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Research Article

Utilization of Waste Plastic Materials as Bitumen-Blends for Road Construction in Oman

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Abstract: Studies are reported in the present work to focus on blending of waste plastic materials (in the form of shredded polyethylene bags) being used as a binding agent in asphalt for road construction. This study compared the results with the standards set by Oman as per MOTC (Ministry of Transportation & Communications) guidelines for asphalt as a road laying material. Polyethylene was used as a binding agent along with bitumen (60/70) grade and dolerite as the aggregate material. The studies showed that not only did the road become a receptacle for plastic waste, but it also had a better strength and durability which were verified by determining the bulk density, stability test, flow test and the density and voids analysis. The experiments have showed that 9 % of low density polyethylene to be an effective binder proportion of polyethylene by weight of bitumen which were in agreement with previous studies. With a stability value of 1590.2 kg, it was 32.5% greater than the standard of a minimum 1200kg; and a flow value of 2.9-3.0 mm was well within the required range. The specific gravity of the material was 2.446. The VMA (voids in mineral aggregate) was 5% while the given range was 4-7%, and the air voids were up to 66.7% showing that it was well within the standard range of 50-70% as per MOTC standards.
Keywords: PE blends in bitumen, utilization of waste plastic materials, road materials standards, waste utilization.

INTRODUCTION

Utilization of plastic materials is ubiquitous in some form or other; more so in the form of carry bags made out of polyethylene (PE), polypropylene (PP), or polyethylene terephthalate (PET) in view of their convenience, light weight and their availability in plenty. Plastic has become a generic term to mean different polymeric materials with high molecular weight. Incidentally PE with an annual global production of 80 million tons merits high in its utilization probably because of its carrying strength vis-à-vis its weight. What is a matter of concern is its disposal problem. Unfortunately, they are not easily degradable, and take pretty long time which is of the order of 100-500 years [1]. This causes a heavy burden on the environment to degrade them. One of the approaches is to go for land filling while the other is to dump them into sea; both are not practicable. Hence, the use of plastics (particularly PE) has received wide criticism all over the world. And at the same time, the use of plastics cannot be done away with totally in view of their light weight. Hence, efforts have been consistently made to find out the alternatives to dispose off the used plastic bags and materials.

One envisaged methodology for this is to blend them with bitumen and use for laying roads [2-5]. Recycled PE materials were also used as asphalt modifiers [6]. It was reported that the average size of the plastic materials should be 2-3 mm; and PVC sheets or flexi sheets should not be used [7]. A detailed description of the process and guidelines for laying roads with plastic blended bituminous materials was also reported by the National Rural Roads Development Agency in India [7]. It suggested that plastic materials could be added up to 8% of the bitumen; whereas Little [8] suggested that LDPE content should not exceed 17% in asphalt-mixed concrete pavement in Europe. The roads had an enhanced durability. It was also reported that roads with plastic blended bitumen had an extended life of at least one or two years more as compared to 3-4 years under normal ideal conditions [9]. There is a number of other advantages also. In view of the above claimed advantages, the present work was taken up to study various combinations LDPE-Bitumen for the purpose of laying roads. Tests were carried out in the laboratory by using Marshal Test Method. The studies have a purported relevance in Oman since there is a potential to lay 60,000 km roads as only 1/3rd of the vast network of road construction has been done so far [10]. The results of blending PE with bitumen were compared with the standards laid down by Oman Ministry of Transport and Communications [11].

MATERIALS & METHODS

Waste materials of polyethylene were collected from local area and shredded to 4.5 mm particle size. Later different proportions of PE waste material (5-11%) were mixed with bitumen (60/70) grade; and experiments were carried out to determine (i) bulk density, (ii) stability, (iii) flow quality and (iv) void analysis. Dolerite (blasted quarry material) was used as aggregate material to an extent of 3.5%.These aggregates were the ones already approved by NESPAK consultants (National Engineering services of Pakistan) for using in the construction of the Batinah Coastal Road Project [10] in Oman.

Experimental Mold Assembly

The mold assembly consisted of cylindrical molds of 4 cm in diameter and 4 cm in height with a base plate and collar extension and a sample extractor for extruding the compact specimen from the mold. The mold was compacted using a compaction and compression device with a breaking head that weighed 4.5kg using a loading machine in which the load was impinged from a height of 18 inches. The mold specimen was shown in **Fig 1**.

