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MECHANICAL PROPERTIES OF UNCONFINED AND CONFINED WITH ARAMID FIBER REINFORCED POLYMER

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Abstract

Fiber reinforced polymer is a new type of reinforced material made from fibers and resins. It is an economical and effective material for repairing both new and existing structures in the construction industry. By utilizing fibers, a construction can save both money and extend its life span. However, using fibers will increase a building strength. This study aims to evaluate the potential of concrete specimens with Aramid fibre reinforcement that may be evaluated for compression, split tensile, flexural, elastic modulus, and impact resistance. Single and double layers of aramid (woven type) were wrapped around the specimens. Mechanical properties of conventional specimens (without wrapping), singly wrapped specimens, and doubly wrapped specimens were investigated. The experimental results show that specimens wrapped in AFRP have better strength than unconfined specimens in both single-layer and double-layer wrapping. The results were tabulated and plotted graphically.

Keywords: AFRP, Fabrication, External wrapping, Mechanical properties.

1. Introduction

The most common artificial substance is concrete. Concrete is crucial to the field of civil engineering. The mixture of cement, sand, gravel, and water is mixed in a certain proportion to produce the hardened mass known as concrete. These components work together to create a plastic mass that can be moulded into any shape. The components utilised to create reinforced concrete fibres include hydraulic cement, water, aggregate, and irregular, discrete fibres. The fiber's main job is to patch up concrete cracks and make the component parts more ductile, which improves the concrete's post-cracking behaviour.

It increases impact resistance, controls drying shrinkage cracking and plastic shrinkage, and decreases the permeability of the concrete matrix, which stops water bleed. The fibre lengthens the lifetime of the concrete [1]. Toughness is the capacity of a substance to withstand pressure and deformation without breaking. Another way to put it is the material's resistance to fracture under stress [2]. Steel bars and wire mesh are less efficient in preventing shrinkage fractures than dispersed fibres. Tension weakness can be lessened by using ordinary

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steel bar reinforcing and, to a lesser extent, by using the right quantity of certain fibres [3-4]. When fibres are added, the composite fibre matrix's behaviour after breaking changes, and its tensile strength increases.

[5] Concrete has a number of issues, including seismic damage, fractures from expansion and contraction, and shrinkage. These issues lead to concrete being attacked by moisture, which weakens the structure's structural integrity and causes steel reinforcement to corrode [6]. FRP materials can be used to repair such damage. It is possible to improve structures to enable changes in load variation or code updates. Since there is a lack of information about FRP materials, it is challenging for civil engineers and other professionals to often use them [7]. Endless fibres (carbon, glass, and aramid) are mixed with a thermosetting epoxy, vinyl ester, or polyester resin matrix to create FRP composites. To transmit weight between them, the resins attach these fibres together [8].

The interaction between the FRP material and the concrete surface must be carefully examined [9]. Compared to steel plates, FRP is more robust, less susceptible to corrosion, and more resistant to harsh conditions. One of the most popular strengthening procedures right now is FRP wrapping [15]. Studies on the strength and durability of FRP under acid attack and temperature fluctuations have helped researchers better understand the superiority and benefits of FRP in concrete construction, as well as its disadvantages. FRP is frequently highly robust, providing significant defence against corrosive attacks from chemicals in harsh weather [10]. The mechanical properties, production method, and materials of FRP have an impact on its performance. In terms of durability and high resistance, FRP beats conventional concrete in projects that are subjected to acid attack and temperature changes [11].

One of the most adaptable construction materials available to architects and engineers is aramid fiber-reinforced concrete [14]. These tiny, very strong threads of reinforced concrete, which have several uses in the building industry, are typically made of cement, sand, and aramid fibres [12]. As a crack arrester, the fibre in a cement-based matrix keeps fractures under stress from growing out of the matrix's flaws and eventually leading to failure [13].

2. Materials and Methods

In this research, the methods and techniques were tested according to the relevant Indian Standards (IS) codes.

2.1 Materials and Properties

The concrete samples were cast with normal Portland cement, with a typical consistency of 32%, a 105-minute initial setting time, and a 523-minute final setting time. Cement has a specific gravity of 3.15. River sand was used as the fine aggregate and crushed granite stone as the coarse aggregate in line with IS: 383-1970. The fine aggregate had a specific gravity of 2.65 whereas the coarse aggregate had a specific gravity of 2.70. The fine aggregate's fineness modulus and absorption were 2.87 and 0.5%, respectively. Similar results were observed for coarse aggregate: 7.40 and 1.0%. Utilising water with a pH value between 6 and 8, which met the specifications of IS: 456-2000, concrete specimen mixing and curing were performed. 'CONPLAST SP 430, a chemical admixture based on sulphonated naphthalene formaldehyde condensate that complies with IS: 9103-1999 and ASTM C494, was employed in this investigation. According to an initial research, concrete cubes have a strength of 33.20 N/mm^2.

