Current Pavement Technologies in Taiwan

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Abstract

Flexible pavements are used on most highway systems in Taiwan, and approximately 13 million metric tons of hot mix asphalt is consumed every year. The recycling of asphalt pavements has been promoted all over the island since 1998, and about 2/3 of hot mix plants has been certified to produce recycled hot mix. Modified asphalt, color asphalt, drainage (porous) asphalt, stone matrix asphalt, Gussasphalt, as well as asphalt rubber have been investigated in laboratories and tested in the field. Adequately using recycled materials, developing sound pavement management system, as well as using innovative procuring processes such as Performance Based Contract are major tasks to improve the effectiveness and efficiency of pavement maintenance works in the future.

Keywords: Recycled HMA, Modified Asphalt, SMA, Gussashalt, Asphalt Rubber, Pavement Management System

1. Backgrounds

Taiwan lies off the southeastern coast of the mainland Asia, across the Taiwan Strait from Mainland China-- a solitary island on the western edge of the Pacific Ocean. To the north lies Japan; to the south rests the Philippines.

The island of Taiwan has an approximate length of 384km (north to south), approximate width of 128km (east to west), and surface area of 36,000km². Due to its mountainous geography, only a quarter of the land can be developed. The east and west of Taiwan is also separated by the Central Mountain Ranges, therefore, road development is concentrated on the gentle sloping plains that lies on the west coast.

According to statistic recordings from the Ministry of Transportation and Communication (MOTC), the total road length in Taiwan is over 37,000km, taking up a total surface area of over one hundred million km²,
which is 1.7 percent of the area that can be developed. The road density in Taiwan is ranked fairly high in the world.

2. Pavements in Taiwan

Due to the high population density and unclear distinction between urban areas, the total road length of city streets is about 44 percent, and the remaining freeways, provincial highways, county roads, country roads and special use roads take up 56 percent. About 90 percent of these roads are paved with asphalt or concrete, so called “high grade roads”.

2.1 Roads and Pavement Structures

Table 1 shows the different kinds of roads in Taiwan along with their perspective length in 2003. National freeways and the 12 east-west expressways completed in recent years are closed road system. With careful planning, MOTC has been always eager to improve freeway network system to around the island. However, MOTC recently encountered much opposition regarding ecological environmental aspects, which produced various uncertainties.

<table>
<thead>
<tr>
<th>Road Length of Taiwan as in 2003(Unit: Km)[1]</th>
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<tbody>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Sum</td>
</tr>
<tr>
<td>37,342</td>
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</table>

Taiwan’s current national highway pavement design consists mainly of 1.5 cm open-graded friction course (OGFC), 10 cm dense grade asphalt concrete (DGAC), 20 cm bituminous treated base (BTB with nominal size of 3.0 cm) and 20 cm granular base (GB with $\text{CBR} \geq 85\%$). The subgrade requirements for CBR value exceed 15%, and its design is shown in Figure 1. While expressway pavement designs consists of 10 cm fine dense graded asphalt concrete (FDGAC), 20 cm coarse dense graded asphalt concrete (CDGAC), and 30 cm granular base, provincial highway network consists of 10 to 20 cm of asphalt concrete surface, 30 to 45 granular base. Lastly, county and/or country road mainly consists of 3-15 cm asphalt concrete surface, 15 to 30 granular bases. Similar road designs are generally used in the United States, proposed by engineering AASHTO method, or Asphalt Institute (A.I.) method.
2.2 Maintenance Works

For the last 20 years, the maintenance of freeways and expressways may include removing full depth roads that show local deformation and serious instability, however, most road maintenance must retain the original elevation restrictions, thus the mill and repave method is used more often. The method generally suggests a standard depth of 5cm, and 10cm for severely damaged or deformed regions. Some freeways only require a 1.5cm depth due to functional defect of OGFC, while a small number of provincial highways ask for a depth of 15cm due to shortcomings in highway construction. In the absence of inclusive statistics and based on informal estimations of heavy national and provincial highway traffic, these highways need to be maintained every four years with the mill and repave method. The heavy traffic also forces the constructions to be conducted in night hours when there are fewer cars on the highways.

