Chemilink In-Situ rehabilitations for various pavements in Malaysia

Y F Tan[1], D Q Wu[2], C H Lim[3] and E Arasu[4]

[1] Project Coordinator, Chemilink Technologies Group, Singapore
[2] CEO, Chemilink Technologies Group, Singapore
[3] Senior Business Manager, Chemilink Technologies Group, Singapore
[4] Project Engineer, Chemilink Technologies Group, Singapore

yihfun_tan@chemilink.com

Abstract. Due to increased traffic volume and conventional pavement designs with poorer subgrades under tropical environment and conditions, most roads are relatively over-loading and the repair or maintenance works to existing pavements become a focus. A super-fast and super-strong technology is required to strengthen the existing pavements in short period with lesser disturbances to both public traffic and operations. Chemical in-situ rehabilitation has become the trend of quick repairs in Malaysia. Chemilink systems have more than 25 years track records in tropical region, its product has been officially approved by Federal Jabatan Kerja Raya (JKR) and Lembaga Lebuhraya Malaysia (LLM) since 2016 in JKR Material List (JMAL). This rehabilitation method can strengthen various pavement base/sub-base courses and achieve higher performances, such as California Bearing Ratio (CBR) values with more than 120% within 24 hours, it also become more popular for pavement upgrading/strengthening and maintenance in airfield and seaport too. It significantly increase overall performances and durability of various pavements with higher technical parameters, faster construction, longer working life and finally overall cost effectiveness. It can utilize the in-situ and local materials in green and sustainable manner. The application procedure include site investigation, mix-design, rehabilitation process, and immediate and long-term performances.

Keywords: Malaysia roads and pavements, In-Situ rehabilitation, Chemilink

1. Introduction

Through decades of economic development, the volume of transport has increased dramatically from 8.8 million to 28.2 million in Malaysia. The design capacity using conventional way sometimes cannot fulfil the increased traffic volume/frequency and loading, as some roads originally may have only been designed for usage of P3, but may currently be under P2 or even P1 conditions because of rapid traffic development. Furthermore, this case may worsen as Malaysia is in the tropical region with high water table and rich rainfall, and there are a lot of marine clay, peat and swampy soils which will greatly affect the bearing capacity and performances of pavements.

Various soil improvement methods have been employed to build roads in these high-water table and soft ground areas, such as vertical drains/consolidation, compaction, grouting, and geo-synthetics reinforcement but with limited effectiveness and success. (Mitchell and Katti, 1981[1]).

Frequent pavement maintenance, repair and/or upgrading for heavy traffic roads have become a tough routine work for JKR and the Town Council. In many existing airports under tropical environment in South-East Asia, a simple re-surfacing cannot meet operational requirements with heavier traffic in terms of frequency and aircraft loading, and thus effective strengthening of the base and sub-base of airfield pavements becomes crucial and necessary especially for those in swampy and soft ground areas (Wu, 2017a[2], Wu, 2017b[3]). The conventional method with replacement of existing quarry materials has significant technical and operational disadvantages for various pavements under heavy operations.

A super-fast and super strong technology introduced by Chemilink is therefore required to strengthen the existing pavements in a short time period with less disturbance to both public traffic and airport/seaport operations.

Since 1995, Chemilink Technologies Group (CTG) has entered Malaysia market and written a new page of rehabilitation history in Malaysia. In the year 1995, JKR and IKRAM tested the soil stabilization product called Chemilink SS-108 in Alor Gajah, Melaka and proved with a testimonial, stated that soil which was stabilized by SS-108 can be easily strengthened from 15% CBR (California bearing ratio) to over 100% CBR within short period but without surface cracking issues that results from cement stabilization. For the past 20 over years, Chemilink has not only assisted JKR in solving many critical technical problems, but has also provided total solutions to Kementerian Luar Bandar dan Wilayah (KKLW), Malaysia Airport Holding Berhad (MAHB), Ministry of Agriculture (MOA) and many other public and private sectors to resolve different engineering issues (Wu & Tan, 2008[4], Lee et al., 2010[5], Huang et al., 2014[6], Wu and Zhang, 2016[7]).

