The Effect of Freeze and Thaw Cycles on Durability of Steel Fibers Concrete

Mays F. Al-Rubaie
Building and Construction Engineering Department, University of Technology/Baghdad.
Email:maysarubaie@yahoo.com

Received on: 31/3/2015 & Accepted on:7/5/2015

Abstract

The new concrete types like steel fibers concrete have intensively investigated during the last decades. Although, many researches had focused on the mechanical properties of steel fibers concrete, few researches had concern with its durability with regards to freezing and thawing cycles. This research is aimed to study the behavior of steel fibers concrete under repeated cycles of freezing and thawing. Four different mixes has been investigated, three with steel fiber content of 0%, 0.5%, 1% and 1.25% as volume fraction of total mix in addition to reference mix without fiber. 60 specimens were tested according to ASTM-C666-97. 90 cycles of freezing and thawing were preformed after 28 days of curing. The compressive strength, flexural strength, Pulls velocity and durability factor, weight change and total absorption were tested after 0, 30, 60 & 90 cycles.

The results show that steel fibers concrete possess an acceptable freezing and thawing resistance. However, a considerable redetection in compressive strength and flexural strength was recorded with the increment of exposure to freezing and thawing cycles. The results also indicate a slight decrease in the specimens' weight with the increase in number of freezing & thawing cycles without any deterioration in the apparent look of specimens. All mixes show close results for total absorption at all stage of the test.

Key words: Steel fibers concrete, freezing and thawing of concrete, Durability of concrete

دراسة تأثيردورات الانجماد والذوبان على ديمومة خرسانة الالياف العددية

الخلاصة

خلال العقود الاخيرة تناولت العديد من الدراسات الانواع الحديثة من الخرسانة مثل الخرسانة الحاوية على الالياف الحديدية. وعلى الرغم من كثرة الابحاث التي اهتمت بدراسة الخواص الميكانيكية لخرسانة الالياف الحديدية, فان عددا قليلا من الابحاث اتجهت نحو دراسة ديمومة خرسانة الالياف الحديدية عند تعرضها لدورات متعاقبة من الانجماد والذوبان. يهدف هذا البحث الى دراسة سولك الخرسانة المسلحة بالالياف المعرضة لدورات من الانجماد والذوبان. شملت الدراسة انتاج ثلاثة خلطات تحتوي على نسب مختلفة من الالياف الحديدية هي 0,5%, 1% و 1,25% كنسبة حجمية من كامل الخلطة بالاضافة الى الخلطة المرجعية بدون الياف. تم فحص 60 نموذج وفقا للمواصفة القياسية الامريكية ASTM-C666-97 وعرضت النماذج الى 90 دورة من الانجماد والذوبان وذلك بعد معالجتها لمدة 28 يوما.

https://doi.org/10.30684/etj.33.6A.17
2412-0758/University of Technology-Iraq, Baghdad, Iraq

اجريت فحوصات مقاومة الانضغاط, معاير الكسر, فحص الموجات الصوتية ومعامل الديمومة, التغير بالوزن والامتصاص الكلي بعد 0, 30, 60 و90 دورة من الانجماد والذوبان. اظهرت النتائج ان لخرسانة الالياف الحديدية مقاومة مقبولة للانجماد والذوبان. على الرغم من تسجيل انخفاض ملحوظ في مقاومة الانضغاط ومعاير الكسر مع ازدياد التعرض الى دورات الانجماد والذوبان. ا شارت النتائج الى انخفاض بسيط في وزن النماذج باستمرار تعرضها الى الانجماد والذوبان دون حصول تدهور في المظهر الخارجي للنماذج. اظهرت جميع الخلطات قيم متقاربة جدا للامتصاص الكلي في جميع مراحل الفحص.

INTRODUCTION

Durability is one of the most critical issues of concrete because of its basic impact in the serviceability life of structures. The structures must have the capacity to oppose the mechanical actions in addition to physical and chemical effects that they are submitted during their expected service life. [1] One of the most essential variables that influence the durability of concrete structures is subjecting to freezing and thawing cycles. It is a complex physical phenomenon which has been intensively investigated during the last 60 years. The deterioration mechanisms of concrete due to repeated cycles of freezing and thawing are not surely knew and keeps on being studied.

