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EVALUATION OF STEEL BRIDGE DECK MA MIXTURE PROPERTIES DURING CONSTRUCTION

Zou Guilian[1], Zhang Xiaoning[1], and Chung Wu[2]

Key words: Guss Asphalt, Mastic Asphalt, steel bridge deck pavement, performance, construction process, Impact Toughness.

ABSTRACT

Responses of steel bridge deck pavement to environmental and traffic loadings are much different from those of normal highway asphalt concrete pavement or concrete bridge deck. Steel bridge deck pavement generally deals with more challenging conditions, especially orthotropic steel bridges (Seim and Ingham, 2004; Medani et al., 2007; Battista et al., 2008; Cong et al., 2009; Kashefi et al., 2010). Therefore, materials used in constructing the steel deck bridges must possess excellent properties. Guss Asphalt (GA) and Mastic Asphalt (MA) are two types of asphalt concrete primarily used in steel deck bridge pavement construction (Eulitz et al., 2004; Ripke, 2009; McFadyen and Blumensen, 2010; Bocci and Canestrari, 2012). These two materials are composed of specifically graded aggregate and high content of asphalt binder to form a coherent, voidless and impermeable solid or semi-solid mass at ambient temperatures, but sufficient fluid at construction temperatures. The asphalt concrete mixtures are placed using hand float or other suitable equipments. No compaction is required. Therefore, these types of asphalt concrete mixtures are termed as poured asphalt mixture. Two different types of poured asphalt mixtures are known: GA and MA. GA was developed in Germany and MA was originated in England. To obtain adequate workability, GA and MA have been mixed and constructed at temperatures between 200°C and 240°C.

In this study, GA and MA mixture samples were prepared using both laboratory mixers and batch plant and truck mixers. Samples were subjected to laboratory testing to evaluate the workability, rutting resistance and fatigue cracking resistance of the poured type asphalt mixture. Test results indicated that mixing time had significant influence on workability, rutting resistance and fatigue cracking resistance of the poured type asphalt mixtures. Longer mixing time and higher mixing temperature resulted in better rutting resistance but lower fatigue cracking resistance(Pauli and Huang, 2013). Therefore, during construction, mixing time and higher mixing temperature need to be controlled to achieve adequate performance for both rutting and fatigue cracking. It is recommended that, during construction, the Dynamic Stability at 60°C and Impact Toughness at 15°C be used as the quality control indexes.

I. INTRODUCTION AND BACKGROUND

Two types of asphalt concrete materials have been generally used in steel bridge deck pavement construction, the Guss Asphalt (GA) and the Mastic Asphalt (MA). GA was originally developed in Germany and known as Guβ in Germany, meaning “river”(Wang et al., 2011). It was officially defined in the 2001 Edition of German Asphalt Concrete Mix Design Specification. As indicated by its original name, GA is characterized by its fluidity at construction temperatures. Because of its self leveling capability at paving temperature, no compaction is required during GA pavement construction.

In the United Kingdom (UK), based on the material’s characteristic, the steel bridge deck asphalt concrete was termed as Mastic Asphalt (MA). In UK, MA had its own system of design, production, and evaluation processes. The primary difference between the GA and MA was the different production processes used in producing these two asphalt concrete mixes. In producing MA, the mineral filler (at ambient temperature), bitumen and fine aggregate (at ambient temperature) are fed into a mixer sequentially and were mixed for about 5 to 6 hours. The product of the mixture (not contain coarse aggregates) is called Mastic Epuré (ME). ME is then fed into a mixing truck, called Cooker, mixed with predetermined proportion of coarse aggregates to produce the final MA. The production of GA did not consist of the two-step process. All ingredients are fed into the batch plant and the mixing of GA only took 2 minutes. The GA mixtures are then

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dumped into the Cooker for secondary mixing and transportation.

In addition, other differences between GA and MA materials include the aggregate gradation, mix design method, and property indexes for evaluation. Despite the differences, both GA and MA have high asphalt content, high fine aggregate content and less coarse aggregate content. Both can flow easily (self leveling) at high (construction) temperature. Therefore, they were termed as poured type asphalt concrete mixtures in this study.

The development of GA started in 1917 in Germany. It was used as water proofing material in building and pavement constructions. GA has been successfully used in steel bridge deck pavement construction, such as Oberkasseler Bridge, Mulheim Bridge, Zoo Bridge, etc. It was later used in steel bridge construction in France, Sweden, Holland, etc. with good performance records.

