SHEAR STRENGTHENING OF RC BEAMS WITH HIGH PERFORMANCE JACKET




Serena Mostosi **Alberto Meda** **Paolo Riva** **Stefano Maringoni**

Abstract

The possibility of strengthening RC elements for increasing the bearing capacity under shear actions is an important issue in the retrofitting field. In RC existing structures, made in the '60s and '70s, the shear reinforcement is often not sufficient to satisfy the prescription of current codes. Hence, in the xc0020retrofitting of these structures it is often necessary to increase the shear bearing capacity.

A possible use of low thickness high performance jackets for shear strengthening purposes is analyzed herein. The jackets are made with a high performance fiber reinforced concrete, with or without an additional 2mm diameter steel-wire mesh. Two different high performance concrete are investigated: a concrete with a self leveling rheology, that can be cast with reduced thickness, and a thixotropic material that can be placed without molds.

The different jackets were used for reinforcing 3m long beams. The elements were tested up to failure and the comparison between the obtained results is presented herein.

Keywords: Shear strengthening, High performance fiber, Reinforced concrete.

1 Introduction

The interest for strengthening and repair RC structures has increased in the last few years. Several existing structures were built referring to old codes and they do not satisfy the prescription of new codes. Furthermore, the request of an increase of the bearing capacity of the existing structures due

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to an increase of the live loads is a typical issue that designers have to consider. In this field, the possibility of increasing the bearing capacity of RC elements under shear actions is of great interest, due to a high probability of having structures lacking in shear reinforcement, typically when build in the '60 and '70.

Traditional strengthening techniques are usually based on the application of RC jackets characterized by a high thickness, higher than 60-70 mm (Fib Bulletin 24, 2003), which can excessively increase the section geometry. The possibility of remarkably reducing the jacket thickness in this kind of intervention has been recently investigated by using high performance fiber reinforced concrete jackets (Martinola et al., 2010; Habel et al. 2007; Alaee and Karihaloo, 2003). The use of high performance fiber reinforced concrete jacket combined with high performance steel mesh has also been investigated (Marini and Meda 2009; Kuneida et al. 2010).

In this research, the attention has been paid to the effect of high performance jackets with reduced thickness on the increase of the bearing capacity under shear actions. The use of two kinds of high performance fiber reinforced concrete has been considered: a material having an almost self levelling rheology, able to fill very thin jackets, and a new developed thixotropic material that can be used for easily create the jacket.

Full-scale tests on 2.85 m long beams have been performed under a four point bending configuration in order to compare the performances of the proposed solutions.

2 Specimen description and experimental set-up

The beam specimens have a length of 2.85 m and e 200x450 mm section, as shown in **Fig. 1**. The beams have been reinforced with longitudinal bottom rebars only, made with 4 steel bars having diameter equal to 20 mm, with a 30 mm net cover. In order to avoid bond slip at the beam end, the rebars were welded to steel plates. The reinforcement ratio results equal to 1.50%. The beams were designed in order to have a shear failure under the chosen load configuration. Neither stirrups nor inclined reinforcement are present.

The beams were cast with a concrete, having an average compressive strength, measured on 150 mm side cubes, equal to 32.63 N/mm^2. According to Eurocode 2 the concrete can be classified as a C20/25 material. Regarding the reinforcement, the steel rebars exhibited an average yielding strength equal to 517.94 N/mm^2 and an average maximum strength equal to 616.21 N/mm^2

