The Influence of Moisture on the Performance of Polymer Fibre-Reinforced Asphalt Mixture

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Abstract. A number of researches have been done worldwide to evaluate the damage caused by water in bituminous pavements. The use of the retained strength ratios obtained from laboratory moisture damage tests is a useful tool in making quantitative predictions of the related damage caused by water. This study involved laboratory work on the effect of water on the performance of bituminous mixtures. Comparisons are made between the performances of Hot-rolled Asphalt (HRA) bituminous mixtures containing base bitumen of 50pen grade to that of a polymer-fibre reinforced HRA mixture. Two types of polymer fibre were studied, namely polypropylene and polyester and these fibre were added in different concentrations in the bituminous mixtures. Changes in both the cohesive properties of the bitumen and the adhesion of the bitumen to the aggregate surface were observed as a result of exposing the bituminous mixtures to moisture. The effect of polymer fibre reinforcement in bituminous mixtures helps reduce the level of moisture damage. This was evident in the lower moisture susceptibility achieved in the polymer fibre reinforced bituminous mixtures as compared to the control mixture. The additional bitumen in the fibre reinforced mixtures also afforded an increased film thickness on the aggregate particles, thus affording additional protection of the mixtures from moisture. The reinforcement of polymer fibres in bituminous mixtures also acts to decrease the moisture sensitivity of the bitumen to aggregate bonding. This may be due to the strengthening of the wetted binder matrix that helps promote both adhesion and cohesion retention.

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1 Introduction

The damaging effects of moisture on the physical properties and mechanical behaviour of bituminous mixtures have been the focus of study for many years. Many laboratory tests have been developed in order to evaluate and quantify the amount of damage that is caused by water on bituminous mixtures. The most widely used laboratory methods in conducting these tests appear to be the immersion-mechanical tests which measure the changes in mechanical properties of the bituminous specimens after exposure to moisture. Typically the results are reported in terms of percentage retained strength of the specimens. This paper is based on some laboratory work and addresses the damaging effect of moisture in polymer fibre-reinforced bituminous mixtures [1].

2 Stripping in bituminous mixtures

The unfilled void spaces in compacted bituminous mixtures are also able to hold sufficient quantities of water that can cause distress and damage and reduce mix performance. The volume of these voids is a variable dependent on the nature of the voids, characteristics of the mix and the degree to which they are compacted in the pavement [2]. The damaging effect of water will give rise to stripping or de-bonding of the bitumen from the aggregate surface. This is brought about by the loss of cohesion and softening of the binder due to the action of the moisture within the bitumen or bituminous mix. Both stripping and softening can occur in the same mix [3]. Stripping is the physical separation of the bitumen and aggregate produced by the loss of adhesion between the bitumen and the aggregate surface primarily due to the action of water or water vapour [4]. It is an aggregate interfacial phenomenon and induces the loss of stability in the bituminous mix that in turn promotes failure [1, 5]. The phenomenon can be further aggravated by the presence of aggregate surface coatings and by aggregates with a smooth texture surface. Stripping is primarily an aggregate problem, but that the type of bitumen used is also important [6]. Softening is the general loss of stability of a mixture that is brought about by a reduction in cohesion within the bituminous mix matrix due to the action of moisture. The resulting damage brought about by water can be assessed quantitatively by mechanical tests in which such properties as loss of tensile strength or decrease of resilient and stiffness moduli have been measured. Moisture induced damage is usually easy to identify when stripping is evident. Where a loss of pavement stiffness or moduli occurs without the visual evidence of stripping, the cause of the problem is less easily recognised [7].

There are a number of laboratory methods and tests that are cited in the literatures that enable the determination of the moisture susceptibility and thus the proneness of bituminous mixtures to stripping or de-bonding. Based on previous work [8], it appears that vacuum saturation of specimens followed by conditioning and testing using the Indirect Tensile test show promise for introducing moisture into the specimens and measuring their strength to predict the moisture susceptibility of the mixtures. Specimens were moisture conditioned before the determination of their structural strengths as those mixtures most susceptible to moisture damage would have the lowest structural strengths following conditions [9]. The retained strength is determined by comparing the dry tensile strength to the wet conditioned tensile strength of the bituminous mixtures.

