

# The Effects of Compaction Methods on Tensile Strength of Foamed Bitumen Mixture

Y. Huan<sup>1</sup>, P. Jitsangiam<sup>2</sup>, H. Nikraz<sup>3</sup> and K. Siripun<sup>4</sup>

<sup>1</sup>PhD candidate, Department of Civil Engineering, Curtin University, P.O. Box U1987, Perth, WA, Australia 6845; PH (61) 8 9266-3207; FAX (61) 9266-2681; email: [yue.huan@postgrad.curtin.edu.au](mailto:yue.huan@postgrad.curtin.edu.au)

<sup>2</sup>Lecturer, Department of Civil Engineering, Curtin University, P.O. Box U1987, Perth, WA, Australia 6845; PH (61) 8 9266-4527; FAX (61) 9266-2681; email: [p.jitsangiam@curtin.edu.au](mailto:p.jitsangiam@curtin.edu.au)

<sup>3</sup>Professor, Department of Civil Engineering, Curtin University, P.O. Box U1987, Perth, WA, Australia 6845; PH (61) 8 9266-7609; FAX (61) 9266-2681; email: [h.nikraz@curtin.edu.au](mailto:h.nikraz@curtin.edu.au)

<sup>4</sup>Research Fellow, Department of Civil Engineering, Curtin University, P.O. Box U1987, Perth, WA, Australia 6845; PH (61) 8 9266-3207; FAX (61) 9266-2681; email: [Komsun.siripun@curtin.edu.au](mailto:Komsun.siripun@curtin.edu.au)

## ABSTRACT

Currently, the introduction of the gyratory compactor replicating the kneading action of the field compaction raises a thought that the conventional 75 blows of Marshall compaction effort would be insufficient to simulate field compaction of the foamed bitumen stabilisation material. Furthermore, the strong laboratory specification of a particular compaction method for the foamed bitumen mixture has not yet been established, therefore the future study in the compaction of the foamed bitumen mixture is needed. This laboratory based study aims to verify the reliable compaction effort for the foamed bitumen mixture. In this study, virgin materials treated with different foamed bitumen contents were compacted by Marshall Compactor and Gyratory Compactor at various blows/cycles, respectively. Upon completion of compaction and curing, density, indirect tensile strength and indirect tensile resilient modulus were performed to determine the suitable compaction technique for such materials. It is expected that the compaction effort achieved the highest density and tensile strength would be selected to compare with field compaction further.

*Keywords:* Foamed Bitumen, Marshall Compaction, Gyratory Compaction

## 1 INTRODUCTION

Recently, the implementation of in-situ foamed bitumen stabilisation in Australia has been increasing considerably. In Western Australia, particularly, it has been vigorously prompted by the City of Canning, demonstrating rather superior engineering performances as a base course in comparison to such traditional stabilisation methods (Leek 2011). However, there are minimal guidelines and standards which are able to assist in the execution of foamed bitumen stabilisation and construction practices are generally modelled from guidelines designed either for unbound granular pavements or for asphalt layer. In order for the popularity of foamed bitumen stabilised materials to continue to grow and further promote sustainability, these guidelines need to be further developed to ensure pavement engineering function, more importantly, to suit localised requirements.

Foamed bitumen is produced when cold water is added to hot bitumen. This causes the bitumen to expand rapidly in size by approximately 15 times its original volume and behave like foam. With this increase in volume comes a much greater surface area and thus finer fractions can be exclusively covered to produce a more cohesive and ultimately stronger mastic, thereby acting to weld coarse fractions to improve tensile strength (Kendall et al. 2001). Nevertheless, a well-qualified foamed bitumen product cannot be fabricated unless an important process is guaranteed and well achieved, that is compaction. It is not difficult to understand that insufficient compaction efforts or inadequate compaction methods are more likely to result in premature failure in field and inferior samples produced in laboratory. This therefore outlines the importance of understanding the effects of implementing different methods and different levels of compaction effort. The specified aim of this project is to achieve an understanding of the effects of compaction effort in terms of two different methods (Marshall and Gyratory) and amount of effort on the tensile strength of foamed bitumen mixtures.

