Composite materials are the main components in the global quest towards sustainable and durable alternatives to steel reinforcement in concrete structural elements. One such example is reinforcement bar made with basalt fibres embedded in a polymeric matrix, where production costs are low but environmental properties and their resistance to corrosion are high.

Reinforcing bars made of basalt fibres are proposed as an alternative to traditional steel tendons for prestressing precast concrete elements. The bars are produced with fibres of mineral origin (basalt) which have a diameter of 10μm (well above the respiratory limit that led to problems associated with the use of asbestos mineral fibres). They are unrolled from the production bobbins and embedded into a polymeric matrix. The bars are then subjected to sandblasting in order to increase their bond properties with concrete (Figure 1).

Wide experimentation regarding characterisation of the mechanical behaviour of BFRP bars and of the structural performance of a full–scale prestressed floor element has recently been carried out within the framework of research project EiroCrete funded by the EU, within the programme FP7-PEOPLE-2012-IAPP – Marie Curie Action: ‘Industry-Academia Partnerships and Pathways’. The consortium of the project comprises the companies represented by the authors.

**Characterisation tests**

The first phase of the research activity was devoted to the mechanical characterisation of the BFRP bars.

The results from tensile tests on short bars (Figure 2a) showed an elastic behaviour up to their brittle failure, which occurred at a high strength between 900 and 1000MPa. The elastic modulus was equal to about 48GPa. When the specimen was taken to tensile failure, the bar was subjected to delamination (Figure 2b).

Despite the strength being lower than prestressing steel, which unavoidably brings a lower prestress potential for a single bar, the low elastic modulus is in fact an advantage in terms of long-term performance of the GT Slab (PCE proprietary slab), since the losses to shortening due to combined elasticity, shrinkage and creep, are significantly reduced.

Since the BFRP bars have a pronounced orthotropic mechanical behaviour, the use of end anchorage wedges typically used for tendons led to early failure of some tests due to the local rupture within the wedge. Special resin-filled anchorages were developed to avoid this failure.

A long–term relaxation test was also carried out on a short bar prestressed at 500MPa (Figure 2c). The results show that BFRP bars are prone to relaxation, since the loss of prestress at 1000 hours was measured to be equal to 8.4%. However, it is worth mentioning that the combination of long–term losses for shortening and relaxation brings values that are in agreement with those traditionally expected for elements prestressed with steel tendons.

Tests devoted to the characterisation of the transfer length of BFRP bars in concrete were also carried out. A very good performance was observed, with full transfer occurring after only ten times the diameter of the bars.

**Full-scale precast roof element**

A structural element having lightweight box section with inner polystyrene blocks and asymmetric lateral corbels (Figure 3), typical of a constructive system introduced by George Tootell in the UK, was selected for the full–scale static test. The element was 10m long, 1.49m wide and 0.4m deep. It was designed according to the criterion to keep a controlled camber in time. To achieve this, 12 BFRP
bars with diameter of 12mm were designed to be positioned in the centre of the 80mm-deep bottom slab of the element. They were placed in such a way as to minimise the torsional effects induced by the non-symmetric section, with a horizontal spacing of 115mm.

The element was reinforced against shear failure according to capacity design, in order to get a flexure-side failure. A shear-reinforcing truss made of 45° inclined short glass-fibre-reinforced polymer (GFRP) bars with a diameter of 6mm spaced at 200mm, linked to an upper and a lower BFRP bar with diameter of 12mm, was placed in each of the two side ribs of the element. Furthermore, short GFRP bars with a diameter of 6mm were installed transversely to grant the full participation of the cross-section.

Self-compacting concrete (SCC) of strength class C55/60 with 4kg/m³ of 38mm-long polypropylene fibres – introduced to increase the stiffness of the element and to obtain a good distribution of cracks – was used.

The formwork selected was 15m long and 2m wide, and so an inner timber formwork was made for the correct shaping of the element. It was necessary to join the prestressed BFRP bars with traditional couplers (Figure 4), since they were supplied in 12m lengths.

The pulling and anchorage operations were performed to the traditional technique used for steel tendons (Figure 5). Despite the prestress of the BFRP bars being limited to 50% of their strength, and despite the positive results of preliminary tests on the anchorages, some bars failed close to the anchorage wedge, confirming the necessity to employ anchorage systems different from those of steel tendons. The element was cast with ten bars in respect of those originally designed, one of which was not prestressed.
The prestress was released after three days of curing. Even with the lower reinforcement, the element showed a small positive camber (see Figure 6, although camber is not completely clear), which was retained during the whole storage phase, of two months and ended with the execution of the static test.

**Load test**

After positioning the slab on two end concrete blocks, the three-point load test was carried out by applying a point load at mid-span through a hydraulic jack reacting over a strong steel frame (Figure 7). Single 10mm-thick timber bearings were placed beneath the element to better distribute the load. Similarly, a steel box profile with a timber bearing underneath was placed below the jack to distribute the load to the upper side of the slab.

The load test was carried out by applying a cyclic load to investigate the elastic and cracking phases, and the ability of the element to recover deflection – typical of prestressed elements under serviceability loads – then increasing the load up to failure. The test results (Figure 8) show an initial stiff behaviour, followed after cracking by a softer elastic phase.
is governed by the elastic elongation of the BFRP bars. The element showed a large deformation capacity (Figure 9), attaining a maximum deflection of 190mm, which corresponded to a slightly larger load than the one predicted by the numerical simulations that were carried out.

The element displayed a practically perfect recovery of the deflection with the complete closing of cracks up to a load equal to 80kN (Figure 10). This is the result of the perfectly elastic behaviour of BFRP bars up to levels of strain close to ultimate.

The cracking pattern was highlighted with a marker during the load test (Figure 10 – the red line illustrates complete recovery post-test load of 80kN). The pseudo-vertical cracks, typical of flexure, are well distributed with a mean spacing of about 40mm and consequent low mean opening. Such a favourable pattern is due to the contribution of the polypropylene fibres.

Collapse occurred in flexure at a section close to mid-span with the brittle failure of the prestressing BFRP bars placed at the bottom slab of the element, as expected (Figure 11).

Concluding remarks
The manufacture and experimentation of a 10m-long GT Slab made of precast fibre-reinforced SCC prestressed with BFRP bars and reinforced in shear with inclined GFRP bars showed an interesting solution towards the development of sustainable and durable steel-free precast elements.

The results of the tests aimed at characterising the mechanical behaviour of the bars showed elastic-brittle behaviour with high strength accompanied by high deformation capacity and a short transfer length associated with a good bond to concrete.

The production of the GT Slab element with asymmetric box section showed that the prestressing systems traditionally used for steel tendons can be employed with success in prestressing BFRP bars, with the exception of the anchorage wedges, which require more investigation.

The results of the three-point static load test carried out on the precast element show an initial stiff phase with fully acting cross-section followed by a post-cracking elastic softer phase characterised by the elongation of the BFRP bars.

A good capacity of crack distribution associated with small mean crack opening was observed, due to the contribution of the polypropylene fibres added to the concrete. The element displayed an almost perfect deflection recovery, with cracks closing up to a load equal to 80kN.

A flexural collapse was attained for tensile failure of the BFRP bars, at a deflection of about 1/50 of the span.