USE OF ROLLER COMPACTED CONCRETE IN COMPOSITE SOLUTIONS FOR HIGHWAYS

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Abstract

Roller Compacted Concrete (RCC) has many attributes; it is a fast, economical and durable alternative to traditional methods of pavement construction. Increasingly clients and specifiers are turning to RCC as first build costs are competitive with asphalt whilst whole life costs are substantially lower thanks to reduced maintenance and greater longevity of concrete pavements.

However the use of RCC is limited in major highway construction as the surface regularity of RCC can make for a noisier and less comfortable ride than an asphalt pavement. There are techniques such as diamond grinding that considerably improve the surface characteristics of RCC making them more suitable for higher speed highway applications. However this paper examines the use of composite pavements which combine RCC construction with high performance thin asphalt wearing surfaces to provide economical solutions for high speed road construction.

The paper outlines construction techniques and specification requirements highlighting the benefits of composite construction in highway construction.

Keywords: Concrete, RCC, asphalt, thin surfacing, highways, roads, composite construction, durability, performance

1. INTRODUCTION

Roller Compacted Concrete (RCC) is a hydraulically-bound material with compressive and flexural strengths similar to structural concrete. It is a zero-slump material that is placed by asphalt paving machines and compacted by roller to achieve a dense and rigid pavement. It is a rapid form of construction that allows pavements to be trafficked in the same time frame as asphalt solutions.

RCC pavements are designed as rigid pavements whilst asphalt pavements are designed as flexible pavements. RCC has the structural design approach of conventional concrete pavements with a construction and mix design approach similar to asphalt.

RCC is not a new product and there are examples of its use in the 1930s but its first recorded widespread use was in the Canadian logging industry in the 1970s where the speed of construction, strength and durability led to an very economic method for the construction of access roads.

Although RCC use continued to grow in North America its use in the UK was restricted to some specialist uses in dam construction until 2010 when a number of suppliers started to investigate the benefits of RCC as an economical and durable alternative to asphalt solutions that dominate the UK pavements market.

Numerous projects have now been completed using RCC although the majority of projects have been in industrial and parking applications. It’s use in highways has been limited due to concerns over noise, skid resistance and ride comfort. This paper outlines a potential solution to these issues by combining the benefits of RCC with the surface finish characteristics of asphalt.

2. CHARACTERISTICS OF RCC

2.1 Strength

Strength is rarely an issue with and strengths above C28/35 are easily achievable with relatively low cement contents (typically below 300kg/m3) providing that the material is fully compacted and cured.

2.2 Freeze thaw resistance

RCC is not air-entrained and experience has shown that air entrainment is not normally needed, even in conditions where there is the potential for freeze-thaw damage. However the aggregates need to be freeze-thaw resistant and there has to be sufficient fine material to give a closed structure and the RCC has to be compacted as required by the specification so that the potential resistance is achieved in practice

2.3 Abrasion resistance

To achieve a high abrasion resistance, a high compressive strength class is often specified along with aggregates that have a high Aggregate Abrasion Value.

2.4 Surface characteristics

Figure 1 show the typical surface finish that is achieved. The surface finish will depend upon the mix proportioning. With such dry concretes, brushed surface finishes such as those obtained with pavement quality concrete are not possible. Consequently it is not possible to get the same skid resistance properties achieved with alternative forms of construction such as pavement quality concrete or asphalt.

Figure 1: Typical surface finish with 20mm (left) and 10 mm (right) maximum aggregate size

These properties of RCC make it a popular choice for use in industrial paving, heavy duty parking and low speed roads.

However the use of RCC in highway construction has been limited due to concerns about skid resistance, noise and ride quality.

2.5 Skid resistance

Considerable research was carried out from the 1950s to the 1970s into this phenomenon. Skidding occurs when friction between tyre and road surface is insufficient to accommodate a particular vehicle manoeuvre, such as braking or cornering (White, 2001). Properties of the road surface, tyre, vehicle and the behaviour of the driver are all significant factors, but this lecture focuses on the road surface properties.

Research found that there are two key factors that influence the skid resistance of the road surface. Firstly, at higher speeds the road surface macrotexture, or visible roughness, is key. With sufficient texture, the majority of water can drain away from the road surface / tyre interface. With insufficient texture, a thick layer of water builds up. Fast-moving vehicles will then tend to ride on the water layer, rather than the road surface. This is called aquaplaning. Clearly if the vehicle is not in contact with the road, skid resistance and manoeuvrability become negligible.