Compaction effects on foam bitumen mixes had been researched previously to supply a good comparison between Marshall and Gyratory method but no clear and final agreement can be concluded yet to determine which is more suitable for foamed bitumen mixtures. Brennen et al. (1983)

firstly investigated these two compaction methods and presented that Gyratory compactor can generate higher density and stability values than Marshall compactor and also suggested that 75 blows of Marshall Hammer did not provide sufficient compaction to simulate initial compaction after construction which required further investigation of a great number of blows to be conducted to achieve better results. However, Nataatmadja (2001) proposed another scenario by comparing with Marshall compactor and Gyratory compactor at different curing regimes by means of resilient modulus. The results indicated that Marshall compaction always exhibited higher modulus results than Gyratory regardless of different curing times even though Gyratory generated a higher density because of higher energy, which may attribute to some migration of fines and bitumen from the upper and bottom surfaces, particularly at low bitumen content values. Apart from the comparison with different compaction methods, Maccarrone et al. (1993) in Australia recommended that compaction effort of foamed bitumen mixture should adopt 150 cycles at 2° and 240kPa loading force using gyratory compactor or 75 blows at one face using Marshall compactor as this condition was believed to produce laboratory samples to well replicate field density.

## 2 LABORATORY EXPERIMENTAL PROCEDURE

### 2.1 Material

All Materials selected for the project were from local sources and are typical of Western Australian pavement materials used in the industry.

#### 2.1.1 Bitumen

The bitumen used was obtained from BP Australia and was of Class-170 thus conforming to AS 2008-1997. C170 bitumen is generally what is used for in-situ foamed bitumen stabilisation due to its consistent and advantageous foaming characteristics. Typical C170 bitumen properties can be seen in Table 1. Three different percentages of foamed bitumen are being investigated in this project, 1%, 3% and 5%, by mass of the total mixture.

Table 1: *Typical characteristics of BP Class 170 Bitumen (BP Australia Pty Ltd, 2008)*

Viscosity at 60°C (Pa.s)	Viscosity at 135°C (Pa.s)	Viscosity at 60°C after RTFO (Pa.s)	Penetration at 25°C (dmm)	Flashpoint (°C)	Viscosity of residue at 60°C of original (Pa.s)	Density at 15°C (kg/m <sup>3</sup> )
170	0.40	300	70	360	180	1.04

#### 2.1.2 Host materials

In this project, two locally sourced virgin materials, crushed rock-base (CRB) and crushed limestone (CLS) were chosen, which are representatives of the materials that are commonly used as a base course and sub-base course in Western Australian road pavement structural system. Both CRB and CLS were nominally graded at a maximum size of 19mm, conforming to Main Roads Western Australia (MRWA) Specification 501 requirement (MAIN ROADS Western Australia 2010).

#### 2.1.3 Active filler

The use of active fillers in foamed bitumen stabilisation is often a common practise and yields a more effective stabilisation of pavements. This is due to pozzolanic reactions which occur and help form cementitious bonds between particles thus producing a more cohesive and stronger material. Hydrated lime was chosen as the active filler in these mixes and had a fixed content of 2% (by mass of dry aggregate) in each mixture.

### 2.2 Foaming condition

A laboratory scale foamed bitumen machine, Wirtgen WLB 10S, was used to produce the foamed bitumen and investigate foaming characteristics. A foamed bitumen product with expansion rate of 15-20 times and half-life of 20s was yielded when 2.5% cold foaming water was injected to roughly 175-180°C hot bitumen.

### 2.3 Mixing process

The apparatus used to mix and combine the raw materials with foamed bitumen was the WLM 30 mixing chamber which functioned in conjunction with the Wirtgen WLB 10S. Prior to the mixing process all constituent quantities were calculated based on the mass of the proposed mix. Each mix contained 60% crushed limestone, 40% crushed rock base, 2% hydrated lime and 8.65% water (optimum moisture content). Prior to injecting the water and foamed bitumen into the mix, the mix had to be “dry mixed” in the WLM 30 mixing chamber for a certain period of time (10-20 seconds) to produce a homogenous, dry material. If this step had been removed from the process, clumps of hydrated lime may have been evident. Once dry mixed, and ready to have the water and foamed bitumen added to the mix, the required mass of foamed bitumen (either 1%, 3% or 5% of the dry material mass) to be added to the mix was input into the Wirtgen WLB 10 S machine. The water was then added to the mixing chamber and mixing commenced for a small period prior to manoeuvring the mixing chamber into the required position to allow the addition of foamed bitumen. Once the bitumen had been added, all materials continued to be mixed for the set time on the WLB 30 of 100 revolutions.