Out of many projects, the Senai Airport runway/taxiway widening with highly-clayey soils (Wu et al., 2008[8]);strengthening of Port Klang container yard under soft and thick marine clay(Tan et al., 2011[9]), Penang International Airport runway and taxiway upgrading under both higher water table and soft ground conditions (Wu et al., 2017[10]),are some of the most difficult but successful projects in Malaysia, not to mention Singapore Changi Airport runway widening projects(Koh et al., 2005[11]) which has featured on Discovery Channel and broadcasted globally since 2008. Due to the superb overall results and excellent long-term performances for road projects of JKR in Malaysia for past many years including performance tests such as the in-situ CBR and Falling Weight Deflectometer (FWD) test conducted by the State and Federal JKRs from time to time to inspect the performance of Chemilink rehabilitated or stabilized base or sub-base courses, the Federal JKR, together with the Highway Authority of Malaysia (LLM) has issued the first approval of Chemilink SS-108 soil stabilization product system (JMAL) in Malaysia (Photo 1.1). This directly and indirectly proves that this innovative system is the first proven solution for rehabilitation and stabilization of soils and crusher run base/sub-base, especially in our tropical climate and conditions. This solution has also been widely used for roads under peat and swampy areas to settle pavement problems with minimized R&R work and creating a "Floating" Semi-Rigid Platform, which is a proven and trusted solution endorsed by JKR Brunei for the past 20 years. In Perak, where the State has a lot of paddy fields, Chemilink stabilized roads can be found nearby with satisfactory performances and durability.

KEPUTUSAN MESYUARAT JAWATANKUASA BERSAMA (JKR-LLM) KELULUSAN PRODUK BAGI KERJA-KERJA JALAN BIL.2/2016

SYARIKAT	: Advanced Stabilization Technologies Resources PLT
PRODUK	: Chemilink Soil Stabilization
MODEL	: SS-108
BAHAN	: Soil Stabilizing Agent
PENGILANG	: Chemilink Technologies Group PTE LTD (Singapura)
KEPUTUSAN	: **LULUS**

ULASAN:

i. Produk telah mematuhi *Standard Specification For Road Works Section 4: Flexible Pavement* (JKR/SPJ/2008-S4 / JKR 20403 0003 07) dan *LLM/GP/T5 08 : Guideline for Malaysia Toll Expressway System - Design Standard.*

Photo 1. Chemilink Approval under JKR Material List (JMAL).

2. In-Situ rehabilitation and "floating" semi-rigid platform effects

Commonly, in road construction, the unsuitable in-situ soft soils or damaged crusher run materials need to be replaced by imported quarry (crusher run) materials as unbound base layer, but due to some limitations, it is difficult for the quarry materials to perform well and have good durability, and such materials may be much expensive in certain districts as well. Moreover, over-exploitation of natural quarry materials would surely cause negative issues to the natural environment. For urban areas and operating airports or seaports, the problem of operational breaking off is more serious than pavement repairing costs as smooth operations without breaking off is the most important and top priority for various operators. Sometimes, the repairing or maintenance working window is only a few hours and there is no way for traditional methods to repair the pavements quickly and effectively.

For the effective solution to all similar problems, the In-Situ Rehabilitation (ISR) is the best method to fulfil all the requirements including technical performances, green and environmental conditions, overall cost effectiveness within the limited construction time. With ISR, limited fresh natural quarry materials, and much less or even no waste disposals are required. By mixing appropriate percentage (few percentage only) of stabilizers or stabilizing agents with in-situ soils or crusher runs, the agent will improve the engineering properties of soils or crusher runs such as the volume stability, various strengths and moduli, stress-strain relationship, permeability and durability. After strengthening the properties, the rehabilitated or stabilized layer can function like the sub-base or base course of various pavements as the bounded platform. This is the green and environmental-friendly technology which minimizes the usage of fresh resources and dumping of existing unsuitable materials, maximizing the use of in-situ existing materials up to 100%, and significantly improving the overall performances to fit or even update real pavement capacities.

There are a lot of conventional stabilizing agents, such as cement, lime, bituminous materials, coal fly ash, slag, polymer types in liquid form and so on. In a tropical region like South East Asia, due to a lot of swampy and soft grounds, and low land areas together with reverse climate conditions such as rich rainfall as well as high water table, peaty and problematic soils, these conventional agents are often

not effective or with some fatal limitations. A stabilization system with the type of polymer modified cementitious stabilizing agent called Chemilink SS-108 sub-series has been specially developed in Singapore and successfully applied in this tropical region and other countries in Asia for infrastructural construction, especially for various pavements since the 1990s, with hundreds of engineering projects (Yong and Wu, 1999[12], Liu et al., 2004[13], Wu, 2011[14]), and this proven system has also been endorsed by some national public works authorities, including the Malaysia Federal JKR and LLM as shown in Photo 1.(CPRU-Brunei, 1999[15],Suhaimi and Wu, 2003[16]).

