WATER SUSCEPTIBILITY BEHAVIOUR OF THE ASPHALTIC CONCRETE (AC) MIXTURE CONTAINING RECYCLED POLYETHYLENE PLASTICS PACKAGING WASTE AGGREGATE REPLACEMENT (AC-PLASTIPHALT)

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ABSTRACT

Laboratory investigations at Civil Engineering Material Unit (CEMU) the University of Leeds, UK have shown that recycled plastics composed predominantly of Polypropylene can be incorporated in conventional Asphaltic Concrete (AC) road surfacing mixtures. In the correct proportions, a definite improvement in stiffness and strength of the resultant AC composites, referred to as (AC-Plastiphalt), have been demonstrated. The mixing and compaction temperatures need to be carefully controlled to cater for the differing softening points of the two plastic types.

This paper presents the mix design and the durability behaviour results of the AC-Plastiphalt mixes, especially on the water susceptibility behaviour. The results show that the AC-Plastiphalt mixes have higher strength than the control mixes at optimum bitumen content. In terms of water susceptibility behaviour, the results indicate that the AC-Plastiphalt mixes have excellent resistance to water damage.

INTRODUCTION

Reuse of bulk wastes is considered the best environmental alternative for solving the problem of disposal. The large volume of composite materials required for the construction and maintenance of road pavements is potentially a major area for the reuse of waste materials. Because the amount of "new" materials like mineral aggregates required in the road construction industry is large, approximately 20,000 tonnes per mile of motorway constructed, the environmental benefits are not only related to the safe disposal of bulk waste but also to the reduction of environmental impacts arising from the extraction of aggregates which include the loss of mature countryside, visual intrusion, heavy lorry traffic on unsuitable roads, noise, dust and blasting vibration.

Plastics Demand and Waste - Plastics are increasingly becoming the materials chosen to develop new solutions and innovative products. This is because of their combination of light weight, strength and rigidity; versatility, durability and cost-effectiveness. In 1998, the plastics consumption in the UK was about 3,647,000 tonnes

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(30,381,000 tonnes across Western Europe). The major use of plastics is in packaging about 41%; 19% in building and construction; 8% in electrical and electronic, 7% in automotive, 4% in large industry, 3% in agriculture and 18% in other household/domestic (APME, 2000). However, despite the huge plastics consumption across all industry sectors, plastics only account for 0.6% of total waste by mass.

Plastic recovery - Recovered plastics might be recycled into new products or used in process engineered fuels, where collected plastics are processed with paper into fuel pellets and then used in conjunction with coal and other fuels in industrial boilers and utility plants. About 30% of the 17.6 million tonnes of all post-use plastics were recovered in Western Europe in 1998 (APME, 2000). Plastic recycling has reached 9.2%, whilst 18.2% was recovered for energy providing heat and electricity for homes and business. In 1998, recycling plastics waste from the distribution and industry sector in Western Europe remained at 22.4% and from municipal solid waste the figure was 64.7%.

The above paragraphs demonstrate the immense scope still available for plastic waste recovery and encapsulation. Bituminous road surfacings offer an ideal opportunity for utilisation of large volumes of waste plastics into a Civil Engineering structure with the possibility of enhancing the strength and life of these modified roadlayers.

This paper presents a laboratory design methodology and durability results especially in water damage susceptibility of plastic modified bituminous mixes. The mix was a continuously graded bituminous composite (Asphaltic Concrete) contained recycled plastics aggregate replacement (**AC-Plastiphalt**). The test results of plastic modified mix was compared with a control mix having a very similar gradation manufactured with conventional mineral aggregates.

DURABILITY OF PAVING MIXTURES

In terms of its application to bituminous paving materials, durability can be defined as the ability of the materials in the asphalt pavement structure to withstand the effects of environmental conditions, such as water, ageing and temperature variations without any significant deterioration for an extended period for a given amount of traffic loading (Scholtz and Brown, 1996). Durability of bituminous mixtures must be taken into account, as the costs of maintenance and rehabilitation of pavement structures that do not endure their design life can be substantial.

a. Factors affecting durability of pavement mixtures

Many factors affect the durability of bituminous mixtures for instance the composition of the bitumen, the type and grading of the aggregate, the interaction between aggregate and bitumen, bitumen content, mixture permeability, construction practices and climate. By assuming that bituminous pavement layer is constructed perfectly according to specifications, then based on the above definition, three major factors will affect the durability of bituminous paving mixtures, i.e. water, ageing and agreed that damage due to water

(moisture damage) and age hardening are the major factors affecting the embrittlement of bitumen.