2.2 Methods of Casting:

The sample was cast in typical steel moulds, which were taken out after a day and submerged in water for 28 days. The specimens were prepared to gain strength from AFRP's exterior bonding when the 28-day curing process was complete. The surfaces were dismembered and finished with sand paper prior to attaching the

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FRP to the specimen exterior surfaces. The concrete surface was washed once again with acetone, and then it was given 30 minutes to dry. This external bonding AFRP in specimens method operates properly at standard room temperature and humidity. The specimens were bonded and then kept at ambient temperature for a week to encourage proper polymerization. Fig. 3 displays the AFRP Confined Concrete Specimens.
Table 3 displays the designations for the specimens. The total number of samples were separated into three groups: control specimens with three numbers, specimens with one layer and those with two layers. To make each example simpler to comprehend, it was shortened.

Aramid fibre reinforced polymer (AFRP): Any synthetic polymer (material made up of multiple long, chain-like molecules) that has repeating units with large phenyl rings joined by amide groups is known as an aromatic polyamide. This concept made use of Kevlar, the toughest fibre on the market that is used to create bulletproof vests. Figures 1 and 2 show the aramid fabric fibre and chemical composition of aramid. Kevlar has a melting point of more than 500 °C (930 °F). The necessary AFRP materials are listed in Table.1.

Fig: 1 Aramid fiber and fabrics

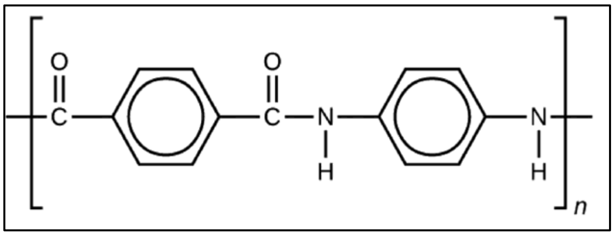


Fig.2 Chemical structure of aramid

Table: 1 Specification of AFRP material:

Properties	**Aramid fiber (Bi-directional)**
Weight of fiber (g/m^2)	158.5
Fiber thickness (mm)	1.36
Nominal thickness per layer (mm)	2.0
Fiber tensile strength	3900

(N/mm^2)	
Tensile modulus (N/mm^2)	131000

The operational link between concrete and aramid fibre was created in this investigation using an epoxy impregnation resin provided by Hayel Aerospace India Pvt. Ltd. It is a two-part system with resin and hardener in a 100:10 (B: H) mixing ratio. The characteristics of the industrialist's matrix delivery are shown in Table.2.

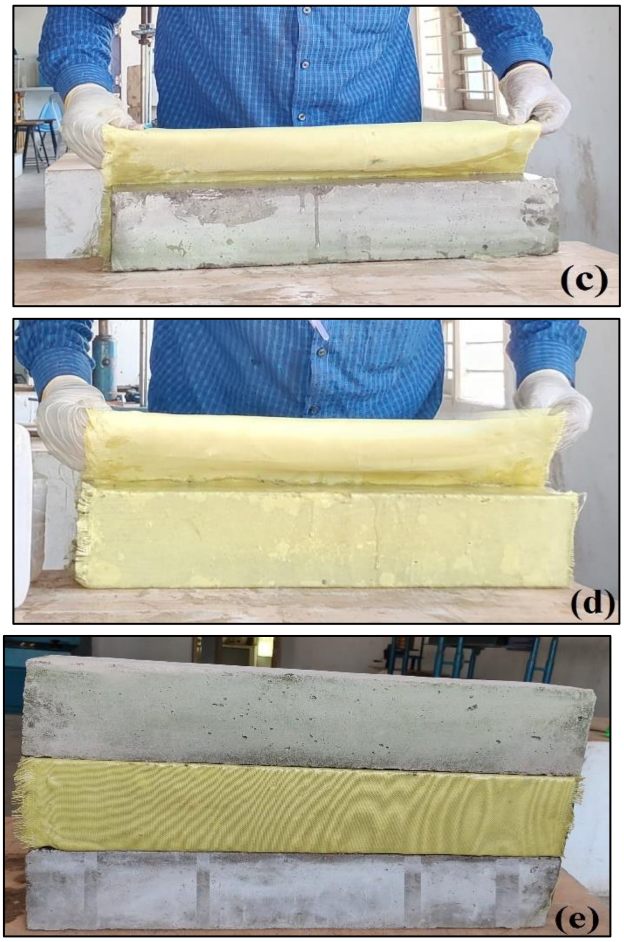
An original liquid epoxy resin with a medium viscosity based on bisphenol-A is called Araldite LY 556. Unmodified aliphatic polyamine with squat viscosity is called Aradur HY 951. To create a uniform mixture, resin and hardener must be regularly combined.

