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Durability and Performance of Ferrocement Infill Wall Panel

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Abstract

Ferrocement is composed of cement mortar reinforced with small diameter closely spaced steel wire mesh to form a thin section conforming high performance of serviceability. The present study investigates the performance of ferrocement panels focused on the mechanical properties, water absorption and durability. A series of specimens were cast with single and double mesh layers. Flexural performance was carried out following sixty days in temperature cycle and in corrosion cell. These results was compared with the controlled sample. The test results shows that the flexural strength performance was reduced by 52% and 35% for single and double layer wire mesh samples respectively followed by corrosion environment. First crack load also changed after completion of sixty temperature cycles. This load is 27.3%, 42.3% and 31.8% of failure load for controlled sample, sample in room air after every temperature cycle and samples in room air following quenching after every temperature cycle respectively for single mesh layer sample, and for double mesh layer sample these values are 38.9%, 30.1% and 17.7%. Early first crack is found for the samples following quenching and cooled in room air; however, both types of samples are in low absorption level. This data represents that double layer mesh specimen exhibits better when compared to single layer mesh specimen in strength and corrosion parameters.

Keywords: Ferrocement; Flexural Strength; Corrosion; Wire Mesh; Temperature.

1. Introduction

The awareness of the durability of the construction elements has emerged as well accepted and preferred option in the field of construction. This might be accomplished by using different approaches to developed cement based composites for structural applications in construction industry. Ferrocement is one of the emerging elements now a day. The definition of ferrocement has been changing in recent time from its early history. Ferrocement materials are like to a reinforced concrete thin element having cement mortar and small diameter of woven wire mesh. Numerous research works argued that the engineering properties of ferrocement structural elements are comparable to the concrete, though in some applications, its performance is improved. Ferrocement which is like a brittle cementitious materials is transformed in to an elastic composite material due to the homogeneously and closely-spaced thin wire mesh in it. This transfer the ferrocement into highly flexible construction materials compared to reinforced concrete in its durability including thermal and acoustic performance. These were concluded from the experimental work completed by Naaman [1], Batson [2], Silva et al. [3], Yardim and Lalaj [4], Yardim et al. [5], Greepala and Nimityongskul [6] and Lilia [7].

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The durability of a ferrocement compound may be defined as its capability to resist cracking, weathering action, chemical attack, abrasion and any other forms of destruction concluded by Ramesht and Jafarn [8]. Ferrocement was first developed by Joseph Lambot in 1856 as an alternative material for boat construction due to its light weight and durability. However, insufficient research history of ferrocement was observed from 1888 to 1948. Pier Luigi Nervi in conducted several experiments on ferrocement after that period stated by Yardim [9]. The first fully ferrocement vaulted roof structure over a shopping center at Leningrad in Soviet Union was built in 1958. Ferrocement is used in different ways in the construction industry today like as wall panels, precast roofing elements, permanent formworks. Batson [2] showed its implication to low-cost housing projects. He provides several applications for rural small economic houses for developing countries. It can be adapted to a wide range of construction techniques because of its versatility, environment-friendly and the readily available raw material, ease of transportation and does not require any special skills or techniques for its construction. Ferrocement had a superior properties in terms of cracks control due to the closely spaced and uniformly distributed reinforcement within the material concluded by Ahmed [10]. Thin structural members and its light structural weight is suitable for substituting for structural elements of exotic shapes such as shells, chimneys, boats, etc. by Waleed et al. [11], Noor et al. [12], Kondraivendhan and Bulu [13] and Masood et al. [14].

The amount of reinforcement in form of mesh is very important for the tensile strength capacity of ferrocement panel. A ferrocement element behaves as an elastic material up to the development of first crack. After this, the ferrocement element will be faced multiple cracking and at that point the wire mesh finally starts to yield. In this stage, the number as well as the width of cracks will carry on to grow in presence of tensile force. Tensile strength capacity of ferrocement has been investigated thoroughly by Desayi and El-kholy [15] and Hussin [16]. The first crack load is increased proportionally to the amount of steel mesh present in the ferrocement element. However Clear [17] concluded that the compressive strength capacity of ferrocement element is largely depended on the properties of cement mortar.