### 2.4 Compaction

On the completion of mixing, samples were ready to be compacted by Marshall and Servopac Gyrotory Compactor, as seen in Figure 1. During compaction process, Marshall specimens should comply with WA Main roads test method 731.1, named Stability and flow of asphalt: Marshall Method while Gyrotory specimens should be in accordance with AS 2891.2.2-1995: Sample Preparation-Compaction of asphalt test specimens using a gyrator compactor (MAIN ROADS Western Australia 2010, Standards Australia 1995). This assured all samples were of good, consistent quality and discrepancies were minimal. Compaction efforts of 50, 75, 90, 120 and 180 blows (cycles for gyrator compactor applied a constant vertical stress of 240kPa and gyrated at 60 rpm at an angle of 2°) were investigated. It should be noted that Marshall compactor applied target blows to each face of the sample. Differences between the Marshall and Gyrotory samples arose in the dimensions, only slightly. The Gyrotory moulds are manufactured very precisely and produce sample diameters of 100mm whilst 101.5mm for Marshall specimens. Three samples of each compaction effort were fabricated to ascertain the most accurate results once testing.



Figure 1. Marshall Compactor (left) and Servopac Gyrotory Compactor (right)

### 2.5 Curing

Both Marshall and Gyrotory specimens were initially placed in an oven set at 60°C for three days. This curing method aimed to achieve similar characteristics of in-situ stabilised material in dry conditions once all moisture had been evaporated. 60°C is a typical hot summer day pavement temperature. (Lee 2003). Upon investigation of moisture content of these samples after curing finished, a moisture content approaching very close to zero was apparent. Subsequently, half of the specimens were cured in such a way to replicate a pavement which had previously been completely dried followed by

saturated conditions. This required drying in an oven alongside the dried samples for three days followed by being unwrapped and fully submerged in water for another 24 hours. Wet samples after saturation can typically illustrate critical behaviour and thus will form the basis of discussion in interpreting the effect of the amount of compactive effort applied to the sample.

## 2.6 Testing

All testing carried out shall investigate properties relevant to the tensile strength of the foamed bitumen treated materials. The two characteristics being investigated in this project are indirect tensile resilient modulus and indirect tensile strength.

### 2.6.1 Indirect tensile resilient modulus

The indirect tensile resilient modulus ( $ITM_R$ ) of a material is a representation of its stiffness and indicates an ability to behave elastically. It is an important characteristic needed to categorise a tensile performance. The resilient modulus of each sample was determined using a repeated load tri-axial (RLT) test apparatus. This test was carried out in conjunction with Australian Standard – AS 2891.13.1-1995. It should be noted here that the above standard is a resilient modulus testing standard initially designed for asphalt specimens but it is referred to here for foamed bitumen treated materials because no set standards for foamed bitumen mixes have been established. The rise time and estimate resilient modulus is therewith adjusted in order to avoid premature failure of the specimens during the test. Table 2 lists some important parameters as required.

Table 2: Target Parameter for  $ITM_R$  Testing

Loading Wave Shape	Haversine	Target Temperature (°C)	25
Loading Pulse Width (ms)	90-110	Target Peak Strain ( $\mu\epsilon$ )	50
Pulse Repetition Period (ms)	3000	Estimated Poisson Ratio	0.4
Preconditioning Pulse Count	5	Estimated Resilient Modulus (MPa)	200-1000
Test Pulse Count	5	10% to 90% Rise Time (ms)	40±5

### 2.6.2 Indirect tensile strength

Indirect tensile strength (ITS) is a good indication of a materials performance with particular consideration to cracking which can be attained using the Marshall Stability machine in accordance with Australian Standard - AS 1012.10-2000. The Marshall Stability machine is a simple machine which essentially applies a load through a loading frame to the sample along the height dimension to yield a tensile fracture. Whilst doing so it could display and record the peak load (in kN) in which the sample withstands prior to failure. Although this recorded value is not the indirect tensile strength of the sample, Equation 1 can be employed to convert the peak load to ITS value.

$$ITS=2000 * P / \pi * L * D \quad (1)$$

Whereby ITS= indirect tensile strength (kPa); P= Maximum applied force indicated by machine (kN); L= Height of specimen (mm); D= Diameter of specimen (mm).

