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Guan-feng An, Wen-yuan Huang, Jing-feng Zhang

Green Road Construction Technologies in Guangzhou

Abstract Total road pavement in Guangzhou reaches 77 $\times 10^6$ m^2. Its huge maintenance and potential rehabilitation calls for a green road system. This paper presents a discussion, first about green road construction technologies together with their applications and development like reclaimed asphalt pavement, rubberized asphalt pavement, and warm mix asphalt; and then, about the key obstacles for promotion and activities, primarily for green road promotion, in the perspectives of the current technical and application situations in China and separately in Guangzhou. Based on environmental and conditional analysis, as well as a development expectation from an industrial viewpoint, this paper creates a development trend of green road technologies.

Keywords: road, green construction, recycling of waste asphalt, rubber asphalt

1 Road in Guangzhou City

According to "The Technical Code of Maintenance for Urban Roads" (2006), the distress and deterioration of asphalt pavement (*Figure 1*) include: pit slot, raveling, upheaval, pumping, depression, peeling, edge failure, bleeding, rutting, alligator cracking (*Figure 2*) and net shaped crack; for the eleven cement concrete pavement types: broken board, potholes, plate angle failure, bare surface, blow up, evenness, slab staggering, pumping mud, cracks to seams, bad joint maintenance. Moreover, the sidewalk has typical deteriorations like broken boards, potholes, depression, etc.

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Guan-feng An (✉)
Guangzhou Municipal Engineering Group, Guangzhou 510060, China
Email: 13318898238@126.com

Wen-yuan Huang
Shanghai Jiao Tong University, Shanghai 200240, China

Jing-feng Zhang
Guangzhou Municipal Engineering Group, Guangzhou 510060, China

Figure 1. Pot hole.

Figure 2. Net shaped cracking.

By the end of November 30, 2011, the total facilities in Guangzhou City (excluding Conghua and Zengcheng City) listed as following: 4,026,208 km of road, 77,129,106 $\times 10^6$ m^2 of pavement, 7064 road sections, 1472 bridges and 153 tunnels. According to PCI evaluation on 72 arterial roads of Guangzhou City in 2011, level A (excellent)

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portion is 48.6%, B (good) is about 50%, C (fair) is 1.4% and no single level D road (unqualified), which indicated that roads in Guangzhou City are generally in good condition.

2 Reclaimed asphalt pavement

2.1 Overview of recycled asphalt pavement (RAP) applications

Reclaimed asphalt concrete thinking was raised by an American in 1915, but the technology didn't draw much attention until the oil crisis in 1970. However, until now, reclaimed asphalt pavement was applied in ordinary applications in most developed countries, with sets of relative regulation policies and specifications.

Big funds were applied to technology since 1974 and really stimulated RAP applications. In 1980, more than 2 million tons of recycled hot mixtures were used in 25 states, while 3.50 million tons were used in 40 states in 1981 according to statistics of the Federal Highway Administration. The amount increased to about 200 million tons until 1985, which is about half of the total amount of asphalt mixture.

In Europe, recycled asphalt pavement also grew fast. Germany is the first one that used RAP in highway pavement maintenance and rehabilitation. All RAP was utilized in Germany until 1978, which was contributed to its machinery industry advantages, including complete system range, good quality and good pricing. Finland and France used RAP in pavement maintenance and low traffic road and then expanded its application in expressway and other important roads after 2000.

Since 1976, RAP technology in asphalt pavement was being researched in Japan. "Guide for reclaimed asphalt pavement" was published by Japan Road Contractors Association in 1984. In 2000, more than 30% (about 47 million tons) of the total asphalt mixture was produced by RAP in nationwide, the ratio of exceeded 80% after 1976.