MA was first used in steel bridge deck construction in UK. The Road and Transportation Association of UK conducted extensive researches on this topic in the 1950's. A 38-mm single layer MA structure was first used to build the Forth Road Bridge, followed by subsequent construction of large-span steel bridges, such as River Sevem Bridge and Humber Bridge. From the performance of the Forth Road Bridge, the service life of the MA bridge pavement could last more than 30 years. In 1988, UK updated its specification and published BS1447:1988 "Specification for Mastic Asphalt (Limestone Fine Aggregate) for Roads, Footways and Pavings in Building" that provided more detailed requirements and instructions for MA mix designs and performance indexes. In 2006, the European Union (EU) defined the MA standards in Chapter 6 of its specification BS EN 13108. MA (Great Britain standard system) and GA (German standard system) should meet this specification.

The technique of MA was originated in Europe; Japanese, however, have further developed the technique and promoted its application. Japanese imported the GA technique from Germany in 1956. In 1988, codes and standards for GA steel bridge deck design and construction were developed based on the study about Honshu-Shikoku Bridges project (Raab and Partl, 1998). Following decades of researches, the structure consisting of GA and Stone Matrix Asphalt (SMA) was used in constructing the Akashi Kaikyo Bridge. Performance of the bridge deck pavement has been very good since its opening to traffic in 1998. According to survey data, more than 70% of bridges in Japan were constructed using GA.

Because of historical background, Hong Kong has always used UK's standards and specifications in infrastructure construction. For example, the construction of Hong Kong Tsingma Bridge, Stonecutters Bridge, and Shenzhen Bay Bridge all used the MA material and techniques, with satisfactory performance. Hong Kong Tsingma Bridge adopted single layer MA structure and was opened to traffic in May of 1997. Up to date, it has performed very well with only minor, localized repairs required. The 2-layer structure of MA+SMA was used in Stonecutters Bridge and Shenzhen Bay Bridge. In recent years, the trend has moved toward to the use of the 2-layer system because of its advantages in functional properties, lower construction cost, and better rideability of pavement.

In China, besides Honk Kong, the GA technique has been used in steel bridge deck pavement construction. Some of the bridges, including the Anqing Yangtze River Bridge (completed in 2004) and the Caiyuanba Yangtze River Bridge in Chongqing (completed in 2007), have performed well to date with no major distresses. These two bridges employed the 2-layer system with the SMA on top of the GA (GA+SMA). Opened to traffic in July of 2003, the Yellow River Highway Bridge in Shandong Province also adapted the 2-layer system. Some localized cracking and shoving occurred and the distresses were repaired. It performed well after the repairs. Another steel deck bridge constructed with the 2-layer system, Queshi Brige in Shantou, was open to traffic in November of 1999. Severe distresses, including rutting, fatigue cracking, water related damages, etc., occurred and the bridge deck pavement was completely reconstructed between November 2006 and January 2007. However, in late 2008, some lateral displacements of the asphalt occurred in the traffic lane due to the heavy vehicles. Some localized rutting was observed in November 2010.

Main structures of steel bridges are generally designed to last for 100 years; however, the life of the steel bridge deck pavement is only about ten years. Some bridge deck pavements need major rehabilitation within five years. One of the major reasons for the premature pavement failures is the extremely high deformation due to the flexibility of the steel bridge deck. Also, because of many different factors, such as traffic loading, wind, temperature, etc., that could affect the steel bridge deck behavior, the stress and strain conditions of bridge deck pavement are more complicated. Two major types of distress are rutting and cracking (Zhang, 1999; Chen et al., 2009; Wimpenny et al., 2009).

II. OBJECTIVES

In both the British Specification BSl447:1988 and the current EU Standards BS EN 13108-6:2006 "Bituminous Mixtures -- Material Specifications -- Part 6: Mastic Asphalt," two property indexes, Hardness Number and Indentation, are defined to represent material's ability to resist permanent deformation. Both indexes measure the depth that a metal rod penetrates the asphalt mixtures and use it to represent the hardness of the material under a specific condition. However, the test conditions are much different from the actual repeated loadings applied by traffic. There are needs to have more representative test methods and engineering indexes that can better describe materials' resistance to rutting, especially in warm regions. Also, there is no engineering index that defines the performance of cracking resistance for MA mixtures.

