# Self-compacting premix

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## Introduction

The use of self-compacting concrete (SCC) has revolutionised the way both precast and in-situ concrete is placed. Additives in the concrete mean that the concrete will compact and achieve the required density without the need for vibration.

The advantages in the precast concrete factory are a much more pleasant and, more importantly, a safer working environment. The moulds can be of lighter construction and last longer.

There are perceived disadvantages in that the mix design has to be adapted to reduce the quantity of large aggregate while increasing the quantity of the fine aggregate. Additionally there must also be an increase in the fines content, which can be achieved either by increasing the cement content or by the addition of cement replacements such as ggbs and pfa.

## Self-compacting additives

The additives used must give the required flow without increasing the water/cement (w/c) ratio but must also control the rheology of the mix to prevent any segregation or bleeding. They are normally based on polycarboxylates.

## Cast Premix GRC

Cast premix glassfibre-reinforced concrete (GRC) has always relied on vibration to fill moulds and to remove entrapped air. This has never been particularly satisfactory and as the fibre content has increased it has become increasingly difficult to get the mix to flow sufficiently to completely fill the mould and to give a satisfactory finish without air holes. This problem is exacerbated when rubber moulds are used which tend to absorb rather than transmit the vibration. Moving empty moulds to the vibrating table and full ones away is another added complication.

## Challenge

The challenge was to design a mix which:

- does not require vibration
- is suitably fluid to completely fill the mould but does not segregate
- gives a surface finish free from voids and air holes
- possesses satisfactory mechanical properties, particularly flexural strength and density.

# Experimental Work

## Experimental programme

The first problem to overcome was to design a suitable mix. It was decided to stay as close as possible to standard GRC practice so a sand/cement ratio of 1:1 was used and the w/c ratio was limited to 0.36.
A series of proprietary SCC and other superplasticisers were tried but although achieving the required flow was straightforward it was always accompanied by segregation. Rheology modifiers were used to reduce the segregation but while they achieved this they also adversely affected the flow. The project was very nearly abandoned but fortunately a new type of plasticiser with an integral stability agent was developed and this gave the required performance. This plasticiser was named Flowaid SCC and it was used throughout the project.

Using this plasticiser, two basic mix designs were developed: one polymer and one non-polymer (Table 1).

| Material | Non-polymer mix | Polymer mix |
|---|---|---|
| Cement | 25 | 25 |
| Silica sand | 25 | 25 |
| Water | 9.0 | 6.75 |
| Polycure FT Extra | 0 | 2.5 |
| Flowaid SCC | 0.25 | 0.25 |

*Table 1. Basic mix designs*

These two mix designs were investigated with a range of fibre types at various percentages. In order to assess the suitability of each mix there were three basic tests.

### *Flow test*

It was felt that the standard slump test was unsuitable, as mixes with a suitable flow would all show the maximum number of rings. A new flow test was therefore developed which proved to be very accurate and to give reproducible results. A stainless steel funnel with a 19 mm spout was fabricated. The funnel was held vertically in a frame and filled with the test mix. The time taken for the mix to completely empty was recorded. When the funnel did not empty or when the time exceeded 100 s, the time was recorded as 100+. The test apparatus is shown in Figure 1.

*Figure 1. Fluidity test apparatus*

## *Segregation tests*

Another simple test was devised where 300 × 600 mm cylinders 5 0 mm in diameter were filled using the funnel (Figure 2) from the previous test. Any segregation was observed and the volume of any bleedwater was measured. On demoulding, an assessment of the quality of the surface finish was made.

*Figure 2. Filling up a cylinder*

### Surface finish

Cast boards and cylinders were visually examined for air holes and other surface defects.

### Mechanical properties

The flexural strengths were measured in accordance with EN 1170 Part 5 [1] with eight coupons being tested from each board produced. The density was measured basically in accordance with EN 1170 Part 6 [2] but using cylindrical rather than rectangular specimens. It was considered that it would be more difficult for air to escape from a 300 mm or a 600 mm high cylinder than from a 10 mm thick flat sample. The 600 mm cylinders were also sectioned horizontally so as to investigate whether there was any change in density with respect to the depth.