Table 2 Properties of the matrix material

Materials	Parts by weight (gm.)
Araldite LY 556	110
Aradur HY 951	20

Table.3 Designation of samples.

Specimen ID	Particulars
CC	Unconfined
CC+1L	Confined with Single layer
CC+2L	Confined with Double layer



(a) Surface preparation (b) Application of Epoxy resin (c) First layer AFRP (d) Second layer AFRP (e) Placing of weight over the wrapping

Fig.3 Fabrication of AFRP

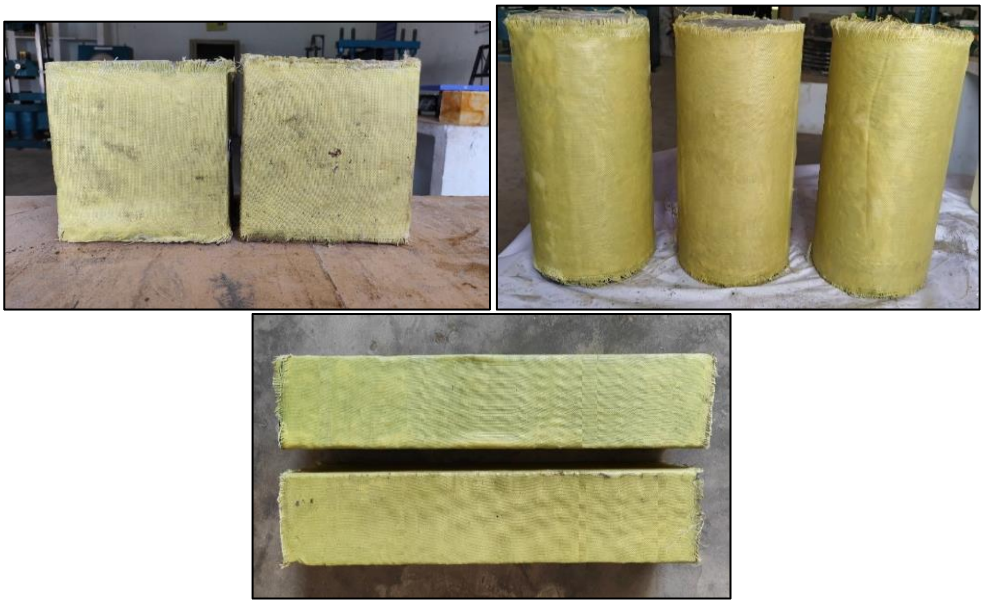


Fig.4 AFRP Confined Concrete Specimens

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3.Experimental investigations

The Indian Standard Code, IS 10262-2007, was followed for creating the mix design for M30 concrete. The preliminary test results of all concrete components were totaled. tests on freshly laid concrete, such as slump cone and flow table tests, Using compression, split tensile, flexural, elastic modulus, and impact resistance as experimental tools, the mechanical behaviour of concrete specimens encased in AFRP was investigated.

3.1 Compression test on concrete cubes

The compressive test is the most often performed test on hardened concrete due in part to its simplicity of use and in part because the bulk of desirable properties of concrete are qualitatively tied to its compressive strength. The compressive test is conducted on specimens that are cube-shaped. For this experiment, standard concrete cubes measuring 150 mm by 150 mm by 150 mm were used.

Fig.5 Test setup for

Fig.6 Failure mode of CC+2L Cube specimen

According to IS 516-1959, these tests were conducted. The tests are carried out using an electro-hydraulic compression testing equipment, and compressive stress is delivered to opposing sides axially at a rate of 800 KN/min. Noted is the compressive load for the ultimate failure. The compression strength test setup and cube failure are shown in Figures 5 and 6, respectively.