In warmer regions of China, summer season is generally long and hot. Additionally, with high traffic volume and severe overloading problem, high-temperature performance becomes very critical for highway and bridge pavements. To improve pavement rutting performance, researchers have studied various techniques, including higher content of Trinidad Lake Asphalt (TLA); harder grade of asphalt binder, moderately pre-aging asphalt mixtures during construction, etc. However, the ability of the asphalt mixture to resist rutting is in conflict with its ability to resist cracking. Therefore, performance indexes are needed to define the materials' ability to resist both rutting at higher temperatures and fatigue cracking.

Tensile strains measured at the top of the wearing course of steel bridge deck pavements can exceed 500 μ strains, which are higher than those observed at the bottom of conventional asphalt pavements. This explains why most distresses reported in the literature for orthotropic steel bridge pavements have been related to fatigue cracking of asphalt mixes. Among the many test methods, Four-Point Bending Fatigue Test and Five-Point Bending Fatigue Test have been frequently used in researches to evaluate fatigue properties of asphalt mixtures (Guo and Prozzi, 2006; Wu, 2009; Hajj et al., 2011; Pouget et al., 2011; Biligiri et al., 2012). However, because of the complex testing procedures and time required in conducting these two tests, they are not suitable for quality control purpose during construction.

In many instances in China, rutting and fatigue cracking have been observed on the same steel bridge deck pavements, at different locations. With the same materials sources, asphalt mixtures, and construction, how could the two conflict pavement distresses occur on the same pavement? It is believed that the most likely reason would be the lack of quality control during construction, such as the lack of control of mixing time and mixing temperature in the Cooker during the production of the MA. The mixing time in the mixing truck can vary from one hour to eight hours. The objectives of this study were to evaluate:

- During production of the MA mixtures, how the mixing time would affect the mixture's fluidity, high temperature properties, and fatigue characteristics?
- What were the interactions between the high temperature properties and the fatigue characteristics?
- During the design and construction of the MA pavement, what would be the appropriate property indexes for defining fatigue characteristics?

III. MATERIALS, SAMPLE PREPARATION AND TESTING

1. Materials

Three types of asphalt binders were evaluated in this study, a conventional asphalt binder, Pen 60/70 grade (designated as A-70), a TLA binder and a blended asphalt binder containing 70% TLA and 30% A-70 binder. Pen 60/70 indicates a penetration grade of 60/70 at 25°C. Properties of the three asphalt binders are shown in Table 1.

Table 1. Properties of asphalt binders-1.

Properties	Unit	Pen 60/70	TLA	70%TLA+30% Pen60/70
Penetration (25°C, 100g, 5s)	0.1 mm	61	3	18
Ring & Ball Temperature	°C	49.0	90.0	65.2
Ductility@15°C (cm)	cm	>100	—	—
Solubility (TCE) (%)	cm	99.9	53.0	67.1
Flash point (C.O.C)	°C	>260	—	>260

Table 2. Specified gradation of limestone fine aggregate.

Gradation of Fine Aggregate*	% by mass	
	Min.	Max.
Retained on 2.36 mm	—	2.5
Passing 2.36 mm & retained on 600 μm	4	21
Passing 600 μm & retained on 212 μm	8	32
Passing 212 μm & retained on 75 μm	8	25
Passing 75 μm	40	56

*Gradation determined by wet sieving method described in BS 812-103.

The aggregate gradation used in MA was much finer than that used in GA. The finer aggregate gradation is generally beneficial to construction quality for steel bridge deck pavement. Therefore the aggregate gradation and mix design method of MA were adopted in this research.

The fine aggregates used in this study were natural limestone ground to the required gradation as shown in Table 2, and were required to have a minimum calcium carbonate content of 80% by mass. The ME is the mixture of the fine aggregate and asphalt binder.

