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Constraints in Using Manufactured Sands in Concrete Pavements in Australia

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ABSTRACT

This paper documents some of the constraints in utilising larger proportions of manufactured sands in concrete pavements. These constraints, are caused mainly, by the current level of knowledge regarding the impact of manufactured sands on skid and abrasion resistance of concrete pavements. Due to shortages of natural sands, along the east coast of Australia in particular, and the need to fully utilise fines produced in quarry operations, progress has been made in utilising blends of manufactured sands and natural sands in concrete pavements. The paper presents a brief review of literature on this subject in USA, France and United Kingdom. It also, briefly, documents work recently carried out in Australia by CCAA (Cement Concrete & Aggregates Australia), referring to the skid and abrasion resistance of concrete pavements using manufactured sands. The paper concludes that, there is no relationship between free silica content and skid resistance. With regard to the abrasion resistance, it is rather the curing conditions and compressive strength that are more important in achieving good results.

Keywords: Manufactured sand, concrete pavements, skid resistance, abrasion resistance, free silica content

INTRODUCTION

Shortages of good quality natural sands for concrete production are becoming more prevalent in Australian eastern states, mainly Victoria, New South Wales and Queensland. The shortages, combined with the imperative need to better utilise quarry dust produced in quarry operations (for a long time considered as a waste product) has resulted in significant progress in utilisation of manufactured sands in concrete.

A CCAA subcommittee established in 2004, has carried out extensive research, resulting in recommendation for national test methods, and limit specifications for manufactured sand. A Guide to the Specification and Use of Manufactured Sand in Concrete has been published (CCAA T60, 2008).

Although significant progress was evident in the area of manufactured sands in concrete, the road authorities in Australia were reluctant to allow large amount of manufactured sands in concrete road pavements, limiting the percentages of manufactured sands in concrete at no more than 50% and, requiring high percentages of silica in natural sands to be blended with manufactured sands. The limited percentage of manufactured sands allowed, was due to the lack of data on the manufactured sand effects on skid and abrasion resistance. In 2010, a CCAA technical study concluded that manufactured sands can successfully be used in concrete pavemens. The study also concluded that the Micro Deval should be used to select the most suitable fine aggregates for concrete pavements construction.

Further studies have been carried out by the CCAA in 2011-2012 (CCAA, 2012), and a scientific paper, based on the studies was presented at the Construction Materials Industry Conference (CMIC 12) in September 2012 (Sirivivatnanon, and Dumitru, 2012).

CONSTRAINTS IN USING LARGER AMOUNT OF MANUFACTURED SANDS IN CONCRETE PAVEMENTS

Two major problems have restricted the usage of larger amount of manufactured sands in concrete pavements.

- The requirement that, minimum 50% by mass natural sand be used in a blend with manufactured sands in a concrete pavement (RMS QA R83).
- The requirement, in the abovementioned specification, of minimum 70% of quartz or cherts in natural sands, with the view to ensure higher skid resistance to the slip formed concrete base. It appears that, the support behind the minimum 70% quartz content in natural sands, came from the British Road Research Laboratory Report LR334 (Weller, and Maynard, 1970). The report highlights that "<u>the use of high silica content natural sands, always yielded higher skid resistance values than did relatively soft sands or crushed fine materials</u>".

Silica Content in Natural Sands

USA

The guidelines for skid resistance pavement design (AASHTO, 1976) stated that, in order to achieve better wear resistance on the concrete pavement surface, several factors are to be considered:

- Wear resistance of concrete increases as cement factor is increased.
- Wear resistance of concrete as the W/C ratio is decreased.
- To provide a good skid resistance, the proportion of fine aggregates in the concrete mix, should be "near the upper limit of the range that permits proper placing, finishing, and texturing. The silicious particle content of the fine aggregate "should be not less than 25%."
- The concrete durability and wear resistance are influenced by the effectiveness of curing.

According to NCHRP Project 01-43 (NCHRP, 2009), the following issues were considered:

- Aggregate properties, with significant influence in concrete pavement friction performance, are hardness and mineralogy.
- Concrete made with aggregates made up of hard minerals only, typically achieve good wear resistance, but will polish quickly under traffic.
- Concrete made with aggregates that are moderately soft, achieve good polishing, but will wear quickly under traffic.
- A wear resistant aggregate is necessary in the mix, but some wearing of the surface is necessary in achieving proper skid resistance.
- The polishing resistance of fine aggregates is the most critical parameter.