## Practical work

The slurry mixes were prepared in a GRC125 combination mixer. After mixing, the 'slurry speed' was measured twice and recorded. The slurry was then weighed into batches of 9 kg and the appropriate amount of fibre for the first mix was mixed in using a drill mixer. The 'speed' was again measured twice and then a test board was cast without vibration.
This procedure was repeated for mixes 2–6, each time the slurry being remixed prior to the addition of the fibre. Before the fibre was added to the final mix the 'slurry speed' was remeasured.
After casting, the boards were covered in polythene prior to demoulding the next day. They were then cured under polythene for seven days and then under ambient factory conditions. Flexural testing was carried out at 28 days.

# Results

## Non- polymer mix

Mix designs and results of "flow speed" and flexural strength are summarized in Table 2 70 6.

| Fibre (%) | Filaments per strand | Filament diameter (µ) | Fibre length (mm) | Strand integrity | Time (s) | LOP (MPa) | MOR (MPa) |
|---|---|---|---|---|---|---|---|
| 2 | 100 | 13/14 | 12/13 | High | 27.47 | 8.05 | 9.33 |
| 2 | 100 | 13/14 | 12/13 | High | 41.86 | 8.88 | 12.19 |
| 2 | 200 | 13/14 | 12/13 | High | 20.80 | 8.03 | 8.50 |
| 2 | 200 | 13/14 | 12/13 | Medium | 53.79 | 8.38 | 8.79 |
| 2 | 200 | 18 | 12/13 | High | 17.18 | 7.13 | 7.29 |
| 2 | 200 | 18 | 12/13 | High | 18.15 | 6.64 | 6.82 |

*Table 2. Non-polymer mix 1*

Date cast: 01/10/07

Slurry speed: Initial 12.72 Final 12.49

| Fibre (%) | Filaments per strand | Filament diameter (μ) | Fibre length (mm) | Strand integrity | Time (s) | LOP (MPa) | MOR (MPa) |
|---|---|---|---|---|---|---|---|
| 2.5 | 100 | 13/14 | 12/13 | High | 85.09 | 7.51 | 9.65 |
| 2.5 | 100 | 13/14 | 12/13 | High | 100+ | 8.39 | 12.09 |
| 2.5 | 200 | 13/14 | 12/13 | High | 38.02 | 6.53 | 8.54 |
| 2.5 | 200 | 13/14 | 12/13 | Medium | 100+ | 7.81 | 10.26 |
| 2.5 | 200 | 18 | 12/13 | High | 22.45 | 6.15 | 7.22 |
| 2.5 | 200 | 18 | 12/13 | High | 22.32 | 6.71 | 7.39 |

*Table 3. Non-polymer mix 2*

Date cast: 02/10/07

Slurry speed: Initial 13.03 Final 14.40

| Fibre (%) | Filaments per strand | Filament diameter (μ) | Fibre length (mm) | Strand integrity | Time (s) | LOP (MPa) | MOR (MPa) |
|---|---|---|---|---|---|---|---|
| 3.0 | 200 | 18 | 12/13 | High | 22.39 | 6.17 | 7.51 |
| 3.0 | 200 | 18 | 12/13 | High | 26.14 | 7.34 | 9.19 |
| 3.5 | 200 | 18 | 12/13 | High | 26.11 | 6.49 | 8.62 |
| 3.5 | 200 | 18 | 12/13 | High | 36.06 | 7.19 | 9.06 |
| 4.0 | 200 | 18 | 12/13 | High | 36.53 | 6.48 | 9.92 |
| 4.0 | 200 | 18 | 12/13 | High | 68.49 | 7.64 | 9.30 |