Figure 2: The consequences of low surface texture and heavy rain – Lewis Hamilton aquaplanes into the gravel trap at the 2007 European Grand Prix.

Secondly, at lower speeds the road surface microtexture, that is the microscopic texture, is the critical factor. Even if the macrotexture has allowed the majority of the water to drain, a water film will remain on the road surface. With sufficient microtexture, the vehicle tyre can break the surface water film and maintain dry contact with the road. Conversely, inadequate microtexture means that dry contact is not established and skid resistance is greatly reduced.

The road surface must provide adequate macrotexture and microtexture. If macrotexture is insufficient, high-speed braking will never become low speed braking; and if microtexture is insufficient, high speed braking will simply become a lower-speed skid. Macrotexture and microtexture are illustrated in Figure 3.

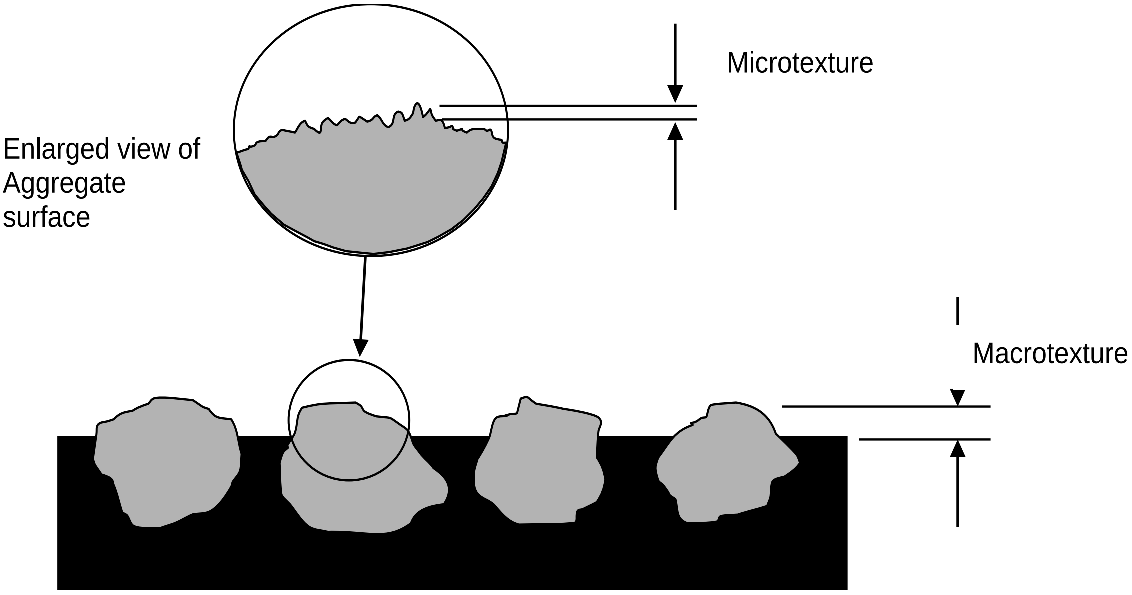

Figure 3: Diagram to show microtexture and macrotexture in the road surface

Surface friction reduces as speed increases. Surface macrotexture limits the size of the friction loss, so surface macrotexture is specified as a proxy for high speed skid resistance.

For thin surface course systems, the Specification for Highways Works (Highways Agency, 2009a) requires that the initial surface macrotexture on high speed roads is not less than 1.3mm, and that the macrotexture is maintained above 1.0mm for at least two years. Typically RCC would have a macrotexture of <0.6mm with the exact value being dependent on the upper aggregate size.

The aggregate used in RCC can be selected to ensure that the microtexture is sufficient for low speed braking but the macro texture is insufficient to provide adequate braking performance at high speed unless the surface is treated by using diamond grinding techniques.

2.6 Noise

Much of the United Kingdom is quite densely populated, and a significant proportion of the population lives close to major roads and traffic noise is an important issue. At lower speeds, traffic noise mainly originates from the engine, gearbox and exhaust of the vehicle. At higher speeds, the noise is principally generated by the interaction between the road surface and the vehicle tyres as shown in Figure 4.