2 Materials used in the investigation mineral aggregates, filler and bitumen

Limestone aggregates and Ordinary Portland cement (OPC) filler and a binder of nominal penetration Grade 50 were used in this study. Some relevant properties of the material used are shown in Table 1.

Table 1. Properties of the mineral aggregate, filler and bitumen used in the investigation.

Material	Percentage by Weight (%)	Relative Density
Coarse Aggregate	35	2.75
Sand	55	2.65
Filler (Ordinary Portland Cement)	10	3.15
	Penetration (0.1 mm)	Softening Point (ºC)
Bitumen	52	48.5

3 Synthetic fibres

Two types of synthetic fibres polypropylene and polyester were used in this study. The fibres were used as a partial replacement of the filler; on an equal volume basis; at two concentrations of 0.5 % and 1 % by weight of the mix. The chopped fibres were the by-products of the textile industry and thus their potential use was desirable on environmental grounds [10].

Table 2. Characteristics of fibres used in the study.

	Specific Gravity	Denier	Length (mm)	Average Diameter (μm)	Degradation Temperature (ºC)
Polypropylene	0.91	6	6	22*	160
Polyester (POL)	1.41	3	6	17*	250

*Values obtained from 20 readings using a light microscope at 400X magnifications.

Some characteristics of the fibres used are shown in Table 2. In order to maintain thermal stability when using the polypropylene fibres, it was decided that the mixing temperature when preparing the Hot Rolled Asphalt (HRA) mixture will not exceed 140ºC and compaction be done at 130ºC.

4 Degree of saturation

The degree of saturation gives a measure of the amount of water that is absorbed by the specimen into its permeable voids. The degree of saturation is thus defined as the ratio of the volume of water in the wet specimen to the total volume of voids in the specimen. The creation of a degree of saturation in the laboratory high enough without damaging the specimens and that the retained strength can be determined involves a moisture conditioning process. Static soaking seems to provide ideal conditions for stripping to occur while both pressure and vacuum saturation procedures may create damage to the specimens. For practical laboratory purposes, static soaking may require too much time. Saturation by partial vacuuming for a short period of time has therefore been used in moisture damage studies on bituminous mixes. If the volume of absorbed water exceeds the volume of voids, the specimen has been supersaturated and damage and should be discarded. A number of researchers have come up with various regimes for vacuuming and saturating the bituminous specimens. The specimens to hot water immersion (at 60°C) for up to 14 days and testing the specimens at different immersion period to determine the retained strength of the specimens.

Table 3. Concrete strain change with temperature.

Temperature (^oC)	Concrete strain (m/m) x 10^{-6}
10	1.0
20	1.6
40	3.2

5 Void structure in bituminous mixtures

The moisture conditioning process attempts to allow water to penetrate and occupy the air voids in the specimen. An appreciation of the void structure in bituminous mixtures is thus very vital. A study to examine the influence of asphalt film thickness, voids and permeability on asphalt hardening in asphalt mixtures and come up with a hypothetical model of the air voids system in a compacted bituminous mixture [11, 12]. Different water saturation techniques were employed in their study that included a 24 hours soaking and vacuuming at different absolute pressures. The model divides the air voids system into three categories; through passage accessible air voids, dead end accessible air voids and non-accessible air voids. The 24 hours soaking allows water to only occupy the through passage accessible voids. The 24 hours soaking and hand pumping allowed the water to occupy the through passage accessible voids as well as a small portion of the dead end accessible voids. Vacuuming with an absolute pressure of 2.5 cm mercury allowed the water to occupy the through passage accessible voids and most of the dead end accessible voids [13].

