Development and Performance of Cement Bound Materials in Road Pavements

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ABSTRACT

The use of cement bound materials (CBMs) for road construction in Qatar is relatively new. CBM improves the structural capacity and durability of pavement, but considerations should be made to the setting time and strength development in hot arid environment, such as in Qatar. The paper presents a laboratory development and performance characteristics of CBM mixtures, with environmental and economic benefits through the use of local and recycled materials. The developed mixtures showed full compliance with the grading, strength and durability requirements of the Qatar Construction Specifications (QCS, 2014). Site data from Ashghal projects indicated the difficulty of producing consistent strength in practice, with the potential of increased strength and associated risk of reflection cracking in the asphalt overlaying. Recommendations are made to improve the construction practice and specification of cement and other hydraulically bound materials to enhance the service life of pavement and support the government strategy of sustainable construction.

Keywords: Cement bound materials; Compressive strength; Construction specification; Durability; Local and recycled materials

1 INTRODUCTION

The use of Cement Bound Materials (CBMs) in road construction has the two-fold benefit of increasing the bearing capacity and enhancing the durability of pavements. CBMs are part of the Hydraulically Bound Materials (HBM) family and generally made with a variety of materials including primary, secondary and recycled aggregates. The binder could be a Portland cement or other slow-hardening industrial by-products of Fly Ash (FA) or Ground Granulated Blast Furnace Slag (GGBS) with an alkali activator (Hassan et al., 2004). CBMs are generally classified based on compressive strength or a combination of tensile strength and modulus of elasticity (BS EN 14227-1, 2013). The Qatar Construction Specification (QCS, 2014): section 6: part 6 classifies CBMs based on their 7-day compressive strength (CBM 1 to CBM 4) with grading, performance and durability requirements.

CBM is generally used as a structural layer within the semi-rigid pavement with an asphalt overlay. The combination of a bound structural layer and an asphalt surfacing has great potential to provide long-life pavements with minimum maintenance. The CBM substrate is relatively strong, durable and provides a good load distribution to the underlying foundation, whereas the asphalt surfacing provides improved riding quality and a protective layer to the structural layer. Higher strength CBM results in increased stiffness, with greater tendency for wide cracks that could reflect through the asphalt overlay (FEHRL, 2009; Hassan et al., 2008).

The first use of CBMs in Qatar was in 2013 as a remedial work for the Corniche project, near the seafront, to overcome durability issues with existing pavement. As bound pavement subbase/base layers, their benefits of increased pavement stiffness, improved distribution of traffic loading, and protection to the pavement foundation were recognized compared to unbound pavement layers. The use of CBMs continued in Qatar over the last few years to include major expressway projects and the new Orbital Highway & Truck Route project with high traffic loadings.

This paper presents a laboratory development of CBM mixtures using local and recycled materials available in Qatar. The strength and durability performance of CBMs were compared to the requirements of QCS 2014. Site data of compressive strength were obtained from Ashghal to assess the performance of CBMs in service. Recommendations are made to improve the wider use of CBMs in Qatar, with consideration of local conditions in Qatar, to support the government strategy of sustainable construction and development.

2 LABORATORY DEVELOPMENT OF CBM MIXTURES

CBM mixtures of CBM 1, CBM 2, CBM 3, and CBM 4 were developed in the laboratories of ReadyMix Qatar. The development was based on the use of 100% local and recycled materials. Details of the CBM mix design and properties are given in Table 1. The Portland cement was supplied by the Qatar National Cement Company (QNCC), and complies with the requirements of the QCS 2014 and BS EN 197-1 (2011), minimum grade of 42.5. The coarse aggregate consisted of 75% local limestone, obtained from sand and rocks crusher, and 25% Recycled Concrete Aggregate (RCA), supplied by Beton concrete. Washed sand from QNCC was used as fine aggregate. The amount of mixing water ranged from 110 to 120 l/m^3, and a superplasticizer based on synthetic polymer was used in the range of 0.6 to 3.75 l/m^3 with increasing content for the various CBM mixtures.

