Sustainable alternative reinforcement technology

The concrete industry faces the major challenge to become more sustainable. An important aspect is new concrete mix compositions so that as little (Portland) cement as possible is used in the concrete mixtures. Also, we must not ignore the contribution of reinforcing steel to emissions: it is estimated that the steel accounts for approximately 21 percent of total CO_2 emissions (in the Netherlands). This is a good reason to pay more attention to this aspect as well.

There are alternatives. Concrete does not necessarily have to be reinforced with regular steel rebar. Other possible forms of reinforcement for various design purposes include structural macro fibres or Fiber Reinforced Polymer (FRP) bars in different materials. For some years, calculation rules for these materials have been available in various Fib Model Codes and (inter)national guidelines. New calculation rules for designing with steel fibre and FRP will be added to the new Eurocode for concrete structures, which is in principle completed.

Reduce kilograms

In particular, this study examines the use of structural steel and basalt fibre, possibly combined with regular steel rebar or basalt to form a hybrid reinforcement design. The purpose of the structural fibre is to reduce the number of kilograms of reinforcing bars and to have a positive effect on crack width control and stiffness. The qualities of basalt bars are their very high strength and the fact that they are non-corrosive. Therefore crack widths require less control and less reinforcement is required. The application of both reinforcements has great potential in aggressive environments.

Figure 1: Test setup four-point bending tests

Reason for the study

The firm Voorbij Prefab produces conventional thin walls for residential homes with a single reinforcement mesh in the middle. They want to produce thicker walls with a double reinforcement mesh on the front and back of the wall plates. However, this type of production does not fit into the automated factory process. In partnership with Bekaert and ABT, the application of constructive macrofibre in the walls was researched in order to save on the reinforcement mesh without sacrificing capacity, while maintaining the current production process as much as possible. This would also save many pounds of steel reinforcement. A true win-win.

Approach

Since the calculation of such materials is not yet included in the Eurocode, it was decided to perform beam tests to determine the material properties for this particular application. The choice was made to establish the performance of different macrofibres: a high-performance steel fibre and a basalt fibre.

These were tested for this study using a standardized three-point bending test on beams with a saw cut according to NEN-EN 14651. Since the fibre performance of structural fibres is highly dependent on the concrete strength, type and fibre content, the following configurations were set apart:

- 15 kg/m^3 5D steel fibre;
- 30 kg/m^3 5D steel fibre;
- 10 kg/m^3 basalt fibre.

Structurally this fibre content was expected to be adequate and there would still be excellent workability without having to change the concrete mix a great deal. In addition, four-

Figure 2: Pouring concrete from the pouring machine at the company of Voorbij Prefab (left) and moulds with basalt rebar (right)

