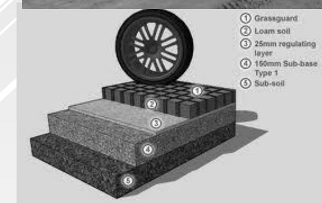
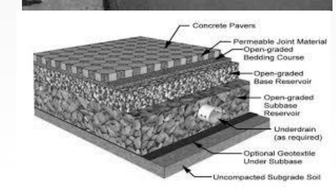
LECTURE 10:
Base courses showing self cementation





Worldwide many secondary materials are used for base courses. A number of these materials show self cementing action and in this part of the lecture notes some attention is paid to the mechanical characteristics of these materials as they were determined as part of a large research program [50] to determine whether or not these recycled materials could be used successfully in pavements. The following materials were investigated (table 23).

Number	Base course material	Code
1	Crushed masonry	MG
2	Mixture of crushed masonry and crushed concrete (50% - 50%)	FF
3	Lava	LA
4	Pelletized blast furnace slag	SS
5	Sand cement	ZC
6	Blast furnace slag	HO
7	Crushed concrete	BG
8	Phosphorous slag	FO
9	MG + 15% electro furnace slag	ME

Table 23: Investigated base course materials.

Test pavements were constructed with these materials. These pavements were placed on a sand subgrade; the base thickness applied was 250 mm. On top of the base materials which didn't show self-cementation (being MG, FF, LA and SS), a 180 mm thick asphalt layer was placed. A 120 mm thick asphalt layer was placed on layers which were expected to show self-cementation (ZC, HO, BG, FO and ME).

Falling weight deflectometer tests were performed at different moments in time to evaluate the increase of the stiffness modulus as a function of time of the base course materials. Figures 100, 101, 102 and 103 summarize the findings.

Base course material	Code
Crushed masonry	MG
Mixture of crushed masonry and crushed concrete (50% - 50%)	FF
Lava	LA
Pelletized blast furnace slag	SS
Sand cement	ZC
Blast furnace slag	HO
Crushed concrete	BG
Phosphorous slag	FO
MG + 15% electro furnace slag	ME

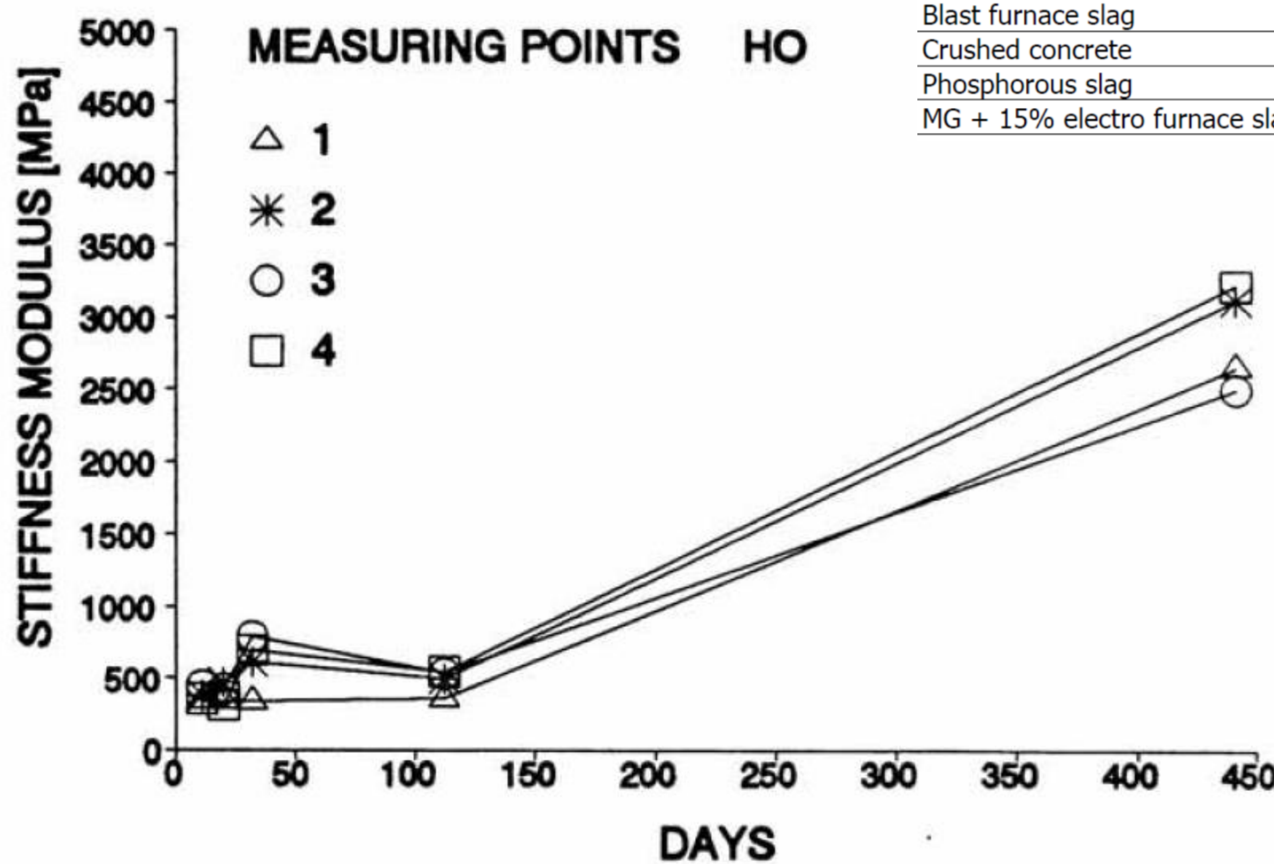


Figure 100: Increase of the stiffness modulus in time of the base course made of blast furnace slag.

