



TECHNICAL REPORT

THE IMMEDIATE TRAFFICKING OF CEMENT BOUND MATERIALS

HIGHWAYS AGENCY

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The British In-situ Concrete Paving Association

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The immediate trafficking of cement bound materials

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Summary

In the UK, cement bound materials currently require a seven-day curing period before trafficking. This has implications for the project programme and thus cost and means that CBM is rarely used for trunk road maintenance work.

In a project collaboratively funded by Highways Agency and Britpave, the immediate traffickability of a range of CBM was examined. The CBM investigated included cement bound sands, marine ballast, recycled material, crushed rock and slag. Aggregate hardness ranged from soft to hard, particle size from uniformly graded to well-graded, and particle shape from angular to rounded. The examination included laboratory testing to establish mechanical stability in the fresh state using the IBI (immediate bearing index) test, and visual assessment of the same mixtures under traffic in the field.

The results established that the better the grading and the more rugous and stronger the particles, the better the IBI value and the ability of the CBM to be trafficked immediately. Thus well-graded mixtures made from hard crushed or flaky aggregates performed well whereas mixtures made from uniformly graded or rounded aggregates performed poorly. Less well but reasonably graded mixtures or well-graded mixtures made from weak aggregate achieved intermediate performance.

On the basis of the findings, the report gives specification guidance and recommendations for the immediate or early trafficking of CBM, identifying those mixtures that can be trafficked early and those that require a curing period whilst strength develops. This will have construction and programme benefits where CBM is used for new work. In addition, it will also now be possible to use certain types of CBM for maintenance work, placing these CBM on a similar footing to that enjoyed by asphalt and unbound materials, which don't require non-trafficking periods, in the trunk road maintenance market place. This will result in more competition.

1 Introduction

Currently the full exploitation of cement bound materials (CBM) in the UK is restricted by specifications that prohibit trafficking for seven days or until the specified seven day strength is achieved. This requirement is based on the premise that CBM need to develop stiffness and strength to withstand trafficking.

Paradoxically, this seven-day restriction has never been applied or specified for UK in-situ recycling work using cement, although it is acknowledged that such recycling has been carried out mainly on minor local authority roads where immediate trafficking requirements have been light. However it is apparent that much of this recycling work has been carried out on roads consisting of unbound structural layers made from well-graded materials that originally were mechanically stable in their own right but have suffered over time from overloading and water susceptible edges and subgrade. As a result, the CBM layer that is produced during the recycling operation is itself mechanically stable before the strength develops.

UK experience with slow setting, slow hardening hydraulically bound mixtures (HBM based on lime/slag and lime/PFA binder combinations) over the last 18 years (see Table 3), both in new work and maintenance, has used this mechanical stability approach and proved that it is possible to traffic HBM immediately in heavier trafficking situations without long term detriment to performance. This use has drawn on well-established Continental practice regarding mixture gradings and aggregate quality for HBM.

It is believed that the above principles of mechanical stability could be transferred to the use of CBM for trunk and other more heavily trafficked roads. The primary advantage would be for maintenance work, which represents a significant proportion of current road spending. At the present time, compared with unbound and bituminous bound materials, CBM is disadvantaged in the maintenance situation since curing periods mean longer possession and programme times, representing significant amounts of money. As a result, CBM has seen little use in maintenance work on the UK's trunk road network.

If it can be shown that CBM, or certain types of CBM, can be trafficked immediately, then there will be more competition for black-top in the trunk road and maintenance field than at present. This will result in:

- The likelihood of the use of more cost effective designs based on CBM.
- Keener prices for black top even if CBM isn't used.

Either way there will be cost savings and benefits.

Under a collaborative project funded by the Highways Agency (HA) and Britpave, this document reports on a field and laboratory exercise that sought to confirm the above Continental and UK experience with HBM to enable the practice employed for CBM in minor roads (in-situ recycling using cement) to be extended to encompass CBM for heavily trafficked roads. The exercise examined CBM with a range of mixture gradations and aggregate quality from live jobs constructed to current UK specifications. It should be emphasised that the work was a confirmation rather than a proving exercise, based on the premise that data and experience already existed in the UK that showed the principle was sound.

The report covers:

- A review of Continental experience
- The Immediate Bearing Index test
- UK experience with immediate trafficking
- The project rationale
- The results
- Discussion of the results
- UK specification advice.