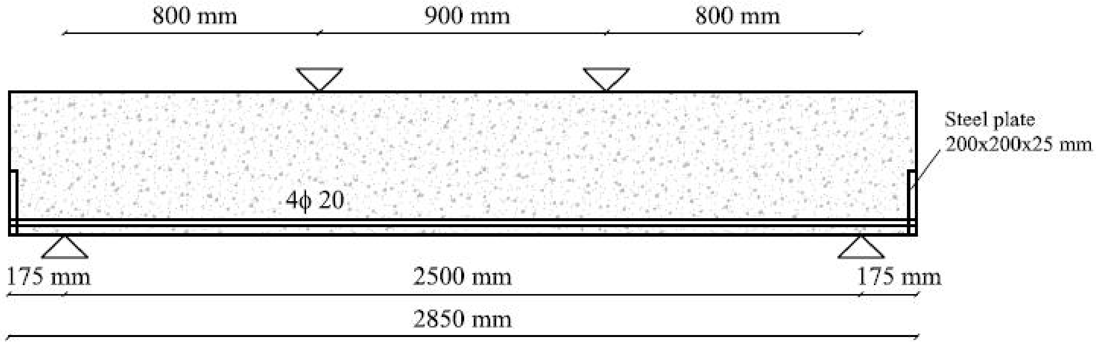


Fig. 1 Beam geometry

One beam was used as reference specimen while the other three beams were strengthened by applying a high performance jacket (**Tab. 1**). Firstly the beam were sandblasted in order to reach a roughness of about 1 mm, able to ensure a perfect bond between the existing concrete and the applied high performance concrete. This technique has been demonstrated effective in previous researches (Martinola et al. 2010). Eventually, the jackets were applied: for the self levelling material moulds were used while the thixotropic material was spread directly on the beam surface (**Fig. 2**). Within the thickness of the jacket was placed a wire mesh. This mesh is made of 2.05 mm diameter bent wires, assembled with a spacing of 25.4 mm. The results of the tensile test performed on single wires show a maximum strength equal to 550 N/mm^2.

Tab. 1 Specimen characteristics.

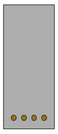
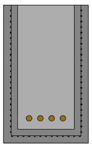
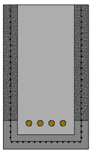
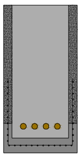
		Thickness	Material	Bond properties	Type Mesh
 Un-reinforced beam	Lower surface	No reinforced	–	–	–
	Lateral surfaces	No reinforced	–	–	
 Beam B	Lower surface	50 mm	self levelling	no primer	Welded wire mesh U bent
	Lateral surfaces	50 mm	self levelling	no primer	
 Beam D	Lower surface	50 mm	self levelling	no primer	Welded wire mesh U bent
	Lateral surfaces	50 mm	thixotropic	Epoxy primer	
 Beam E	Lower surface	50 mm	self levelling	no primer	Welded wire mesh U bent to a height of 20 cm on the lateral surfaces
	Lateral surfaces	30 mm	thixotropic	no primer	

Fig. 1 Sandblasted and jacketing application.

The beams were tested under a four point bending configuration, by adopting a steel reacting frame (**Fig. 3**). The load was applied by means of an electromechanical jack having a loading capacity of 1000 kN with a PID close loop control system. The test were conducted by imposing the displacement of the actuator with a constant speed equal to 0.01 mm/sec.

The beams were placed on roller steel supports (**Fig. 4**) with a span of 2.5 m. A steel beam was placed between the jacket and the specimen in order to apply the load in two points having a distance of 0.9 m. Thus the shear span ratio (i.e. ratio between the distance of the loading point respect to the support and the effective depth) resulted equal to 1.9.