## 3 RESULT AND ANALYSIS

### 3.1 Compaction Effects on Dry Density

As expected in either compaction method, with an increase in compaction effort, a greater density can be observed. Also expected, is the trend of an increase in FB content achieving a lower density despite the same amount of compaction effort webbing applied, which can be clearly seen in Figure 2. This arises from the less dense bitumen replacing space of the denser CRB and CLS when addition bitumen was added thereby reducing the overall density of the sample. It can also be seen in Figure 2 that the Gyratory compaction density curves never completely plateau, not like Marshall compaction illustrates a peak value. This possibly shows that greater compaction effort may have been implemented for the gyratory compactor to achieve optimum densities. Another trend can also be found to support this is that at a given dry density value, a higher number of gyrations of Gyratory compaction are required to produce comparable samples to the Marshall compaction. For example, if

75 blows of Marshall compaction is used as a reference point for heavy duty traffic, approximate 150 gyrations of Gyratory compaction is equivalent with the very similar dry density.

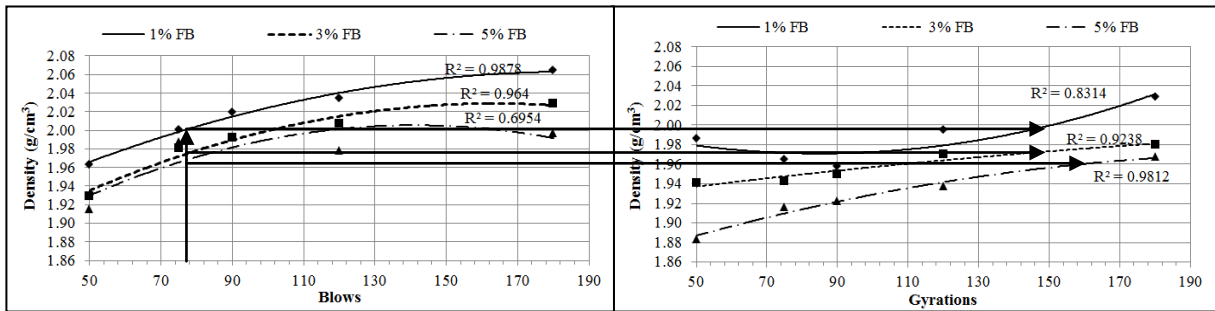


Figure 2. Dry density versus Marshall blows (left) and Gyratory gyrations (right)

### 3.2 Compaction Effects of indirect tensile strength

Figure 3 depicts a comparison in indirect tensile strength between Marshall and Gyratory compaction efforts. It is shown that minimal range between values in Gyratory compaction is evident and that an increase in gyrations does not always result in a higher ITS. A very different trend that Marshall compaction is far more sensitive with the increasing number of blows however, is apparent within the Marshall Sample data range. It is very clear that with an increase in number of blows, an increase in ITS can be observed. This correlation wasn't as strong for the 1% FB data however. When comparing the ITS value at a similar density between Marshall and Gyratory compaction, taking the density at 75 blows and 150 gyrations for example, a very close ITS value can be obtained at whichever bitumen content.

For the Gyratory samples, under soaked conditions, it is evident from the right figure that optimum compaction effort occurs between 100 and 130 gyrations where dry densities within the range of 1.92g/cm<sup>3</sup> – 2.00g/cm<sup>3</sup> were visible. Whereas, soaked Marshall Samples reveal optimum compaction efforts of 150-170 blows and above where dry densities of 2.00g/cm<sup>3</sup> – 2.06g/cm<sup>3</sup> were achieved. The Marshall samples exhibit a maximum range of ITS values of around 350kPa compared to a maximum increase in sample strength of gyratory samples of 100kPa. This further supports the trend that samples subject to Marshall compaction is more inclined to strength gain.