6 Experimental procedures

As the water susceptibility of the mixes was to be determined, the specimens were tested in both the dry and wet condition. The dry conditioning involves curing the specimens at room temperature for two days prior to testing. The wet conditioning involved subjecting the bituminous samples to a combination of air vacuum, vacuum saturation and static soaking. Air vacuuming is to evacuate all the accessible pores from air and water. The objective of vacuum saturating the specimens was designed to accelerate the moisture damage process. It is extremely important that the process of vacuum saturating the specimens do not result in a degree of saturation greater than 100 %, which is indicative that more water was introduced into the voids than there are void spaces, making comparison between samples no longer valid. Fig. 2 is a schematic diagram of the vacuum saturation apparatus. In this study, the specimens were placed in a thick-walled desiccator jar. Valves (W) and (A) are closed and valve (V) which led to the vacuum pump is opened. The air vacuuming process takes about half an hour to drive out all the air trapped in the accessible voids. Distilled water was then used to fill the jar to about 2 cm above the specimens and about 3 cm below the top rim of the jar. This was followed by a 1-hour vacuum saturation period at 1 atmospheric pressure, which was considered a pre-treatment of moisture condition and a means of water-saturating the specimens, during which time the jar surfaces was gently agitated. After one hour of vacuuming, the vacuum was removed and the inside of the jar was allowed to reach ambient atmospheric pressure and the specimens undergoing static soaking for a period of 24 hours for the purpose of achieving a constant weight of the specimens (fully saturated condition).

Fig. 3 shows the relationship between the degree of saturation and bitumen content for the control Hot-Rolled Asphalt (HRA) mix in comparison with the fibre modified mixes. The general trend is in the degree of saturation to decrease with increasing bitumen content. The addition of fibres appears to bring about an increase in the degree of saturation, this increase being more pronounced at the higher fibre concentration. This may be the result of the higher porosity that is associated with the higher fibre content mixes. The polypropylene mixes appear to exhibit better result than the polyester fibre mixes. For all the mixes, the saturation lines obtained appear parallel to one another with a somewhat similar slope. This is indicative that the degree of saturation in all the mixes decreases consistently with increasing bitumen content.

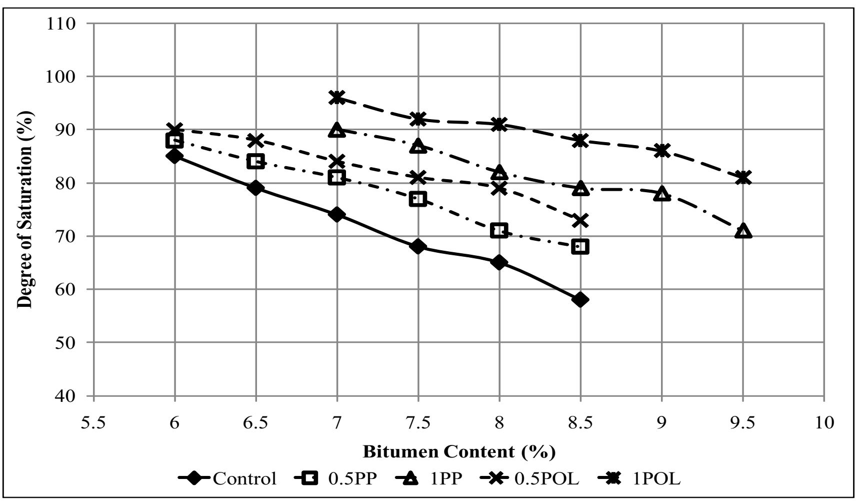

Fig. 3. Degree of Saturation vs. Bitumen Content.

Fig. 4 and Fig. 5 show the variation between the calculated and measured porosity between the control and the polypropylene fibre modified mixes and the polyester fibre modified mixes respectively. The calculated porosity gives a measure of all the voids in the specimens that include both the accessible and non-accessible voids while the measured porosity as was obtained from the moisture conditioning process determined only the accessible voids. The calculated porosity therefore is always greater than the measured porosity as shown in the figure. The general trend is the porosity decreases with increasing bitumen content. The result of adding fibres to the HRA mix resulted in higher porosity in the resulting mix. The relationship between the measured and calculated porosity is plotted graphically in Fig. 6 resulting in a linear relationship between the two. The point of intercept of the lines with the calculated porosity axis gives an indication of the percentage of non-accessible or unconnected pores in the respective mixes. The addition of fibres appears to reduce the percentage of non-accessible pores in the mix, this reduction was seen to be more pronounced in mixes with greater fibre content. A general trend shown from the figure suggests that increasing the bitumen content resulted in an increase in the unconnected voids as the bitumen fills up the void space or continuous channels in the specimen. Subsequently, this reduces the connectivity of the voids. The presence of the fibres also suggests an increase in the connectivity of the voids as the porous nature of the fibres gave a continuous channel (path) of void space. It must also remember that the control mix gave lower porosity than the fibre incorporated mixes, thus justifying its behaviour as in Fig. 6.