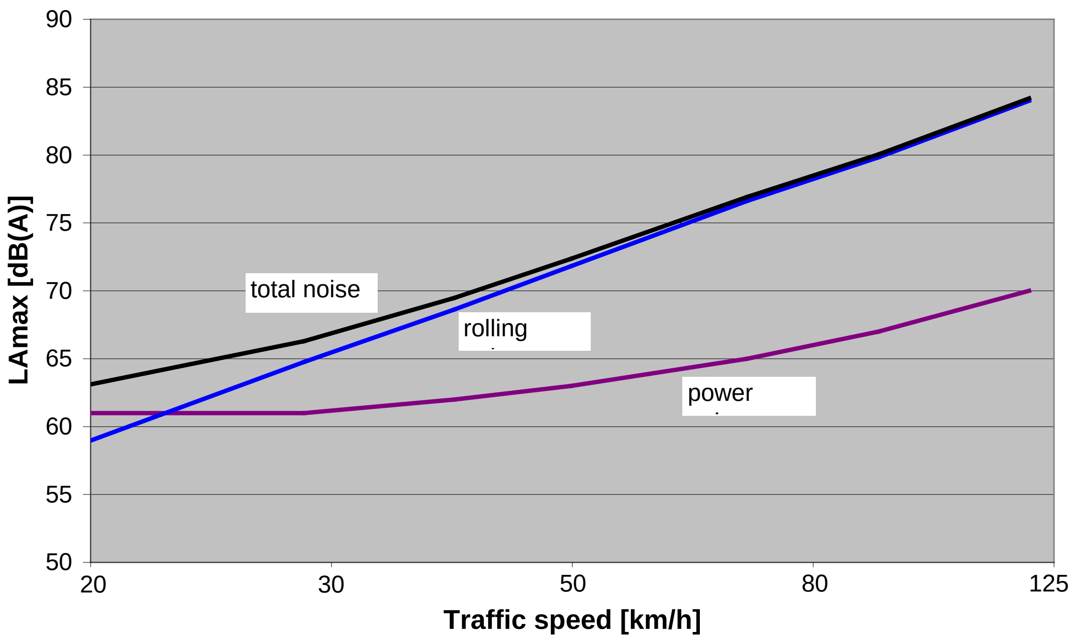

Figure 4: Noise from light vehicles at various speeds (F. Besnard et al, 2003)

The contribution of the road surface to noise is related to the macrotexture, that is, the visible roughness and megatexture which is the degree of smoothness of the surface with a wavelength between 50mm and 500mm.

Noise is generated by compression of air between the tyre and the road. The shorter the escape path for the air, the lower the noise generated. Generally, greater macrotexture gives shorter escape paths and leads to lower noise. The nature of the macrotexture, whether it is positive and negative, also has a major impact on noise. With positive texture, the tyre is constantly striking the aggregate projecting above the surface, leading to vibration of the tyre wall and additional noise. On the other hand, with negative texture, air pressure is reduced in the contact area between the tyre and the road. The voids within the surface may even absorb some sound, and the sound that escapes is at lower frequency.

The lower macro texture of RCC means that in comparison to asphalt there is much higher tyre noise at high speed. The noise levels can be reduced by diamond grinding and grooving but even with this technology it cannot match the performance of high performance asphalt solutions.

2.7 Ride Quality

Ride quality can be defined as the degree of comfort provided to road users by the road surface. This property is a combination of the evenness of the road, together with vehicle speed and the ability of the vehicle to protect occupants from any unevenness of the surface. Evenness is the degree of surface regularity at wavelengths over 500mm.

Motor car design and suspension systems usually compromise between comfort, which requires a high centre of gravity and soft suspension, and handling, which requires a low centre of gravity and firm suspension. Lorry design and suspension systems also have to allow for load carrying, which reduces comfort.

However, suspension systems can only isolate the vehicle from irregularities than are shorter or narrower than the dimensions of the vehicle, that is the microtexture, macrotexture and most of the megatexture elements of the surface. Longer wavelength unevenness may even be amplified by the suspension. The principal consequence of this is increased driver fatigue, though back pain and reduced vehicle control can also result (Granlund and Lindström, 2004).

Surface regularity is provided by the correct installation of appropriate road pavements using good surfacing practice. This vital and wide ranging subject is beyond the scope of this paper.