A recycling situation survey in road materials for 14 countries was performed by the International Economic Cooperation Organization in 1997 and white paper for road recycling strategy was published. World situations for reclaimed asphalt pavement were:

1) Reclaimed ratio of RAP material is 75%–100%;

2) Hot recycling, the most commonly used technology is applied widely, which uses RAP in surface layers, RAP was seldom used as land filling materials and other purposes;

3) Cold recycling was not commonly used, no matter the place or in plant processes;

4) Hot in place recycling had been adopted in more countries, but was widely used only in a small amount of countries.

2.2 State of art in China

Province level studies (including provinces of Shanxi, Hubei, Hebei, etc.) have been performed since the 1980s. Test sections of more than 80 km were constructed in Shanxi province in 1982; Highway maintenance agencies in Hubei province were encouraged to be involved in the reclaimed experiment research. Research project of "Recycling of Waste Asphalt Mixture" was issued by the Ministry in 1983, of which the research frame was adding appropriate light oil in old residual oil road to soften and recover relative pavement. Finally more than 30,000 m^2 test sections were paved in four cities included Suzhou, Wuhan, Tianjin, Nanjing after three years of research. The filed observed results showed that performance of the recycled pavement was not lower than the conventional hot mix asphalt concrete pavement. Besides, Hunan province tried adding emulsified asphalt in the surface material of old residual oil pavement. However, since 1990, the recycling promotion had a hard time because the paving industry was fully occupied following 20 years of large scale highway construction.

In recent years, the pavement industry is switching to the maintenance age while recycling technologies become the focus again. The feasibility of technology and economy has been proved by many recycling attempts. Also performance of recycled pavement is not lower than the conventional hot mix asphalt concrete pavement.

Overall, technology of recycling waste asphalt concrete in China had not been widely applied because of a lack of strong and definite support from the government. Although, some leading asphalt pavement contractors imported recycling equipment and really could provide qualified recycled asphalt mixture. But unfortunately, many of the equipment were left unused because of the lack of RAP resources or different understanding of RAP value and performance of facility owners and agencies. Most of the recycled material was paved in a parking lot and a low volume road.

Limited cities like Beijing, Shanghai have released special incentives, policies, and specifications for recycled asphalt.

Four government departments in Beijing City released "the Recycling Old Management Measure of Asphalt Concrete Material in Beijing" on May 24, 2002, which identified that all the RAPs must be collected, transported to the authorized plants, and abandoned. Land fill usage was not permitted. Besides, the requirements of collection, transport, measurement and production of the old asphalt concrete are defined clearly. However, because of different marketing considerations and multiple and conflicting management from different departments of government, the policies didn't achieve their objectives. The cost of transportation was another problem. In the end, the authorized plants were put in a very difficult situation because of very limited RAP resourcing and recycled mixture marketing requirements. It is reported that the Beijing municipal committee and road transportation agencies are re-organizing the mandatory policies of reclaiming asphalt pavement materials to fit in marketing situation.

The Municipal Administration Department of Shanghai (2006) released "Regulations of the Hot Reclaimed of Waste Asphalt Mixture" on March 15, 2006, which identified the requirements of the waste asphalt mixture collection and treatment, the use of the reclaimed mixture, and administration on the whole process. The sets of regulations got evolvements later, the reclaimed ratio increasing year by year. 370,000 tons of waste asphalt mixtures were collected, and 680,000 tons of hot reclaimed material used in asphalt paving in shanghai from 2009 to 2010. In order to further enhance the recycling work of roads, Shanghai issued strengthening policies involving city and district level agencies in specific administration activities.

2.3 RAP in Guangzhou

Reclaimed asphalt pavement is a technological blend, of certain portions of new asphalt, aggregate, rejuvenator (if necessary) together with special equipment to renew pavement structure. According to the different mixing and construction temperature, reclaimed asphalt pavement technologies could be hot recycling and cold recycling. Besides, asphalt pavement recycling can be divided into plant mixed recycling and place recycling. According to recycling process and jobsite arrangement, it could be in place or in plant. Relative national level specification "Technical Specifications for Highway Asphalt Pavement Recycling" (2008) has already been published.