Original research was taking into account that water extends 9 percent when it freezes. [2] Further researches proposed more mechanisms. Hydraulic pressure theory suggests that damaging stresses can create if water is displaced to accommodate the advancing ice front in concrete. In the event that the pores are critically saturated, water will start to flow to make space for the expanded ice volume. The concrete will rupture if the hydraulic pressure exceeds its tensile strength. [3, 4]

The continuous development in concrete technology leads to produce new types of concretes to improve its mechanical properties and durability. One of these new types is steel fibers reinforced concrete (SFRC) which is defined as concrete made with hydraulic cement containing fine and coarse aggregate and discontinuous discrete fiber. SFRC is generally used to enhance static and dynamic tensile strength, energy absorbing capacity and better fatigue strength. [5]

In Iraq, Many applications of SFRC had been conducted in the last decades, especially in runways, bridges and precast units. There is no doubt that SFRC poses superior ultimate strength and ductility. While there is uncertainty about its durability with regards to freezing and thawing. This research aimed to investigate the effect of freeze and thaw cycles on durability of steel fiber concrete.

Experimental WorkMaterials

1. Cement

Ordinary Portland cement was used in preparing all mixes, which is commercially known (LAFARGE UCC). Tables (1) and (2) shows the chemical composition and physical properties respectively which conform to Iraqi Standard Specification No.5/1984[6].

2. Fine Aggregate: -

Fine aggregate from Al-Ukhaidher region was used in this study. Fig (1) shows the grading of sand which conforms to Iraqi standard specifications No. 45/ 1984 [7]. The used sand is within Zone three. The absorption, sulfate content, fineness modules and specific gravity for the used sand are 1%, 0.5%, 2.8 and 2.6 respectively.

3. Coarse Aggregate: -

Crushed gravel from Al-Niba'ee region was used in this work. Fig (2) shows the grading of the used coarse aggregate which is conforms to Iraqi standard specification No. 45/1984 (7). The maximum size of used crushed gravel is 10 mm. The absorption, sulfate content and specific gravity are 0.5%, 0.1% and 2.64 respectively.

4. Steel fiber:-

Micro steel fibers were used in this study. Each steel fiber has a diameter about 0.175mm and length of approximately 13 mm. Table (3) shows the properties of this fiber.

5. High Range Water Reducing Admixture (HRWRA):-

A high performance concrete superplasticiser based on modified polycarboxylic ether polymer and commercially named Glenium 54 was used as water reducing admixture. Its density and PH value are 1.07 g/cm3 (at +20° C) and 5 respectively. The high range water reducing admixture was complies with ASTM- C490-99 (8) type F.

Mixes and Mixing of Concrete Batches:

In this research, an experimental investigation was performed to study the effect of rapid freeze and thaw cycles on durability of steel fibers concrete. Four different concrete mixes were produced with steel fibers content of 0%, 0.5%, 1% and 1.25% as volume fraction. The mix proportions are shown in Table (4). Sixty specimens with different dimensions were prepared to carry out the overall experimental program.

All dry composition (except steel fibers) are mixed for about three minutes then the superplasticiser was dissolved in water and added to the dry composition and mixed together for five minutes. Steel fibers were randomly distributed into the mix slowly in five minutes during mixing process.

Test methods:-

Freeze-thaw test in the concrete series were conducted according to ASTM C 666(9) (Procedure B: rapid freeze-thaw under air conditions). It was applied on prismatic specimens at the dimensions of 100x100x400 mm. The experiment was conducted after the specimens had been cured for 28 days. The heat of the specimens was lowered gradually to -17.8° C in 3 hours. Then it was increased to 4.4° C in 1 hour (total cycle duration is 4 hours). 90 cycles were made and the specimens were examined after each 30 cycles.

The ultrasonic pulse velocity test was determined according to ASTM C597-02 (10), using (100×100×400) mm prisms. The test was made before freezing and thawing and after each 30 cycles. The durability factor after 90 freeze-thaw cycles through ultrasound instrument was calculated by dividing the square of the pulse velocity after freeze-thaw cycles by the square of the pulse velocity before freeze-thaw cycles and then multiplying the result by 100. (11)

The compressive strength test was determined according to B.S.1881: part 116 (12) on 100mm cube specimens at 0, 30 60 and 90 cycles. Flexure test was carried out on 100×100×400 mm prisms (two third point loading) according to B.S.1881: part 118 (13). Flexure test was mad after 30, 60 and 90 cycles. Weight change was also made for concrete mixes after each 30 cycles.