*Table 4. Non-polymer mix 3*

Date cast: 03/10/07

Slurry speed: Initial 12.13 Final 14.05

| Fibre (%) | Filaments per strand | Filament diameter (μ) | Fibre length (mm) | Strand integrity | Time (s) | LOP (MPa) | MOR (MPa) |
|---|---|---|---|---|---|---|---|
| 2.0 | 200 | 13/14 | 6 | Medium | 18.22 | 5.74 | 7.71 |
| 2.5 | 200 | 13/14 | 6 | Medium | 23.88 | 7.08 | 7.99 |
| 3.0 | 200 | 13/14 | 12/13 | High | 58.86 | 7.35 | 11.14 |
| 3.5 | 200 | 18 | 12/13 | High | 18.85 | 7.75 | 8.71 |
| 2.0 | 200 | 18 | 19 | High | 21.22 | 7.59 | 8.34 |
| 2.0 | 200 | 18 | 25 | High | 35.31 | 7.41 | 10.01 |

*Table 5. Non-polymer mix 4*

Date cast: 09/10/07

Slurry speed: Initial 11.67 Final 13.01

| Fibre (%) | Filaments per strand | Filament diameter (μ) | Fibre length (mm) | Strand integrity | Time (s) | LOP (MPa) | MOR (MPa) |
|---|---|---|---|---|---|---|---|
| 3.0 | 200 | 13/14 | 6 | Medium | 16.17 | 6.63 | 7.79 |
| 3.5 | 200 | 13/14 | 6 | Medium | 22.99 | 7.43 | 9.12 |
| 4.0 | 200 | 13/14 | 6 | Medium | 100+ | 7.17 | 10.18 |
| 2.5 | 200 | 18 | 19 | High | 17.82 | 6.94 | 8.61 |
| 3.0 | 200 | 18 | 19 | High | 100+ | 7.58 | 9.97 |
| 2.5 | 200 | 18 | 25 | High | 100+ | 6.49 | 8.86 |

*Table 6. Non-polymer mix 5*

Date cast: 10/10/07

Slurry speed: Initial 8.86 Final 10.01

The results show that the flow properties are affected by:

- type of size
- strand configuration/filament diameter
- fibre percentage
- fibre length.

Figures 3–6 illustrate this. When more than one board has been produced with the same fibre type, configuration and content then an average result has been used.

