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IMPACT OF ELEVATED TEMPERATURE, CHEMICAL AND WORKMANSHIP ON PERFORMANCE OF BEAMS WITH NEAR SURFACE MOUNTED FRP BARS

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Abstract: Near surface mounted (NSM) is growing exponentially into the strengthening and repair of concrete structures over the past decades worldwide. CFRP NSM offers a superior strength over conventional steel reinforcement as well as a good durability in various environmental service conditions. However, the effect of elevated temperature, adhesiveness and chemicals has not been sufficiently studied. This study aims at assessing the impact of elevated temperatures, adhesives and chemicals on beams exposed to flexural loading. To meet this objective, a set of 60 beams were prepared with locally available NSM and exposed to temperature of 70, 120 and 180 °C for 1, 2, 4 and 8 hours. Beams were also evaluated with three levels of adhesiveness placement and were also, exposed to five weeks of wetting and drying in fresh water, brine, water and magnesium sulphate. The results of this work reveal that CFRP bars NSM mounted at a depth of 25 mm introduces more than double flexural strength of conventional steel reinforced beams. Exposure to different degree temperature at various duration, placement of adhesive and exposure to chemical all lead to substantial drop in the flexural strength and thus affect the potential gain of NSM. This study should be resumed by future research work to Construction industry needs to be aware of the findings of this work to make better use of its implementation in future repair and retrofitting.

1 INTRODUCTION

Strengthening of already existing reinforced concrete (RC) members is becoming a necessity because of the destructive harsh environmental conditions, the increased service loads, the errors in design which is caused also during construction. NSM system depends on composite action between bonded CFRP rod and steel reinforced concrete member. So, this composite action is reached by installing CFRP rods in the groove and bonding it with the epoxy. As such, this system functionality is limited on how well is the CFRP rod bonded with the epoxy, indicating in turn the bond to the concrete member. At a specific strain, enough differential elongation happens between the RC and the CFRP section, letting the section lose the composite action, CFRP to debond, and considering the CFRP reinforcement failed. The strain is debonding strain and it is the leading factor in the designing of the NSM reinforced members. At elevated temperature, the organic polymer matrix mechanical properties decrease which accordingly reduces the ability of transmitting forces between fibers and the concrete surface. Consequently, this structural system is considered as ineffective. Furthermore, when temperature increases, deterioration of adhesive bond and slipping of the boundary appears and it is commonly known that FRP materials are exposed to mechanical properties degradation when at elevated temperature. Mechanical properties of FRP materials at high temperature are scarce. Also, there is lack of information concerning the mechanical properties and bond properties of FRP materials when exposed to elevated temperature. The objectives of this research is to assess the impact of elevated temperatures, adhesives, and chemicals on beams exposed to flexural loading. To meet this objective a set of sixty beams were prepared with locally available NSM and exposed to temperatures of 70, 120 and 180 °C for 1, 2, 4 and 8 hours. Beams were also evaluated with three levels of adhesiveness placement and were also exposed to five weeks of wetting and drying in fresh water, brine water and magnesium