Base course material	Code
Crushed masonry	MG
Mixture of crushed masonry and crushed concrete (50% - 50%)	FF
Lava	LA
Pelletized blast furnace slag	SS
Sand cement	ZC
Blast furnace slag	HO
Crushed concrete	BG
Phosphorous slag	FO
MG + 15% electro furnace slag	ME

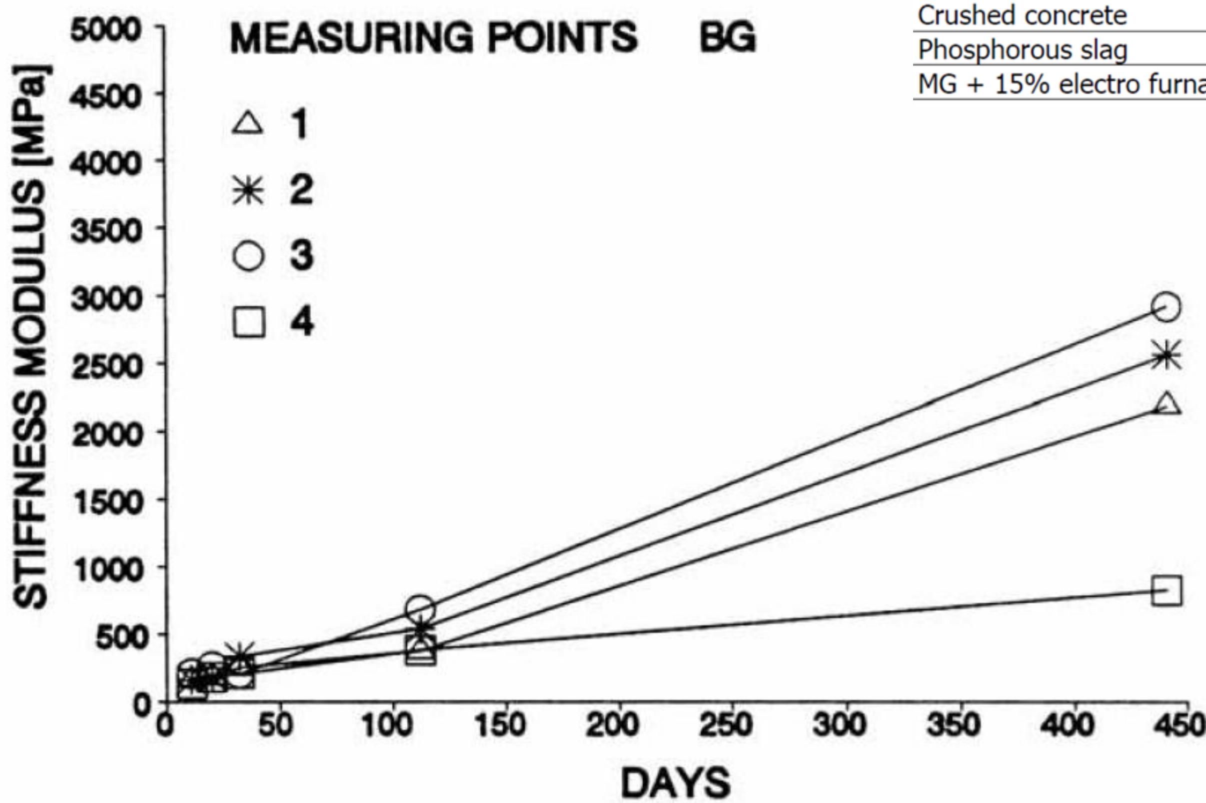


Figure 101: Increase of the stiffness modulus in time of the base course made of crushed concrete.