2 Continental experience

Until the introduction in France of slow setting and hardening hydraulically bound mixtures (hereafter in this report called HBM), the fast setting and hardening HBM based on cement (hereafter called CBM), were treated like CBM in the UK; namely there was a two hour working period between mixing and final compaction and a seven day non-trafficking period. The introduction and use of HBM in France some 40 years ago influenced their attitude towards CBM and initiated the development of new tests and new practices for CBM.

French highway engineers realised that the adoption of HBM as widely used paving materials hinged on flexibility of use. In short, no one would use it if it had to be cured/non-trafficked until significant strength was reached - that is, for periods greater than that required by CBM. This was a period already viewed as unacceptable by many French highway engineers and led them to examine the necessity for curing periods for HBM and CBM.

The French investigation revealed that curing/non/trafficking periods were unnecessary provided certain requirements for mixture grading and aggregate quality were observed. In short, the quality of the aggregate and the grading of the mixture determined whether the layer was mechanically stable immediately after compaction and thus able to carry the initial loads through aggregate interlock without detriment to long-term performance.

As a result of the use and development of HBM in France, the use of CBM in France now benefits from immediate trafficability in the majority of cases. Both CBM and HBM therefore have found extensive use in France in maintenance work, even as overlays.

The practice of immediate trafficking based on the physical properties of the mixture prior to setting is not unique to France. Germany and the Netherlands have a long successful history of use of HBM based on slow hardening slag mixtures using the concept of good grading and aggregate quality for these mixtures for both good short and long-term performance.

3 Immediate Bearing Index test

The French work into immediate trafficability of treated materials found that, for certain materials, a variant of the standard CBR test proved useful in assessing the suitability of a mixture for trafficking. In particular the ‘immediate CBR test without surcharge’ was found to provide a quick laboratory-based test for determining the trafficability of fine and medium grained mixtures. Thus the French IPI (indice portant immediat) test was born, known in the UK as the immediate bearing index or IBI test.

There is not one value of IBI above which immediate trafficking is possible. Instead the value necessary for trafficking was found primarily to be function of the type of material being treated. Thus a treated clay would have a different value to a treated sand. The French experience for treated clays and sands is summarised in Table 1.

Table 1: Summary of the French IBI recommendations for immediate trafficking of hydraulically treated mixtures made from cohesive and sandy materials

Broad description of material to be treated	Grading of the material prior to treatment	Plasticity index of the material prior to treatment	IBI value of the mixture (i.e. including binder) for immediate trafficking
Clay	> 35% passing 80 micron	> 25	> 10
Clay	As above	12 to 25	> 15
–	As above	< 12	> 25
Sandy	< 35% passing 63 micron	< 12	> 35 (> 50 for base application)

Under French regulations, the immediate trafficking of mixtures not included in the table but made from similar materials has to be based on data specific to the site and material.

In connection with the IBI test, it should be noted:

- For treated clay mixtures, the IBI is determined on material at the standard Proctor optimum water content compacted into CBR moulds using standard Proctor compaction.
- For treated sand mixtures, the IBI is determined on material at the modified Proctor optimum water content compacted into CBR moulds using modified Proctor compaction.
- In both cases, the determination is carried out immediately after compaction on only the bottom of the CBR specimen and without the use of any surcharge rings.

In the case of coarse-grained mixtures using well-graded aggregate of say, a stated hardness and a minimum percentage of crushed/angular faces, it is not clear if the IBI test was ever used or if it were, whether the results were meaningful. Whatever the case, it is unnecessary in France to carry out the IBI test on HBM/CBM provided the mixture is well-graded and the requirements summarized in Table 2 are followed.

Table 2: Broad summary of the French recommendations for the immediate trafficking of coarse-grained well-graded HBM

Layer	Aggregate characteristic	Traffic				
		Very light	Light	Medium	Heavy	Very heavy
Subbase	Los Angeles coefficient, kN	≤ 45	≤ 45	≤ 45	≤ 35	≤ 35
	Percentage of crushed material in aggregate	> 30	> 30	> 30	> 30	> 30
Base for new road	Los Angeles coefficient, kN	< 45	< 35	< 35	< 35	< 30
	Percentage of crushed material in aggregate	> 30	> 30	> 30	> 60	100
Base as overlay constructed under live traffic	Los Angeles coefficient, kN	< 45	< 35	< 35	< 35	< 30
	Percentage of crushed material in aggregate	> 30	> 30	> 60	100	100

4 UK experience of immediate trafficking of CBM and HBM

The first recorded instances of immediate trafficking of CBM in the UK, involving in-situ recycling using cement, were in 1985 at two sites in East Sussex, on the B2096 in Netherfield and an unclassified minor road in Dallington village. Since that time, the process has been repeated on many occasions. The performance of the early use of the technique carried out between during 1985 and 1987, is recorded in an ETSU report [1]. Although not the subject of the referenced report and therefore not discussed in it, all the jobs referred to were constructed under a specification permitting immediate trafficking. It is apparent from the report, and in particular the discussion on performance, that this has had no detrimental effect on their performance.