Durability is defined as 'ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration', according to ACI Committee [18]. That is, durable concrete will be holding its original form and quality, when exposed to the environment. Temperature variation/weathering action and corrosion are leading parameters against durability of ferrocement panel. Bangladesh is a tropical country where three major seasons are present, a hot, humid summer; a moderate cool, rainy monsoon season and a cool and dry winter. Summer temperatures range between 30 °C ~ 42 °C. April-May is the warmest month in most parts of the country and January is the coldest month when the average temperature for most portion of the country is about 10°C. The climate of Bangladesh is generally influenced by monsoon and categorized by high temperature and heavy rainfall with excessive humidity. Generally the humidity throughout the year is 70% ~ 85% according to Sattar and Khan [19], cause dam weather. The various measuring techniques for ‘durability’ in reinforced concrete is applicable to ferrocement due to the ingredients used in ferrocement almost same except coarse aggregates. The reinforced cement concrete members are in expands or contracts due to the temperature variations and same things are happen in ferrocement panels. So this temperature variation may causes thermal expansion and contraction and probably cause for thermal cracking. Along with this, Corrosion of steel mesh in ferrocement is one of the major deterioration parameter in this type of structures. Close form of wire mesh in ferrocement is played an important role to prevent crack formation in its surface and finally transform it as a suitable structural element compared to concrete. A great deal of research has been conducted to investigate corrosion behavior of ferrocement wall panel exposed to saline/sea water by Masood et al. [14].

Mechanical property of ferrocement or the water cement ratio or minimum cementitious content is not only the major issues for the durability. How a member performs in ambient environment or in severe exposure condition with satisfying all performance level is the key point consideration for the durability. Heating and cooling cycle and corrosion test are tests to find out the performance criterion of durability. Clear cover is an issue for corrosion. Generally in concrete the minimum cover is about 25 to 30 mm. However, it was found that the bottom cover in ferrocement is about 3 to 5 mm stated by Mansur [20]. Most of the previous research has been focused on cracking behavior and ultimate strength of ferrocement in flexure. Steel wire mesh in ferrocement elements is corroded mainly due to presence of chloride ions and carbon dioxide to the steel surface. The corrosion products showed as red-brown dust (hydrous ferric oxide Fe_2O_3. $3H_2O$) are usually deposited around the reinforcing component in the concrete, which exhibits an expansive stresses around the steel mesh. The corrosion products occupy a volume equal to three to six times that of the original level, which may be liable for crack generation and spall of the concrete cover. The carbonation depth in a concrete after 15 years of normal indoor exposure is approximately equal to 5mm, which gives the importance of investigate the performance of ferrocement panels. This, in turn, results in enormous losses, direct and indirect, all over the world noted by Elavarasan [21].

In Bangladesh the jump of development and construction activity achieved since last two decades was even beyond the expectations rather dreams three decades ago. It has prompted the demand for fast, cost-effective and durable construction elements for buildings industry. A major portion of load is coming from partition wall in most of the building. Infill walls in framed structure give about 25% load compared to the total loading in a building structure. Moreover, the size and shape of structural elements like column, beam and foundation of ordinary buildings are mainly dependent for this loading. Thus, any amount of weight reduction improves the service capacity of the structural elements and finally on the service life. This attracts the researcher to look for ferrocement lightweight wall panel as a good alternative of traditional infill wall of concrete or burned clay brick unit.

2. Methodology

2.1. Material Properties

The properties of used materials, such as specific gravity, absorption, fineness modulus and unit weight were done according to ASTM C128, ASTM C128, ASTM C136, ASTM C29 testing standards respectively in the material lab of the Department of Civil Engineering of KUET, Bangladesh. River bed sand of F.M. 3.2, unit weight 1488 Kg/m^3, absorption 3.8% was used as fine aggregate. Sieve analysis result of this sand is shown in Table 1. Wire mesh available in the local market was collected and used to prepare the sample. The wire was had square opening of 12.5× 12.5 mm and diameter was 1mm. Several wires were taken from the mesh and tested separately in the laboratory to determine the average yield stress and ultimate strength. The average measured values of yield stress fy and ultimate strength fu, are 451.97, 530.71 MPa respectively. Portland Composite Cement was used as binding material. Ordinary tap water collected from laboratory was used for casting and curing the specimens.