Base course material	Code
Crushed masonry	MG
Mixture of crushed masonry and crushed concrete (50% - 50%)	FF
Lava	LA
Pelletized blast furnace slag	SS
Sand cement	ZC
Blast furnace slag	HO
Crushed concrete	BG
Phosphorous slag	FO
MG + 15% electro furnace slag	ME

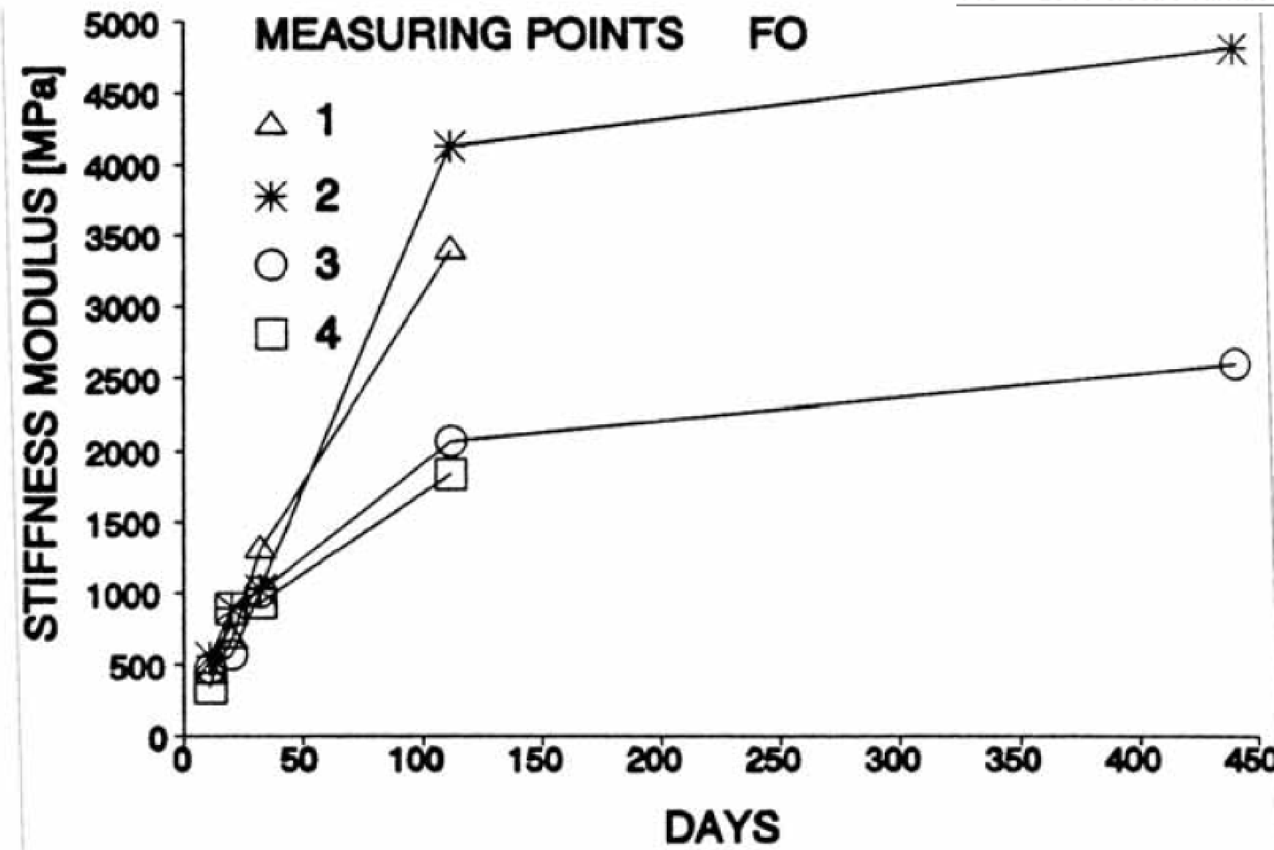


Figure 102: Increase of the stiffness modulus in time of the base course made of phosphorous slag.

Base course material	Code
Crushed masonry	MG
Mixture of crushed masonry and crushed concrete (50% - 50%)	FF
Lava	LA
Pelletized blast furnace slag	SS
Sand cement	ZC
Blast furnace slag	HO
Crushed concrete	BG
Phosphorous slag	FO
MG + 15% electro furnace slag	ME