What the document in fact is saying is that, a blend of hard and high resistant wear aggregates with moderately softer aggregates, is the best outcome in achieving a good wear resistant, and skid resistant concrete pavement. Furthermore, the document, also, highlights the importance of proper curing, in order to achieve good durability and skid resistance.

FRANCE

An important document about the surface characteristics of concrete pavements (Nissoux, 1977) concluded that:

- The in-depth treatment of fresh concrete provides good skid resistance.
- Macro roughness must be designed as early as the construction of the pavement.
- During the pavement construction, anything which may reduce the strength of the surface should be avoided.
- Effective curing products should be spread correctly.

The document does not refer to limits for silica content in fine aggregates.

UNITED KINGDOM

Work was carried out by the Ministry of Transport (RRL Report LR334 (Weller, Maynard, 1970) and LR335 (Weller, 1970).

The reports have concluded that:

- The most important constituents, in a concrete pavement mix, in order to achieve good skid resistance, are the fine aggregates.
- The harder sands, in general, exhibit a better skid resistance at the end of a dry wearing stage.
- During the period of wet polishing, the skid resistance of mortars made with harder sands decreases and, the mortars made with softer sands exhibit an increased skid resistance.
- Based on several types of fine aggregates used in the research, the document concluded that "the use of high silica content natural sands, always yielded high skid resistance value than did relatively soft sands or crushed fine materials".

It is important to note that, there are no limits suggested for silica content in the fine aggregates. The conclusion drawn on silica content, can be easily explained, considering the type of fine aggregates used in the trial mixes (flint gravel, dolomitic limestone, soft dolerite, gritstone). However, there is no explanation why calcinated bauxite with no high percentage silica, "was always superior to any sand."

AGGREGATE PROPERTIES WITH SIGNIFICANT INFLUENCE ON PAVEMENT FRICTION PERFORMANCE

As noted previously, the following issues must be considered:

1. Aggregates made up only with hard minerals resist wear, but, may polish easily under traffic.
2. Aggregates made up only with softer minerals achieve good skid resistance, but, wear easily under traffic.
3. A blend of wear resistant aggregate and soft mineral aggregates are ideal in ensuring that, some wearing of the concrete surface occur, resulting in higher skid resistance as a new micro texture. Fine aggregates, with angular edges and cubical or irregular shape, provide higher level of microtexture (Figure 1), with rounded edges or elongated shape aggregates exhibiting lower micro texture.

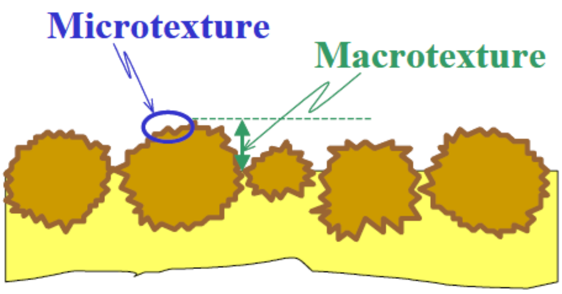

Figure 1. Microtexture and Macrotexture (Flintsch et al, 2003)

4. Aggregate properties, with significant influence on pavement friction performance, are hardness and mineralogy.

With regard to rock hardness and mineralogy, it is important to note that, according to Mohs scale, minerals are classified as:

Hard > 6

Soft 3-5

Considering Mohs scale (Figure 2), and the requirements of minimum 70% quartz in natural sands as per RMS Q83, it is obvious that:

Diamond	10
Corundum	9
Topaz	8
Sillimanite	7.5
Cordierite	7-7.5
Quartz	**7**
Garnet	6.5-7.5
Olivine	6.5-7
Epidote	6.0-7
Chalcedony	6
Pyroxenes	5-7
Amphiboles	4-6.5
Apatite	5
Zeolite	3.5-5.5
Fluorite	4
Dolomite	3
Calcite	3
Gypsum	2
TALC	1

Sands containing these minerals are excluded if there is not 70% quartz

Sands containing these minerals are excluded if quartz content is not 70%

Figure 2. Mohs Scale (hardness) (NCHRP, 2009)

- Natural sands, containing minerals with hardness higher than 7 (quartz), are to be considered unsuitable in concrete pavements, if the quartz levels is not minimum 70%.