Table 1. Sieve analysis for River Bed Sand

Sieve No.	Weight retained, gm	Cumulative weight retained, gm	Cumulative % retained	F.M. value
4	0.00	0.0	0.0	
8	54.30	54.3	10.9	
16	149.50	203.8	40.8	
30	171.60	375.4	75.1	3.2
50	94.10	469.5	93.9	
100	25.00	494.5	98.9	
	Total sample = 500 gm		Sum = 319.5	

2.2. Specimen Preparetion

Specimens were prepared to perform different laboratory tests. Two types of specimens were prepared to find out the flexural capacity, corrosion in aggressive environment and temperature effect. The specimens are designated as type A and type B for single and double layer mesh respectively. Total thickness for single and double layered mesh samples were 30 mm. A gap of 5mm was provide in between two meshes for sample B, which makes outer clear cover of mesh is 2.5 mm less compared to the sample "A". Tested specimens were prepared using wooden form of 0.3×0.3 m in surface area. At first the steel meshes was cut accordingly and flat it. A typical view of the sample before and after construction are shown in Figure 1, these sample were used for corrosion test. Others samples were prepared in same way except the electric wire.

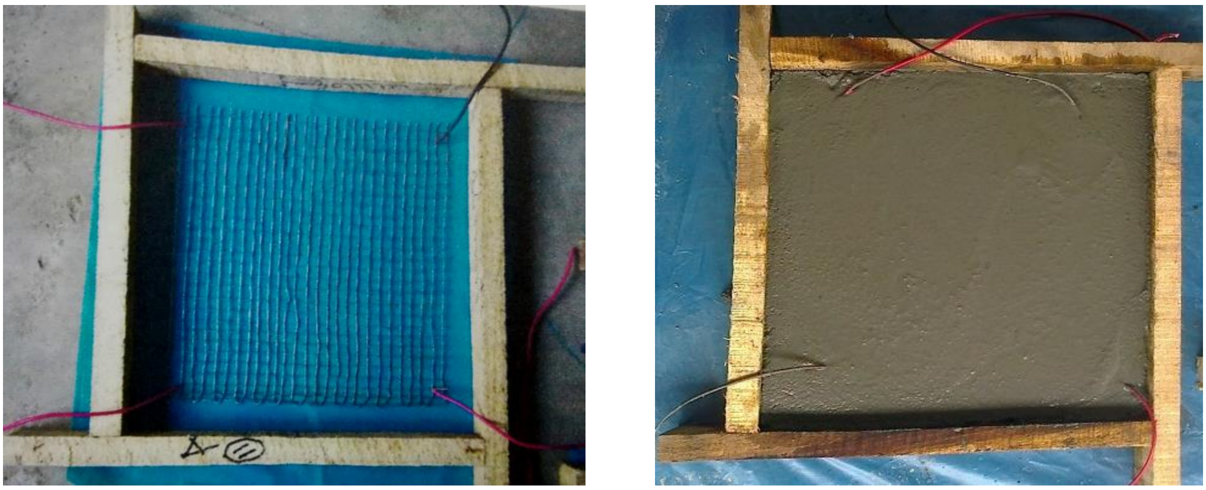

Figure 1. Casting procedure of ferrocement specimen

To fulfill the corrosion test setup all corners of the mesh wire was attached by electric wire. After completing all necessary arrangements, leak proofing, confirming the side clearance of wire mesh, well mixed mortar was placed and compacted to ensure a homogeneous body. Mixing proportion of cement and sand was 1:2 and and w/c ratio was 45%.

The specimens were removed from wooden mold and stored in water chamber for curing up to 28 days following 24 hours of mixing and placing. General information of samples with identity number used in this work is shown in Table 2.

Table 2. Sample Description

Sample No	Length (mm)	Width (mm)	Thickness (mm)	Mesh layer
A	300	300	30	Single
B	300	300	30	Double

2.3. Corrosion Setup

For this experiment, a water tub of 600 mm long 400 mm wide and 350 mm deep was prepared by masonry brick and thick polythene paper in temporary type. Total 16 numbers of the sample are placed in the water tub at a time. To ensure the sample gapping in the chamber, a thin jute rope was used to grip the samples. Then the water tub was filled with water with salinity of 35000 mg/liter. A copper plate was placed in water and connected with the wire mesh through adapter as shown in Figure 2.