Table 1: CBM mix design and properties

Material/Property		**CBM 1**	**CBM 2**	**CBM 3**	**CBM 4**
Mix design	Portland cement (kg/m^3)	80	120	150	190
	Coarse aggregate (kg/m^3)	1500	1480	1480	1475
	Fine aggregate (kg/m^3)	690	710	690	650
	Water (l/m^3)	120	110	110	115
Properties	Fresh density ((kg/m^3)	2302	2300	2331	2386
	Average 7-day strength (MPa)	5.70	8.30	12.70	19.60
	Minimum 7-day strength (MPa)	5.50	8.00	12.20	18.60
	Retained strength (%)	97	95	96	93
QCS 2014: Min average 7-d strength (MPa)		**4.5**	**7.0**	**10.0**	**15.0**
QCS 2014 Min individual, MPa		**2.5**	**4.5**	**6.5**	**10.0**

Figure 1 shows the grading of CBM materials, together with the grading envelope specified in the QCS 2014. The results show that both CBM 1 and CBM 2 have almost the same grading, and falling within the specified grading envelope in the QCS 2014. Similarly, CBM 3 and CBM 4 have identical grading, and fit nicely within the mid-range of the specified limits. It is clear that the grading envelope for CBM 1 and CBM 2 provides a wider grading range for the use of different materials.

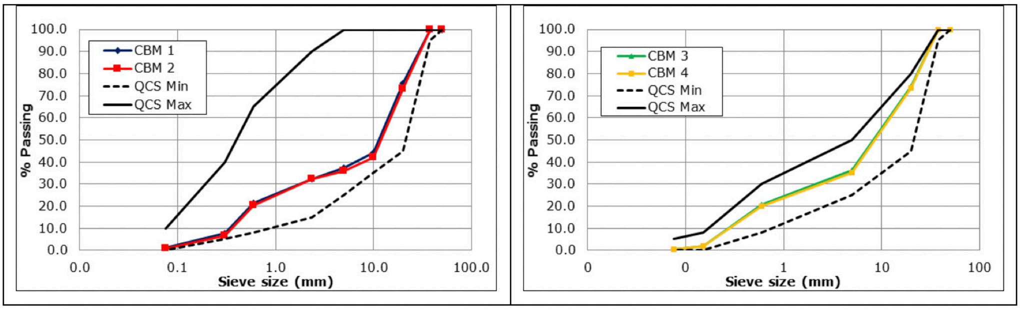

Figure 1: Grading of CBM mixtures with QCS 2014 limits

After mixing, the fresh CBM material was poured into cube molds (150mm) and compacted in two layers using a vibrating hummer, following the procedure described in BS EN 13286-51 (2004). The surface of the casted cubes was levelled and covered with wet hessian and polyethylene sheets overnight. On the following day, the cube specimens were removed from molds and cured in sealed plastic bags until required for testing at 3, 7, and 28 days. Sixteen cubes were prepared for each mix. The fresh density was determined by weighing the cube molds before and after filling with CBM materials, and the average values are given in Table 1. The values ranged from 2300 to 2386 kg/m^3, with increased density for higher cement content.

The cubes were tested for compressive strength as per BS EN 12390-3 (2019) at the age of 3, 7, and 28 days and the results are presented in Figure 2. The QCS 2014 specifies a minimum average 7-day compressive strength for the various CBM mixtures. Table 1 shows that the average 7-d strength for all CBM mixtures exceeded the minimum specified values. The QCS 2014 also specifies a minimum individual value for each CBM type, and all the developed CBMs satisfied the minimum strength requirements of the QCS 2014.