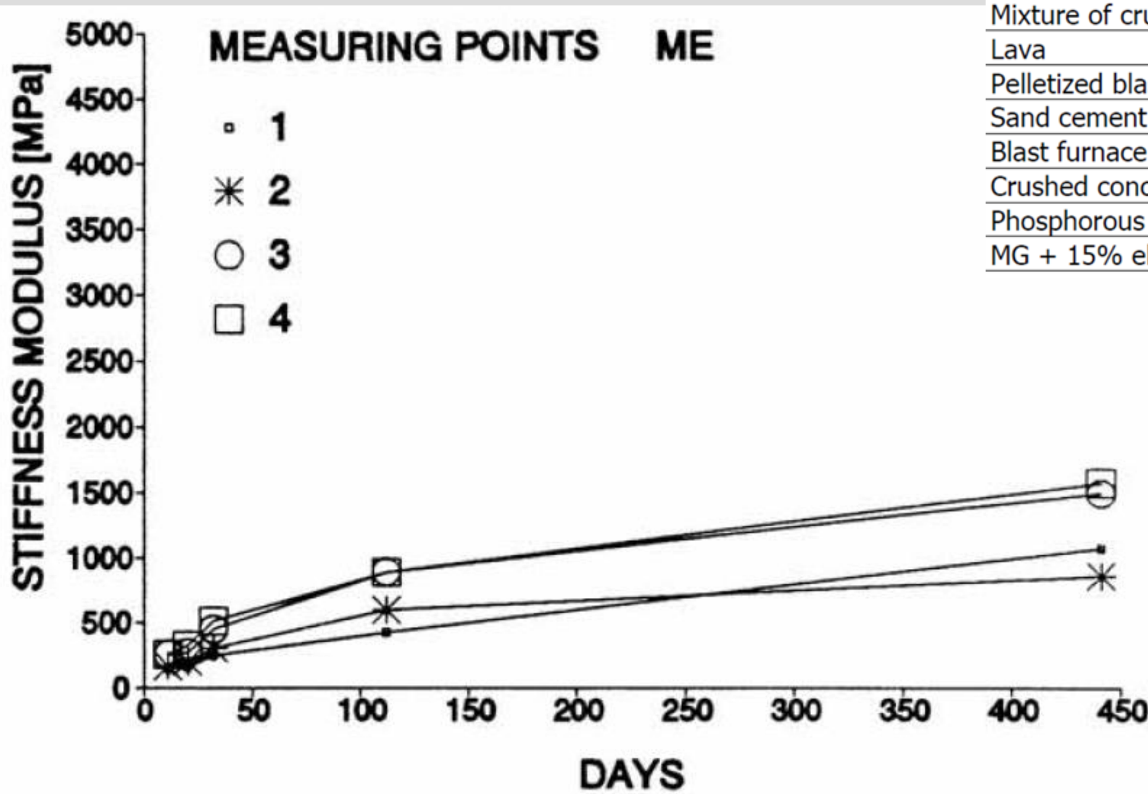


Figure 103: Increase of the stiffness modulus in time of the base course made of crushed masonry mixed with electro furnace slag.

Two aspects call the attention.
a. there is a strong increase of the stiffness modulus in time,
b. there is a relatively large amount of scatter in the data.

Similar trends have been reported by van Niekerk [48]. He analyzed the development in time of crushed concrete – crushed masonry mixture (63% crushed concrete) without and with addition of 10% blast furnace slag. Figures 104 and 105 shows the Mr relationships that were obtained.

