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Effect of using low density poly ethylene modifier on engineering properties of bituminous binder

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Abstract

The behaviour of conventional bituminous binder is highly susceptible to temperature and environment, which in association with intensive traffic loading cause manifold deterioration in bituminous pavements. To maintain serviceability in these pavements, frequent and costly maintenance and rehabilitation works are needed, which is not feasible for developing countries like Bangladesh. The use of modified bituminous binder has gained considerable interest in many countries because of an awareness of the need to conserve fund, energy, environment and natural resources. Consequently, it is necessary to study the possibility of blending locally available polymers with bitumen using low cost equipments and thereby to reduce the frequency and cost of maintenance and rehabilitation. In this study, the engineering properties of Low Density Poly Ethylene (LDPE) modified bituminous binder have been compared with those of unmodified bitumen through a set of standard laboratory tests. Results reveal that properties like penetration, ductility and specific gravity of the LDPE modified binder decrease while the softening point, viscosity and adhesiveness increase with LDPE content in the bituminous binder. This study also includes a non standard film thickness test, which reveals that the binder coating thickness increases significantly with LDPE content in the bitumen. Thus with LDPE modified pavements, the bond between aggregates and binder become stronger and thereby pavement perform better especially under submerged conditions. Stripping test also reveals that the increased film thickness of LDPE modified binder makes it more water resistant and thereby imparts more endurance than that of unmodified binder. Since LDPE modified bituminous binder has the potential to make pavements long lasting, to reduce construction cost and maintenance frequency, it holds a huge potential and a great prospect in prevailing weather conditions and road construction practices in Bangladesh.

Keywords: Pavement rehabilitation, polymer modified bituminous binder, low density poly ethylene.

1. Introduction

Conventional bituminous binder is highly susceptible to temperature. Also, its behaviour is greatly influenced by other environmental factors like air, solar radiation and water. These detrimental environmental agents in association with intensive traffic loading cause deterioration and distress such as cracking, stripping, bleeding, deformation, rutting, fatigue, potholes, age hardening etc. in bituminous pavements. The properties of traditional bitumen, in particular temperature susceptibility, can be improved by adding polymer to it. From previous studies (Al-Dubabe, I.A. et al., 1998; Ambwani G.R. et al., 1993; Beatty, C.L. et al., 1995; Baker, R.E., 1998; Chari, C.T. et al., 1997) it has been found that the use of Polymer Modified Binder (PMB) in pavements can lengthen the pavement life and reduce the frequency of maintenance and rehabilitation. Consequently, the use of polymer as an admixture is gaining popularity around the world, especially in developed countries (Gupta, A.K., 1997; Hussein, M. et al., 1999).

Table 1
Viscoelastic properties of base bitumen

Property	Test Method	Value
Specific Gravity	AASHTO T228-93 / ASTM D70-76	1.030
Softening Point (^oC)	AASHTO T47-8 / ASTM D6-80	45
Penetration (0.1 mm, 25^oC)	AASHTO T49-93 / ASTM D5-86	87
Ductility (cm)	AASHTO T53-92 / ASTM D36-89	100+
Loss on Heating (%)	AASHTO T51-93 / ASTM D113-79	0.06
Viscosity (Centistokes, 135^oC)	AASHTO T49-93 / ASTM D5-86	331

Table 2
Physical properties of low density poly ethylene (LDPE)

Property	Value
Density (pcf)	59.56
Specific Gravity	0.953
Melting Point (^oC)	115.1
Melt Flow Index (g/600s, 190^oC)	36.07

Table 3
Results of specific gravity test on unmodified and LDPE modified bitumen

Test Method	LDPE Content (%)	Specific Gravity
AASHTO T228-93 ASTM D70-76	0.0 (Unmodified)	1.0300
	2.5	1.0250
	5.0	1.0204
	7.5	1.0195
	10.0	1.0175

Another important reason for using modified binders, particularly in the developed countries, is from environmental considerations. The modifiers that are normally used for modification of raw bitumen such as scrap tyres, poly ethylene shopping bags, rubber products etc. are not environment friendly. As polymer products take a very long time to decompose, the dumping of these materials poses a great threat to the environment and makes waste management very expensive. To some extent, the alternative use of these environmentally hazardous materials in pavement construction gave a way of reducing waste disposal problem.

Although, in Bangladesh the use of poly ethylene shopping bags has recently been prohibited, polymer is being extensively used as covers or as containers of different commodities. It is anticipated that their increase in volume will pose a great problem in the management of these environmentally hazardous wastes. If these waste materials are useable in pavements, it will minimise the cost of management of these disposed wastes and will be environment friendly.

