tayeh et al. [19] examined the bond strength of conventional concrete (NC) and ultra-high-performance concrete (UHPC) in 2013. They found that the UHPC had excellent bonding with the conventional concrete substrate's surface. Since the majority of the tests' fractures occurred in the conventional concrete substrate, they concluded that the bond strength was even higher than that of the conventional concrete substrate [20]. In 2016, during research, Rosen [21] investigated various methods for measuring shear strength at the interface between a concrete bed and a concrete cover. The findings of this research show that the results depend on the test method used to evaluate the shear strength and show the importance of repairing the surface of a substrate in shear strength for bonded coating [22]. In 2017, Vandhiyan et al. [23] investigated the strength of the bond between old and new concrete layers using an epoxy-based bonding agent during an experimental study. Analysis of the results shows that the use of an epoxy-based bonding agent leads to improved bond strength [24]. Croes [25] in 2019 investigated the effect of the difference in elastic moduli between two concretes and showed that a large difference in elastic moduli may reduce the shear strength of the interface. [26]. In 2019, Sharma et al. [27] investigated the behavior of shear strength at the interface of NC-UHPC during experimental research consisting of 10 laboratory samples. The results of this research show that increasing the roughness depth in the reinforcement area has a positive effect on the shear capacity of the interface [28]. According to the studies done and the importance of connecting old and new concrete, in this article, the effect of freezing and thawing cycles on the shear strength of the joint band according to the change of parameters such as the amount of foaming material, water-cement ratio, grade of cement used, and duration of operation, was investigated. Innovation of the present research: This study was designed to systematically investigate the effect of freeze-thaw cycles on the shear strength of old and new concrete joints. In this study, key parameters include:

- Different surface preparation methods
- The effect of water-cement ratio in fresh concrete
- The effect of the number of freeze-thaw cycles has been investigated

Research Objectives

1. Quantitative assessment of the reduction in joint shear strength under freeze-thaw cycles
2. Identification of optimal methods for improving joint performance in harsh environmental conditions
3. Providing a predictive model for estimating joint service life in cold environments

Given the increasing need to strengthen existing structures and the expansion of construction in cold regions, it is of vital importance to accurately understand the bonding behavior of old and new concrete under freeze-thaw cycles. This research, by providing accurate experimental data and comprehensive analyses, takes an important step towards improving implementation methods and increasing the safety of reinforced structures. The findings of this study can be used as a scientific basis for updating design codes in cold regions

## 2 Materials and Methods

***<u>Materials</u>:*** In this research, to investigate the effect of freezing and thawing cycles on the adhesion between new and old concrete, experiments have been conducted in the laboratory. For this purpose, a sand sample with a modulus of elasticity of 3.05 with the largest aggregate size of 25 mm and a bulk density of 1438 kg/m$^3$ has been used. In order to determine the mixing plan, according to the cement quality and water-cement ratio, the amount of water in each mixture is calculated. To determine the concrete mixing plan, the mixing plan method of the ACI regulation [29] was used.

In this study, for old concrete, concrete with the same granularity as new concrete with a life of at least 90 days, grade 350 and a water-cement ratio of 0.4 was used. In the connection created between old and new concrete, no other agents such as glue, fibers or interface elements such as rebar, etc. have been used. Concrete is a material that absorbs and holds water. Water absorption is one of the unfavorable factors and is harmful for concrete, because it increases the possibility of freezing and erosion. Experience has shown that aerated concrete has a much lower water absorption percentage than airless concrete, so in this research, the shear strength of the joint under the effect of changing the water-cement ratio of concrete samples was investigated. Also, the temperature of zero degrees Celsius is the temperature at which pure water freezes, while the water in concrete, which is a solution of various salts, will freeze at a temperature lower than zero degrees. Another influencing factor in the freezing temperature of water is the size of its cavities that are filled with water. The smaller the size of the hole, the lower the freezing temperature will be, which causes concrete destruction during the freezing and thawing periods. When the water temperature reaches zero degrees and freezes, the volume of water increases by 9%. With this increase in volume, the water that still remains in the cavity as a fluid is exposed to hydraulic pressure, which if the water in the cavity does not have a way to discharge this hydraulic pressure, will cause tensile stresses in the concrete and lead to concrete destruction. In each period, the pressure applied to each of the holes causes the hole to expand and causes the hole to contain more water in the following periods and when it absorbs water and imposes an increase in volume and pressure to the concrete. Therefore, the effect of bubble-forming materials on the shear strength of the joint under the effect of the freezing and thawing cycle is one of the very important factors that must be investigated.

According to the stated contents, the desired variables in this research, which were used in two tests to determine the shear strength and the tensile strength of the connection surface, are a combination of the following conditions:

- The grade of cement used in three cases is 300, 350 and 400 kg/m$^3$ .
- The use of foaming agents at 5 levels of 0, 0.15, 0.25, 0.35 and 0.45 percent by weight of cement used.
- Using three ratios of water to cement (W/C) equal to 0.4, 0.45 and 0.5.
- Start of 300 cycles of melting and freezing in 3 modes (after 3, 7, 14, 21and 28 days of curing new concrete). In all cases, the above tests have been performed on the mentioned compounds for comparison without applying the melting and freezing cycles. That is, the total number of test cases is 540.
- Regarding pre-wetting the old concrete surface, there are different opinions to provide the best conditions. The AASHTO AGC ARTBA committee recommends a dry surface except on hot and dry summer days [30]. While the Canadian Standards Institute recommends that the surface be wet 24 hours before pouring new concrete. The Swiss National Road Institute recommends soaking the old concrete for 48 hours but having a dry surface during concreting, which was done here. In addition, other environmental conditions including ambient temperature and mixing time are almost the same in all samples.
- The cement used in all samples is Portland cement type 2.
- Consumable bubble maker is type S-2000.

**Fig. 1 - Preparing concrete by adding aggregate and cement**

**Fig. 2 - Sample prepared**

**Fig. 3 - Prepared sample undergoing freezing**

***Methods**:* To measure the effect of melting and freezing cycles on adhesion load between old and new concrete, the samples were placed in a special device for this test with performance according to ASTM C666. [31] The ASTM C666 [31] standard has proposed two methods for checking the melting and freezing cycles of concrete:

→ Both freezing and melting processes of samples are done in water.

→ The freezing process takes place in air and the melting process takes place in water.

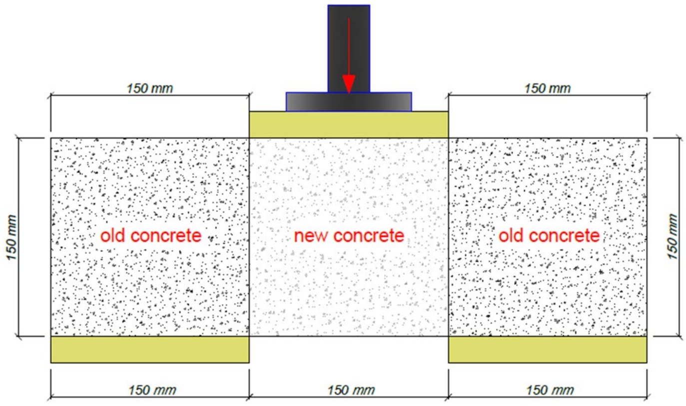
Method A is the most common method and is generally considered as a more severe method that has a greater ability to find weak materials, so both ASTM C233 and ASTM C494 standards prescribe Method A, so this method was used in this research.

The periods of melting and freezing for both methods include lowering the temperature of the samples from 4°C to -18°C and raising it from -18°C to 4°C alternately and in a period of less than 2 hours and no more than 5 hours. In method A, the time required to increase the temperature of the samples should not be less than 25% of the time required for the samples to cool down. The temperature of the samples should never be less than -19 degrees Celsius and more than 6 degrees Celsius. The beginning of the ice and freezing test is by placing the samples in hot water at the beginning of the thawing cycle. The test on the samples continues until the samples are exposed to at least 300 cycles of thawing and freezing. Each freeze-thaw cycle was considered for 4 hours, and the samples were frozen for 3 hours and placed in water for 1 hour during the melting process.

In order to evaluate the bond strength of old and new concrete, shear strength test has been used. In this experiment, a mold with internal dimensions of 45 x 15 x 15 cm (length 45 cm, width and height 15 cm) was used to prepare the samples in such a way that the sides of the mold were filled with old concrete cubes (after processing) and We fill the middle of the mold with new concrete and process it. Shear strength testing machine is presented in Figure 3.

(a) (b)

Figure 3. (a): Shear strength testing machine. (b) Sample freezer

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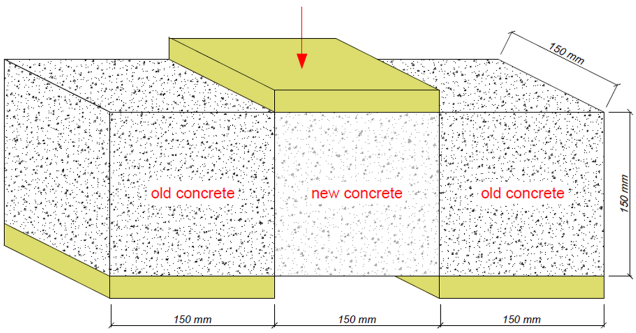



(b)

Figure 4. Connecting new and old concrete and applying force for performing shear strength testing

In the shear strength test, the samples were already exposed to melting and freezing cycles, and by keeping them fixed on the new concrete, the *P* action of the old concrete was compared to the applied load. The shear stress is calculated according to equation (1), where $\tau_a$ is shear stress (MPa)

$$\tau_a = \frac{P}{2a^2}, \tag{2}$$

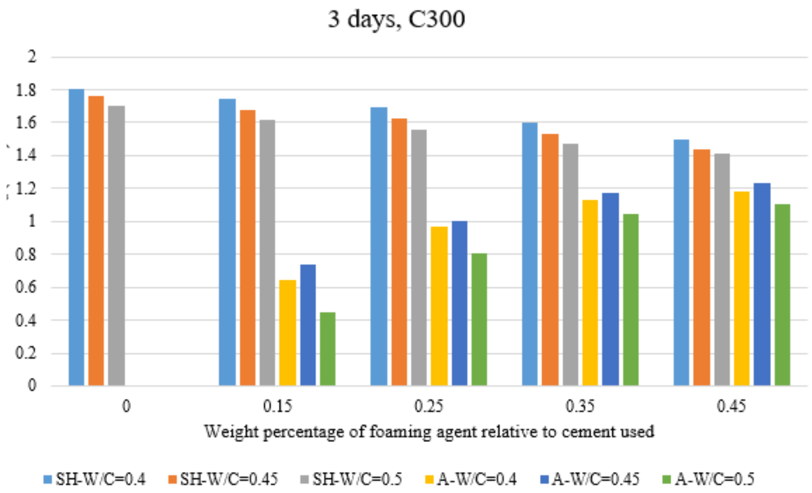
where $a^2$ is the cross section.

