The semi-rigid pavement with higher performances for roads and parking aprons

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ABSTRACT

Concrete pavement with good wear/tear and chemical resistances has great difficulties in maintenances and repairing, while asphalt concrete can easily be repaired but is not durable if under heavy loading and chemical impact. The semi-rigid pavement system has been developed by combining the advantages of the both pavements to perform like concrete but to be easily maintained like asphalt concrete. This system is formed by porous asphalt concrete and polymer modified grouting material which is poured into the porous asphalt concrete. It has gradually become popular for years internationally as a surface layer of those pavements under serious conditions such as in road junctions, airport aprons and heavy loading yards. A commonly used semi-rigid pavement system in Singapore for both airport parking aprons and road junctions is introduced in this paper. The properties and specifications for both porous asphalt concrete and polymer modified grouting material are discussed and highlighted, which deliver the special advantages and benefits from the system to a sustainable pavement development. Furthermore in the paper, several typical projects completed with this system are studied together with the presentation of installation procedure.

Keywords:
Semi-Rigid Pavement, Concrete Pavement, Asphalt Concrete, Porous Asphalt Concrete, Grouting Material

1. INTRODUCTION

1.1 TYPICAL PAVEMENT DESIGN TYPES FOR ROAD CONSTRUCTION

Road pavements shall be designed in consideration of traffic loadings and evaluations on sub-grade status, environmental factors and available construction materials. Two different types of pavement design systems are conventionally used in the construction of roadways, i.e. flexible and rigid pavements **[3]**. The flexible pavement is typically constructed by bituminous and granular materials; meanwhile the rigid pavement is typically constructed by Portland cement concrete which composes of crushed rock, sand, hydraulic cement, water and additives in order to achieve its engineering properties.

1.2 DEFINITION OF SEMI-RIGID PAVEMENT

Semi-rigid (or in some countries called as semi-flexible) pavement is originally termed as Resin Modified Pavement (RMP) which was developed in France in early 1960's as a cost effective alternative to Portland cement concrete pavement **[2]**. The semi-rigid pavement is a composite pavement material consisting a porous asphalt concrete (PAC) with air voids between 25-30% (by volume of Marshall mix design) which is filled or flooded by a special formulated high performance polymer modified cement mortar grouting material as shown in Figure 1. Based on this definition, the semi-rigid pavement system is the combination the characteristics of Porous Asphalt Concrete (PAC) and Portland cement concrete (PCC) pavement. Since 1990's, semi-rigid pavement has become popular throughout in Europe countries, United States, Africa and Asia region for new and maintenance of civil infrastructures construction such as roads, airfields, sea ports, industrial heavy loading yard, and etc.

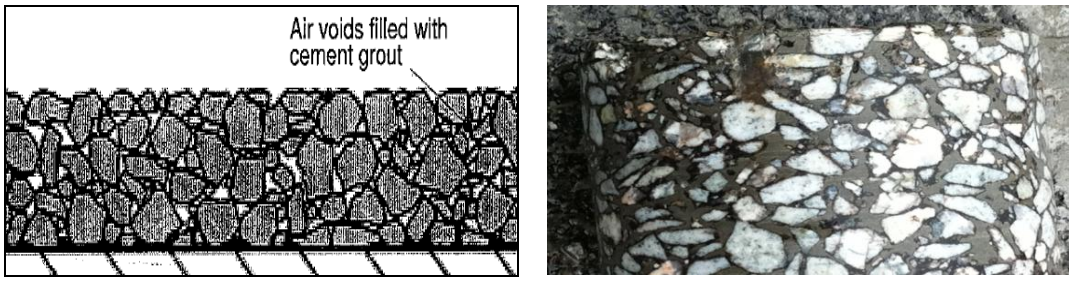

Fig. 1 Porous asphalt concrete (left) and a semi-rigid pavement cored sample (right)

1.3 ADVANTAGES OF SEMI-RIGID PAVEMENT

The general comparison among Asphalt Concrete (AC) and Portland Cement Concrete (PCC) and Semi-Rigid Pavement (SRP) is given in Table 1.

Table 1: Properties compassion among AC, PCC and SRP

Compared Properties	Asphalt Concrete (AC)	Portland Cement Concrete (PCC)	Semi-Rigid Pavement (SRP)
Resistance to rutting/deformation	Poor	Good	Good
Skid resistance properties	Good	Poor	Good
Resistance to petroleum products, oil and chemical	Poor	Good	Good
Resistance to moisture damage	Poor	Good	Good
Maintenance and repair	Easy	Difficult	Easy
Life span	Lower	Higher	High
Flexural strength properties	Low	High	High
Expansion joint	Not required	Required	Not required
Installation and open to traffic	Within hours	0.5~3.0 months	Within 24 hours
Construction and maintenance costs	Lower const. cost; High maint. cost	Higher const. cost; Low maint. cost	Low const. cost; Low maint. cost

From the table, it can be found that the semi-rigid pavement system has combined almost all advantages and benefits from both conventional pavement systems (i.e. asphalt concrete and cement concrete). One of the most important benefits of the semi-rigid pavement is easy and fast construction and maintenance of the asphalt concrete pavement and another is to have higher strength properties and better durability which is similar to those of the cement concrete pavement. After the combination, the semi-rigid pavement has been equipped with high strength properties to withstand heavy traffic, good skid resistance, impermeable, durable but with fast construction and easy maintenance. It is the key reason of why the semi-rigid pavement has become more and more popular.