In terms of roadway maintenances, most of the county and country roads adapt the overlay method. After several times of overlays, the thickness of asphalt concrete exceeds more than 10cm. For the roads located in urban area, protests and oppositions from both families and shop-owners force the agencies to use the mill and repave method before the implementation of hot mix recycling. After the implementation of hot mix recycling, almost all roads are adopting mill and repave methods.
The frequency of maintaining the country and township roads is dependent on the amount of traffic, construction quality, conservation funding, and even resident requests or rapid development that asks for numerous excavations for water supply, electricity, cable, and other pipeline excavations. The frequency of conservation for county and township roads is dependent on the different sections of the volume of traffic, construction quality, conservation funding, or even residents, such as differences in the requirements of great changes--some sections of the community have higher demands for water supply, electricity, cable, and other pipeline excavation because of rapid development, so these roads have to be milled and repaved more frequently, possibly every one or two years. Other roads require less frequent conservation due to lower volume of traffic and fewer excavations.

In recent years, Taiwan's rising awareness of environmental protection presented many engineering difficulties including obtaining gravel and proper disposal of soil waste.

Asphalt pavement recycling can not only reduce the demand for aggregate supply, but can also solve problems regarding the disposal of materials. Thus this method is highly encouraged by engineers in Taiwan. Since 1998, Taiwan has begun to promote hot mix recycling in central asphalt plants, according to the adoption of mandate, the public road agencies must adopt a certain proportion of recycled asphalt concrete, and hot mix asphalt recycling plants must be certified. By the end of 2006, 105 hot mix recycling plants have been certified, accounting 65 percent of the total mixing plants. Distressed asphalt road surface is milled and sent back to the hot mix plant, and after the recycling process, the asphalt surface is paved back onto the road. This process has become a standard way for maintenance of highways. While the public agency promotes the recycling method, the hot in place recycling (HIPR) has also introduced by some contractor. It is generally believed that due to high population density, narrower roads, and various man-holes, HIPR teams aren’t easily accepted, and when applied on highways, the standard of quality control cannot be met. Also, some contractors tried to introduce cold in place recycling such as foam bitumen process but these turned out to be unsuccessful due to similar reasons.

### 2.3 Pavement Materials

Apart from the small numbers of industries located in the mountainous roads that still use cement concrete pavement, hot mix asphalt concrete became the main road material in Taiwan since 1970. In early 1990, a proposal to use rigid
pavement (concrete pavement) was practically tried during the construction of the second North-South Freeway. For 10 years, a total length of 30 km jointed plain concrete pavement (JPCP) distributed at north, central, and south section for 10 km each along the Freeways No 3 were constructed and evaluated, but the pavement showed slightly lower smoothness and high levels of traffic noise. In 1970, after the Taiwan government has started promoting local infrastructure construction project along with the development of petrochemical industry, asphalt materials can be obtained conveniently. Many regional companies obtain asphalt concrete technology and equipments from Japan, especially companies of hot mix batch plants, as shown in Figure 2. According to the statistic provided by the Taiwan Association of Asphalt Industry, since 1990, Taiwan’s regional hot mix asphalt plants maintained a number of approximately 160 plants, as shown in Figure 3. In addition, Taiwan’s mean annual air temperature (MAAT) is higher than 20°C, and the air temperature rarely goes below 10°C. As long as it’s not raining, hot asphalt concrete can be mixed and paved almost everyday, and under these circumstances, exclusive hot asphalt concrete mix can be made. This causes the hot mix asphalt to excel in the pavement market while other cold mix asphalt or in-place stabilizations can hardly make it into the market. Although there are no official statistics, the Public Construction Commission (PCC) uses the sales of asphalt binder to estimate that Taiwan uses 13 million metric tons of hot mix asphalt concrete in 2001.