Fig 1 : Mold assembly

Experimental Procedure

The experimental flow sheet is shown in Fig 2. The coarse aggregate, fine aggregate, as well as the filler material were taken in the proportion in order to adhere to the requirements of the standards of the MOTC of Oman. On mixing plastic with asphalt, polymerized bitumen was formed. The collected plastic waste products (plastic bags) made out of polyethylene were separated and cleaned. The plastic bags were shredded into small pieces and were passed through a 4.5 mm sieve. The aggregate (Dolerite; cent percent blasted quarry material) was heated to 170°C, and the shredded plastic waste was added. Since the plastic usually softens at 130^{o} C, it softens and coats the aggregate. The melted plastic was then added to the heated Bitumen at160°C and mixed well. As the polymer and the bitumen were in the molten state, they got mixed, and the blend was formed at the surface of the aggregate material in different proportions (5/95, 7/93, 9/91,11/89). Mixing temperature was 160-165^{o}C. Marshall mold compaction was made at the temperature of 145^{o}C by using 75 blows on each side. **Table 1** showed the lab trial specimen preparation with the amount of polyethylene and bitumen used in grams as per the respective percentages.

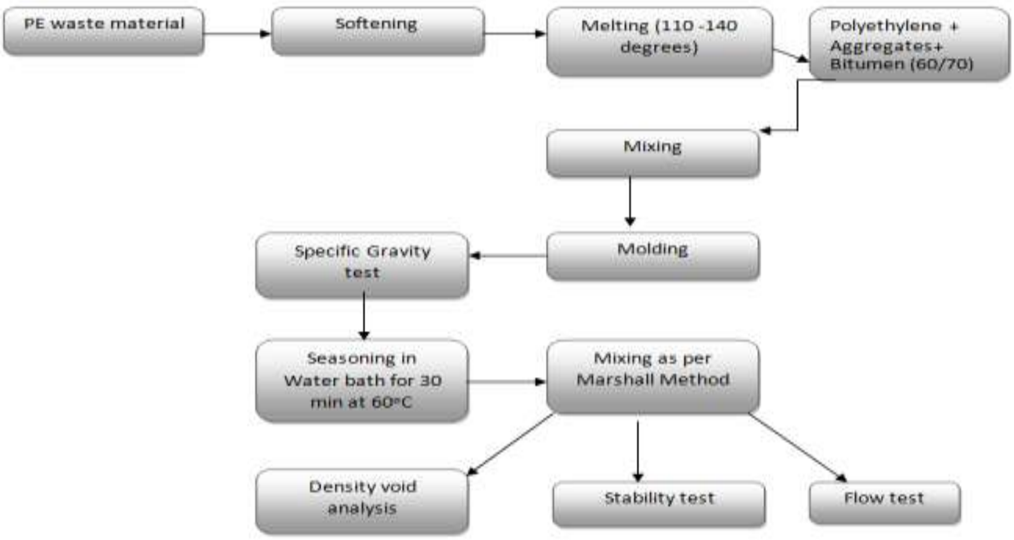

Fig-2: Process flow diagram

Table 1 : Composition of various samples.

Sample Type	Plastic (PE)	Bitumen	% of PE
A	2.1 g	39.9g	5
B	2.94g	39.06g	7
C	3.78g	38.22g	9
D	4.66g	37.34g	11
E	0.00	42.00g	0

Analytical Methods

In the Marshall test method of mix design, compacted mold samples were prepared in triplicate for each binder content (a total of twelve samples) to determine the optimum binder content. All these molds were subjected to the following tests:

Bulk Specific Gravityof compacted material

The bulk specific gravity of the sample was determined by weighing the sample in air and in water. The specific gravity of the bulk compacted material (G_{mm}) of the specimen was determined by :

$$G_{mm}= \frac{Wa}{Wa-Ww}$$ **Eqn. 1**

WhereW_a= weight of sample in air (g), W_w=weight of sample in water (g).

Marshal Stability

The Marsha stability of a test specimen is the maximum load resistance that the standard test specimen will develop at 60°C when tested. In the stability test the specimen was immersed in a bath of water at 60° C for a period of 30 minutes. After this it was placed in the Marshall stability testing machine and loaded. The total maximum load taken in kg (that causes failure of the specimen) was taken as Marshall Stability. The minimum requirement is 1200kg according to the MOTC standard (**Table 2**).