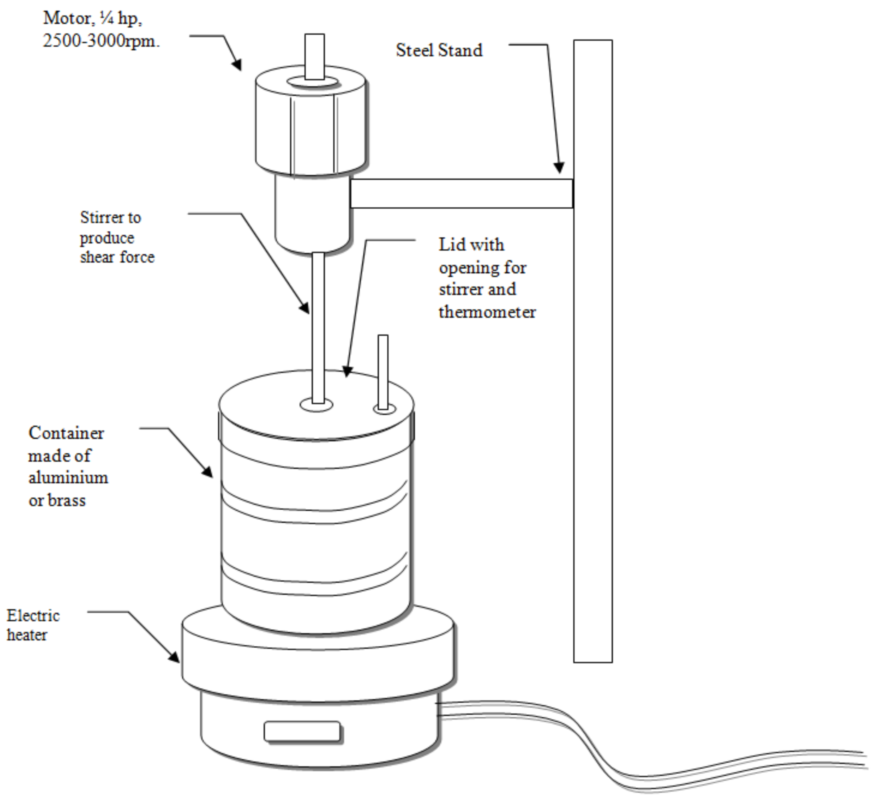

Fig. 1. Assembled polymer blending system.

Due to poor quality of resurfacing work and lack of proper drainage facilities, the pavements of Bangladesh, particularly in the urban areas, deteriorate shortly after its construction. Stripping of aggregates is one of the main causes of pavement failure in Bangladesh and this takes place due to the combined effect of wheel load and rain or floodwater. In Bangladesh, another reason for premature failure of pavement is high temperature in summer season. In summer, the weather becomes very hot and the ambient temperature of the pavement nearly reaches the softening point of the binder. As a result, the traditional binder becomes soft and flow condition arises in the pavement. At this flow condition, pavement distress such as bleeding, heaping and rutting induced by the movement of overloaded vehicles causes serious riding problems.

Because of these severe weather conditions of Bangladesh, every year almost all of the major roads in urban area need a massive rehabilitation work particularly immediately after the monsoon period. Frequent maintenance work not only involves large amount of money but also interrupt normal traffic flow with consequent discomfort and delay to road users. In this regard, the use of polymer modified bitumen (PMB) in pavement construction and rehabilitation work has the potential to minimise the frequency of maintenance work and thereby provide an economical solution. PMB, due to its improved viscoelastic properties, has the potential to alleviate some common problems like bleeding, heaping, rutting etc of binder during peak summer temperature and stripping of aggregates in flood prone areas. Consequently, there is a scope to minimise maintenance cost and frequency by using PMB. The specific objective of this study is to assemble a device to blend Low Density Poly Ethylene (LDPE) with fresh bitumen using low cost equipment and thereby to compare the engineering properties of LDPE modified bitumen with those of unmodified bitumen at various LDPE contents through a set of laboratory tests.

2. Methodology

Bitumen is a semisolid cementing material. As a road material, its performance has to be evaluated with respect to some engineering properties, which can be determined from a set of laboratory tests. LDPE changes these properties when it is blended with fresh bitumen. The main objective of this study is to assess and quantify the pattern of changes that LDPE imparts on the engineering properties of fresh bitumen. To achieve this objective, a set of laboratory tests on reference binder and LDPE modified binder at various LDPE contents is necessary. To maintain the uniformity, it is very important to have a precise description and specification of the materials involved in this study. It is also necessary to assemble a device to blend LDPE with fresh bitumen using low cost equipment.

2.1 Material specification

Bitumen is a cementing material, whose function is to hold the aggregate together in bituminous pavement. The quality of bitumen depends on its crude source, refining process and chemical composition. The chemical composition of bitumen affects the compatibility of bitumen with polymer. Bitumen is normally designated by 'grade' although it does not indicate the overall quality of bitumen. The characteristics of base bitumen affect the extent of quality improvement of the modified bitumen. In this study, 80/100 penetration grade bitumen is used, which has been obtained from a petroleum refinery. The chemical composition of the bitumen is unknown. The viscoelastic properties of base bitumen are shown in Table 1.

