The Hashemite University
Civil Engineering Department

REHABILITAION AND STRENGTHENING THE FLEXURAL CAPACITY OF LIGHTWEIGHT REINFORCED CONCRETE BEAMS USING NEAR-SURFACE MOUNTED CARBON FIBER REINFORCED POLYMER [NSM-CFRP] STRIPS.

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1. Introduction

There are a number of sustainability and environmental problems resulting from the extraction of coarse aggregates for the manufacture of concrete. Additionally, there is a shortage of normal aggregates (NA) in several countries as a result of a worldwide utilization of millions of tons of aggregate from various sources. Recently, due to the decreasing in the self-weight of reinforced concrete (RC) structures, lightweight concrete (LWC), which is often composed of coarse lightweight aggregate (LWA), has become a potentially practical substitute for conventional normal weight concrete (NWC). Because LWC has better qualities than conventional NWC—such as fire resistance, a higher strength to weight ratio, a lower density, a lower thermal conductivity, better sound insulation, and a smaller cross-section size—it has drawn a lot of interest from researchers and engineers in recent years.

Throughout their service life, **concrete structures** can become deficient or face deterioration and damage, requiring strengthening and rehabilitation. Therefore, the strengthening and rehabilitation process has emerged as the best option/method for extending the service life of deficient or damaged structures and improving their load carrying capacity, since replacing or rebuilding them would involve significant financial outlays, time, and effort. So, the strengthening and rehabilitation process is the most economical one. **Fiber-reinforced polymer (FRP)** materials have been used to strengthen and rehabilitate the shear and flexural capacity of the RC structures. These fibers were usually made of glass, carbon, aramid, or basalt with different shapes like strips, bars, sheets, laminates, and plates. The most recent and promising methods now being utilized for strengthening and rehabilitating damaged reinforced concrete structures are **Externally Bonded (EB)** and **Near-Surface Mounted (NSM)** techniques, both of which use fiber reinforced polymer (FRP) materials. Both techniques are used to enhance the shear and flexural capacity of RC structures. Nowadays, the Near-Surface Mounted (NSM) method has been mostly used. In this method, the FRP **strips** or **bars** are bonded into longitudinal grooves cut in the concrete cover using epoxy resin, which reduces the possibility of catastrophic FRP de-bonding from the concrete substrate.

2. Problem Statement

Recently, the NSM technique attracted the researchers' attention and became favoured over the EBR, because it has many advantages over the EBR method, including: (1) higher bonding efficiency; (2) delaying the de-bonding problem; (3) better protection of the FRP reinforcement from hostile environmental effects; and (4) better fire resistance. Several experiments were carried out to study the flexural behaviour of RC beams strengthened with Near-Surface Mounted Carbon Fiber Reinforced Polymers (NSM-CFRPs) technique with different configurations and parameters, such as: (1) shapes of FRPs; (2) types of FRPs; (3) length of FRPs; (4) number of FRP layers; (5) number of grooves; and (6) spacing between FRPs. There was a lack of research studies that investigated improving the flexural capacity of rectangular Lightweight Reinforced Concrete (LWRC) beams with constant reinforcement ratio, strengthened and rehabilitated using the NSM-CFRP technique. This research aims to study the flexural performance of rectangular (LWRC) beams with the same compressive strength while preserving a constant reinforcement ratio **($0.5\rho_{max}$)**, strengthened and rehabilitated using the NSM-CFRP strips. The main parameters to study in this research are: (1) number of CFRP strips; (2) the length of CFRP strips, and (3) the percentage of pre-loading (0% or 60%).

3. Research Importance and Objectives

Generally, the main objective of this research is to study experimentally the flexural behaviour of rectangular lightweight reinforced concrete (LWRC) beams with the same compressive strength and a constant reinforcement ratio **($0.5\rho_{max}$)**, strengthened and rehabilitated using the near-surface mounted carbon fiber reinforced polymer technique (NSM-CFRP).

→The essential objectives of this research are as follow:

- To investigate experimentally the impact of using the NSM-CFRP strips in improving the flexural capacity of LWRC beams in terms of the failure mode, ultimate capacity, deflection, and crack patterns.
- To investigate the effect of using different configurations of NSM-CFRP strips on the flexural strength of LWRC beams.
- To investigate the effect of using different configurations of NSM-CFRP strips on the flexural rehabilitating of LWRC beams.
- To investigate the effect of using different NSM-CFRP strips configurations on the flexural strengthening and rehabilitating of LWRC beams.
- To determine the optimum configuration of NSM-CFRP strips to be adopted.
- To compare the findings of the theoretical code design equations with the experimental results for the tested beams.

4. Experimental Program

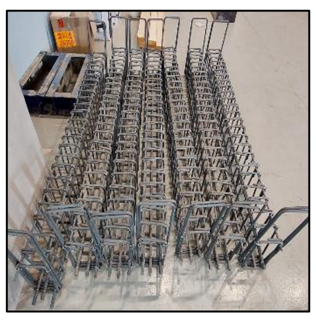
4.1 Material Properties:-

Several materials were used to study strengthening and rehabilitating the flexural behavior of Lightweight Reinforced Concrete (LWRC) beams; involving lightweight aggregate (LWA) and reinforcement steel, which they were utilized in casting phase. Whereas NSM-CFRP strips, and epoxy adhesive, will be utilized later in strengthening and rehabilitating phases.