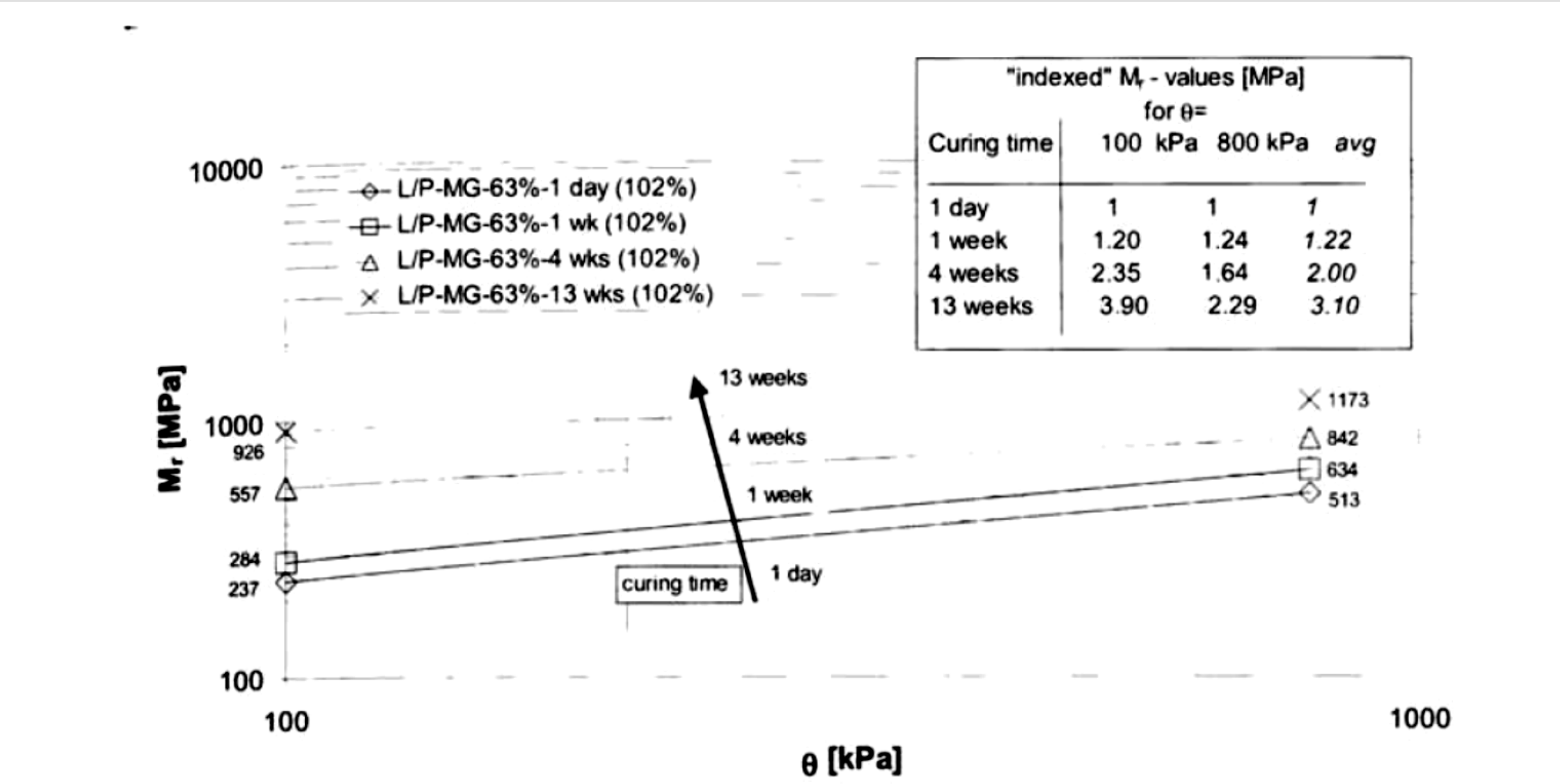


Figure 104: Development in time of the stiffness of a crushed concrete – crushed masonry mixture.

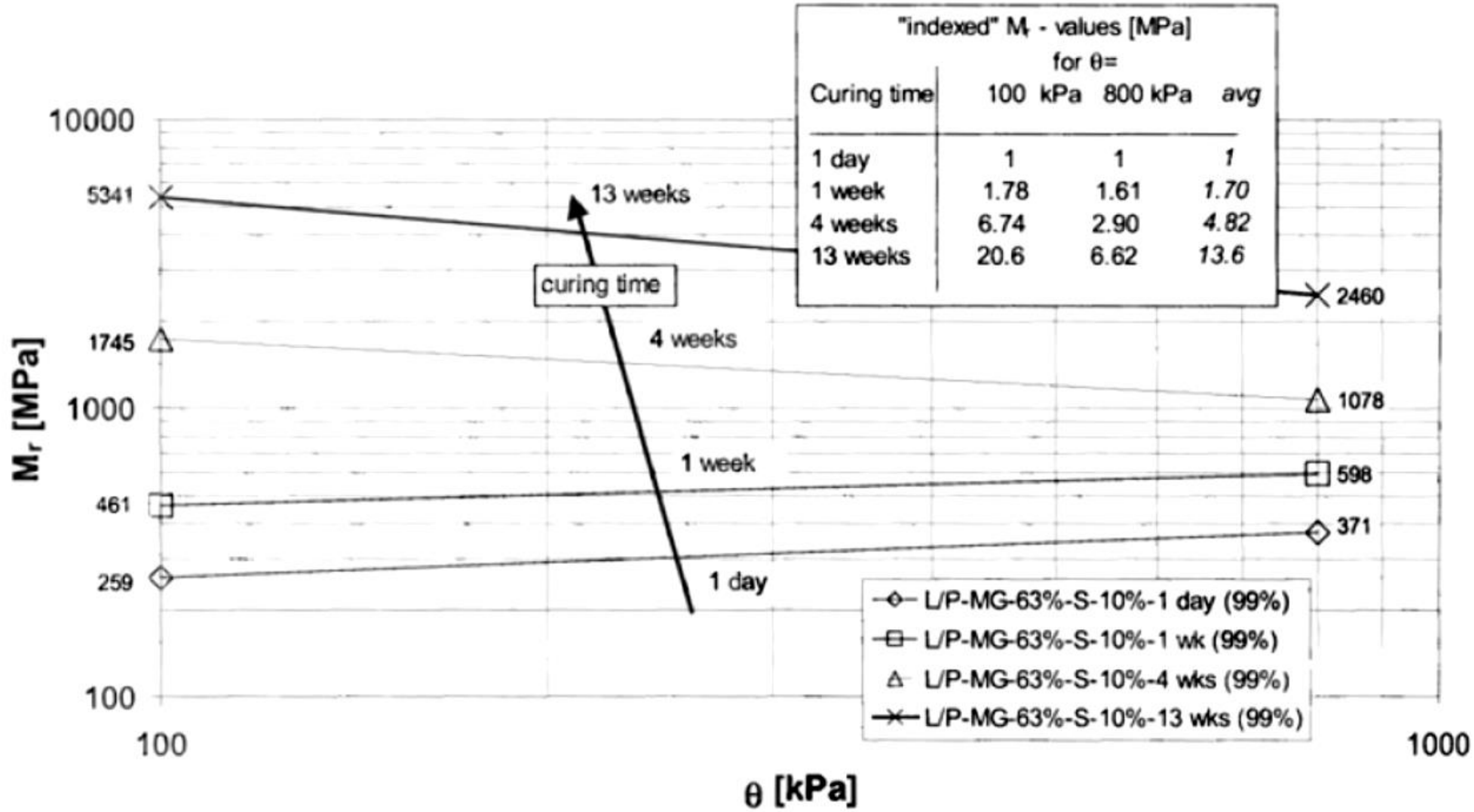


Figure 105: Development in time of the stiffness of a crushed concrete – crushed masonry mixture to which 10% of blast furnace slag is added.