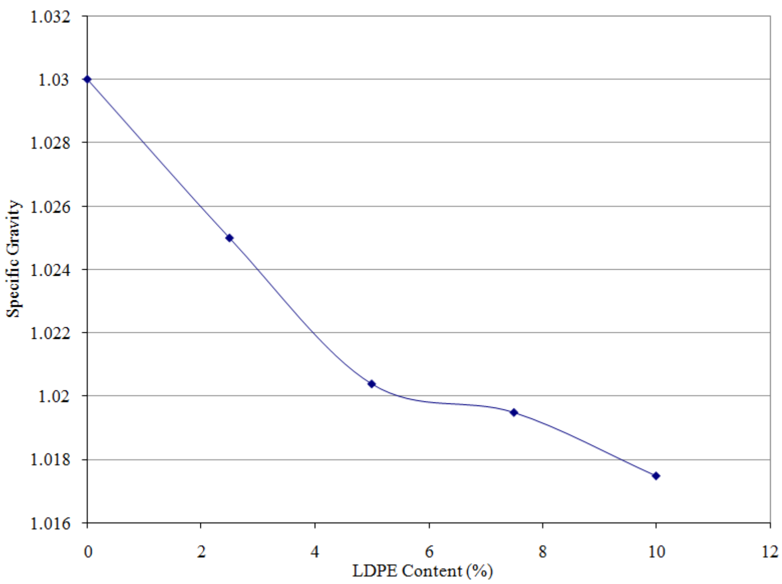

Fig. 2. Variation of specific gravity with LDPE content in bitumen.

Polymers are grouped according to their chemical composition. The members of a polymer group are classified by their structure, molecular weight and density. Linear and low density polymers generally have high compatibility to blend with bitumen. In this study, Low Density Poly Ethylene (LDPE) has been used as modifier not only for the purpose of compatibility test but also to perform the laboratory tests to compare the engineering properties of unmodified bitumen with those of LDPE modified bitumen. LDPE, which is available in the local market in pellet form, possesses some important properties as shown in Table 2.

2.2 Compatibility test

Because incompatible polymer cannot be blended with bitumen, it is necessary to carry out a compatibility test to assess whether it is possible to mix LDPE with bitumen at all. For this purpose, a trial blend was prepared with Low Density Poly Ethylene (LDPE) at a concentration of 5%. The duration of mixing was 25-30 minutes and the mixing temperature was kept between 160^{o}C-180^{o}C. The process was carried out in a can with capacity of 125 gm and taking 50 gm of bitumen. Mixing was performed by stirring manually and heat was provided by a gas burner. The homogeneity of the blend was examined by visual inspection under floodlight. From the compatibility test it has been observed that LDPE is compatible with bitumen and can be used to modify bitumen by applying mixing force manually.

Table 4
Results of penetration test on unmodified and LDPE modified bitumen

Test Method	LDPE Content (%)	Penetration (Tenth of mm)
AASHTO T49-93 ASTM D5-86	0.0 (Unmodified)	87
	2.5	65
	5.0	55
	7.5	35
	10.0	24

2.3 Blending

The blending device consists of three parts, a tripod stand having clamping facilities, a container and a stirrer. The container is made of brass and has a capacity of 2.5 litre of liquid bitumen. The container is cylindrical and its internal diameter is 14 cm and height is 15 cm. A steel rod flattened at one end is used as stirrer. A loop is formed at the other end of the stirrer to make it easy to hold. The container can be clamped to the tripod stand firmly, so that it does not overturn during vigorous stirring of mixture. The fabricated blending device is shown in Figure 1.

At first, a number of trials were made in order to get a homogeneous binder, as a result of which the following procedure was adopted. About 1200 gm of bitumen was taken in the container. Then the container with bitumen was placed on the tripod stand and heated with a gas burner. A piece of asbestos net was used below the container to ensure uniform distribution of heat. Moreover, bitumen was heated for five minutes and stirred continuously to avoid local overheating. As the temperature of bitumen reached 160^{o}C, the required quantity of LDPE was added and mixed manually. The mixture was then vigorously stirred for 25-35 minutes keeping the temperature between 160^{o}C-180^{o}C depending on the amount of polymer. At this stage it was observed that a uniformly dispersed binder had formed in the container. It was also found that once the binder is formed by using the above procedure, it can be stored for future use without any segregation of the two components and the binder prepared in this way could be used any time in future for laboratory tests like those with unmodified bitumen.

Following the above blending procedure, a total of four blends were prepared with LDPE contents of 2.5%, 5%, 7.5% and 10%. For each percentage of LDPE the required blending time was almost same. But the applied shear force and blending temperature had to increase with the increase of LDPE content. However, it was not possible to record the change of applied shear force and blending temperature in this manual blending device. It is necessary to use a thermostatically and mechanically controlled blending system to observe the change of these factors.