Two mechanisms by which water can damage the structural integrity of the bitumen-aggregate interface, firstly water can cause loss of cohesion (strength) and stiffness of the bitumen; and secondly, water attacks the adhesive bond between the bitumen and the aggregate in the mixture (stripping). These two water damage mechanisms result in decreasing the strength of pavement layer (Scholtz and Brown, 1996). The detachment of bitumen off the aggregate (or stripping) is in conjunction with mixtures which are permeable to water. The less the air voids content in a compacted mixture the less risk of stripping (Whiteoak, 1991).

Age hardening of the bitumen also affects the durability of the bitumen-aggregate matrix. This behaviour, however, is not presented in this paper.

b. Moisture damage to bituminous paving mixtures

The methods of predicting and controlling moisture damage in bituminous mixtures have been studied by Lottman *et al* (1987). The evaluation of moisture damage in bituminous mixtures was based on the ratio of the mechanical properties of wet conditioned to the values of unconditioned specimens. This ratio is inversely proportional to the moisture sensitivity of bituminous mixtures, the lower the ratio the higher the sensitivity. A range of tests were carried out in this investigation including indirect tensile strength tests, resilient modulus tests, fatigue cracking and wheel tracking tests. The ratios of the values measured were then analysed to develop a method of predicting and controlling moisture damage in bituminous mixtures. Moisture damage models in pavements were also evaluated in this study.

Fwa and Oh (1995) studied the effect of moisture conditioning procedure on the properties of bituminous mixtures. Dense graded bituminous mixtures were manufactured with target air voids content of 3 to 5 percent. The two types of moisture treatments applied in this study were a cyclic wetting-drying treatment and a water immersion treatment. The wetting-drying treatment was conducted by spraying the specimens with tap water at 28°C and then drying using ceramic heaters at 60 °C. A 4-hour treatment cycle consisting 2 hours of wetting followed by 2 hours drying. In total 150 wetting cycles were performed. The water immersion treatment was carried out by immersing compacted specimens in water at 28°C for 24 hours.

Two mechanical properties were evaluated in this study i.e. resilient modulus (M_R) and indirect tensile strength (T_S). The evaluation based on the percentage retained values of M_R and T_S. This value was defined as a ratio of the value at a zero moisture content to level i moisture content.

The results found in this investigation indicated that the continuous 24-hour water immersion was more effective in introducing water into compacted bituminous mixtures compared to the repeated wetting-drying treatment method.

It was also found that different processes of introducing water into compacted specimens could have different effects on the measured properties of the mixtures. Introducing water into a specimen by the wetting and drying method resulted in lower measured values of M_R and T_S compared to the initial value of zero moisture. On the other hand, introducing moisture by water immersion resulted in higher values of M_R and T_S compared to the initial value at zero moisture.

Introducing water into a specimen by the wetting and drying technique resulted in increasing the values of M_R and T_S as the moisture content decreased. On the other hand, introducing moisture by water immersion resulted in decreasing these values as the moisture content decreased.

MATERIALS USED AND SPECIMEN MANUFACTURE

Figure 1 shows the aggregate gradation of the control and Plastiphalt dense graded Asphaltic Concrete (A.C.) mixtures. The A.C. gradation was developed at Leeds (Zoorob *et al*, 1999) using maximum aggregate packing principles and is specifically designed to withstand combinations of heavy traffic stresses at elevated temperatures.