![Figure 2 Typical Hot Mix Recycling Plant in Taiwan](image)

**Figure 2** Typical Hot Mix Recycling Plant in Taiwan [2]
Except for the 1.5cm thick friction layer that uses the open graded design on freeways, most asphalt concrete adopts the dense graded design. The binder uses a penetration of 85/100 grade asphalt. The last 10 years mark the usage of AC-grade asphalt with AC-10 as the most commonly used. In theory penetration of 85/100 and AC-10 is not entirely the same, but in practice it’s basically the same. According to the frequent rutting damage in Taiwan, although most rutting is due to poor designs or bad quality construction, the academic community is still persistent on their use of harder asphalt. In recent years, certain organizations have started using AC-20. Perhaps it’s because of the all year spring, and the fact that Taiwan seldom has bitter winters or blazing summers, the road’s surface temperature only reaches about 60°C. Therefore there are no problems addressing “the use of overly hard asphalt, causing low-temperature cracks” or “the use of overly soft asphalt, causing deformation”. As the petrochemical industry developed, asphalt produced by government-owned CPC is fairly stable in quality. According to the evaluation of aging characteristic by using thin film oven, the viscosity of asphalt is doubled, thus Taiwan’s AC-10 and AC-20 is also similar to AR2000 and AR4000. The academics have followed U.S. SHRP’s
research results and have begun to study the application of PG-grade asphalt. Since statistics on local temperature is not complete and there’s no fear of low-temperature cracks, the PG type of asphalt that should be used has not been decided. Because the equipment is not yet universal, the engineers fail to recognize the effectiveness of using the right asphalt binder and have no intentions of adopting this method.
The quality of sand and crushed aggregates is one of the key factors to prevent deformation. Taiwan is gifted with adequate topography and clime that makes the rivers fast and the serious erosions provide many high-quality river sand and gravel resources. However, in the last 20 years, construction of water reservoirs caused changes in erosion and rivers are now ecologically protected, sand and gravel are no longer easily maintained. There’s a shortage of aggregate sources when faced with large construction projects, apart from exploiting land mines for sand and gravel, starting five years ago, river sand are imported from mainland China. Currently, Taiwan adopts no specification for aggregate, crushing sites are all done on a small scale with no systematic quality management system. These factors may be the main reasons for high variation of aggregate quality.

2.4 Particular Pavements

In recent years, due to the application of material science and related technology, pavement material has many new developments. Taiwan has been test and evaluated on modified asphalt, color asphalt, porous (drainage) asphalt, SMA, Gussasphalt, asphalt rubber, and other special type of asphalt pavement. Many studies and trials are still being conducted and evaluated. Compare to traditional asphalt, the amount of application of these new types of asphalt are still relatively infrequent.

Obtained directly from the refining, conventional asphalt has a nature of a certain limit, and often can not meet the specific needs of the situation. The asphalt will be required to undergo appropriate “modification”, providing more choices for highway engineers. Although the traditional asphalt paving demonstrated good performances in many different applications, however, by adding a different quality agent and producing a new generation of “modified asphalt” may be applied to places of heavy traffic, high friction, drainage layer, and other special occasions. In 1998, Taiwan also award a new CNS 14184 [polymer modified asphalt] to improve the national standards of asphalt, as shown in Table 2 using reference of ASTM D5892-956a of the IV-C, IV-E, and IV-F and the
Organizationalaffiliation:JapaneseRoadAssociation.

<table>
<thead>
<tr>
<th>Item</th>
<th>For general pavement</th>
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<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>Penetration, 25°C, 100g, 5s, 1/10mm (min.)</td>
<td>65</td>
</tr>
<tr>
<td>Viscosity, 60°C, 1 s⁻¹Pa. s (poise), (min.)</td>
<td>250(2500)</td>
</tr>
<tr>
<td>Viscosity, 135°C, mm²/s (cSt), (max.)</td>
<td>3000</td>
</tr>
<tr>
<td>Flash point, COC, °C, (min.)</td>
<td>232</td>
</tr>
<tr>
<td>Solubility in trichloroethylene, %, (min.)</td>
<td>99</td>
</tr>
<tr>
<td>Separation, difference °C</td>
<td>record</td>
</tr>
<tr>
<td>Tests on RTFOT residue</td>
<td></td>
</tr>
<tr>
<td>Elastic recovery, 25°C, 10cm elongation, %(min.)</td>
<td>60</td>
</tr>
<tr>
<td>Tests on RTFOT residue</td>
<td></td>
</tr>
<tr>
<td>Penetration, 4°C, 200g, 60s (min.)</td>
<td>15</td>
</tr>
</tbody>
</table>

Color asphalt is occasionally used in the places that need enhancing pavement, such as parking lots, parks pavement, paved highway service area, or private company pavement. The materials used are imported transparent asphalt mixed with different colored powder then made into colored hot mix asphalt concrete. Due to the use of transparent toner, the price of this kind of pavement is rather expensive. The colored asphalt is vulnerable to dust and vehicle oil, which mixes and pollutes the original colors, rendering them as unsightly. Thus, it is suggested that this kind of asphalt be used in relatively clean occasions, such as private stations, showing promising visual effects.