2 Literature Review

Several investigations were made by researchers all over the world in retrofitting of RC beams area. Many parameters were considered starting from strengthening material type, number of layers, wrapping scheme, and concrete grade for both analytical models and experimental. Using composite materials gives several advantages, as being easier and faster in installation, has a smaller weight and much higher durability than traditional steel reinforcements. The FRP is the composite material which is most widely used. FRP consist in different types of fibres (glass, aramid and carbon) embedded in polymer matrix, where is mostly epoxy resin. FRP resembles a composite material made from a fibre reinforcement matrix of polymer. Fibres regularly are in the form of aramid, glass, and carbon. Other forms of fibres which sometimes are used are as paper, asbestos and wood. Regarding the polymer itself, it comes in the different forms as thermostatic plastic, epoxy, polyester and vinyl ester. FRP applications are not only limited to construction industry; it was initially used in aerospace, automotive industries and marines. Implementation of FRP materials continues to grow to almost all advanced fields of engineering. The key of this widespread of FRP materials is its new advanced systems development. These new developments of FRP materials include innovative reinforcement's types as the carbon nanotubes and nanoparticles in addition to high performance adhesive systems the main function of composite materials is enhancing primarily the structures strength and stiffness. This is accomplished by having stronger material with lower density in weak matrix polymer. The composite materials mechanical properties depend on the component's properties specifically the matrix and fibres accompanied by their manufacturing process. As a result, it is particularly important to understand the components properties to be able to understand the composite materials properties. FRP have been widely used in numerous fields such electrical, automotive, aerospace, marine, sporting industries and military. Nevertheless, it differs when we come to environmental factors and loading conditions, especially affecting the long-term performance and durability of the applications of the construction industry. Reasoning all this back to durability challenge which is offered by construction industry nature. The durability mainly is about whether if environmental factors is a singular or an assembly of exposures which will be involved. Each FRP system, has a distinctive Tg which is the glass transition temperature of the polymer matrix or adhesive is lower than that of the surrounding temperature; its range is usually from 60 to 82 °C depending on the available FRP systems. As established in many preceding studies, the adhesive bond softens usually when temperature gets close to Tg which leads to substantial reduction in elastic modulus and strength. The FRP strengthening systems ability to define temperature limits is still questionable and neither fully specified nor denied. There are no enough experimental verifications that supports the limitation of the glass transition temperature. Accordingly, the interface between NSM FRP composite materials and concrete will always represent a weak point in the strength of the system. There is a noticeable gap in the CFRP strengthened concrete structures durability field. Further investigation is required to try to resolve the deficiencies in all various aspects. The bond performance of NSM CFRP rods is a multifaceted one because of the many interactions between load, temperature, time and stress. FRP strengthened systems is claimed that it can be effective during the fire scenarios. Conversely, additional studies and investigations are needed to fully understand its impact when subjected to different environmental parameters and its performance on the bond. As from the above we can get that different elevated temperatures not only decreases strength and stiffness, but it also affects the adhesive deformability in the bond.

3 Experimental Work

3.1 Outline

The preparation and design of beam specimens for this experimental work was performed with accordance to the ACI 318-14 code and ACI 440.2R-08 guidelines. The CFRP rod diameter is 12 mm and the following dimensioning were considered:

a) Minimum depth of the groove (D) = 1.5ϕ = 1.5 × 12 mm = 18 mm
b) Clear groove spacing = 2D = 36 mm
c) Clear edge distance = 4D = 72 mm

The short-term tensile strength, as opposed to long term, was used for this calculation, since the beams are expected to go under short term loading conditions in a three-point flexural test. Based on these calculations, the beam specimens dimensioning was carried out. Afterwards, 60 beams were casted for testing, with the purpose of scaling them to work within the available manpower, constraints of cost and handling of the beam specimens in the lab. The 12 mm CFRP rods are only available along the beam lengths, meaning that the maximum bonded length which is investigated in this experimental work is 0.75 m. To meet the condition of clear edge distance of 72 mm, a minimum of 72mm of concrete will be added to both sides of the CFRP rod through the longitudinal direction of the beam, amounting to beam minimum required length of 0.75 m. For the practicality of construction and to be able to give a reasonable supporting length of concrete for the pedestals, a beam length of 0.75 m was selected, 0.15 m was selected as the width of the beam and the thickness of the beam was selected to be 0.15 m. Owing to beam size, minimum conventional steel reinforcement of 2ϕ8/m and 2ϕ10/m top and bottom reinforcement respectively, with yield strength of 240 MPa, was selected. This was conducted for ensuring the beam tension failure under three-point loading. The target is 28-day concrete compressive strength with range of 30-35 MPa, which is a conventional concrete representative range. Some obstacles encountered while going through the study which are mainly related to lab work which was performed. This is related to the fact of dealing with considerably heavy weight specimens which need careful handling, in addition to special labour and equipment type. The beam pouring was executed over six days, ten sample each day, with a three-day gap in between to allow for the curing of the samples that were poured. Also, vibrator handling, where the vibrator temperature increases significantly, and it might cause burns if it is held at a different point other than the one instructed. In addition to its heavy weight which was a physical challenge. Moreover, the groove surface preparation, which was performed by putting a wooden strip along the length of all beams to help with FRP installing. This wooden strip was removed after the concrete cured and the challenging part was to keep it in its place during pouring the concrete.