The hot recycling in plant produces a mixture in the hot mix plant. Plant and heating process really influence the final quality. On other hand, the ratio of waste asphalt mixture and the selection of rejuvenator, as well as new asphalt, also have a great effect on the performance of the recycled asphalt mixture, as shown in *Figure 3*.

Figure 3. Hot recycling asphalt pavement.

2.3.1 Mixing temperature

Heating of RAP had greater influence on the quality of the recycled asphalt mixture compared to conventional asphalt mixture. Too much heat may cause serious aging for old asphalt while too low of a temperature may influence dispersing uniformity of the rejuvenator and new asphalt, both of which will cause poor quality.

2.3.2 RAP feeding process

Different processes also have a large impact on the quality of recycled asphalt mixture. If fed too early, RAP may age too much, but if too late, the prolonged heating time may reduce productivit.

Rejuvenator should be added ahead of new asphalt. Otherwise, the rejuvenator would be mainly diluted by new asphalt rather than old asphalt and that old asphalt cannot be recovered. Also the dispersement of final binder might be uneven, which may cause inadequate bond.

2.3.3 RAP percentage

RAP usage ratio is the main economic index of recycled asphalt pavement, which is restricted by the equipment, and also decided by the performance requirement of recycled asphalt mixture.

Batch plant has lower RAP preheating capability compared to continuous plant. Quality of the recycled asphalt mixture is sensitive to the mixing ratio of RAP and typically has a smaller RAP ratio.

2.3.4 Rejuvenator feeding

The earlier the rejuvenator contact with RAP, the better the final performance might be, for it is beneficial to the recycling quality of old asphalt. If rejuvenator is sprayed before heating, in grading composition uniform of the old stock pile, the quality of RAM can be improved to some extent.

No matter through the batch plant or continuous mixing equipment, rejuvenator should be added only in RAP. If not, effectiveness of rejuvenator will be reduced even with longer mixing time.

Years between 2000 and 2010 saw the sharp growing of public facilities in Guangzhou City. In 2010 (Asia Game year), 16×10^6 m^2 pavement (generate 1.59 million ton of RAP) was milled off. Currently, annual RAP generation is about 480,000 tons. If the entire RAP could be well recycled, the city will get great benefits on economy, society and environments.

Currently, the research and production of recycled waste asphalt mixture in Guangzhou are mainly driven by corporations. A few of leading asphalt mixture producers like Guangzhou Municipal Engineering Group developed, promoted, and invested in hot recycling systems, which already established a capability for large scale recycling. But the fact is, most of RAP are used for land filling and not backed by asphalt mixtures. Situations of existing plants are very similar to Beijing.

According to the "Technical Specifications for Construction of Highway Asphalt Pavement" (2005), Recycled asphalt mixture trial sections were paved in recent years, which proved that reasonable application of recycled asphalt mixtures will save material and direct investment of projects. On the other hand, RAP can only be well utilized separately by professional equipment and specialized producers. It's recommended to city administration that specific comprehensive policies should be released as soon as possible.

3 Asphalt rubber

3.1 State of art

Retainment numbers of automobiles increased sharply in China in recent years and a large number of waste tires are produced every year simultaneously. Without sustainable treatment, these waste tires will cause big societal and environmental problems. The goal of the 12th five-year planning of central government set material recycling research and industrialization as one of the goals for sustainable development of China. Tire rubber recycling of course is one of the key components of the activities.

The use of rubber to improve the performance of asphalt can be tracked to the 19th century in the 80s. In 1804, the UK had the first patent of modified asphalt adding natural rubber to improve the performance. However, research of the scrap tire crumb rubber as a modification agent to improve the performance of asphalt started in the 1950s. The pioneer of asphalt rubber technology is the United States. In the 1950s, Americas Bureau Public Road (BPR) conducted a laboratory research to evaluate "the influence of different rubber on properties of asphalt". They adopted the 14 different kinds of rubber powder and three kinds of asphalt (including the low density type, low sulfur type, and low asphalting type). BRP's following research was "Laboratory research on asphalt rubber mixture". This study adopted a broader vulcanized and devulcanized rubber, which includes scrap tire rubber, styrene-butadiene rubber (SBR), natural rubber, poly-butadiene rubber and devulcanized rubber. The modifiers were added into asphalt mixture by both wet and dry process.