Flow

The flow value is a measure of the total movement or strain in units of 0.25mm occurring in the specimen between the conditions of no load and the point of maximum load during the stability test. The total amount of deformation that occurred at maximum load was recorded as flow value, and tabulated in Table 3. The required range was between 2.0 to 3.5mm according to the MOTC standard (Table 2).

Table 2 : MOTC Specifications

Parameter	Value
Marshall stability at 80° C (Kg)	1200
Flow (mm)	2-3.5
Voids in mineral aggregate, (VMA)	12%(minimum)
Air Voids	4-7%
Voids filled with Bitumen, (VFB)	50-70%
Loss of Marshall stability by submerging specimens in water at 60 degrees C for 24hrs compared to stability measured after submersion in water at 60° C for 30 min	Max.25%
% air voids at refusal	Min.2%

Bulk Specific Gravity and Void Analysis

Some of the following parameters were considered here [12]

Bulk specific gravity of mix (G_{mb})

The bulk specific gravity is the actual specific gravity of the mix after considering air voids and is defined as :

G_{mb}= Weight of the mix/ Volume of the mix. **Eqn. 2**

Percent of air voids (VA)

It is the percentage of air voids in the compacted mixture which includes the small air spaces between the coated aggregate particles. And the volume percentage of the air voids in a compacted mixture can be determined by using this method:

$VA = 100 \times (G_{mm} – G_{mb})/ G_{mm}$ **Eqn. 3**

Voids in mineral aggregate (VMA)

The voids in the mineral aggregate are defined as the inter granular void space between the aggregate particles in a compacted paving mixture which includes the air voids as well as the effective asphalt content and is expressed as a percentage of the total volume. The VMA is dependent upon the bulk specific gravity of the aggregate and is expressed as a percentage of the bulk volume of the compacted paving mixture. Hence the VMA can be calculated by subtracting the volume of the aggregate determined by its bulk specific gravity from the bulk volume of the compacted mixture.

$VMA = 100 \times (G_{mb} x\ P_s/G_{sb})$ **Eqn. 4**

Where, G_{sb} is the bulk specific gravity of the bulk aggregates, and P_s is the percentage of the non-aggregate material and is equal to 96.5 (100-3.5).

Voids Filled with Bitumen (VFB)

VFB is the voids in the mineral aggregate frame work filled with bitumen binder. It is the percentage of the inter granular void space between the aggregate particles (VMA) that are filled with bitumen. It is determined by:

$$VFB = 100\ (VMA - VA)/\ VMA \qquad \textbf{Eqn. 5}$$

RESULTS AND DISCUSSION

The experimental results are discussed with reference to the following tests:

- bulk density,
- stability,
- flow and
- void tests.

The results were compared with the Omani standards of Ministry of Transport and Communication. There were 12 sample molds in total and each one was subjected to three different kinds of tests at least, leading to a minimum of 36 tests.

Stability& Flow

There were 12 sample molds which were tested for stability and flow. Three molds for each binder type contained 5 % of plastic with 95% of bitumen , 7% of plastic with 93% of bitumen, 9% of plastic with 91 % of bitumen and 11% plastic with 89% of bitumen respectively. The stability and flow data of each of the four binders were shown in **Fig 3** and **Fig 4**.

From the stability data of all the four binders, we noted that the binders B and D had a better stability as compared to C. But the binder C was preferred because it could utilize a greater percentage of waste plastic as compared to B. Although binder D (with 11% PE) contained more plastic than C (9%), one of the molds of D broke down after curing (being immersed in a bath at 60°C). Thus, the most suitable stability-tested binder was C with 9% of polyethylene.

The effect on the flow was minimal but well within the range. There was hardly any distortion when the load was applied which was only 2.9 mm on an average (**Fig.4**).

Since the binder C (9/91) was noted to be the best from the Marshall stability and flow data, further studies on void analysis were reported for that binding sample.

Bulk Density

The bulk density or the specific gravity of each of the specimens was determined by Eqn (1), and tabulated (**Table 3**). These data were used for further experimental works and analysis such as the density and void analysis.