The UK history of use of HBM does not go as far back as recycling; the first recorded use of HBM in the UK was in 1987. Equally the subsequent use of HBM has not been as extensive as recycling using cement but nevertheless there is a reasonable history, which is summarized in Table 3. The roads involved have, to the writer's knowledge, been maintenance free.

Table 3: Use of slow setting/slow hardening HBM based on slag and PFA

Year	Job and traffic details	HBM details	Pavement design
1987	Pembury by-pass, Kent - 500 m trial section 13 million standard axles (msa)	FSBM (Flushing slag bound mixture: 85% phosphorus slag aggregate and 15% granulated blast furnace slag + sea water as activator)	320 mm FSBM as sub-base & base under 130 mm surfacing
1997	Hale Street by-pass, Kent 25 msa	FSBM (as above but activator changed to 3% 6 mm-down steel slag)	350 mm FSBM as sub-base & base under 120 mm surfacing
1997	A421 Tingewick bypass, Buckinghamshire – used as a temporary diversion for 15 months	Lime/GGBS treated boulder clay	350 mm layer as base and sub-base to 130 mm bituminous surfacing
1997	A52 reconstruction, Staffordshire* 8 msa	GFA (Granular material treated by PFA and lime) using planings as aggregate	300 mm GFA as sub-base & base under 100 mm surfacing
1998	Wainscott Bypass, Kent 45 msa	FSBM (as for Hale St)	290 mm FSBM as sub-base & base under 180 mm surfacing
1999/ 2000	Ramsgate Harbour Relief Road, Kent* 20 msa	GFA using granite aggregate	320 mm GFA as sub-base & base under 130 mm surfacing
2000	A130 Bypass (A12 – A127) DBFO project, Essex 80+ msa	Lime/GGBS treated London clay	300 mm enhanced capping
2000/ 2001	Burntwood Bypass* 30 msa	GFA using incinerator bottom ash (IBA) as aggregate	350 mm GFA as sub-base and base under 130 mm surfacing
2001	M25 reconstruction at Clacket Lane 80+ msa	FSBM (as for Hale St)	As enhanced capping to new concrete pavement
2002	A6 Clapham Bypass, Bedfordshire 70 msa	Lime/GGBS treated boulder clay	250 mm standard capping
2002	Lichfield Southern Bypass, Staffordshire* 20 msa	GFA using planings as aggregate	330 mm GFA as sub-base and base under 100 mm surfacing
*These projects discussed below.			

Having been directly involved, the writer knows that none of the projects in Table 3 had a specified seven day non-trafficking period, although it is acknowledged that, in some of the cases, immediate trafficking was light, or delayed, particularly on the new build schemes. Despite this, the trafficking details of five of the jobs in the table are worth highlighting and discussing.

GFA for the A52 reconstruction work, 1997: Freshly laid and compacted GFA was subject to immediate trafficking by fully loaded 8-wheeler lorries bringing in fresh GFA and the bituminous binder course (Figure 1). Except for minor surface disturbance under turning traffic, no distress in the form of measurable rutting or cracking was apparent. Subsequent coring and falling weight deflectograph work has illustrated that the long-term performance was not jeopardized in any way due to the immediate trafficking [2]

Figure 1: *A52 Reconstruction, Staffordshire, 1997 – trafficking and overlaying fresh GFA subbase*

FSBM for the M25 reconstruction work, 2001: Similarly to the A52, such was the site access and programme that freshly laid and compacted FSBM was usually overlain immediately with CBM subbase (Figure 2). Again no measurable rutting or cracking was apparent with no evidence of any effect on performance.

GFA for the Lichfield Bypass, 2002: The same situation and results as for the A52.

In each of the above cases, the performance under immediate trafficking was impressive without noticeable deformation or cracking. In every case the compressive strength of the HBM would have been barely measurable at the time of direct trafficking, and certainly unlikely to have been more than 0.5 MPa if measured, and thus significantly lower than the 4.5 MPa strength at seven days (or 'at-trafficking' strength) of the lowest category of CBM permitted by the SHW prior to November 2004. Therefore the ability to carry traffic immediately without detriment to long-term performance can only have been a function of mechanical stability due to the mixture gradings employed and the fact that, in every case, the aggregate quality (respectively planings, slag, planings) was good.