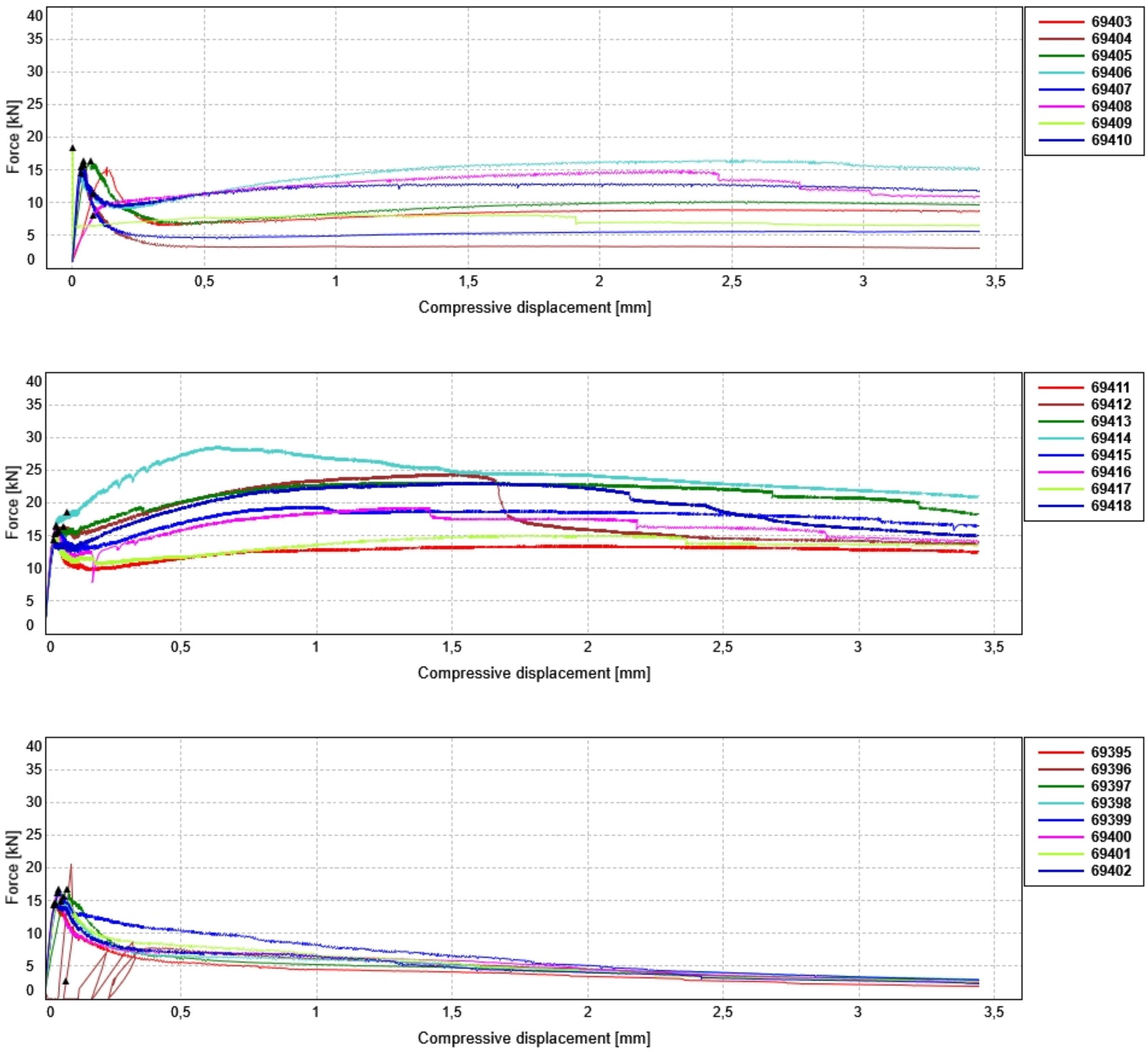

Figure 3: Results three-point bending tests according to NEN-EN 14651 on fibre-only beams with 15 kg/m³ 5D steel fibre (top), 30 kg/m³ 5D steel fibre (middle) and 10 kg/m³ basalt fibre (bottom) (Source Bekaert)

point bending tests were performed on beams of 150 x 150 x 1000 mm, distinguishing between the following reinforcement configurations:

1. 2*2Ø6 bars of rebar B500 B (reference);
2. 2*2Ø6 bars of basalt reinforcement;
3. 30 kg/m³ 5D steel fibre (fibre-only);
4. 10 kg/m³ basalt fibre (fibre-only);
5. 30 kg/m³ 5D steel fibre + 2*2Ø6 rebar (hybrid);
6. 30 kg/m³ 5D steel fibre + 2*2Ø6 basalt reinforcement (hybrid);
7. 10 kg/m³ basalt fibre + 2*2Ø6 basalt reinforcement (hybrid).

These tests were conducted to learn more about the failure and cracking behaviour of such beams, and to assess the effect of hybrid reinforcement on them.

Results of three-point bending tests

Eight beams per reinforcement configuration were produced and their fibre performance was tested. The moulds were filled with (fibre) concrete, which was mixed in the pouring machine at Voorbij's plant.

Results of the three-point bending tests are shown in Figure 3. Please note that:

- The beams with 15 kg/m³ steel fibre have deviating results and the capacity no longer increases beyond the cracking point;
- Most beams with 30 kg/m³ steel fibre show bending-hardening behaviour;
- The beams with 10 kg/m³ basalt fibre still retain residual capacity, but this decreases as deformation increases. The likely cause is that much of the fibres broke during the concrete mixing process. When these fibres are dosed with the already mixed concrete, the performance is expected to be better.

For all these fibres, a certain tensile capacity after tearing must be taken into account. This makes it possible to reduce the amount of rebar, or even omit rebar. Also, other applications may see a significant reduction in labour required.