# 3 Results and Discussion

In this part, the shear strength of the joint of new and old concrete under the effect of changing different parameters (weight percentage of foaming material used, grade of cement, water-cement ratio and curing time) in two cases with and without applying the freezing and thawing cycle is investigated. In this research, 300 cycles were used for freezing and thawing.

The combined effect of water-cement ratio and weight percentage of foaming materials on shear strength: To investigate the combined effect of weight percentage of foaming material and water-cement ratio on shear strength and bond strength of old and new concrete from five levels of foaming material 0, 0.15, 0.25, 0.35 and 0.45, according to the weight percentage of cement used and three ratios Water to cement ratios of 0.4, 0.45 and 0.5 were used in the experiments. In figure 5, 6, 7, 8 and 9, the number of changes in shear strength in relation to the change in the weight percentage of foaming materials in three periods of 3, 7, 14, 21 and 28 days for concrete with the grade of cement used 300, 350 and 400 kg/m$^3$ are shown.

In these figures, SH-W/C=0.4, SH-W/C=0.45, and SH-W/C=0.5 correspond to concrete samples with a water-cement ratio of 0.4, 0.45, and 0.5, respectively, under test conditions without melting and freezing cycles. And A-W/C=0.40, A-W/C=0.45 and A-W/C=0.5, respectively, corresponding to concrete samples with water-cement ratio 0.4, 0.45 and 0.5 under test conditions with melting and freezing cycle (SH for the state without melting and freezing cycle and A for the state with freezing and thawing cycle). Also, in the figures of this section, concrete samples with cement grades of 300, 350 and 400 kg/m$^3$ respectively with C300, C350 and C400 and curing period of 3, 7, 14, 21 and 28 days respectively with 3 days, 7 days, 14 days, 21 days and 28 Fasting is displayed. According to figure 5, 6, 7, 8 and 9, for the case with melting and freezing cycles, the shear stress increases with the increase in the weight percentage of the foaming material, but in the tests without the melting and freezing cycle, the shear stress decreases with the increase in the weight percentage of the foaming material. In conditions with a cycle of melting and freezing, for concrete with a high percentage of encapsulating materials, the air in the concrete makes it easier for the water in the cavity to reach the surrounding air cavities when the hydraulic pressure due to frost in the cavities increases. Reduce the pressure. For this reason, this type of concrete is more durable against freezing and thawing cycles. In conditions without melting and freezing cycles, with an increase in the weight percentage of encapsulating materials from zero to 0.45, for concrete with a water-cement ratio of 0.4, 0.45 and 0.5, the shear stress value decreases by 8.83%, 10.12% and 9.85% for a 28-day curing period and a cement grade of 300, respectively, by 7.94%, 7.11% and 5.72% for a 28-day curing period and a cement grade of 350, respectively, and by 7.84%, 7.9% and 8.61% for a 28-day curing period and a cement grade of 400, respectively. But for laboratory conditions with melting and freezing cycles, the amount of shear stress increases significantly with the increase in the weight percentage of foaming materials, so that for concrete with a water-cement ratio of 0.4, 0.45 and 0.5 in the 28-day curing period and for concrete With a grade of 300 kg/m$^3$, with an increase in the weight percentage of the foaming material from zero to 0.4, the amount of shear stress, respectively, from a very small value of 0.29 , 0.43 and zero reaches 2.53, 2.6 and 2.34 MPa, for concrete with a water-cement ratio of 0.4, 0.45 and 0.5 in the 28-day curing period and for concrete With a grade of 350 kg/m$^3$, with an increase in the weight percentage of the foaming material from zero to 0.4, the amount of shear stress, respectively, from a very small value of 0.32 , 0.47 and zero reaches 2.83, 2.92 and 2.63 MPa and for concrete with a water-cement ratio of 0.4, 0.45 and 0.5 in the 28-day curing period and for concrete With a grade of 400 kg/m$^3$, with an increase in the weight percentage of the foaming material from zero to 0.4, the amount of shear stress, respectively, from a very small value of 0.31 , 0.50 and zero reaches 2.89, 3 and 2.73 MPa.

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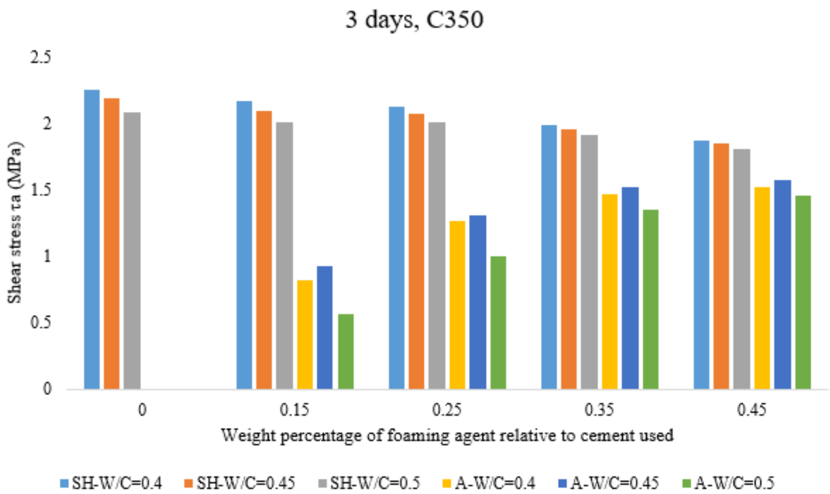


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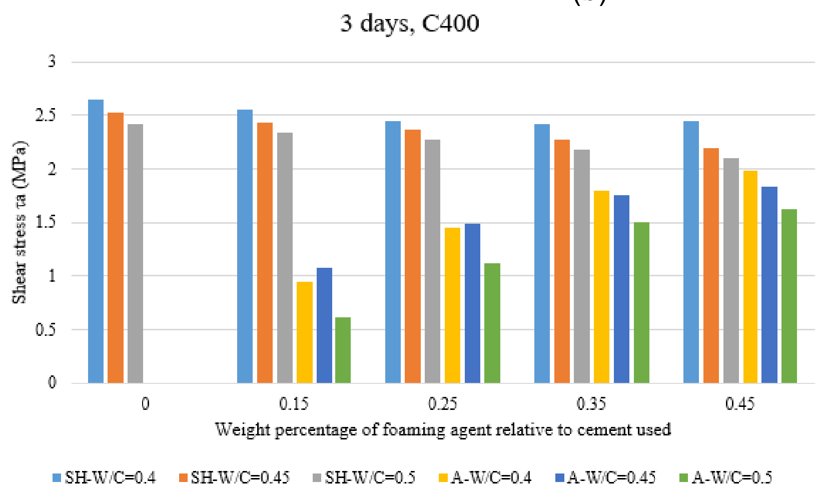
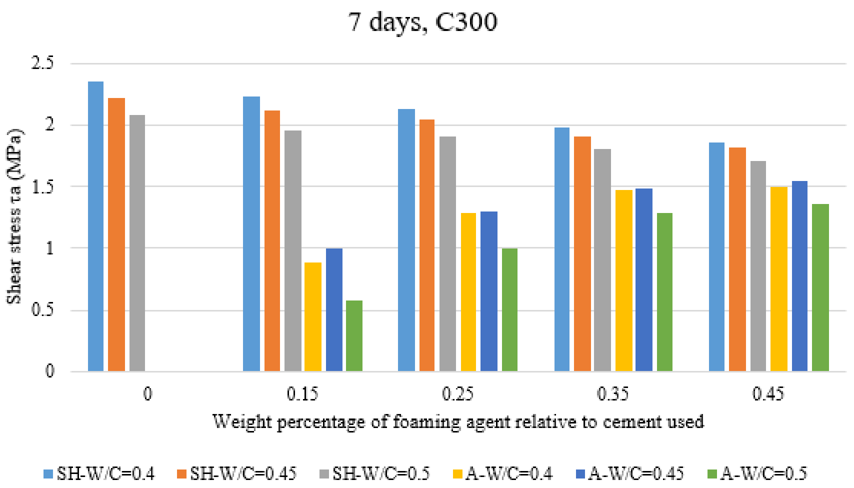



(c)

Figure 5. The rate of change in shear strength with respect to the change in the weight percentage of foaming agents in three water-to-cement ratios for different cement grades during a curing period of 3 days: (a) C300; (b) C350; (c) C400

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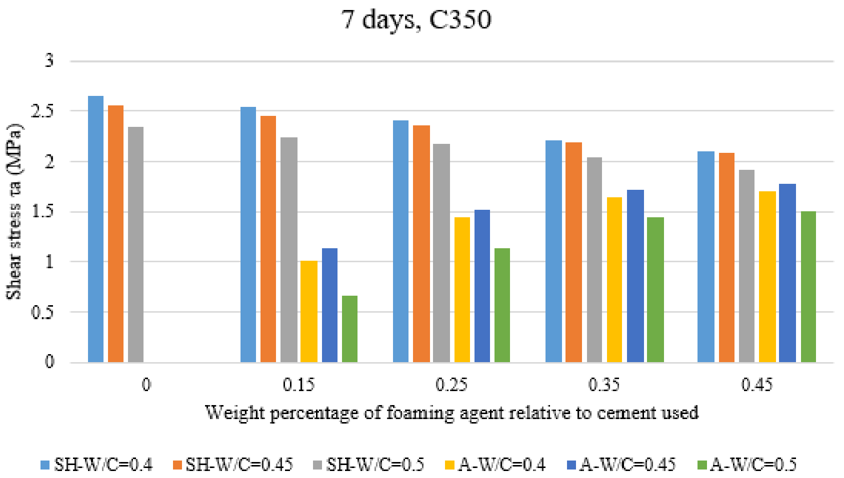