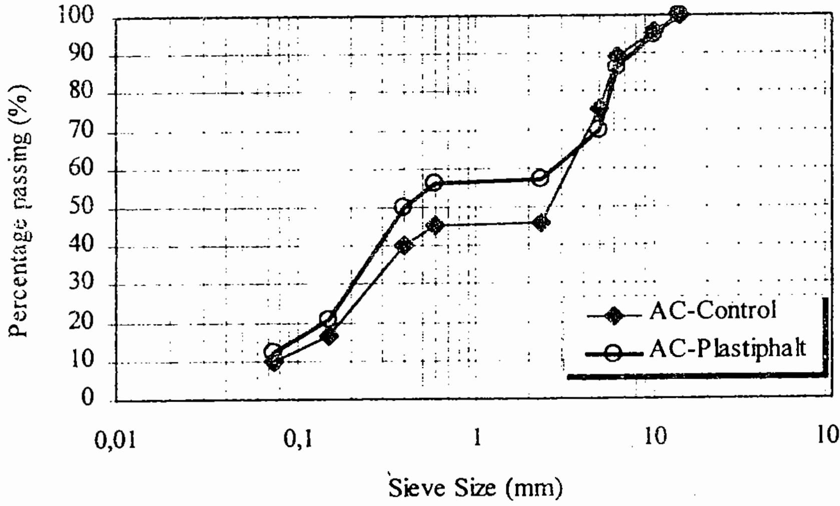

Figure 1 - Aggregate gradations used in this investigation

The plastic pellets, used in the AC-Plastiphalt mix were predominantly composed of low density polyethylene (LDPE) of single size (5.0-2.36 mm). Table 1 shows the characteristics of the bitumens and waste LDPE plastic pellets used in this investigation.

It was decided in this investigation to replace by volume the mineral aggregate fraction having the same size as the plastic granules in the original A.C mixes with LDPE pellets. The aggregate gradation of the resultant Plastiphalt mixes was therefore very similar in terms of volumetric proportions to the original control mixes.

Based on the selected gradings and the size of the waste plastic granules; a maximum of 29.7% by volume of the total AC-control mix was replaced with waste LDPE plastics to create the AC-Plastiphalt mixes.

Table 1. Characteristics of the bitumens and waste LDPE plastics used in the investigation

Test description	Bitumen types		Waste LDPE plastic pellets
	50-pen	100-pen	
1. Penetration at 25 °C (dmm)	54	98	---
2. Specific gravity	1.03	1.02	0.92
3. Softening point (°C)	48.5	45	120
4. Melting point (°C)	---	---	140

The Leeds Design Method (Cabrera, 1996) was then used to obtain the optimum bitumen content (o.b.c.) of the design mixture. At o.b.c, further investigations and tests were carried out to fully characterise the properties of the design mixture. The mixing and compaction temperatures need to be carefully controlled to cater for the differing softening points of the two plastic types.

For the A.C control mixes, the combined aggregates and bitumen were mixed in a thermostatically controlled preheated twin paddle mixer at a mixing temperature of 150 °C which resembles the optimum bitumen viscosity of 0.2 Pa.s. On the other hand, a compromise between the optimum bitumen viscosity and the softening and melting points of the waste plastics had to be considered for the Plastiphalt mixes. It is recognised that for optimal compaction the viscosity of the bitumen should lie between 2 and 20 Pa.s (Whiteoak, 1991). Compaction of all specimens was carried out using a gyratory compactor (Gyropac) at 125 °C for the AC-Plastiphalt. The energy of compaction applied with the Gyropac was set at 240 kPa vertical pressure. The number of compactive revolutions for the AC-Plastiphalt was 120 gyrations corresponding to heavy compactive efforts at a fixed angle of gyration of 2°.

The o.b.c for both mixtures was determined using the Leeds Design Method (LDM). The LDM recommends that the o.b.c for dense graded mixtures should be obtained as the arithmetic mean of the o.b.c at maximum compacted mix density, minimum voids in the mineral aggregate (VMA), and maximum stability. The Marshall quotient (MQ) (kN/mm) values are defined as the ratio of Marshall stability (kN) to flow (mm). The o.b.c for the AC-Control mix was calculated at 5.0% which agrees with previous investigations (Zoorob *et al*, 1999), whilst the o.b.c for AC-Plastiphalt mix was determined at 6.0% (Zoorob and Suparma, 2000).

LABORATORY TESTS FOR WATER SUSCEPTIBILITY

In this paper presents two types of laboratory test for water susceptibility of compacted bituminous mixture. These two methods referred to as:

1. Resistance to stripping, and
2. Effects of long term immersion on stiffness

The testing procedures of these two methods are described as follows.

Testing procedure resistance to stripping

Detachment of bitumen off the aggregate (or stripping) is associated with mixtures which are susceptible to long term moisture damage. There is little risk of stripping in low void content dense asphalts or macadams. In materials that are permeable to water, even those that are relatively dense, there is a risk of stripping, resulting in a loss of internal cohesion and possibly disintegration of the surfacing. The potential for stripping is a function of the affinity between the aggregate and the bitumen and its consequent ability to resist the displacing effect of water.

The most common types of laboratory testing procedures applied are the immersion mechanical tests. These involve measurement of a change in a mechanical property of a compacted bituminous mixture after immersion in water. The ratio of the property after immersion divided by the initial property is thus taken as an indirect measure of stripping.