4.1.1 Lightweight Aggregate Concrete (LWAC) and Reinforcement Steel:-





4.1.2 Near-Surface Mounted Carbon Fiber Reinforced Polymer (NSM-CFRP) strips:-

This figure shows the SikaCarboDur® S1.525 strips, which were obtained from SIKA Jordan company.

NSM-CFRP strips SikaCarboDur® S1.525 will be used to strengthen and rehabilitate the flexural capacity of the (LWRC) beams. This material is characterized by a unidirectional and high-performance strengthening system; hence it contributes to improve the structural performance. The following table shows the mechanical and physical properties of the NSM-CFRP strips as per the manufactured company.

Width (mm)	15
Thickness (mm)	2.5
Modulus of elasticity (GPa)	165
Tensile Strength (MPa)	3100
Density of carbon fiber (gm/cm³)	1.60
Strain at break	>1.70%

4.1.3 Epoxy Resin:-

Epoxy adhesive is one of the chemical substances used to bond the NSM-CFRP with RC beams. This substance interacts strongly and prevents fiber separation from the RC surface.

Epoxy adhesive is more efficient and provides strong bonds when attached to concrete rather than steel reinforcement. It is very important to choose an epoxy type with optimum strength, thus the maximum strength of NSM-CFRP is reached and failure due to carbon fiber separation is prevented.

In this experimental program, Sikadur®-30 LP will be used. It was obtained from the supplier Sika Jordan. This resin is solvent-free, has high moisture resistance, high strength, and high modulus of elasticity. The following table shows the properties of Sikadur®-30 LP resin.

Type : Sikadur®-30 LP Resin : part A (white) Hardener : Part B (black) Packaging : 6Kg A+B (light grey)	
Density	1.65 kg/lt
Tensile strength	15-18 MPa (7 days)
Bond strength	Concrete fracture > 4 MPa
E-Modulus	Compressive: 10 GPa Tensile: 10 GPa
Shrinkage	0.04 %

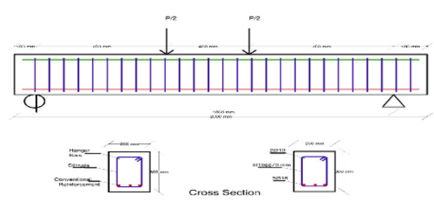
4.1.4 Lightweight Aggregate (LWA):-

The implementation of structural lightweight concrete (LWC) in the construction industry offers several advantages, including a high strength-to-weight ratio, reduced dead load for foundation and structural design, decreased likelihood of earthquake-related damage to a structure, strong tensile strain capacity, superior sound and heat insulation properties, low coefficient of thermal expansion, enhanced durability, allows smaller cross-sections in load-bearing elements, and corresponding reduction in the size of foundations.

Light Weight Concrete (LWC) has gained popularity in recent decades due to its inherent characteristics, which include affordability and design flexibility. Numerous investigations have been conducted in the field of LWC to examine the structural performance in diverse applications. Lightweight materials can be used in concrete as fine aggregate or coarse aggregate to produce LWC. Lightweight concrete's (LWC) inherent properties offer a potential range of applications for structural aims. The properties include workability, density, compressive strength, split tensile strength and flexural strength property.

4.2 Test Specimens:-

To achieve the objectives of this proposed study, a series of seven 2000 mm x 200 mm x 300mm (Length x Width x Height) simply-supported LWRC beams with a rectangular cross-section will be tested under two concentrated loads (monotonic four-points bending test) up to failure, to investigate the effect of using NSM-CFRP strips on the flexural behaviour of strengthening and rehabilitating LWRC beams. Different strengthening and rehabilitating configurations of NSM-CFRP strips will be adopted. The specimens were divided into three groups. First group is the control beam group and consisted of only one control LWRC beam (LWRC-CB) without using any NSM-CFRP materials. The second group is the strengthened beams and consisted of three LWRC beams. Third group is the rehabilitated beams and consisted of three beams. The three LWRC beams will be loaded to 60% of the ultimate load before the NSM-CFRP strips are used to simulate the rehabilitation process.




4.3 Test Setup:-

In order to assess the use of NSM-CFRP strips on the flexural beam capacity, a series of seven simply supported rectangular LWRC beams with the same compressive strength and constant reinforcement ratio will be subjected to a monotonic four-points bending test up to failure. All beam specimens will be supported by a hinge at one end and a roller at the other with a 100 mm edge overhanging. A load cell will be used to measure the applied load and 2 potential meters will be used to measure the vertical displacements at the centre of the beams, one at the bottom side and the other one at the lateral top side. The load will be applied incrementally until failure. A data acquisition system will be used to draw the load-displacement curves for each specimen. The test specimens will be tested in the structural laboratory at the Hashemite University.

During the casting process, standard concrete cubes of 100 × 100 × 100 mm were taken from the concrete mixes, in addition to standard concrete cylinders of 100 × 120 mm. To conduct the compressive strength after 28 days, a total of fourteen cubes were cured then tested using the MATEST device. The other fourteen cylinders will be tested later using The MTS testing device, as shown in the following figures.



5. Experimental Results

The experimental results will be obtained later after testing the specimens inside the structural laboratory at the Hashemite University. And more work will be done inside the lab including the implementation of the NSM-CFRP strips by means of Sika Jordan company.

6. Acknowledgements

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