*Type of size*

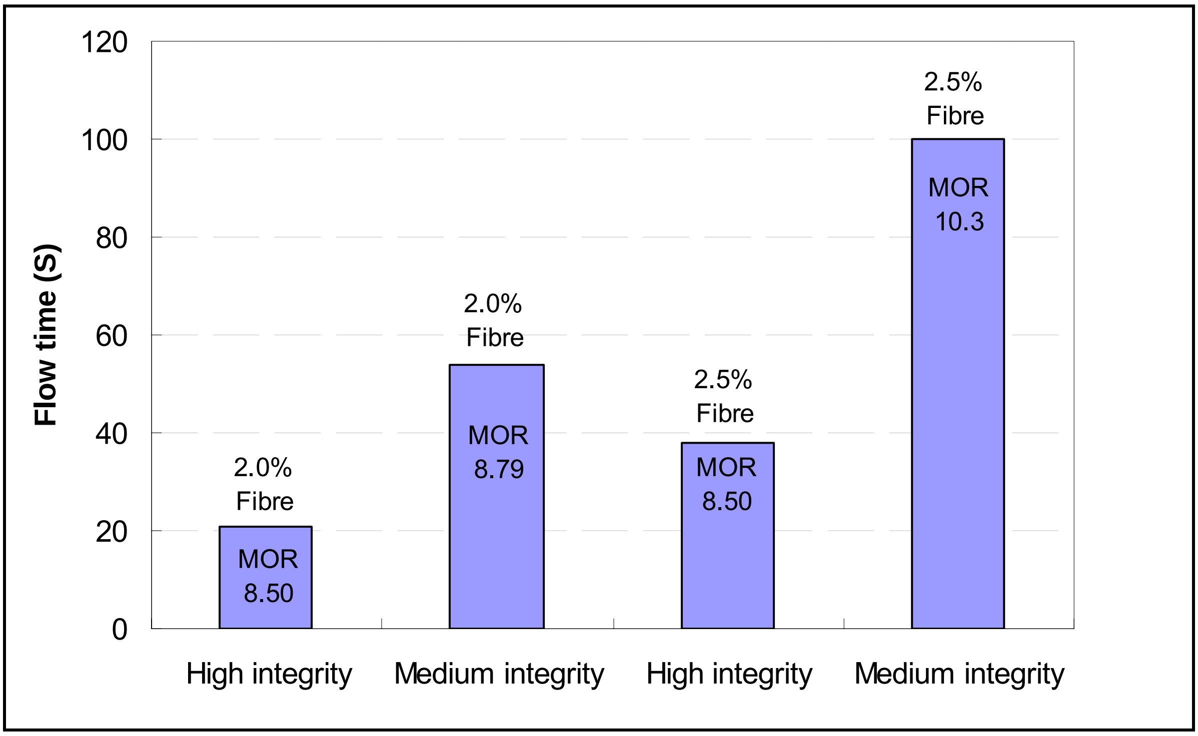


*Figure 3. Comparison of high/medium integrity size*

The results clearly show that a high-integrity size normally found on a specialist premix fibre is required.

## Strand configuration/filament diameter

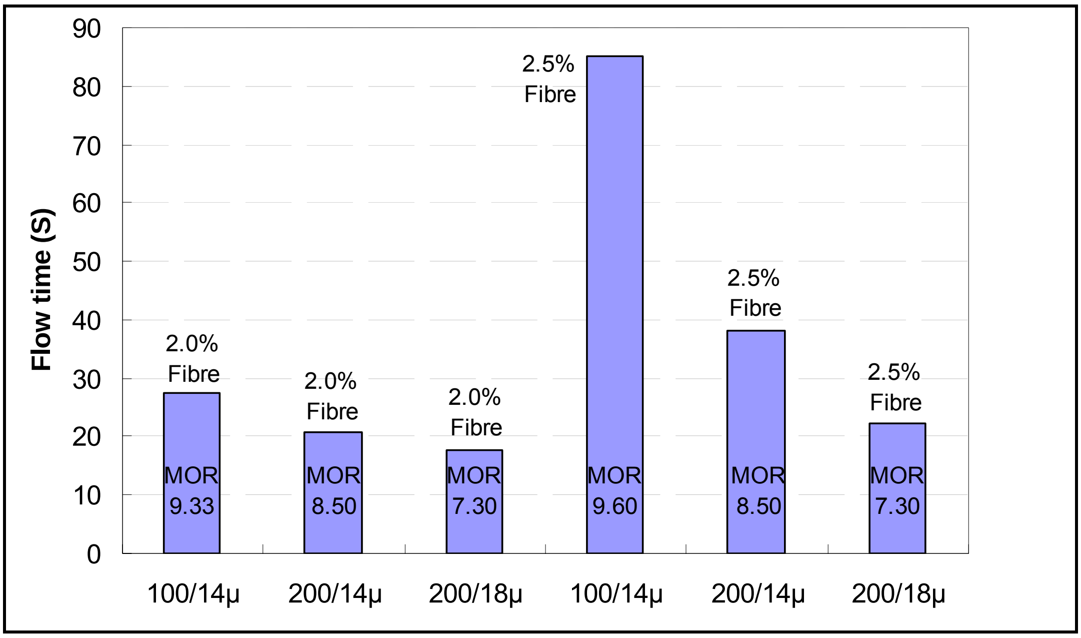


*Figure 4. Variation of strand configuration/diameter*

The flow time is affected by the number of reinforcing elements. As the number of reinforcing elements increases so the flow time increases. An increase in the filament diameter and/or the number of filaments making up the strand reduces the number of reinforcing elements and so the flow time decreases and hence the workability increases.