2.4 Laboratory testing

In order to investigate and compare the engineering properties of LDPE modified bitumen with those of unmodified bitumen, a total of seven tests were performed (six standard and one non standard) on a total of five samples of bituminous binder (four modified and one unmodified). All of the standard tests were carried out following the AASHTO/ASTM designation. A non standard test, named ‘Film Thickness Test’ was carried out on unmodified bitumen as well as on LDPE modified bitumen in order to study the variation of film thickness on aggregates with LDPE content. Although the film thickness test was not a standard one, it was performed in order to get an indirect measure of coating thickness on aggregates.

Table 5
Results of softening point test on unmodified and LDPE modified bitumen

Test Method	LDPE content (%)	Softening Point (^oC)
AASHTO T53-92 ASTM D36-89	0.0 (Unmodified)	45
	2.5	48
	5.0	54
	7.5	61
	10.0	68

Table 6
Results of ductility test on unmodified and LDPE modified bitumen

Test Method	LDPE Content (%)	Ductility (cm)
AASHTO T51-93 ASTM D113-79	0.0 (Unmodified)	100+
	2.5	94
	5.0	70
	7.5	45
	10.0	19

In order to obtain representative test results, the specimen preparation and testing were carried out as precisely as possible following the AASHTO/ASTM standards and guidelines. In case of abnormal or unexpected results, the tests were repeated. In spite of this, due to instrumental error a few tests have produced inconsistent results. For instance, the results obtained from the ‘Loss on Heating’ test were found to be abnormal due to absence of highly sensitive balance in the laboratory. As mentioned earlier, a total of seven laboratory tests were performed on both unmodified bitumen sample as well as all the LDPE modified bitumen samples at various LDPE contents. The tests are listed as follows:

- Specific Gravity Test (Standard)
- Penetration Test (Standard)
- Softening Point Test (Standard)
- Ductility Test (Standard)
- Viscosity Test (Standard)
- Loss on Heating Test (Standard)
- Stripping and Coating Test (Standard)
- Film Thickness Test (Non Standard)

All the standard tests conform to the AASHTO/ASTM standards. The only non-standard test namely the ‘Film Thickness Test’ does not conform to any standards and is briefly described below.

Two steel spheres of suitable size are used to determine the binder film thickness on the surface. The spheres are heated in the oven at 150^{o}C and the binder is heated separately at 150^{o}C-155^{o}C. The heated spheres are placed into the binder in a container and stirred for 2-3 minutes. The spheres are brought out and allowed to rest on a thin ring. The coated spheres are cooled to room temperature. The lower portion of the spheres is smoothened with a slightly hot knife. Then the weight of the coated spheres is taken. The difference between the weight of the coated spheres and that of uncoated spheres gave the weight of binder adhering to it. Coating thickness is calculated by simply by taking the volume of binder divided by the surface area of steel spheres. However, the volume of binder can be easily obtained by dividing the weight of binder with the density (or specific gravity) of the binder, which is determined separately in the 'Specific Gravity Test'. Because the film thickness is negligible compared to the diameter of the sphere, the resulting film thickness is fairly accurate. It should be noted that the film thickness was determined at 25^{o}C.

Table 7
Results of loss on heating test on unmodified and LDPE modified bitumen

Test Method	LDPE Content (%)	Loss on Heating (%)
AASHTO T47-83 ASTM D6-86	0.0 (Unmodified)	0.060
	2.5	0.065
	5.0	0.040
	7.5	0.060
	10.0	0.053

Table 8
Results of viscosity test on unmodified and LDPE modified bitumen

Test Method	LDPE Content (%)	Viscosity (centistokes)
AASHTO T49-93 ASTM D5-86	0.0 (Unmodified)	331
	2.5	630
	5.0	1117
	7.5	1572
	10.0	9494

3. Analysis of test results

The main objectives of this study were to investigate the quality improvement of bituminous binder after adding Low Density Poly Ethylene (LDPE) to it. To assess and quantify the quality improvement and to compare the properties of unmodified binder with those of LDPE modified binder several tests such as Specific Gravity, Penetration, Softening Point, Ductility, Loss on Heating, Viscosity, Film Thickness and Stripping and Coating tests were carried out on both unmodified bitumen as well as LDPE modified bitumen. The test results were plotted against LDPE content and from the plot, the effect of using LDPE modified binder was observed.

3.1 Specific gravity test results

The results of 'Specific Gravity Test' are shown in Table 3 and Figure 2. From the Table and Figure, it is observed that the specific gravity of LDPE modified bitumen decreases with LDPE content. The specific gravity of unmodified bitumen was 1.0300. For 10% LDPE content, this value of specific gravity dropped to 1.0175. Since the specific gravity of LDPE is less than that of bitumen, consistent with expectation, the specific gravity of LDPE modified binder decreases with the LDPE content in bitumen.