The weight of three (100mm) cube specimens of each mix had been recorded. After 28 days of curing the specimens had weigh and this weight considered as wet weight before expositor to freezing and thawing cycles, then it had been recorded after 30, 60 and 90 cycles. To obtain the total absorption value for the concrete mixes the specimens had oven dried at temperature of 110±5°C for 24 hours after each time and weight again. The total absorption calculated as:

$$\text{Total absorption} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} * 100\%$$

Test result and discussion:-

❖ **Pulls velocity and durability factor:-**

The result of pulls velocity test for all mixes are illustrated in Table (5). The result shows that the incorporation of steel fibers increases the pulls velocity due to the fact that the ultrasound waves move faster in metal than in concrete. The results also show a reduction in pulls velocity with the increasing of freezing and thawing cycles. The percentage of decrease after 90 cycles is (4, 9.8, 4.7 and 5.7) % for Mix-0, Mix-0.5, Mix-1 and Mix-1.25 respectively. This reduction is due to micro cracks in concrete induced by freezing and thawing cycles. Table (5) also shows the durability factor results after 90 cycles. The results show acceptable values (> 60%) for all mixes. The highest durability factor for concrete steel fibers mixes was recorded with mix-1 which contains 1% of steel fibers as volume fraction.

❖ **Compressive strength:-**

The compressive strength test conducted before freezing and thawing cycles and after 30, 60 and 90 cycles. The result of the test are shown in Fig (3) and illustrated in Table (6). The result show that's the incorporating of steel fiber led to increase the compressive strength. The percentage of increasing is (31, 44 and 42) % for mixes with 0.5, 1 and 1.25% of steel fibers respectively as compared with plain concrete (Mix-0). This is due to remarkable rule of fibers in preventing cracks. These results are agreed with previous finding. [(14)]

After exposing to freezing and thawing cycles a significant reduction in compressive strength can be observed for all mixes. Although after 30 cycles no mix shows a reduction in compressive strength higher than 9%. The plain concrete (mix-0) shows the higher percentage of reduction (24.4%) after 90 cycles. Mixes with steel fiber shows a lower deteriorated behavior as compared with plain mix, where the percentage of reduction in compressive strength after 90 cycles was (20.3, 16.9 and 18.7)% for Mix-0.5, Mix-1 and Mix-1.25 respectively. The reduction in compressive strength is attributed to the voids between the fiber-matrix interfaces induced by freezing and thawing cycles. These results are conformed with previous study [(3)]

❖ **Flexural strength:-**

Flexural strength studies were investigated after 30, 60 and 90 cycles. The results are depicted in Table (7) and plotted in Fig. (4). The results show a considerable increasing in flexural strength as increasing the percentage of fibers in the mixes. These results are compatible with previous researches [(5, 15, 16)]

Despite of the slit reduction in flexural strength, steel fiber mixes posses an acceptable resistance to freezing and thawing cycles as compared with plain mix. This enhancement was attributed to the crack arresting role for the steel fibers. Where, the percentage of increasing in flexural strength for Mix-0.5, Mix-1 & Mix-1.25 as compared with plain mix, was (30.7, 46.2 and 53.8)% after 30 cycles and (54.3, 85.7 and 108)% after 90 cycles respectively.

❖ **Wight changes & absorption:-**

The results of percentage of decreasing in wet and dry weights are shown in Fig (5) and Fig (6) respectively. The results show a slight reduction in weight for all mixes with continuing expositor to freezing and thawing cycles. This is attributed to high compressive strength and dense structure of the concrete mixes which is refers to low deterioration due to freezing and thawing. These results were agreed with Hamoush, et. al.[17] results. It was also notice that's no crumbling or flaking in the specimens surfaces or edges are occurred after exposing to freezing and thawing cycles.

The total absorption results are listed in Table (8) and plotted in Fig (7). It is obvious that the total absorption didn't exceed 1.6 % for any mix and at any time. This is attributed to high density and low permeability.