GFA for the Burntwood bypass, Staffordshire, 2000/2001: This was different from the other projects in that the aggregate was incinerator bottom ash and thus very weak compared with the slag or planings used in other projects. In addition the GFA was laid during the winter months. It suffered under trafficking and the frosty conditions, exhibiting softening and deformation and required replacement of a small quantity, less than 5%, of the GFA in the worst affected areas. Other less affected areas were not removed and subsequent deflectograph surveys have not revealed any long-term deterioration, despite the initial limited surface softening and deformation [2]

Figure 2: *M25 Reconstruction, Clacket Lane, 2001 – fresh FSBM being overlaid by CBM*

GFA for Ramsgate Harbour Relief road, 1999/2000 [2]**:** Although it is not possible to be certain, the main cause of the trafficking problem at the Burntwood Bypass (above) was probably a function of the weakness of the IBA rather than winter working, since another GFA job, carried out the previous winter at Ramsgate Harbour Relief Road, did not present any problems under traffic. The good performance at Ramsgate was probably due the fact that the aggregate for the GFA was good quality hard, well-graded granite, although it must be noted that the winter climatic conditions were probably more favourable at Ramsgate than at Burntwood.

TRL report 408 [3] is also of direct relevance here. This report presents findings, including the effect of trafficking, on a wide range of HBM mixture types. In this proejct, three of the mixtures were subject to early life trafficking in the TRL's Pavement Trafficking Facility (PTF). These three types are listed below.

- A lime (3%) and gypsum (4%) treated PFA (93%).
- A lime (4%) and PFA (15.5%) treated china clay sand (80%) with 0.5% sodium carbonate added as an accelerator
- An all-slag mixture – 10% steel slag fines + 20% granulated blast-furnace slag + 70% air-cooled blast furnace slag.

Trafficking problems were evident with the first and third mixtures. This was due in part, as reported in TRL 408, to batching problems producing a low water content for the first and a high water content for the third. The second mixture, with a batched water content consistent with the optimum, was successfully trafficked within 24 hours of laying.

It should be noted that the trafficking was heavy in the PTF and would equate to trafficking in practie over a long period. In the PTF facility loading is applied by a dual wheel travelling at 24 kph. The trafficking is canalised without lateral distribution of the wheels. Loading was initially applied at a wheel load of 40 kN (equivalent to a single standard axle) and then increased to 56.4 kN; the maximum permitted UK axle load on the public road. Each mixture received the equivalent of at least 5000 standard axles over a three week period.

From the report it is also possible to compare the performance of the second mixture with two other china clay sand mixtures that had conventional curing/non-trafficking periods of 7 days. These other mixtures were treated with cement. The report concludes that:

- For the same thickness, 8 to 10 mm maximum deformation was recorded at completion of trafficking for the mixture that was immediately trafficked after laying, compared with 3 mm for the two china clay mixtures that were subjected to trafficking only after a seven-day non-trafficked curing period.
- Yet on the basis of the measurement of the development of surface modulus over 35 days, there was no difference in performance between the three mixtures.

It can be concluded from TRL 408 that under immediate trafficking, limited deformation may be normal with some mixtures but is not detrimental to long-term performance. This confirms the findings for the GFA at Burntwood, where limited softening and deformation has not proved to affect the long-term performance.

TRL 408 also suggested that as a result of the trafficking trials, a surface modulus of at least 50 MPa, measured with an applied stress of 200 kPa on a 300 mm diameter plate, should be attained before trafficking commences.

5 Project rationale

From the preceding sections in this publication is apparent that:

- Immediate trafficking of both CBM and HBM is well established on the Continent.
- Immediate trafficking has also been proven with a range of HBM under both summer and winter conditions in the UK.
- Care needs to be taken when using weak aggregate.
- Limited deformation does not appear to affect long-term performance.

The rationale for the project was therefore, not to ‘reinvent the wheel’, but to determine whether the experience from the Continent and from the UK with HBM and CBM recycling could be adopted for CBM in general in the UK, with some modification of the technique if necessary. This assessment would be based on the examination of a range of UK CBM mixtures, not theoretical mixtures made up in the laboratory, but mixtures from live jobs. The assessment would include:

- Observation in the field of the behaviour of the selected CBM under immediate trafficking.
- IBI testing of the production mixture made up in the laboratory to establish whether this laboratory test, which can be carried out at mixture design stage, could be used to determine the trafficability of the CBM examined.