3.2 Penetration test results

In general, penetration is used to measure the consistency of semisolid and solid bituminous materials. It is used to classify semisolid bituminous materials into standard consistency grades. Since grade does not signify quality, the penetration test has no relation to quality of binder. It is an empirical test.

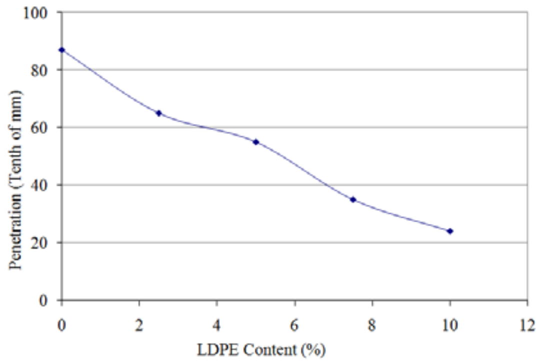

Fig. 3. Variation of penetration with LDPE content in bitumen.

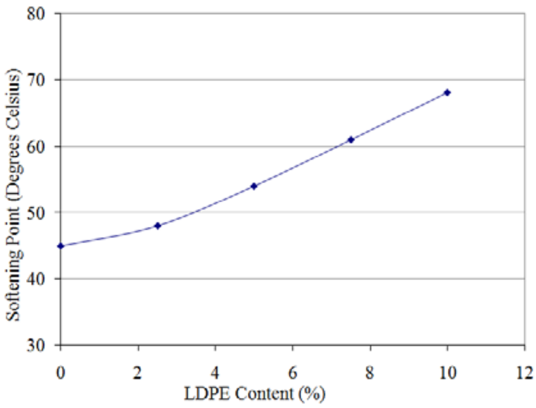

Fig. 4. Variation of softening point with LDPE content in bitumen.

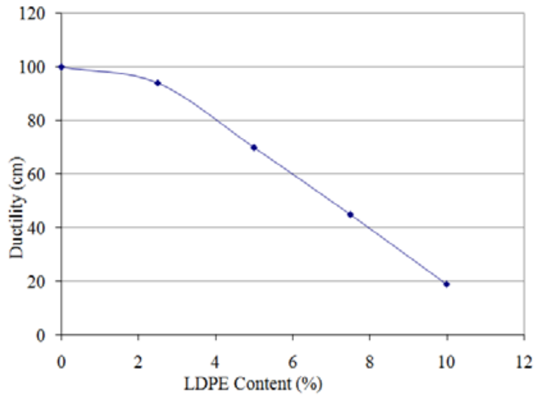

Fig. 5. Variation of ductility with LDPE content in bitumen.

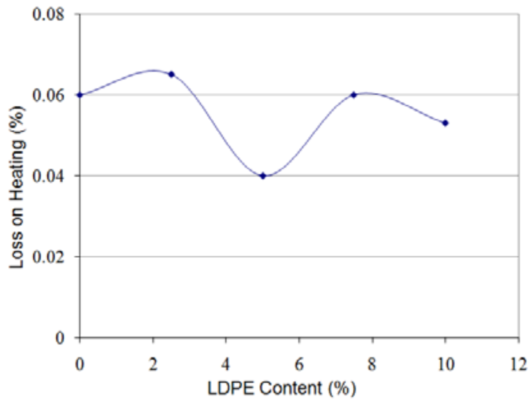

Fig. 6. Variation of loss on heating with LDPE content in bitumen.

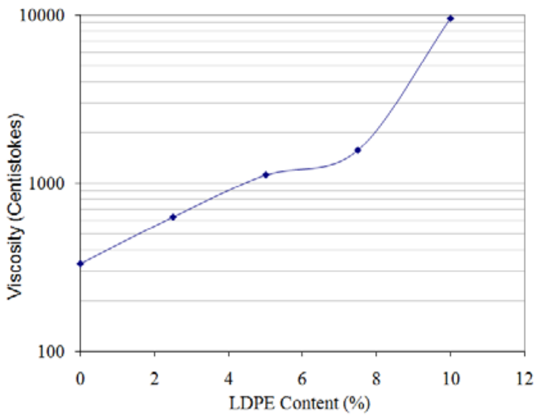

Fig. 7. Variation of viscosity with LDPE content in bitumen.

