EFFECTS OF AGGREGATE GRADATIONS ON PROPERTIES OF GROUTED MACADAM COMPOSITE PAVEMENT

N.M. Husain, H.B. Mahmud, M.R. Karim and N.B.A.A. Hamid
Department of Civil Engineering
University of Malaya
Kuala Lumpur, Malaysia
nadiah.husain09@gmail.com

***Abstract*–Grouted Macadam composite pavement (GMCP) is generally a composite pavement which is manufactured by preparing a highly workable fluid mortar which is specially designed with a very high early and 28 day strength (1 day - 45 MPa, 28 day - 105 MPa) by filling the flowing fluid mortar into a very open porous asphalt skeleton (25-32% Voids in Mix - VIM). The combination of both components will produce a semi-rigid pavement or GMCP which has the best features of both rigid concrete and flexible bituminous pavement where it will replace the conventional wearing course. This paper will investigate the significance difference of GMCP produced by the 3 different aggregate gradations by Road Engineering Association of Malaysia (REAM) in volumetric properties, durability and strength. The best quality fluid grout was chosen to fill the porous asphalt skeleton and GMCP was subjected for compression test, VIM and indirect tensile test (IDT) to check on its performance. The results show that the 3 different aggregate gradations significantly affect the volumetric properties, durability and strength. Furthermore it will also help in reducing pollution and helps with the current environmental problems.**

Keywords: Grouted Macadam Composite Pavement, Fluid Grout, Porous Asphalt

I. INTRODUCTION

Road surfacing pavement has always been one of the major issues in most developing countries. Finding the best design of surfacing layer had been a positive competition among manufacturers and designers. Road surfacing pavement demands adequate strength to ensure satisfactory durability. Both pavement types have their own advantages and also shortcomings. As for example, rutting as a result of increased stresses in heavy-duty pavements is the main cause of deterioration of flexible asphalt surfacing [1]. Rigid pavement on the other hand can be susceptible to relatively slow setting times during the construction phase and poor riding quality (and noise) caused by the joints required to accommodate differential expansion/contraction during service [2]. In environmental point of view, rigid pavement has caused quite numerous of issue which includes, pollution of noise from the poor riding quality and also the emission of noxious gas during the production of cement (environmental problem).

However, another alternative solution to overcome the limitation and drawback caused by the commonly road surfacing would be the joint-less semi-rigid pavement surfacing. The resultant combination consist both the flexibility from the bituminous component and the rigidity from the cement constituent. Semi-rigid pavement surfacing composed of porous asphalt skeleton filled with the best selection of fluid grout was tested. Thus, producing a very high workability fluid grout and at the same time attain a relatively high compressive strength is required to bond together the two composition with minimal porosity (<10%). Porous asphalt skeleton is manufactured by using bitumen as binder, course and fine aggregates. Very open porous asphalt is required in order to allow a self compacting cementitious grout to impregnate into the porous asphalt skeleton under the influence of gravitational force. Thus it is important that the porous asphalt skeleton achieve a very high air voids content of 28-32%. The sample which has a depth of 100mm each maintains a very thick layer of bitumen coating the aggregates. The amount of cement used in this type of pavement is only 30% of the total volume wearing course. Compared to the rigid pavement, grouted macadam composite pavement (GMCP) has produced a composite structure which at the same time helped in reducing air pollution with the use of lesser amount of cement but gives a distinct value of strength. This statement will clearly helped with the environmental issues corresponded to air pollution.

II. BACKGROUND

GMCP is manufactured by the production of both a very open porous asphalt skeleton together with a very high workability fluid grout. This paper mainly focuses on the production of wearing course i.e GMCP that gives a better quality and durability, to lessen the environmental impact towards the surrounding area. The production of GMCP were chosen from 3 different aggregate gradations (Upper limit, mid-pt, lower limit) [3] and the best selection of fluid grout will be chosen to fill the porous asphalt skeleton via gravitational force. GMCP will then undergo a volumetric test, indirect tensile test (IDT) and compression test to check on its performance.

Porous asphalt skeleton was produced by using Marshall method with 50 compaction blows on upper and lower face of the sample. The 50 compaction blows were acceptable compaction value for medium traffic flow [4] and an acceptable value to produce a desired voids in mix (VIM). The desired VIM is essential towards producing GMCP as it

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will enhance the ease of filling the voids by fluid grout via gravitational force without the aid of vibration as it may damage the porous asphalt due to high percentage of air voids.

III. OBJECTIVES

This paper will investigate the significance difference of GMCP produced by the 3 different aggregate gradations in volumetric properties and durability (resilience modulus and strength).

IV. METHODOLOGY

A. Porous Asphalt

The materials used in the investigation are the conventional bitumen 80/100, crushed aggregates with porous mix gradation and also Portland cement acts as filler. Crushed aggregates and bitumen 80/100 were supplied by local a supplier. Table 1 and 2 below show the physical test that was conducted on the course aggregates and bitumen binder respectively. Fig. 1 shows the 3 aggregate gradations for porous mix. Table 3 shows the temperature for the preparation of Marshall mix.