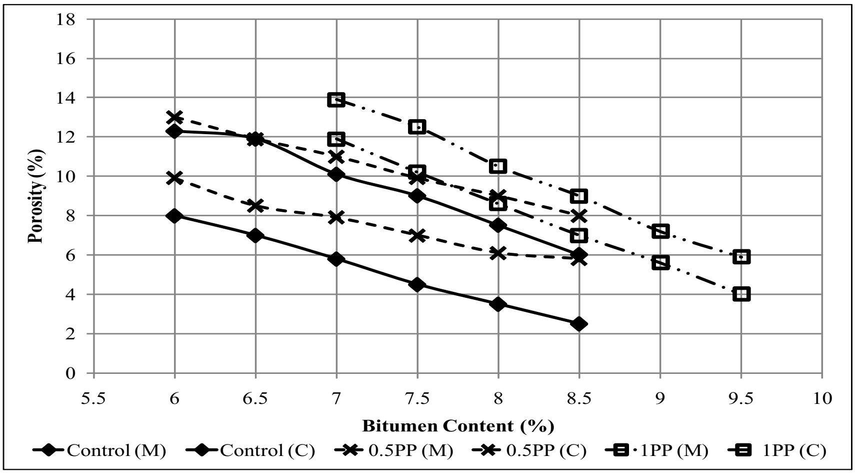

Fig. 4. Calculated and Measured Porosity vs. Bitumen Content for Control and PP Fibres.

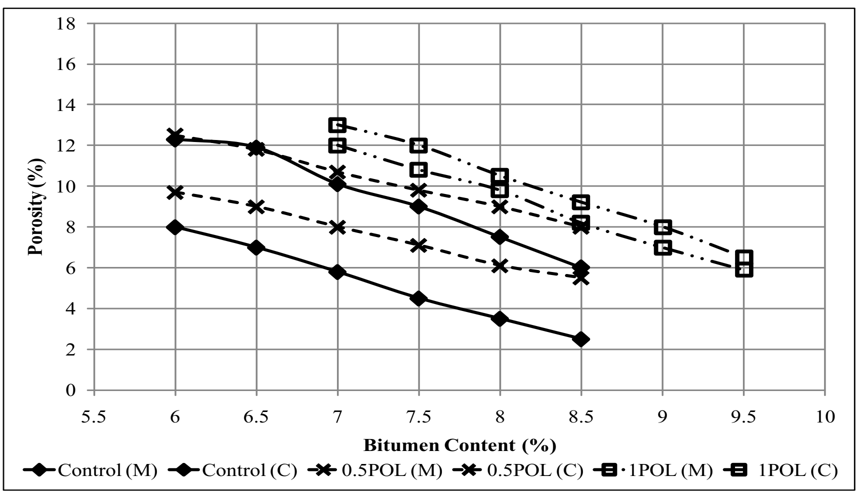

Fig. 5. Calculated and Measured Porosity vs. Bitumen Content for Control and POL Fibres.

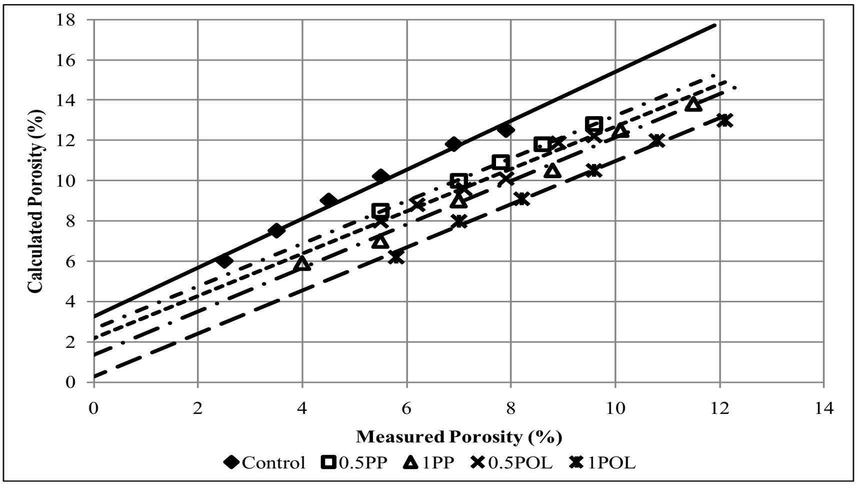

Fig. 6. Calculated vs. Measured Porosity for Different Mixes.

