Developing a HP (High Performance) GRC Formulation

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Abstract

The use of Precast UHPC (Ultra High Performance Concrete) products is becoming increasingly widespread and some amazing projects have been completed.

This paper will investigate if a similar product could be developed for the GRC Industry.

Information which was freely available on the internet was used to develop the various mix designs tested and raw materials were used which were widely available. It was necessary to “think outside the box” and use low water/cement ratios, which appeared to be insufficient for hydration. Very fine sands which are outside the limits for standard GRC formulations also had to be used.

The work is ongoing but formulations with significantly enhanced properties have already been developed.

INTRODUCTION

Initially it was decided to investigate UHPC mixes which had already been developed. This proved difficult as certain formulations were not freely available and others were subject to licence agreements or required large up-front payments. It was possible to obtain three products, which were either bought from the internet or direct from the developer. It was hoped that if these formulations proved to be successful, they could be adapted for general use within the GRC industry.

INITIAL WORK STAGE 1

Three separate formulations were obtained. One of these was obtained directly from an online supplier the other two were from producers who were currently developing UHPC mixes.

The recommended mix designs were followed and after mixing, 3% glass fibre was added to each mix and test boards were cast.

The 28 day Flexural Test Results are shown in Figure 1 and they are compared to the requirements of GRCA Grades 8 and 10.

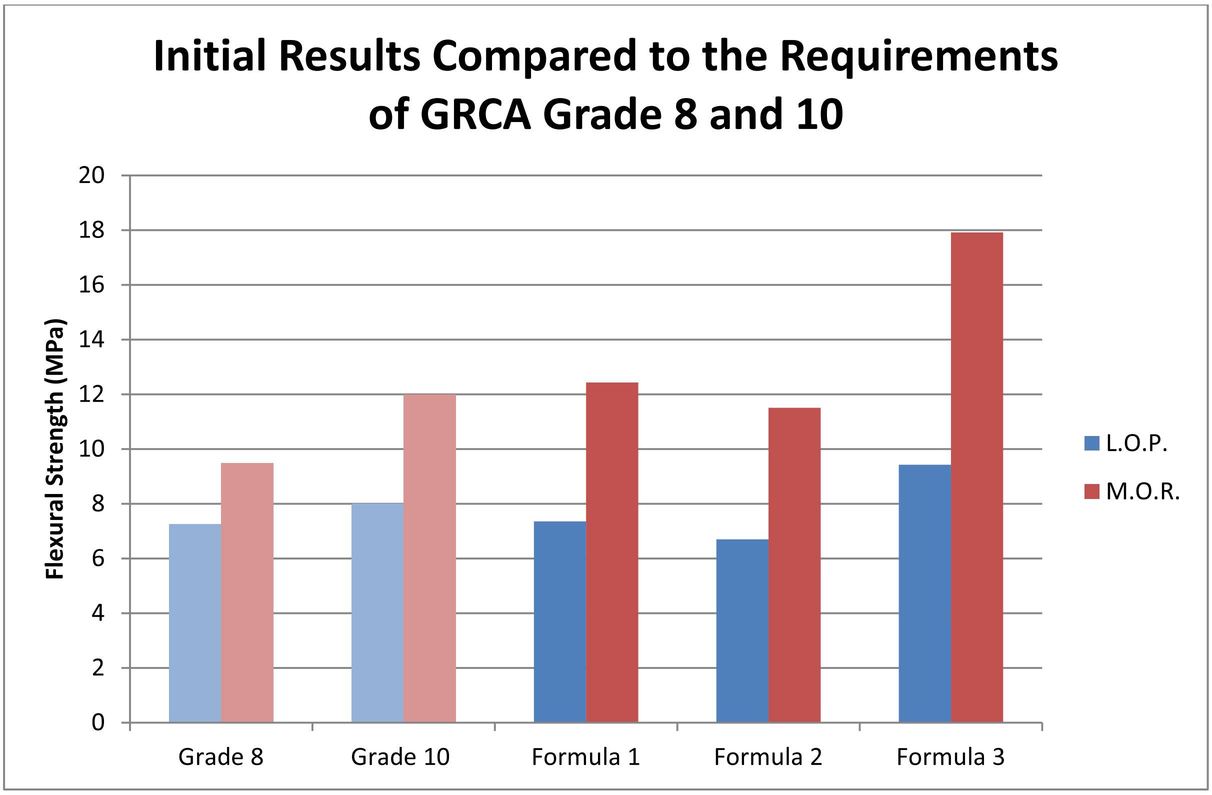

Figure 1. *Initial Results Compared to the Requirements of GRCA Grade 8 and 10*

Two of the formulations were very disappointing and it was decided not to progress further with them. However, the third was very encouraging and showed us that a GRC Premix with enhanced properties was possible. Unfortunately, Formula 3 had certain drawbacks, commercially it turned out to be difficult to guarantee supply, and technically it was very fast setting and unsuitable for subsequent spray production.

After this setback, it was decided to proceed independently and develop an in-house formulation.

A considerable amount of data was available on the internet and further information was obtained from “Ultra-High Performance Concrete and Nanotechnology in Construction” - The proceedings of Hipermat 2012 International Symposium on UHPC and Nanotechnology for High Performance Construction Materials. Kassel March 7-9, 2012

Materials

From the information gained we realised that the materials required must be considerably finer than those typically used for GRC production but we also wanted these materials to be freely available.

We decided to use the following for our trials.

Emsac 500S Microsilica Emulsion	Elkem Materials
Coarse Silica Sand (Standard GRC sand)	Available locally
Fine Silica Sand	Available locally
Limestone Flour	Available locally
White Pozzolan based on recycled glass	Imported

Ordinary Portland Cement CEM 1 52.5R was used for all the initial trials. Several different types of plasticizer were used.

Many formulations referred to a quartz powder, with particle diameters of 10-70 microns, however it was not possible to find this locally, so it was decided to use either the limestone flour or the white pozzolan as a substitute.