TABLE I. PHYSICAL TEST ON COURSE AGGREGATES

Physical Test	Value
Flakiness Index (FI) [5]	20.8
Elongation Index [6]	21.2
Aggregate Crushing Value (ACV) [7]	24.3

TABLE II. PHYSICAL TEST ON BITUMEN 80/100

Physical Test	Value
Softening Point, °C – [8]	45 – 50
Penetration – mm [9]	80 – 100
Ductility – mm [10]	80 – 100
Flash Point, °C – [11]	200

TABLE III. TEMPERATURE FOR MARSHALL MIX PREPARATION

Preparation	Temperature (°C)
Mixing Temperature,	160 – 180
Compaction Temperature,	135 – 140

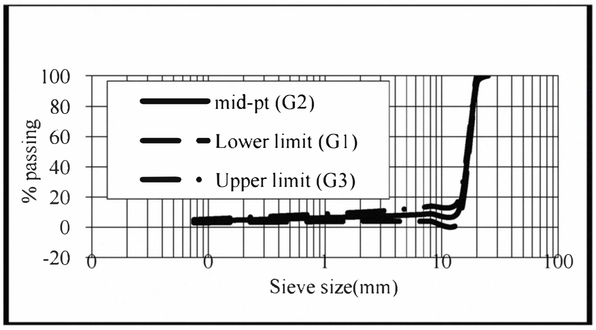

Figure 1. Aggregate Gradations for Porous Mix

B. Fluid Grout

The main cementitious binders that were used were the ordinary Portland cement (OPC) and additive-H. OPC was supplied by a local manufacturer and comply with the requirements of BS EN 197-1:2000. Additive-H is a pozzolanic material which was added before mixing with water. The addition of additive-H helped to improve particle packing and at the same time provide high compressive strength to the mix. High range water reducer (HRWR) in a fluid grout mix is well known as it allows a reduction in water/cement ratio and at the same time maintains the desired pourable consistency required [3]. The current HRWR used was supplied by a local manufacturer, which was a polycarboxylic ether (PCE) based. It emphasizes on acceleration of the cement hydration process which helps in early stripping of forms/early strength.

C. Targeted Values

The main requirement for fresh fluid grout was to have a pourable consistency that allows rapid penetration into the porous asphalt skeleton. Several fluid grouts with varying composition were produced by trial and error in order to achieve the desirable workability. Table 4 shows the requirement on fluid grout and porous asphalt for the purpose of GMCP.

TABLE IV. PHYSICAL TEST ON COURSE AGGREGATES

Test	Requirement
Workability	11 – 16 s
Compressive Strength	1 day: 45 – 50 MPa 28 day: 95 – 105 MPa
VIM Porous Asphalt	25 – 32 %

V. RESULTS AND DISCUSSIONS

A. Volumetric Properties

1) Air Voids Test - VIM

Fig. 2 shows the VIM for the three different aggregate gradations G1, G2 and G3. The line connecting the 3 aggregate gradations shows the mean VIM of each group which varies from 9.93% - 11.60%. The figure has clearly shown that VIM increases as the aggregate gradation moves from the lower limit up to the upper limit of the aggregate gradations. VIM of GMCP is inversely related. This is obviously due to the fact that higher air voids of porous mix will allow a better fluid grout penetration compared to a much lower air voids of the porous mix. This will eventually help in filling the air voids created via interlocking system created by the aggregates of the porous mix. The targeted minimal porosity of GMCP for this study was 10% or less. This is to support the idea of producing a semi-rigid composite pavement. Thus it should have the allowable porosity of high strength concrete which is 10% or less. From the results obtained, GMCP gave quite a reasonable result and more laboratory experiments are in progress to reduce the porosity further. The low porosity values obtained for the GMCP which are comparable to that of high performance concrete [12].

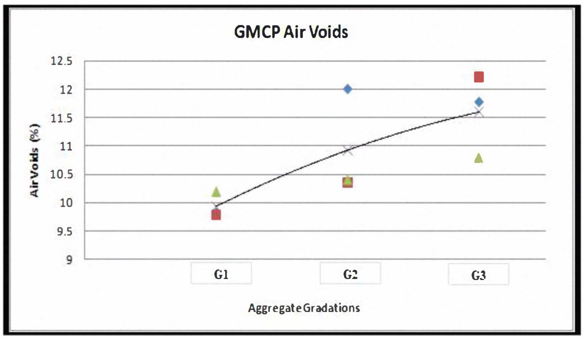

Figure 2. Voids in Mixes of 3 Aggregate Gradations

2) Bulk Density (G_{mb})

Bulk density or bulk specific density (G_{mb}) was found to have a close relationship with the changes of air voids. Referring to Fig. 3, G_{mb} is inversely related with the VIM. Both Fig. 2 and 3 shows quite a distinct effect towards one another. The relationship of VIM and bulk density is due to the densification of mixes. In the case of GMCP, the higher value of G_{mb} obtained compared to porous asphalt mix is obviously caused by the filling of fluid grout into the porous mix. The line connecting the 3 aggregate gradations shows the mean of G_{mb} of each group varies from 2.22 g/ml to 2.27g/ml. Previous studies done on grouted macadam shows similar results with the current investigation [12]. This result used in the current investigation has proven that the chosen porous mix gradations are suitable and acceptable.