The range of CBM thought desirable to examine was determined on the basis of grading, shape and 10% fines value, selected to include if possible:

- Poorly and well-graded medium and coarse grained mixtures.
- Hard to soft natural aggregate and recycled materials.
- Rounded, flaky and angular (crushed) material.

6 Results

6.1 Mixture characteristics

Road and specialist contractors were contacted to ascertain whether the mixture criteria in Section 5 could be met from live jobs. With the exception of coarse sand, the criteria were met, although it took a year to obtain the requisite range of CBM.

The requirement to examine a well-graded medium grained mixture made from a natural coarse sand was satisfied by using China clay sand since this material had been used in TRL 408 discussed previously. Thus a china clay mixture was produced in the laboratory for IBI purposes whilst the observations under immediate trafficking were taken from the conclusions reached in TRL 408 described above in section 4.

Table 4 below details the materials used for the project. Some comments on the 10% fines results in Table 4 are given below.

- The values designated 'greater', were either in excess of 50 kN or assumed to be greater than 50 kN. For example the granite for mixture M8 and the slag for M10 were not tested but the 10% fines was assumed on visual examination to be over 50 kN. All results measured and indicated as over 50 kN were in fact over 100 kN.
- Where designated 'less', e.g. for M7, the actual value was between 40 and 50 kN.
- Where designated 'uncertain', e.g. for M9, this was a recycled material with 50% black-top in the 10 mm to 14 mm range and the material had a tendency to squash rather than crush in the test. For the record the 10% fines value of the aggregate was over 100 kN.
- Where designated N/A, no test was possible as the material was sand with no sizes in the 10 – 14 mm range, which is the size required for establishing 10% fines.

Table 4: Mixture characteristics

Mixture ref	Material family	Description of aggregate	10% fines – less or greater than 50 kN	Mixture grading (includes cement)	Cement content by dry mass
M1	Sand & gravel	Sea dredged	Greater	Poorly graded	6%
M2		Ex-pit but flakey	Greater	Well graded	6%
M3		As above + 6% PFA	Greater	Reasonably graded	15% **
M4	Sand	Bunter sand*	N/A	Uniform thus poorly graded	5%
M5		70% Bunter sand + 30% PFA	N/A	Uniform thus poorly graded	5%
M6		China clay sand	N/A	Poorly graded	7%
M7	Rock	Oolitic limestone	Less	Reasonably graded	6%
M8		Granite + 14% PFA	Greater	Reasonably graded	5%
M9	Recycled	Sand, stone & asphalt	Uncertain	Well graded	7%
M10		Slag + 14% PFA	Greater	Well graded	4%

** Not used on site but opportunity taken to measure the IBI to establish the effect of PFA in the mixture.*

*** This was actually roller compacted concrete*

Table 4 includes a column titled 'mixture grading'. The descriptions in the column are based on the gradings and uniformity coefficients Cu (ratio of the sieve size through which 60% of the mixture passes in relation to the sieve size through which 10% passes) in Table 5. For mechanical stability under traffic, the section on mechanical stabilisation in Soil mechanics for road engineers [4] indicates that a uniformity coefficient in the region of 50 is ideal, although acceptable values could range from 20 to over 100. Generally values over 100 might indicate too much fine fines, whilst values of less than 10 would indicate uniformity of grading, i.e. single size.

With regard to the grading description in Table 4, the following should be noted:

- The terms well-graded and uniformly graded are used in the normal sense.
- The aggregate for mixture M1, designated 'poorly graded', was excessively sandy and lacking in fine fines. It is postulated that its performance would have benefited from the addition of, say, 10% PFA.
- M3, designated 'reasonably graded', had excessive fines through the inclusion of 6% PFA and a high (15%) cement content. This was a roller compacted concrete and it is postulated that this mixture would have been better without the PFA.
- M6 was designated 'poorly graded' and in hindsight would have benefited from the addition of PFA as in the TRL 408 work.
- M7, designated 'reasonably graded', had excessive fines but was also slightly 'bony' and thus prone to segregation.
- M8, designated 'reasonably graded', was 'light' in mid-range material and prone to segregation.