## Fibre percentage

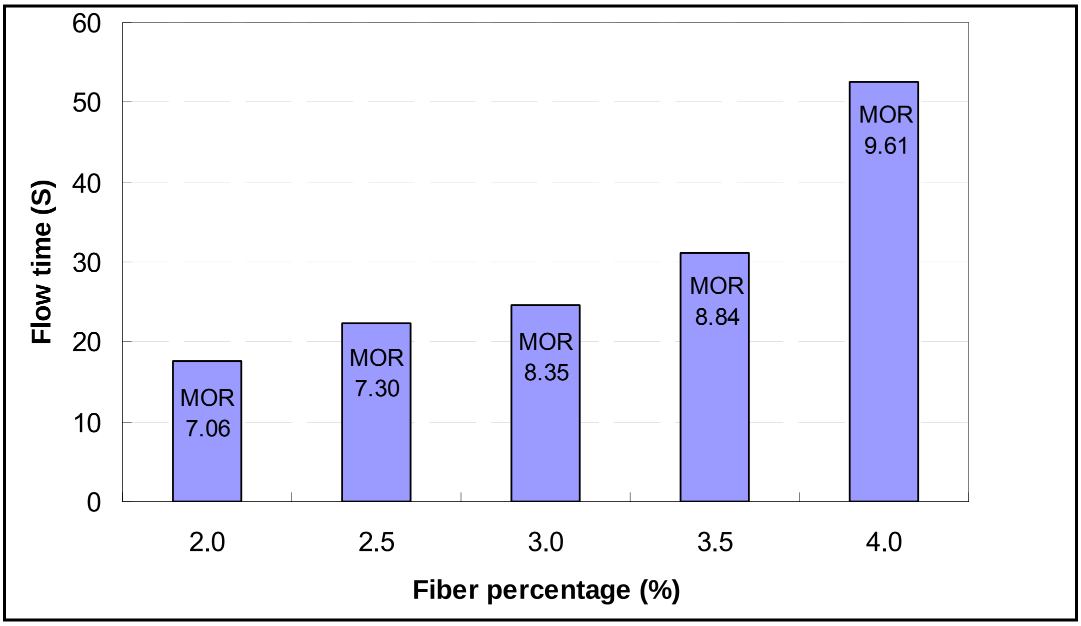


*Figure 5. Variation of flow times for increasing fibre content of 18µ fibres*

As expected, as the fibre percentage increases, the flow time also increases.