1.4 THICKNESS OF SEMI-RIGID PAVEMENT

In practice, the semi-rigid pavement has been used for both new and maintenance of civil infrastructures especially for roads, airfield parking aprons as well as taxiway junctions, and industrial heavy loading yards. The major application of the semi-rigid pavement for road construction is at traffic light intersection (junction) with a typical thickness of 50mm as the wearing layer. Meanwhile, for very heavy loading cases such as taxiway junction, the thickness design could be a single layer with 50mm to 75mm thick or double layers with 50-75mm thick for each layer.

2. SEMI-RIGID PAVEMENT COMPONENTS & PROPERTIES

The semi-rigid pavement consists two main components which are porous asphalt concrete (PAC) and the high performance polymer modified cement mortar grouting material. In Singapore, the semi-rigid pavement has been categorized under special materials category with the properties of porous asphalt and mortar grouting material conforming to “Code of Practice for Works on Public Streets 10th March 2009 revision 2 section 9.6 for Material Specifications & Quality Control”.

2.1 REQUIREMENTS OF POROUS ASPHALT CONCRETE (PAC) PROPERTIES

The first component of the semi-rigid pavement is the Porous Asphalt Concrete (PAC) and one of PAC main properties shall consist 25-30% of air voids by volume (Marshall mixed design). Typically, the design of PAC includes the selection of aggregate gradation, determination of bitumen content, mixing and compaction procedure. The main components of PAC shall also consist the typical properties are shown in Table 2 **[4]**.

For the coarse aggregates inside of PAC shall consist of clean, angular, crushed granite stone and are free from dust, dirt and other deleterious materials. The properties of the coarse aggregates must conform to the requirements shown in Table 3 **[4]**.

Table 2: Main components of PAC

Components	% by weight
Bitumen 60/70 pen	3.6% to 4.6%
Lime filler	4.0%
Cellulose fibers	0.2%
Crushed aggregates	91.7%

Table 3: Coarse aggregate properties

Properties	Allowable value	Testing method
Crushing value	<20%	BS 812 part 110
Flakiness index	<20%	BS 812 part 105
LA abrasion (500 revolutions)	<20%	SS 73:74
Silt content of aggregate	Not more than 0.3%	BS 812 part 1

2.2 REQUIREMENTS OF POLYMER MODIFIED CEMENT MORTAR PROPERTIES

The second component of the semi-rigid pavement is a high performance polymer modified cement mortar. Polymer modified cement mortar shall be mixed with the

designed water to form a free-flowing grouting mortar. The most important factors for design of modified cement mortar are the flow time and compressive/flexural strength properties. Chemilink SS-141 is a high performance polymer modified cement mortar material which has specially been designed for the semi-rigid pavement system. The properties of this SS-141 polymer modified cement mortar have been compared with "Code of Practice for Works on Public Streets for Material Specifications & Quality Control (section 9.6)" and two public project tender specifications in Singapore and shown in Table 4 **[1, 4, 5]**. However it is our opinion that the strict requirement on the flowing time (fluidity) is neither necessary nor practical because the SS-141 product with longer flowing time can fully fill the voids of PAC even up to 80mm deep.

Table 4: Properties of SS-141 polymer modified cement mortar

Properties	Curing time	Chemilink SS-141	Code of Practice for Works [(a)]	Project Tender document [(b)]	Project Tender document [(c)]
Fluidity (workability) ASTM C939	---	13-27sec	---	10-14sec	10-14sec
Compressive strength (BS EN 12390)	12hrs	20-30MPa	---	---	---
	1day	55-85MPa	≥55MPa	---	---
	7days	100-120MPa	---	---	≥40MPa (8-d)
	28days	120-140MPa	≥110MPa	40-50MPa	
Flexural strength (BS EN 12190)	28days	7-15MPa	≥15MPa	6-8MPa	≥6MPa
Setting time (EN 196-3)	---	2-3hr; 3-6hr; 6-8hr	8-12hours	2-3hours	2-3hours

Notes:
[(a)] Code of Practice for Works on Public Streets 10th March 2009 revision 2 section 9 for Material Specifications & Quality Control, Singapore.
[(b)] Project tender specification by LTA PS-13-16.
[(c)] Project tender specification by Changi Airport Group "Technical Specification for Taxiways".

2.3 REQUIREMENTS OF THE SEMI-RIGID PAVEMENT PROPERTIES

The properties of the semi-rigid pavement after combination of the Porous Asphalt Concrete (PAC) and SS-141 polymer modified cement mortar are shown in Table 5 **[1, 4, 5]**, which can conform to or even be higher than the requirements from general specifications as mentioned above.