However The Specification for Highway Works (Highways Agency, 2009b) places tolerances on surface levels of newly constructed roads. In addition, longitudinal surface regularity is specified using a rolling straight-edge. This device is a 3 metre long frame with rows of small fixed wheels along each side. In the centre is a pair of wheels that are not fixed, but able to move up and down. Thus the fixed wheels provide the overall level over the 3m length and the moving wheels drop down into any depressions or rise up over any bumps.

It is difficult to achieve the longitudinal surface regularity requirements with RCC and it can lead to an uncomfortable ride compared to asphalt or traditional concrete pavements.

3. COMPOSITE CONSTRUCTION

RCC has many advantages as a road pavement material: Speed of application, economy, high stiffness leading to reduced fuel consumption, lower whole life cost and environmental benefits.

On the other hand asphalt pavements have advantages related to skid resistance, lower noise, reduced surface spray and improved ride quality.

The use of a composite solution utilising an RCC base with a thin high performance asphalt wearing course can utilise the strengths of both materials whilst overcoming the drawbacks associated with each material.

4. DESIGN FOR RCC COMPOSITE CONSTRUCTION

The design of a RCC composite will be influenced by the volume of traffic utilising the road, the maximum speed and the ground conditions. Factors to be considered would be the overall thickness of the road, the strength of the RCC, the type and thickness of the asphalt overlay and the need for sub base materials beneath the RCC.

There is no specific guidance for the design of RCC roads in the UK but the Highways Agency design model can be used to establish the thickness of the required road based on the volume of traffic expressed as millions of standard axels (msa).

The design chart shown in figure 5 can be used although it is based on traditional Cement Bound Granular materials which have much lower strength than RCC and therefore the recommendation for the asphalt overlay are excessively thick.

The use of RCC base coupled with high performance polymer modified surface course materials allows the thickness of the overlay to be reduced whilst still maintaining overall performance.

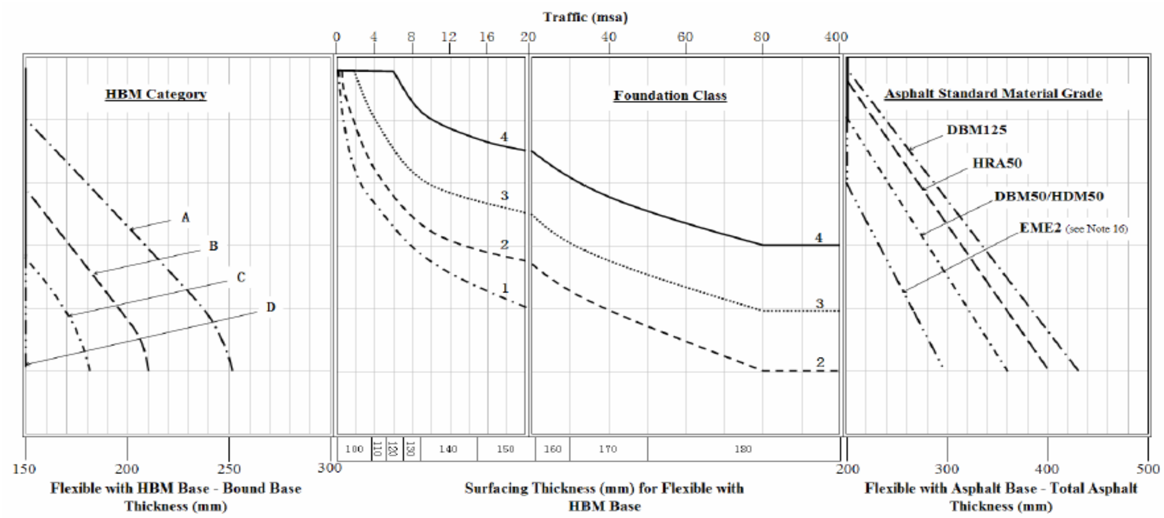

Figure 5: Design Chart for composite construction

5. SPECIFICATION OF ASPHALT OVERLAY

Stone mastic asphalt (SMA) consists of an interlocking network of high PSV coarse aggregate particles, with the voids between the coarse particles almost filled with a mastic of bitumen, filler, sand and cellulose fibres. When installed and compacted, this gives a surface course which is dense throughout most of the layer, but has an open, negative texture at its surface. This leads to a skid-resistant, deformation-resistant and relatively quiet surface.

