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Evaluation of Aging and Moisture Damage Potential of Warm Mix Asphalt Incorporating a Synthetic Wax Additive

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Abstract: This paper presents the effects of a warm mix additive on the moisture damage of warm mix asphalt (WMA). Asphalt mixtures were made using different WMA contents (0, 2 and 3%) at different compaction temperatures. Aging properties were studied from the effects of artificial long-term aging on resilient modulus (M_R) and indirect tensile strength (ITS) of WMAs. Moisture damage was investigated in term of tensile strength ratio (TSR) of unaged and aged specimens conditioned in one and three cycles of freezing and thawing. The results showed that the aging significant affected the M_R and ITS of WMA. The additive content increased with air voids but in contrary with the bulk density. Hence, the use of higher additive content can be more beneficial in terms of resilient modulus. Decreasing compaction temperature could significantly decrease the ITS while the TSR of WMA reduced as compaction temperature decreased. From moisture damage tests, the TSR of aged samples was found to be lower than that of unaged samples.

Keywords: WMA, Moisture Damage, Aging, Resilient Modulus, Wax Additive.

Introduction

During the construction of transportation amenities and infrastructures, the emission of greenhouse gases into the atmosphere is among the prominent causes of pollution. One of the latest technologies developed in the field of highway engineering, Warm Mix Asphalt (WMA) technology, has numerous benefits that are not connected to greenhouse gas emissions [1-4]. The technology of WMA is also environmentally friendly because it produces asphalt at considerably lower temperatures than Hot Mix Asphalt (HMA). The WMA technology achieved temperature reduction by using additives, which can be classified as chemical additives, organic additives and water-containing foaming additives or processes [5-7]. The basic purpose of adding additives is to strengthen mix workability by reducing the viscosity of the bitumen. Thus, this produces lesser emissions and creates improved working conditions [8-10]. The preservation and protection of both natural and workspace environments are the main objectives in the field of road engineering Worldwide there is an ever-increasing use of new environmentally friendly materials and techniques. One of these innovative processes includes WMA [7,11-13]. Such asphalt mixtures, compared to traditional HMA, can be mixed and compacted at lower mixing and compaction temperatures thereby reducing CO_2 and fume emissions and promoting low energy consumption and operative benefits [4-16]. It was reported that the mixing temperatures of WMA ranged from 100°C to 140°C compared to the mixing temperatures of 150°C to 180°C for conventional HMA [17-21]. In this paper, the effects of a new friendly environmental material named RH-WMA on the basic properties of asphalt mixtures were investigated.

RH-WMA is a relatively new warm mix additive that was designed to reduce the viscosity of the asphalt binder at elevated temperatures. The ability of WMA additives to decrease the binder viscosity leads to lower production temperatures of asphalt mixtures.

Lowering viscosity allows the aggregate to be coated completely by the binder at lower mixing temperatures [11,18-19]. Lower mixing and compaction temperatures can result in incomplete drying of the aggregate. The resulting water trapped in the coated aggregate may cause moisture damage. Hence, the stripping potential of this product needs to be investigated. On the other hand, aging plays a key role in the long-term performance of asphalt mixtures especially when it acts in combination with moisture damage. Therefore, the stiffness properties of the mixture before and after aging conditioning can provide good information about the performance of WMA [20-24]. Thus, this paper compares the volumetric and mechanical properties of WMA containing warn mix additives to traditional mixtures.

Materials and Method

A virgin PG64 asphalt binder used in the mixtures was obtained from Shell Bitumen Company, Singapore. Malaysia was used as the control binder; the physical and rheological properties are shown in Table 1. A wax-based WMA additive called RH-WMA developed in China was used as the warm mix additive [25]. RH-WMA was added into the base binder at 2% and 3% by the total mass of the asphalt binder as recommended by the producer. RH-WMA was blended with the binder at 145°C using an electrical propeller mixer for 30 minutes to ensure uniformity and homogeneity of the binder blend.

Granite as a source of mineral aggregates used in the preparation of all the mixtures was supplied by Kuad Quarry Sdn. Bhd., Penang. Malaysia was used for producing AC14 mixtures based on local specifications.