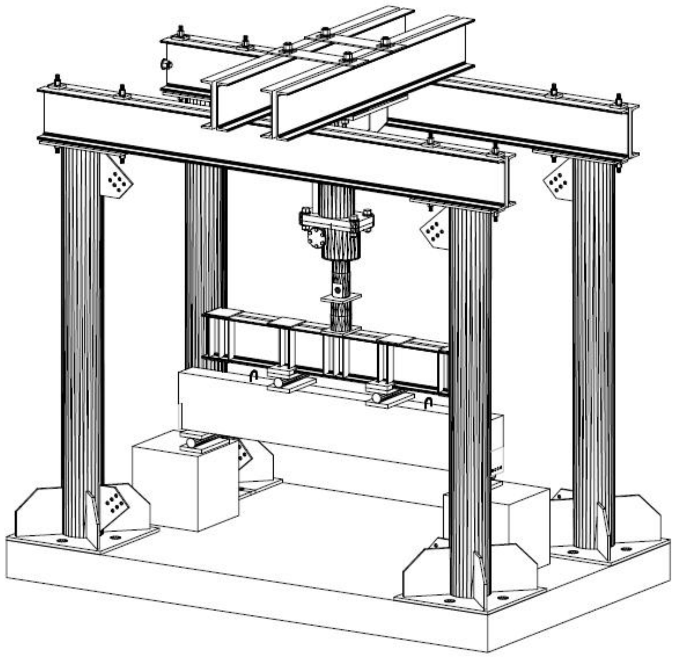


Fig. 2 Loading frame.

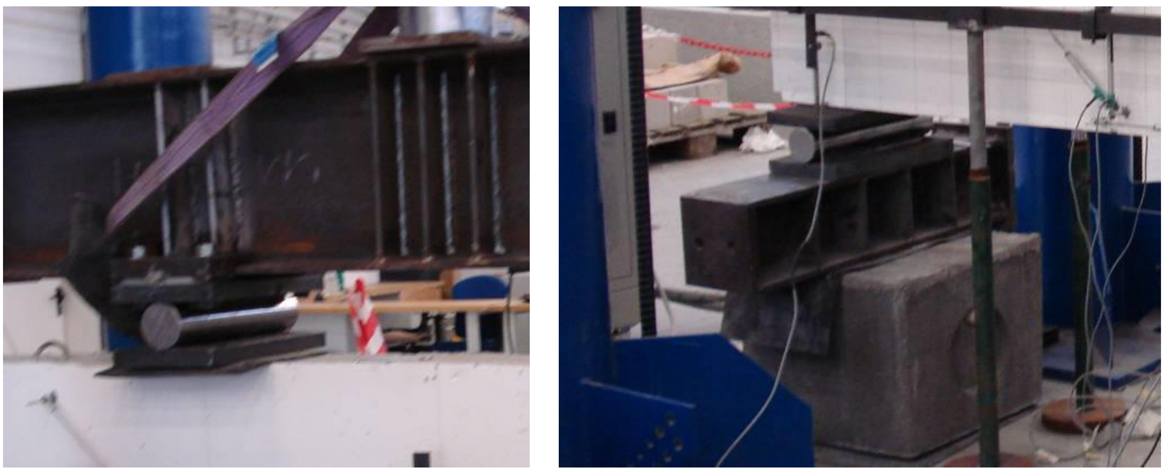


Fig. 3 Beam support and loading points.

In order to measure the beam deformations, potentiometric and LVDT transducers were used for monitoring the vertical displacement, the crack opening due to shear and bending and the supports displacement, as shown in **Fig. 5**. A 100 mm spaced grid has been drawn on the specimen surface in order to recorder the crack pattern by means of a high-resolution camera.

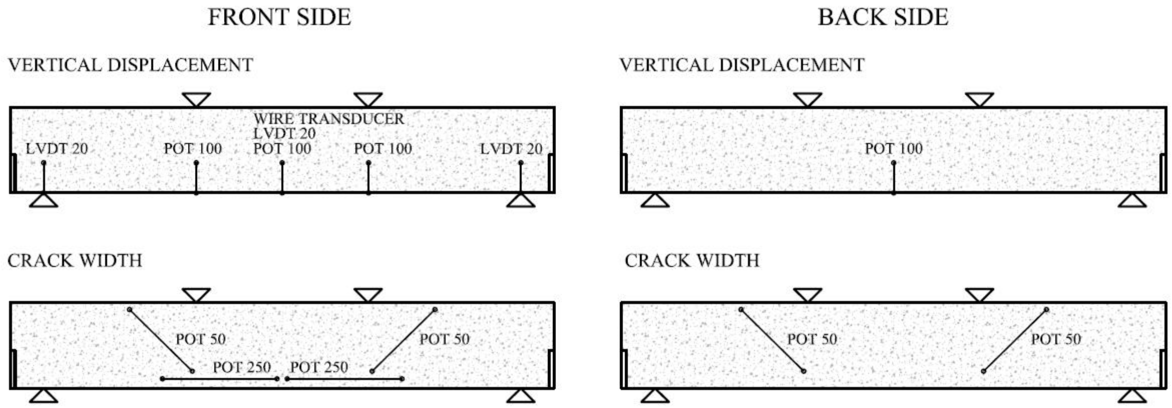


Fig. 4 Instrument devices.