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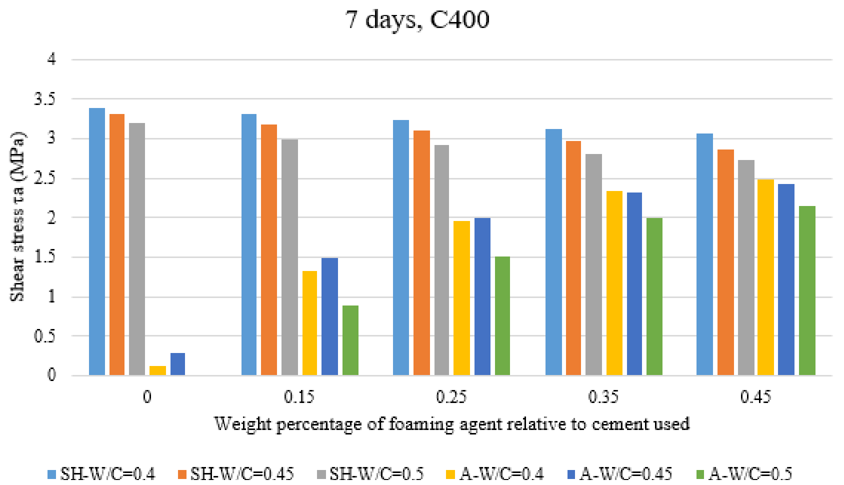
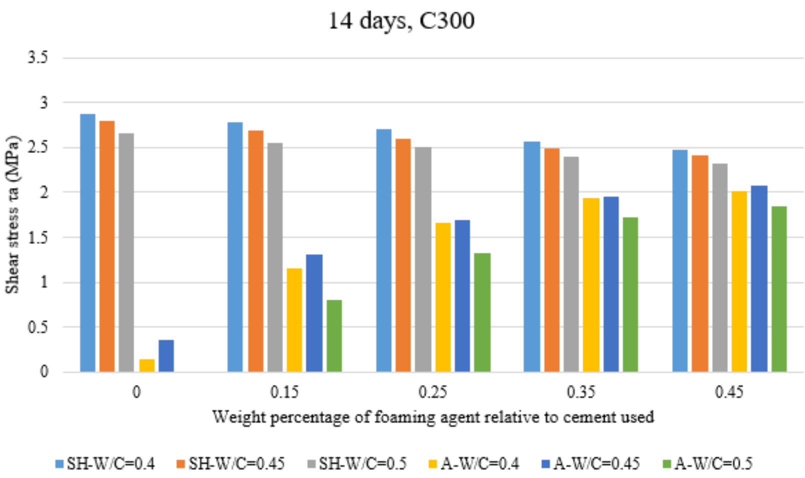



(c)

Figure 6. The rate of change in shear strength regarding the change in the weight percentage of foaming agents in three water-to-cement ratios for different cement grades during the 7-day curing period: (a) C300; (b) C350; (c) C400

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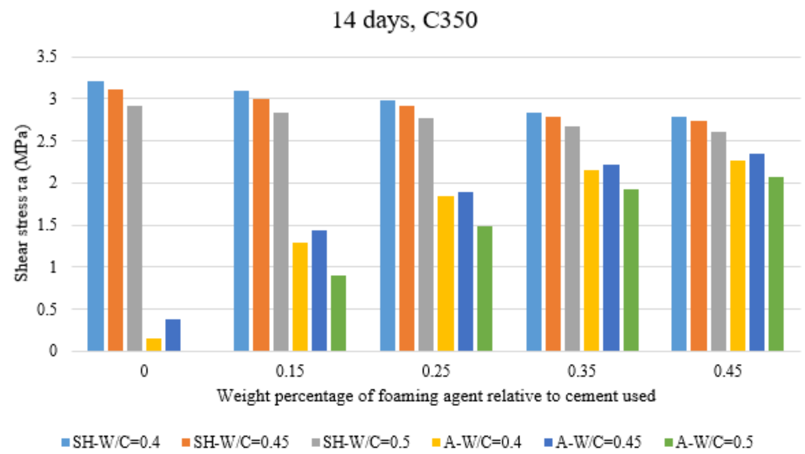


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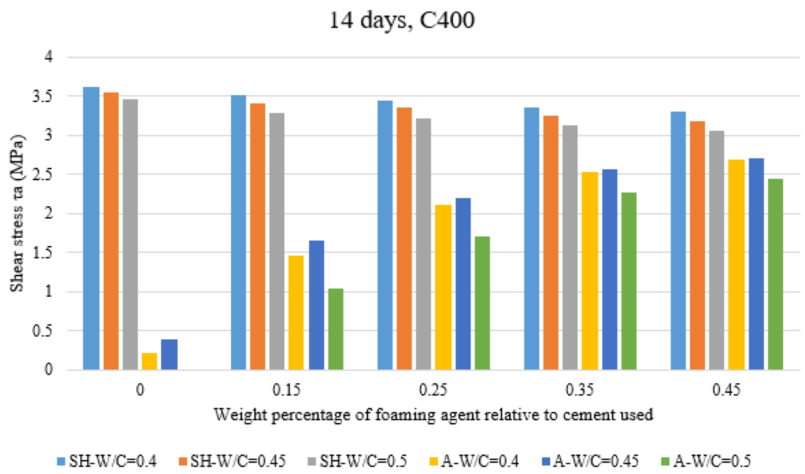
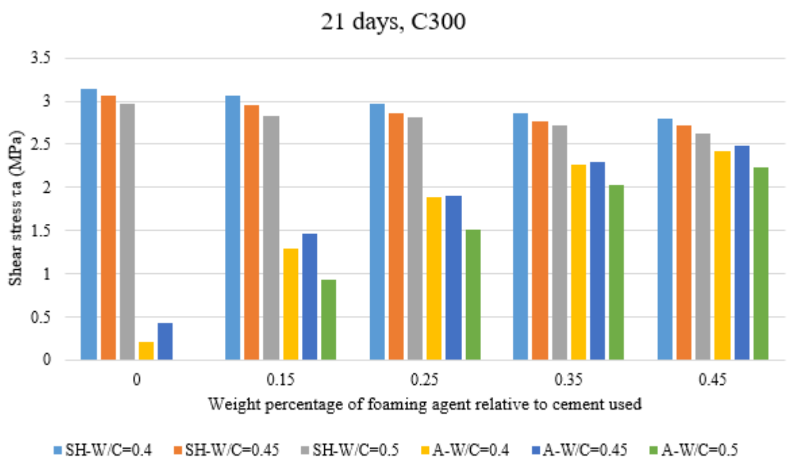



(c)

Figure 7. The rate of change in shear strength regarding the change in the weight percentage of foaming agents in three water-to-cement ratios for different cement grades during the 14-day curing period: (a) C300; (b) C350; (c) C400

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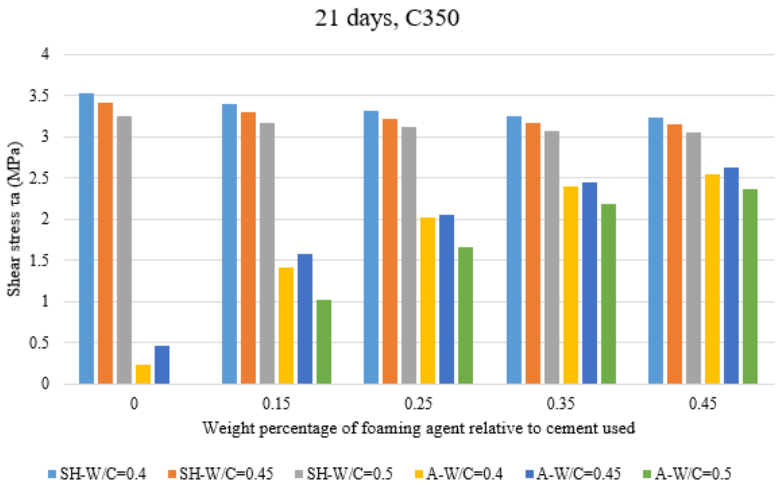


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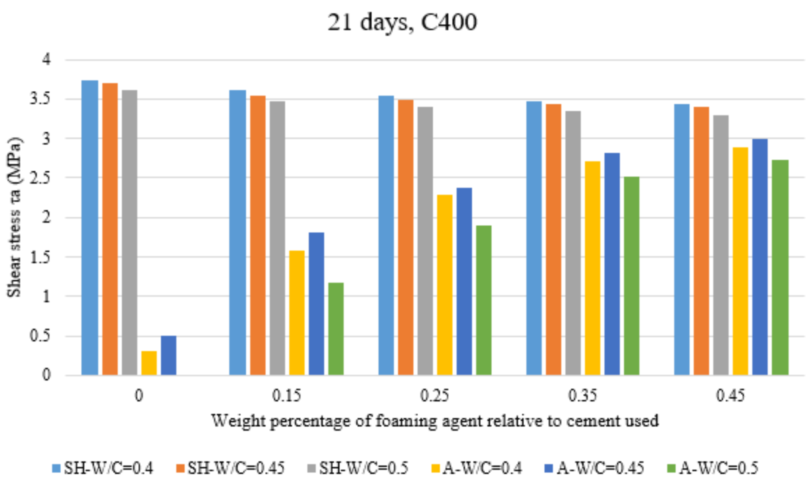


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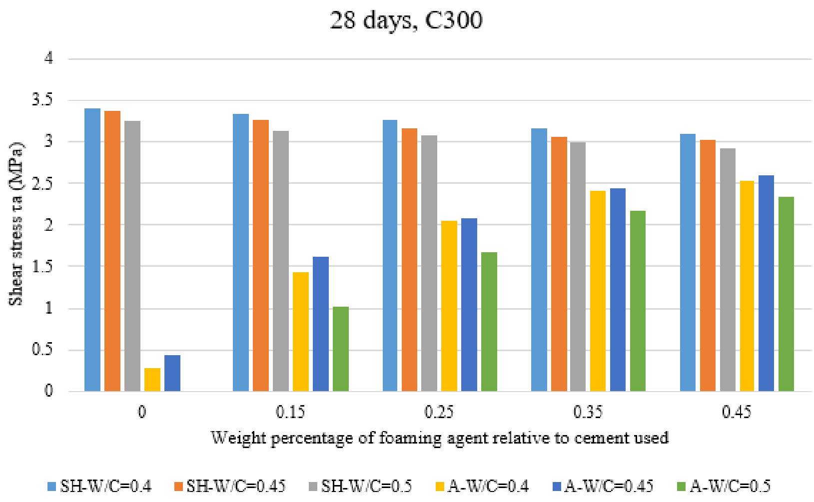
Figure 8. The rate of change in shear strength regarding the change in the weight percentage of foaming agents in three water-to-cement ratios for different cement grades during the 21-day curing period: (a) C300; (b) C350; (c) C400