Thin surface course systems are asphalt mixtures usually based on the use of polymer modified bitumens which give enhanced durability and flexural characteristics. They are similar to stone mastic asphalt, or very thin open asphalt concrete, and share their skid resistance, noise reduction and deformation resistance characteristics. Thin surfacings are supplied as “systems”. Their design, manufacture and installation are vital to the achievement of the desired road surface properties.

A composite RCC road structure is exceptionally durable in the lower layers which means that maintenance will only require the replacement of worn out surface course. Thin surface course systems can be replaced rapidly, helping to reduce traffic disruption and other user costs associated with road works.

Use of thin surface course systems will allow the thickness to be reduced to below 50mm.

6. INSTALLATION OF RCC COMPOSITE ROADS

RCC should not be placed on standing water or placed in heavy rainfall. To minimise the risk of damage due to freezing at an early age, RCC should not be placed when the ambient temperature is less than 5°C.

RCC is usually placed with an asphalt paving machine. Conventional asphalt paving machines compact the RCC by either tamping or vibration. Combination paving machines compact the RCC by a combination of tamping and vibration. As conventional machines achieve about 80% to 85% of the design density and combination machines > 90% of the design density, further rolling is essential. Combination machines are needed to place thick layers of RCC but, when these are not available, conventional paving machines are used to place the RCC in two 100mm to 150mm layers instead of one thick layer. Detailed guidance on installation of RCC can be found in The ERMCO guide to Roller Compacted Concrete.

In order to ensure the full benefit of a composite solution it is essential to ensure a good bond between the RCC and thin surface course.

To achieve this a tack coat of a cationic bitumen emulsion should be applied directly to the freshly laid RCC as soon as possible after the final rolling of the concrete.

Following the application of the tack coat and immediately prior to the installation of the thin surfacing a hot polymer modified cationic bitumen bond coat should be machine applied at a uniform rate of 0.35kg/m^2.

The strength of the bond coat can be measured and the results from a recent contract are shown in figure 6 confirming that the methodology outlined comfortably exceeds the minimum requirement of 0.7Mpa.

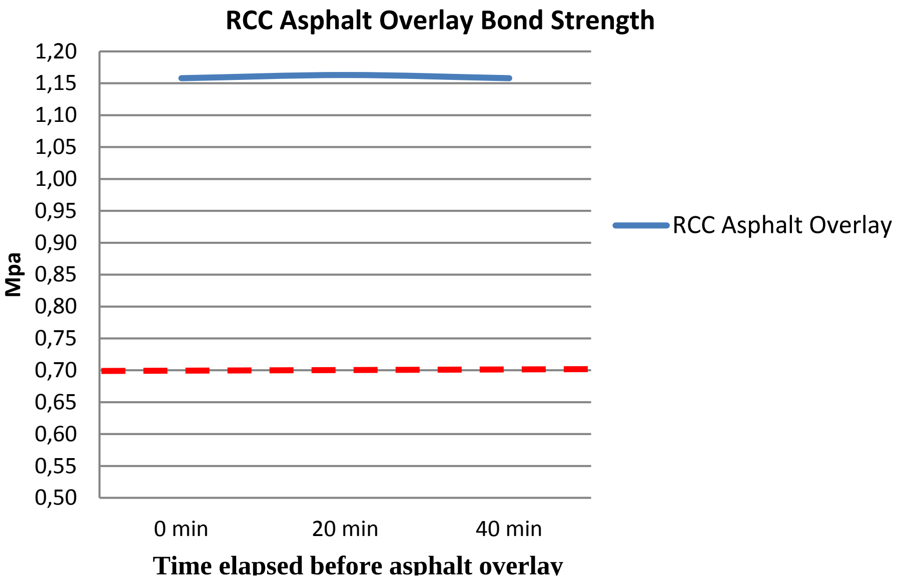

Figure 6: Asphalt overlay bond strengths

Over time reflective cracking of the asphalt overlay above the RCC joints will occur and to prevent the need for post installation repairs it is recommended that sealed joints are formed in the asphalt aligned with the RCC joints.

7. CONCLUSIONS

The use of an RCC Thin Surface Asphalt composite construction in high speed roads overcomes the limitations associated with the use of a full depth RCC or full depth flexible construction. It provides the rigid, durable and low cost pavement associated with concrete pavements combined with the low noise, high skid resistance properties associated with Thin Surface Asphalt systems.

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