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Effectiveness of Various Methods of Jacketing for RC Beams

Sachin S. Raval[a], Urmil V. Dave[b]*

[a]*Assistant Professor , Department of Civil Engineering, Gandhinagar Institute of Technology, Gandhinagar 382721, India*
[b]*Professor , Department of Civil Engineering, Institute of Technology, Nirma University, Ahmedabad 382481, India*

Abstract

Strengthening of Reinforced Concrete (RC) beams is required due to design errors, deficient concrete production, bad execution processes, damage due to earthquake, accidents such as collisions, fire, explosions and situations involving changes in the functionality of the structure etc. Jacketing has been considered as one of the important methods for strengthening and repairing of RC beams. Jacketing of RC beams is done by enlarging the existing cross section with a new layer of concrete that is reinforced with both longitudinal and transverse reinforcement. In the present investigation, 10 beams of size 150 mm x 300 mm x 2100 mm are cast. 4 RC beams are prepared with smooth surface; on the other hand, 4 RC beams are prepared with chipped surface. Remaining two RC beams are considered as control beams. Eight RC beams have been jacketed using additional reinforcement for 60 mm thickness all-round. Four different methods have been employed for jacketing of RC beams. These methods include use of dowel connectors and micro-concrete, bonding agent and micro-concrete, combined use of dowel connectors, bonding agent and micro-concrete and use of only micro-concrete without dowel connectors and bonding agent, respectively. After 28 days of curing period and completion of jacketing process, these RC beams are tested under two point loading system. Measurements taken during testing were central displacement, failure load, and failure mode & crack patterns. Effectiveness of each type of jacketing methodology on smooth surface was compared with chipped surface for the RC beams. As an outcome of investigation, for smooth surface RC beam, superior performance was observed for the beam jacketed using combined dowel connectors and bonding agent with micro-concrete. For chipped surface RC beams, superior performance was observed for the beam jacketed using only micro-concrete and without use of dowel connectors and bonding agent.

Keywords: Jacketing, Smooth/Chipped surface, Dowel Connectors, Bonding Agent, Micro-concrete

Nomenclature

C	Control RC beam
QSD	RC beam with smooth surface jacketed using dowel connectors and micro-concrete
QSB	RC beam with smooth surface jacketed using bonding agent and micro-concrete
QSDB	RC beam with smooth surface jacketed using dowel connectors, bonding agent and micro-concrete
QSM	RC beam with smooth surface jacketed using only micro-concrete
QPD	RC beam with chipped surface jacketed using dowel connectors and micro-concrete
QPB	RC beam with chipped surface jacketed using bonding agent and micro-concrete
QPDB	RC beam with chipped surface jacketed using dowel connectors, bonding agent and micro-concrete
QPM	RC beams with chipped surface jacketed using only micro-concrete

* Corresponding author. Tel.:+91-2717-241911-15; fax: +91-2717-241917
E-mail address: sachin.raval88@gmail.com, urmil.dave@nirmauni.ac.in.

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1. Introduction

It is known that many buildings designed based on old codes were susceptible to serious damage during an earthquake. Old buildings have been structurally designed for much lesser seismic actions when compared to buildings that are designed today. Structural rehabilitation brings a structure or a structural member to a specified safety and performance level. Depending on state of a structure or structural members, rehabilitation can be divided into two categories: Repair and Strengthening. Repair is the rehabilitation of a damaged structure or a structural member, on the other hand strengthening is upgrading an undamaged structure or the member. One popular solution to the problem of strengthening old reinforced concrete (RC) structures is to place jackets around the structural elements. Jackets have been constructed using concrete jacketing, steel jacketing, precast concrete jacketing, external prestressing and FRP wrapping.

Different researchers have employed various methods of jacketing for reinforced concrete (RC) elements [1-5]. The jacketing of RC beams was done by using additional reinforcement and for connection between lateral and longitudinal reinforcement bar of old and new beam Z bars were introduced before concreting. Better mechanical behavior of the jacketed RC beams was observed as compared to that for ordinary RC beams of the same dimensions, despite the fact that the core parts of the jacketed RC beams were damaged [6]. Surface preparation plays important role before jacketing for superior performance of RC jacketed beam. Difference in the behavior of jacketed beams was observed whose interfaces have been ‘‘fully roughened’’ or ‘‘partially roughened’’ [7].