- Natural sands, containing minerals with hardness equal or higher than 6, are to be, also, considered unsuitable in concrete pavements, if the quartz level is not minimum 70%.

This is a matter of concern for the industry, and steps are being implemented to address the issue.

OTHER APPROPRIATE TESTS TO BE CONSIDERED

MBV (Methylene Blue Value)

Grading/particle size distribution, shape and surface texture, durability tests, chlorides and sulphates etc, were properly considered in the CCAA T60 document.

It is well known that, the type of microfines in fine aggregates and concrete water demand, of a concrete pavement mix manufactured with such microfines, are extremely important.

The MBV (Methylene Blue Value) is a valuable parameter in identifying the potential for active clays in microfines. The CCAA T60 document recommends that, a manufactured sand is suitable to be used in concrete, providing that the multiple of MBV and the percentage passing of 75 micron size of the product is less than 100.

It is important to note that, the MBV results may be influenced by (Dumitru, and Crabb, 2000).

- wet or dry sieving;
- particle size of the sample tested;
- type of clay present in the microfines.

Some effects of the type of clays and effects on dry and wet sieving on MBV results are presented in Table 1 and Table 2.

Table 1. Effects of type of clay on MBV results

Fraction tested	% of Clay Introduced	MBV mg/g (ISSA Test Method)	
		Bentonite	Kaolinite
75 μm	0	10.0	10.0
	1.0	11.0	-
	2.5	16.0	-
	5.0	21.0	10.0
	10.0	-	10.5
<75 to 45 μm	0	6.5	6.5
	1	9.5	-
	2.5	13.0	-
	5.0	17.0	7.0
	10	-	7.5
<45 μm	0	10.5	10.5
	1	13.0	-
	2.5	15.5	-
	5.0	20.5	10.0
	10.0	-	10.5

Table 2. Effects of dry and wet sieving on MBV results

Fraction tested	Type and % of clay added to the original sample	MBV mg/g (ISSA Test Method)	
		Dry sieving	Wet sieving
-75μm	0	10.0	14.5
-75 + 45μm	0	6.5	2.0
-75μm	**Bentonite**		
	1.0	11.0	17.0
	2.5	16.0	18.5
	5.0	21.0	25.5
-75 + 45μm	1.0	9.5	5.0
	2.5	13.0	7.5
	5.0	17.0	13.0
-75μm	**Kaolinite**		
	5.0	10.0	14.5
	10.0	10.5	14.5
-75 + 45μm	5.0	7.0	3.0
	10.0	7.5	4.0

MICRO DEVAL

Current durability test methods in Australia, for both natural and manufactured sands (i.e. sodium sulphate soundness, sand equivalent, degradation factor), are not able to determine the resistance to wear, or, the results are difficult to correlate. In fact, NCHPR 2009 report has considered magnesium sulphate soundness as being more consistent than sodium sulphate, from results point of view, recommending a loss of < 10% after 5 cycles.

Work carried out by CCAA (2012), has identified Micro Deval test as a good option to evaluate the relationship between Micro Deval value and skid resistance (Sirivatanon and Dumitru, 2012). It was concluded that, there is a good relationship between skid resistance and Micro Deval loss, with a clear reduction of skid resistance with increasing percentage loss of Micro Deval value (Figure 3), with a Micro Deval value figure of 15% being considered to be specified as an upper limit.