3 Experimental results

3.1 Beam without HPFRC jacket

Firstly, the test on the RC beam without the HPFRC strengthening jacket has been carried out. **Fig. 6** shows the total applied load versus midspan displacement curve, as evaluated by considering the average of the signals on both sides and correcting the results by subtracting all support displacements. The beam shows a linear elastic behaviour up to a load of 50 kN, corresponding to the onset of the first vertical cracks in the zone between the two load points.

When the load reached a value of 200 kN a shear cracking developed. Shear cracks appeared at an angle of approx. 30 deg from the horizontal and they were located in the spans between load points ant supports (shear spans). The beginning of each cracking mode (vertical and shear cracks) is marked by a noticeable change of slope in the load displacement plot.

At 450 kN load one of the shear cracks quickly widened. Together with both a sudden drop of load and the closure of all other cracks.

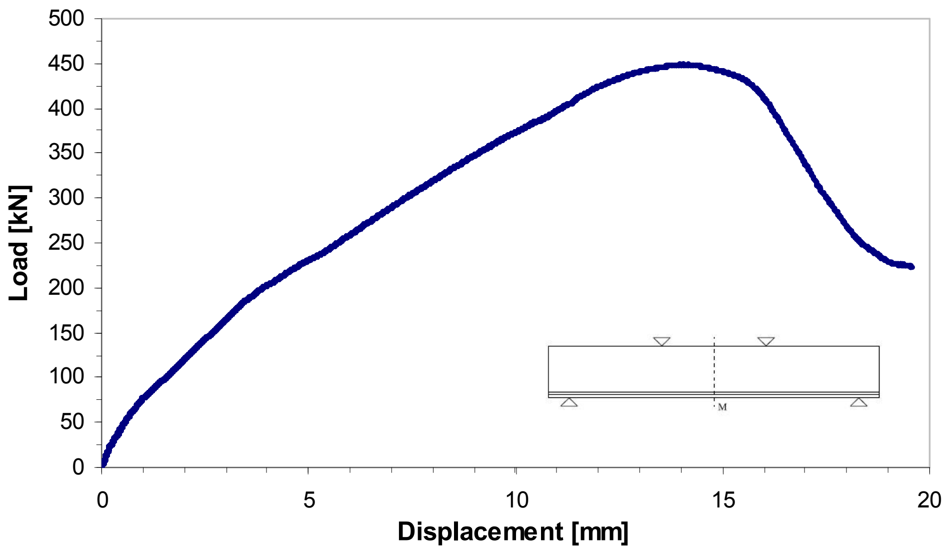


Fig. 5 Un-reinforced beam: curve of the load versus midspan displacemen

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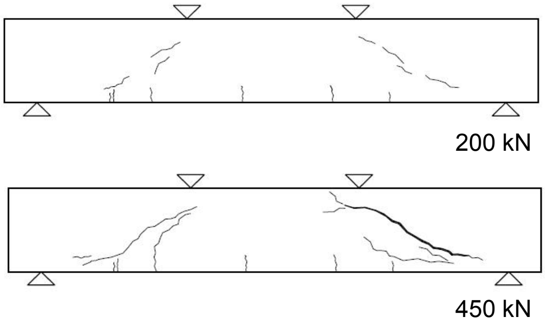

Fig. 6 Crack pattern evolution

Fig. 7 Crack pattern at failure

3.2 Beam with HPFRC jacket

The three beams strengthened with the HPFRC jacket exhibited a flexure failure. The behavior of the beams is shown in **Fig. 9**. The behaviour of the three beams with strengthening jacket is similar to each other.