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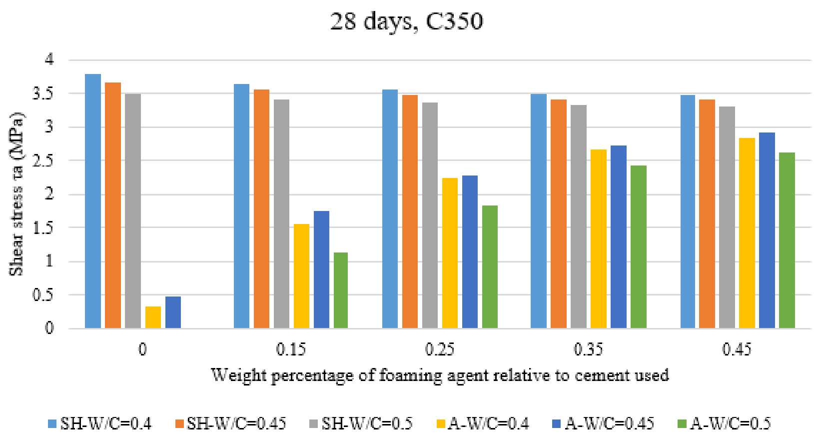


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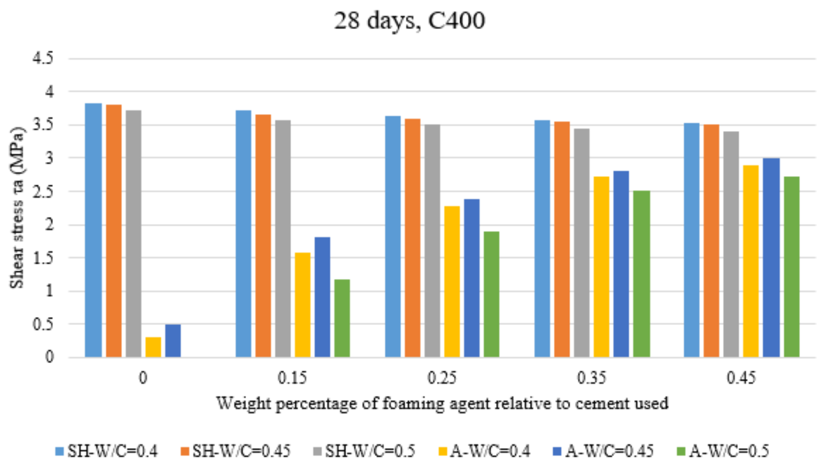
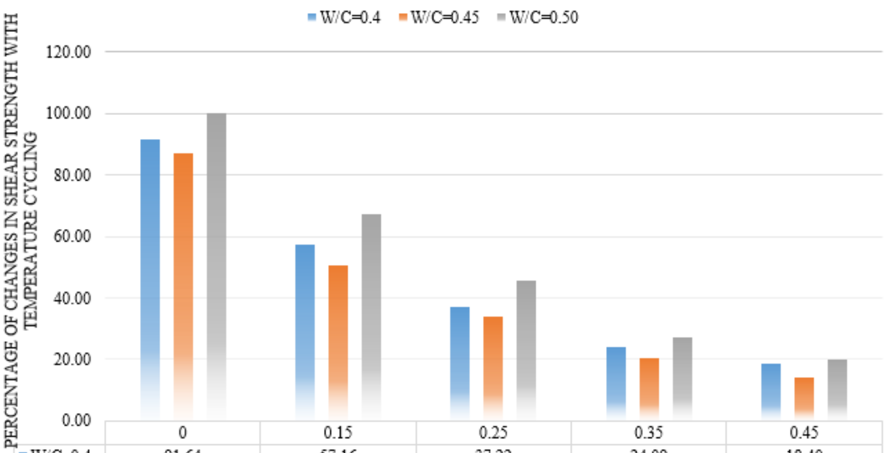



(c)

Figure 9. The rate of change in shear strength regarding the change in the weight percentage of foaming agents in three water-to-cement ratios for different cement grades during the 28-day curing period: (a) C300; (b) C350; (c) C400

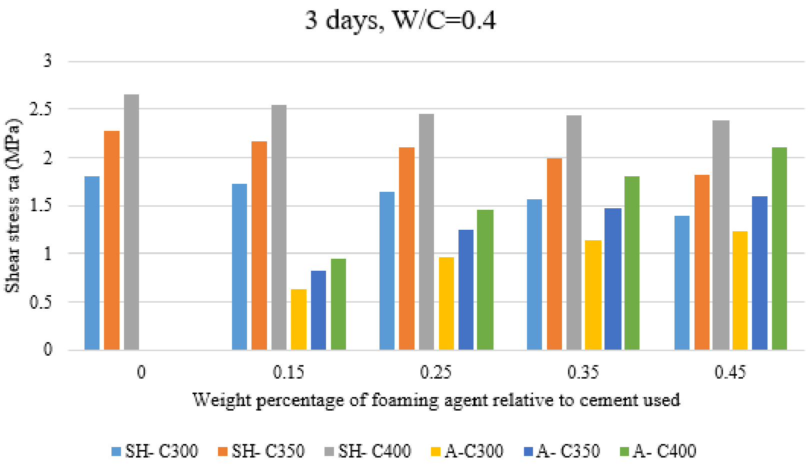



| | 0 | 0.15 | 0.25 | 0.35 | 0.45 |
|---|---|---|---|---|---|
| W/C=0.4 | 91.64 | 57.16 | 37.22 | 24.09 | 18.40 |
| W/C=0.45 | 87.07 | 50.60 | 33.95 | 20.33 | 14.10 |
| W/C=0.50 | 100.00 | 67.13 | 45.74 | 27.09 | 20.05 |

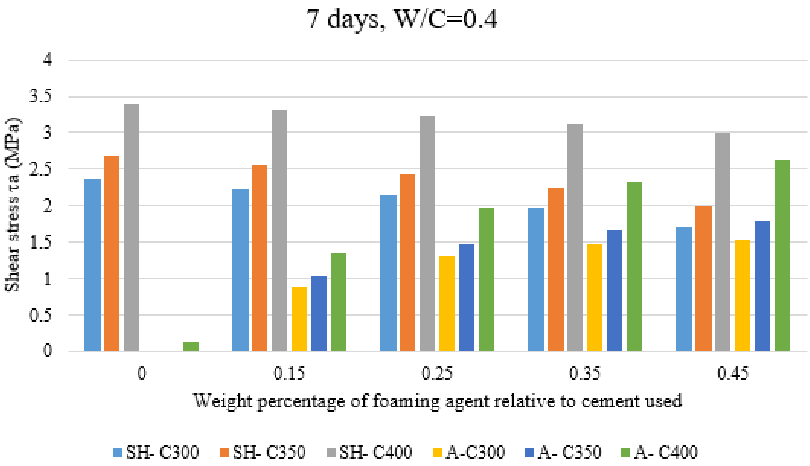
Figure 10. Percentage reduction in shear strength under the effect of temperature cycles for different water to cement ratios

In Figure 10, the percentage reduction in shear strength under the effect of freezing and thawing cycles is shown on average according to the changes in the ratio of water to cement and the number of foaming agents used during the 3, 7, 14, 21 and 28-day curing period for three grades of cement used. This can be seen in this figure, the amount of shear strength after applying the temperature cycle for three water-cement ratios of 0.4, 0.45 and 0.5 in the concrete sample with zero bubbles, as average decreases by 92.9%, for concrete with 0.25% bubble consumption, it decreases by 38.97% and for concrete with 0.45% bubble consumption, it decreases by 17.51%. According to figure 10, the highest and lowest percentage of reduction in shear strength per weight percent of foaming material, respectively, is related to the ratio of water to cement of 0.5 and is 0.45.

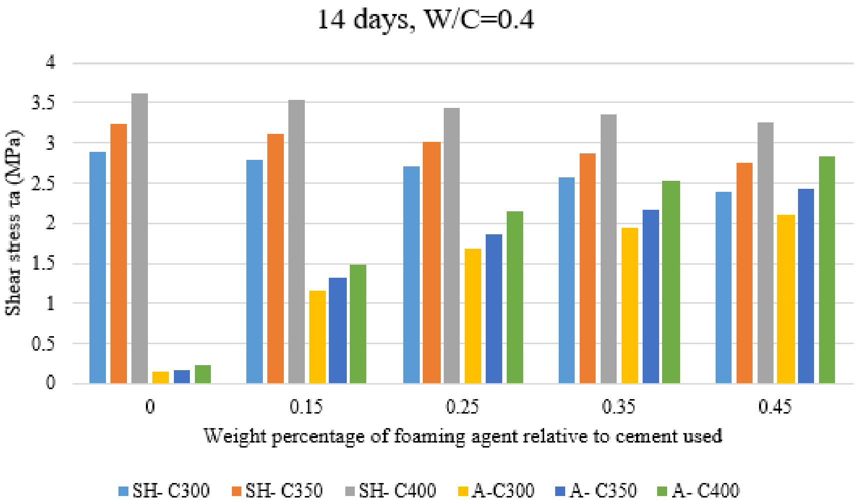
The combined effect of different grades of cement used and percentage by weight of foaming materials on shear strength:Concrete with cement grades of 300, 350, and 400 kg/m$^3$ was used to examine how variations in cement grades and the weight % of foaming additives affected shear strength. The combined impact of various cement grades and the weight % of foaming additives on shear strength is depicted in Figures 11, 12 and 13. Concrete samples with cement contents of 300, 350, and 400 kg/m$^3$ under test conditions without a thaw-freeze cycle are represented by SH-C300, SH-C350, and SH-C400 in these figures, while concrete samples with cement contents of 300, 350, and 400 kg/m$^3$ under test conditions with a thaw-freeze cycle are represented by A-C300, A-C350, and A-C400, respectively. For concrete with a strength of 300, 350, and 400 kg/m$^3$, the shear stress decreases by an average of 10.78, 7.90, and 8.47 percent for different water-to-cement ratios and curing periods, respectively. Figures 11, 12 and 13 show that in the case with the melting and freezing cycle, the shear stress increases with increasing weight percentage of the foaming material, but in the experiments without the melting and freezing cycle, the shear stress decreases with increasing weight percentage of the foaming material from zero to 0.45. When the weight percentage of the foaming agent is increased from zero to 0.45, the shear stress increases by 568.29, 571.73, and 558.30 percent, respectively, for concrete with strengths of 300, 350, and 400 kg/m$^3$ in a 28-day curing period and a water-to-cement ratio of 0.45. This is because the shear stress increases from a very small value of 0.41, 0.46, and 0.48 to 2.74, 3.09, and 3.16 MPa under laboratory conditions, with a melting and freezing cycle.