The base or sub-base rehabilitated or stabilized by Chemilink SS-108, can form a "floating" semi-rigid platform, which will function as a continuous slab with sufficient strengths, as if it were floating on the existing soft grounds. The concept of this floating semi-rigid platform is like a boat, where it floats on peat or marine clay with high water content or in high-water table area. The rehabilitated/stabilized layer is also almost impermeable to water and thus it is difficult for water from the bottom to penetrate the inside of the rehabilitated stabilized layer(s) and subsequently to damage the base/sub-base courses and even up to the surface layer. The platform can also minimize differential settlements as it acts as the whole bounded platform rather than individual loose materials.

3. Design criteria and construction

3.1. Rehabilitation design and new QC criteria

The standard design for ISR with crusher run or equivalent is as follow:

- Base (7-day): CBR □90-120%, and/or UCS □3.0-6.0 MPa (UCS: unconfined compressive strength)
- Achievable Stiffness Modulus (28-day):2,000-8,000MPa
- Chemical Binder Dosage: 1.50-3.00% (based on the dry weight of the soil or crusher run to be treated)

However, the new QC criteria has been introduced as below which evolutionally changed and strengthened the QC assurance under time contains:

- CBR≥120% within 24-hour

After rehabilitation or stabilization within 24 hours, the in-situ CBR test can be carried out before laying of asphalt concrete surface.

3.2. ISR construction procedure

The installation process of ISR is very simple and easy, from spreading, in-situ mixing, to compaction completion. First of all, for the road or pavement to be rehabilitated, the existing premix has to be removed until the base layer. Then spread the stabilizing agent evenly either mechanically or manually onto the surface of the in-situ soil or crusher run to be stabilized, followed by in-situ mixing using an advanced self-running mixer called Stabilizer or Recycler. Two rounds of mixing are generally required in both dry and wet mixings. The dry mixing is mainly to ensure that the stabilizing agent is evenly mixed with in-situ soil or crusher run, and the wet mixing is to achieve OMC (optimum moisture content) status of the mixture for proper compaction, and also for further mixing homogeneity. Finally, the mixture is compacted by roller or other appropriate compactor after it is levelled with a motor grader. In-situ CBR test can be conducted within 24 hours and there is immediate laying of asphalt concrete after the in-situ CBR test.