Coarse aggregates are materials substantially retained on a 2.36 mm sieve. The total percentage of coarse aggregate in the MA mixtures also includes the portion of fine aggregates retained on a 2.36 mm sieve. It was specified that the coarse aggregate content in MA mixtures shall be 45% ± 10% by weight of the total mixture, for heavily stressed areas. However, no gradation is specified in the British Specifications for coarse aggregate. The soluble asphalt binder content shall be between 14% and 17%, by weight of ME. In this study, the percentage of coarse aggregate was 45%, by weight of the total MA mix, and the remaining 55% consisted of ME, which were the mixtures of the fine aggregates (including mineral fillers as part of the fine aggregates) and the asphalt binder. The percentage of soluble asphalt binder was 14.5% by weight of the ME. The limestone fine aggregate gradation and the asphalt binder content used in this study and the specification requirements are listed in Table 3.

2. Traditional Method for MA Mixture Preparation in Laboratory

Traditionally, MA mixtures were produced in the laboratory

Table 3. Gradation of fine aggregate and the soluble asphalt binder content.

Gradation	Sieves size (mm)					Soluble Asphalt Binder Content (%)
	>2.36	0.6~2.36	0.212~0.6	0.075~0.212	<0.075	
% by weight	0	16	20	23	41	14.5
BS1447:1988	0~2.5	4~21	8~32	8~25	40~56	14~17

Fig. 1. Traditional mixer in laboratory.

following processes listed below:

- A-70 bitumen & TLA were heated to 160°C to 170°C in the oven and mineral fillers were prepared at ambient temperature. They were then weighed and fed into the mixer (Fig. 1). The mixer was heated by gas and the mixing temperature was under controlled condition. Inside the mixer, the agitating vanes were operated by a diesel engine. The mixtures were allowed to reach 170°C to 190°C and were then mixed for additional 30 minutes.
- The fine aggregates, at air temperature, were fed into the mixer and entire mixture was mixed for 30 minutes after the mixing temperature reached between 180°C and 195°C. The product was called ME.
- The coarse aggregates were then added into the mixer at air temperature, and the mixture was mixed for another 30 minutes to 120 minutes as needed, at a mixing temperature between 180°C and 195°C.
- A batch of MA produced in the laboratory weighted between 200 kg and 800 kg.

The sequence for producing the MA mixture in the laboratory is summarized in Table 4.

Table 4. Production process of MA in the laboratory.

Feeding sequence	Mixing temperature, °C	Mixing time, min
Pen60/70 + TLA + filler	170~190	30
+ fine aggregate	180~195	30
+ coarse aggregate	190~215	30-120 (as needed)

Fig. 2. Enhanced mixer in the laboratory.

3. Enhanced Method for MA Mixture Preparation in Laboratory

The process of producing MA mixtures was notoriously slow because of the unheated aggregates used in the mixing process. An enhanced mixer was designed and manufactured by ChangDa Highway Engineering CO. Ltd, as shown in Fig. 2. The working principle of the mixer was the same as the Cooker truck. The device could control the temperature and rotational velocity automatically.

The Pen 60/70 asphalt binder and TLA were heated to 160°C~170°C in an oven, and the mineral fillers, fine aggregates and coarse aggregates were all heated to 190°C~200°C in ovens in the laboratory. In producing the MA mixtures with this enhanced mixer, the heated fine aggregates and coarse aggregates were weighed and fed into the enhanced mixer and were mixed for 2 minutes. The heated fillers, Pen 60/70 bitumen and TLA were then added into the mixer in this sequence. The mixture was then mixed at controlled temperatures normally in the range between 200°C and 230°C for certain amount of time. The effects of the mixing time on the performance of the MA mixtures were part of the study objectives. The mixer is capable of producing batch mixtures in the amount between 150 kg and 300 kg per batch.

4. MA Mixture Preparation in Batch Plants

As described in an earlier section, the traditional production

Fig. 3. Mixing Truck - Cooker.

process of British MA mixtures is a 2-step process. ME is first produced in the batch plant. Coarse aggregates and the ME are then mixed in the Cooker (Fig. 3) to produce the final MA mixture. This process generally takes more than six hours. On the other hand, the GA mixture production consists of only a single step. All ingredients are mixed in the batch plant. To be more efficient, the mixtures used in this study were produced using a modified method developed from a combination of these two processes. In this research, the mix design, including the aggregate gradation requirement, asphalt binder content determination, etc., was based on the MA method while the mixing and production followed the GA method.

5. Laboratory Testing

The sample preparation methods used in the laboratory are intended to simulate the production process in the batch plant. The specimens produced using the three processes should be comparable. In the laboratory testing in this research, all three methods were used to prepare specimens, to ensure that no bias would be introduced by using different sample preparation methods.