3 days, W/C=0.4
Shear stress τa (MPa)
3
2.5
2
1.5
1
0.5
0
0
0.15
0.25
0.35
0.45
Weight percentage of foaming agent relative to cement used
SH- C300
SH- C350
SH- C400
A-C300
A- C350
A- C400

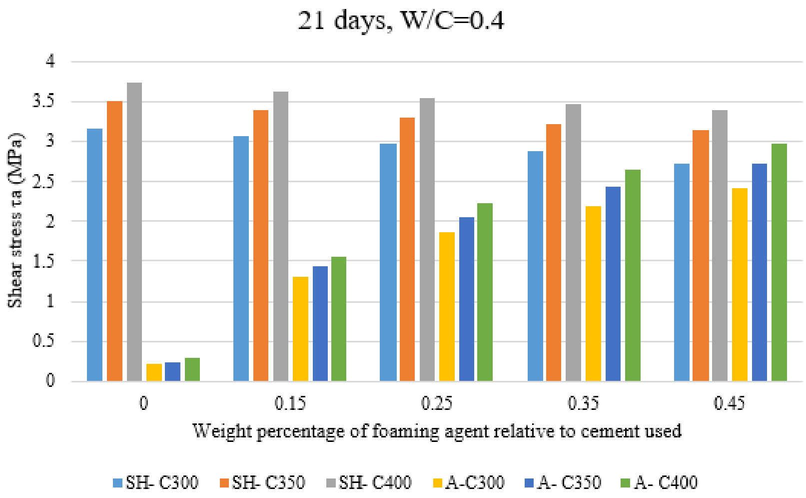
(a)


7 days, W/C=0.4
Shear stress τa (MPa)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.15
0.25
0.35
0.45
Weight percentage of foaming agent relative to cement used
SH- C300
SH- C350
SH- C400
A-C300
A- C350
A- C400

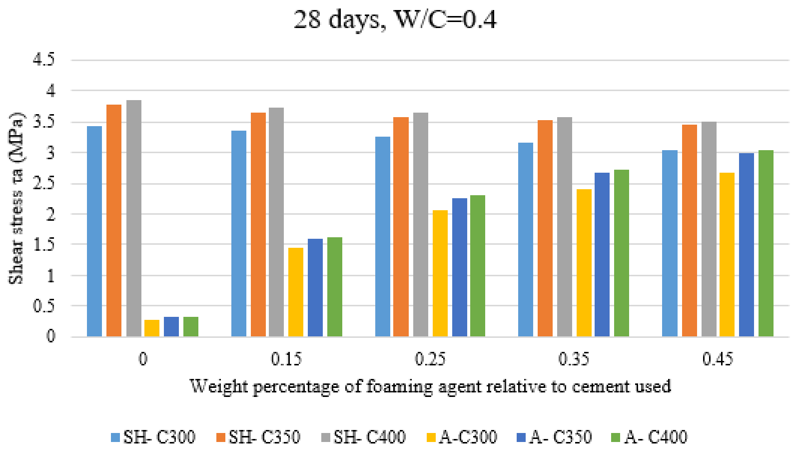
(b)


14 days, W/C=0.4
Shear stress τa (MPa)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.15
0.25
0.35
0.45
Weight percentage of foaming agent relative to cement used
SH- C300
SH- C350
SH- C400
A-C300
A- C350
A- C400

(c)

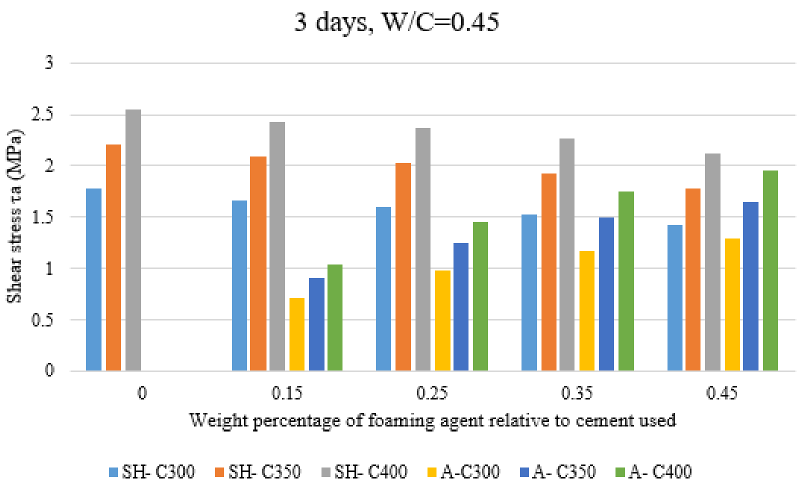



(d)

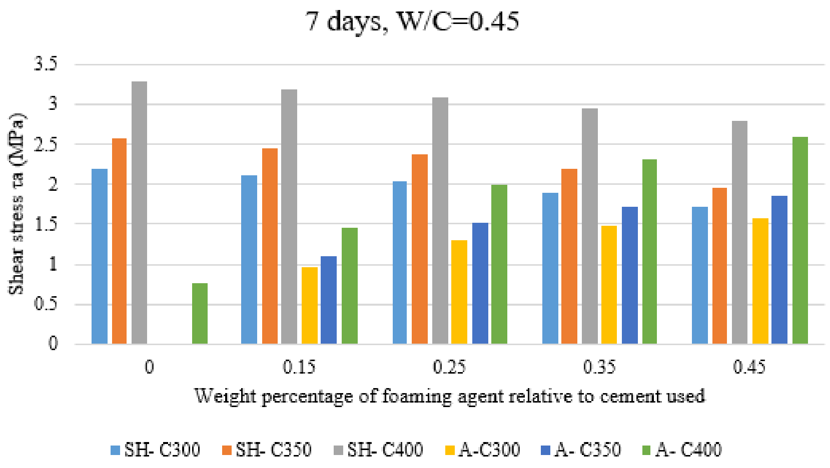



(e)

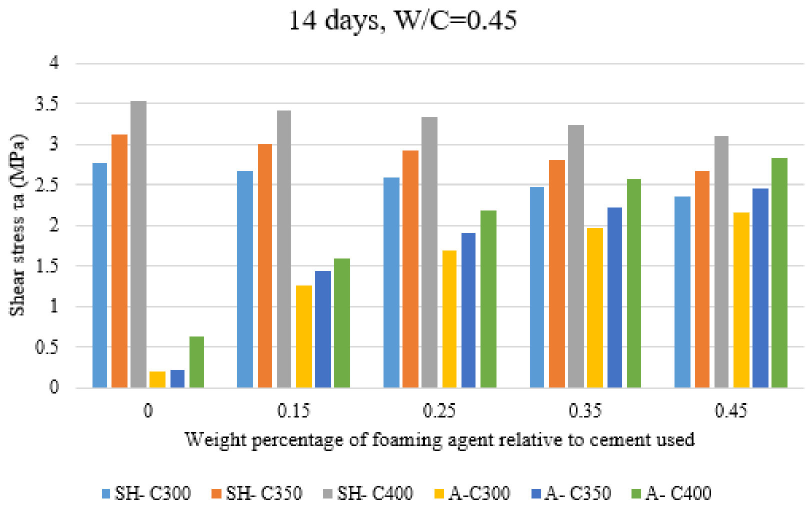
Figure 11. The rate of change in shear strength regarding the change in the weight percentage of foaming agents in different cement grades at a water-to-cement ratio of 0.4: (a) 3 days of curing; (b) 7 days; (c) 14 days; (d) 21 days; (e) 28 days



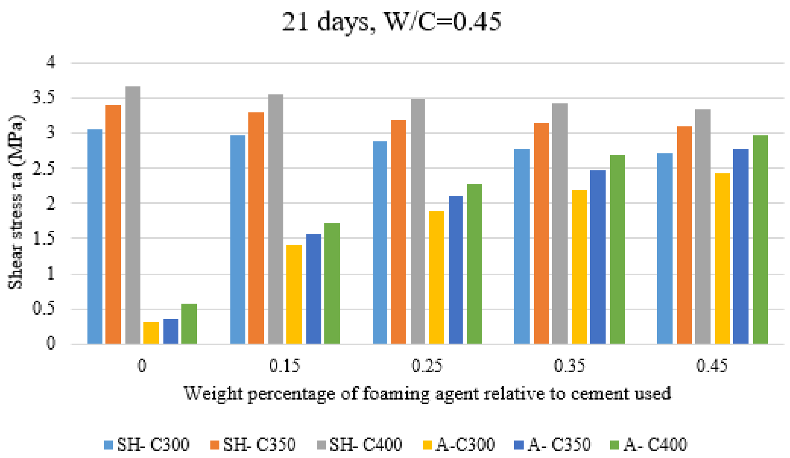

(a)


7 days, W/C=0.45
Shear stress τa (MPa)
3.5
3
2.5
2
1.5
1
0.5
0
0
0.15
0.25
0.35
0.45
Weight percentage of foaming agent relative to cement used
SH- C300
SH- C350
SH- C400
A-C300
A- C350
A- C400

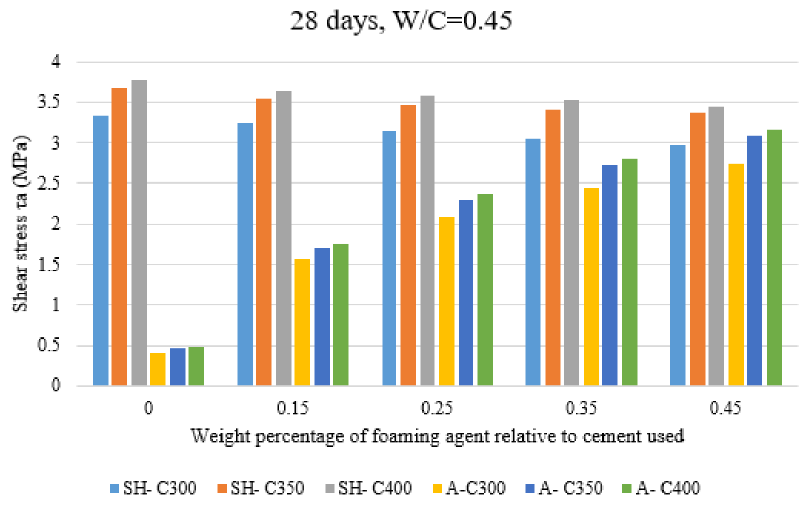
(b)


14 days, W/C=0.45
Shear stress τa (MPa)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.15
0.25
0.35
0.45
Weight percentage of foaming agent relative to cement used
SH- C300
SH- C350
SH- C400
A-C300
A- C350
A- C400

(c)