Conclusions

1- There is a considerable effect for freezing and thawing cycles on the compressive strength of steel fibers concrete. Where the expositor to 90 cycles of freezing and thawing led to reduction in compressive strength up to 20% for Mix-0.5.

2- As compared with plain concrete, steel fibers concrete mixes possess an acceptable resistance to freezing and thawing with regards to flexural strength. Where the plain concrete mix lose about 46% of its flexural strength while the steel fibers concrete mixes lose about (31-36%) of its flexural strength after 90 cycles.

3- All mixes shows an acceptable pulse velocity and durability factor (> 60%) after 90 cycles of freezing and thawing.

4- No big change in weight has been recorded after freezing and thawing for all mixes, although better results are recorded for steel fiber mixes.

5- All mixes posses very close values for total absorption at all times of tests. The values varied from (0.3 -1.6%).

Table (1): Chemical composition for ordinary Portland cement

Chemical Composition		
Oxide	Ordinary Portland cement	Limits of Iraqi standard specification No. 5/ 1984
CaO	62.40	-
SiO_2	21.85	-
Al_2O_3	4.76	-
Fe_2O_3	3.41	-
MgO	2.35	≤5.0%
SO_3	1.45	≤2.8%
Na_2O	0.38	-
K_2O	0.35	-
L.O.I.	1.60	≤4.0%
I.R.	0.60	≤1.5%
L.S.F.	0.85	0.66-1.02%
Main Compounds (Bogue's equations)		
C3S	46.98	-
C2S	27..20	-
C3A	6.84	-
C4AF	10.38	-

Table (2): - Physical properties of ordinary Portland cement

Physical Properties	Ordinary Portland cement	Limits of Iraqi specification No.5/1984
Fineness (Blaine method) cm^2/gm	3200	≥2300
Soundness by Autoclave %	0.35	≤ 0.8
Setting time (Vicat's method) Initial setting time, hrs: min Final setting time, hrs: min	 2:40 4:40	 ≥45 min ≤10 hrs
Compressive strength at 3days, MPa7days, MPa	17.3 24.5	≥15 ≥23

Chemical and physical tests are made by the National Center for Geological Survey and Mines.

Table (3): properties of steel fiber**s**

Description	Length	Diameter	Density	Tensile Strength	Aspect Ratio
Straight	13mm	0.2mm	7800 kg/m^3	2600MPa	65

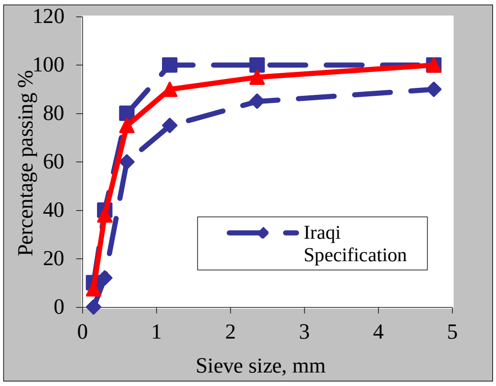

Figure (1):- Grading of fine aggregate

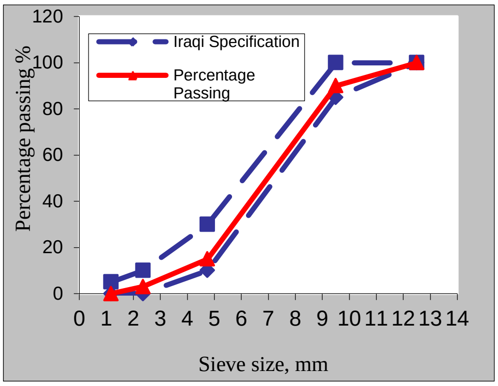

Figure (2):- Grading of coarse aggregate

Table (4):- Mix proportion to provide mixes with slump of 170 ± 10 mm

Material	Mix-0%	Mix-0.5%	Mix-1%	Mix-1.25%
Cement (kg/m^3)	450	450	450	450
Fine agg.(kg/ m^3)	700	700	700	700
Coarse agg. (kg/ m^3)	1100	1100	1100	1100
Water (kg / m^3)	157	148	144	145
super plasticizer (l/ 100 kg cement)	2	2.7	3	3
Steel fibers (kg/ m^3)	-	39	78	97.5
Steel fibers V_f (%)	-	0.5	1	1.25