Drainage (and or porous) asphalt is also introduced to Taiwan in recent years, since this kind of asphalt helps reduce the island’s urban heat, demonstrating promising effects of porous pavement. It also improves drainage systems, making it safer for high-speed driving in rain.

Researches are still looking into pavement surfacing, structural design, and materials of choice. Quite a few cement material and even some asphalt material is lacking in load bearing capacity. Drainage asphalt is simpler and can be said as modification of OGFC that make the gradation more open (higher air voids) and pavement thicker. It may be necessary to be used with modified asphalt and/or fiber in order to maintain the durability and not loose the function of demand. In a recent resurfacing of the freeway project, Japanese manufacturers provided a very high
viscosity product with an absolute viscosity of poises at 60°C. Europe and the United States uses SMA for heavy traffic pavements, the coarse aggregate of the main structure is very stable, solid, and have good anti-deformability, and the high volume of asphalt filling in the aggregates create a thicker asphalt film. This makes the road have a better anti-fatigue, anti-ageing, and anti-stripping abilities. Introduced by some fiber vendors, Taiwan also introduced SMA and tried on some heavy traffic pavements, some cases have good results, while other will soon be susceptible to failure. Most of the cases attributed to failure is due to the poor shape of coarse aggregates, associated with poor design and planning, and bad compaction. If we can solve the coarse grain shape aggregate problem, other shortcomings can be made up by experience.

Pavements on the orthotropic steel deck bridges, in addition to providing the necessary smoothness for vehicles, must also have a waterproof layer. Paving on bridges with larger span would require material with greater flexibility and accommodate to higher local deflection of steel deck. Conventional dense graded asphalt mix experienced vertical cracks that are difficult to restore and renew on several steel bridges such as Guandu Bridge. In 1997, Gussasphalt used on the steel bridge of a county road (Miaoli County Sindong Bridge) was first introduced by the Japanese. Then used on a larger scale in 1999 on the southern section of Freeway No. 3, Gaopingsi Bridge. The Japanese jointed contractor is responsible for both cases of material design and construction quality control. Then in 2001, the Taipei City Daihiih Bridge and the 2002 Taiwan provincial highway four-lane bridge, Cianjin Bridge, were finished by local manufacturers and academics. But the main construction equipment, the heating mixer (Cooker) and special paver, shown in Figure 4, were all rented from Japanese companies with hired engineering technicians that provided proper guidance for the entire process.
In 2000, along with the assistance of EPA, Taiwan began the research on the ground tire rubber in combination with asphalt pavement research which resulted in the asphalt rubber (AR) project. Personnel were sent to the United States on a study tour to learn the developments and technology of used ground tire rubber asphalt blending. In December, 2000 and May, 2001, with the assistance of the Taiwan Highway Bureau, two AR pavement test sections were constructed as pilot projects: one with Gap-Graded design and the other with Open-Graded design. The four-year field results demonstrate their satisfactory performance and the potential to replace modified asphalt in domestic usage. The field data collected from the demonstration projects conducted from years 2000 to 2004 indicate that the suitability of using the wet process AR blend method in Taiwan with local asphalt and ground tire rubber [4]. The pavement didn’t show signs of deformation or cracking that’s often seen on roads that bear heavy traffic, the overall result is successful. The expected result should exceed those of traditional asphalt concrete pavements and to verify the use of rubber on asphalt to the United States, giving them a positive view.

3. Future Developments

In 2004, Taiwan’s 2nd North-South Freeway is completed and opened to traffic. Together with all the 12 east-west expressways completed in the near future, highway engineering in Taiwan enters into a new era, “the era
of highway maintenance”. Highway agencies responsible for maintenance face the question of “how can limit funding be most efficiently used, while providing high-quality roads”. The biggest challenge that lies in the foreseeable future will be developing an efficient pavement maintenance management system and to adopt local materials that enhance pavement characteristics.