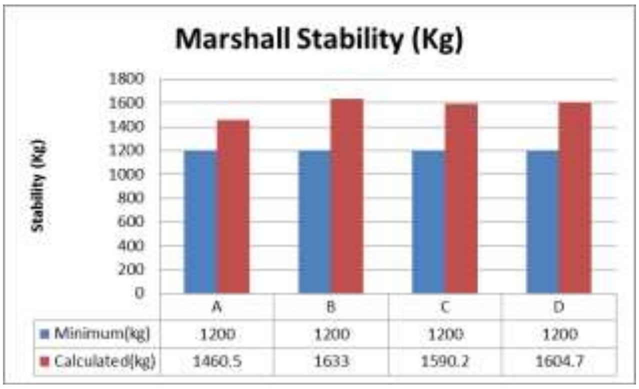

Fig. 3 : Stability data of various binder combinations

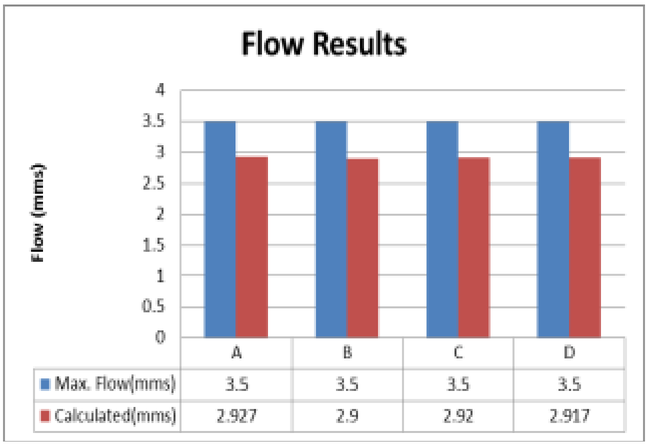

Fig. 4 : Flow data of various binder combinations

Table 3 :Specific Gravity, Marsha Stability and Flow data of various samples*.

Sample	Specific gravity	Marshal stability (kg)	Flow (mm)
A	2.440	1460.5 (1200)	2.927 (3.5)
B	2.455	1633.0 (1200)	2.900 (3.5)
C	2.446	1590.2 (1200)	2.920 (3.5)
D	2.443	1604.7 (1200)	2.917 (3.5)

* The values in parenthesis were those given by MOTC, Oman

Determining the Air voids for sample 3

The air voids or spaces in the binder were measured, and assessed for the effect of polyethylene content on them. The following were the measured values for the sample.

G_{mm}=2.566
C_{sb}=2.768
G_{mb}=2.437
P_s =96.5%

VMA (voids in the mineral aggregate) = $\boldsymbol{100 - (G_{mb}\ P_s \div G_{sb})}$
= 100 – (2.437 x 96.5) ÷2.768
= 15%
VA(voids filled with air) =$\boldsymbol{100 \times (G_{mm} - G_{mb})\ G_{mm}}$
= 100 x(2.566- 2.437) ÷ 2.566 =5%
VFB (voids filled with bitumen) = ***100 x (VMA- VA) ÷ VMA***
=100 x (15-5) ÷ 15=66.7%

Marshal stability of 1590.2 kg was 32.5% greater than the standard of a minimum 1200kg. The flow range of 2.9-3.0 was also well within the required range. The air voids (VA), VMA and VFA were all within the standard ranges (**Table 4**).The results were noted to be satisfactory as all the values adhered to the Omani specifications.

Table 4 : Comparison of test results with MOTC specifications

Parameter	Value	Achievements
Marshall stability at 60^o C (kg)	1200	1590.2
Flow (mm)	2-3.5	2.92
Voids in mineral aggregate, (VMA)	12%(minimum)	15%
Air Voids	4-7%	5%
Voids filled with Bitumen, (VFB)	50-70%	66.7%
Loss of Marshall stability by submerging specimens in water at 60^o C for 24hours compared to stability measured after submersion in water at 60^o C for 30 min.	Max.25%	11%
% air voids at refusal	Min.2%	N/A

CONCLUSIONS

Since bitumen grade of 60/70 guidelines match with the general specification of MOTC, the same has been adapted in the present work for using in Marshall Stability Method. The studies conclusively showed that that the waste plastic materials could be incorporated as a binding agent for the construction of roads. Low density polyethylene (LDPE) to an extent of 9% Sample C) was found to be the most effective binder proportion. Previous studies have also shown similar results [13,14].

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