Very less amount of information is available in the literature regarding the requirement of the surface of the RC beam during execution of the jacketing process. Also, it is essential to find more information on behavior of RC beams when jacketed using different methods of jacketing in order to avail overall enhancement of its performance. Therefore, ten RC beams of 150 mm x 300 mm x 2100 mm have been cast in the present investigation. The surface of four beams is kept as cast and the surface of other four beams is chipped up to 10-15 mm all around the beams. Two beams have been considered as the control beam. Four different methods have been employed for jacketing of the RC beams. These methods include use of dowel connectors and micro-concrete, bonding agent and micro-concrete, combined use of dowel connectors & bonding agent and micro-concrete and only the use of micro-concrete. All four methods have been employed for jacketing of the RC beams with the smooth surface as well as the chipped surface [8].

2. Experimental Programme

2.1. Theoretical consideration

Design of control beam has been conducted based on provisions of IS 456 [9]. Beams are designed as under-reinforced section. 20 mm cover was provided. The grade of concrete for the beam is assumed as M15. It is further assumed that the beam is required to be strengthened by jacketing considering its structure design made before 30 years using codal practices available at that time. Fig.1 shows reinforcement details for control RC beam.

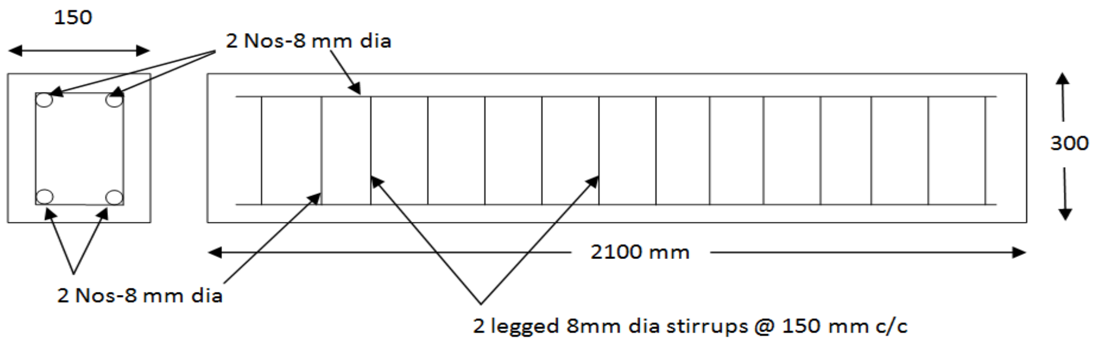

Fig. 1. Reinforcement Details of Control Beam

The RC beams are jacketed after 28 days of curing period. The dimensions of the jacketed beam is considered as 270 mm x 420 mm x 2100 mm. Thickness of jacketing is considered based on assumption of 20 mm clear cover and 6 mm diameter stirrups to be provided. For making new concrete easily flowable through section of jacketing, projection from inner beam surface to the face of new reinforcement stirrups is assumed as 40 mm. Minimum tension reinforcement is provided for jacketed beam. Therefore, total jacketing thickness is kept 60 mm all around. Fig.2 shows stress diagram for the jacketed beam.

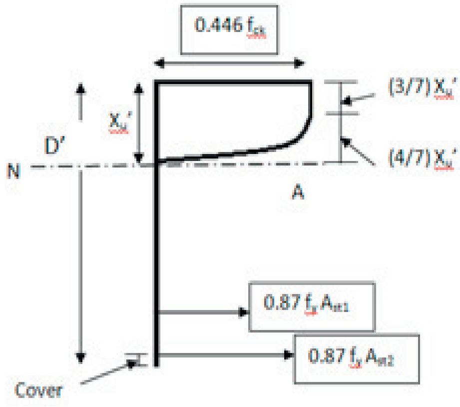

Fig. 2. Stress Diagram for Jacketed Section

Actual depth of neutral axis X_u' for the jacketed section was calculated using (1)

$$[0.446 \times f_{ck}' \times b' \times (3/7) \times X_u'] + (2/3) \times [0.446 \times f_{ck}' \times b' \times (3/7) \times X_u'] = (0.87 \times f_y \times A_{st1}) \times (0.87 \times f_y \times A_{st2}) \quad (1)$$

Putting value of X_u' from (1) into (2) M_u is calculated.

$$M_u = (0.36 \times \frac{Xu'}{d'})[1 - 0.42 \times \frac{Xu'}{d'}] \times b' \times d'^2 \times f_{ck}' \quad (2)$$

The ultimate single load to be countered by the simply supported beam is evaluated using (3)

$$P/2 = M_u/a \quad (3)$$

Where, M_u is ultimate mid-span bending moment, P is analytical failure load, b' is width of jacketed beam, d' is effective depth of jacketed beam, f_{ck}' is strength of micro-concrete for 28 days for jacketed beam, f_y is grade of steel for jacketed beam, A_{st1} is area of tension reinforcement for the control beam, A_{st2} is area of tension reinforcement for the jacketed beam and a is distance between supports and point load shown in Fig. 3, respectively.