- All mixes have slump values equal to 170± 10 mm

Table (5):- Ultrasonic pulse velocity and durability factor

Mixes	Ultrasonic pulse velocity (km/sec) at				Durability factor after 90 cycles (%)
	0 cycles	30 cycles	60 cycles	90 cycles	
Mix-0%	4.16	4.08	4.21	4.00	92.4
Mix-0.5%	4.82	4.49	4.44	4.35	81.4
Mix-1%	4.94	4.88	4.82	4.71	90.1
Mix-1.25%	4.71	4.60	4.49	4.44	88.9

Table (6):- Compressive strength (MPa) for all mixes

Mixes	Compressive strength MPa after			
	0 cycles	30 cycles	60 cycles	90 cycles
Mix-0%	45	42	38	34
Mix-0.5%	59	56	50	47
Mix-1%	65	62	60	54
Mix-1.25%	64	58	55	52

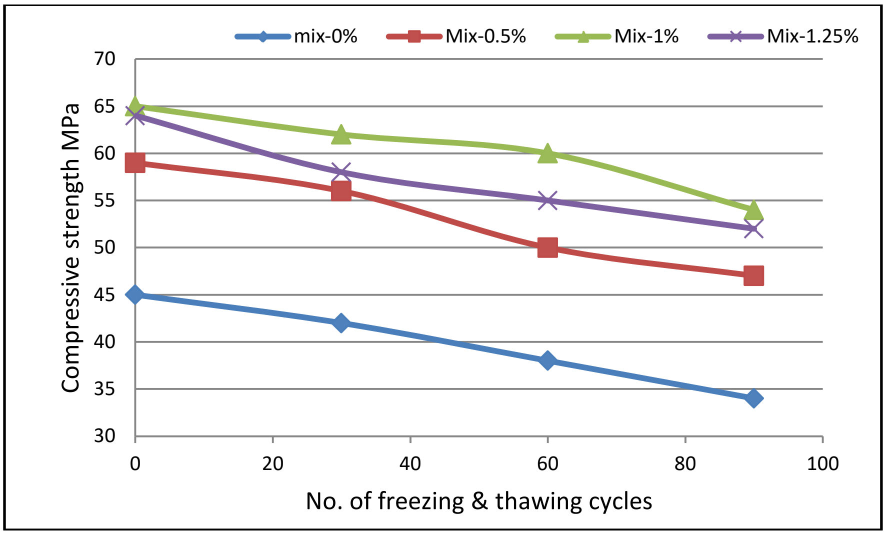

Figure (3):- Compressive strength vs. No. of freezing and thawing cycles

Table (7):- Flexural strength (MPa) for all mixes

Flexural strength MPa after			
Mixes	**30 cycles**	**60 cycles**	**90 cycles**
Mix-0%	6.5	4.5	3.5
Mix-0.5%	8.5	6.8	5.4
Mix-1%	9.5	7.9	6.5
Mix-1.25%	10.8	8.8	7.3