The first asphalt rubber seminar was held in Chicago by Asphalt Institute of American in 1960. In the late 1950s and 1960s, research work was still limited to laboratory study. Application of rubber asphalt in asphalt pavement began in the 1960s and 1970s, with two directions: "dry process" and "wet process".

In the late 1960, two Swedish companies (Skega AB and ABV) developed the first crumb rubber modified asphalt mixture by dry process, which was branded as Rubit TM.

Wet process in practice began in the 1960s. Material engineer Charles McDonald in Phoenix City of Arizona State, United States, cooperated with a local asphalt company (Sahuaro Petroleum) and developed a method to add crumb rubber into asphalt at elevated temperature. This formed a kind of high flexible and elastic material to pothole patching, which was known as the Band-Aid patching with 9.5 mm aggregate on surface. This material was then used as a binder for surface treatment application. In 1968, ADOT paved the first surface treatment with rubber asphalt. ADOT applied the first asphalt rubber stress absorption interlayer (SAMI) in 1972 and the first open graded asphalt rubber mixture in 1975.

In the late 1980s, Rose Rubber Industries in Florida State of US developed the continuous blending technology, which added rubber continuously compared to batch feeding for McDonald process. Later on, the plant mixed process "terminal blend" was different from the McDonald process of a kind of wet process technology. Its purpose was to produce homogeneous rubber modified asphalt binder, which could be stored for a long time without stirring, then rubber modified asphalt could be produced in central plant and delivered to hot mix plants.

In 2004, the full set of equipment producing asphalt rubber (wet process) was imported by Guangzhou Gold bond. After 10 years of industrialization promotion, the pavement industry recognized its outstanding cracking resistance, noise reduction and fatigue resistance.

3.2 Application of asphalt rubber in Guangzhou

Administration of Quality and Technology Supervision of Guangdong Province (2012) published local standard "Technical Specifications for Rubberized Asphalt Pavement Engineering (2011)" in March, 2012, which played a key role in promoting asphalt rubber technology.

Rubber asphalt has many performance advantages including: high temperature stability, low temperature performance, anti-aging, fatigue resistance and moisture stability. Asphalt rubber is a well performance, balanced modified asphalt. The performance characteristics of rubber asphalt are as follows:

3.2.1 High temperature stability

Viscosity of asphalt increases with rubber powder, the ability to resist high temperature deformation is improved. High viscosity of asphalt not only improves the ability to resist deformation, but also strengthens the bond of asphalt and aggregate. It's also very good waterproof material.

3.2.2 Excellent cold season performance

Rubber is designed to resist extremely cold environmental fatigue, with a large portion of rubber inside, asphalt rubber presents excellent flexible and anti-cracking performance.

3.2.3 Anti-aging and anti-cracking deformation

Tires rubber contains a lot of protective agents, such as antioxidants, a heat stabilizer, base metal inhibitors, an ultraviolet ray absorber, and the effective in light shielding of carbon black filler. Therefore, asphalt rubber presents better anti-aging and improved anti-cracking performance compared to other modified asphalt.

3.2.4 Moisture stability

Asphalt rubber mixture not only has good adhesive power, but has the thicker cement membrane, and the water stability of improved roads. Besides, the adhesion comparison test showed that for ordinary asphalt adhesiveness to granite stone the level was between 2–3, while asphalt rubber adhesion was within levels 3–4.

3.2.5 Noise reduction

Because of improved road surface flexibility and sound-absorbing characteristics, traffic noise on rubber pavement can be reduced for 2–5 db.