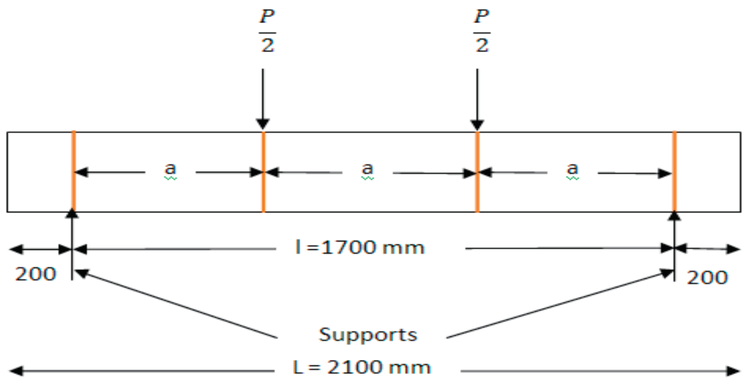

Fig. 3. Distance between Support and Point Load

Fig.4 shows reinforcement details for jacketed RC beam.

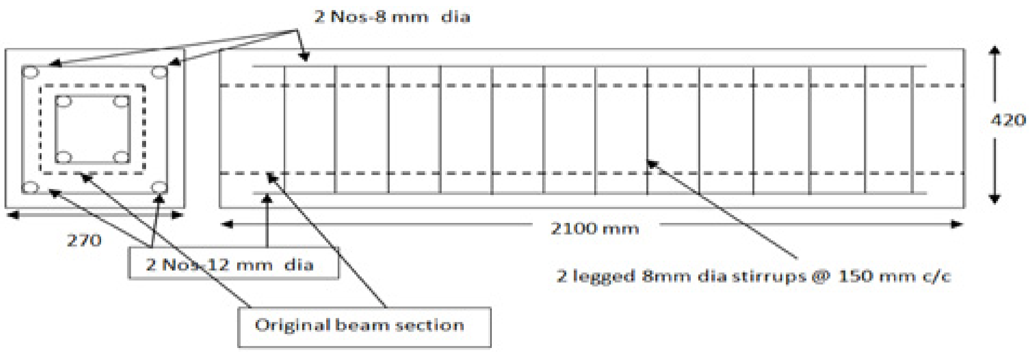

Fig. 4. Reinforcement Detail for Jacketed Beam

2.2. Material Properties

Micro-concrete has been used for jacketing of all the beams. It is Portland-cement-based, shrinkage-compensated, construction grout. It does not rust, bleed or harm metals on contact. Table 1 shows typical properties of micro-concrete provided by the manufacturer [10].

Table 1. Typical properties of micro-concrete

Aspect	Free flow grew powder
W/P ratio by weight	0.17 (Flowable)
Mix Density(Flowable)	2100 kg/m^3
Compressive Strength (70 mm cube)	15 MPa at 1 day
	25 MPa at 3 day
	35 MPa at 7 day
	50 MPa at 28 day

Bonding agent is a two component epoxy system. Base & curing agent give thick non porous and highly resistant films with excellent adhesion were used as bonding agent for the beam jacketing. Table 2 shows typical properties of the bonding agent provided by the manufacturer [11].

Table 2. Typical properties of bonding agent

System	Two Components
Mixing Ratio	2:1 Base and Curing Agent
Coverage	4 to 6 Sq.mt./kg
Pot Life	30 to 35 minutes
Application	By Brush, injection
Cleaning	Thinner
Storage and Shelf life	12 to 18 months in tight container

8mm diameter HYSD bars are used as dowel connectors. The dowel connectors of 120mm x 50 mm are used. The dowel connectors are fixed in concrete using the bonding chemical. Fig. 5 shows dimensions for dowel connectors.