Three types of tests, Lueer Fluidity Test (LFT), Wheel Tracking Test (WTT) and Impact Loading Test, were performed in the laboratory to evaluate the fluidity, rutting resistance at higher temperatures, and fatigue characteristics of the steel bridge deck asphalt mixtures, respectively.

1) Lueer Fluidity Test

In the German GA system, the Lueer Fluidity Test (LFT) is used to measure the workability of the GA mixture. The LFT apparatus consists of a container, a support frame and a plum-shaped cylinder, as shown in Fig. 4. The cylinder is made of brass with a weight of 995 g. A pair of indicators spaced 50 mm apart are marked on the upper part of the bar. The time required for the GA mixture to pass through the 50-mm indicators is called the Lueer fluidity of a GA mixture. The Lueer fluidity value of a mixture is generally required to be less than 20 seconds at 240°C to ensure adequate workability. It is important to note that, even though the LFT is conducted at a temperature of 240°C, the construction temperature of the GA steel bridge deck pavement is normally lower than 230°C. Keeping the construction temperature lower reduces the possibility of excessive aging during paving. Therefore, in this study, the test was performed at the actual temperature after mixing.

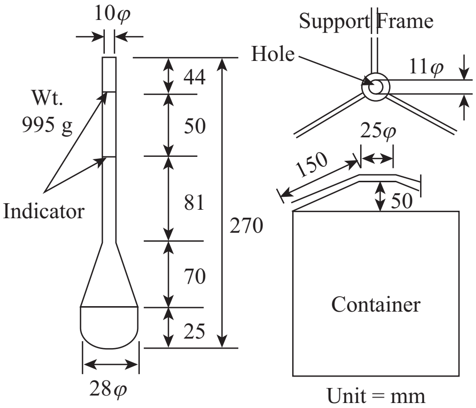

Fig. 4. Lueer Fluidity Test.

Fig. 5. Wheel Tracking Test.

2) Wheel Tracking Test

Many test methods have been used in evaluating rutting resistance of asphalt mixture (JTG E20-2011). In this study, a Wheel Tracking Device (WTD) was used to evaluate high temperature performance of the various asphalt concrete specimens, in accordance with Chinese Standard Test Method T0719-2011. The WTT method is originated from the Transport and Road Research Laboratory in Great Britain. The test was performed at a temperature of 60°C; loading speed of 42 times per minute; and with a wheel contact pressure of 0.7 MPa. Total deformations were measured on the specimen surface after it was subjected to 60 minutes of repeated wheel loading. The Dynamic Stability was also recorded. Dynamic Stability is defined as the number of wheel loadings required to induce a 1-mm deformation during the testing time frame from 45 minutes to 60 minutes.

Fig. 6. Impact Toughness Test.

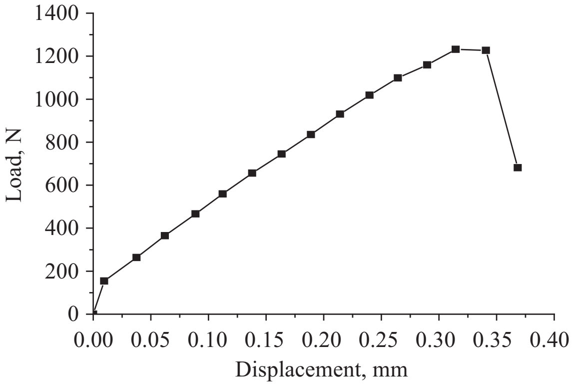

Fig. 7. Load-displacement curve Load-displacement.

3) Impact Loading Test

The Impact loading Test had been used to evaluate the fatigue characteristics of asphalt mixtures in a pavement system (Zou et al., 2013). In this study, asphalt concrete specimens made with different materials were compacted to the size of 30 cm × 30 cm × 5 cm. The specimens were then cut into beams with the size of 25 cm × 3.0 cm × 3.5 cm. After cured in the water bath for four hours at constant temperature of 15°C, the beam specimens were subjected to impact loading, with a loading speed of 50 mm/min.