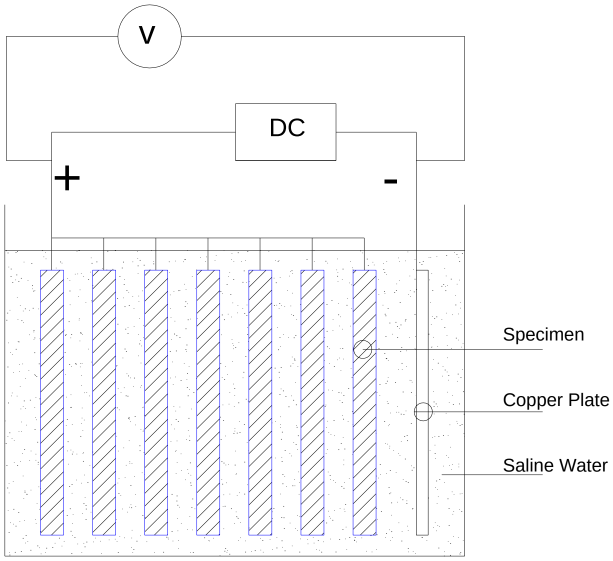

Figure 2. Current application diagram

An external adapter is used to supply the current in the test system from an AC source. At the starting time of experiment, 3 volts was supplied, however, the measured average output voltage throughout the experiment was 2.56 volt and it was varied from 2.45 to 2.65 through the experiment time of four weeks. The one of the two ends of the adapter had connected to the copper plate which was placed in the water tab and other end was connected to the wire mesh in the specimen. Samples were ready for flexural performance testing after 60 days of removing from corrosion chamber. A pictorial view is shown in the Figure 3 after 10 days of removing the sample from corrosion chamber showed that the sample surface was rusted.

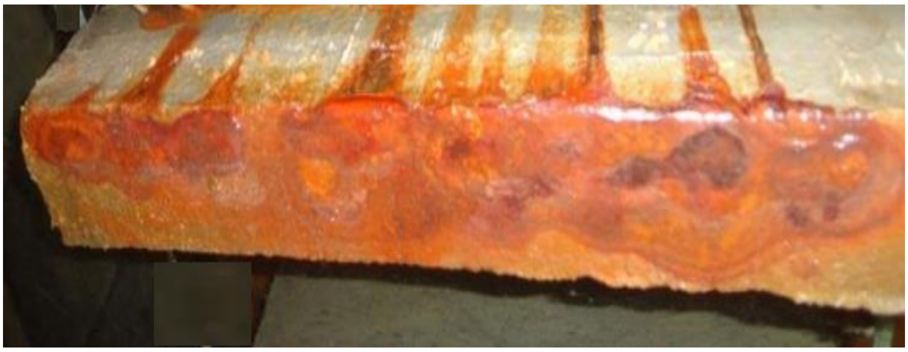

Figure 3. Sampel after 10 days of removing from corrosion chamber

2.4. Temperature Effect

To find out the temperature effect, total 48 numbers of the sample were prepared, half of them were prepared with single layer and rest of them were double layer wire mesh. These samples were tested followed different cooling condition after removing from oven shown in Table 3. Two numbers of samples were tested under each group and provide the average result in this work. To observe the temperature effect, 24 numbers of samples were kept in oven at 105 ºC for 12 hours. After completion of 12 hours heat cycle, 12 samples were kept in room air and others were in quenching for 30 minutes before stored in room air for another 12 hours for cooling. Such heating and cooling of total 24 hours completed a temperature cycle. Maximum sixty numbers of such temperature cycles were performed to found the temperature performance of ferrocement panel. In each cycle 6 numbers of picture were taken for each sample just after removed from the oven, quenching and before placed in the oven again. A constant distance was maintained to capture the pictures.