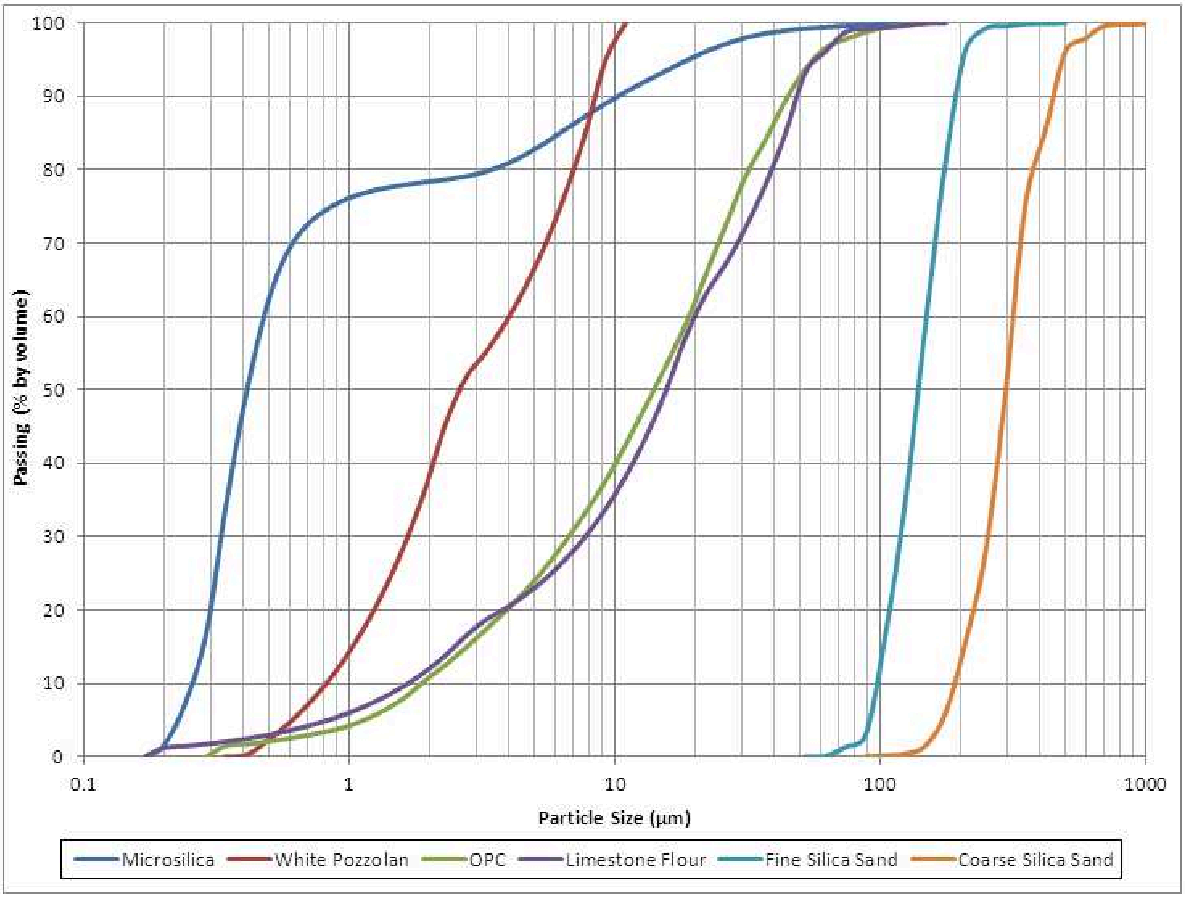

Figure 2. *Grading curves*

The grading curves for the raw materials used are shown in Figure 2, median particle sizes for each material are shown in Table 1. See Image 1 for a visual representation of the particle packing.

Material	**Median Particle Size (µm)**
Microsilica	0.41
White Pozzolan	2.63
OPC	14.3
Limestone Flour	15.6
Fine Silica Sand	140
Coarse Silica Sand	297

Table 1. *Median particle size*

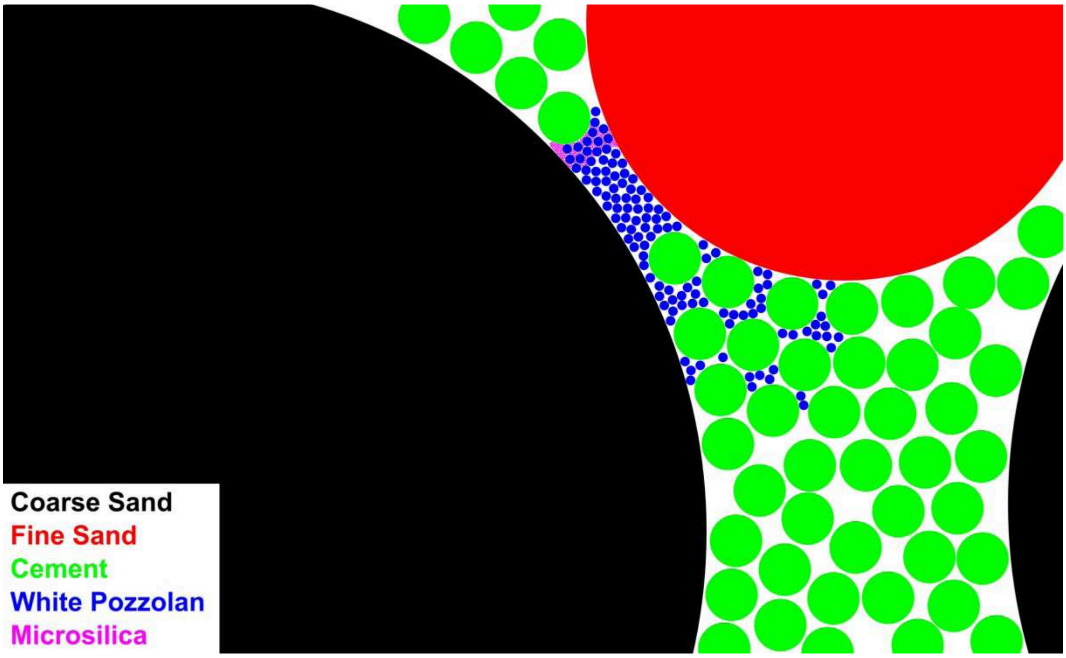

Image 1. *Visual representation of the particle packing*

STAGE 2

As mentioned above, the fine quartz powder was proving difficult to obtain and whilst waiting for alternatives, we carried out several trials using the standard GRC silica sand with microsilica and other pozzolans.

The flexural testing results are shown in Figure 3.

These results gave between Grade 8 and Grade 10 and were similar to what one would expect from a sand/cement matrix.