The test method selected for this investigation is based on AASHTO T165-77 or ASTM D4867 (1996). The method consists of initially subjecting compacted bituminous specimens to immersion in water at 60 °C for 24 hours. In accordance with the specifications, the specimens are subsequently tested for Marshall stability. In this study in addition to conducting the Marshall test at a predetermined flow (deformation) value, conditioned specimens were also tested for the indirect tensile stiffness modulus (ITSM), indirect tensile strength (ITS) and dynamic creep tests. The ITSM and ITS tests were performed at 20, 40 and 60 °C. Dynamic creep testing was only carried out at 60 °C. It was assumed that when a plastic modified sample performed better than the control mixture at 60°C which is quite a severe temperature, there would be no need to reconfirm the creep behaviour at 40°C.

The ratio of each tested property of the bituminous specimens after water conditioning at 60°C to identical specimens not subjected to the conditioning process is known as the retained value and is usually quoted as a percentage. The retained value can be calculated using the following equation.

$$\Delta s = \left(\frac{s_{24h}}{s_0}\right) \times 100$$

where: Δs = retained value (%), s_{24h} = average test value of specimen cured for 24 hours, s_0 = average test value of specimen without conditioning

Testing procedure of the effects of long term immersion on stiffness

At this stage, the bituminous specimens were subjected to long term immersion to investigate the effect of moisture on the stiffness characteristics. The testing procedures are as follows:

1) In the first stage, the indirect tensile stiffness modulus (ITSM) of all dry (unconditioned) specimens was measured.
2) At the second stage the compacted specimens are placed in a dessicator and vacuumed at approximately 50 mbar for one hour. At the end of the period, water was allowed to enter the dessicator and fully immerse the specimens. Vacuuming was maintained for a further one hour to allow the water to penetrate the majority of the accessible air voids in the specimens.
3) Vacuuming was removed and the specimens were left immersed in water at room temperature for an extended period of time.
4) At various time intervals, immersed specimens were removed for ITSM testing. The periods of water immersion applied in this investigation were 2, 4, 6, 8, 10, 12, 16 and 20 weeks.
5) The results are typically reported in terms of percentage retained stiffness. Retained stiffness is calculated as the ratio between stiffness values after conditioning in water to stiffness values before immersion conditioning.

RESULTS AND DISCUSSIONS

Resistance to stripping

1) AC-Control

The effects of moisture conditioning at 60°C for 24 hours on the mechanical properties of the AC-Control mixture was only observed on the Marshall stability value. The results measured indicated the loss of stability values in the range of 15% (Alawi, 2000).

2) AC-Plastiphalt

Table 2 presents the test results of the effects of moisture conditioning at 60°C for 24 hours on the mechanical behaviour of the AC-Plastiphalt mixture.

The results shown in Table 9.1 indicate that the AC-Plastiphalt mixture retained 100% of its pre-conditioned stability values. In comparison, the retained stability of the control mixture (AC-Control) after immersion was only 85% (Zoorob *et. al.*, 1999).

The dynamic creep stiffness values and the slopes of creep curves of the moisture conditioned AC-Plastiphalt mixtures show improved creep performance. The creep stiffness value nearly doubles and indicates that water does not affect the AC-Plastiphalt mixture. In terms of creep recovery, there was no indication that the elastic rebound values recorded at the end of the creep test were in anyway affected.

The indirect tensile stiffness modulus (ITSM) and static indirect tensile strength (ITS) values of the moisture conditioned AC-Plastiphalt specimens were found to be at least as good as the unconditioned samples.

In ASTM D4867-96, the degree of moisture sensitivity is expressed by the tensile strength ratio TSR as determined using the indirect tensile test at room temperature and according to this standard the acceptable TSR value is 80%. The results presented in Table 2 indicate that the TSR value of AC-Plastiphalt mixture was in excess of 90% at all test temperatures, and according to the American Standard

Table 2. Water conditioned characteristic values of AC-Plastiphalt mixtures

Properties	AC-Control mixture (Unconditioned)	AC-Plastiphalt mixtures		
		Unconditioned (original)	60°C, 24h water conditioned	Retained value (%)
1. Marshall Stability (kN)	16.9	37.3	39.5	> 100
2. Marshall quotient/MQ (kN/mm)	4.6	5.1	5.2	> 100
3. Creep properties at 60 °C:				
a. Creep stiffness (MPa)	8.32	6.55	13.43	> 100
b. Slope of creep line	1.49	0.49	0.21	(better)
c. % creep recovery after 1 hr unloading at	0.57	12	13	> 100
4. ITSM (MPa) at:				
a. 20°C	5683	2815	3232	> 100
b. 40°C	865	770	996	> 100
c. 60°C	283	235	230	98
5. Static ITS (kPa) at:				
a. 20°C	1250	1508	1462	97
b. 40°C	460	706	671	95
c. 60°C	175	318	321	> 100

Mechanical properties of moisture conditioned specimens at 60°C for 24 hours indicate that the water conditioned specimens of AC-Plastiphalt mixtures perform better than the unconditioned and the control mixture in terms of its resistance to stripping.