3.2 Materials Selection

3.2.1 Sika Carbodur Rods

The sika Carbodur rods are known as carbon fibre rods designed for structural strengthening and it comes as part of the Sika Carbodur system which is composed of the rod and the adhesive. The CFRP rods may be used as NSM strengthen reinforced concrete beams and slabs. Epoxy adhesive is used for the rods bonding. There were two epoxy adhesive types, firstly the Sikadur 30 which is for normal temperature and secondly the Sikadur 30LP for high temperature, where Sikadur 30LP is the one used in this work and has Tg of 52° C as per Sika’s specifications. The Sika Carbodur rods are used for enhancing the flexural capacity of structures. Along with, enhancing serviceability and durability by decreasing crack width, deflection and fatigue.

3.2.2 Steel Reinforcement

A steel mesh was prepared using 2Ø8/m and 2Ø10/m top and bottom reinforcement respectively, as well as stirrup Ø8/m every 100 mm for the long direction of the beam. The steel used is mild steel, which is generally known to have a yielding strength of 240 MPa. U-shaped hinges at the corners where used to avoid debonding failure

3.2.3 Cement

Ordinary Portland cement was used type I (ASTM C150) with a specific gravity of 3.3. It is being produced by the Suez Cement Company which complies with the international standards (EN 197/1-2011) and the Egyptian standards (ES 5756/1-2013).

3.2.4 Coarse Aggregates

Surface dry crushed dolomite stones were used as coarse aggregates in this work from the local quarry near Suez with a maximum nominal size of (MNS) < 40 mm and a specific gravity of 2.55 (based on ASTM C 127-88).

3.2.5 Fine Aggregates

The sand used in this study is attained from a local quarry near Suez and a specific gravity of 2.51 (based on ASTM C 128).

3.2.6 Water

A clean potable water was used for the process of mixing and for any purposes of cleaning during the pouring procedure.

3.2.7 Retarding Admixture

Type D admixture was used found in ASTM C 494, targeting for a higher compressive strength through lowering the water cement ratio. Plasticizer type D is obtained from Sika, with commercial name Sika Plastiment, to enhance the concrete workability.

3.2.8 Epoxy Adhesive

The bonding epoxy adhesive used is Sikadur 30 LP. It is thixotropic which consists of two components; component A and component B in a pallet of 6 kg. Component A is the main part of the epoxy adhesive and it comes in a form of a white paste. Component B a dark grey paste which is the second part. This material complies with the international standards (EN 1504-4). It is recommended to be used at elevated temperatures laying in the range from +25 to +55°C. This material has a no-sagging behavior with a high abrasion and a mechanical resistance. Over and above, it is liquids and water vapor impermeable. It provides an extremely strong adhesion to the CFRP rods and concrete.

3.3 Sequence of Work

Knowing the quantities of water, coarse aggregate and fine aggregate, and taking into consideration, the following assumed parameters for the mix design: a) No correction for saturation potential/surface moisture of aggregates. b) M.N.A is 19 mm (based on ASTM C136). c) Fineness Modulus is 2.25 (based on ASTM C136). d) Slump of 30-50 mm

These parameters had to be assumed as limitations in the resources required to determine the specific gravity of cement according to ASTM C188-95. No adjustments were made by assuming that the aggregates are in saturated surface dry (SSD) condition. The concrete mix design is summarized in Table 1 below:

Table 1 - Mix Design

Item	Quantity
Water	185
Cement	400
Coarse Aggregate	1150
Fine Aggregate	600
Plasticizer Type D	2 litres

The above mix gives a normal strength concrete mix with compressive strength of 30-32 MPa after 28 days. It was decided that the sixty beams would be poured continuously for consecutive 6 days. The required volume of concrete in each beam (0.75 m × 0.15 m x 0.15 m) was calculated to be 0.0169 m^3. An additional 20% of the beam volume was added to each beam as contingency, accounting for possible losses during pouring. Consequently, each beam would require 0.02 m^3. Since the available concrete mixer has a capacity of 0.11 m^3, 5 beams would be poured in one batch. Each day of pouring would therefore require two concrete mixer batches (2 × 0.11 m^3), to pour ten beams.

3.4 Experimental Variables

This section provides the different variables investigated in this study shown in Table 2 and Figure 1. These variables are which the NSM RC beam specimens with the same reinforcement ratios, were tested against and its effect on the specimen flexural strength.