After some research, we decided to base our next formulations on the Andreassen model of particle packing

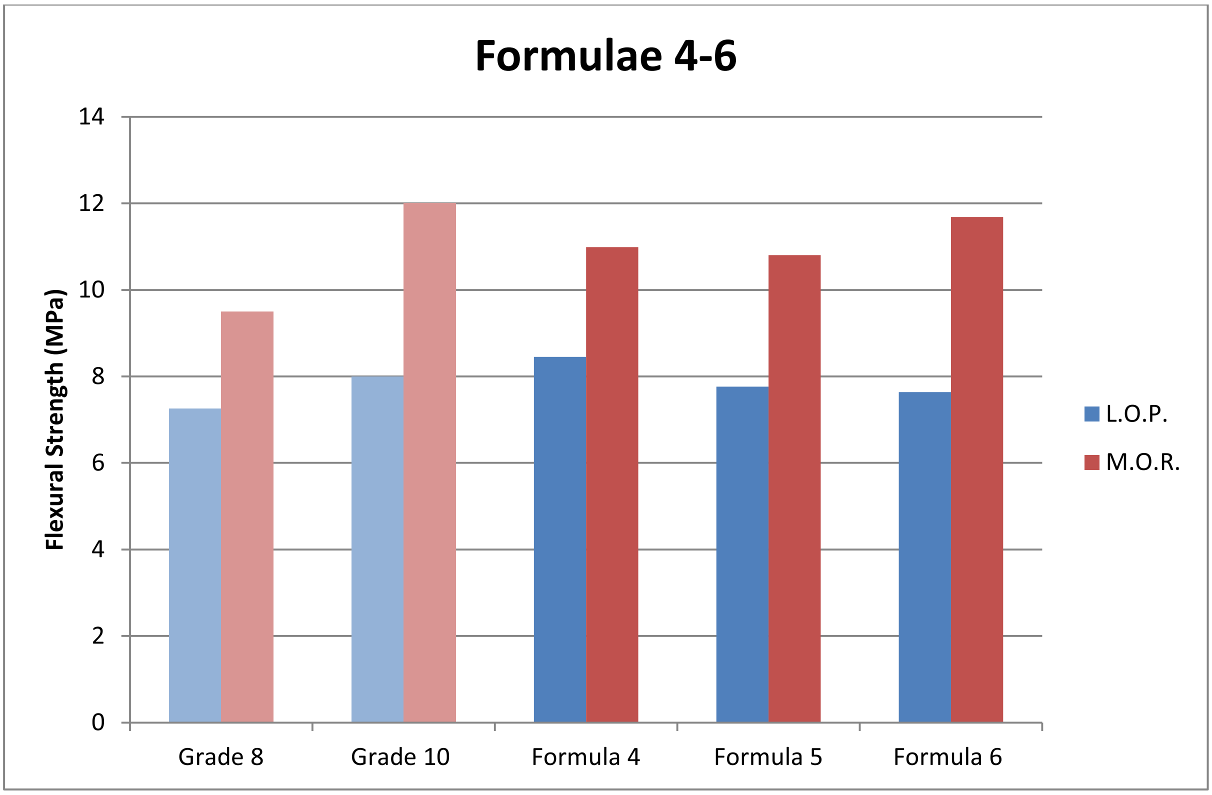

Figure 3. *Formulae 4-6*

STAGE 3

Fine silica sand and limestone flour was now available and mixes were developed based on an Andreassen curve, with a q-value of 0.37.

These results were much more encouraging and the last formulation tested, Formula 9, gave properties far in excess of Grade 10 GRC. However, we had still not reached the strengths obtained from one of the initial products, Formula 3.

It was becoming obvious that to succeed we had to get as close as possible to the ideal grading. After further research, we decided to base our formulations on the modified Andreassen model of particle packing:

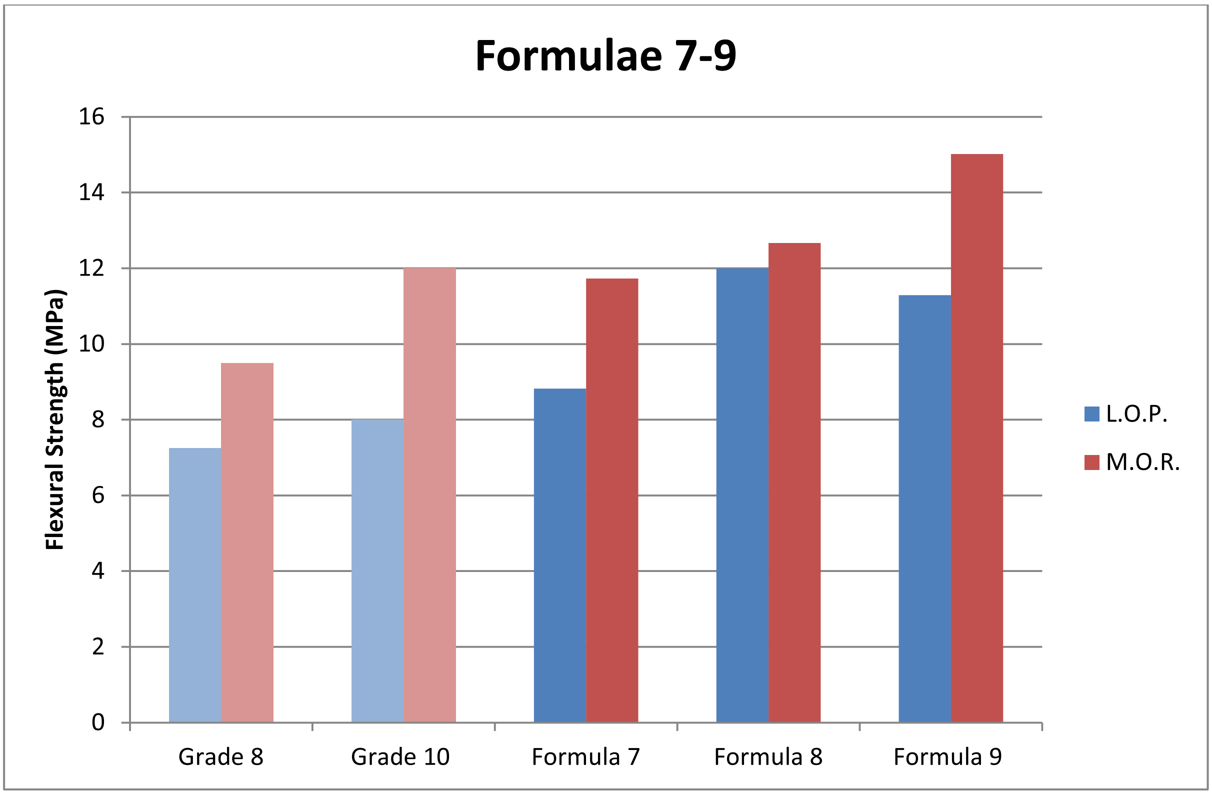

Figure 4. *Formulae 7-9*

STAGE 4

We then modified the idealised Grading Curve and modified the mix proportions in line with q=0.37, and later q=0.28.