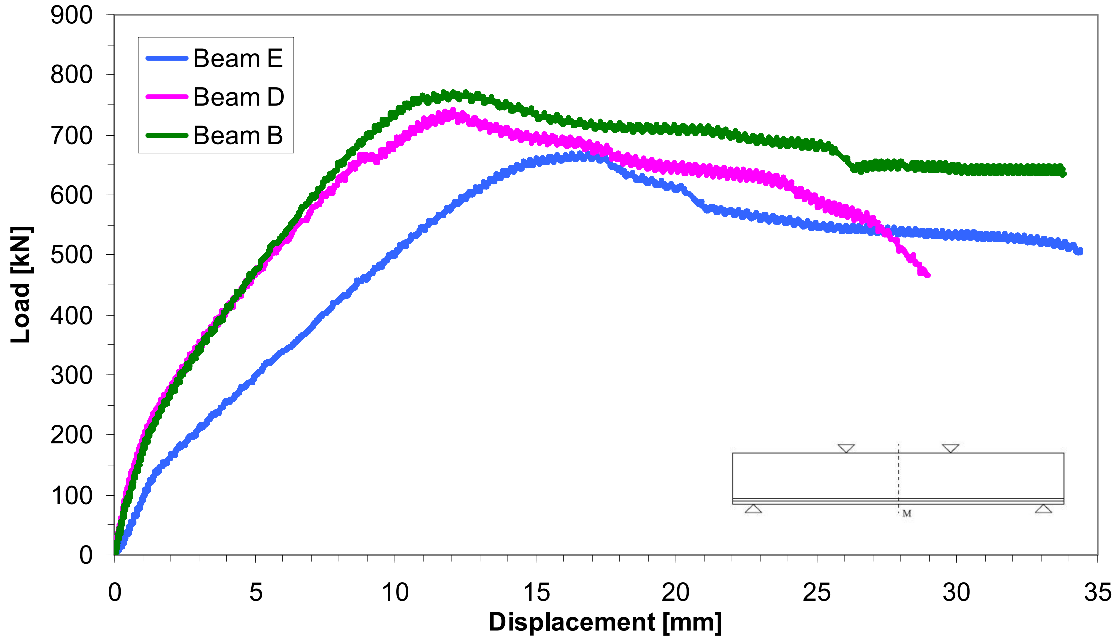

Fig. 8 Reinforced beams: curve of the load versus midspan displacemen

All beams behaved according to the same failure pattern. With increasing the load, a first vertical crack appeared in the central portion of the specimen; when this phenomenon took place, a slope change could always be observed in the load displacement curve. After the first cracking a few small vertical cracks developed in this portion between the two load points. Such cracks, with increasing load, propagated in depth and number also beyond the two point loads. Subsequently, shear cracks (inclined cracks) appeared at higher load in both shear spans.

Under maximal load, a macro vertical crack, located between the two point loads, determined the collapse of the specimen. After collapse, the load decreased and stabilized at a level equal to about 80% of maximum load. A significant further displacement could be performed until crushing of the concrete took place; at this point, the test was interrupted.

Load values and principal displacement measurements for all beams are reported in **Tab. 2**.

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Furthermore, beams D and E displayed cracks located along the joint between self-levelling and thixotropic material (see **Fig. 10**). Such cracks developed roughly at the same time as did shear cracks and were located mostly in the shear regions between load points and supports.