Results of four-point bending tests

Failure moments of all beams with reinforcement bars and hybrid reinforcement are shown in figures 4 and 5. Failure loads are shown in Figure 6. The results show the following:
The fibre-only beams had the least capacity. Beams with steel fibre still showed bending-hardening behaviour, with multiple cracks forming before collapse;

- Beams with regular rebar or with basalt reinforcing bars had equivalent capacity.
- This is because the yield stress of the steel rebar was high and the basalt rebar is pulled out of the concrete or gives reduced shear capacity;
- The anchoring length of basalt reinforcement is longer. Fewer cracks develop. Due to the low modulus of elasticity, the cracks are wider;
- The hybrid reinforced beams have a higher capacity.
- In addition, more cracks occurred with smaller crack spacings and crack widths.

Potential

The test results are promising and clearly show the behaviour and potential of the different reinforcement technologies. Based on these tests, it is estimated that reinforcement in the proposed walls of Voorbij can be (largely) replaced by steel fibres. For practical reasons, further research will be conducted for a hybrid design with a single mesh in the middle. The number of kilograms of rebar will be significantly reduced.

The results will be used to produce and test plates to demonstrate through 'Design-by-testing' that this design meets the

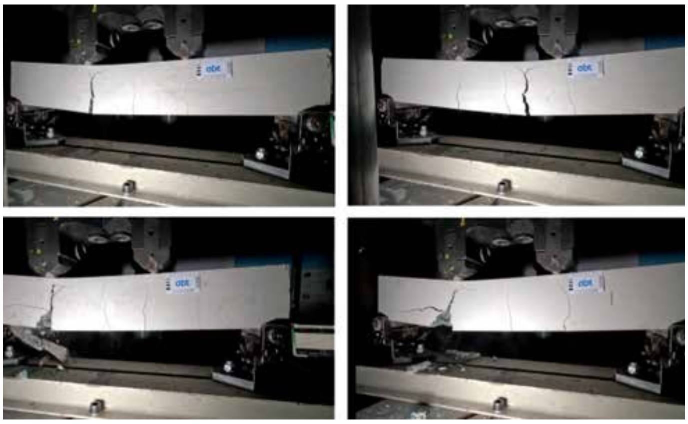

Figure 4: Beam tests with rebar just before collapse. Only regular rebar (top) and basalt reinforcement (bottom)

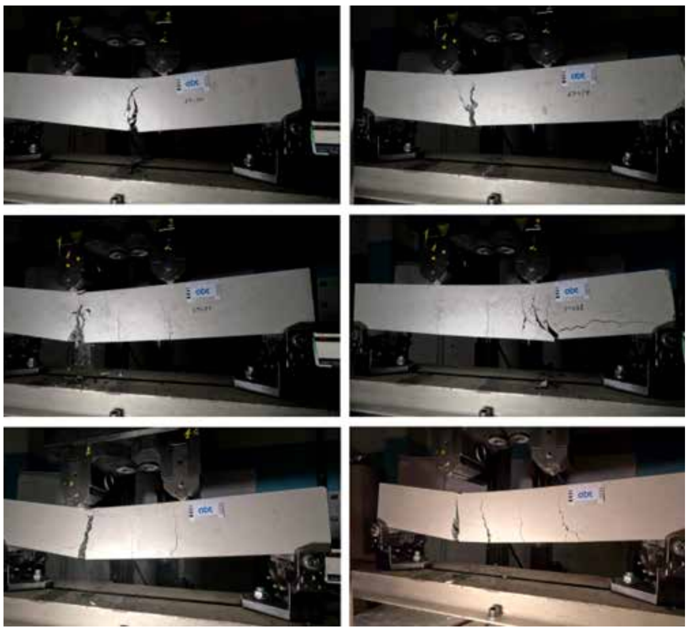

Figure 5: Beam tests with hybrid reinforcement just before collapse. Regular rebar with steel fibre (top), basalt reinforcement with steel fibre (middle) and basalt reinforcement with basalt fibre (bottom)

requested requirements. In addition, the production of the panels will gain experience such as on the finishing of the fibre-reinforced panels.
Because the behaviour of macrofibres depends on many variables and the availability of material properties of FRP reinforcement in concrete are still relatively limited, these tests were still necessary. The experiments will gather much information about the behaviour of different materials.