We also reduced the water/cement ratio still further by increasing the plasticizer above normal dosage rates.

At last the result we were looking for. Formula 13 gave the highest result we had known for a cast premix with 3% glass fibre. The % Strain to MOR was 0.266% which is also extremely high for premix GRC.

Grading curves for the formulae compared to the Andreassen curves are shown in Figures 6 and 7.

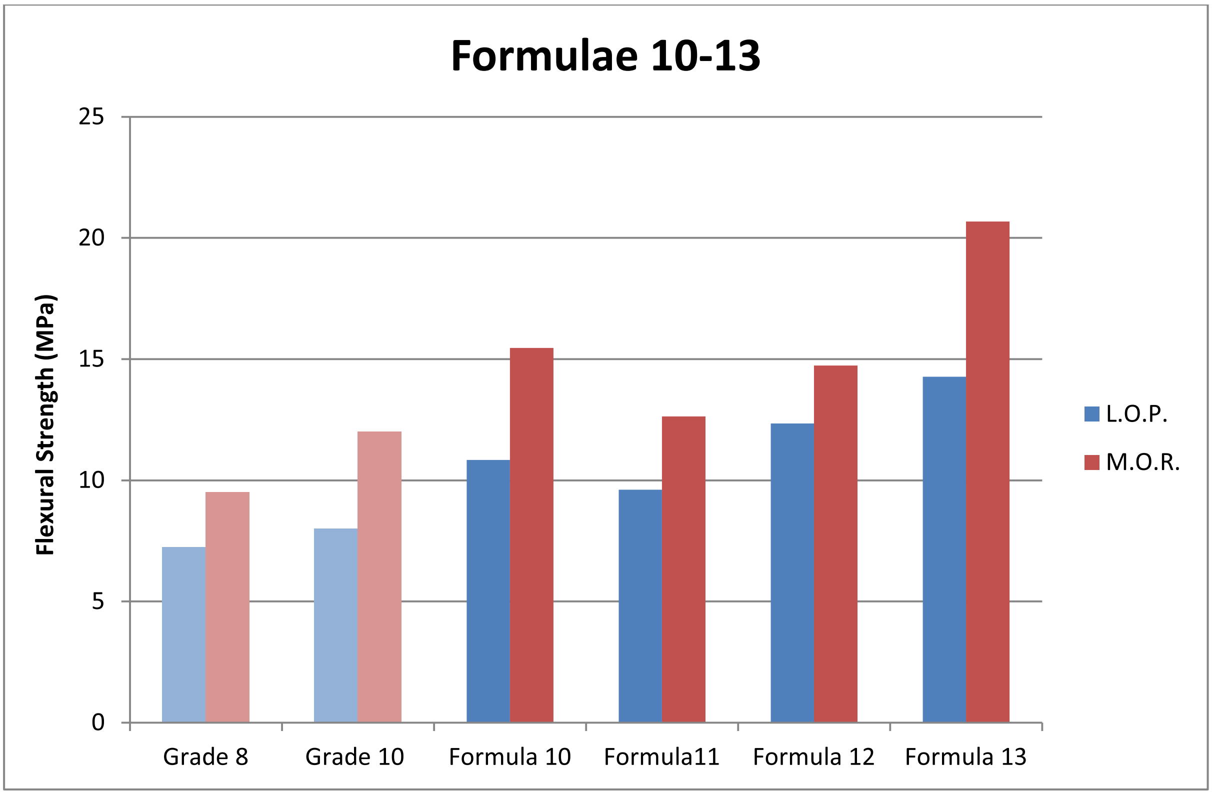

Figure 5. *Formulae 10-13*

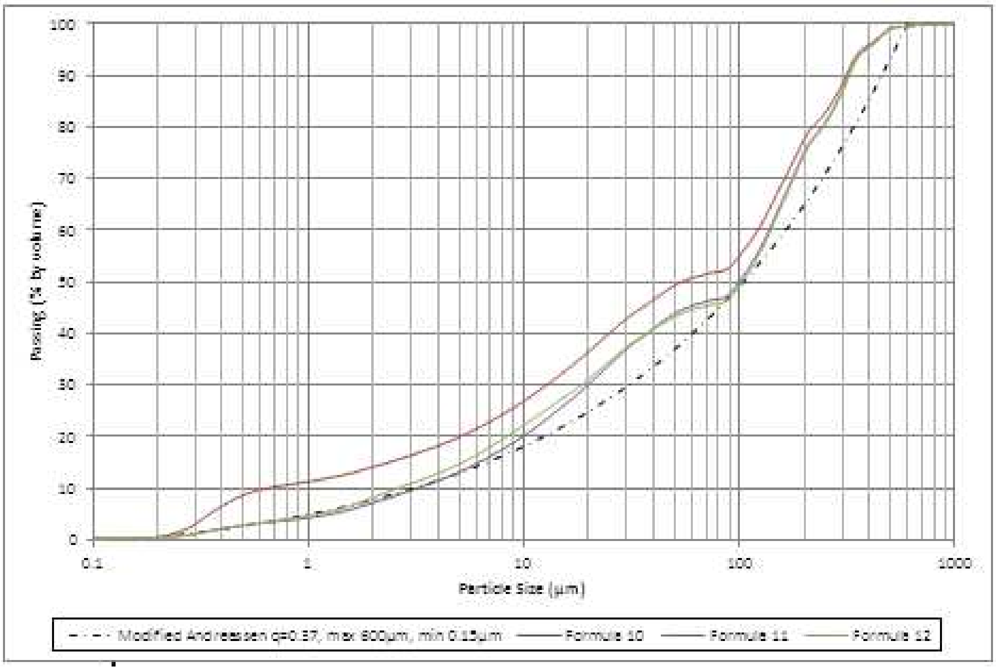

Figure 6. *Grading curves for the formulae compared to the Andreassen curves*

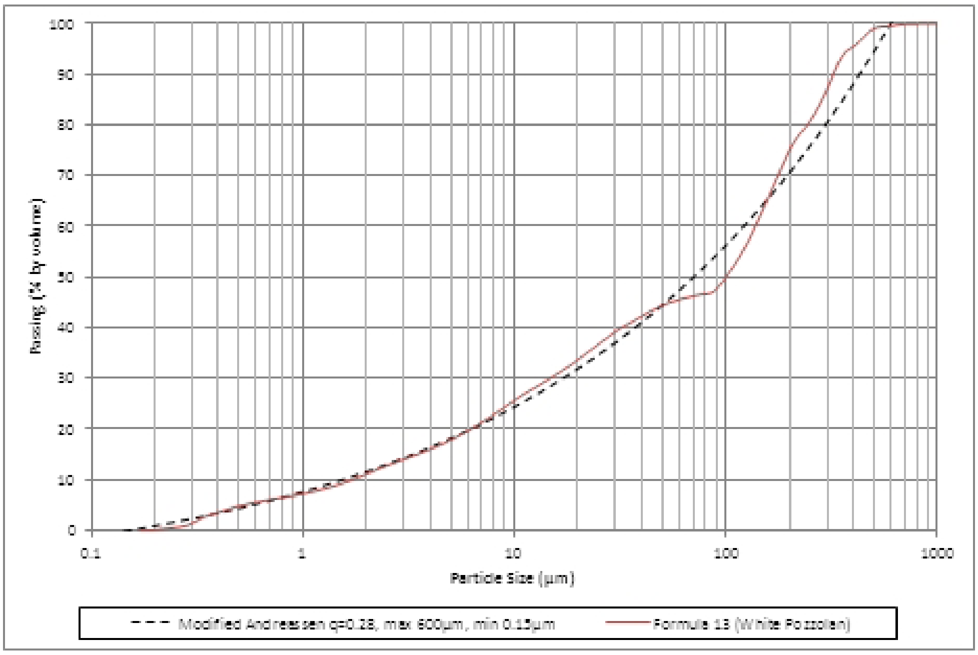

Figure 7. *Grading curves for the formulae compared to the Andreassen curves*

Formula 13 was repeated and test boards were produced using 10x10 net in each face, and also by the Hand Spray technique with 5% glass fibre.

The Stress/Strain Curves for the Hand Spray and Premix Results are reproduced in Figures 8 and 9 respectively. Their corresponding properties are shown in Tables 2 and 3.

Table 2. *Hand spray properties*

Test No	Face in Tension	LOP (MPa)	MOR (MPa)	Strain to LOP (%)	Strain to MOR (%)	Ym (GPa)
1	Mould	15.636	43.039	0.064	0.823	24.295
2	Trowel	11.015	30.004	0.070	0.802	15.844
3	Mould	11.197	26.282	0.098	0.878	11.436
4	Trowel	13.806	34.224	0.059	0.783	23.314
Mean		**12.914**	**33.387**	**0.073**	**0.822**	**18.722**

Table 3. *Premix properties*

Test No	Face in Tension	LOP (MPa)	MOR (MPa)	Strain to LOP (%)	Strain to MOR (%)	Ym (GPa)
1	Mould	14.717	24.124	0.050	0.343	18.998
2	Trowel	15.155	17.386	0.060	0.244	31.036
3	Mould	13.466	17.077	0.051	0.125	29.067
4	Trowel	14.389	19.568	0.050	0.205	25.069
Mean		**14.432**	**19.539**	**0.053**	**0.229**	**26.042**