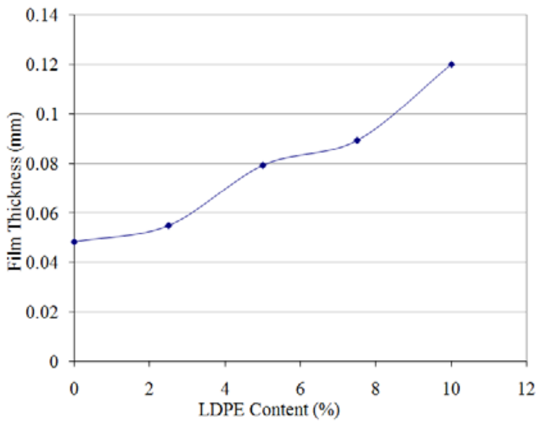

Fig. 8. Variation of film thickness with LDPE content in bitumen.

The results of 'Penetration Test' on unmodified bitumen and LDPE modified bitumen are shown in Table 4. A plot of penetration versus LDPE content is shown in the Figure 3. The test was performed at 25^{o}C. From the Table and Figure, it can be observed that the penetration decreases almost uniformly from a value of 87 in case of pure bitumen to 24 in case of bitumen with 10% LDPE content, which represents a 72% drop in penetration. This implies that LDPE increases the consistency and stiffness of bitumen.

Table 9
Results of film thickness test on unmodified and LDPE modified bitumen

LDPE Content (%)	Specific Gravity	Sphere No.	Diameter (mm)	Surface Area (mm^2)	Wt. of Coating (gm)	Vol. of Coating (cm^3)	Film Thickness (mm)	Average Film Thickness (mm)
0.0	1.0300	1	42.5	5675	0.295	0.2864	0.0505	0.0482
		2	41.8	5489	0.260	0.2524	0.0460	
2.5	1.0250	1	42.5	5675	0.297	0.2898	0.0511	0.0549
		2	41.8	5489	0.331	0.3229	0.0588	
5.0	1.0204	1	42.5	5675	0.470	0.4606	0.0812	0.0791
		2	41.8	5489	0.431	0.4224	0.0770	
7.5	1.0195	1	42.5	5675	0.513	0.5032	0.0887	0.0892
		2	41.8	5489	0.502	0.4924	0.0897	
10.0	1.0175	1	42.5	5675	0.688	0.6762	0.1192	0.1198
		2	41.8	5489	0.673	0.6614	0.1205	

Generally, lower values of penetration are preferable for bitumen to use in tropical countries to prevent bleeding in pavement. On the other hand, bitumen in pavement gradually hardens due to aging or oxidation process and penetration value falls with time. Serious cracking may occur when penetration value falls below 20. This characteristic of binder causes bleeding to new pavement and cracking to aged pavement. The use of modified binder may be a solution of this problem. Since polymer like LDPE is a non-biodegradable substance, initially its presence in the binder will decrease the penetration of modified bitumen but it has the potential to retard the time dependent hardening process or further reduction of penetration of binder. Thus, it enhances the performance of pavement.

3.3 Softening point test results

The 'Softening Point Test' results are presented in Table 5 and Figure 4. Softening point is a measure of the temperature at which the binder reaches flowing condition under the weight of a standard steel ball. It is not a measure of melting point. From the Table and Figure, it can be observed that the softening point increases from 45^{o}C in case of unmodified bitumen to 68^{o}C in case of bitumen with 10% LDPE content, which indicates the rise by 23^{o}C. It can be implied from the results that as the addition of LDPE increases consistency of the binder, higher temperature will be required to make the modified binder soft. It indicates that the temperature susceptibility of binder significantly decreases with polymer content. This improvement will reduce the problem of bleeding during hot season, which is one of the most important modes of pavement distress in tropical countries like Bangladesh.

3.4 Ductility test results

Table 6 and Figure 5 represent the 'Ductility Test' results. The results indicate that the ductility sharply decreases with LDPE content in binder. The ductility of unmodified bitumen was 100+ cm, which fell to 19 cm for bitumen with 10% LDPE content representing a loss of ductility by 81%. This implies that the use of LDPE as a modifier has pronounced effect on the ductility of bitumen. From Figure 5 it can also be observed that the change of ductility with LDPE content is not linear. The rate of change of ductility increases with LDPE content.

Ductility is the measure of internal cohesion of the binder. It is an important property of binder, which imparts cementing quality in bituminous mixes. Although it is generally believed that bituminous materials with high ductility have good binding properties, they may perform quite differently in service. Initial ductility alone does not indicate whether the binder will perform well in service period or not. Generally, the ductility of bitumen decreases with time and the rate of decrease may not be same for all types of binders. Using LDPE with bitumen can decelerate the rate of change of ductility, although initially it reduces the ductility compared with that of unmodified bitumen. Because excessive reduction of ductility may render the binder unfit as pavement material, selection of maximum feasible LDPE content may be limited by the ductility of modified binder. However, in one hand polymer decreases the ductility whereas on the other hand it increases the elasticity of the binder. In this regard, modified binder with lower ductility could be used safely in the bituminous mixes.