Table 2 - Four Sets Used in the Study

Set Number	Number of Beams	Set Materials	Adhesive Material
Set 1 (Control)	3	Plain Concrete	None
Set 2 (Control)	3	RC	None
Set 3 (Control)	3	RC+CFRP Rods (12 mm Diameter)	Epoxy Adhesive (Sikadur 30 LP)
Set 4	51	RC+CFRP Rods (12 mm Diameter)	Epoxy Adhesive (Sikadur 30LP)

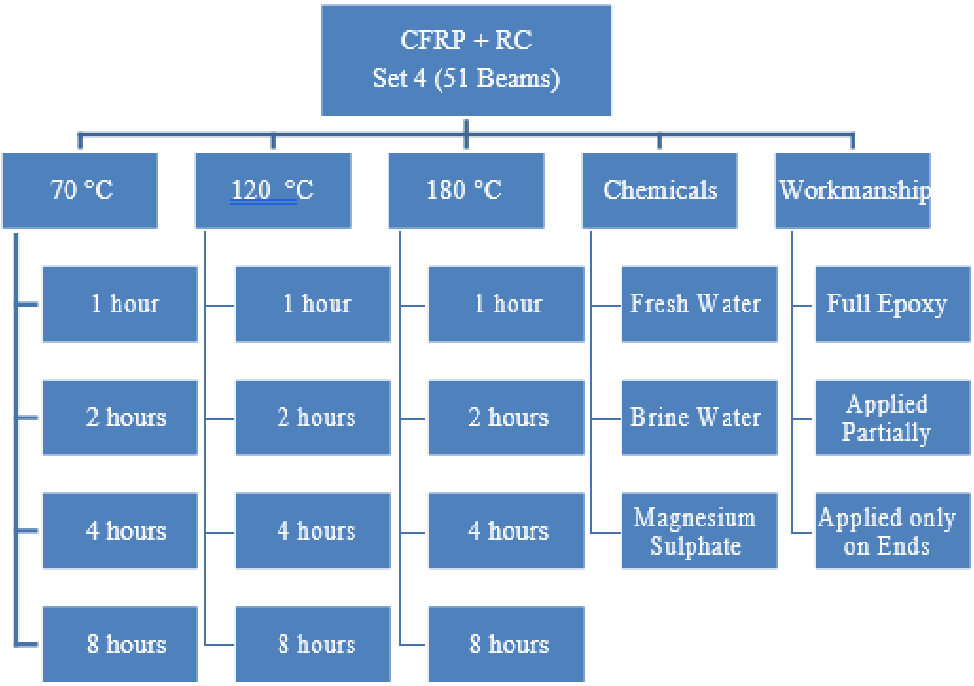

Figure 1 - Testing Parameters (3 Replica for Each Parameter)

4 Results

The key findings of the effect of adhesiveness, elevated temperature over different durations and chemicals attack on the response of the NSM RC beams are adhered. It is worth mentioning that it is also depended on workmanship, so having a perfect specimen is theoretical. In addition, the number of beams tested for each variable are three beam specimens, so it can be within the resources of this study.

4.1 Flexural Strength Results

Comparing between the flexural strength increase of beams from conventional concrete without reinforcement, to reinforced concrete, to reinforced concrete with NSM CFRP to see the increase of flexural strength. The results below show that in conventional environmental conditions the flexural strength of NSM CFRP can increase to reach 212 % the flexural strength of the nominal flexural strength of RC as shown in Figure 2 and Table 3. This percentage is confined to the amount of steel reinforcement used and thus is expected to change when steel reinforcement ratio is altered.

Table 3 - NSM Flexural Strength Results

Parameter	Results			Average ± Standard Deviation (kN)
NSM	121	130	125	125 ± 4.4
Steel	60	60	57	59 ± 1.8
Plain	10	11	12	11± 1.1