These figures clearly show an increase of the stiffness in time and also show that the stiffer the materials becomes, the less dependent the stiffness is from the stress conditions.

Figure 106 shows the permanent deformation behavior of the masonry – concrete base material when mixed with 10% slag. The figure shows that the permanent deformation is very small but also that the permanent deformation suddenly increases rapidly if the stress ratio reaches values of 0.47 and higher. At a stress ratio of 0.4 no significant deformation develops. It is recommended to use this value for design purposes.

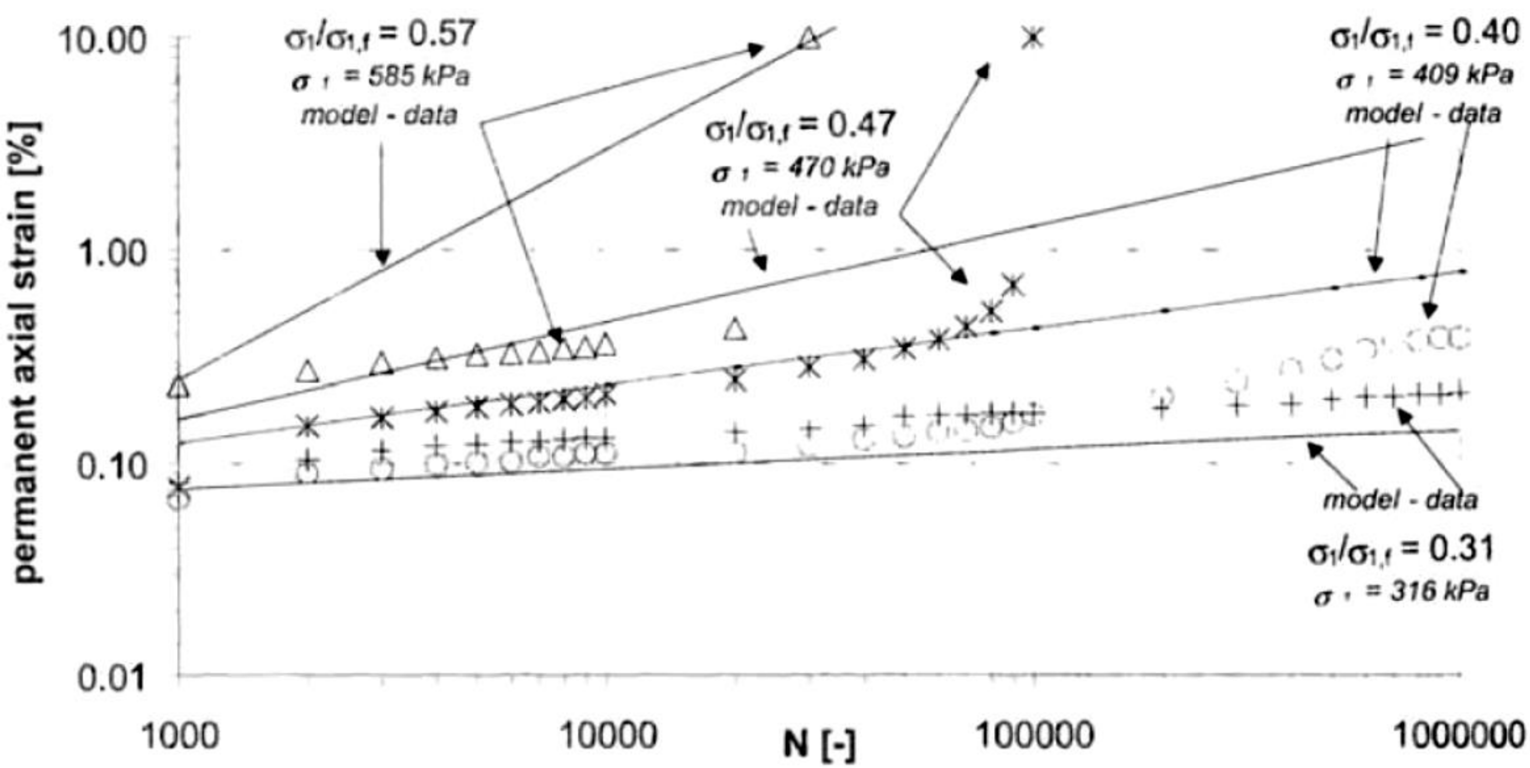
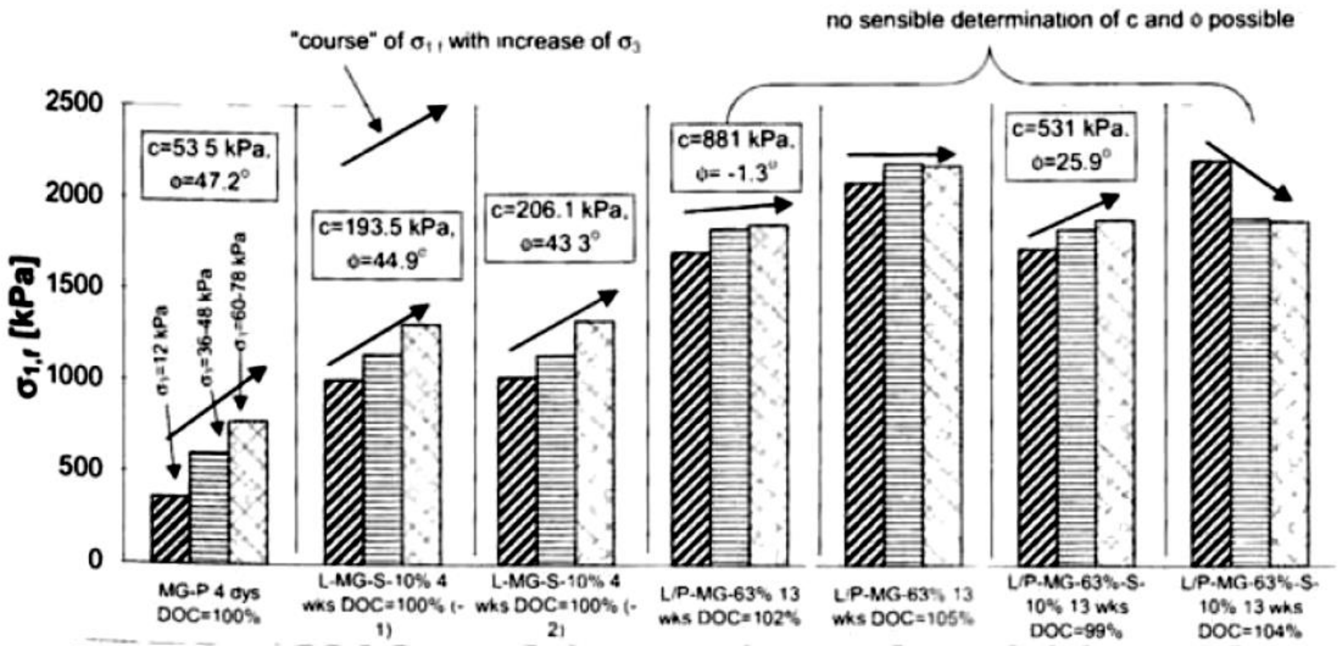