3.2.6 Stress absorbing

Asphalt rubber stress absorbing membrane has strong antireflective capability. On the other hand, asphalt rubber mixture has higher binder content and better fatigue resistance. Asphalt overlays together with asphalt rubber SAMI is a very widely accepted overlay solution on cement concrete pavement.

Length of the asphalt overlay on highway S116 crossing Xianmao Mountain is 2.13 km. The paving road section was shown in *Figure 4.* This project using the asphalt rubber overlay reduced more than 20% of construction time, road traffic noise was reduced more than 2 db.

The section of Li lake road in Zengcheng City has a total length of 4.52 km; SAMI-R (about 113,000 m^2) was adopted as a function of anti-reflective overlay in the project. The paving road section was shown in *Figure 5.* The SAMI-R improved the antireflective ability significantly. There are still no reflective cracking, rutting, bleeding and other distress until now.

4 Development trends of road green technologies

Development of the road green construction technologies typically has 3 steps. Firstly, the concept of technology is

Figure 4. Asphalt overlay project of cap mountain peak section in S116 line.

Figure 5. The renewal project of Li lake road in Zengcheng City.

based on some interdisciplinary thinking (around how to save energy conservation, reduce emission and environmental impact); Secondly, solution development and application trials. Technologies were enriched and applied in some small scale projects under the support of user/government. Many technologies were cancelled in this stage because of economic or technical inefficiency. Finally is the large-scale applications, which not only decided by the technical itself, but also comprehensive conditions like society and economy development stage, basic industry development level, administration and evaluation system and other local restrictions.

4.1 Preventative maintenance technologies

As the most effective way to prolong the service life of pavement, and reduce pavement life-cycle cost, preventative maintenance technologies totally are green engineering technologies. Typical preventive maintenance technologies include fog seal, chip seal, micro-surfacing and ultrathin overlay. Fog technologies could be divided into two types, surface sealing and surface recovery. The former creates a very thin and wear-resistant sealing layer, while the later recovers asphalt on the top 10 mm of surface concrete. East China University of Science and Technology combined the two together to develop a process named dual fog rooting seal. First, the fog is used for surface recovery. Then it creates the wear-resistant layer, which already has applications nearly 1 million square meters mostly on the expressway. Chip seal is a cost effective way for surface sealing, mostly used in northwest provinces. Recently, with fiber reinforcement, chip seal began its wide use in south and east provinces. Micro was accepted by expressway owners but they still don't satisfy with noise issue. To reduce noise in cars, fiber and gap gradation were considered in recent years. Ultra overlay has also evolved into two types: open graded mixture + emulsified asphalt bond layer and gap graded dense mixture combined with warm mix technology + hot asphalt bond. The former constructs fast, with a thickness of 1.5–2.5 cm, needs expensive special equipment; the latter constructs in common mode, with a thickness of 2–3 cm.

4.2 Hot recycling technology of asphalt pavement

Hot recycling (RAP ratio exceed 50% in some place) is widely used in some gray areas, which means a lack of quality control and administration. On the other hand, hot recycling material typically still is not permitted in arterial roads and expressways. The asphalt mixture producers with a good quality control system and advanced recycling plant are not encouraged in the market place. Administration actions are being taken in recent years to change current conditions. One important action is to establish RAP material collection administration system together with RAP trade platform. Another key action is to establish recycled asphalt mixture quality control system and market admittance procedure.