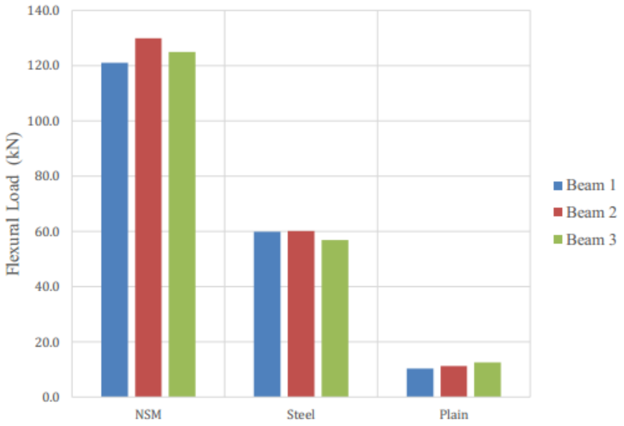

Figure 2 - Relation between Increasing flexural load of NSM over RC and Plain Concrete

4.2 Temperature

A detailed analysis on different temperatures effects at different time intervals, to see how this affects the specimens. The temperature and time effects on CFRP a percentage deterioration ratio graph of all the data are presented in Figure 3. We can conclude from this graph that as temperature and duration increase the flexural load of the specimens drop. However, at 70 °C the flexural load increased as time passed, and at 180°C for 1 hour yielded higher flexural load than that of 70°C at 1 hour, which should not be the case with FRP, this may indicate an experimental error which led to the increase in flexural load as exposure duration and temperature increased or that at time of flexural testing the specimens returned to the Tg of the material which eliminated the temperature effect. So, if averaging all data for each temperature, it concludes that as temperature increases the flexural load of NSM CFRP decreases which gives us an inversely proportion relation between the temperature and time and that CFRP is not prompt to high temperature for long time periods.

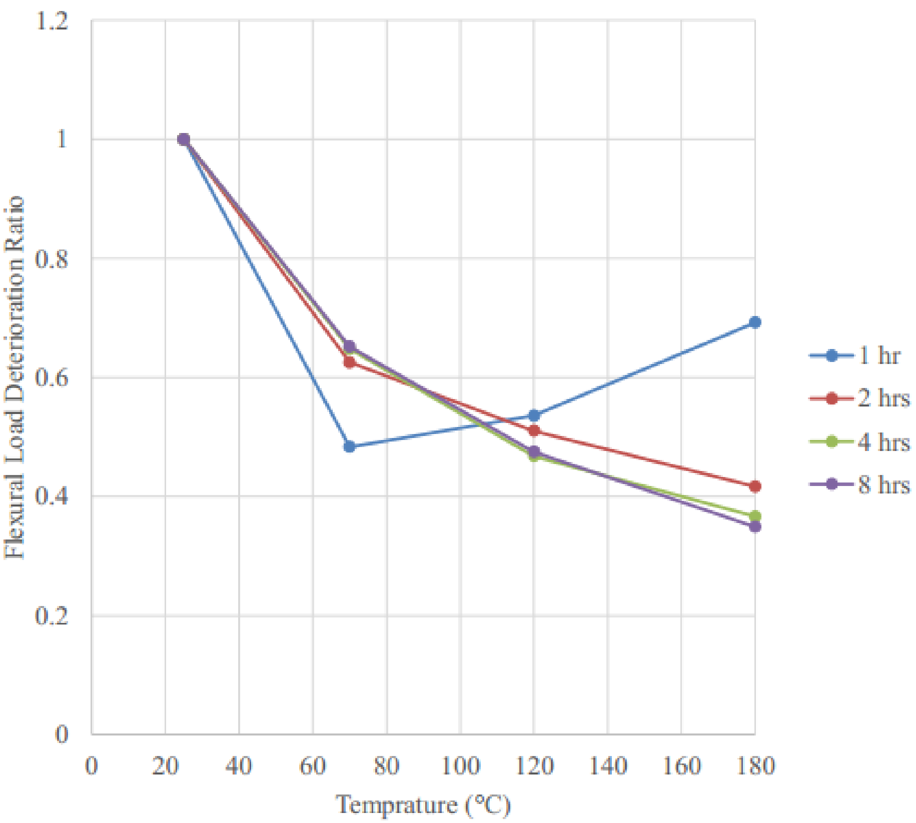

Figure 3 - Specimens Flexural Load Deterioration Ration between different Temperatures and Various Durations

4.3 Workmanship

Workmanship also affects the flexural strength of the beam specimen. So, applying different partial epoxy to the beams as shown in Figure 4 and results shown in Figure 5.