Figure 106: Permanent strain as a function of the σ_1 / σ_{1f} ratio for a crushed concrete – crushed masonry base (63% concrete) to which 10% of blast furnace slag is added, after 4 weeks curing.

The rapid increase in strength in time as a result of self-cementation is also shown in figure 107. After 13 weeks the failure stress has reached a value of about 1.7 MPa and seems to be independent of the confining stress level. From the results presented in figure 107, it is clear that these types of material can provide significant stiffness and strength to the pavement structure.



	MG-P 4 dys DOC=100%	L-MG-S-10% 4 wks DOC=100% (-1)	L-MG-S-10% 4 wks DOC=100% (-2)	L/P-MG-63% 13 wks DOC=102%	L/P-MG-63% 13 wks DOC=105%	L/P-MG-63%-S-10% 13 wks DOC=99%	L/P-MG-63%-S-10% 13 wks DOC=104%
12	364	1007	1023	1705	2080	1720	2195
40	603	1144	1141	1831	2184	1824	1881
70	780	1310	1330	1854	2171	1875	1867

material / curing time / DOC -variant

Figure 107: Stress at failure (σ_{1f}) at different confinement levels (σ_3) for crushed concrete – crushed masonry mixtures (63% crushed concrete, indicated with MG-63%) and a similar mixture with 10% blast furnace slag (indicated with MG-63%-S-10%), at different moments in time.

One should however be aware of the fact that the all the results presented so far (including those of the test sections shown in figures 100 to 103) are obtained on undisturbed material. The material was allowed to develop self-cementation and during the curing time no loads were applied. In reality however (heavy) construction traffic will use the prepared base course as a roadway which means that significant stresses and strains will be induced which might result in premature damage. The effect of this has also been studied by van Niekerk [48] and some of his findings will be presented hereafter.

In his study to determine the effect of early loading of a self cementing material, a 300 mm base layer consisting of a mixture of crushed concrete – crushed masonry mixed with 10% blast furnace slag was place on a sand subgrade. The base was compacted to a degree of compaction of approximately 105%. A double surface treatment was applied to protect the base from climatic influences. After construction of the base, the loading schedule as shown in figure 108 was applied

Type of load	# of points	Code	Week													
			0	1	2	3	4	5	6	7	8	9	10	11	12	13
Construction traffic 70 kN	2	CT-70	construction													
Traffic load 70 kN	2	T-70														
Traffic load 50 kN	2	T-50														
Traffic load 30 kN	2	T-30														
Traffic load 10 kN	2	T-10														
Delayed traffic 50 kN	2	DT-50														
Reference point	2	R														
Total	14															

Figure 108: Loading schedule.

The traffic loads were not real traffic loads but repeated falling weight deflectometer tests. A total of 100 load repetitions per day was applied per loading position. The stiffness modulus of the self-cementing base course was back calculated using the measured deflection bowls as input. Some results are shown in figure 109.