4.3 Cold recycling technology of asphalt pavement

Cold recycling is "depth" green pavement technology, which has green advantages like zero emission, no pollution, great resource demand reduction, great direct investment reduction and sustainable recycling. When the structure of asphalt pavement is failed (condition might be worse in China because of cement treated base), the cold recycling technology is preferred because it could use more than 80% RAP in asphalt mixture. Recycling trains were adopted in United States (including milling planer, sieving, mixing, and paving four units or two units at least), while single unit in site recycling was adopted in European. The equipment is very expensive and domestic manufacturers still can't provide similar products. On the other hand, when people begin to consider cold recycling, cement treatment base failed, and in-site recycling can't recover the base at the same time. Cold in plant recycling was promoted very well in the last five years in China. Plants for cold recycling were optimized and stable productivity exceeded 400 tons/hour, sieving and RAP feeding system could also match the same productivity. In Jiangxi Province, cold in plant recycling has already become the typical rehabilitation solution, which really provided key distribution while balancing the big upgrading plan of the insufficient road structure and limited budget. In Shanghai, cold in plant recycling also was involved as key solution for structure failure in outer ring road rehabilitation project.

4.4 Warm mix asphalt technology

Energy consumption and emissions of the batching plant is a key challenge for mixture producers. Influenced by Kyoto Protocol, warm mix asphalt technology was carried out firstly in Europe. Technologies like foam, polymer wax, fine aggregate with crystal water were developed soon. In 2002, representatives of the US Asphalt Pavement Association visited Europe. Then warm mix technology developed very fast in US. Annual total consumption of WMA reached 41.1 million tons in 2010, and 68.7 million tons in 2011. Specification for warm mix asphalt mixture were issued in at least 14 state DOTs by 2011. Since 2004, China followed the same steps. Many world first warm mix applications happened in China, including extremely long tunnel paving, cold season paving, high altitude paving, asphalt rubber WMA and large proportion RAP in plant recycling. However, good beginnings do not always lead to good results. WMA didn't go to large scale application. Compared with America, the conclusion is that the green concept is not enough to support promoting a technology. Large-scale application in United States depended on engineering value like compaction incentive, fuel saving, more RAP etc. Some cities gave subsidies to plant which used WMA to promote the technology. But because of a lack of effective and performance based supervision, things got out of control.

4.5 Cold mix asphalt mixture technology

Cold mix asphalt mixture uses emulsified asphalt or cutback asphalt as a binder, produced, stored and constructed under ambient temperature conditions. Mixing and paving under ambient temperature is always the development goals of green pavement technology. Emulsified asphalt is the major binder option because it is easy to get, cost low, and has no obvious volatility like the cutback asphalt. In Europe, especially in France, cold mixing mixture has routine applications. CMA is usually used in low traffic roads, village roads, plot roads, and supplying difficult region. Cold mixes are being promoted in a few dry and remote areas in China, such as Xinjiang and Gansu provinces. America uses cut back cold mix in family road and cold patching. Still there is much work to be done to improve the performance and enhance cost effectiveness to have cold mix involved more in common conditions.

4.6 Asphalt rubber technology

Recycling of waste tires is a worldwide problem. Treatment like land filling and oil refining or as fuel, will all introduce environmental problems. Meanwhile, original use (rubber products or asphalt modifier) definitely is the best and greenest way to digest abandoned tire rubber and it is always the best approach to become sustainable and green. Tire rubber was applied in road engineering as early as 1940s. Asphalt rubber became the most commonly overlay material in Arizona, California, Texas and Florida in United States, as well as South Africa and other countries. There were also relative applications in Portugal, Spain, Australia, France, and Brazil. In China, asphalt rubber didn't become a commonly used material because of below problems: (i) Small/temporary projects or mixing station, together with high binder content, led to increased cost for final user; (ii) Not compatible to traditional asphalt supplying system, difficult to have them involved. (iii) Unstable property, quality deviation would be out of permission if it can't follow strict procedure control. In recent year, for wet process, central producing and central supplying seemed to become the industry objective, more and more traditional suppliers are involved in the evolvement. International conference AR2012 and international seminar of rubber asphalt held in Nanjing in end of 2013 showed the similar trend. In the past three years, Shanghai Jiao Tong University developed customized rubber composite modification technology, by which traditional asphalt supplier could produce stable composite rubber modified asphalt (could be used in almost all the places that SBS modified asphalt were used) by their SBS modification equipment and procedure.

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