Fig. 6 shows the testing in progress and a typical load-displacement curve is presented in Fig. 7. The parameter "Impact Toughness", represented by the area under the loading-displacement curve (to the failure point), was used to characterize the fatigue capacity of the GA and MA mixtures. Materials with higher Impact Toughness values posses higher ability to resist fatigue cracking.

IV. RESULTS AND DISCUSSIONS

1. Workability

The LFT was first performed on specimens prepared in the laboratory using the Enhanced Method. The tests were performed at two different temperatures, 200°C and 240°C and the results are presented in Fig. 8. As shown in Fig. 8, at both 200°C and 240°C, the Lueer Fluidity values of the MA mixtures decreases at the beginning of the mixing operation (to 60 minutes or 90 minutes, depending on the testing temperature), indicating an increase in fluidity. This increase in fluidity is probably caused by the shear thinning of the materials in the early stage of the mixing. As the mixing time increases, the Lueer Fluidity value increases, due to the aging of the materials. The figure also shows that, in the early mixing stage, the MA mixture tested at 240°C has better fluidity than that at 200°C. As indicated in Fig. 8, at mixing temperature of 240°C, the MA mixture has high fluidity at the beginning stage of the mixing, as compared to that mixed at 200°C. However, at 240°C mixing temperature, the fluidity decreases rapidly after mixing time reaches 120 minutes because of faster aging of the MA mixtures.

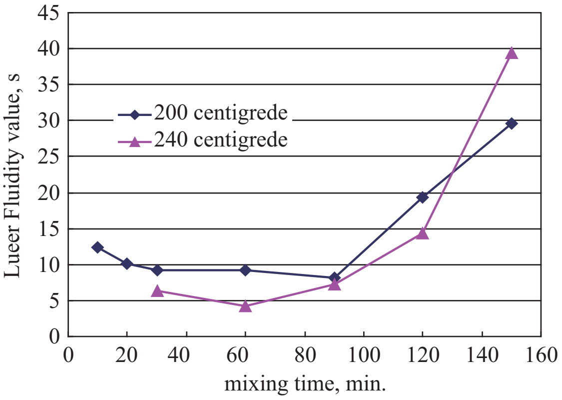

Fig. 8. Effect of mixing time on the Lueer Fluidity values (enhanced lab method).

The production of MA mixtures during construction are different from the production in the laboratory since the mixing speed, tightness, and the volume are different between the laboratory mixer and the mixing truck (Cooker). To be more closely simulate the actual condition during construction, batch plant produced MA mixtures were subjected to the LFT. In the batch plant production process in the study, all ingredients were heated to specified temperatures and were fed into the batch plant following specified sequence. The materials were then mixed in the batch plant for two (2) minutes. The MA mixtures were then fed into the Cooker for additional mixing and transportation. As mentioned, the time required for the mixing in the Cooker was not clearly defined. It could vary from one hour to eight hours during construction.

The effects of mixing time in the Cooker on the workability of the MA mixtures are presented in Fig. 9, with mixing temperature ranging from 210°C to 235°C. Dates of testing are shown on the figure. The test results shows similar trends as observed from the LFT results for the laboratory prepared samples (Fig. 8). Because of the shear thinning phenomenon of the mixtures in the early mixing stage, the Lueer Fluidity values decrease with increasing mixing time, to approximately

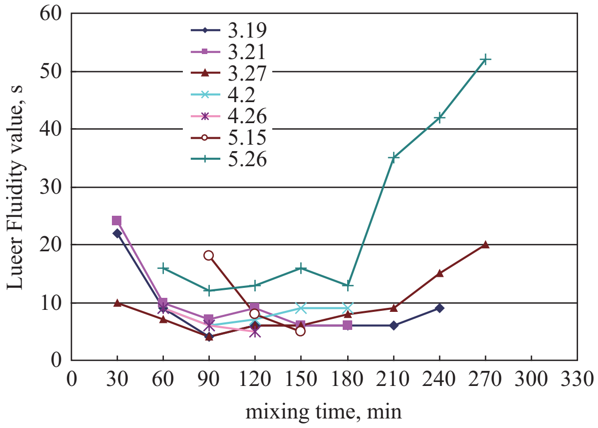

Fig. 9. Effect of mixing time on the Lueer Fluidity values (Cooker).