Table 3. Specimen designation for testing under different condition

Normal condition		Temperature effect			
Single layer mesh (A)	Double layer mesh (B)	Single layer mesh (A)		Double layer mesh (B)	
		Specimen cooled in air	Specimen cooled in water and then air	Specimen cooled in air	Specimen cooled in water
A-9	B-9	A-1	A-3	B-1	B-3
A-10	B-10	A-2	A-4	B-2	B-4
A-11	B-11	A-5	A-7	B-5	B-7
A-12	B-12	A-6	A-8	B-6	B-8

2.5. Flexural Test Procedure

In order to perform the flexural strength test, center point loading was confirmed according to the procedure of ASTM C293. The ferrocement wall panels were loaded with a shear span of 250mm. A load was applied at mid of the shear span by Universal testing machine in the laboratory. Two deformation dial gauges was attached at the mid position in two sides of the specimen. The dial gauges are 12 mm range and minimum measuring unit was 0.01 mm. Deformation was measured at the interval of 0.2 kN increased of the load. All tests were performing under a constant rate of loading. The configuration provides in such a way to provide a uniform loading of the specimen and prevents the frictions between the specimen and the supporting point.

2.6. Water Absorption Test

Water absorption test was performed as per the specifications of BS 1881: Part 122, this method is also known as water immersion method. In this experiment the samples were oven dried at 105±5 ^{0}C for a period of 72±2 hours. All specimens were cooled in a dry room place for 24 hours after removed from oven and weighed it. After completion of the previous process, specimens were immerged in water in such a way that the top of water maintained at least 30mm over the samples for 30 minutes and then withdrawal it. Samples were again weighted after removing the excess water from its surface and make its surface dry by dry cloth. The water absorption value was then calculated. Accordance to Concrete Society Technical Report [22], the typical values of the water absorption of concretes rating the type of concrete cured in water and tested at 28 days as per the recommendations and test procedures of BS 1881 BS, which defined as, Very low, low and high absorption concrete having water absorption value is < 3%; 3–4%, and > 4% respectively".

3. Results and Discussion

It has become required to examine the structural behave of ferrocement wall panel in open environment, where the temperature, humidity and rainfall conditions are different throughout the year. These parameters are mostly effect the surface cracking condition of ferrocement panels. For this corrosion on the panel was tested in this study. The results of the tested specimens in flexure after and before corrosion are shown in Figure 4. The controlled specimens are those which were kept in normal room environment after 28 days curing and there were no corrosion and temperature cycle was involved. Samples tested after sixty days of removing from corrosion cell, it is observed that corrosion had a major effect on flexural strength of ferrocement plank. Flexural strength of the samples are reduced by an amount of 52% and 35% due to corrosion effect for single and double mesh samples respectively when compared with the controlled sample. Double meshed sample exhibits 27% and 38% higher strength compared to single mesh sample without and within corrosion cell respectively. First crack was observed at 3.27 and 1.94 kN load level for controlled sample of double and single layer mesh respectively. However, after facing in corrosion environment, the first crack loading was very close for single and double layered mesh element. The similar behavior of increasing flexural strength with increasing wire mesh layer in ferrocement panel was found in the study of Milon et al. [23] and Abdullah and Mansur [24]. Double mesh samples exhibit better performance than single mesh samples both under normal and corrosion condition.