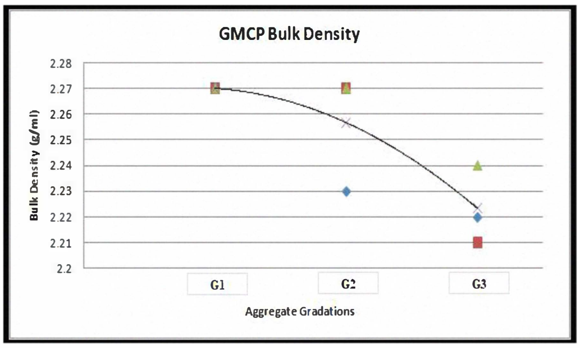

Figure 3. Bulk Density of 3 Aggregate Gradations

B. Durability

1) IDT – Resilience Modulus

IDT is also referred to as resilience modulus test is a property whereby materials absorb energy when it is deformed elastically and upon unloading, this energy is recovered. The greater the resilience modulus, the stiffer the material gets, thus the higher it resists deformation. This will basically lead to a better resistance towards permanent deformation, thus improved the resistance towards rutting. It is clearly stated that when the resilience modulus is at the highest, it indicates the stiffest material condition under a recoverable deformation behavior. Fig. 4 shows the resilience modulus of the 3 aggregate gradations made with the best quality of fluid grout. It can be concluded that the resilience modulus is significantly affected by the changes of aggregate gradations. The stiffness of GMCP is much higher compared to those of porous asphalt mix [12, 13, 14, 15, 16, and 17]. This is due to the fact that fluid grout that fills the voids has already increased the pavement stiffness via its individual strength. In fact, G1 gave the highest stiffness modulus considering the higher amount of fluid grout inserted into the porous mix.

Since G1 VIM is much higher compared to the other 2 aggregate gradations, thus it allows a higher amount of fluid grout impregnated into the porous mix. According to [18], higher value in resilience modulus is most desirable to build a less thick pavement which will still maintain its structural integrity. Comparing to the previous studies, the current sample provided relatively good resilience modulus and can be utilized for heavy traffic road corridors [12][14][19].

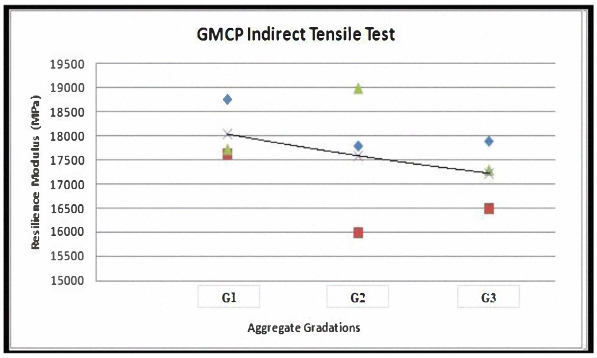

Figure 4. Resilience Modulus of 3 Aggregate Gradations

C. Quality

1) Compressive Strength

The targeted compressive strength of GMCP for day 1 is 5 MPa. Fig.5 shows clearly the effect of GMCP towards the 3 different aggregate gradations. The line connecting the 3 aggregate gradations indicated the mean compressive strength varying between from 5.3 MPa – 5.57 MPa. The highest strength obtained was from G1 with 6.09 MPa. As explained earlier, the higher air voids achieved has helped the final composite to be able to attain a better and justified strength.

Above all, the 3 aggregate gradations gave a reasonable remark of strength and most importantly achieved the targeted value. GMCP samples exhibited a much higher 1 day compressive strength value compared to the conventional flexible pavement of 3 MPa. This result obviously will help in producing and improving the quality of pavement currently being used in Malaysia.

With the high compressive strength achieved, it is basically shown that low maintenance pavement is produced implying less number of resurfacing construction work to be done. It will eventually help in some of the environmental issues due to the fact that less air pollution is produced during the construction. With this result, it is clearly shown that the product of GMCP is suitable for construction but more laboratory tests are in progress to validity the durability property of the pavement.

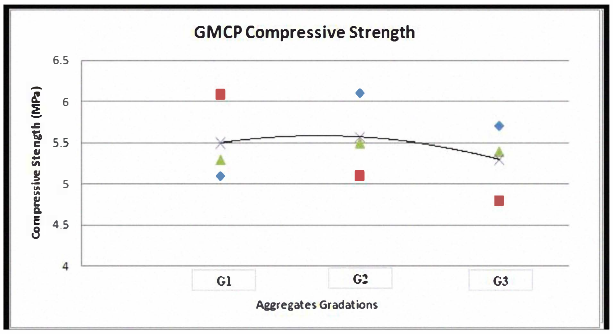

Figure 5. Compressive Strength of 3 Aggregate Gradations

VI. CONCLUSION

GMCP gave a reasonable strength with lower porosity, higher bulk density and much higher resilience modulus. With the results achieved, it is clearly shown that GMCP may help in reducing pavement resurfacing thus at the same time helps in reducing the emission of air and noise pollution.

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