3.5 Loss on heating test results

The results of 'Loss on Heating' test are shown in Table 7. This test requires very sensitive balance to weigh the material. But due to unavailability of sensitive balance in the laboratory, this test could not be performed accurately. From the results presented in the Table, no distinct effect of LDPE on loss of heating of modified binder could be inferred. Although for few instances the tests were repeated, the results were anomalous. The loss of material for base bitumen is 0.06% and that for 5.0% and 7.5% LDPE modified bitumen are found to be 0.04% and 0.06% respectively. Variation of loss on heating with LDPE content in bitumen is presented graphically in Figure 6.

3.6 Viscosity test results

Viscosity is an important property of bituminous binder, which indicates the performance of bitumen with temperature. Consequently, the classification of bitumen based on viscosity is considered better than that based on penetration. Moreover, mixing and compaction temperatures of hot paving mixtures depend on the viscosity of binder. Binders with higher viscosity increase the thickness of coating on aggregates and can minimise stripping in pavement.

In this study, the Kinematic test was performed to determine the kinematic viscosity of the binders. The results of 'Viscosity Test' are summarised in Table 8 and graphically presented in Figure 7. It is observed from the results that the viscosity of LDPE modified binder increases substantially with LDPE content.

In general, binder with higher viscosity is necessary to construct pavement in tropical countries like Bangladesh. In case of conventional binder, it is very difficult to select harder bitumen meeting the specification requirements other important properties such as ductility. In this respect, the use of LDPE modified binder in the paving mixture could be a better solution.

3.7 Film thickness test results

This non standard test was performed by using a solid steel sphere in order to determine the film or coating thickness of binder on aggregates when LDPE is added to bitumen. As the surface texture of the sphere is quite different from that of aggregates, it would be nothing but an indicative test. Moreover, because aggregates are porous and irregular in shape, the amount of binder, film thickness and nature of film on aggregates would be different from that on a solid sphere. The experimental results have been plotted against LDPE content as shown in Figure 8, from which it can be observed that the film thickness on smooth surface increases with LDPE content. Expectedly, due to its additional viscosity, the polymer results in such increase of film thickness. From Table 9, it is obvious that the increase of film thickness even on smooth spherical surface is very significant and pronounced. With 10% LDPE content the increase of film thickness is nearly 150% with reference to that of the original binder. Certainly, it is expected that the film thickness of binder would be even more on aggregates.

Table 10
Results of stripping and coating test on unmodified and LDPE modified bitumen

LDPE Content (%)	Cycle 1 (18 hrs under water at room temperature)	Cycle 2 (18 hrs under water at 40°C)	Cycle 3 (72 hrs at drying at room temperature and 18 hrs under water at 40°C)	Cycle 4 (72 hrs at drying at room temperature and 18 hrs under water at 60°C)
0.0	Above 95%	Below 95%	Below 95%	Below 80%
2.5	Above 95%	Below 95%	Below 95%	Below 85%
5.0	Above 95%	Above 95%	Above 95%	Above 95%
7.5	Above 95%	Above 95%	Above 95%	Above 95%
10.0	Above 95%	Above 95%	Above 95%	Above 95%

From the above results, it can be inferred that the thicker film on aggregates would be helpful in preventing water to enter the aggregates. Thus with LDPE modified pavements, the bond between aggregates and binder would be stronger and thereby pavement performance would be better especially under submerged conditions.

3.8 Stripping and coating test results

'Stripping and Coating Test' of binder was performed at four different test conditions. In order to get a meaningful comparative result, the test was performed progressively for up to four cycles with changing test conditions. In the first cycle, the test was carried out according to ASTM standards for all the test samples including unmodified and LDPE modified binder. Observation was made qualitatively after 18 hrs of immersion at room temperature. Obtaining no significant results for any of the test samples, the experiment was repeated for three times successively by gradually accelerating the harshness of test conditions.

In the second cycle, observation was made on the same test specimens after another cycle of 18 hrs submergence at 40^{o}C. The third cycle of the test was carried out after allowing 72 hrs drying of the test specimens at room temperature and subsequent 18 hrs submergence at 40^{o}C. The final cycle of observation was made after 72 hrs drying of the test specimens at room temperature and subsequent 18 hrs submergence at 60^{o}C. Although the test method suggests the stripping and coating test results to be expressed as 'below 95%' or 'above 95%', in order to make a meaningful comparison among binders with and without polymer, the experimental results are also expressed at different threshold values. The 'Stripping and Coating Test' results are presented in Table 10. Comparing the test results, it can be concluded that the effect of stripping is less with LDPE modified bitumen as compared to that of unmodified bitumen. Test results show that the retention of binder on aggregates for base bitumen is less than that for LDPE modified bitumen. Moreover, it can be observed that the phenomenon of stripping decreases with higher proportion of LDPE content. It can be observed from the Table that even after the 4th cycle of aggressive test conditions, with 5% LDPE content the stripped area is only 5% which is 20% for unmodified bitumen. It implies that the increased film thickness of LDPE modified binder makes it more water resistant and thereby imparts more endurance than that of unmodified binder.