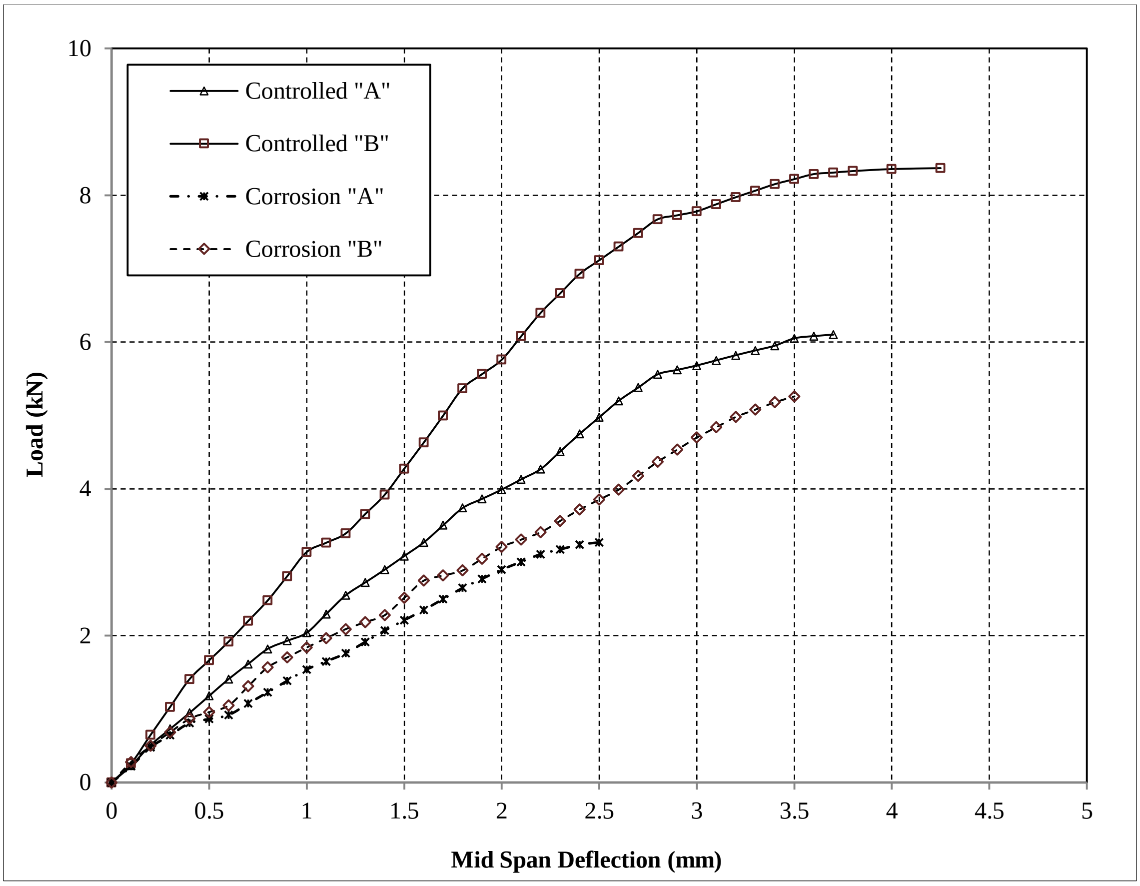

Figure 4. Load and deflection curve of single (A) and double (B) meshed specimen

Cracks were found after 60 temperature cycles in the single layer wire mesh sample (type A). However, there were no visible cracks up to same temperature cycles for samples with double layer steel wire mesh (type B). To observe the crack each samples were marked in four equal segments of 150mm x 150mm and marked the sample as S-1, S-2 up to S-8. A fixed height was maintained at the time of captured the top view of the segment. After completion of every five cycle, top view of the segments were captured and find out the presence of crack or any other form of distress in the surface of the panel. Crack was observed only a single segment of one sample (S-8) of type “A” which was followed cooled in water and then in room air after removing from oven. Ferrocement planks with double layer wire mesh, exhibits better performance under temperature effect. So ferrocement wall panel is performed well under thermal condition in natural environment of Bangladesh. Similar findings concluded previously by Kandaswamy and Ramachandraiah [25]. Typical images of sample no S-8A under different temperature cycles are shown in Figure 5.

(a) (b) (c)

Figure 5. Specimen after (a) 45 cycles (b) 60 cycle (c) Zoomed view of cracked surface

Water absorption test was performed confirming BS 1881: Part 122. Three specimens from type A and B were oven dried at 105 ^{0}C for 72 hours. All specimens were cooled in a dry place in the laboratory for 24 hours after removing from oven. Then the specimens were weighed and put it in water bath in such a way that ensure 30 mm of water was leveled over the top of the specimens. Weighted it after removing from water following swipping the surface water from the sample. The water absorption value was then calculated and listed in Table 4. Mousavi [26] showed quite similar trending for amount of weir mesh in ferrocement panel. From the result it is found that the ferrocement panels of A and B are catagorise as Low absorption concrete. This concluded that the amount of wire mesh has no significant effect on the water content of the ferrocememnt panel.