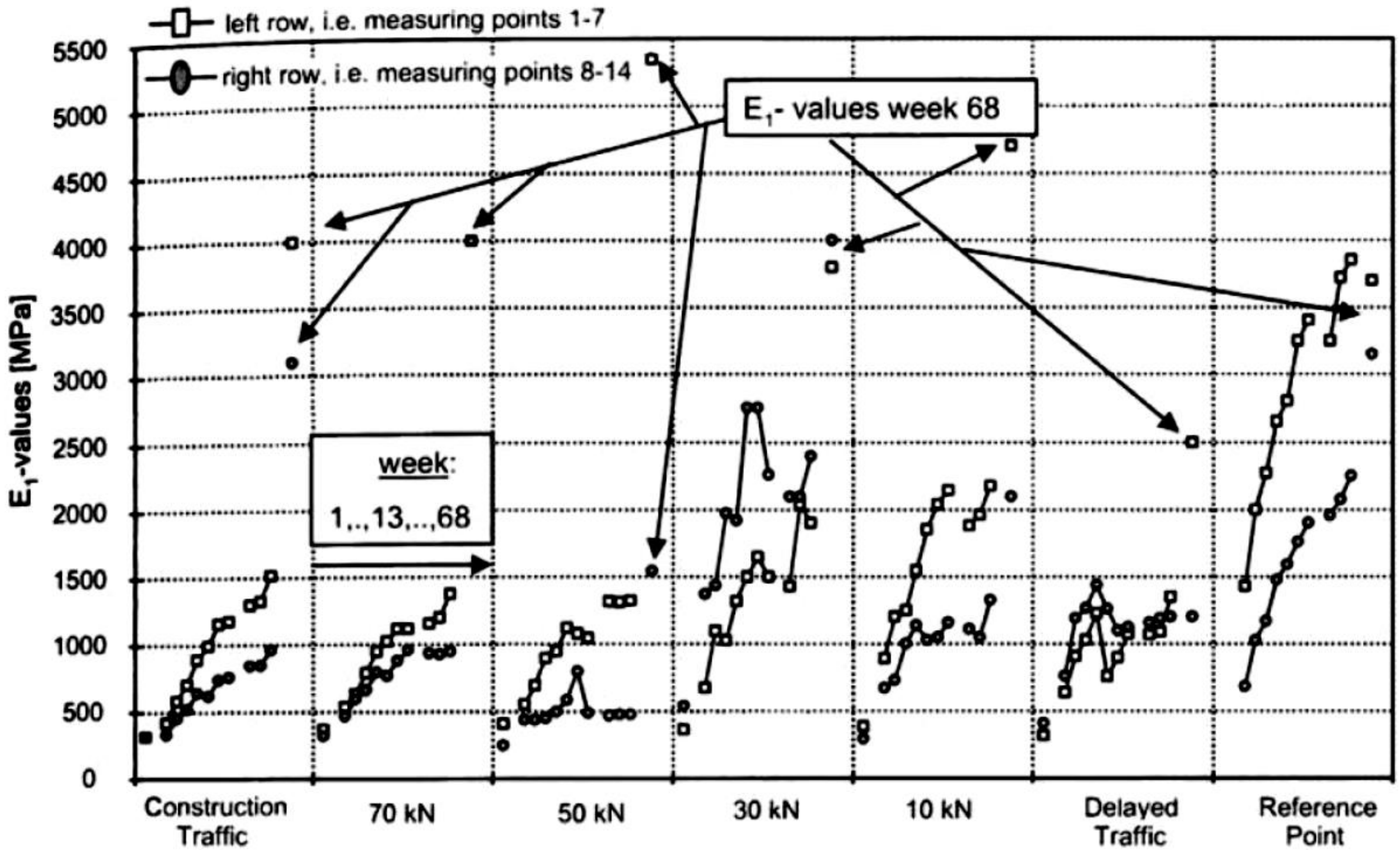


Figure 109: Development in time of the stiffness of a self-cementing base course as a function of the applied load.

Figure 109 clearly shows that the stiffness development of the base course is strongly influenced by the loading schedule. Also a significant amount of healing was observed during the period in which the section was not subjected to repeated loading by means of the falling weight equipment (period between week 13 and week 68). Furthermore quite some scatter in the results can be observed.

The figure also shows that heavy construction traffic has a significant influence on the stiffness development. Due to the high stresses and strains, self-cementation will hardly occur or develops slowly.

Since the falling weight loads were directly applied on the base course, an analysis was made to determine which falling weight load would simulate more or less the tensile strain at the bottom of the base when it had been covered with a 150 mm thick asphalt layer. It appeared that the 10 kN load simulated that the strain level fairly well. From figure 109 we can conclude that due to the 10 kN load, the stiffness modulus reduces to about 50% of its undisturbed value.

In conclusion this means that the negative of effect of traffic in general and construction traffic in particular should be taken into account when designing pavements with self-cementing base courses. For design purposes, it is recommended to adopt a stiffness value that is 50% of the value determined in the laboratory on undisturbed samples.