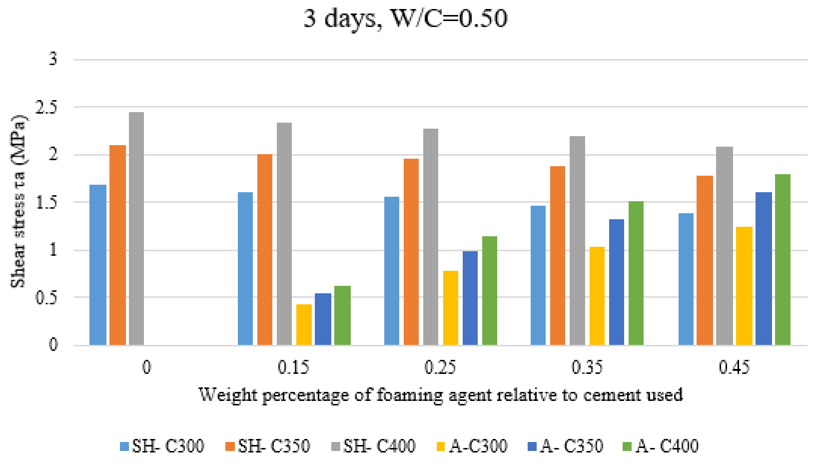

21 days, W/C=0.45
Shear stress τa (MPa)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.15
0.25
0.35
0.45
Weight percentage of foaming agent relative to cement used
SH- C300
SH- C350
SH- C400
A-C300
A- C350
A- C400

(d)

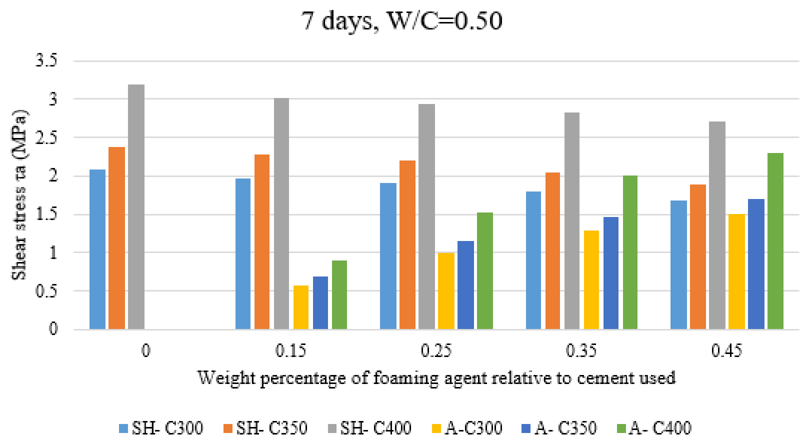



(e)

Figure 12. The rate of change in shear strength regarding the change in the weight percentage of foaming agents in different cement grades at a water-to-cement ratio of 0.45: (a) 3 days of curing; (b) 7 days; (c) 14 days; (d) 21 days; (e) 28 days

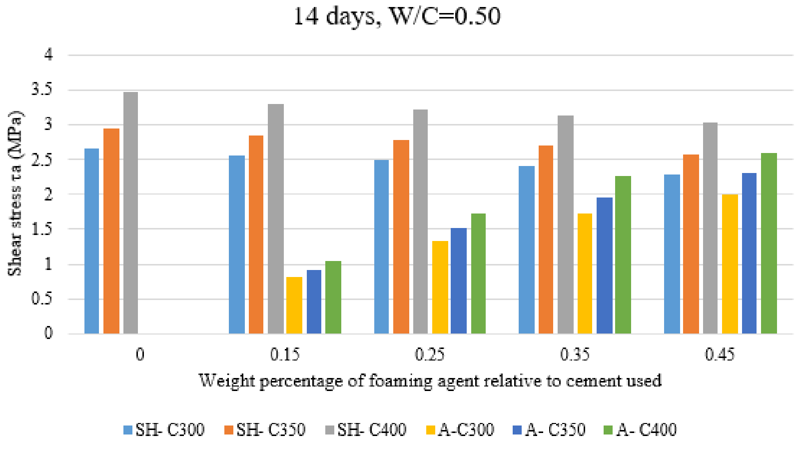



(a)

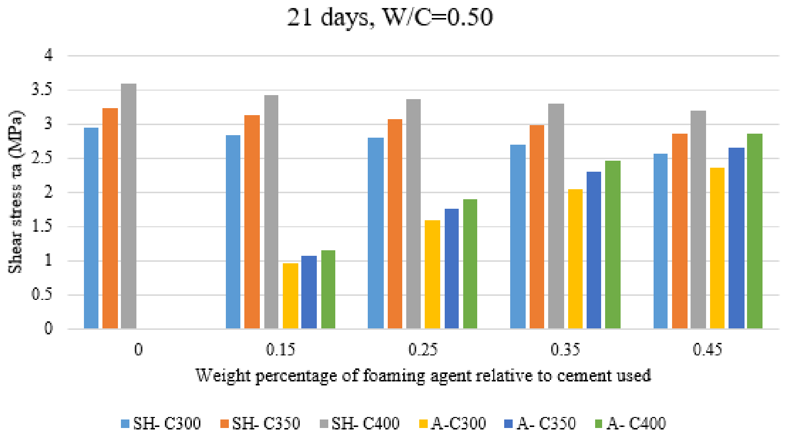



(b)

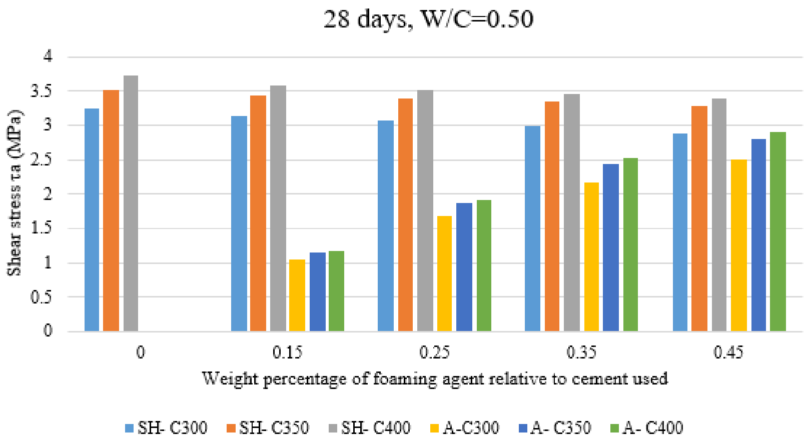
Ehsani, A.; Nasimi, S.H.; Shambina, S. L.
Shear strength at the interface of old and new concrete: Foaming agent content and freeze-thaw cycles impact;
2026; AlfaBuild; 37 Article No 3704. doi: 10.57728/ALF.37.4




(c)




(d)




(e)

Figure 13. The rate of change in shear strength regarding the change in the weight percentage of foaming agents in different cement grades at a water-to-cement ratio of 0.50: (a) 3 days of curing; (b) 7 days; (c) 14 days; (d) 21 days; (e) 28 days

Concerning the change in cement grade and the amount of foaming agent utilized throughout the average 28-day curing time for three water-to-cement ratios, Figure 14 illustrates the percentage of shear strength drop caused by freeze-thaw cycles. As shown in this figure, The concrete sample with a foaming agent of 0 experiences an average reduction of 91.58%, 87.5%, and 100% for water-cement ratios of 0.4, 0.45, and 0.5, respectively .after applying temperature cycling for three grades of 300, 350, and 400 kg/m$^3$, While the concrete sample with a foaming agent of 0.45 experiences an average decrease of 12.72, 8.43, and 14.18 percent for water-to-cement ratios of 0.4, 0.45, and 0.5, respectively. Figure 14 shows that the decline in shear strength under the influence of temperature cycling is not significantly affected by the kind of cement used for concrete with varying levels of foaming agents.

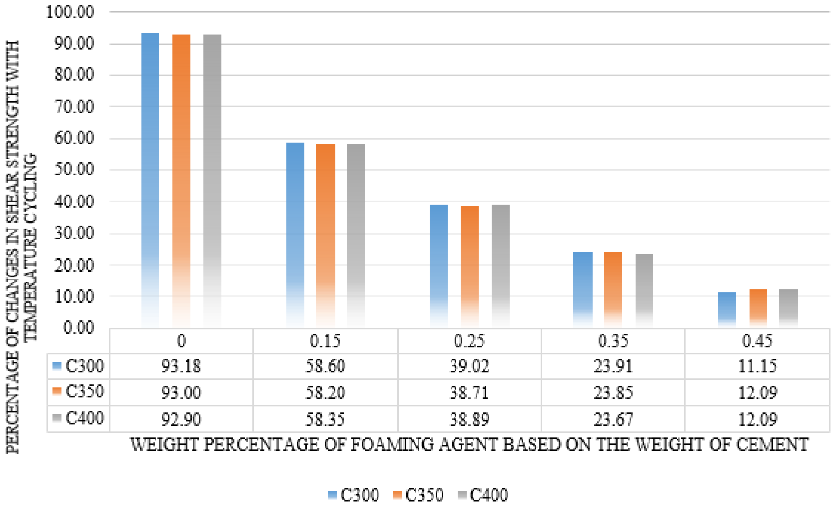
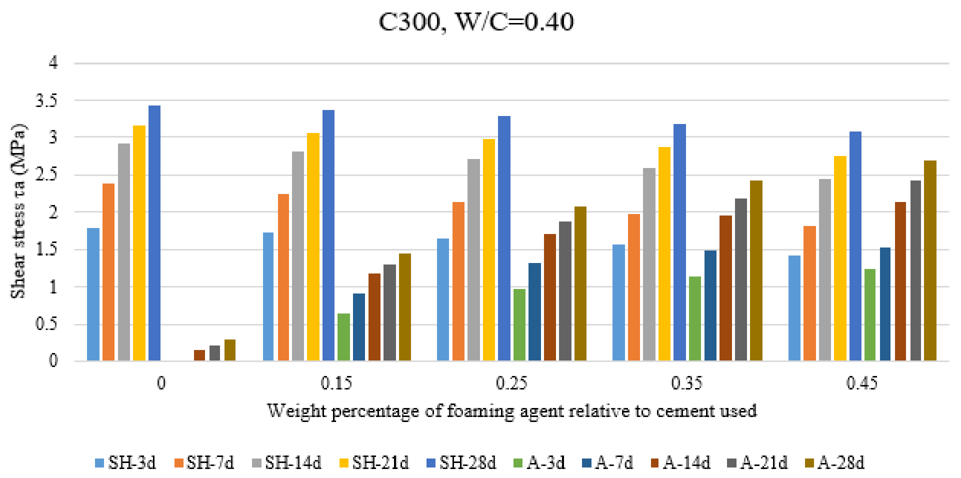