Table 1: Properties of PG64 binder

Aging condition	Test Properties	Value
Original binder	Viscosity at 135°C (Pa.s)	0.425
	Softening point (°C)	43
	Penetration (0.1 mm)	81
	Ductility (cm)	>100
	Flash point (°C)	331
	G*/sin δ at 64°C (Pa)	1486
Short-term aged binder	G*/sin δ at 64°C (Pa)	2830

This aggregate was washed, dried, and sieved according to the proposed aggregate gradation. Table 2 show the engineering properties of the aggregate used.

Table 2: Engineering properties of aggregates used [26]

Property	Test result	Test method
Coarse aggregates bulk density	2.62	AASHTO T85
Absorption (%)	0.40	AASHTO T85

Fine aggregates bulk specific gravity	2.57	AASHTO T84
Flat and elongated (%)	23.3	BS 812-105
Los Angeles abrasion value (%)	23.86	AASHTO T96
Aggregate crushing value (%)	19.25	BS 812-110

Different types of fillers have different effects on the performance of asphalt mixtures [27]. This paper was made to prepare asphalt mixtures using a non-conventional filler named Pavement Modifier (PMD) which is locally available in Malaysia. Thus, the secondary aim of this investigation is to examine the effect of this filler as an anti-stripping agent on the performance of asphalt mixtures. PMD is a grayish-black powder mineral filler and it is used as an anti-stripping agent. The addition of approximately 5% of PMD by aggregate weight acts as mineral filler in asphalt mixtures. Fig. 1 shows the RH-WMA and PMD filler used in this paper.

RH-WMA PMD

Fig. 1: The warm mix additive and filler used

For the production of fully binder-coated aggregates in the laboratory, the HMA construction temperature was selected at 160°C for the PG64 binder, while the WMA construction temperatures were selected based on laboratory experiences. Table 3 shows the mixing and compaction temperatures of mixtures. RH-WMA mixtures were workable enough to be compacted at selected lower compaction temperatures.

Table 3: Construction temperatures of HMA and WMA

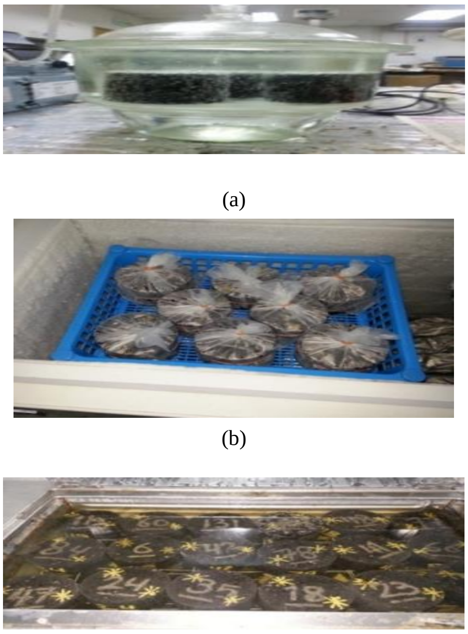
RH-WMA (%)	Mixture Type	Construction temperatures (°C)	
		Mixing	Compaction
0	HMA	160	150
2	WMA	130, 115, 100	125, 110, 95
3		130, 115, 100	125, 110, 95

For more ease of reference, mixtures were designated according to their mixture type (W for WMA and H for HMA), binder type (64 for PG64 binder), compaction temperatures (125°C, 115°C and 95°C) and RH-WMA content (2% and 3%). Hence, W2RH64C125 denotes the WMAs prepared using a PG64 binder containing 2% RH-WMA, compacted at 125°C.

The volumetric properties of fabricated mixtures were determined based on the bulk-specific gravity, air voids and voids in mineral aggregates. The resilient modulus test and indirect tensile strength test were selected to determine the stiffness properties of the mixture before and after aging conditioning.

The water sensitivity of asphalt mixtures was determined using TSR. Three test specimen sets were prepared and separated. All specimens were compacted to an air void content of 7 ± 1% using a gyratory compactor. The first set of specimens (dry) was left at room temperature for one day and then conditioned at 15°C before the TSR test. The second set of specimens (wet) was left at room temperature for one day and then subjected to one cycle of freeze-thaw. The third set of specimens (wet) was left in the room for 1 day and then subjected to three cycles of freezing-thaw. Indirect tensile strength (ITS) test was conducted on the samples to evaluate the moisture sensitivity of HMAs and WMAs.

