Low Density Polyethylene Modified Dense Graded Bituminous Macadam

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Abstract— This paper presents the use of waste polythene carry bags in flexible pavement construction. Reclaimed plastic waste derived from low density polyethylene (LDPE/PW) carry bags from kitchen waste and plastic bottles have been used as additive in flexible pavements. Purposes of using above materials are to utilize environmentally unacceptable waste material and to develop a better material mix to resist increased traffic load and pressure resulted in cracks in the pavement surface. In the present study the plastic waste was cleaned and cut into a size such that it passes through 2-3mm sieve using shredding machine. In this study Dense Bituminous Macadam (DBM) mix has been prepared by using plain bitumen as a control specimen and bitumen mixed with low density polyethylene (LDPE/PW) in different proportions such as 2, 4, 6, 8, 10 and 12% by weight. The Marshall Stability tests were conducted on control and modified DBM mixes. It has been observed that the plastic waste modified bitumen mix show better binding property, stability, density and more resistant to water. Hence, the present technology will not only strengthen the road construction but also increases the road life as well as will help to improve the environment.

Keywords— **Plastic Waste, Bituminous Mixes, LDPE/PW, DBM, Marshall Stability Tests**

INTRODUCTION

Recycling of waste materials serves important purpose of eliminating an expensive and environmentally unacceptable solid waste disposal problem. At present, considering the risks associated with land filling of waste materials and its disposal problem, researchers have been finding ways of incorporating recycled materials into bituminous pavements construction, that have brought about action throughout the world [1]. Increased traffic and high pressures resulting from heavy vehicles have been among the factors causing cracking and premature failure of pavements. Various solutions have been proposed to minimize the susceptibility of bituminous concrete mixtures to cracking. In recent years, there has been a rapid increase in using additives in bituminous concrete mixtures to improve its properties. LDPE has been used by many researchers to modify bitumen and to improve the properties of bituminous mixes [2]. Bitumen is a viscous material that has been derived from crude petroleum and has been used in paving roads. This paper deals with the viability of using reclaimed polyethylene derived from low density polythene carry bags collected from domestic waste as an additive in flexible pavement construction. Plastic roads mainly use plastic carry-bags, disposable cups and LDPE bottles that are collected from garbage dumps as an important ingredient of the construction material. When mixed with hot bitumen, plastics melt to form an oily coat over the aggregate and the mixture is laid on the road surface like a normal tar road. The durability of the roads laid out with shredded plastic waste is much more as compared with roads of ordinary mix. While a normal 'highway quality' road lasts four to five years it is claimed that plastic-bitumen roads can last up to 10 years. Rainwater will not seep through it because of the plastic in the bitumen. So, this technology will result in lesser road repairs. And as each kilometre of road with an average width requires over two tonnes of polyblend, using plastic will help to reduce non-biodegradable waste. The cost of plastic road construction may be slightly higher compared to the conventional method. However, this should not deter the adoption of the technology as the benefits are much higher than the cost. Plastic increases the melting point of the bitumen and makes the road retain its flexibility during winters resulting in its long life. By mixing plastic with bitumen the ability of the bitumen to withstand high temperature is also increases. The plastic waste is melted and mixed with bitumen in a particular ratio. Normally, blending takes place when temperature reaches 45.5°C but when plastic is mixed, it remains stable even at 55°C. The vigorous tests at the laboratory level proved that the bituminous concrete mixes prepared using the treated bitumen binder fulfilled all the specified Marshall mix design criteria for surface course of road pavement. There was a substantial increase in Marshall Stability value of the BC mixes, of the order of two to three times higher value in comparison with the untreated or ordinary bitumen. Another important observation was that the bituminous mixes prepared using the treated binder could withstand adverse soaking conditions under water for longer duration.