Figure 14. Percentage of decrease in strength of the object under the effect of temperature cycles for different cement grades

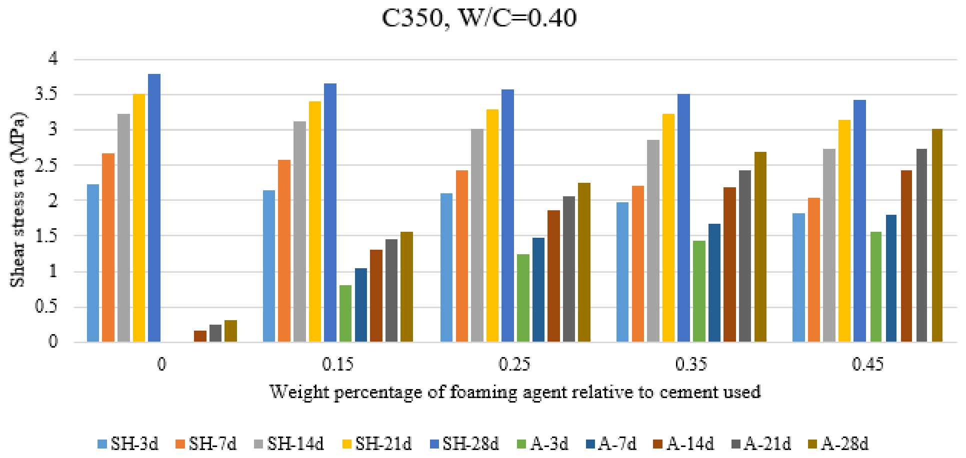
The impact of curing time and foaming agent weight % on shear strength together: As seen in Figures 15, 16 and 17, the combined impact of curing time and weight % of foaming agents on shear strength was examined in this section of the study. These graphs demonstrate how the shear strength of concrete samples with varying foaming agent concentrations at each water to cement ratio rises noticeably with longer curing times, both with and without the melting and freezing cycle. Curing time has a significant impact on increasing shear strength in settings with a melting and freezing cycle. For instance, concrete with a foaming agent concentration of 0.45 has a significantly higher effect than concrete with a foaming agent content of zero. The impact of curing time on increasing shear strength, for instance, is almost the same for concrete with varying foaming agent contents in circumstances without a melting and freezing cycle.

Frost resistance is the ability of hardened concrete to withstand thawing and freezing cycles. In other words, aerated concrete will be more durable than unaerated concrete if water seeps through and freezes. It is clear that the freezing of fresh concrete is unaffected by concrete aeration. The purpose of air bubbles is actually to prevent concrete damage by compensating for the increase in volume caused by freezing, even though they restrict the amount of water that can penetrate the concrete. This happens if even a small amount of water penetrates the concrete and freezes due to a dropping temperature.

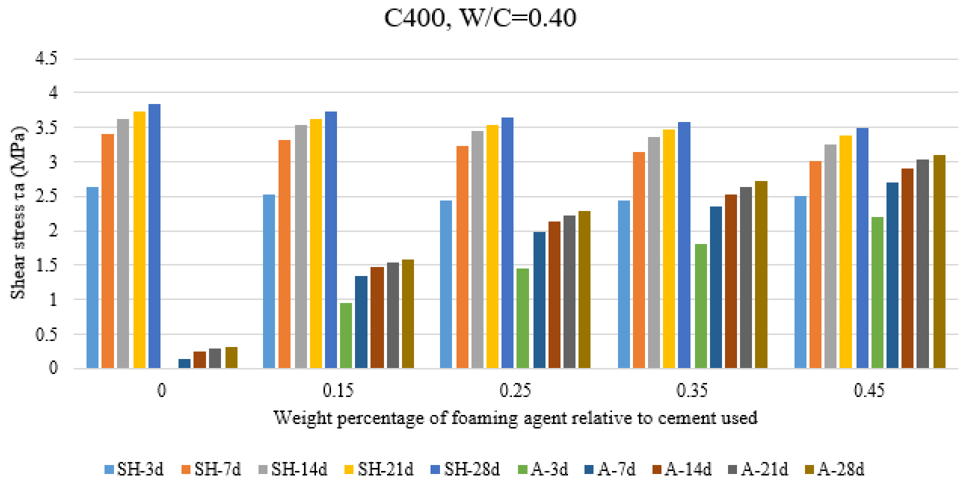
Figure 18 shows the average percentage of shear strength drop caused by freeze-thaw cycles for three different cement grades, together with the amount of foaming agent employed and the change in curing time. Figure 18 shows that the concrete sample with zero bubbles experiences an average 94.66 percent drop in shear strength after applying a temperature cycle for five curing periods of 3, 7, 14, 21 and 28 days, while the concrete sample with 0.45 bubbles experiences an average 19.52 percent decrease. Figure 18 shows that the curing periods of 28 and 7 days, respectively, are associated with the biggest and lowest percentage reductions in shear strength in concrete with any weight % of foaming agent other than zero weight percentage.




(a)

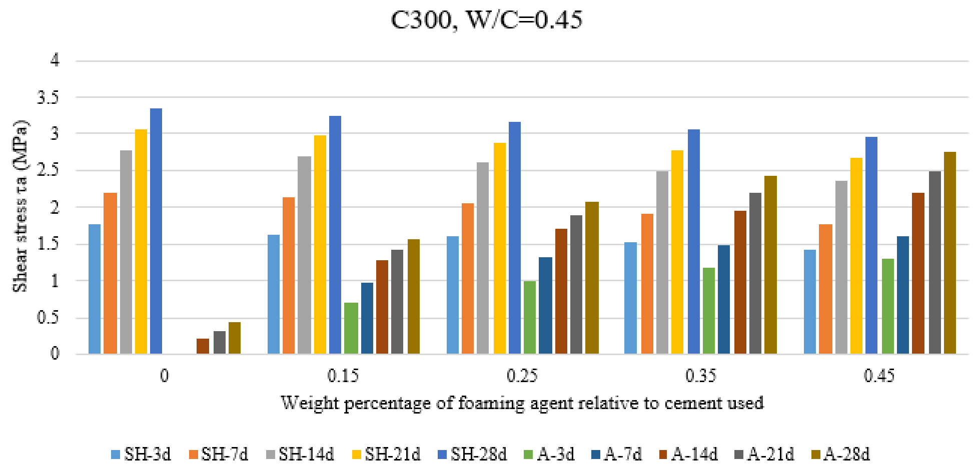



(b)

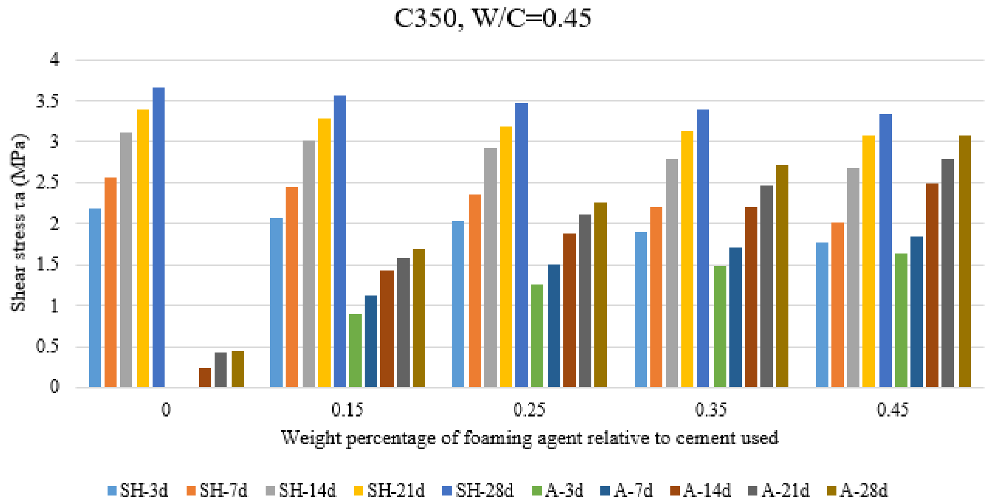



(c)

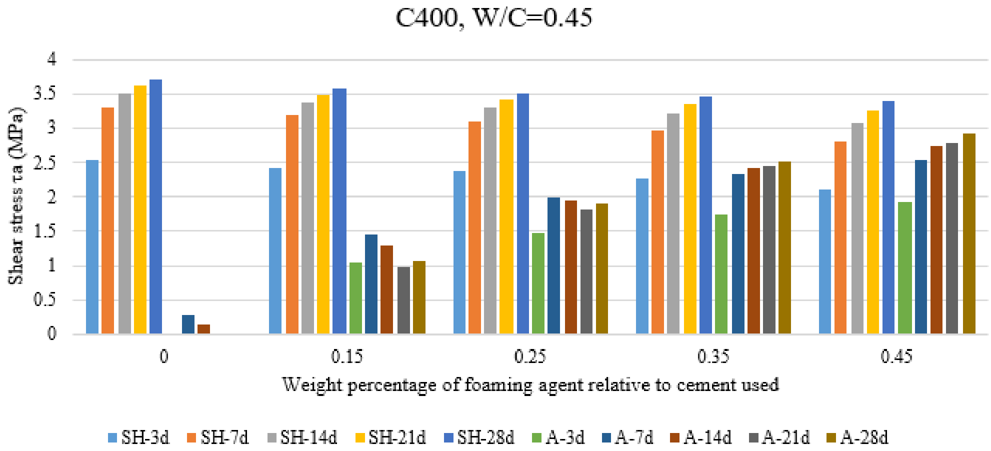
Figure 15. The rate of change in shear strength due to the change in the weight percentage of foaming agents in different curing periods for different cement grades at a water-to-cement ratio of 0.4: (a) C300; (b) C350; (c) C400




(a)