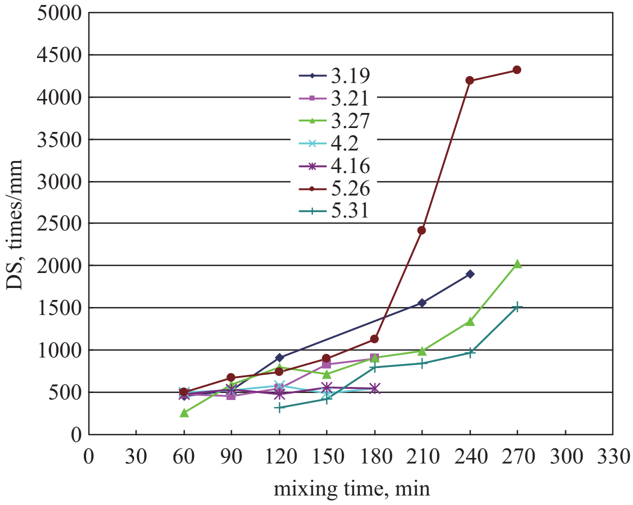

Fig. 10. Effect of mixing time on DS.

120 minutes. The values then increase due to aging of the mixtures. All curves had U shapes; however, within the four-hour mixing time in the Cooker, the resulted Lueer Fluidity values are all under the acceptable value of 20 seconds. Also, except the last test results (conducted on May 26), all other curves are relatively close, indicating good repeatability of the test results. The slight differences are probably caused by the testing variability and the slightly different mixing temperature.

During the last round of mixing (May 26), the mixing temperature was adjusted to 235°C and the mix proportion was also adjusted, with slightly higher content of coarse aggregate (5.26 curve in Fig. 9). The higher coarse aggregate content probably results in the slightly higher Lueer Fluidity values in the early mixing stage. The sudden jump on the values after 180 minutes of mixing is probably caused by the more severe aging induced by the higher mixing temperature.

Compared to the test results from Fig. 8, mixtures produced by the batch plant and the Cooker generally maintain acceptable Lueer Fluidity values (high fluidity) after four hours of mixing. With the Cooker, the larger mixing vane and higher mixing speed induce more shear thinning of the mixtures and slower aging process. The tightness and larger volume of the Cooker (compared to the laboratory mixer) can also reduce the gaining of the mixture.

2. High Temperature Performance

The ability of the MA mixture to resist permanent deformation has generally been represented by the Hardness Number or Indentation in Europe. However, many areas in China, the weather is much warmer than those in Europe. For example, high temperature in the month of July 2013 in Hunan, Shanghai and Hongzhou reached 35°C for more than 25 days, with three (3) consecutive days reaching 40°C. Furthermore, the highway and bridge pavements in China normally carry heavy traffic volume and weight, with severe overloading problem. The use of a simple penetration test might not be able to assess the high temperature performance of the MA mixtures.

In this study, the Wheel Tracking Tests were performed to evaluate the MA mixture samples' ability to resist rutting at higher temperatures. MA specimens used in this test were produced by the batch plant and fed into the Cooker truck to keep mixing at about 230°C; this process is the same as the conditions during construction. The specimens were subjected repeated loading for 60 minutes and deformations were measured on the specimen surface. Dynamic Stability (DS) was also recorded. DS is defined as the number of wheel loadings required to induce a 1-mm deformation during the testing time frame from 45 minutes to 60 minutes. The effects of mixing time on the DS are shown in Fig. 10. It can be observed from Fig. 10 that the ability for the MA mixtures to resist rutting at high temperatures increases with longer mixing time. The increase becomes more significant after mixing time reaches 180 minutes, while DS values are generally low when the mixing time is less than 120 minutes. It indicates that some adequate aging of the MA mixtures at early stage would be desired for better rutting performance.

3. Fatigue Performance

Impact Loading Test was performed on the MA mixture samples prepared under the same conditions as during construction. The performance index, Impact Toughness, computed from the load-displacement curve from the test, was used in assessing the material's ability to resist fatigue cracking. Tests results are presented in Fig. 11. As shown in this figure, the Impact Toughness decreases with longer mixing time, indicating reduced ability to resist fatigue cracking.