4. Conclusions and recommendations

The primary objective of this study was to carry out a comparative analysis of Low Density Poly Ethylene (LDPE) modified bituminous binder and unmodified bituminous binder. The qualitative improvement of LDPE modified binder at various LDPE content was studied by comparing their characteristics with those of unmodified binder. The summary of test results and important findings can draw the following conclusions:

- Blending of LDPE with bitumen requires a blending temperature around 160°C-180°C and the maximum time required for LDPE to react with bitumen is about 30 minutes.
- For the production of LDPE modified binder in small quantity, the manual method of blending is quite suitable.
- The specific gravity of LDPE modified binder falls with LDPE content.
- The penetration of LDPE modified binder drops with LDPE content and at 10% LDPE content the drop is 72%, which signifies that the consistency and stiffness of bitumen improves with LDPE content.
- The softening point of LDPE modified binder rises with LDPE content and at 10% LDPE content the rise is 23°C, which signifies that the temperature susceptibility of bitumen decreases with LDPE content.
- The ductility of LDPE modified binder drops with LDPE content and at 10% LDPE content the drop is 81%, which signifies that the internal cohesion of bitumen improves with LDPE content.
- The viscosity of LDPE modified binder rises with LDPE content, which signifies that the temperature susceptibility of bitumen decreases with LDPE content.
- The binder film thickness increases significantly with LDPE content in bitumen and at 10% LDPE content, the increase of film thickness is nearly 150%, which signifies that the coating thickness of LDPE modified binder would be more with aggregates in the bituminous mix.
- The coating of the LDPE modified bitumen on aggregate is stronger than that of unmodified bitumen on aggregate and better adhesive property of the modified binder makes the bituminous mixes more impermeable to water and delays the stripping process.
- Since LDPE modified bituminous binder has the potential to make pavements long lasting, to reduce construction cost and maintenance frequency, it holds a huge potential and a great prospect in prevailing weather conditions and road construction practices in Bangladesh.

Due to narrow scope of the study as well as some inherent limitations and constraints, the following recommendations can be made for future studies:

- To partly solve the undesirable stockpiling of non biodegradable waste, a similar study should be conducted with reclaimed or waste polymers.
- To study the time dependent behaviour of binders, elastic and ductile recovery tests should be performed.
- Because imported LDPE is costly, an economical feasibility analysis should be undertaken before the practical use of pure LDPE with bitumen to assess whether bitumen with LDPE is commercially beneficial from economic point of view or not.
- In order to ascertain the complete behaviour of LDPE modified binder, a comprehensive test programme including fatigue and permanent deformation tests with varying parameters such as test temperatures, loading conditions etc. need to be conducted in order to determine the life of the pavements and the resistance to plastic deformations.

References

Al-Dubabe, I.A.; Wahhab, H.I.A.A.; Asi, I.M.; Ali, M.F. (1998), "Polymer Modification of Arab Asphalt", Journal of Materials in Civil Engineering, August 1998 Vol., No.3, pp. 161- 171.

Ait-Kadi, A., Brahimi, B. and Bousmina, M. (1996), Polymer Engineering and Science, Vol. 36, p.12, 1724-1733.

Ambwani, G.R.; Shukla, R.S.; Gupta, O.P. (1993), "Modified Binder for High Traffic Density Road Corridors", Indian Highways, June 1993 Vol., No.2, pp 152 – 164.

Baker, R.E. (1998), "Polymer Modified Bitumen", Indian Highways, January 1998 Vol., No.12, pp 18–25.

Beatty, C.L.; Fricke, A.L.; Zaman, A.A. (1995), "Rheological Properties of Rubber Modified Asphalt", Journal of Transportation Engineering, Nov/Dec 1995 Vol., No.21, pp 22-28.

Chari, C.T.; Bopiah, V.; Srivastava, A.; Shukla, R.S.; Verma, V.C. (year), "Polymer Modified Asphalt Products for Highways and Airport Pavements", Indian Road Congress Vol., No.5, pp 171-189.

Goodrich J.L. (1988); "Asphalt and polymer modified asphalt properties related to the performance of asphalt concrete mixes", Journal of the Association of Asphalt Pavement Technologists, Vol. 57, p.116-160.

Gupta, A.K. (1997), "Rubberised Roads: A CRI Experience", Indian Highways, Apr 1997. Vol., No.4, pp 124 – 135.

Hossain, M.; Swartz, S.; Hoque, E. (1999) "Fracture and Tensile Characteristics of Asphalt-Rubber Concrete", Journal of Materials in Civil Engineering, Nov 1999. Vol., No.12, pp 25-34.

Islam, M. S. (2003), "A Study on the Prospects of Using Polymers in Bituminous Binder and Mixes", M. Engineering Project Thesis, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), May 2003.