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3.2 Split tensile test on concrete specimens:

Concrete cylinders were employed for the research's standard test. Nine cylinders were used to perform the investigation. While the remaining six cylinders were contained with single and double layer AFRP mat for 28 days of curing, the three reference cylinders were cast and tested without any wrapping. For this test, 150mm diameter by 300mm long cylinders are employed, in accordance with IS 516-1959. The test setup for a Split tensile strength machine and failed samples are shown in Figures 7 and 8.

Fig.7 Test setup for Split

Fig.8 Failure mode of CC+2L Cylinder specimen

3.3 Flexure test on concrete specimen:

A conventional concrete prism of 100 mm by 100 mm by 500 mm was utilised for this investigation. According to IS: 516 1959, the exam was conducted. The experimental research have employed nine prisms. Six reference prisms were contained with single- and double-layer AFRP mats, and three reference prisms were evaluated without any wrapping. Following the external bonding of the AFRP in the specimens, the prism surface is cleaned, and it is then labelled correctly and put in the testing apparatus. The prism is loaded manually in two points, and the dial gauge readings are recorded all the way up to the failure mode. The prism test configuration for a flexural test machine and failed samples are shown in Figs. 9 and 10. the separation between the crack's line and the

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Fig.9 Test setup for Flexural Strength

Fig.10 Failure mode of CC+2L prism specimen

Closer support is measured on the tensile side of the specimen to select the appropriate formula for calculating its modulus of rupture. The results are obtained by taking the mean values of three prisms, with the results for each specimen type shown in Table 6

3.3 Modulus of elasticity:

According to (IS 456, 2000), cylindrical specimens with dimensions of 150mm x 300mm are used to calculate the E for concrete values. The specimens are taken out of the curing tank after 28 days and left to dry. Six reference cylinders were contained with single and double layer AFRP mats, while the other three were examined without any wrapping. The cylinder is marked as needed, and the compressometer is placed over it. The compressometer dial gauges are set to zero, and a load is applied. Readings from the dial gauge are taken at 10kN intervals until the specimen fails. Figures.11 and 12 show the test setup with the cylinder sample and failed cylinder pattern. The observed load and deformation values are used to generate stress-strain curves.

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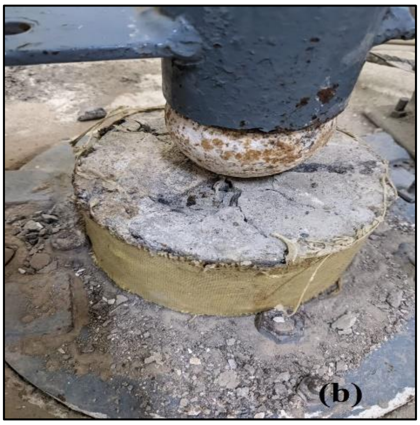
Fig.11 Test Setup for Modulus of Elasticity

Fig.12 Failure mode of CC+2L Cylinder specimen

3.4 Impact resistance:

ACI 544.IR-96 was used to measure impact resistance on specimens with dimensions of 152.4 mm in diameter and 63.5 mm in thickness.

Fig.13 Impact test setup



a) Initial Crack   b) Final crack

4.Results and discussion

The mechanical performance was investigated using compression, splitting tensile, flexure, modulus of elasticity, and impact tests. Results are reported and discussed.

4.1 Test results for Compressive strength:

The results of the compressive strengths for the conventional (without wrapping), single-wrapped, and double-wrapped specimens are shown in Table 4.

Table.4 Results of Average Compressive Strength

Specimen ID	Average compressive strength in (N/mm^2)	
	7 days	28 days
CC	25.19	33.20
CC+1L	36.47	45.62
CC+2L	48.78	58.04

The CC, CC+1L, and CC+2L specimens had average compressive strengths of 33.20 N/mm^2, 45.62 N/mm^2, and 58.04 N/mm^2 at 28 days, respectively, according to the above data. For single and double layer configurations, the compressive strength of concrete cubes contained by bidirectional AFRP mat improved by

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37.30% and 74.80%, respectively. The compressive strength of the various specimens are graphically compared in Fig.14.