3.1 Sound Integration of Pavement Management System

In the era of highway maintenance, the efficiency of the management of the road engineers becomes very significant. The future will put special emphasis on private enterprises and concept of financial management. Therefore, the road engineers should understand and recognize the purpose of road management, how to achieve this objective, and how to persuade decision makers to accept this important concept, “pavement management system (PMS) is an integration platform for management not only a computer program to help decide which section to be repair first.” Professionals should have the desire for change in order to come up with new ideas and use less funding to achieve greater effects. How to get the greatest support in road agencies and to receive greatest support from higher level administrators becomes an essential question. The key to implement pavement management system is to be determined to establish a working system of road management.

With highly development information technologies in Taiwan, the sound integration of PMS is proposed to be based on geographic information system together with location service of global positioning system (GPS) and personal wireless communication devices as shown in Figure 5. The scheme is to offer road users an in-time reporting of distresses, effective scheduling of repairs, complete monitoring and controlling of road condition, and better decision making based on knowledgeable resources.

As concerns on improving the efficiency and effectiveness maintenance works, an innovative procuring process is under investigation. Performance Based Contract (PBC) has been successfully implemented in road maintenance in other countries for two decades. Unlike the traditional contracting methods, the PBC measures the performance of road maintenance projects based on outcomes of the works rather than the outputs of work processes. It has been demonstrated from previous experiences to improve the cost effectiveness and job efficiency significantly. The domestic road maintenance works can be expected to improve if such innovative contracting method is adopted in Taiwan. However, application of such system requires a set of proper performance
indicators, and a mechanism of determining relationships between the invested funds and the associated performance measures. That particular study aims at establishing the specifications required for implementation of PBC in Taiwan.

**Figure 5** The System Sketch for Integration of IT technology in PMS[5]

### 3.2 Beneficial Use of Waste Materials

After careful examination of the past 30 years of maintenance experiences, particularly in countries like Taiwan that have a rapid economic development, road transportation demands were deeply affected by political, economical, cultural, environmental, and other complex factors. Keeping the road users in mind, the most difficult demand to satisfy is to provide smooth traffic conditions on highways. Conventional performance factor such as ride quality is not the major concern. Engineers responsible for the highways should focus on traffic engineering to direct smooth vehicle flow. When there is a distressed pavement, the engineer should act in an efficient and mature manner and apply restoration methods. Limited by the demands for smooth traffic flow, there is little time for forensic
study or preservation of pavements. On both provincial and county highways that are affected by rapid economic development and right of way, pavement distresses are closely related to the extension of underneath utility lines. Mountainous roads are in turn usually affected by slope failure, debris flow and landslides. The importance of maintenance is focused on highway disaster mitigation. Design period or analysis period for pavements does not exceed 10 years. Milling and repaving road is routine work. Pavement materials are not limited by conventional requirements on strength and durability. The success on hot mix recycling in the recent 10 years has proved that the use of wastes, such as steel slag, municipal solid waste incinerator bottom ash, and sewage sludge ash, is beneficial and will be tried and evaluated as long as its of reasonable physical property and are environmental friendly.

4. Conclusions

Pavement engineering has become an independent science and technology. Its main concerns include structural design, mix design, pavement material, pavement evaluation, and pavement management system. Except for successfully induced hot mix recycling, new technologies are introduced at a rapid pace, adopting knowledge and techniques from Europe, the United States, and other advance countries, including the use of various new materials and methods such as modified binder, porous asphalt, color asphalt and Gussaphalt. Taiwan also obtained the adequate equipment and experience for the various types of pavement evaluation methods and will be further developing a sound management system based on routine pavement maintenance and well developed information technology. Innovative procuring processes, such as performance base contract, and beneficial use of local waste materials will also be developed in the future.

Reference


[5] Jiang S. W., Yan C. E., and Lee P. I., “Development of Public Transportation Asset Maintenance and Management System,” a research project supported by Transportation Research Institute, MOTC, Taiwan, 2005, executed by Taiwan Construction Research Institute.