Table 5: Mixture gradings

Percentage passing	Mixture									
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
50 mm							100			
40 mm	100	100	100				92	100	100	
28 mm								91	98	100
20 mm	93	93	94			100	65	76	94	99
10 mm	80	79	82	100	100	93	48	42	80	66
5 mm	68	62	68	99	99	84	40	34	57	46
2.36 mm	62	49	56	98	98	69	35	30	35	36
1.18 mm		41	49	96	97			28		31
600 micron	45	33	42	95	96	46	30	26	19	28
300 micron	24	20	31	92	93	30	28	25	14	25
212 micron				72	80					
150 micron		14	25	26	47	14		23	11	21
75 micron	6.5	13	23	13	31	9	22	18	10	17
Uniformity coefficient (D60/D10)	15	80	100	3	8	16	160	150	50	80
Grading description	Poor	Well	Reasonable	Poor (uniform)	Poor (uniform)	Poor	Reasonable	Reasonable	Well	Well

The following sections, covering the IBI results and the visual assessment of the effects of immediate trafficking, record the findings from the study.

6.2 IBI results

According to French practice, the IBI is determined solely on the bottom face of the CBR specimen using mixture prepared at the modified Proctor optimum water content (OWC) on specimens compacted using modified Proctor energy (BS heavy compaction). This differs from UK CBR practice, where testing is carried out on both top and bottom faces of specimens compacted to refusal by vibrating hammer.

In order to reflect French practice as closely as possible, the IBI specimens were made using modified Proctor compaction, but at the OWC determined from vibrating hammer compaction or the target water content (TWC) since this was the data that was available and which related directly to the site material.

Depending on the nature of the mixture, the modified Proctor OWC would usually be somewhat wetter than vibrating hammer OWC. The IBI testing was therefore repeated at 1.2 x the OWC or TWC on the basis that by including the higher water content, the testing would cover French practice. It was also repeated, at 0.8 x OWC, to cover the dry side in the case of an erroneously determined OWC. In the majority of cases, the IBI was determined on the top as well as the bottom faces of the specimen. The results are given in Table 6.

Table 6: IBI results

Mixture ref	IBI results (each recorded figure an average of 3 results)					
	0.8 x OMC/TWC		OMC/TWC		1.2 x OMC/TWC	
	Top face	Bottom face	Top face	Bottom face	Top face	Bottom face
M1	17	90	20	60	7	66
M2	Not determined	120	Not determined	90	Not determined	43
M3	Not determined	130	Not determined	90	Not determined	40
M4	50	100	30	50	10	15
M5	60	130	25	50	5	10
M6	6	43	11	50	5	31
M7	Not determined	Not determined	101	187	12	17
M8	100	200	50	100	50	100
M9	–	–	25	35	3	5
M10	370	> 380	> 380	> 380	170	220

6.3 Visual assessment of immediate trafficability

Trafficability was assessed by visual examination of the CBM under immediate trafficking by a few passes of either a fully-loaded lorry/dumper truck or where present, a pneumatic tyred roller. The results are given in Table 7.

Table 7: Visual assessment of trafficability

Mixture ref	Observation	Rating
M1	Significant surface disturbance	Poor (see Figure 3)
M2	Minimal rutting and surface disturbance	Excellent (see Figure 4)
M3	Minimal rutting and surface disturbance but roller shear cracks due to excess fines	Satisfactory
M4	Not assessed	Not assessed
M5	No significant rutting but surface easily disturbed and sheared through lack of cohesion	Poor (see Figure 5)
M6	Taken from TRL 408, i.e. rutting up to 8 mm, assessed as not detrimental to long term performance in TRL 408	Satisfactory
M7	No marking or visible deformation	Excellent ((see Figure 6)
M8	Assumed similar to M7	Not observed
M9	No marking or visible deformation, although assessment was based on observation of performance just under wheels of roller, but could have been susceptible to more deformation with heavier wheeled traffic	Satisfactory
M10	Some minor deformation under first passes of loaded lorry tyres but thereafter lorry acted like a pneumatic-tyred roller and produced a tightly sealed rut-resistant surface	Excellent (see Figure 7)

Figure 3: *Mixture M1 showing significant surface disturbance under trafficking*

Figure 4: *Mixture M2 after trafficking by loaded lorry*

Figure 5: *Mixture M5 showing shearing under roller*

Figure 6: *Mixture M7 under pneumatic-tyred roller*

Figure 7: *Mixture M10 showing improvement under tyred traffic after vibrating roller compaction*

7 Discussion

Table 8 presents a summary of all the data. For ease of comparison, the mixtures have been broadly ordered in descending order based on their performance.