Tests were conducted at 15°C using a loading rate of 50 mm/min until failure. A low temperature of 15°C was used because the asphalt mixture becomes brittle under low temperatures and therefore disintegrates easily when subjected to external loads. Thus, the low-temperature condition ensures that asphalt mixtures achieve near-elastic properties [28]. A higher TSR is generally believed to indicate improved resistance to moisture-induced damage. Moisture conditioning was performed in the laboratory to evaluate the effects of accelerated water conditioning through a freeze-thaw cycle on compacted asphalt mixtures. The conditioning of all the compacted samples was performed according to ASTM D4867 (2006) procedures with the only modification of using distilled water with the addition of Na2CO3 at 6.62 gm concentration instead of distilled water. Water with Na_2CO_3 was used to increase the pH value to enhance the stripping rate/damage inside the asphalt samples. The samples were immersed in the solution and vacuumed for 15 min to achieve saturation levels between 55% and 80% as shown in Fig. 2a. These samples were later exposed to freezing conditions at -18±3°C for 16 hours as shown in Fig. 2b and thawing condition at 60°C for 24 hours as one cycle according to ASTM D4867 (2006) as shown in Fig. 2c. Three sets of samples including unconditioned, conditioned in one freeze–thaw cycle, and conditioned in three freeze–thaw cycles were separated.



(a)

(b)

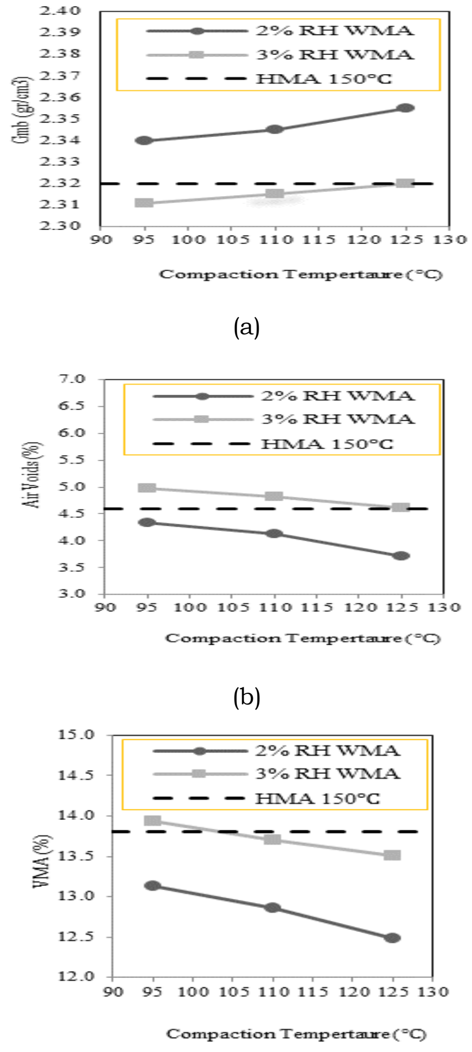
(c)

Fig. 2: Moisture conditioning (a) Vacuum saturation (b) freezing cycle (c) Thawing cycle

Test Results and Discussions

Several studies have been carried out evaluating the properties of WMA. It has been found that warm mix additives work in different ways either in reducing the viscosity of the binder or improving the workability of the mix at lower temperatures [29]. This section investigates the effects of compaction temperatures on the volumetric properties of WMA containing different amounts of RH-WMA additive. With lower compaction temperatures, WMAs might result in several problems, such as inadequate volumetric properties like higher air voids and lower VFA. Akisetty et al [30] showed that the warm mix processes were effective in improving the volumetric properties of rubberized mixes at a certain range of compaction temperatures.

Fig. 3a shows the relationship between the compaction temperature and bulk-specific gravity of the asphalt concrete mixtures. It is observed that the bulk specific gravity increases with the increase of compaction temperature. This is true for all mixtures containing different RH-WMA content. The increase in temperature decreases the viscosity of the mixture and in turn, facilitates easy compaction.