The concept of utilization of plastic waste in construction of flexible road pavement has been found since 2000 in India. Use of plastic waste in the bitumen is similar to polymer modified bitumen. The blending of recycled LDPE to asphalt mixtures required no modification to existing plant facilities or technology [3]. Polymer modified bitumen has better resistance to temperature, water etc. This modified bitumen is one of the important construction materials for flexible road pavement [4]. Since 90's, considerable research has been carried out to determine the suitability of plastic waste modifier in construction of bituminous mixes [5-6]. Zoorab & Suparma [7] reported the use of recycled plastics composed predominantly of polypropylene and low density polyethylene in plain bituminous concrete mixtures with increased durability and improved fatigue life. Dense bituminous macadam with recycled plastics, mainly low density polyethylene (LDPE) replacing 30% of 2.36 to 5 mm aggregates, reduced the mix density by 16% and showed a 250% increase in Marshall Stability value; the indirect tensile strength (ITS) was also improved in the 'Plastiphalt' mixtures. Little [8] has found that resistance to deformation of bituminous concrete modified with low density polyethylene was improved in comparison with unmodified mixes. It was found that the recycled polyethylene bags may be useful in bituminous pavements resulting in reduced permanent deformation in the form of rutting and reduced low temperature cracking of pavement surfacing [9]. Bindu et al. [10] investigated the benefits of stabilizing the stone mastic asphalt (SMA) mixture in flexible pavement with shredded waste plastic. Conventional (without plastic) and the stabilized SMA mixtures were subjected to performance tests including Marshall Stability, tensile strength and compressive strength tests. Triaxial tests were also conducted with varying percentage of bitumen by weight of mineral aggregate (6% to 8%) and by varying percentage plastic by weight of mix (6% to 12% with an increment of 1%). Plastic content of 10% by weight of bitumen is recommended for the improvement of the performance of stone mastic asphalt mixtures. 10% plastic content gives an increase in the stability, split tensile strength and compressive strength of about 64%, 18% and 75% respectively compared to the conventional SMA mixes. Polymers and fibres are the commonly used stabilizing additives in SMA. Based on many research reports and engineering case studies [11] it has been shown that the use of stone mastic asphalt (SMA) on road surfaces can achieve better rut-resistance and durability. Recycled LDPE of a size between 0.30 and 0.92 mm replacing 15% aggregates in asphalt surfacing nearly doubled the Marshall quotient, and increased the stability retained (SR) by 15%, implying improved rutting and water resistance. A 20% increase of binder content was added in this case [12].

Plastic roads would be a boon for India's hot and extremely humid climate, where temperatures frequently cross 50°C and torrential rains create havoc, leaving most of the roads with big potholes. The government is keen on encouraging the setting up of small plants for mixing waste plastic and bitumen for road construction. It is hoped that in near future there will be strong, durable and eco-friendly roads which will relieve the earth from all type of plastic-waste. Therefore, keeping in mind the utility of plastic wastes in the flexible pavement construction the present study has been carried out, which will not only helpful in improving the stability of mixes but it will also help in mitigating the ill effects to the environment caused due dumping of these wastes.

TEST MATERIALS

In this study, the materials used are:

(i) Bitumen
(ii) Plastic waste (LDPE/PW)
(iii) Aggregates

Bitumen

The bitumen used in this study was of VG-30 grade. It was tested in the laboratory for basic conventional tests such as Penetration, Ductility, Softening Point, Specific Gravity, Viscosity and Flash Point. The results obtained from the above tests are tabulated in the Table-1.

Table-1 Properties of Bitumen

Property	Values	Test Method
Penetration	67 (1/10th of mm)	IS: 1203-1978
Ductility	74 cm	IS: 1208-1978
Softening Point	45^{0}C	IS: 1205-1978
Specific Gravity	1.021	IS: 1202-1978
Viscosity	2.25 Poise	IS: 1206-1978
Flash Point	225^{0}C	IS: 1209-1978

Low Density Polyethylene (LDPE)

Low Density Polyethylene (LDPE) comprises of house hold polythene and soft drink bottles that were collected from local dump sites. Collected waste materials were washed with soap and water and shredded into small pieces of size 2 to 3 mm by shredding machine. The physical properties of LDPE used in this study are given in Table-2.

Table-2 Properties of Low Density Polyethylene (LDPE)

Property	Value
Melting Temperature	> 240° C
Boiling Point	> 360° C
Glass Transition Temperature	80° C
Amorphous Density at 25° C	1.39 gm/cm^3
Molecular weight of repeat unit	199.2 gm/mol
Specific Gravity	1.40 gm/cm^3

Stone Aggregates

The physical properties of stone aggregates used in this study are shown in Table-3.