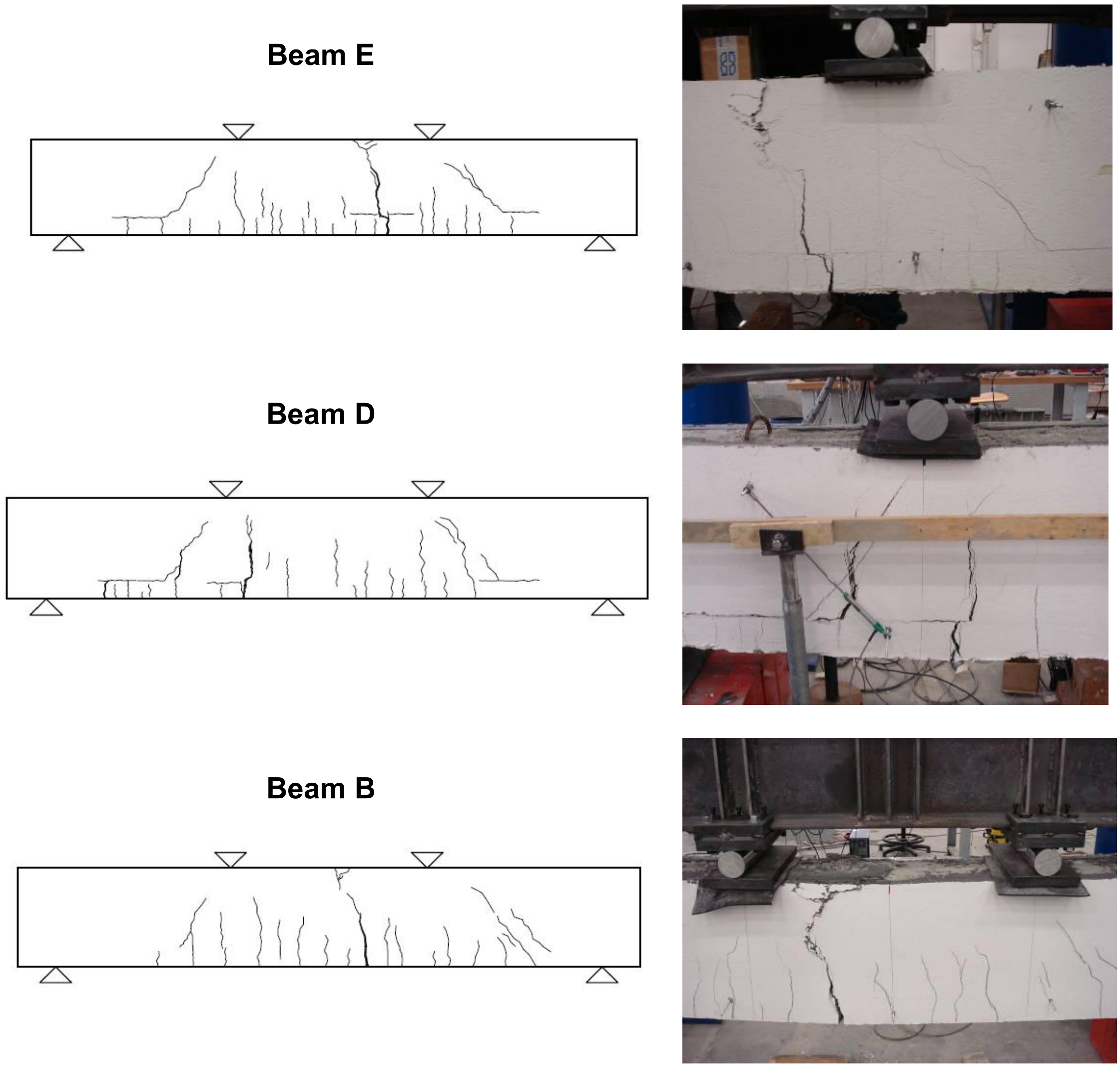

Fig. 9 Crack pattern at failure for the beam with HPFRC jacket

Tab. 2 Load and displacement achieved by experiment

Designation	Load first vertical crack	Load first shear crack	Maximum load	Midspan displacement at maximum load
	[kN]	[kN]	[kN]	[mm]
Beam E	135	290	670	16.9
Beam D	150	350	741	12.1
Beam B	210	380	773	11.9

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4 Discussion of the results

Fig. 11 shows a superposition of **Fig. 6** and **Fig. 9**, allowing to compare the behaviour of bare and reinforced beams.

A series of four experiments demonstrated the effect of the HPFRC jackets in determining the collapse mode of the beams as well as in influencing the post-cracking behaviour and the crack formation and evolution.