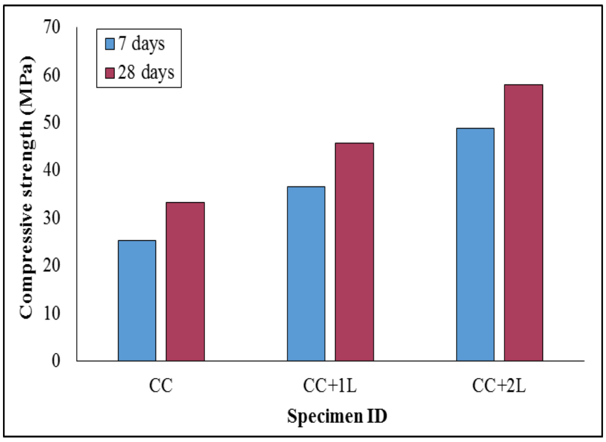

Fig.14 Compressive strength of various specimens

4.2 Test results for splitting tensile strength:

The results of the split tensile strength for the conventional (without wrapping), single-wrapped, and double-wrapped specimens are shown in Table 5.

Table.5 Results of Average splitting tensile strength

Specimen ID	Average Split tensile strength (N/mm^2)
CC	4.10
CC+1L	6.26
CC+2L	8.14

The CC, CC+1L, and CC+2L specimens' average Split strengths at 28 days, as shown in the above table, were 4.10 N/mm^2, 6.26 N/mm^2, and 8.14 N/mm^2, respectively. For single and double layer confinement, the split tensile strength of concrete cylinders rose by 52.60% and 98.53%, respectively. Fig.15 shows a visual comparison of the split tensile strengths of the various specimens.

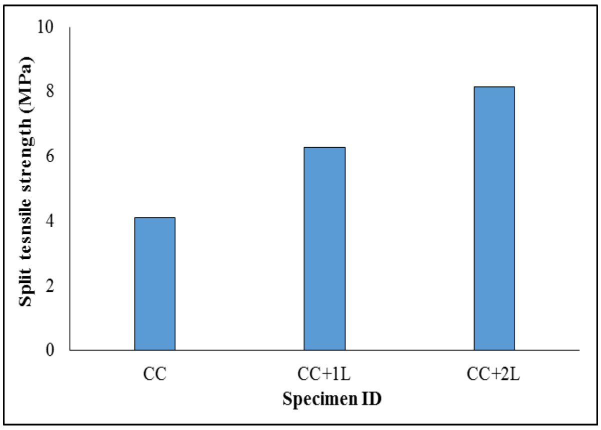

Fig.15 Split tensile strength of various specimens

4.3 Test results for flexural strength:

The results of the flexural strength for the conventional (without wrapping), single-wrapped, and double-wrapped specimens are shown in Table 6.

Table.6 Results of Average flexural strength

Specimen ID	Average flexural strength (N/mm^2)
CC	4.30
CC+1L	6.65
CC+2L	8.44

The CC, CC+1L, and CC+2L specimens' average flexural strengths at 28 days were, in accordance with the above table, 4.30 N/mm^2, 6.65 N/mm^2, and 8.44 N/mm^2, respectively. In Fig.16, the flexure strengths of the different specimens are graphically compared.

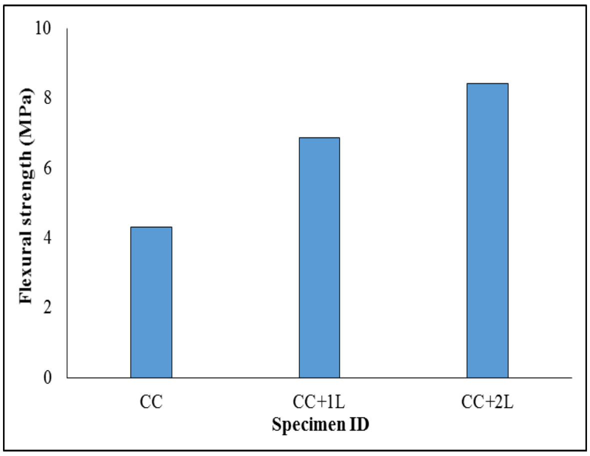

Fig.16 Flexural strength of various specimens

4.4 Test result for Modulus of elasticity:

The results of the modulus of elasticity for the conventional (without wrapping), single-wrapped, and double-wrapped specimens are shown in Table 7.

Table.7 Results of Modulus of elasticity

Specimen ID	Modulus of Elasticity x 10^4 at 28days in (Gpa)
CC	21.16
CC+1L	41.25
CC+2L	44.55

Cracks are delayed by bidirectional AFRP mats. The elastic modulus was calculated in this study by taking the slope of the stress-strain curve at 40% of the maximum stress. The CC specimens failed brittle, whereas the CC+1L and CC+2L specimens failed ductile. Fig.17 shows the stress-strain curves for various specimens. The ductility increases by CC+2L when confined by bidirectional AFRP mats. Maximum stress, however, was

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observed in CC+2L. The elastic modulus of concrete cylinder confined by bidirectional AFRP mat increased by 94.00% and 110.53% for single and double layer, respectively.