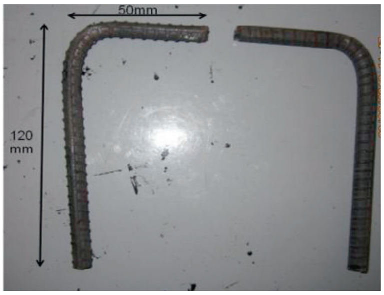

Fig. 5. Dimensions for dowel connectors

2.3. Jacketing methods

Method I Jacketing of beams using dowel connectors and micro-concrete: Dimension of the dowel connectors selected is 120 mm x 50 mm. These connectors are fixed on the surface of the beam up to 80 mm. Therefore, out of 120 mm length, 80mm length of the connectors is adjusted inside the concrete and the remaining 40 mm length is extended up to stirrups for the jacketed beam. Dowel connectors are fixed on 150 mm width side and 300 mm depth side surfaces of the beam throughout the span of 2100 mm at 300 mm c/c spacing in staggered pattern using bonding chemical as shown in Fig. 6.

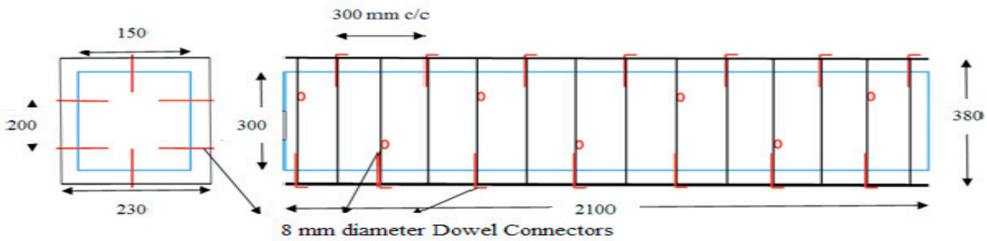

Fig. 6. Location of dowel connectors on beam

Method II Jacketing of beams with bonding agent and micro-concrete: The bonding agent is applied on the beam using brush on its surface. After application of the bonding agent, the jacketing is done. Fig. 7(a) shows application of dowel connectors on the beam with smooth surface. Fig. 7(b) presents application of the bonding agent on the beam with chipped surface.

(a) (b)

Fig. 7. (a) Application of dowel connectors on beam with smooth surface and (b) Application of bonding agent on beam with chipped surface

Method III Jacketing of beams with combined use of dowel connectors, bonding agent and micro-concrete: First the dowel connectors are fixed on the concrete surface of the beam. After that the bonding agent is applied on the beam surface. Jacketing of the beam with smooth surface using dowel connectors, bonding agent and micro-concrete is shown in Fig. 8 (a).

Method IV Jacketing of beams using micro-concrete without dowel connectors and bonding agent, only micro-concrete has been used. The jacketing of the beam with chipped surface without using dowel connectors, bonding agent and using only micro-concrete is shown in Fig. 8 (b).

(a) (b)

Fig. 8. (a) Dowel connectors and bonding agent applied on beam with smooth surface and (b) Beam with chipped Surface to be micro-concreted only

2.4. Testing setup

All RC beams are tested using loading frame facilities of the laboratory. The beams are tested in flexure under two-point loading system. The two-point load system is believed to be creating a portion of pure bending along span of the beams which allows smooth transfer of load, application of constant moment and occurrence of their failure in the said zone. Hence, the two-point loading pattern is preferred as compared to that of single-point load system in the present investigation. The beam is placed simply supported on either side by steel column support. The load is applied using hydraulic jack of 500 kN capacity. The load is transferred from the jack to steel I beam and on to the steel rod. The dial gauge is used to measure the deflection at the centre of the beam. The dial gauge is kept in such a way so that it remains in contact with the bottom side of the tension surface of the beam. Details of test setup are presented in Fig. 9.

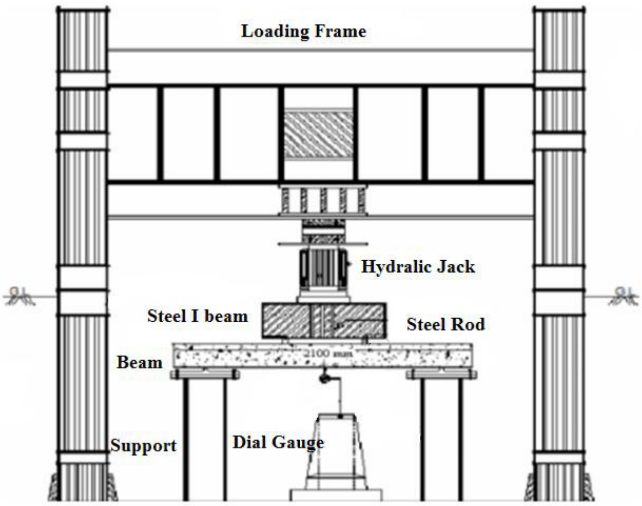

Fig.9 Details of test setup for beam

3. Results and discussion

3.1. Load Carrying Capacity

Load carrying capacity of the jacketed beams is ranging from 260 kN to 300 kN. Experimental load carrying capacity for jacketed beams is presented in Fig. 10.