From the visual examination under immediate trafficking, it was apparent that:

- All the mixtures with the exception of those based on rounded or uniformly graded material appeared capable of withstanding immediate or early trafficking,
- Well-graded mixtures made from hard (10% fines > 50 kN) 100% crushed or flaky material are capable of sustaining immediate trafficking,
- Reasonably well-graded mixtures, made from 100% crushed aggregate with 10% fines > 30, or flaky aggregate with 10% fines > 50, appeared capable of sustaining immediate trafficking,
- From TRL408, mixtures made from gritty well-graded sand appeared capable of sustaining early (say after 24 hours) if not immediate trafficking.
- Well-graded CBM made from mixed hard and weak aggregates including a proportion of crushed material (say > 30%), as produced say from an in-situ recycling operation, appeared capable of sustaining early (say after 24 hours) if not immediate trafficking.

Table 8: Summary of all data

Mixture reference number	Aggregate	10% fines – less or greater than 50 kN	Grading of mixture (includes cement)	Uniformity coefficient, Uc	Cement content	Visual assessment of trafficability	IBI at bottom at OWC	IBI at bottom at 1.2 x OWC
M10	Slag + 14% PFA	Greater	Well-graded	80	4%	Excellent	>380	220
M8	Granite with 14% conditioned PFA	Greater	Reasonably graded	150	5%	Not observed but assumed excellent on basis of IBI results	100	100
M7	Oolitic limestone	Less (just)	Reasonably graded	160	6%	Excellent	187	17
M2	Flakey pit sand & gravel	Greater	Well-graded	86	6%	Excellent	90	43
M3	Flakey pit sand & gravel + 6% PFA	Greater	Reasonably graded	100	15%	Satisfactory	90	40
M9	Recycled sand, stone & asphalt	Uncertain	Well-graded	50	7%	Satisfactory	35	5
M6	China clay sand	N/A	Poorly graded	16	7%	Just a laboratory mix but assumed satisfactory from TRL 408*	50	31
M1	Rounded sea dredged sand & gravel	Greater	Poorly graded	15	6%	Poor	60	66
M4	Bunter sand	N/A	Fine & uniform, thus poorly graded	3	5%	Just a laboratory mix but assumed poor from M5	50	15
M5	70% Bunter sand + 30% PFA	N/A	Ditto	8	5%	Poor	50	10

** Better grading through inclusion of PFA than mixture tested here for IBI*

For IBI, the following discussion is based on results from the bottom face from Table 6 for the water contents, OWC and 1.2 x OWC, which encompass French practice. These results are shown in Table 8.

- With the exception of M9 and M1, there is a trend of increasing IBI as the physical characteristics (grading, hardness, particle angularity) improve,
- The results for M9 and M1 do not follow the trend; M9 probably because it consists of a mixture of soft to hard materials with the soft dominating in the IBI test, thus giving a low result compared with in situ performance; M1 perhaps because the CBR mould provides a level of restraint that does not apply in the field,
- As physical characteristics deteriorate, there is a trend that the IBI at 1.2 x OWC gets progressively much lower than the IBI at OWC suggesting that the poorer the aggregate properties the more susceptible the IBI result is to water content and the more susceptible the mixture is to deformation under immediate trafficking.
- Comparing the IBI results with the performance under trafficking, it is apparent overall that performance increases with increase in IBI and that immediate trafficability seems possible provided:

  For coarse-grained mixtures, the IBI at 1.2 x OWC is greater than 40.

  For sandy mixtures, the IBI at 1.2 x OWC is greater than 30.
- The IBI of 30 for sandy mixtures is in close accord with the French recommendation of 35 in Table 1.

Overall the results confirm that:

- The French recommendations of specifying physical characteristics in the case of well-graded coarse-grained mixtures and IBI in the case of medium to fine-grained mixtures can be used to permit the early trafficking of CBM in the UK.
- When carrying out IBI testing, the bottom face values should be determined for both vibrating hammer OWC and 1.2 X OWC. Grossly divergent values give an indication of moisture-sensitive material, and thus possible poor performance under traffic.
- With anything other than mixtures made from hard (10% fines > 50 kN) well-graded 100% crushed aggregate, a site assessment using a pneumatic-tyred roller (PTR) should be carried out until further experience is gained.
- A degree of rutting/deformation is not detrimental. It is difficult to be precise about the value, but rutting/deformation up to say 10 mm is probably acceptable.
- In the same way it is difficult to be precise about surface disturbance and looseness. Whatever the mixture, some disturbance is inevitable. It should be recognized that this will be recompacted under site traffic and the placement of the next layer. Mixtures containing PFA will be beneficial here because of the ‘cementing’ reserve offered by PFA.
- UK specification advice can be based on the findings here, together with French experience, UK experience with recycling and HBM, and TRL 408, in particular the latter’s finding in respect of plate loading tests.