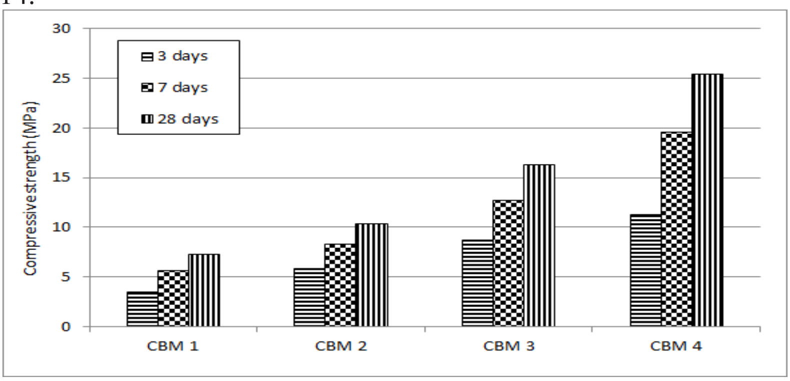

Figure 2: Average 7-day compressive strength of CBM mixtures

The QCS 2014 also specifies a retained strength value of a minimum 80%, as determined from the ratio of the average compressive strength after immersion in water to the average control strength. The retained strength provides an indication of the durability of CBM mixture when exposed to water. The results in Table 1 show retained strength values ranging between 93 to 97% for the development of CBM mixtures, much exceeding the minimum specified limit. In general, the strength and durability results obtained from the laboratory development show that local and recycled materials could be effectively used for the production of CBM materials with full compliance with the QCS 2014 requirements.

3 SITE data

While the QCS 2014 specifies minimum average and minimum individual compressive strength values at the age of 7 days, project specifications tend to specify a range of compressive strength values at the same age. Most of the projects specified a 7-day compressive strength values between 3.0 and 7.0 MPa, with the preference towards the lower specified value to minimize the occurrence of reflective cracking. The Ashghal QSD team (Quality and Safety Department) provided site data on the 7-day compressive strength of CBM materials constructed in various projects and the results are given in Table 2 under the heading of CBM. Loose CBM materials were collected during construction, compacted on site into cubes (150mm), and tested for compressive strength at the age of 7 days. Table 2 also provides construction data on the 7-day compressive strength of core samples extracted from the laid CBM.

Table 2: CBM average 7-day strength values from site data

CBM Type	CBM	CBM 3
Average compressive strength, MPa	4.5	8.5
Min compressive strength, MPa	0.7	7.0
Max compressive strength, MPa	12.7	9.1
Project specified Minimum strength, MPa	3.0	QCS 2014
Project specified Maximum strength, MPa	7.0	-

Site data for the different CBM projects showed a wide variation of the 7-day compressive strength achieved on site. The CBM average 7-day compressive strength was 4.5 MPa, well within the specified range of 3.0 to 7.0 MPa. However, the minimum 7-day strength was 0.7 MPa, much lower than the minimum specified value for the project of 3.0 MPa. The maximum was 12.7 MPa exceeding the maximum specified strength value of 7.0 MPa. The CBM results indicate the difficulty of achieving a consistent strength for the specified low strength CBM.

The core results of CBM 3 satisfied the minimum individual strength but not the average strength requirement. However, core strength results are expected to be lower than cube strength for the same materials. The CBM 3 results also show a small variation between the minimum and maximum strength values achieved on site, between 7.0 and 9.1 MPa, and indicating strength that is more consistent for CBM made with higher cement content.

4 DISCUSSION OF RESULTS

The laboratory development of CBMs demonstrated the potential use of local and recycled aggregate materials with full compliance with the QCS 2014 requirements. CBMs were made with coarse aggregate of 25% RCA and 75% local limestone, and the cement content varied from 80 kg/m^3 for CBM 1 to 190 kg/m^3 for CBM 4. The developed mixtures satisfied the strength requirements and achieved high values of retained strength, indicating good durability and resistance to water damage. During the laboratory development, it was noticed the low cement content of 3% in CBM 1 was not adequate to coat all the aggregate particles. However, for CBM 2 and above (cement content of 5% and above), the mix looked more homogeneous with adequate binder. Site data also indicated the inconsistent compressive strength, especially for CBMs with low cement content.

CBM layers are expected to crack after construction due to shrinkage and thermal movements, and the intensity of cracks is expected to exceed in hot environment, such as in Qatar. The QCS 2014 specifies that after compaction and immediately before overlaying, the CBM surface shall be well closed and free from movement, cracks, loose materials, ruts, or other defects. It also specifies that all defected areas shall be removed, to the full thickness, and replaced with new CBM layer.