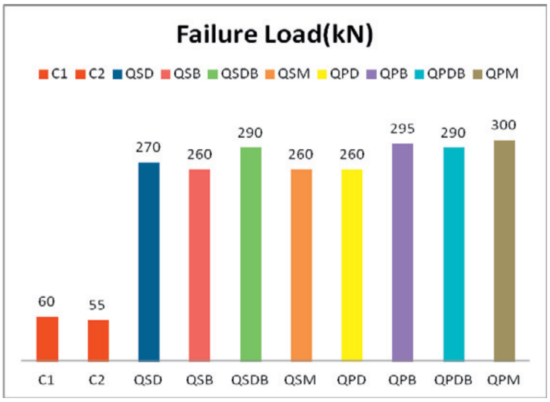

Fig.10 Load Carrying Capacity for Strengthened Beams

Percentage increment in failure load is observed as 340.68% to 408.48% for jacketed beams as compared to that of the control beams in general. 3.84% to 11.53% increment in failure load is observed amongst all jacketed beams with smooth surface. Percentage increment in failure load is ranging from 1.69% to 15.38% amongst all jacketed beams with chipped surface.

For RC beams with smooth surface, increase in failure load of 357.63%, 340.68%, 391.53% and 340.68% has been observed for QSD, QSB, QSDB and QSM, respectively as compared to that of the control beams. Increase in failure load of 6.89%, 10.34% and 10.34% has been observed for beam QSDB beam as compared to that of the QSD, QSB and QSM, respectively. Thus, higher load carrying capacity has been observed for beam QSDB amongst all smooth surface jacketed beams. This suggests that combined use of dowel connectors and bonding agent with micro-concrete is more effective technique as compared to other jacketing techniques used for beams with smooth surface.

For beams with chipped surface, increase in failure load of 340.68%, 400%, 391.53% and 408.48% has been observed for beams QPD, QPB, QPDB and QPM, respectively as compared to that of the control beam. Increase in failure load of 13.33, 1.66% and 3.33% has been observed for the beam QPM as compared to that of beams QPD, QPB and QPDB, respectively. Higher load carrying capacity has been observed for beam QPM amongst all chipped surface jacketed beam. Thus, use of only micro-concrete without using dowel connectors and bonding agent is more effective jacketing technique as compared to other jacketing techniques used for beams with chipped surface.

Comparing performance of smooth surface and chipped surface beams, reduction in failure load of 3.7% has been observed for beam QPD as compared to that for beam QSD. Increment in failure load of 13.46% has been observed for beam QPB as compared to that for beam QSB. Failure load carrying capacity of beam QPDB and beam QSDB has been observed at par. Increment in failure load of 15.38% has been observed for beam QPM as compared to that for beam QSM. Thus, it is evident from above comparison that the implementation of various jacketing methods has proved more beneficial for RC beams with chipped surface as compared to that for beams with smooth surface.

3.2. Displacement

Displacement is measured at mid span for the jacketed beams at interval of every 10 kN load till the failure of the beams. Load verses displacement relationship for jacketed beams at mid span is presented in Fig. 11.

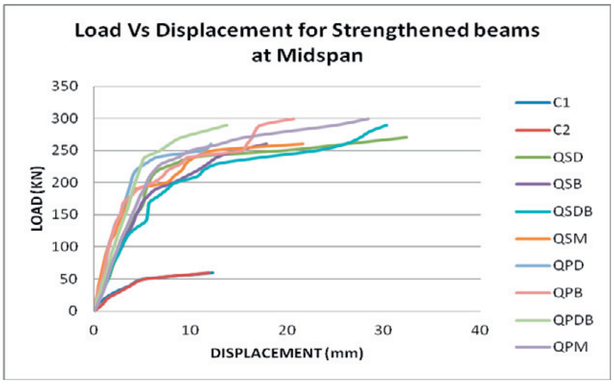

Fig.11 Load-Displacement relationship for Jacketed Beams

Percentage increment in displacement at mid span at failure load is ranging from 6.78% to 81.34% amongst all smooth surface jacketed beams. On the other hand, percentage increment in displacement at mid span at failure load is observed from 13.36% to 134.24% amongst all chipped surface jacketed beams.