*Fibre length*

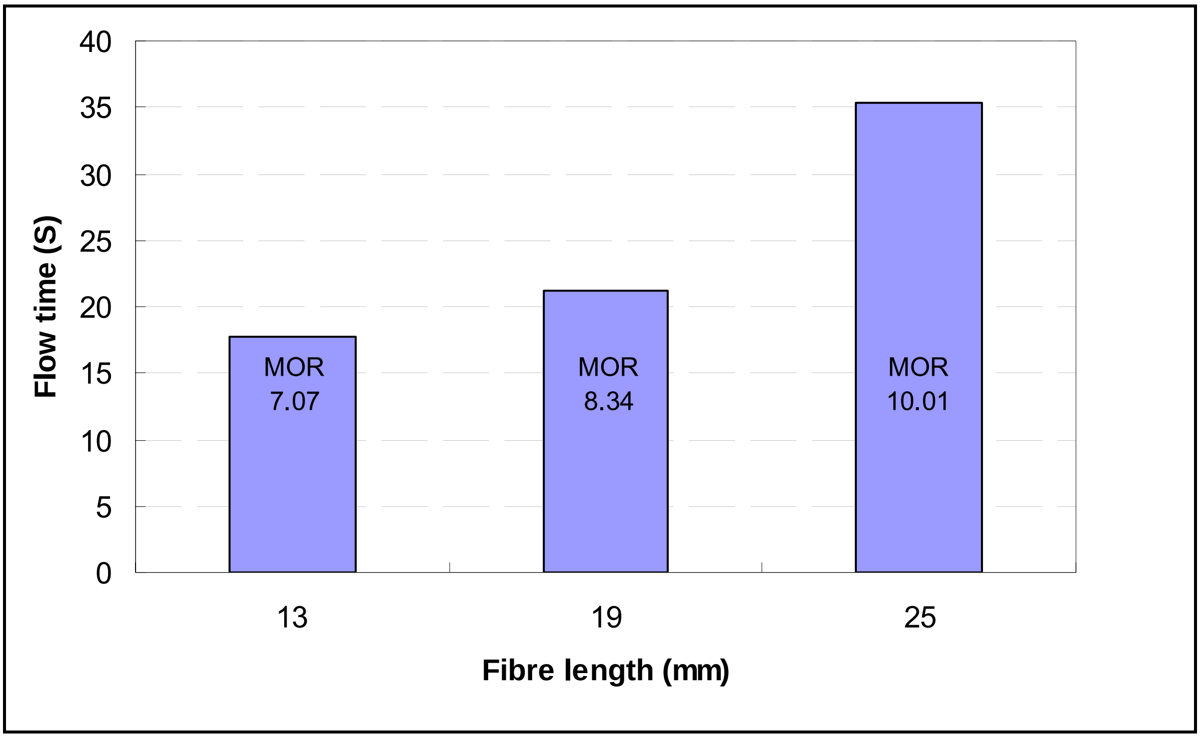


*Figure 6. Variation of fibre length 2% content*

The flow time increases with increasing fibre length.

# Overview

It is clear from the above how the four factors discussed affect the workability, but workability is not the only parameter and the mechanical properties must also be taken into consideration. Moving from a medium to a high integrity size does not appear to increase the flexural strength. As shown in Figure 4 and previous publications [3]–[5], the strand configuration/filament diameter has a significant effect and as the number of reinforcing strands increase so there is an increase in the flexural strength. There is also an increase in flexural strength with increasing fibre content. A 36% increase was obtained when the fibre content was doubled from 2% to 4%. There was also shown to be an increase in flexural strength with an increase in fibre length.

Based on the above, it can be seen that there is a compromise between achieving high fluidity and achieving satisfactory flexural strengths.

For non-polymer mixes it was decided to consider only mixes that had a speed less than 30 s and a flexural strength in excess of 8 MPa (modulus of rupture (MOR)).

The mixes shown in Table 7 met these criteria.

| Fibre (%) | Filaments per strand | Filament diameter (µ) | Fibre length (mm) | Strand integrity | Time (s) | LOP (MPa) | MOR (MPa) |
|---|---|---|---|---|---|---|---|
| 2.0 | 100 | 13/14 | 12/13 | High | 27.47 | 8.05 | 9.33 |
| 2.0 | 200 | 13/14 | 12/13 | High | 20.80 | 8.03 | 8.50 |
| 3.0 | 200 | 18 | 12/13 | High | 26.64 | 7.34 | 9.19 |
| 3.5 | 200 | 18 | 12/13 | High | 26.11 | 6.49 | 8.62 |
| 2.0 | 200 | 18 | 19 | High | 21.20 | 7.59 | 8.34 |
| 3.5 | 200 | 13/14 | 6 | Medium | 23.00 | 7.43 | 9.12 |

*Table 7. Suitable mixes*

The above glassfibre configurations were then tried with polymer mixes.

## Polymer mix

| Fibre (%) | Filaments per strand | Filament diameter (µ) | Fibre length (mm) | Strand integrity | Time (s) | LOP (MPa) | MOR (MPa) |
|---|---|---|---|---|---|---|---|
| 2.0 | 100 | 13/14 | 12/13 | High | 25.00 | 8.90 | 10.84 |
| 2.5 | 200 | 13/14 | 12/13 | High | 27.83 | 9.78 | 10.74 |
| 2.5 | 200 | 18 | 12/13 | High | 18.69 | 10.50 | 10.80 |
| 3.0 | 200 | 18 | 12/13 | High | 23.39 | 8.49 | 9.89 |
| 2.0 | 200 | 18 | 19 | High | 22.05 | 9.18 | 10.53 |
| 2.5 | 200 | 18 | 19 | High | 31.93 | 9.42 | 10.08 |