Table-3 Properties of Stone Aggregates

S. No.	Aggregate tests	Tests Results	Requirement as per Table 500-14 of MORTH (IV Revision) Specification
1.	Crushing Value (%)	24.8	-
2.	Impact Value (%)	20.0	Max 24 %
3.	Los Angeles Abrasion Value (%)	25.0	Max 30 %
4.	Water Absorption (%)	0.50	Max 2 %
5.	Specific Gravity of Coarse Aggregates	2.81	2.5-3.0
6.	Specific Gravity of Fine Aggregates	2.75	
7.	Specific Gravity of Filler	2.65	

Fillers

Fillers consist of finely divided mineral matter such as rock dust, hydrated lime or cement. Filler has an important effect on the voids content and the stiffness of the bitumen-fines matrix. The filler material used in the study is stone dust and cement. Out of the 5 percent filler, 3 percent stone dust and 2 percent cement was used. The grading requirements for mineral fillers indicated in Table-4.

Table-4 Grading requirements for Mineral Filler

IS Sieve (mm)	Cumulative Percent Passing by Weight of Total Aggregate
0.6	100
0.3	95-100
0.075	85-100

EXPERIMENTAL PROGRAMME

The present study deals with the preparation and testing of Dense Bituminous Macadam (DBM) mixes. In this study DBM mixes were prepared (as per the Marshall mix design procedure vide ASTM designation D 1559-62 T) by adding bitumen to the mix (as per the Job Mix Table-5) by weight of aggregates and the LDPE (PW) were added in different percentages to the mix by weight of bitumen (VG-30). Mixtures were prepared with 0, 8, 10, 12 and 14% by weight of bitumen. The Marshall specimens were kept in water bath at 60 ± 1ºC for 24 ± 1 hours. These are called conditioned specimens. The specimens kept in thermostatically controlled water bath maintained at 60 ± 1ºC for 30 to 40 minutes are called unconditioned specimens. The ratio of Marshall Stability values of conditioned specimens to that of unconditioned specimens is termed as Retained Stability. Marshall Stability tests were conducted on control (plain bitumen) and LDPE (PW) modified bituminous mixes.

Table-5 Job Mix for 50 mm DBM (Grade II)

Materials		Quantity (%)	Specific Gravity
Aggregates	25 - 10 mm	38	2.67
	10 - 5 mm	25	2.73
	5 mm	32	2.76
Fillers	3% Stone Dust+2%Cement	05	2.63

RESULT AND DISCUSSIONS

The results of Marshall Stability Tests are presented and discussed to bring out the effect of plastic waste on various properties of DBM mixes. The DBM mixes were prepared with plain bitumen as a control specimen and modified specimens were prepared with bitumen mixed with plastic waste.

Optimization of Plain Bitumen in the Mix

The Marshall Stability tests were conducted on the mix prepared with plain bitumen of VG-30 grade. On the basis of stability, flow, bulk density, air voids in the mix and voids in mineral aggregates values the optimum binder content was determined as 4.5%, which is shown in Table-6. It has been observed from the result shown in Table-6 that the mix possessed fair to good strength, however, the bulk density of the mix was on the lower side.

Table-6 Properties of the Mix (DBM) with Plain Bitumen

S. No.	Parameters	Values
1.	Marshall Stability Value (S)	889 kg
2.	Marshall Flow Value (F)	3.46 mm
3.	Bulk Density of the Mix (G_m)	2.01 g/cc
4.	Air Voids in the Mix (Vv)	5.65 %
5.	Voids in Mineral Aggregates (VMA)	14.20 %
6.	Voids Filled with Bitumen (VFB)	74.8%
7.	Optimum Bitumen Content	4.5%

Effect of LDPE On Strength of DBM Mixes

The plastic waste (PW) was mixed with bitumen in 2, 4, 6, 8, 10 and 12% and the Marshall Stability test was conducted on the specimens prepared with each percentage. The avarage values of all vital parameters were taken out of the three replicate tests specimens of most significant percentages (8, 10 and 12%) of plastic waste which are shown in Table-7 and Figs. 1 to 6.