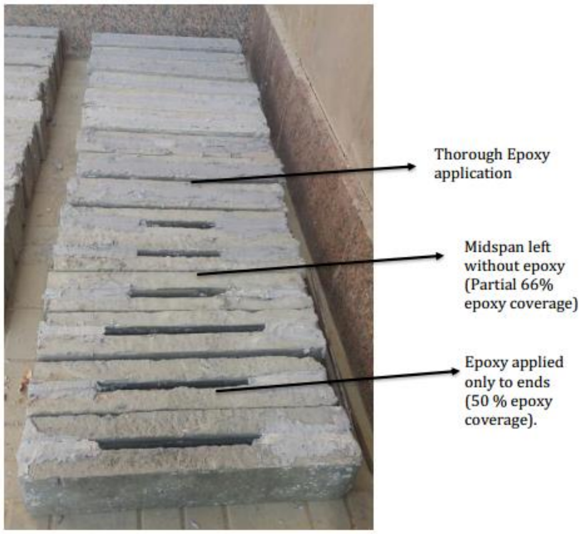

Figure 4 - Different workmanship Epoxy Application effects

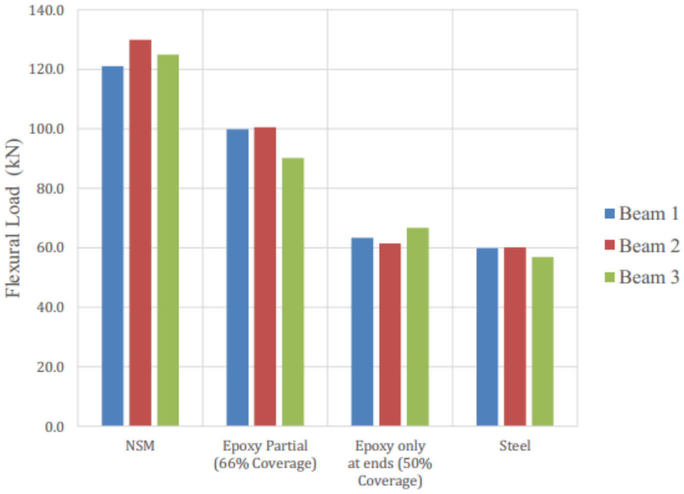

Figure 5 - Workmanship and epoxy coverage percentages affecting the flexural load of the specimens

Testing these beams, it concludes the results that, if the epoxy is not applied in a good way and that if the workmanship slacked during applying the epoxy or thought that they could be cost reducing and saving epoxy, and that it would not affect the result of the flexural strength required, they are defiantly mistaken. CFRP can go to nearly the same flexural strength of not having any CFRP in the first place. The epoxy application affects the flexural strength intensely, so it is of high importance to ensure that the epoxy is well applied

4.4 Chemicals

Chemicals affect concrete flexural strength and is one of the main reasons for flexural strength deterioration, in this study three types of chemicals were used to compare between there different effects on specimen flexural strength, these chemicals are fresh water, saturated brine water, and 10% concentration magnesium sulphate, Figure 6 below shows the effect of each chemical on the beams. Three specimens were used for testing for each type of chemical, the beams were left for five weeks and were exposed to drying and wetting to expedite the effect of the chemicals on weekly bases. The three beams for each chemical type were left in three different containers which were designed for this study along the five weeks, they were designed to allow the beams to be maneuvered while drying and wetting and have a total surface contact with the chemicals as shown in Figure 7.

Figure 6 - Showing the effect of chemicals on the specimens, Fresh water effect (Top Beam), Magnesium Sulphate (Middle Beam) and Brine Water Effect (Bottom Beam)

Figure 7 - Container Used for the Chemicals Testing

The specimens soaked in water does not affect the flexural strength of concrete, however being exposed to brine water decreased it by around 30 % due to the sodium chloride attack but moving to magnesium sulphate which had the strongest deterioration of them decreased the specimens strength by 40 % which shows how aggressive chemicals can get in attacking and reducing the flexural strength of the beams.