*Table 8. Polymer mix 1*

Date cast: 13/11/07

Slurry speed: Initial 12.44 Final 13.79

| Fibre (%) | Filaments per strand | Filament diameter (µ) | Fibre length (mm) | Strand integrity | Time (s) | LOP (MPa) | MOR (MPa) |
|---|---|---|---|---|---|---|---|
| 2.5 | 100 | 13/14 | 12/13 | High | 27.03 | 10.69 | 12.21 |
| 3.0 | 200 | 13/14 | 12/13 | High | 28.38 | 9.54 | 11.81 |
| 3.5 | 200 | 13/14 | 6 | High | 23.53 | 9.56 | 11.37 |
| 3.5 | 200 | 18 | 12/13 | High | 21.78 | 7.74 | 9.63 |
| 3.0 | 200 | 18 | 19 | High | 31.06 | 7.96 | 11.01 |
| 2.5 | 200 | 18 | 25 | High | 100+ | 9.29 | 10.90 |

*Table 9. Polymer mix 2*

Date cast: 14/11/07

Slurry speed: Initial 11.66 Final 11.69

| Fibre (%) | Filaments per Strand | Filament diameter (μ) | Fibre length (mm) | Strand integrity | Time (s) | LOP (MPa) | MOR (MPa) |
|---|---|---|---|---|---|---|---|
| 2.0 | 100 | 13/14 | 12/13 | High | 20.09 | 13.70 | 14.70 |
| 2.5 | 100 | 13/14 | 12/13 | High | 27.38 | 12.90 | 14.00 |
| 2.5 | 200 | 13/14 | 12/13 | High | 25.09 | 12.71 | 13.27 |
| 3.0 | 200 | 18 | 12/13 | High | 19.71 | 11.74 | 12.53 |
| 3.5 | 200 | 18 | 12/13 | High | 23.44 | 11.10 | 12.30 |

*Table 10. Polymer mix 3*

Date cast: 17/11/07

Slurry speed: Initial 10.50 Final 10.81

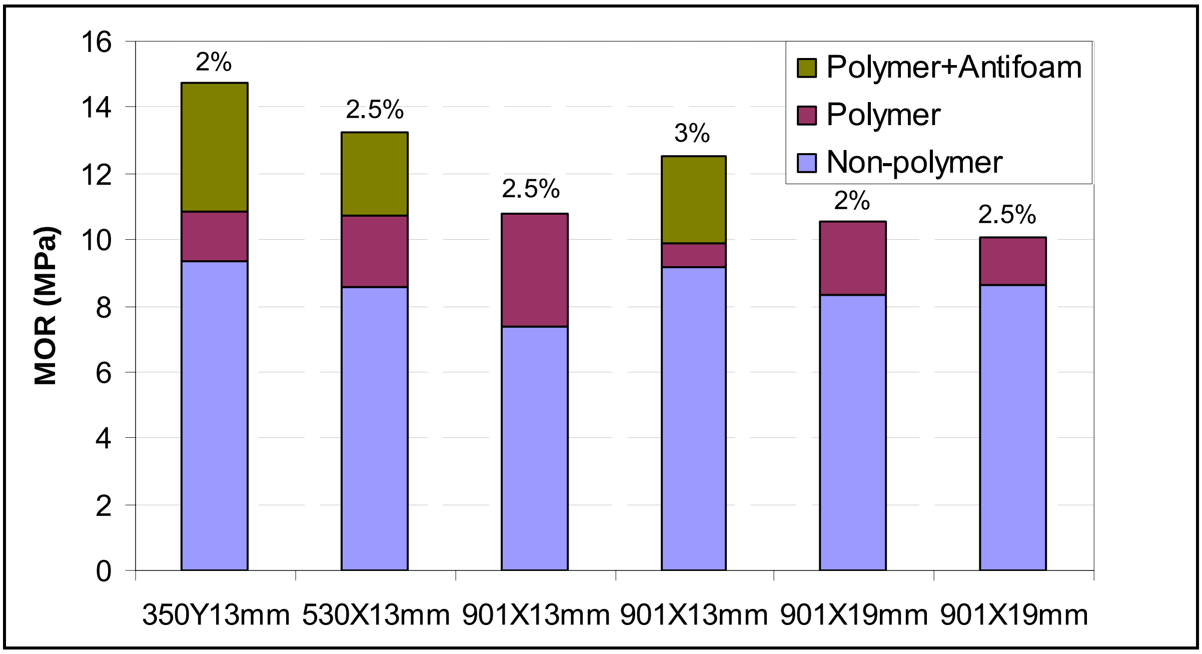


*Figure 7. Effect of polymer and anti-foam on strength*

Similar workabilities were achieved but the strengths obtained from the polymer mix were approximately 25% higher than the non-polymer one. Further increases in strength were obtained by increasing the fibre content and particularly by adding an antifoaming agent to the mix as shown in Figure 7.