Table 4. Water absorption result of ferrocement panel

Sample No.	Specimen Weight in gm				Water Absorption %	
	Dry Specimen		Wet Specimen			
	Type-A	Type-B	Type-A	Type-B	Type-A	Type-B
1	6292.0	6407.7	6512.2	6657.6	3.5	3.9
2	6339.5	6321.1	6549.3	6541.1	3.3	3.5
3	6131.3	6188.5	6376.6	6423.7	4.0	3.8

Flexural performance of single layer mesh specimen after quenching is 34% less when compared it with cooled in normal room environment due to temperature effect is shown in Figure 6 and this amount is 36% for double layer mesh elements shown in Figure 7. However, ferrocement panel having double-layer wire mesh exhibits about two times strength capacity than single layer in both cooling conditions after temperature effect. It may be concluded here that the double layer wire mesh exhibits better performance when compared to single layer mesh element.

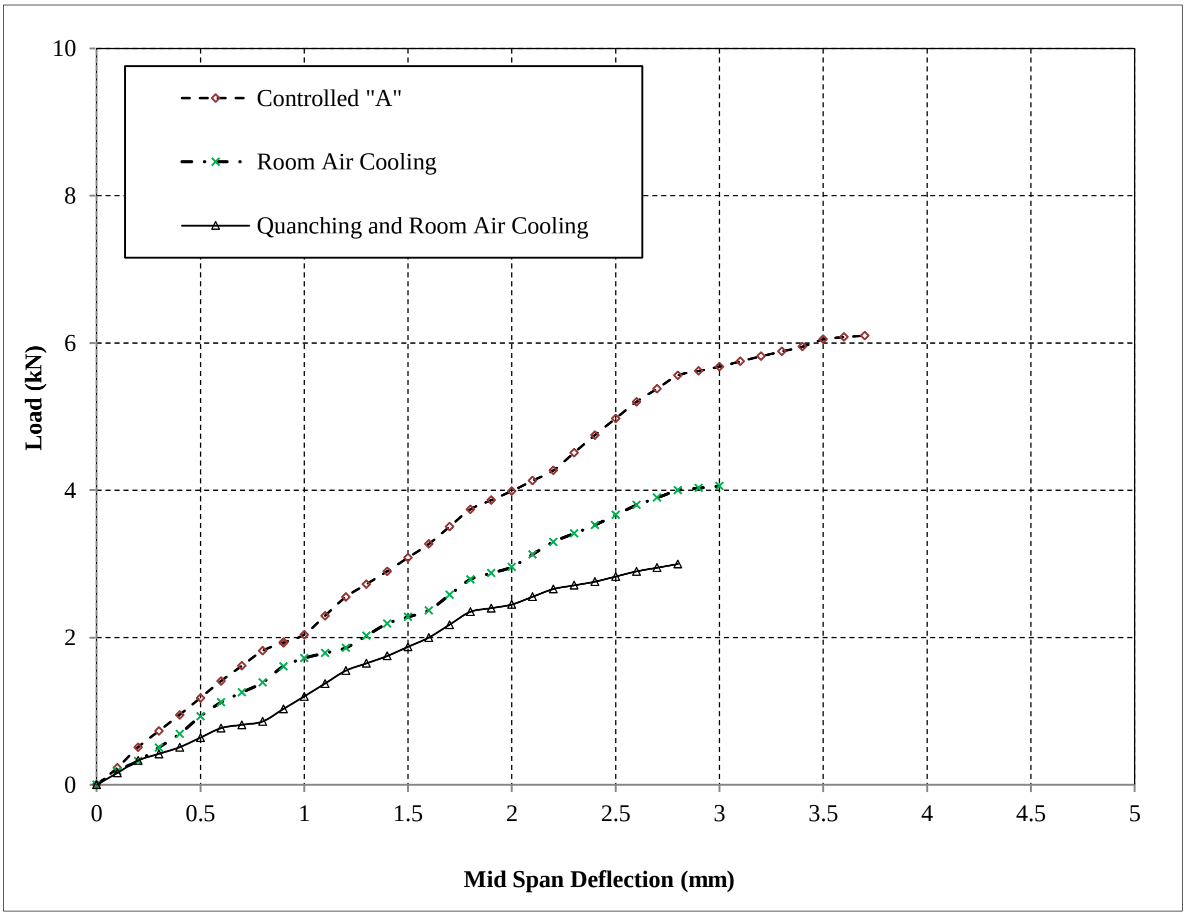

Figure 6. Flexural performance of specimen “A” after 60 temperature cycle

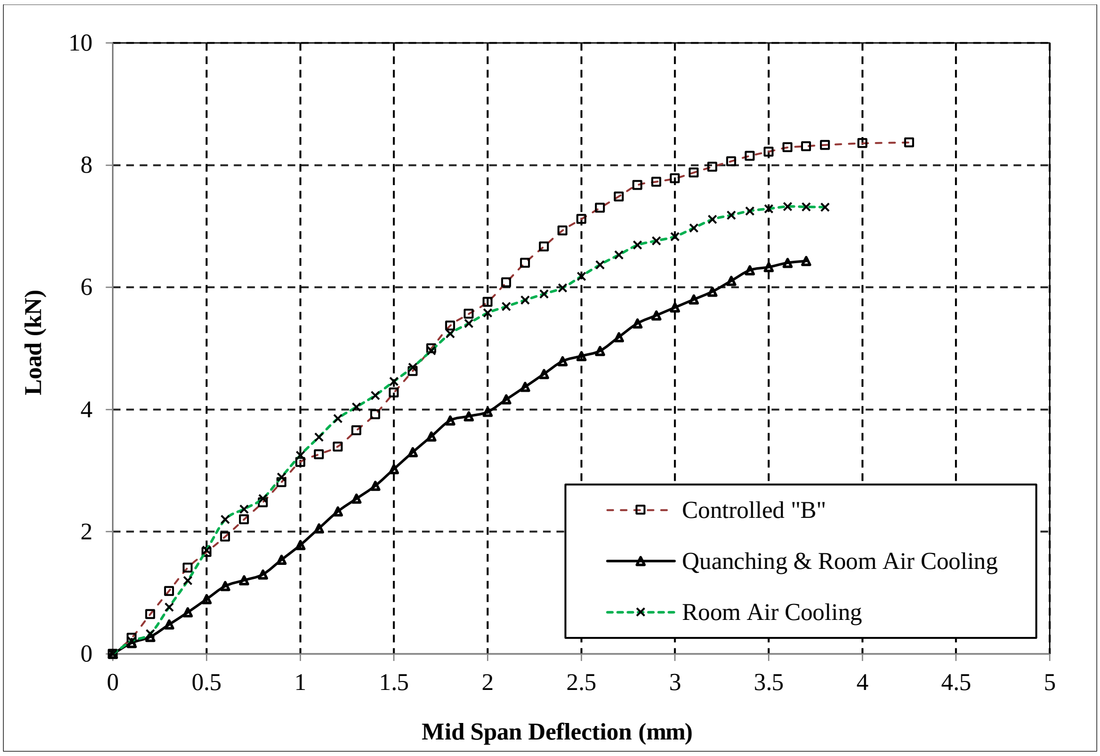

Figure 7. Flexural performance of specimen “B” after 60 temperature cycle

Increasing temperature up to 100 ºC, the strength was decreased in comparison to room temperature was observed by Al-Rifaie [27] is similar to this research work. First crack load also changed after completion of sixty temperature cycles. This load is 27.3%, 42.3% and 31.8% of failure load for controlled sample, sample in room air after every teperature cycle and samples in room air following quenching after every temperature cycle respectively for single mesh layer sample, and for double mesh layer sample these vaues are 38.9%, 30.1% and 17.7%. Early first crack is found for the samples following quenching and cooled in room temperature after every temperature cycle for both samples.

4. Conclusion

Based on the test performed in this work, the flexural strength performance was reduced by 52% and 35% for single and double layer wire mesh samples respectively followed by corrosion environment when compared it with the controlled sample. Double layer mesh exhibits 27% higher strength compared to the single layer mesh element in case of controlled condition. Water absorption of ferrocement panel is not related with its mesh amount.

Flexural performance of single layer mesh specimen after quenching is 34% less when compared it with cooled in normal room environment due to temperature effect. Quenching in ferrocement panel showed higher amount of flexural strength loses in single layer mesh element than double layer. Flexural performance of single layer mesh specimen exhibits about 33% and 50% strength drops when cooled in normal room environment and quenched respectively, however, 22% and 13% strength was dropped for double layered meshed element. Specimen with double layer meshed gives better performance compared to the single layer elements.

5. Acknowledgement

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6. Conflicts of Interest

The authors declare no conflict of interest.

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