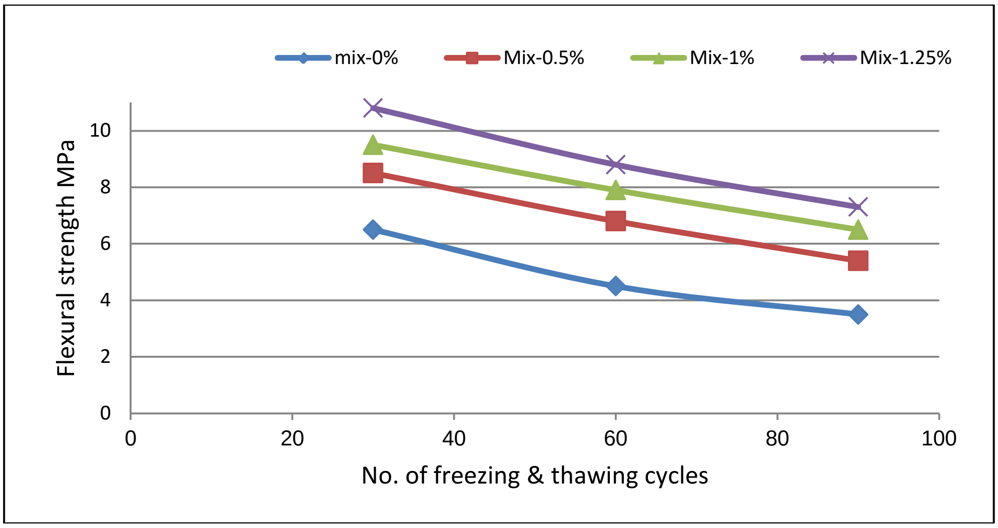

Figure (4):- Flexural strength vs. No. of freezing and thawing cycle

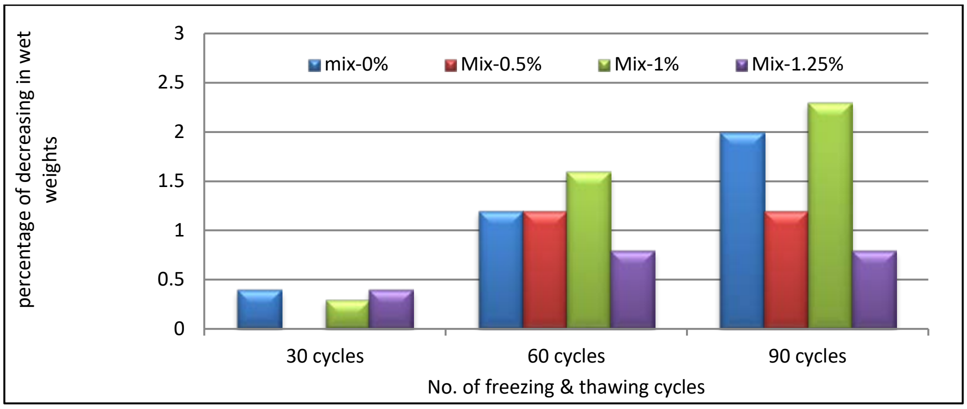

Figure (5):- Percentage of decreasing in wet weight

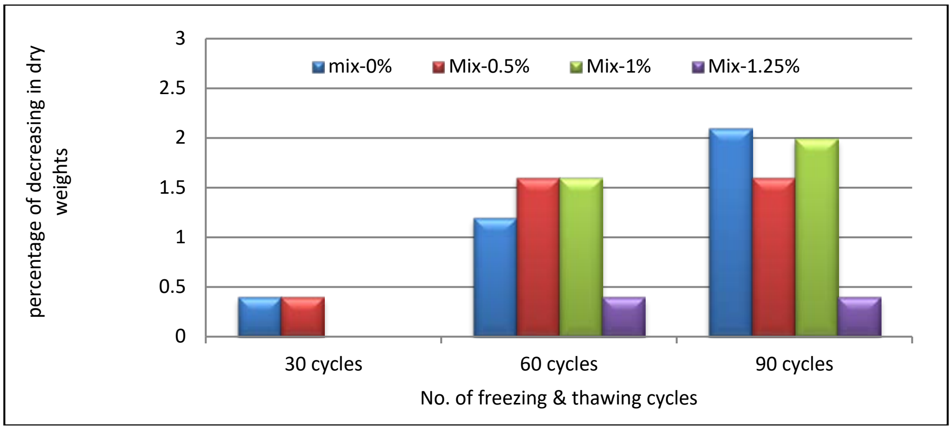

Figure (6):- Percentage of decreasing in dry weight

Table (8):- Total Absorption (%) for all mixes

	Total absorption (%) after			
Mixes	**0 cycles**	**30 cycles**	**60 cycles**	**90 cycles**
Mix-0%	0.8	0.8	0.8	0.8
Mix-0.5%	1.2	1.6	1.6	1.6
Mix-1%	0.8	0.3	0.8	0.4
Mix-1.25%	0.8	0.4	0.4	0.4