So here is a request to do this more often to gain knowledge and experience. The addition in the Eurocode will then only be a formality and no longer a condition for applications in a design. After all, it can already be done now.

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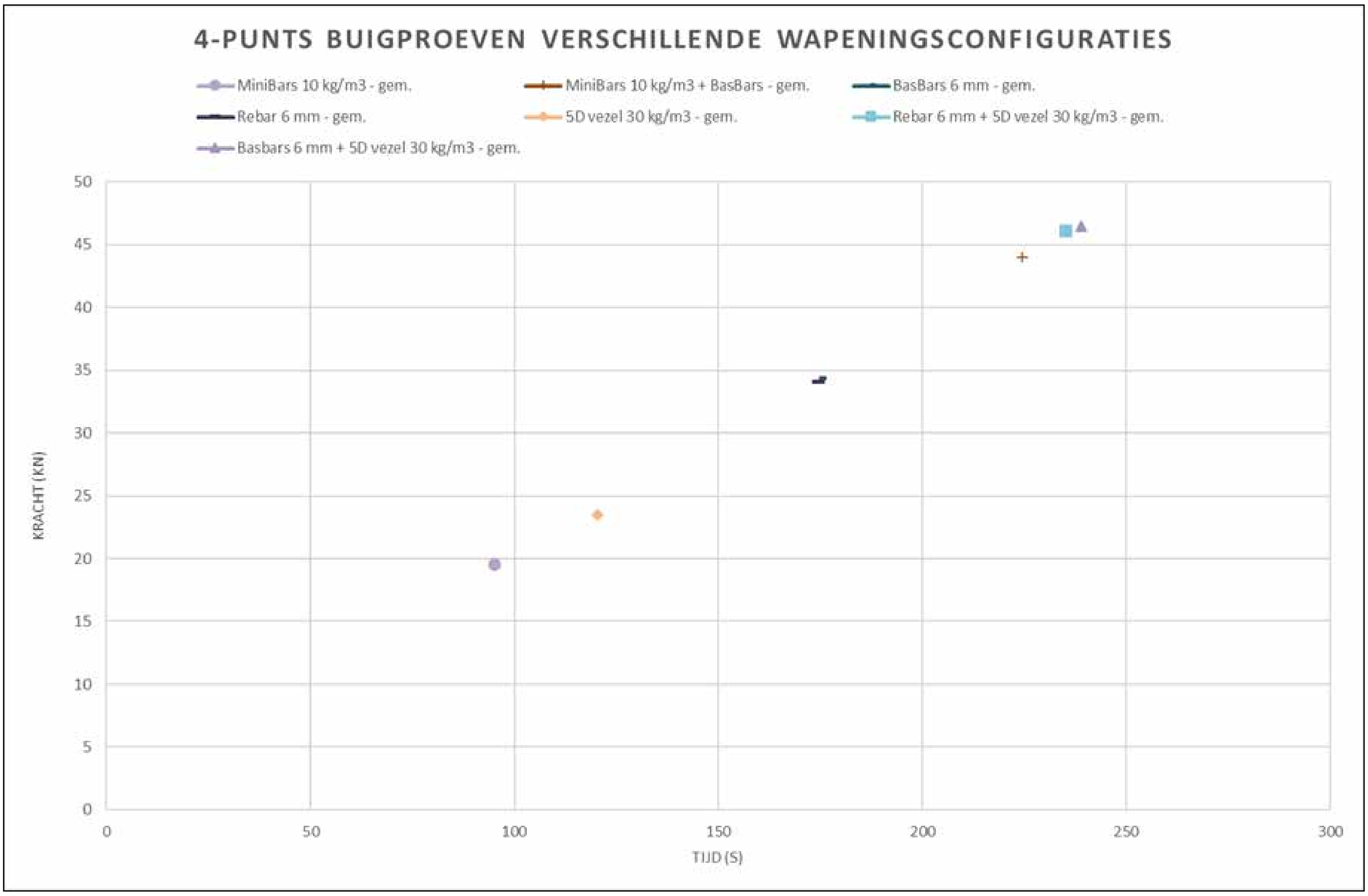

Figure 6: Test results four-point bending tests. Fibre-only beams have the lowest capacity, bar-based beams have medium capacity and hybrid reinforced beams have the highest capacity