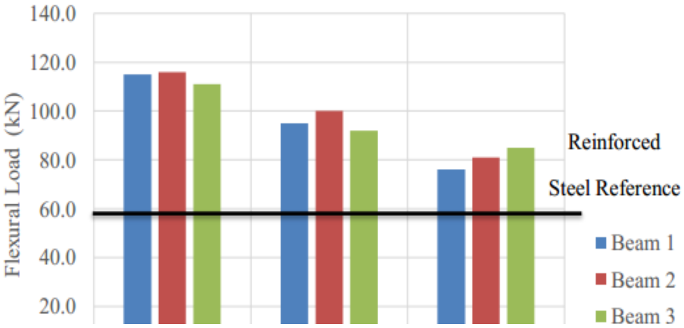

Figure 8 - Chemicals Effect on Flexural Load of the Specimens

4.5 Deflection

The impact of CFRP on the load deformation performance after the exposure to different chemicals, so plotting all deflection curves all together for a better observation of the deflection data as shown in Figure 9 below. Concluding that if the stiffness of the specimens increases, its yields less deflection.

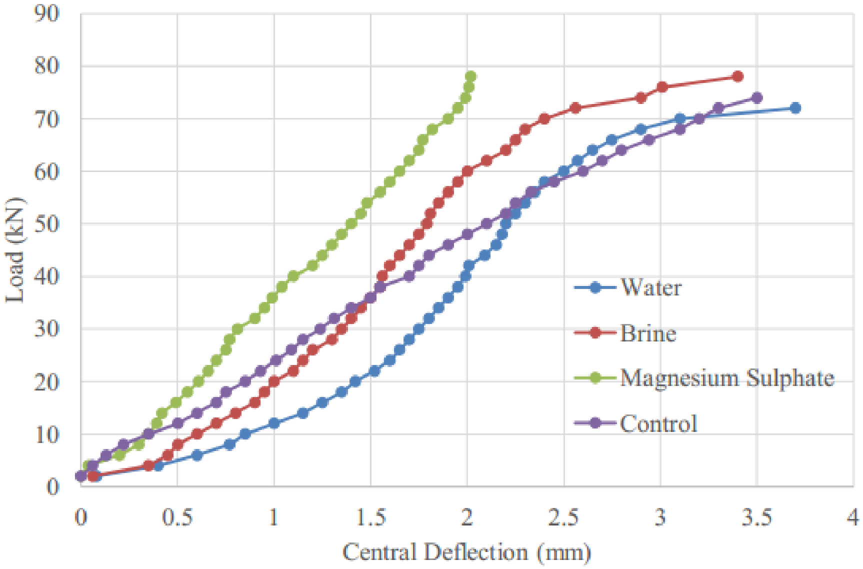

Figure 9 - Deflection data Compiled Results

5 Conclusions

Based on the methodology of applications, procedures, materials incorporated, and other parameters associated with this work, and taking into consideration the work limitations as well as statistical and experimental variations, the following conclusions can be drawn:

1. Designing NSM beams has led to substantial increase in flexural strength compared to conventional reinforced steel beams. This increase surpassed 200% of the flexural load of the steel reinforced control beams in respect to the ratio of CFRP to reinforced steel used.
2. There is a substantial drop in the flexural load in the NSM beams upon the exposure to 1 hour and temperature of 70 °C such decrease continues as duration increases to 8 hours. However, one can argue that exposure to 70 °C in the range of 2 to 8 hours results are similar in results.
3. Exposing NSM beams to 180 °C for extended hours yielded the smallest flexural load that was as high as 66 % from the control room temperature beam with the exception of 180 °C the drop of flexural strength is somewhat proportional to the increase of exposure duration.
4. Care should be taken that thorough application of epoxy with good workmanship is indispensable for benefiting from NSM strengthening effect. For instance, less thorough application epoxy can lead to almost zero gain of NSM.
5. While, test duration for beams exposed to fresh water, brine water, and magnesium sulphate was relatively small, a drop in flexural strength has taken place for up to 35 %.

Recommendations

The following recommendations can be indicated:

1. Validated through larger set of concrete mix design, steel, types of adhesive and NSM reinforcement with different diameters with NSM place at various depth from concrete surface.
2. Include larger set of exposure temperatures, larger durations and possibly with exposure to fire not just elevated temperature.
3. Extended the chemicals exposure to several month in a cycling manner to depict more real-life conditions of chemical attach.
4. Study bond behaviour of NSMP FRP strengthening systems needed including additional possible influencing parameters and combinations of them.
5. Durability aspects of long-term effects such as creep and fatigue.
6. Executing NSM using CFRP on Full Scale beams

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