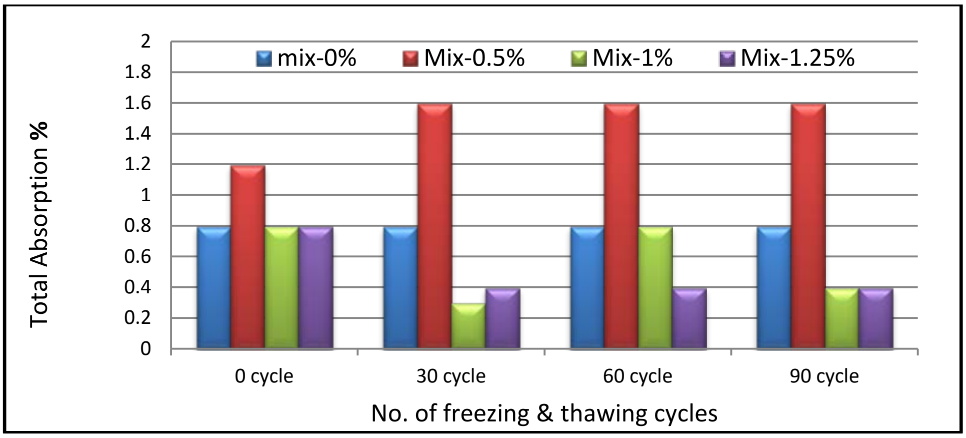

Figure (7):- Percentage of Total Absorption vs. No. of freezing and thawing cycle

References:-

[1].Frazão, C., Camões, A., Barros, J. and Gonçalves, D. "Durability of Steel Fiber Reinforced Self-Compacting Concrete". Twin Covilhã International Conferences, 5th Int'l Conference on The Concrete Future, Portugal, 26-29 May 2013.

[2].Bazant, Z. P. , Cttern, J. C., Rosenberg, A. M., Gaidis, J. M "Mathematical Model for Freeze- Thaw Durability of concrete" paper for center of concrete and geomaterials, North Western University, Evaston, 1988.

[3].Behfarnia, K. "Studying The Effect of Freeze and Thaw Cycles on Bond Strength of Concrete Repair Materials", Asian Journal of Civil Engineering (Building And Housing) Vol. 11, No. 2 (2010) Pages: 165-172, 2010.

[4].Wang, K., Steffes, R. & Lomboy, G. "Investigation into Freezing-Thawing Durability of Low-Permeability Concrete with and without Air Entraining Agent" Final Report for National Concrete Pavement Technology Center Institute for Transportation Iowa State University, June 2009.

[5].Mohod, M. V. "Performance of Steel Fiber Reinforced Concrete" International Journal of Engineering and Science ISSN: 2278-4721, Vol. 1, Issue 12 (December 2012), PP 01-04 www.researchinventy.com

[6].Iraqi Standard Specification No.5/1984 " Portland cement"

[7].Iraqi Standard Specification No. 45/1984 "The aggregates of the natural resources used in concrete construction ."

[8].ASTM C 494/C 494M-99, "Standard Specification for Chemical Admixtures for Concrete", Vol.04.02, 2003.

[9].ASTM C 666, "Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing" Vol.04.02, 2003.

[10].ASTM C597-02, "Standard Test Method for Pulse Velocity through Concrete", Vol.04.02, 2003.

[11].Yildirim, S. T. & Ekinci, C. E. " Effects on Freeze-Thaw Durability of Fibers in Concrete" Fırat University, Construction Education Department, Elazığ,Turkey,2005.

[12].B.S.1881, Part116, 1989, "Method for Determination of Compressive Strength of Concrete Cubes", British Standard Institution.

[13].B.S.1881, Part118, 1989, "Method for Determination of Flexural Strength", British Standard Institution.

[14].Taher, M. J. "Evaluation Some Properties of High Performance Concrete Reinforced with Steel Fiber" MSc. Thesis, Department of Building and Construction Engineering, University of Technology, 2013.
[15].Khalil, W. I., Gorgis, I. N., Mahdi, Z. R. "Mechanical Properties of High Performance Fiber Reinforced Concrete" University of Technology, Eng. & Tech. Journal, Vol.31, Part (A), No.7, 2013.
[16].Sarsam, K. & Al-Azzawi, Z. M. "Mechanical Properties of High-Strength Fiber Reinforced Concrete" University of Technology, Eng. & Tech. Journal, Vol.28, No.12, 2010.
[17].Hamoush, M., Darder, M. Abu-Lebdeh, S. and Mohamed, A. " Freezing and Thawing Durability of Very High Strength Concrete", American J. of Engineering and Applied Sciences, ISSN 1941-7020 Vol. 4 , Issue 1, 2011, PP 42-51