## Density

This is an important consideration because it must be shown that the specified density can be achieved without the need for vibration. Results are shown in Table 11.

| Mix | Fibre | Wet density (t/m³) | Oven dry density (kg/m³) | Water absorption (%) |
|---|---|---|---|---|
| Non-polymer | 3% 901 X 13 mm | 2.19 | 1.97 | 10.22 |
| Polymer 1 | 2% 530X 13 mm | 2.04 | 1.86 | 8.90 |
| Polymer 2 | 3% 901X 13 mm | 2.03 | 1.85 | 8.80 |
| Polymer/antifoam | 2% 350Y 13 mm | 2.18 | 1.97 | 9.36 |
| Polymer/antifoam | 2.5% 350Y 13 mm | 2.19 | 1.99 | 8.86 |
| Polymer/antifoam | 2.5% 530X 13 mm | 2.19 | 2.00 | 8.80 |
| Polymer/antifoam | 3.0% 901X 13 mm | 2.19 | 2.01 | 8.48 |
| Polymer/antifoam | 3.50% 901X 13mm | 2.18 | 1.99 | 8.48 |

*Table 11. Wet and dry density and water absorption*

These results are consistent with high-quality well-compacted GRC and clearly show that satisfactory compaction is being achieved without vibration.

In addition two of the 600 mm cylinders were split into four sections of 150 mm high each and the density of these sections was tested. Results are shown in.

| Mix | Fibre | Wet density (t/m³) | Oven dry density (kg/m³) | Water absorption (%) |
|---|---|---|---|---|
| 1 (Top) | 2% 350Y | 2.17 | 1.98 | 8.57 |
| 2 | 2% 350Y | 2.16 | 1.98 | 8.30 |
| 3 | 2% 350Y | 2.14 | 1.97 | 8.20 |
| 4 (Bottom) | 2% 350Y | 2.21 | 2.01 | 9.08 |
| 1 (Top) | 2.5%530X | 2.17 | 1.99 | 8.29 |
| 2 | 2.5%530X | 2.17 | 1.99 | 8.34 |
| 3 | 2.5%530X | 2.16 | 1.98 | 8.47 |
| 4 (Bottom) | 2.5%530X | 2.15 | 1.97 | 8.34 |

*Table 12. Density of different sections of 600 mm cylinders*

The results show that satisfactory compaction was achieved throughout the sample.

## Segregation/bleeding

Segregation and/or bleeding were not apparent during any of the mixes or tests.

## Surface finish

All the cast sample boards, even those with high fibre contents, were free from air holes. The cylinders showed some air holes, as would be expected. It was not possible to correlate the number of these to a particular mix design or fibre content.

# Conclusions

1. Self-compacting premix has been shown to be a viable alternative to vibration casting.
2. A special additive is required which will give the required flow properties without segregation.
3. Typical mechanical properties for premix can be achieved. Polymer mixes gave higher properties than non-polymer. The addition of an antifoaming agent also increased flexural strength.
4. Very high densities were achieved.
5. Provided a high-integrity fibre was used then the required mechanical and flow properties could be achieved with a range of fibre types and percentages. Suitable fibres are shown in Table 13.

| Code | Filament diameter (μ) | No. of filament | Length (mm) | Percentage (%) |
|---|---|---|---|---|
| ACS13H350Y | 14 | 100 | 13 | 2.0 |
| ACS6H530X | 14 | 200 | 6 | 3.0–3.5 |
| ACS13H530X | 14 | 200 | 13 | 2.0–2.5 |
| ACS13PH901X | 18 | 200 | 13 | 3.0–3.5 |
| ACS19PH901X | 18 | 200 | 19 | 2.0–2.5 |

*Table 13. Suitable fibres found in this project*

# References

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