While the tendency is to produce low strength CBMs to minimize the risk of reflection cracks in the asphalt overlay, there is a need to provide consistent strength and uniform support to the pavement across its whole length. The UK Specification for Highway Works (Highways England, 2016), Volume 1, Series 800 specifies induced cracks for all HBMs that are expected to reach a compressive strength of 10 MPa at 7 days. Transverse cracks are induced in the fresh CBM/HBM by grooving the layer between ½ to 2/3 of its thickness, and filling the grooves with a bitumen emulsion before final compaction (Figure 3). The transverse cracks will not prevent the CBM from shrinkage and thermal movements, but will accommodate them to minimize the effect of reflection cracking. The technology is relatively cheap, has been successfully used in the UK, and could be implemented in the following revisions of the QCS.

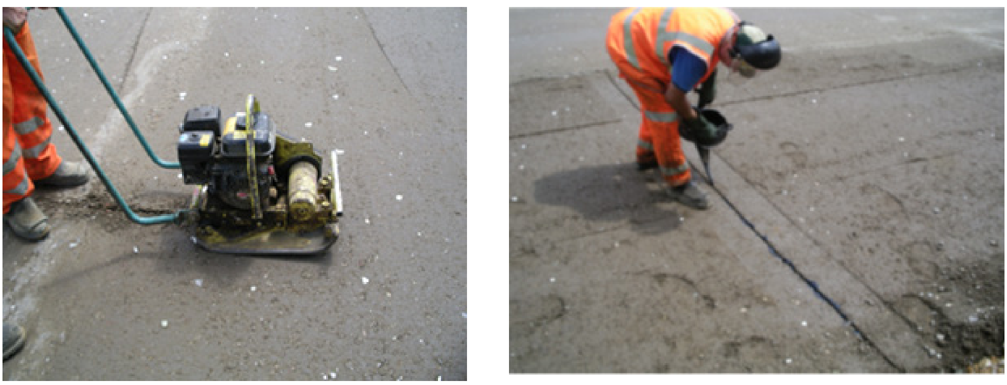

Figure 3: Induced cracks (left) and filling the grooves (right) of CBM

Another factor contributing to the inconsistent strength of CBM is the setting time of Portland cement and inadequate curing on site. The QCS 2014 specifies that laying and compaction of the CBM shall be made within 2 hours from mixing the cement with water, and a minimum curing period of 7 days immediately after compaction. The hot weather in Qatar could greatly accelerate the rapid hardening of cement and evaporation of mixing water, and hence influence the strength and cracking of CBMs. Cement replacement materials, such as FA and GGBS, provide alternative Portland cement with improved performance and impact on the environment. The use of FA and GGBS increases the setting time of the binder due to slow-hardening and provides with more homogeneous mixtures with consistent strength and support to the pavement structure.

There is no doubt that the use of CBMs in construction will enhance its structural capacity and durability towards more sustainable construction. Qatar relies mainly on imported aggregate for pavement construction with large volume of construction waste accumulated in landfill sites (Hassan et al., 2015). The importance of sustainability in the development of Qatar was made clear in the Qatar Second National Development Strategy (2018-2022) with a specific target to use 20% of recycled materials within the total materials used in construction projects.by 2022 (PSA, 2018). The versatility of CBMs and ability to accommodate a range of recycled materials with improved performance will support the government strategy of sustainable development with protecting the environment.

5 CONCLUSION

- Mixtures of CBM 1, CBM 2, CBM 3, and CBM 4 were successfully developed in the laboratory with 100% local materials in Qatar.
- The CBM mixtures were made with 75% limestone aggregate and 25% Recycled Concrete Aggregate (RCA) and Portland cement.
- The laboratory mixtures satisfied the grading and strength requirements of the QCS 2014 with retained strength exceeding 90%, indicating good durability and resistance to water damage.
- Site data of 7-day compressive strength showed a high variation of the results, especially for CBM with low cement content.
- To minimize the risk of reflection cracking, improvement in construction practice could be achieved by inducing transverse cracks when the 7-day strength exceeds 10 MPa.
- Recommendations are made for the use of cement replacement materials to improve the performance of CBMs in service.

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