For RC beams with smooth surface, higher displacement at mid span has been observed for the beam QSDB as compared to that for beams QSD, QSB and QSM in general. Thus, higher displacement of beam QSDB has been observed amongst all smooth surface jacketed beams due to higher failure load. This suggests that combined use of dowel connectors and bonding agent with micro-concrete is more effective jacketing technique as compared to other techniques for beams with smooth surface.

For RC beams with chipped surface, higher displacement at mid span has been observed for the beam QPM as compared to that for beams QPD, QPB and QPDB in general. Thus, higher displacement of the beam the QPM has been observed amongst all chipped surface jacketed beams due to higher failure load. Therefore, use of only micro-concrete without using dowel connectors and bonding agent is more effective jacketing technique as compared to other techniques used for beams with chipped surface.

Comparing performance of smooth surface and chipped surface beams, at par displacement at mid span has been observed for beam QPD & beam QSD as well as for beam QPDB & beam QSDB. Higher displacement at mid span has been observed for beam QPB as compared to that for beam QSB as well as for beam QPM as compared to that for beam QSM. Thus, it is clear from this comparison that the implementation of various jacketing methods has proved more beneficial for RC beams with chipped surface as compared to that for beams with smooth surface.

3.3. Failure Mode and Crake Pattern

Initial cracks are observed between 20 kN to 30 kN load for control beams. Cracks are observed in pure bending portion for the control beam. Cracks are seen in middle third portion for the control beams on majority occasions. Crake pattern for control beam is as shown in Fig. 12.

Fig. 12 Crake Pattern for Control beam

Initial cracks are observed between 150 kN to 210 kN load for jacketed beams. Cracks are observed in pure bending portion for the jacketed beam. Most of the cracks are seen in middle third portion for jacketed beams on majority occasions. Continuous cracks are observed on bottom face for the jacketed beams. At the time of failure, the cracks are extended up to top bonding plane of old to new concrete for the jacketed beams. Crack widths in range of 5 mm to 10 mm have been observed for the jacketed beams with smooth and with chipped surfaces, respectively. Maximum crack widths in range of 8 mm to 10 mm have been observed for beams QSDB and QPM at the failure load. Crack patterns for beams QSD and QSB are shown in Fig. 13, respectively. Fig. 14 presents crack patterns for beams QSDB and QSM, respectively. Crack pattern for beams QPD and QPB are shown in Fig. 15, respectively. Fig. 16 gives the crack pattern for beams QPDB and QPM, respectively.

(a) (b)

Fig. 13 (a) Crake Pattern for Beam QSD (b) Crake Pattern for Beam QSB

(a) (b)

Fig .14 (a) Crake Pattern for Beam QSDB (b) Crake Pattern for Beam QSM

(a) (b)

Fig .15 (a) Crake Pattern for Beam QPD (b) Crake Pattern for Beam QPB

(a) (b)

Fig .16 (a) Crake Pattern for Beam QPDB (b) Crake Pattern for Beam QPM

4. Conclusions

Following concluding remarks have been made on basis of the work conducted:

- The experimental results clearly demonstrated that jacketing can enhance structural properties for the RC beams.
- For smooth surface jacketed beams, highest load carrying capacity has been observed using jacketing technique of combined dowel connectors and bonding agent with micro-concrete as compared to other jacketing techniques used.
- Higher displacement at higher load has been observed for smooth surface jacketed beams using jacketing technique of combined dowel connectors and bonding agent with micro-concrete as compared to other jacketing techniques used.
- For chipped surface jacketed beams, highest load carrying capacity has been observed with jacketing technique of using only micro-concrete as compared to other jacketing techniques used.
- Higher displacement at higher load has been observed for chipped surface jacketed beams with jacketing technique of using only micro-concrete as compared to other jacketing techniques used.
- Implementation of various jacketing methods has proved more beneficial for RC beams with chipped surface as compared to that for beams with smooth surface.

Thus, it can be observed from above study that jacketing of RC beams may always be employed as one of the very promising technique for enhancing the performance of the beams in case of change in use of the structure. Use of dowel connectors & bonding agent with micro-concrete as well use of micro-concrete alone have emerged as better techniques of jacketing RC beams as compared to other jacketing alternatives employed in the present investigation. For better employment of the jacketing techniques, chipping of the surface is is strongly recommended for the RC beams.

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