Table 5: The properties of the semi-rigid pavement with SS-141

Properties	Curing time	Chemilink SS-141	Code of Practice for Works [(a)]	Project Tender document [(b)]	Project Tender document [(c)]
Compressive strength (EN 12190)	12hrs	3-5MPa	---	---	---
	1day	6-8MPa	---	---	---
	8days	9-12.5MPa	---	---	---
	28days	10-14.5MPa	7-10MPa	≥7MPa	7-10MPa
Flexural strength (BS EN 12190)	28days	6-7MPa	≥3.5MPa	≥3MPa	≥3.5MPa
Skid resistance (ASTM E303)	---	60-90BPN	---	≥60BPN	---
Curing time	---	4-8hrs	---	4-8hrs	4-8hrs

3. CONSTRUCTION OF SEMI-RIGID PAVEMENT

Since the semi-rigid pavement is the combination of Porous Asphalt Concrete (PAC) and high performance polymer modified cement mortar materials, the construction of semi

pavement can be divided into 2 major stages including the laying of porous asphalt concrete and grouting of polymer modified cement mortar material.

A. Laying of porous asphalt concrete with the detail steps shown in Figs. 2a-2d.

Fig. 2a Milling of existing AC surface

Fig. 2b Spraying primer coat

Fig. 2c Laying PAC to design thickness

Fig. 2d PAC surface after compaction (air voids 25-30%)

B. Grouting injection of polymer modified cement mortar

After laying of porous asphalt and when the surface temperature of porous asphalt concrete (PAC) has been reduced to the desire temperature such as 50-60°C, the next stage is to grout the high performance polymer modified cement mortar into the PAC layer. The detailed steps of such grouting are shown in Figs. 3a-3d.

Fig. 3a Mixing of the mortar with water

Fig. 3b Grouting of the mortar

Fig. 3c Levelling and vibration (if needed)

Fig. 3d Semi-rigid pavement surface

4. CASE STUDIES FOR ROADS & AIRFIELDS

Since 2005, Chemilink SS-141 high performance polymer modified cement mortar has popularly been used in civil infrastructure projects in Singapore for:

a) Industrial heavy loading yards
b) Airport parking aprons and potential taxiway junctions
c) Heavy traffic roads and junctions

The engineering properties of the semi-rigid pavement for those projects have fully conformed to the specification requirement as stated in Table 5. The most typical design thickness of the semi-rigid pavement for those projects is **50mm** except that a **75mm** thick layer has been adopted for one project trial as the potential airport taxiway junction design. From the cored samples after construction, Chemilink SS-141 polymer modified cement mortar has showed (Fig. 6b) good penetration ability even for **75mm** thickness of the semi-rigid pavement.

4.1 ASPHALT CONCRETE PLANT (2005)

Fig. 4a Semi-rigid pavement after hardened

Fig. 4b Good ability to chemical/oil attacks

4.2 CHANGI INTERNATIONAL AIRPORT APRONS (2007)

Fig. 5 Semi-rigid pavement for airport aprons construction in progress

4.3 IMPROVEMENT AND RESURFACING WORKS ON PARALLEL AND RUNWAY ENTRY TAXYWAYS AT CHANGI AIRPORT (2010)

Fig. 6a Semi-rigid surface after hardened

Fig. 6b Coring samples (**75mm thick**)

4.4 HEAVY TRAFFIC ROADS AND JUNCTIONS

A. Sungei Kadut Street 1 (2010)

Fig. 7a Construction in progress

Fig. 7b Heavy traffic road in use

B. South Buona Vista Road & Junction (2011)

Fig. 8 Semi-rigid pavement system in construction in city area

5. CONCLUSIONS

1) Applications of the semi-rigid pavement have become more and more popular for civil infrastructures due to its fast construction, easy maintenance and high strengths to withstand heavy traffic and better durable properties. The semi-rigid pavement has successfully been applied for roads, parking aprons and industrial heavy loading yards in Singapore for past years.
2) Chemilink SS-141 is the high performance polymer modified cement mortar for the semi-rigid pavement system and its engineering properties and performances have fully conformed to the various public specifications in Singapore. The main properties of Chemilink SS-141 polymer modified cement mortar are:
   - Compressive strength: ≥55MPa (1day) and ≥110MPa (28days);
   - Flexural strength: 7-15MPa (28days); and
   - Optimum Water/Powder (W/P) ratio is 0.25-0.30.
3) The properties and performances of Chemilink SS-141 polymer modified cement mortar can be adjusted in order to meet different design requirements for the semi-rigid pavement at different conditions.
4) The properties of the semi-rigid pavement have also conformed to the specifications and the major parameters are:
   - Compressive strength: 6-8MPa (1day);
   - Compressive strength: 10-14.5MPa (28days); and
   - Flexural strength: 6-7MPa (28days)
5) From the construction experience, SS-141 grouting material with a wide range of flowing time (fluidity or workability) can penetrate into 75mm deep or more to form a thicker of semi-rigid pavement thickness, while a typical design thickness is 50mm.

6. REFERENCES

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