(a)

(b)

(c)

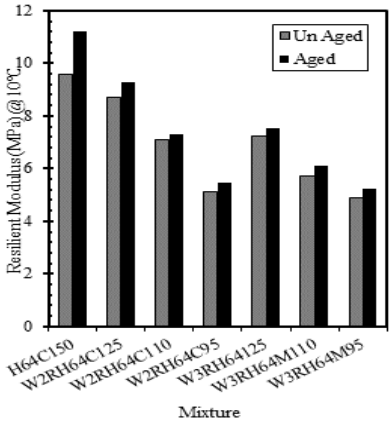
Fig. 3: Relationship between compaction temperature and (a) bulk specific gravity, (b) air voids, (c) voids in mineral aggregates

The relationship between compaction temperature and air voids is shown in Fig. 3b. Fig. 3b clearly shows that the percent air void decreases with increasing compaction temperature. This is also true for all mixes containing different RH-WMA content. The decrease in percent air void with the increase in compaction temperature is due to the lubricating effect of asphalt concrete keeping the viscosity of the binder suitable for compaction.

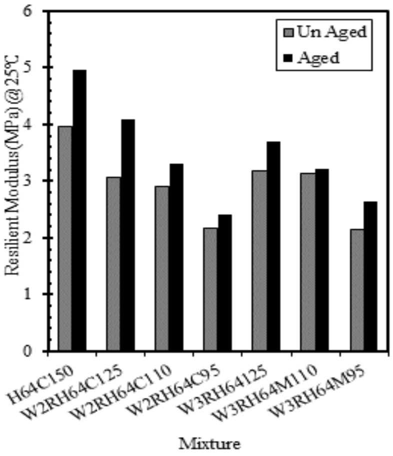
Fig. 3c shows the relationship between compaction temperature and % VMA. It is noticed that the percent (VMA) decreases with the increase of compaction temperature. The increase in the compaction temperature increases the lubricating effect of the binder due to a decrease in viscosity. This increases its workability and therefore improves the compaction process which in turn decreases the percent air voids and percent voids in mineral aggregates.

Resilient modulus (M_R) is used in mechanistic pavement design. It is used as one of the inputs in multi-layered elastic methods and finite elements to evaluate structural pavement response under traffic loading. The resilient behavior of the mixture depends on the binder type, test temperature, aggregate gradation and aging condition.

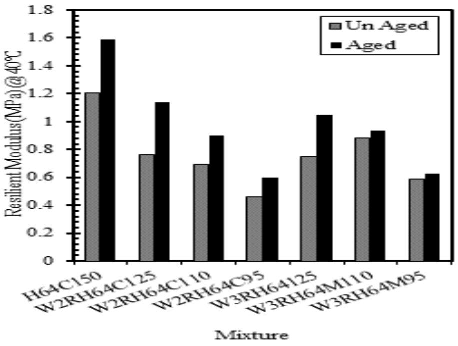
The relationship between resilient modulus and RH-WMA content for un-aged and aged asphalt mixtures at different compaction and test temperatures are shown in Fig. 4. Results show that compaction temperature, RH-WMA content, and test temperature affect the resilient modulus of asphalt samples. Since higher compaction temperatures have a stiffening effect on the asphalt binder rheology, the resilient modulus of samples fabricated at higher compaction temperatures is greater than those fabricated at lower compaction temperatures. Also, the resilient modulus of samples increases due to aging but reduces when the test temperature increases. Generally, the resilient modulus of WMA samples is lower than the corresponding values of HMA.



(a)



(b)



(c)

Fig. 4: Resilient modulus results tested at (a)10°C, (b) at 25°C, (c) at 40°C

ITS test results of un-aged and aged asphalt mixtures are presented in Fig. 5. It can be observed from the figure that HMA mixture has a higher value of ITS than WMA mixture at test temperature of 15℃.