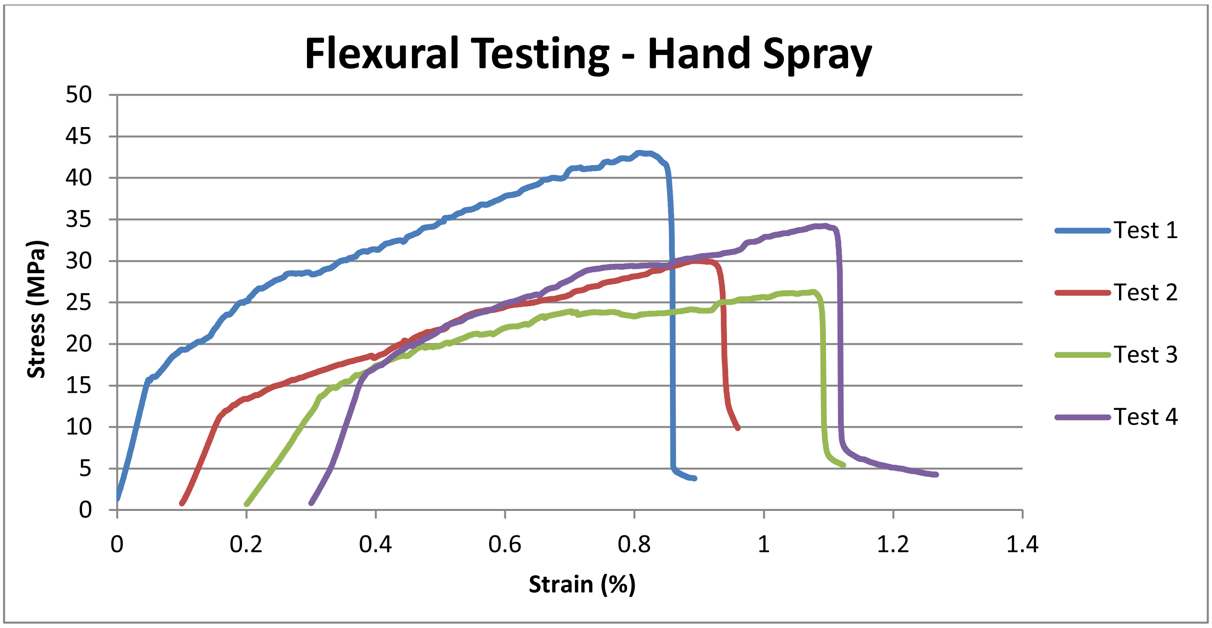

Figure 8. *Flexural testing – Hand spray*

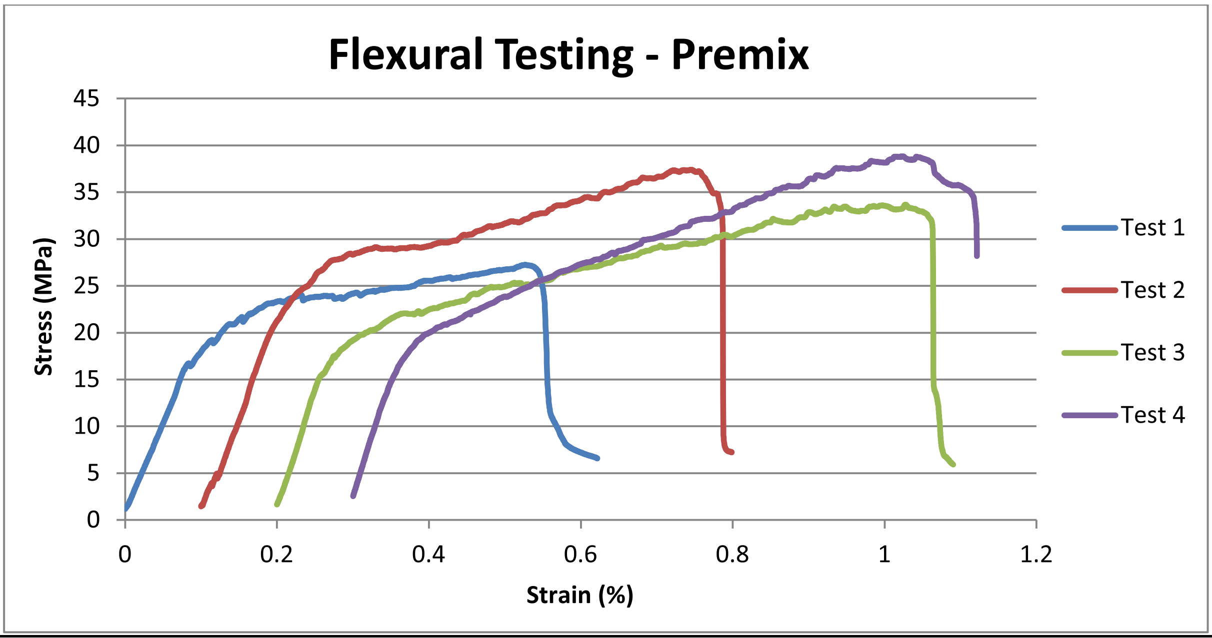

Figure 9. *Flexural testing - Premix*

The full results are summarized in Figure 10 and compared to Grade 18 GRC.

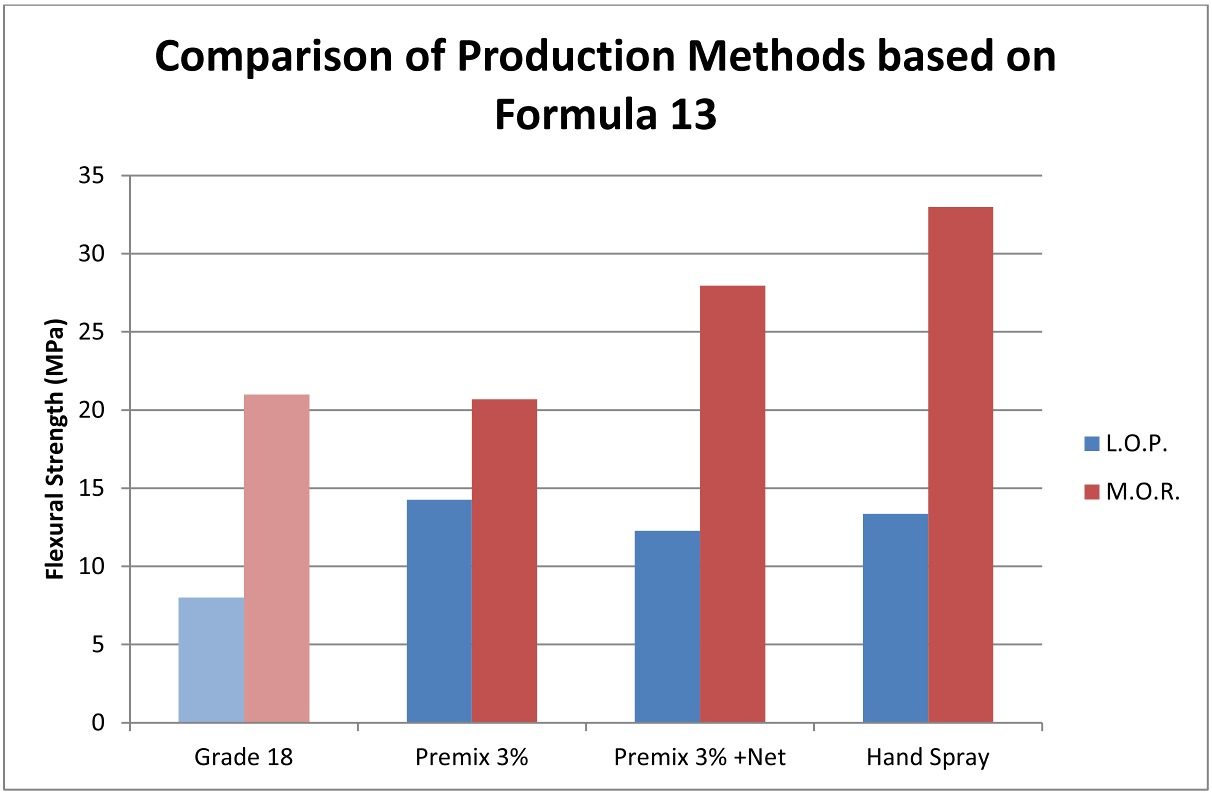

Figure 10. *Comparison of Production Methods based on Formula 13*

These results were very encouraging, and showed that a GRC formulation with enhanced properties could be achieved, using widely available raw materials.

The LOP results of 12-14MPa were particularly encouraging, showing that increased matrix strengths could be obtained irrespective of the production method used.

Formula 13 was then modified to replace the imported white pozzolan with locally available limestone flour. A comparison of the two grading curves is shown in Figure 11. A full mix was produced and four sample boards were cast, using the premix technique with 3% glass fibre. Two of the boards were tested at 28 days and the other two were kept for testing at a later date.

The results are shown in Figure 12 and compared with the requirements of the various GRCA Grades 8, 10 and 18.

The Modulus of Rupture was slightly lower, but the Limit of Proportionality was correspondingly slightly higher. This gave encouragement that a satisfactory HP GRC could be produced without the need for import.