Effects of long term immersion on stiffness

Table 3 presents the ITSM values of all the bituminous mixtures investigated after water immersion at various time intervals. The retained stiffness values are also expressed in Table 3. The effect of moisture on the stiffness of the mixtures can be described as follows:

1) With the exception of AC-Plastiphalt mixture, the effect of prolonged exposure to water on the AC-Control mixture was to cause a gradual reduction in the indirect tensile stiffness values of these mixtures.
2) In the case of the AC-Plastiphalt mixture, the retained stiffness values increased with increasing immersion time up to a peak value, beyond which the ITSM values began to gradually decrease. After 20 weeks immersion, the ITSM value remained in excess of 100% of the unconditioned value. The water did not adversely affect the strength of the AC-Plastiphalt mixture. It is not clear why the ITSM values on a bituminous composite should increase with time of immersion, the AC-Plastiphalt mixture became unaffected by water.
3) Table 4 shows the volumetric properties of the specimens used in the moisture damage investigation. It can be seen that, the porosity of the mixture strongly affected the mixture degradation process caused by moisture. The porosity of AC

4) Porosity is accepted as a major factor influencing the resistance to moisture ingress and hence damages. In such cases, increased compactive effort would be an obvious solution to improve performance. Table 5 shows results from an earlier work on a very similar AC-Control mix subjected to the same conditioning procedure as in this investigation (Alawi, 2000). The results demonstrate the effects of increasing compactive effort on reducing moisture susceptibility of the AC-Control mixture. It is very clear that the higher the compactive effort, the higher the ITSM values of the mixture. After 6 weeks water immersion at room temperature, increasing the initial compactive effort results in reducing the percentage loss of ITSM value by 5%.

Table 3. ITSM values of all bituminous mixtures investigated after water conditioning at various time intervals

Immersion time (weeks)	ITSM values (MPa)		Retained ITSM values (%)	
	AC-Control	AC-Plastiphalt	AC-Control	AC-Plastiphalt
0	6437	2974	100	100
2	5510	3429	86	115
4	5427	3694	84	124
6	5099	3934	79	132
8	5029	4049	78	136
10	4832	3989	75	134
12	4792	3970	74	134
16	4658	3973	72	134
20	4570	4004	71	135

Table 4. Volumetric properties of specimens

Properties	Bituminous mixture type	
	AC-Control	AC-Plastiphalt
1. Mixture density (g/cm^3)	2.53	2.03
2. Porosity (%)	6.50	3.30
3. VMA (%)	13.6	14.8

Table 5. Effect of level of compactive effort on the moisture susceptibility of AC-Control mixture

Immersion time (weeks)	AC-Control mixture			
	Medium level compaction effort GTM at 2°, 80 revolutions, 240 kPa, porosity = 9.5% (Alawi, 2000)		High level compaction effort, GTM at 2°, 120 revolutions, 240 kPa, porosity = 6.5%	
	ITSM value	% loss	ITSM value	% loss
0	5057	0	6437	0
2	4263	16	5510	14

CONCLUSIONS

1. Mechanical properties of moisture conditioned specimens at 60°C for 24 hours indicated that the water conditioned AC-Plastiphalt specimens perform even better than the unconditioned control mixture in terms of its resistance to stripping. However, this phenomenon was not observed in the HRA-Plastiphalt mixtures which was mainly due to the higher porosities of the HRA-Plastiphalt mixes compared to the HRA-Control.
2. With the exception of AC-Plastiphalt mixture, the effects of prolonged exposure (20 weeks) to water on the AC-Control, HRA-Control and HRA-Plastiphalt mixtures was to cause a gradual reduction in the indirect tensile stiffness values of these mixtures. In the case of the AC-Plastiphalt mixture, the retained stiffness values increased with increasing immersion time up to a peak value, beyond which the ITSM values began to gradually decrease.

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