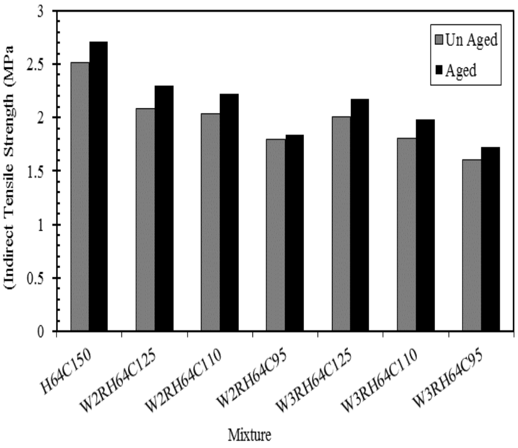
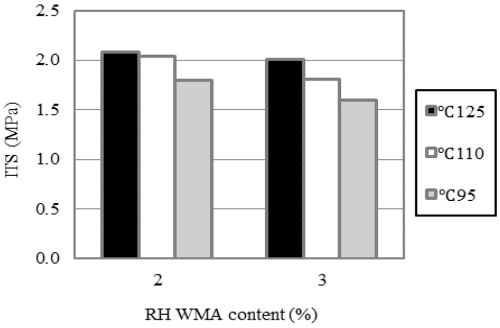
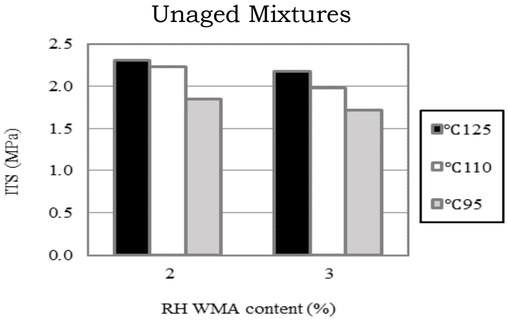


Fig. 5: Indirect Tensile Strength at 15°C

The influence of RH-WMA content, compaction temperature and aging condition on the ITS are presented in Fig. 6. The results show that there is an insignificant difference in the ITS of WMA samples prepared by employing different RH-WMA content and compacted. The RH-WMA content had limited impact on the ITS of un-aged and aged samples. On the other hand, the ITS of WMA increases with mixing temperatures, regardless of RH-WMA content and aging condition. This is because higher mixing temperatures lead to more aging and stiffen the binder. In addition, the density of the mixture increases as the mixing temperature increases. It also shows that ITS decreases as RH-WMA content increases irrespective of mixing temperature. For all mixtures, the aging of HMA and WMA increases the ITS of the asphalt mixtures.



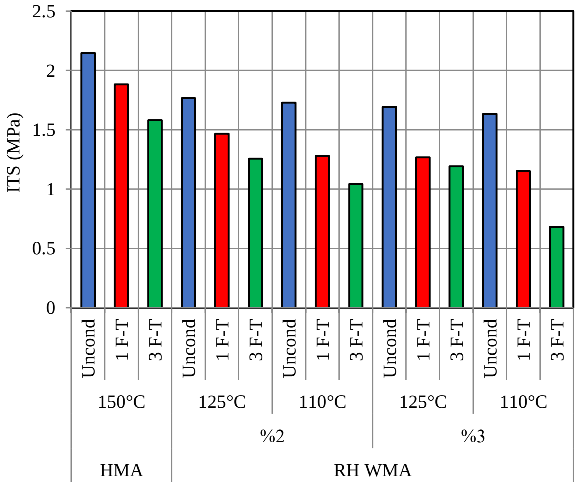

Unaged Mixtures

Aged Mixtures

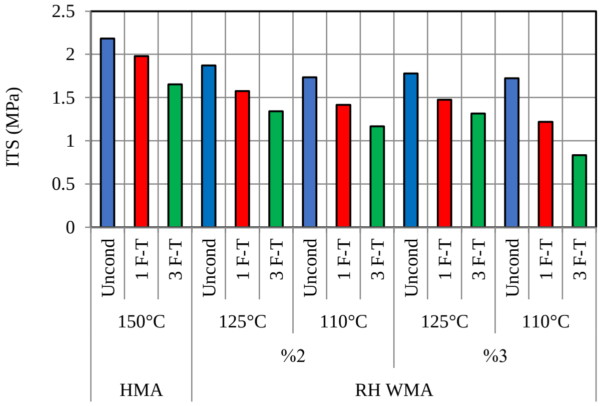
Fig. 6: Relationship between ITS and RH-WMA content for unaged and aged mixtures

Indirect tensile strength (ITS) of asphalt mixtures indicates their overall strength and their resistance to cracking. ITS results of samples at different moisture conditioning are shown in Fig. 7. From the figures, HMA has higher dry and wet ITS than WMA regardless of RH-WMA content and aging condition.