The beams with HPFRC jacket show, as opposed to no reinforced beam, a collapse from flexure, with a limited influence of the shear effects. Therefore the jacket has the same action of the shear reinforcement and can replace it very well.

It is worth noting that beams B and D, that have the same dimensions (same 50 mm jacket thickness, same reinforcement), showed a very similar load displacement curve, at least until maximum load was reached.

It can be noticed as the HPFRC layer allows to increase the maximum load of the beam. For the beams D and B, that have the same 50 mm jacket thickness, the capacity increases 1.7 times, while if the jacket have a thickness of 30 mm on the lateral surfaces (beam E), the maximum load increases 1.5 times.

The propose tecnique allows to remarkably increase the beam stiffness, as a consequence the midspan displacement before the maximum load has been reduced.

Finally, it can be noticed that, while the un-reinforced beam have a brittle failure, for the three beams strengthening with HPFRC the post peak behavior becomes softening.

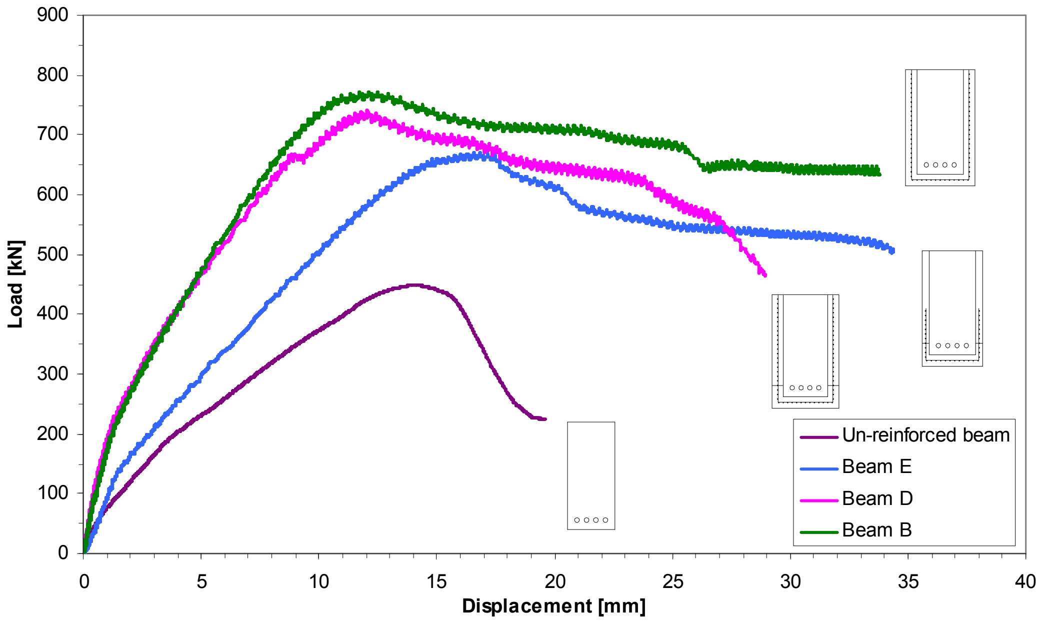

Fig. 10 Load vs. Midspan displacemnt – Comparison of the results

5 Conclusion

The possible use of HPFRC material for shear strengthening R/C beams has been investigated with full scale application. Experimental studies were conducted on the shear strengthening of RC beams with HPFRC to confirm the effectiveness of this strengthening technique and to study the effects of jacket thickness on the ultimate shear strength of beams.

On the basis of the experimental results the following conclusion can be drawn:

- The application of the HPFRC jacket has provided an increase of the maximum load of R/C beams and a increase of its stiffness;
- It is observed that the ultimate strength of a beams with a HPFRC jacket increases with increasing jacket thickness;
- For the beams strengthening with a HPFRC jacket the failure was governed by a bending mechanism, with a limited influence of the shear effects. The shear strengths of these beams must be higher than the load levels defined by flexural failure.
- The proposed technique, which involves the use of thixotropic material, can be easily used in structural application for create the jacket.

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