Photo 2(a)(i) Manual Spreading

Photo 2(a)(ii) Mechanical Spreading

Photo 2(b)(i) Dry Mixing

Photo 2(b)(ii) Wet Mixing

Photo 2(c)(i) Compaction

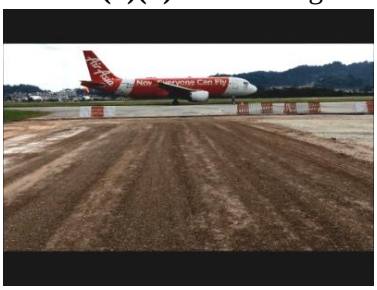

Photo 2(c)(ii) Finished Layer of Stabilized Base

Photo 2(d)(i) In-Situ CBR Test

Photo 2(d)(ii) Laying of Asphalt

Photo 2(d)(iii) Immediate Opening Concrete Photo to Traffic

4. Project case studies

4.1. Various pavement testing results

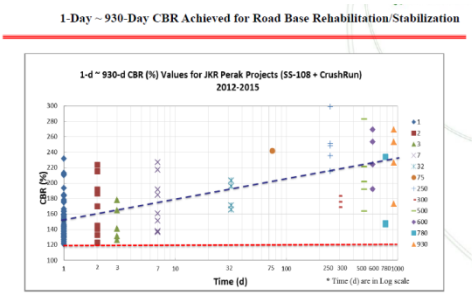

Figure 1a Perak State CBR Testing Results

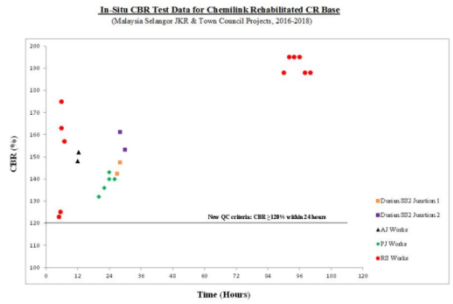

Figure 1b Selangor State CBR Testing Results

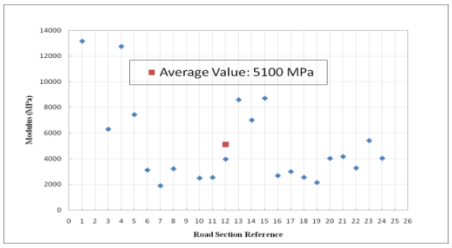

Figure 2a Average Stiffness Modulus

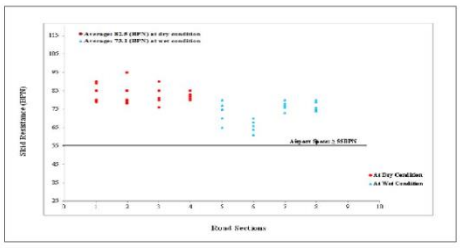

Figure 2b Average Skid Resistance

As shown in Figure 1, JKR Perak has recorded 3 years CBR data of the rehabilitated base continuously from 2012 to 2015 to get the strength development from 1 day up to 930 days. Figure 1a and 1b show that overall CBR on the first day is more than 120% and then, CBR increases consistently. Similarly, most of the CBR Testing Results at Selangor were taken within 24 hours, and the minimum CBR is more than 120%. Figure 2a shows that the average Stiffness Modulus of several operational projects with rehabilitated base is 5,100MPa, which is between the Modula of asphalt concrete and cement concrete and thus has properties of a semi-rigid platform. For the skid resistance of the stabilized base (Figure 2b), the average surface skid resistance data under wet and dry conditions are 73BPN and 82BPN respectively, which is much higher than the standard airfield/highway pavement requirement of 55BPN and furthermore verifies that the rehabilitated base has better binding effect with the bottom of upper asphalt concrete layer.

The bonding between asphalt concrete and road base is important, however, the type of test cannot be carried out at site. From understanding, roughness of stabilized layer is an important criteria for good bonding, as such, skid resistance test is carried out to determine the value of skid resistance and estimate the bonding of asphalt concrete with stabilized road base. No debonding of Chemilink stabilized road base and asphalt concrete layer has been found in any projects or sections.

4.2. Senai Airport runway and taxiway widening

Senai International Airport runway (a half-strength design) and taxiways (a full-strength design) were widened in 2007-2008 after similar works were done successfully in Singapore Changi Airport (Koh, et

al., 2005[11]). The local soils were nearly 100% clayey soil (liquid limit up to 88%, plastic index up to 46%, and moisture content up to 42%, about two times of OMC). With SS-108 soil stabilization, these "unsuitable" clays were strengthened and met all the technical requirements with no defects in any form detected during and after about 5 years in full airport operations. Average UCS is 2.1 MPa, CBR is 120%, resilient modulus is 6,000 MPa and compaction degree is 98%. (Figure 3a & 3b after Wu et al., 2008[8]).

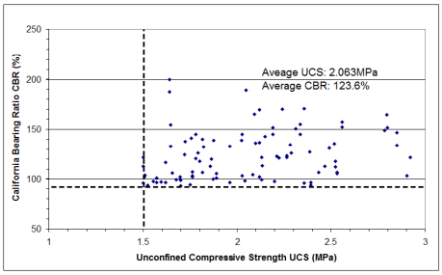

Figure 3a CBR vs. UCS Result of Senai

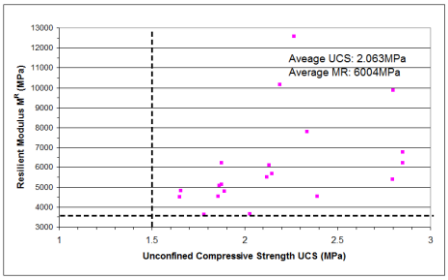

Figure 3b Resilient Modulus vs UCS Senai Runway and Taxiway Widenings

4.3. Penang Airport taxiways rehabilitation

As shown in Figure 4., two layers of the base course of total thickness of 600mm were rehabilitated or stabilized, in which the lower base (Base-2) with 300mm thickness was optional if the existing crusher run materials had reasonable CBR values of not less than 30% to 60%. At the design stage, the rehabilitated materials requirements for both Bases-1 & -2 were at minimum CBR of 180-200% and UCS of 3-5MPa at 7-day in laboratory conditions, meeting most international and local standard requirements.