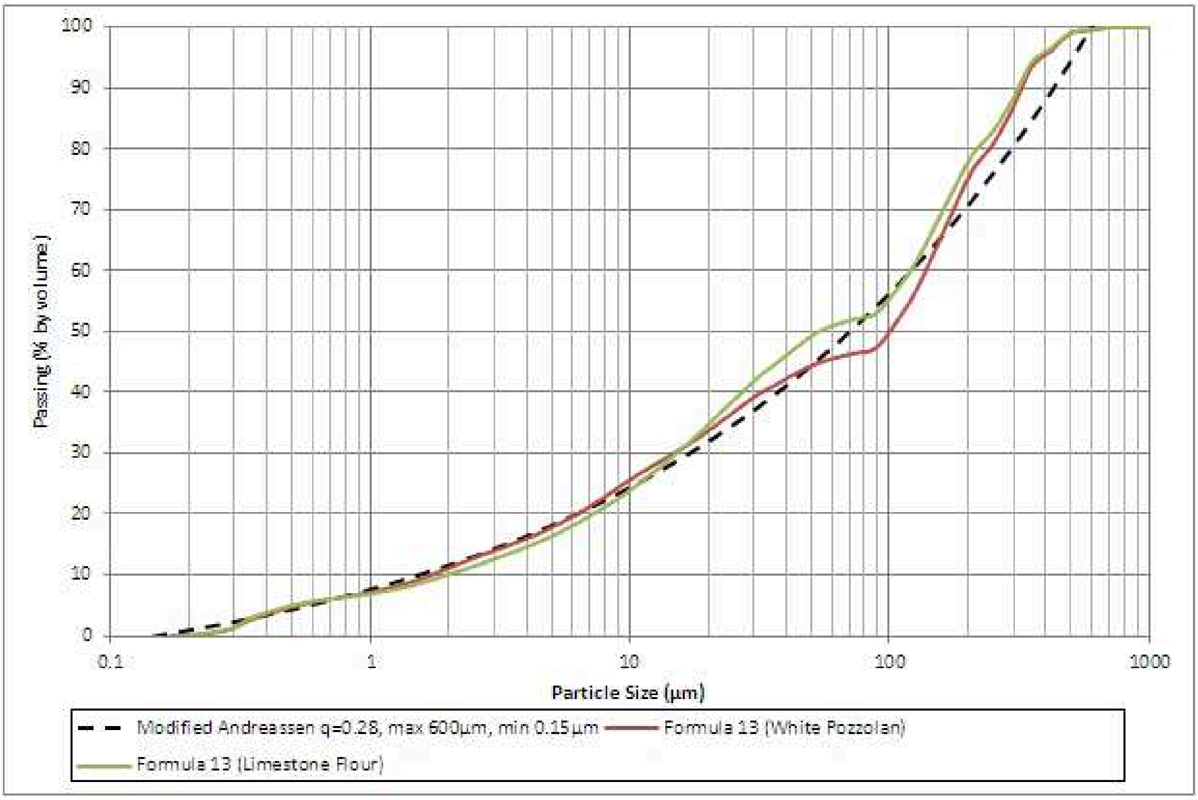

Figure 11. *Comparison of the two grading curves*

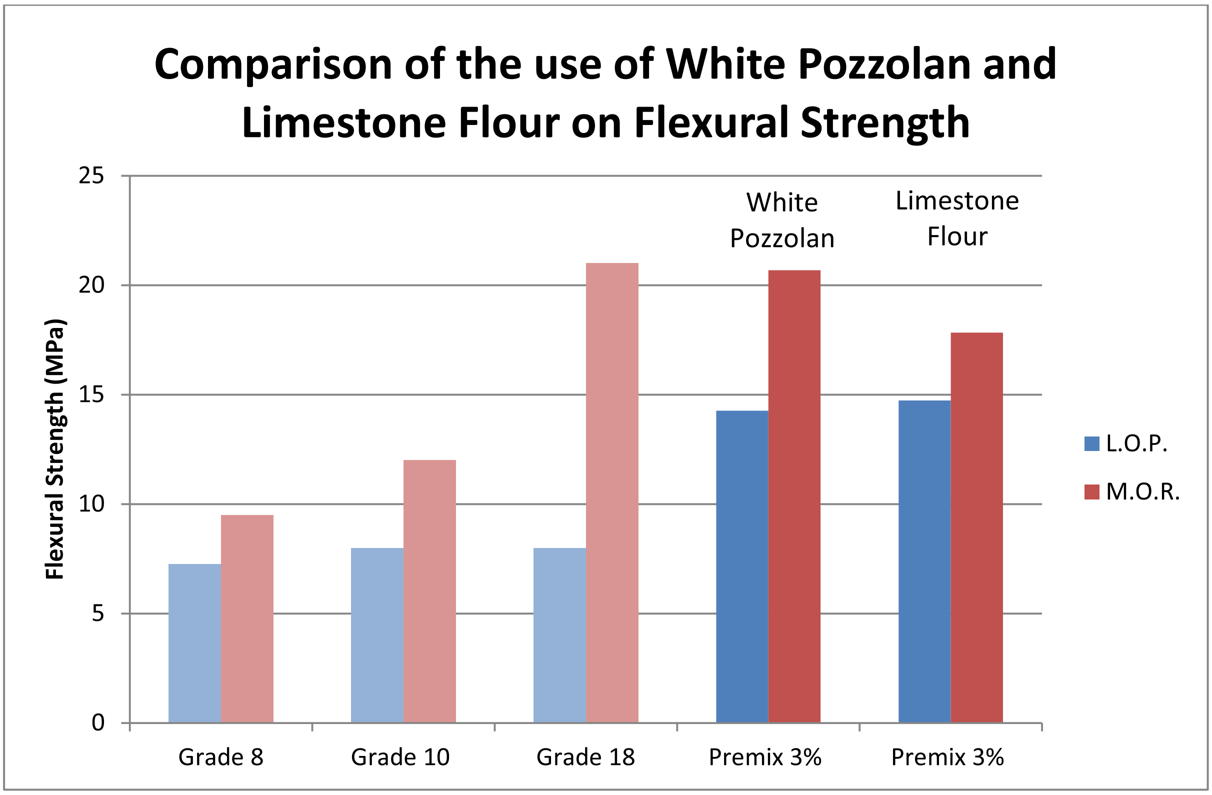

Figure 12. *Comparison of the use of White Pozzolan and Limestone Flour on Flexural Strength*

Density and Water Absorption
With HP GRC mixes, the particle packing is improved and this should show in increased density and reduced water absorption. As can be seen from the results in Table 4, this was confirmed.