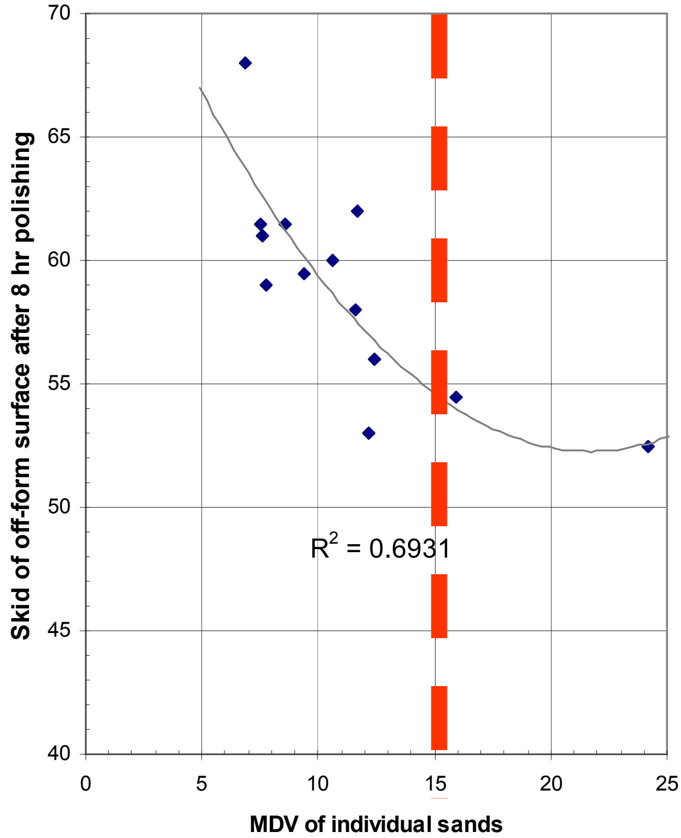

Figure 3. Relationship between Micro Deval value and skid resistance

It is interesting to note that, a similar correlation has been established in the USA, (Rached and Fowler, 2012), concluding that using an AI (Acidity Index) of 60% or a Micro Deval percent loss of 12%, good skid resistance concrete pavement could be achieved.

The differences between the proposed Micro Deval value limits, between the study in Australia and the study in the USA, are due to differences in type of equipment used for skid resistance, and in particular due to the types of fine aggregates used. In USA, carbonaceous aggregates have been largely considered, but not such fine aggregates were used in concrete trial mixes in the study carried out in Australia.

In Japan, a study was carried out on durability of micro fines, (Kaya, et al 2010), aiming at the effective use of dry micro fines, when producing well-shaped manufactured sand using a dry process. The study has concluded that, the exclusion of particles less than 40 micron will prevent the increase of water demand in concrete mixes, and three durability tests (accelerated neutralisation, water permeability and freeze-thaw) were considered to assess manufactured sands durability.

TWO MICRON (2µm)

The current limit for 2 micron fraction in sands is less than 1%, the test being limited to sands with at least 4% passing 75 micron fraction.

The results are in general affected by the density of the solids in suspension and, are also, overestimated if montmorillonite (an expansive clay) is present, or, are underestimated if kaoline (a non-expansive clay) is present.

The test does not pick up the expansive or non-expansive clay, and it is necessary that the type of clay is to be determined, if the 2 micron is higher than 1%.

Studies carried out (Dumitru et al 1999) have concluded that:

a) Up to 3-4% kaoline (non-expansive clay) introduced in a concrete mix results in

- high compressive strength
- lower shrinkage
- lower permeability
- lower chloride diffusion

b) Up to 1-2% bentonite (expansive clay) in a concrete mix, resulted in lower compressive strength, shrinkage, permeability and chloride diffusion.

CONCLUSIONS

Discussions between industry and transport authorities should continue, in order to address several current constraints in using manufactured sands in concrete pavement mixes.

These constraints refer to:

- minimum percentage of natural sands in blends with manufactured sands;
- percentage of quartz in natural sands;
- issues related to some of the conditions that may influence the MBV results;
- the 2 micron limits in manufactured and natural sands, and the need to determine the type of clay present.

Recent studies carried out in Australia by CCAA (Sirivivatnanon and Dumitru 2012) have concluded that:

- The critical properties of fine aggregates in concrete pavements are: durability (Micro Deval) for skid resistance and, concrete compressive strength for abrasion resistance.
- Other essential properties for fine aggregates in concrete are: shape, surface texture and, in particular, consistent particle size distribution.
- There is no correlation between free silica content and skid resistance.
- The Micro Deval value should be considered, as it correlates with skid resistance and, should be used as a performance based specification.
- It is important to note that recently, the Transport Authority in New South Wales has made major changes in the specification for concrete pavement, allowing unlimited amount of manufactured sand, dropping the free silica content request, and adopting Micro Deval as a major durability assessment of manufactured sand.

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