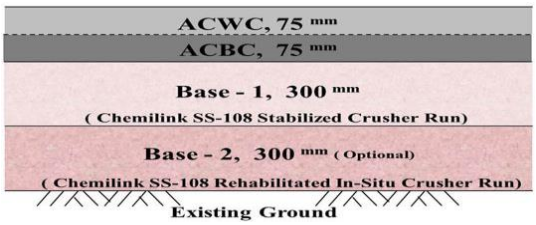

Figure 4. Design of Taxiways Strengthening by In-Situ Rehabilitation

In this Penang International Airport taxiway strengthening project, the 24-hours CBR test criteria was endorsed to shorten the duration of taxiway closing instead of a normal 7-day test (Wu et al., 2017[10]). This 24-hours testing can reflect the early strengths of the rehabilitated/stabilized base in meeting the minimum requirements and then proceed to another stage as soon as possible. This is also to avoid long time idling and closing of the working area.

In normal cases, if the working quality had failed and was only known 7 days later when the airport operations are in process already, the resulted damages would be irrecoverable, and the overall losses could be significant. With the 24-hour testing data as shown in Figure 5, it shows that the average in-situ CBR result is 172% within 24 hours, which is 40% higher than the new QC criteria with requirement of 120%. Figure 5 also shows that the CBR value of the base before ISR only ranges from 20% to 60%, and thus the quick strengthening effect looks very impressive.

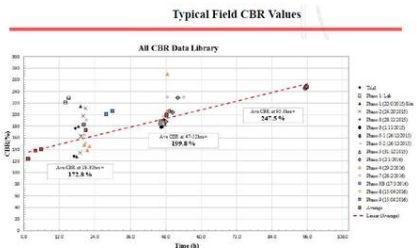

Figure5a In-Situ CBR Results

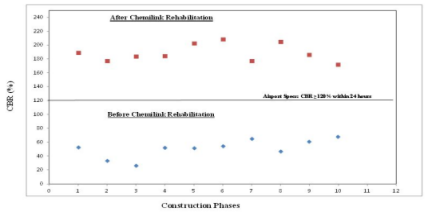

Figure 5b. Comparison of Average CBR Values before and after Strengthening at Each Construction Phase.

4.4. Strengthening of Port Klang container yards

Over the years, the deterioration and serious differential/total settlements of the compacted crusher-run sub-base and concrete surface layer due to factors such as soft marine clay foundation and seepage rendered the container stacking yard unserviceable. The in-situ crusher-run material was recycled using SS-108 in either two layers of 200 mm thickness each or one layer of 300 mm thickness. The project Phase-I was completed in 2011. The average UCS value (7-d) achieved is 2.9 MPa (Specs $\geqslant$ 2.0 MPa) and CBR is 140% (Specs $\geqslant$ 120%) (Figure 6). The overall performances are satisfactory to date (Tan et al., 2011[9]). The Phase II works were completed in 2013 with satisfactory results as well.

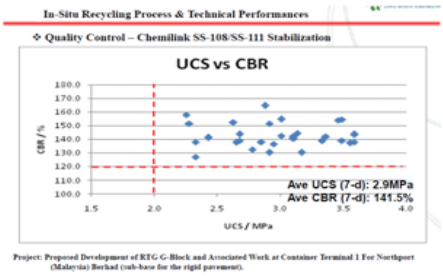

Figure 6. CBR and UCS Results of Port Klang Container Yard.

5. Conclusions

Chemilink Stabilization is the proven technology, especially over swampy and soft ground areas, in South East Asia for the past 20 over years. The in-situ rehabilitation/stabilization technology and system

have significantly promoted the re-use and recycle of the in-situ materials so as to reduce dumping of existing material and the import of fresh quarry materials.

Chemilink is the first approved rehabilitation/stabilization solution with the sub-series product in Malaysia under JMAL. Not limited to JKR and LLM, Chemilink also assisted Malaysia Airport and Seaport in solving the quick repairing difficulties with higher strengths, shorter construction duration, much superior technical performances and durability, and finally overall cost effectiveness. The rehabilitated base/sub-base courses are satisfactory, and no defects or failures have been found during the long-term operations.