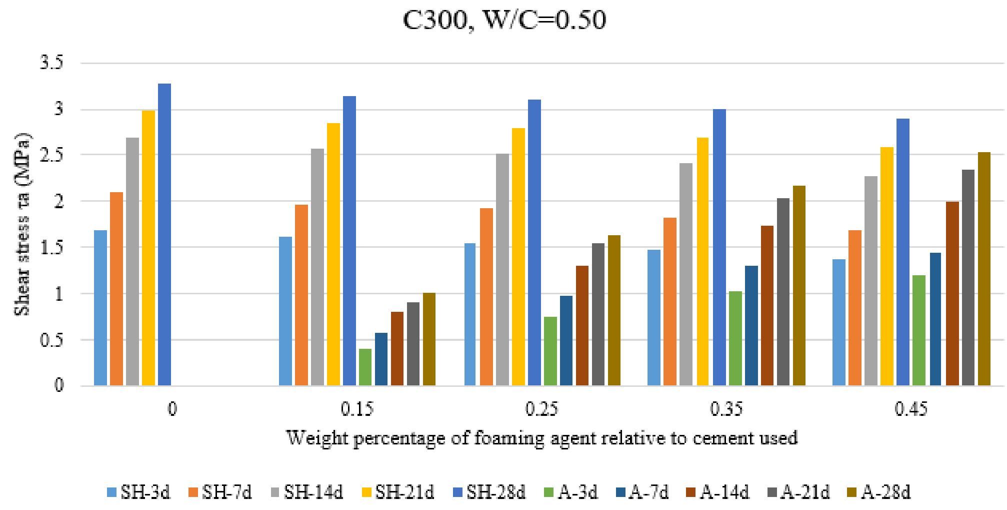



(b)

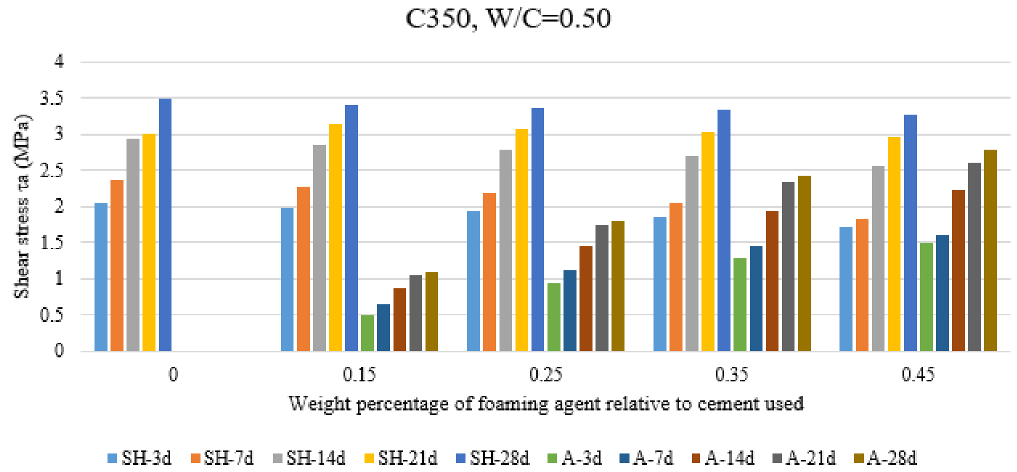



(c)

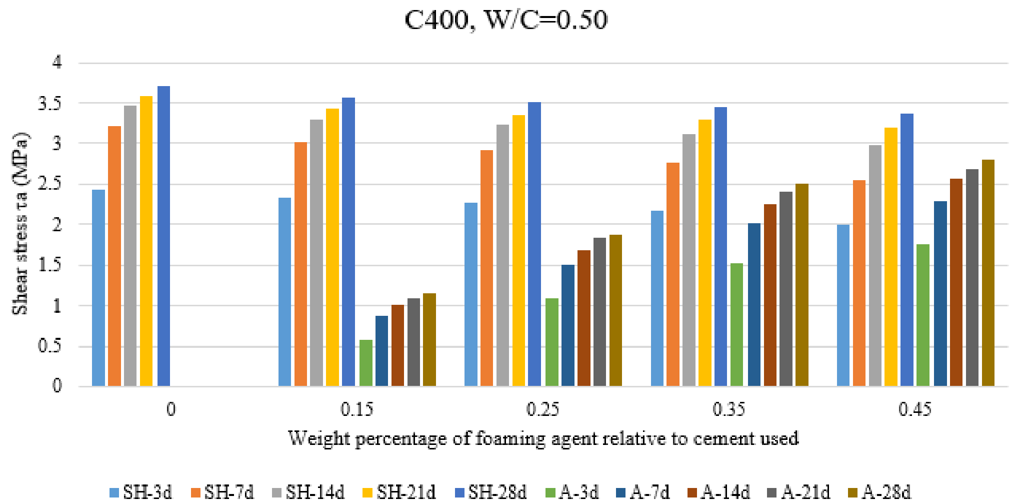
Figure 16. The rate of change in shear strength due to the change in the weight percentage of foaming agents in different curing periods for different cement grades at a water-to-cement ratio of 0.45: (a) C300; (b) C350; (c) C400




(a)

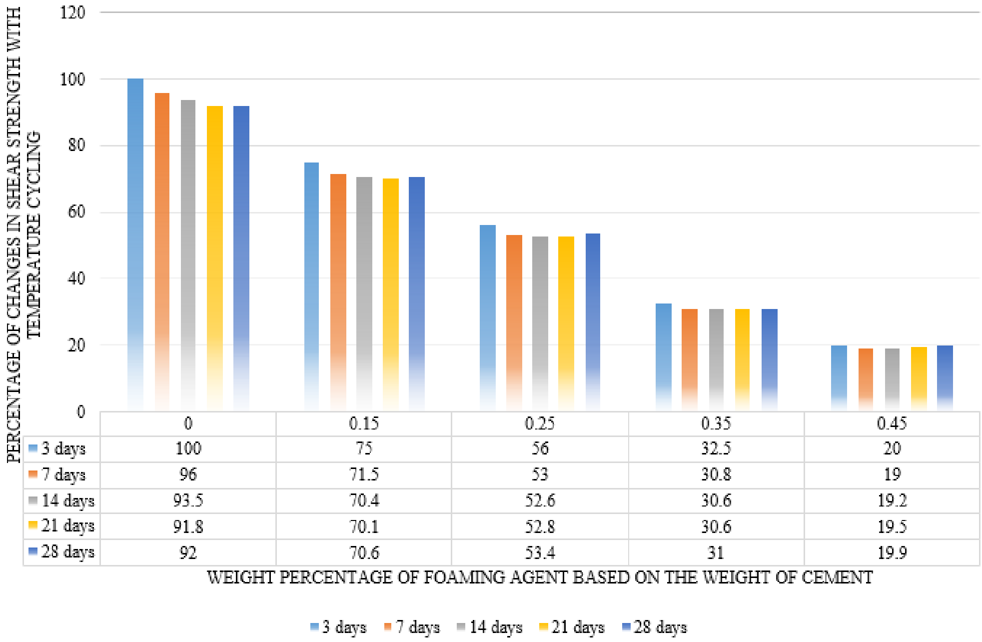



(b)




(c)

Figure 17. The rate of change in shear strength due to the change in the weight percentage of foaming agents in different curing periods for different cement grades at a water-to-cement ratio of 0.5: (a) C300; (b) C350; (c) C400




| | 0 | 0.15 | 0.25 | 0.35 | 0.45 |
|---|---|---|---|---|---|
| 3 days | 100 | 75 | 56 | 32.5 | 20 |
| 7 days | 96 | 71.5 | 53 | 30.8 | 19 |
| 14 days | 93.5 | 70.4 | 52.6 | 30.6 | 19.2 |
| 21 days | 91.8 | 70.1 | 52.8 | 30.6 | 19.5 |
| 28 days | 92 | 70.6 | 53.4 | 31 | 19.9 |

Figure 18. Percentage of resistance reduction on the object under the effect of temperature cycles for different curing times

# 4 Conclusions

This study used a laboratory model to examine the impact of freeze-thaw cycles on the shear strength of new and old concrete. This study systematically investigated the effects of foaming agent content, cement grade, water-to-cement (W/C) ratio, and curing time on the shear strength of the interface between old and new concrete under successive freeze-thaw cycles. The key findings are summarized as follows:

Foaming Agent Content and Shear Strength: 1-Increasing the foaming agent content (0 to 0.45 wt%) led to a significant reduction in shear strength under normal conditions (without freeze-thaw cycles), with decreases ranging from 5.72% to 10.12%, depending on the W/C ratio and cement grade. 2-However, under freeze-thaw conditions, higher foaming agent content (0.45 wt%) substantially improved frost resistance, increasing shear strength by up to 571.73% compared to non-aerated concrete. This is attributed to the entrained air bubbles mitigating internal hydraulic pressure caused by freezing water.

Cement Grade Influence: 1-Higher cement grades (C400) exhibited better resistance to shear strength degradation under freeze-thaw cycles compared to lower grades (C300). 2-The reduction in shear strength was least pronounced in C400 concrete, particularly at longer curing periods (28 days), indicating that higher-strength cement enhances durability in cold environments.

Water-to-Cement Ratio Impact: 1-A higher W/C ratio (0.5) accelerated shear strength loss due to increased porosity, whereas lower ratios (0.4) provided better resistance. 2-The highest percentage reduction in shear strength per weight percent of foaming agent was observed at W/C = 0.5, while the lowest was at W/C = 0.45.

Curing Time Effects: 1-Longer curing periods (28 days) significantly improved shear strength retention, particularly in aerated concrete, due to continued hydration, enhancing the interfacial bond. 2-Early-stage curing (3–7 days) experienced the most rapid strength loss, highlighting the importance of sufficient curing before exposure to freeze-thaw conditions.

Critical Threshold of Foaming Agent Content: A nonlinear relationship was observed between foaming agent content and shear strength loss, with a critical threshold at 0.25–0.35 wt%. Beyond this range, the strength reduction rate increased sharply.

Practical Implications: The findings provide crucial insights for optimizing foam concrete mixtures in cold climates, particularly for applications requiring a balance between lightweight properties and structural durability. Recommendations include:

- For Structural Repairs in Cold Regions: Using higher-grade cement (C400) with a moderate foaming agent content (0.25–0.35 wt%) and a low W/C ratio (0.4) can enhance frost resistance.

- For Non-Load-Bearing Insulation Concrete: Higher foaming agent content (0.45 wt%) can be employed to improve freeze-thaw resistance while maintaining thermal insulation properties.
- Curing Protocols: Ensuring a minimum 28-day curing period before exposure to freeze-thaw cycles maximizes interfacial bond strength.

Further studies could explore: 1. The combined use of supplementary cementitious materials (SCMs) like silica fume or fly ash with foaming agents to enhance interfacial strength. 2. The long-term durability of old-new concrete joints under real-world environmental exposure, including deicing salts and cyclic wetting-drying. 3. Advanced surface treatment techniques (e.g., mechanical roughening, chemical bonding agents) to further improve shear resistance.

In conclusion, this research contributes to the understanding of foam concrete behavior under freeze-thaw conditions, offering practical guidelines for material selection and mix design in cold-region construction and repair applications. The results underscore the importance of balancing air entrainment, cement grade, and curing duration to ensure durable and resilient concrete structures.

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