	T1	T2	L1	L2
Wet density	2.29	2.27	2.33	2.32
Dry density	2.15	2.13	2.19	2.17
Water absorption	0.07	0.07	0.07	0.07
	Wet Density g/	**Dry Density g/**	**Water Absorption%**	
Mean value	2.30	2.16	6.70	

Table 4. *Density and water absorption*

White Cement
It is realised that many GRC products are either white or involve light shades based on white cement. It is therefore important that a white option is available. Formula 13 was therefore modified to include white cement and white microsilica. The white microsilica was supplied as a powder rather than an emulsion. The microsilica was pre-dispersed in its own weight of water and the dispersion was thoroughly remixed prior to use.

A full mix was produced and varying fibre additions used. The workability was generally poor and this is an area which will require further investigation.

Flexural Testing on the five boards produced was carried out at 28 days and the results are shown in Figure 13.

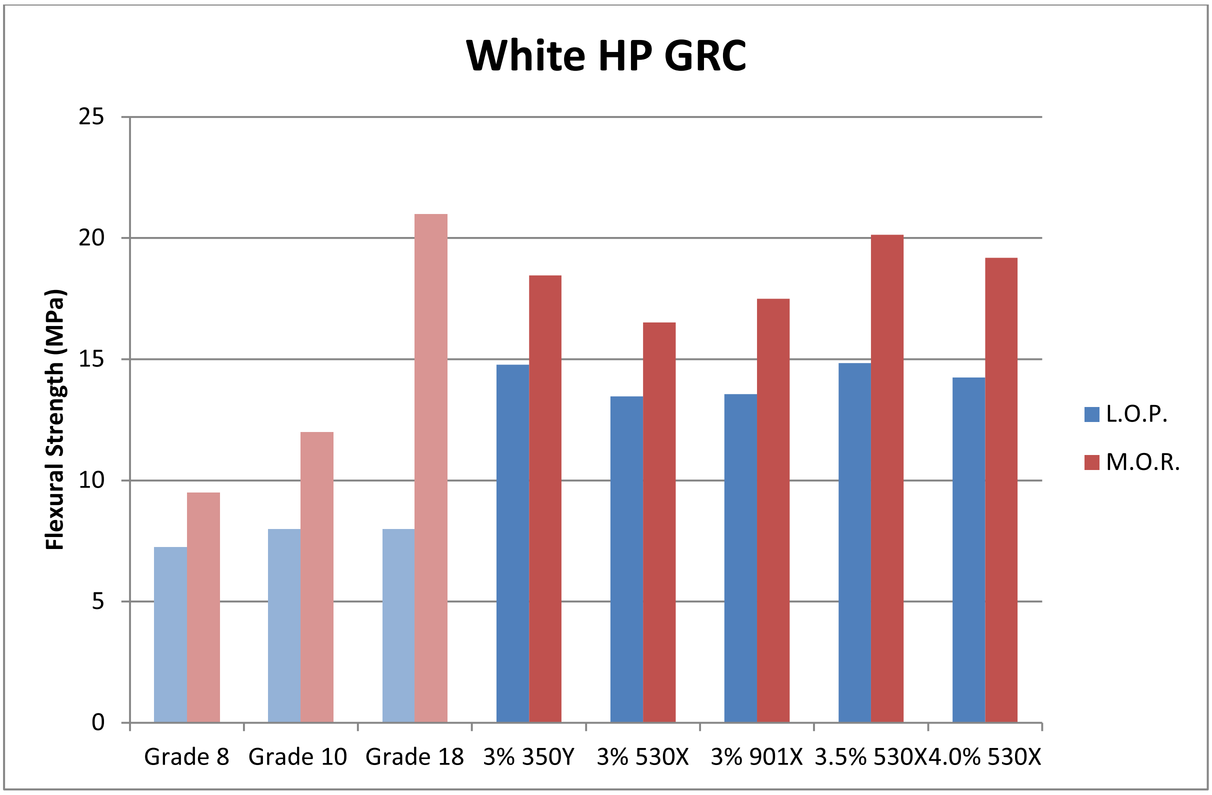

Figure 13. *White HP GRC*

Mix Designs Used

The mix design used for Formula 13 and its modifications are shown in Table 5. In many ways they are similar to a standard formulation, with a 1:1 sand/cement ratio. The main differences being the finer particles used, the lower water/binder ratios and the increased plasticizer content.

Table 5. *Mix design used for Formula 13 and its modifications*

	Formula 13		
	HP GRC	**HP GRC**	**HP White GRC**
Material	A	B	
	05-Nov	25-Nov	16-Dec
Cement OPC 52.50	24.8	28.8	25
Coarse Silica Sand	16	14	16.1
Fine Silica Sand	16.0	14	16.1
Microsilica Emulsion	6.4	6.4	4.8
Limestone Flour		4	
White Pozzolan	4.0		4.03
Flowaid SCC			
Flowaid A – Optional, after mixing	0.32	Not added	0.63
Flowaid B	0.64	0.64	0.63
Added Water	3.84	3.2	3.89
Total Water	7.71	6.85	7.17
Water/Cementitious Components	0.241	0.214	0.228
The microsilica and white pozzolan are considered as cementitious components and the water content of the plasticizer is allowed for in the total water.			

DISCUSSION

It is felt that the project has fulfilled its purpose in producing a HP GRC Matrix using widely available raw materials. Not everything is understood, particularly in terms of the water/cement ratio. Conventional thinking is that as the sands and fillers get finer, more water is required, but the opposite seems to be the case. It is also difficult to comprehend how there is sufficient water for hydration. The plasticizer additions are considerably higher than in a standard GRC mix and in calculating the total water/binder ratio, the water content of the plasticizers must be allowed for.

Several plasticizers were developed and used during the project and there is still scope for further optimisation to get the required levels of workability.

FUTURE

There is the potential to introduce a new matrix to the GRC industry, which will allow products to be made which were not possible in the past. In order for this to be achieved, it is necessary for manufacturers to further develop the formulations outlined in this paper, and to produce full scale products rather than the flat boards produced in this report. Designers also have an important role to play. There is no point in producing a higher strength matrix if these enhanced properties are not reflected in the design.