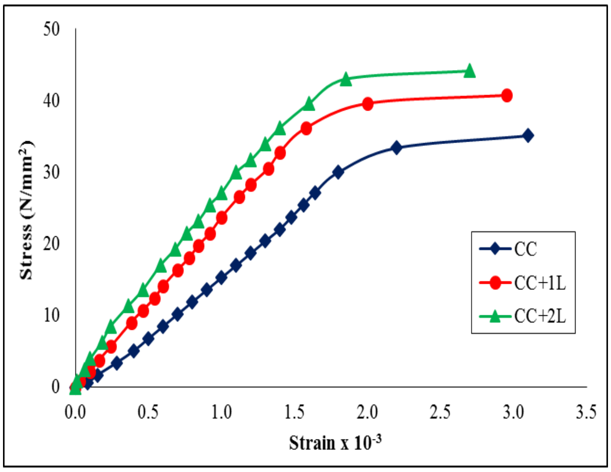

Fig.17 Stress-strain curve for various specimens

4.5 Test result for Impact resistance:

The results of the Impact resistance for the conventional (without wrapping), single-wrapped, and double-wrapped specimens are shown in Table 8. The number of blows was used to calculate impact energy (one blow has 19.89 Nm or Joules). At 28 days, the initial and final cracks of a CC specimen

Table.8 Results of Impact resistance

SI.NO	Specimen ID	Initial crack		Final crack	
		No.of blows	Impact energy (Nm)	No.of blows	Impact energy (Nm)
1	CC	12	238.68	20	397.80
2	CC+1L	20	388.35	32	575.62
3	CC+2L	28	517.14	46	756.20

the initial and final cracks of a CC specimen were 238.68 (12 blows) and 397.8 Nm (20 blows), and for CC+1L and CC+2L specimens, the initial crack started at an energy of 388.35 (20 blows), 517.14 Nm (28 blows), and the final crack started at an energy of 575.62 (32 blows), 756.20 Nm (46 blows), respectively. According to these experimental findings, concrete specimens confined with AFRP composites have a greater impact energy than unconfined specimens, and specimens with double layers have a higher impact energy than specimens with single layers. For single and double layer confinement, the impact energy of concrete specimens rose by 44.70% and 90.10%, respectively. In Fig. 18, the impact resistance of the various specimens is visually compared.

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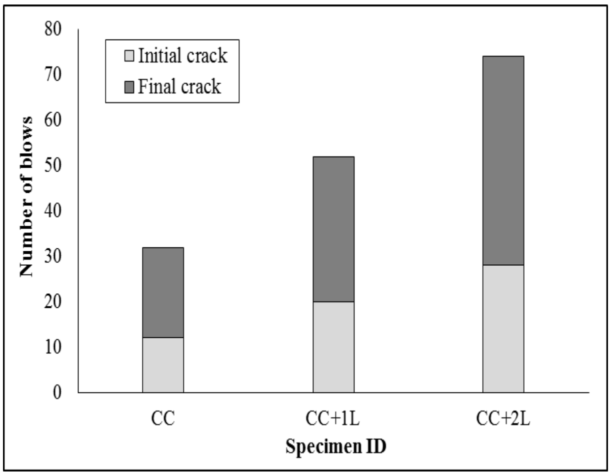

Fig.18 Impact resistance of various specimens

5. Conclusion

By testing concrete specimens with and without AFRP confinement for compression, split tensile, flexural strength, elastic modulus, and impact resistance, the capability of AFRP was investigated. The findings of the experiments have led to the following conclusions:

- At 28 days, concrete that had been double wrapped in aramid fibres had better compression, splitting tensile, rupture modulus, elastic modulus, and impact resistance than conventional specimens by 74.80%, 98.53%, 95.27%, and 110.53%.
- The specimen wrapped with double layers has better strength than the specimen wrapped with single layers.
- The findings of the experiment demonstrated that AFRP-confined specimens were stronger than unconfined ones.
- As a result, FRP enclosure is most beneficial when retrofitting existing structures, such as RC and steel bridges, fly-overs, and in particular offshore structures, to reinforce them and guard against supplemental corrosion.
- AFRP may be used to strengthen and retrofit structures more successfully than traditional techniques since it is less costly than CFRP and has a greater modulus.

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