The ITS of WMA compacted at 125°C was comparable to those of HMA (150°C) these ITS of HMAs were higher than the ITS of WMA mixtures compacted at 110°C. This finding indicates that reducing the production temperature of WMA may lead to an increased tendency toward moisture sensitivity. This condition can be partly attributed to the reduced asphalt binder aging. Similar results were obtained for dry and wet ITS. However, a trend is evident in the effect of temperature reduction. In addition, comparing the ITS results shows that as compaction temperature decreases, the ITS value decreases for both specimens containing 2% and 3%. However, low compaction temperature causes high binder viscosity and results in inadequate compaction [31].



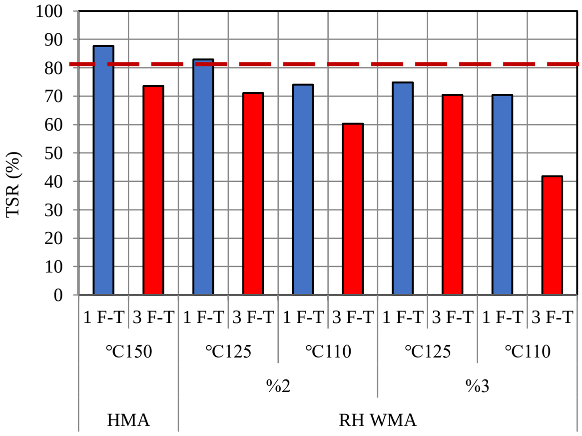
(a) Unaged asphalt mixtures



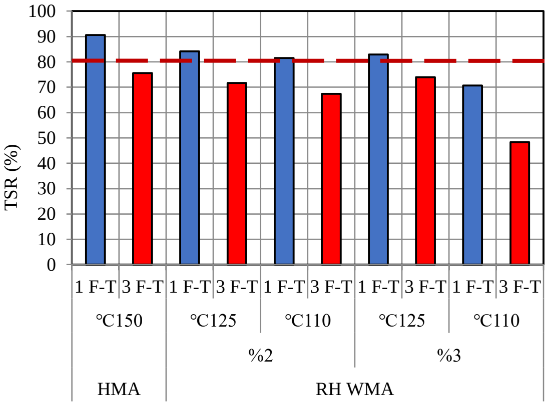
(b) Aged asphalt mixtures

Fig. 7: ITS at different moisture conditioning

Tensile strength ratio (TSR) is commonly used as one of the indicators of moisture damage potential for asphalt mixtures. TSR of unaged and aged HMA and WMA conditioned by one and three cycles of freeze-thaw are presented in Fig. 8. From the figures, the TSR of aged samples is higher than that of unaged samples. It means that selected laboratory aging conditions could not accelerate moisture damage of samples. For instance, the TSR of aged WMA compacted at 125°C containing 3% of additive after one cycle of freeze-thaw is higher than 80%, while the corresponding value for unaged samples is lower than 80%. As expected, the effects of three freeze-thaw for reducing TSR is higher than that of one freeze-thaw. This is because of severe moisture damage in three cycles of freeze-thaw as compared to one cycle of freeze-thaw. The TSR of HMA is higher than that of WMA. It means that lower compaction temperatures increase the potential for moisture damage. In most cases, 3% of additive showed lower TSR as compared to 2% additive regardless of compaction temperature and number of moisture conditioning.



(a) Unaged asphalt mixtures



(b) Aged asphalt mixtures

Fig. 8: TSR at conditioned by one and three cycles of freeze-thaw

Conclusions

The research work investigated the mechanical and volumetric properties of WMA, in order to evaluate its potential and limits as compared to traditional HMA. The investigation was conducted by analyzing HMA and two WMA's made with two contents of RH-WMA additive. Based on the findings of the experimental test results, the following conclusions were drawn:

HMA mixtures significantly had higher dry and wet ITS than other mixtures. The test results revealed that reducing the production temperature of WMA may result in increased susceptibility to moisture-induced damage, whereas increasing the wax additive content (2, 3% of the weight of the asphalt binder) negatively affects WMA performance.

The test results indicated that long-term aging improved the moisture resistance of WMA mixtures regardless of WMA additives. The decrease in compaction temperature significantly reduced the ITS.

With respect to water sensitivity results, the addition of a higher amount of synthetic wax did not increase the potential for moisture damage. Moreover, lower mixing temperatures resulted in a decrease in the tensile strength ratio of the mixtures.

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