References

1. Mitchell, J.K. and Katti, R.K. (1981). **Soil Improvement – State-of-the-Art-Report**, Proc. of the 10th Inter. Conf. On SMFE, Vol. **1**, pp. 261-317.
2. Wu, DQ (2017a). **Chemical-Soil Stabilization for Sub-Grade Improvement,** Symposium on Airfield Infrastructure of Airports – Engineering and Future Development, SAIA 2017, Singapore Aviation Academy, October 02-03, 2017, Singapore.
3. Wu, DQ (2017b). **In-Situ Rehabilitation (ISR) Method for Pavement Strengthening,** Symposium on Airfield Infrastructure of Airports – Engineering and Future Development, SAIA 2017, Singapore Aviation Academy, October 02-03, 2017, Singapore.
4. Wu, D.Q. and Tan, P.C. (2008). **Chemilink Stabilization Technologies for Roads and Airfields**, Seminar on Soil Subgrade Stabilization, Public Works Department (JKR) of Malaysia and Road Engineering Association of Malaysia, July 15, 2008, Legend Hotel, Kuala Lumpur, Malaysia (key-note speaker.
5. Lee M., Tan P.C., Daud and Wu D.Q. (2010). **Green Approach to Rural Roads Construction – Stabilization of In-situ Soils and Construction Wastes**, *the 7th Asia Pacific Conference on Transportation and the Environment*, June 03-05, 2010, Semarang, Indonesia.
6. Huang, F., Romy, T., Wu, D.Q. and Shazali, B. (2014). "**A Quick Repair Approach for Damaged Roads in West Malaysia**", *9th Malaysian Road Conference*, November 10-12, 2014, Kuala Lumpur, Malaysia.
7. Wu, D.Q. and Zhang Y.L. (2016). **Pavement Strengthening by In-Situ Rehabilitation & Semi-Rigid Pavement Methods**, the Proceedings of Bridging the East and West: Theories and Practices of Transportation in the Asia Pacific (via 11th Asia Pacific Transportation Development Conference and 29th ICTPA Annual Conference) and a selected paper from the proceedings and published by ASCE (American Society of Civil Engineers), pp. 123-132, May 27-29, 2016, Hsinchu, Taiwan, China.
8. Wu, D.Q., Shaun Kumar and Tan, P.C. (2008). **Chemical-Clay Stabilization for Runway Widening at Sultan Ismail International Airport, Malaysia**, 13th Singapore Symposium on Pavement Technology (SPT 2008), May 23, 2008, National University of Singapore, Singapore.
9. Tan, P.C., Daud, Lee, M. and Wu, D.Q. (2011). **Pavement Rehabilitation by In-Situ Recycling – A Case Study on Seaport Container Yards and Road**, *the 16thSingapore Symposium on Pavement Technology* (SPT 2011), May 27, 2011, Engineering Auditorium, National University of Singapore, Singapore.
10. Wu, DQ, Dato' Hamid MA and Dato' Aminnudin BY (2017). **In-Situ Rehabilitation for Taxiway Strengthening in Operational Airport**, *the 10th International Conference on Road and Airfield Pavement Technology*, August 08-10, 2017, Hong Kong, China.
11. Koh, M.S., Lim, B.C. and Wu, D.Q. (2005). **Chemical-Soil Stabilization for Runway Shoulders Widening at Singapore Changi Airport**, the *4th Asia Pacific Conference on Transportation and Environment (4th APTE Conference*), Nov. 8-10 2005, Xi'an, PR China.

12. Yong, T.C. and Wu, D.Q. (1999). **Chemical Stabilization for Road Construction in Brunei Darussalam**, *the First International Conference on Transportation for Developing Countries on Threshold of the 21st Century*, Nov. 18-19, 1999, Hanoi, Vietnam, pp. I.26 – I.32.
13. Liu, Q., Wu, D.Q. and Gui, Z. (2004). **The Application of Non-Standard Stabilizers to the Base Course of Rural Roads**, the *1st International Conference on Sustainable Waste Management*, June 10-12, 2004, Singapore, pp. 178-190.
14. Wu, Dong Qing (2011). **A Green and Effective Approach for Pavements in Tropical Region**, *the 24th ICTPA Annual Conference & NACGEA International Symposium on Geo-Trans*, May 27-29, 2011 – Hyatt Regency Irvine, Los Angeles, California, USA, Paper No. S3-008, pp. 1-12, the Proceeding of the Conference (ISBN 978-0-615-42857-4; the Invited Key-Note Presentation with Outstanding Presentation Award).
15. CPRU-Brunei (1999). "**General Specification for Pavement Stabilization**", GS 07:1999, *Construction Planning and Research Unit (CPRU)*, Ministry of Development, 1st Edition, Brunei Darussalam.
16. Suhaimi, H.G. and Wu, D.Q. (2003). **Review of Chemical Stabilization Technologies and Applications for Public Roads in Brunei Darussalam**, REAAA Journal (The Journal of Road Engineering Association of Asia and Australia), Vol. **10**, No.1 PP7021/8/2003, pp. 42-53.