4. Interrelationship between the High Temperature Performance and the Fatigue Performance

From the results discussed in the previous sections, the mixing time of the MA mixture has conflicted effects on the mixture's rutting and fatigue characteristics. To evaluate how the two performance indexes, DS and Impact Toughness relate

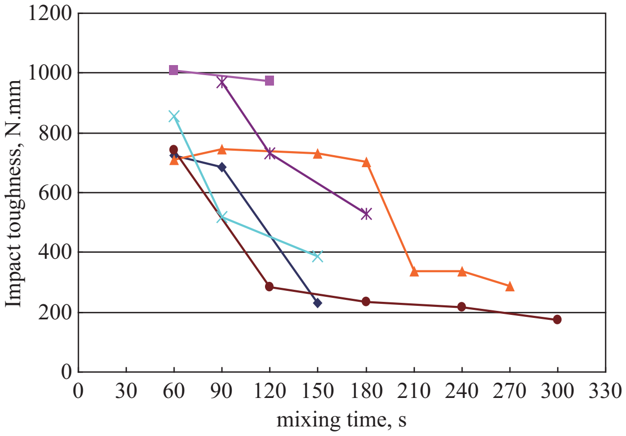

Fig. 11. Effects of mixing time on the impact toughness.

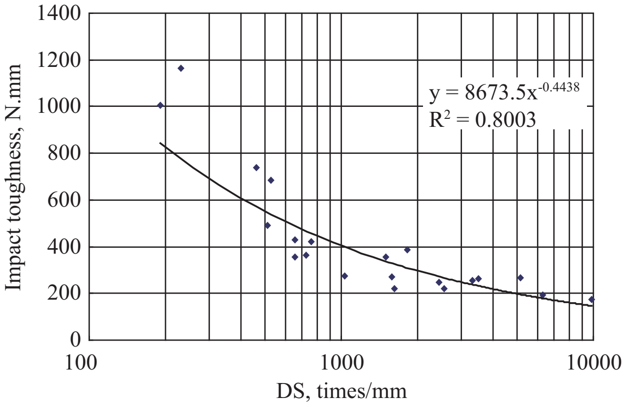

Fig. 12. Relationships between Impact Toughness and Dynamic Stability.

to each other, MA mixture samples for rut testing were prepared in the laboratory and were subjected to WTT. After the WTT, samples outside of the testing areas were cut into additional samples and were subjected to Impact Loading Test. The relationship between the Impact Toughness and the DS is shown in Fig. 12. From the figure, it can be observed that there exists an exponent relationship between these two indexes. As the DS increases, the Impact Toughness decreases rapidly. Therefore, mixing time requirement needs to be specified to achieve both acceptable DS and Impact Toughness. Normally, during construction, the DS at 60°C and Impact Toughness at 15°C are used as the quality control indexes.

V. CONCLUSIONS

From this study, the following conclusions can be drawn:

1. In early stage of mixing, because of the shear thinning phenomenon, the Lueer Fluidity values decreases (increasing workability) with increasing mixing time. However, towards the later stage, increasing mixing time results in decreased workability, probably due to aging of the materials. The Lueer Fluidity-mixing time curve generally has a u-shape.
2. Mixing temperature had influences on the fluidity and aging of the MA mixtures. As indicated in Fig. 8, at mixing temperature of 240°C, the MA mixture had high fluidity at the beginning stage of the mixing, as compared to that mixed at 200°C. However, at 240°C mixing temperature, the fluidity decreased rapidly after mixing time reached 120 minutes because of faster aging of the MA mixtures.
3. MA mixtures produced in the laboratory and during construction could be different. The mixing truck used during construction (Cooker) had faster mixing speed, better tightness and bigger volume, which could influence the MA mixtures produced. During construction process, laboratory developed mix design needs to be verified with the plant/Cooker produced mixture.
4. The ability of the MA mixture to resist rutting increased with increasing mixing time, especially after three hours of mixing, due primarily to the acerbated aging. With less than two hours of mixing, the ability in resisting rutting was generally low. Therefore, adequate aging would be desirable for better rutting resistance.
5. Impact Toughness decreased with increasing mixing time, which was the opposite to the Dynamic Stability of the MA mixture.
6. There existed an exponent relationship between Dynamic Stability and Impact Toughness. As the Dynamic Stability increased, the Impact Toughness decreased rapidly. Therefore, mixing time requirement need to be specified to achieve both acceptable Dynamic Stability and Impact Toughness. It is recommended that, during construction, the Dynamic Stability at 60°C and Impact Toughness at 15°C be used as the quality control indexes.

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