The indirect tensile strength (ITS) ratio is effectively an indication of the amount of strength loss due to the effect of water. The variation of the indirect tensile strength ratio and the degree of saturation is shown in Fig. 7. The ITS ratio shows it decreasing with increasing degree of saturation for all the mixes. The lines obtained are rather parallel to one another indicative that the decrease is somewhat similar. The fibre-modified mixes exhibited higher ITS ratios of around 11-25% over the control mix.

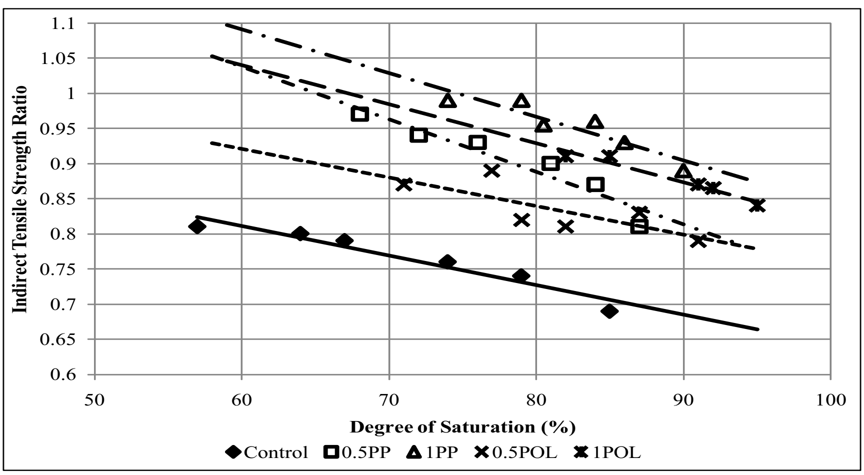

Fig. 7. Calculated vs. Measured Porosity for Different Mixes.

It is appropriate to be reminded that the fibre incorporated mixes had higher porosity and permeability than the control mixes that will permit easier access to water and increase the potential for stripping. It may thus appear that the more viscous binder of the fibre-incorporated mixes had a better cementing and adhesive property at the binder-aggregate interface that resulted in a reduction in stripping. It is believed that de-bonding may not have been solely responsible for the decrease in wet tensile strength values but other moisture damaging factors such as binder matrix softening may have been responsible as well.

7 Conclusion

Based on this study, the following conclusions can be drawn:

i. Changes in both the cohesive properties of the bitumen and the adhesion of the bitumen to the aggregate surfaces may occur as a result of exposing the bituminous mixtures to moisture. Polymer fibre incorporation into bituminous mixtures helps reduce the high level of moisture damage that was noted from the control mix. The polyester fibre modified mixes also showed lower moisture susceptibility than those of the polypropylene mixes at the same fibre concentration. However, the 0.5% fibre concentrated mixes showed better resistance to water damage than that at the 1% concentration.

ii. It is important to remember that mixes with polymer fibres had greater bitumen content and yet greater void contents than the control mix. Regarding resistance to moisture damage, these two parameters would be expected to oppose each other. Suffice to say that the additional bitumen in the fibre mixes increased the film thickness on the aggregate particles thus affording additional protection from moisture. The 0.5% fibre concentration may have provided enough reinforcement across the plane of failure in the mixtures while the 1% fibre concentration may have far too high void contents that allowed for more water penetration into the mixtures.

iii. The incorporation of polymer fibres in bituminous mixtures also acts to decrease the moisture sensitivity of the bitumen to aggregate bonding. This may be due to the strengthening of the wetted binder matrix which promote both adhesion and cohesion retention.

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