8 UK specification advice

On the basis of the CBM reported and discussed, Table 9 offers conservative specification advice. Mixtures not catered for by the classifications listed in the table, should continue to have a seven day non-trafficked curing period.

Table 9: Specification guidance for immediate trafficking of CBM

Main works	Nominal size of mixture	Grading	Crushed or planings component of mixture	Flaky, broken, irregular or gritty component of mixture	10% fines value of aggregate	IBI_{bottom} at 1.2 owc determined by vibrating hammer *****	Trafficking (PTR as specified in column 1)
Together with vibrating roller compaction the main works shall include finishing compaction using a pneumatic-tyred roller (PTR) as specified below****	31.5, 20 & 14 mm	Well-graded*	100%	N/A	> 50	N/A	Immediate without conditions
	As above	As above	N/A	100%	> 50	N/A	Immediate subject to PTR site assessment
	As above	Reasonably graded**	100%	N/A	30 – 50	N/A	
	As above	As above	N/A	100%	> 50	N/A	
	As above	As above	> 30%	N/A	> 50	N/A	When measured surface modulus on site >50 MPa*** and subject to PTR site assessment
	10 mm	Well-graded*	> 30%	N/A	N/A	> 50	
	6.3 mm	Reasonably graded**	N/A	100%	N/A	> 35	

** Must conform to gradings in Appendix.*

*** Mixture shall be without significant size gaps and shall have a uniformity coefficient Cu > 20 .*

**** Measured with an applied stress of 200 kPa on a 300 mm diameter plate.*

***** With a wheel load of not less than 3 tonnes operating at a minimum tyre pressure of 4 bar.*

****** Determined in accordance with BS EN 13286–47 [5]*

9 References

1. ETSU. *The performance of roads reconstructed by cold insitu recycling 1985 – 1987.* General Information Report, ETSU, Harwell, 1994.

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3. ATKINSON, CHADDOCK & DAWSON. *Enabling the use of secondary aggregate and binders in pavement foundations.* TRL Report 408, TRL, Wokingham, 1999.

4. TRRL. *Soil mechanics for road engineers.* Stationery Office. 1952.

5. BS EN 13286–47: 2004, *Unbound and hydraulically bound mixtures* – Part 47: *Test method for the determination of California bearing ratio, immediate bearing index and linear swelling.*

Appendix

Table A1: Grading envelopes for well-graded CBM mixtures (includes cement)

Sieve (mm)	0/31.5 mm Option A	0/31.5 mm Option B	0/20 mm Option A	0/20 mm Option B	0/14 mm Option A	0/14 mm Option B	0/10 mm Option A	0/10 mm Option B
40.0	100	100	–	–	–	–	–	–
31.5	85-100	85-100	100	100	–	–	–	–
25.0	75-100	75-100	–	–	100	100	–	–
20.0	65-94	66-95	85-100	85-100	–	–	–	–
16.0	–	–	–	–	–	–	100	100
14.0	–	–	–	–	85-100	84-100	–	–
10.0	44-78	48-82	55-7	60-88	68-97	73-97	85-100	85-100
6.3	–	–	42-75	47-76	50-84	60-87	62-91	62-93
4.0	26-61	34-68	32-66	39-66	38-71	48-74	48-81	49-84
2.0	18-50	26-58	23-54	29-53	26-56	35-57	33-64	36-66
0.5	8-30	16-38	11-31	18-34	13-32	20-35	17-36	22-40
0.25	6-22	13-30	8-23	14-27	10-23	15-25	12-25	17-30
0.063	3-11	7-18	3.5-11	8-19	4.5-11	9-19	6.5-13	10-20

NOTE: The gradings are taken from and comply with the British Standards for HBM covering cement bound granular mixtures [A1} and fly ash bound mixtures {A2}. The A options cover the use of cement or cement with ground granulated blast-furnace slag, whilst the B options cover the combination of cement with fly ash (known as PFA in the UK) where the fly ash content is greater than the cement content.

References

A1. BS EN 14227–1: 2004, *Hydraulically bound mixtures* – Specifications – Part 1: *Cement bound granular mixtures.*

A2. BS EN 14227–3: 2004, *Hydraulically bound mixtures* – Specifications – Part 3: *Fly ash bound mixtures.*





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