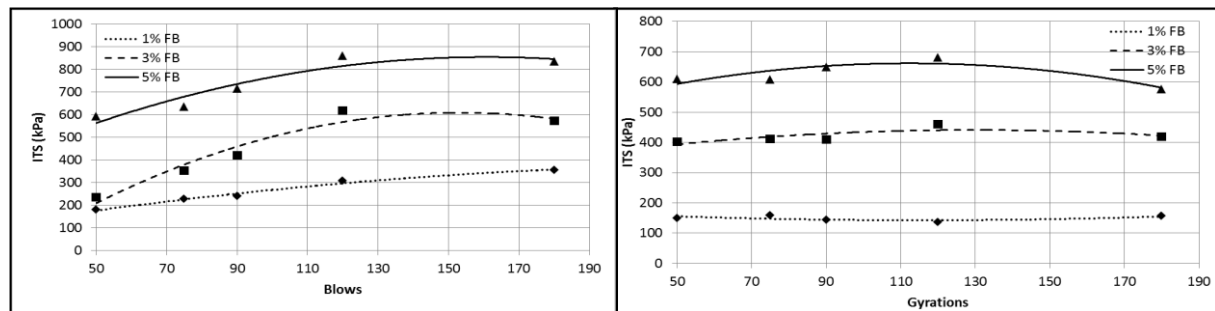


Figure 3. ITS (soak condition) versus Marshall blows (left) and Gyratory gyrations (right)

### 3.3 Compaction Effects of indirect tensile resilient modulus

It can be seen in Figure 4 that generally, with an increase in compaction effort, for either compaction method, a greater resilient modulus can be expected. This trend however, is far more obvious for the Marshall compaction samples, which is also evident from the figures is the continuous inclination of 1% FB and 5% FB content samples. The gyratory samples whereas all display maximum points at approximate 110-130 gyrations on their curves followed by a decline, a very similar peak point found in ITS observation. This reveals the first difference arising between Marshall compacted samples and gyratory compacted samples. Another finding upon analysis is the apparent range difference between low and high levels of compaction effort. Marshall Samples revealed a greatest range of 5000MPa whereas gyratory samples revealed a maximum range of only 2000MPa. Very clearly depicted in Figure 4, is a 50% greater maximum value of resilient modulus when compared to the gyratory samples.

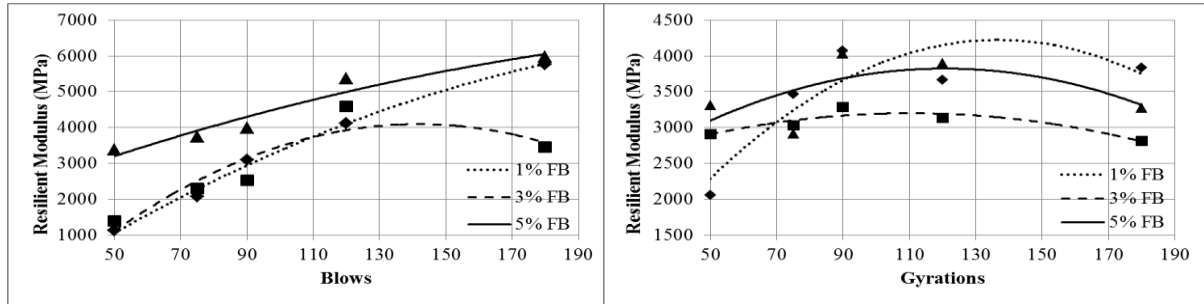


Figure 4.  $ITM_R$  (soak condition) versus Marshall blows (left) and Gyrotory gyrations (right)

#### 4 CONCLUSION AND RECOMMENDATION

Upon analysis it is reasonable to conclude that 150 gyrations of Gyrotory compaction when applying 240kPa force and at an angle 2 degrees is proven to be equivalent to conventional 75 blows of Marshall compaction to simulate heavy duty traffic based on similar dry density and tensile strength. It also reveals that higher levels of Marshall compaction appear to positively affect the indirect tensile strength of foamed bitumen materials whereas increases in gyrotory compaction effort appears to impact it significantly less. Resilient modulus of Gyrotory samples seems to be much more sensitive to Marshall Compaction. Studies incorporating greater levels of compaction from the gyrotory compactor are needed to clarify this finding and will allow for much more effective comparisons. A recommendation for further compaction studies on foamed bitumen would include the exclusion of Hydrated Lime in order to decrease the amount of variables and focus on compaction exclusively.

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