The variation of stabilty value of the mix comprises of plain and modified bitumen shown in Table-7 and Fig. 1. It has been observed from Fig. 1 that the stability values of mixes modified with plastic waste have been increased significantly upto the tune of 14% at 12% waste as comapred to mix prepared with plain bitumen. This shows the enhancement in strength of the mix due to addition of plastic waste which siginifies that the inclusion of plastic waste increases the density of the mix.

Effect of LDPE On Flow Value of DBM Mixes

The variation of flow value of the mix is shown in Fig. 2. It is evident from the Fig. 2 that flow value of mix was decreasing with increase in the waste content in the mix from 8 to 12%. However, the maximum decrement in flow value is observed at 12% waste content which is about 34%. The decrease in flow value shows that the mix become more stable even at 60^0C temperature.

Effect of LDPE On Bulk Density of DBM Mixes

It is evident from Fig. 3 that the bulk density of the mix was also increasing with increase in the plastic waste content. The most significant percenatge of waste is observed as 12% at which the density is maximium (2.51g/cc). Which about 25% more than the density of the mix prepared with plain bitumen.

Effect of LDPE On Percenatge Air Voids of DBM Mixes

Fig. 4 shows the variation the Air Voids (Vv) values with waste content. It has been oberved that the Vv values were significantly changing from 5.65 to 3.17% from 0 to 12% waste content. However, the decrease in Vv values were observed as 44% at 12% waste content. The decrement in the Vv values show that the stability of the mixes were improving on addition of plastic waste.

Effect of LDPE On Voids in Mineral Agrregates of DBM Mixes

The variation of VMA of the mixes are shown in Fig. 5. It is evident from the Fig. 5 that VMA value of mix was increasing with increase in the waste content in the mix from 8 to 12%. However, the maximum increment in the VMA value is observed at 12% waste content which is about 44%.

Effect of LDPE On VFB of DBM Mixes

Fig. 6 shows the variation in the VFB values with waste content. It has been oberved that the decrement in the VFB values were observed at 10 and 12% waste content which are about 11 and 14% respectively.

Table-7 Results of DBM Mixes for Varying Percentage of LDPE

S. No.	LDPE Waste	Bitumen Content	Marshall Stability Value	Flow Value	Bulk Density of the mix	Air Voids	VMA	VFB
			S	F	G_m	V_v		
	%	%	kg	mm	gm/cc	%	%	%
1.	0.0	4.5	889.0	3.46	2.01	5.65	14.2	64.8
2.	8.0	4.5	945.0	2.60	2.25	4.83	16.9	69.7
3.	10.0	4.5	970.5	2.41	2.35	4.20	19.8	71.6
4.	12.0	4.5	1012	2.30	2.51	3.17	20.5	73.9

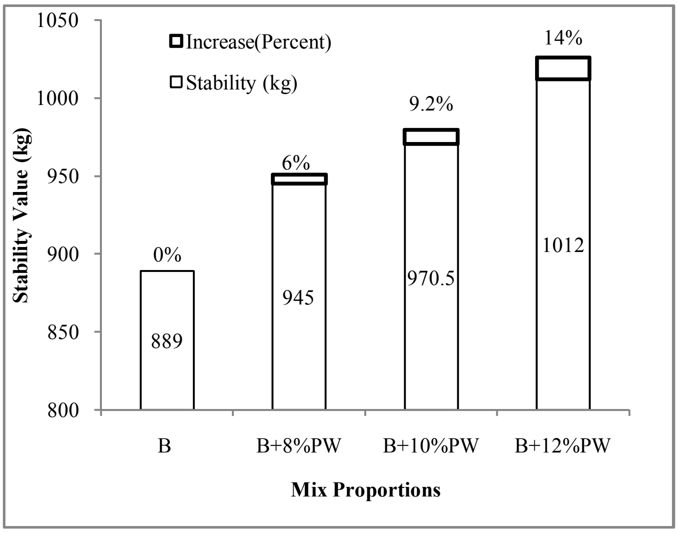

Fig. 1 Variation of Stability Values of Mixes with LDPE (PW)

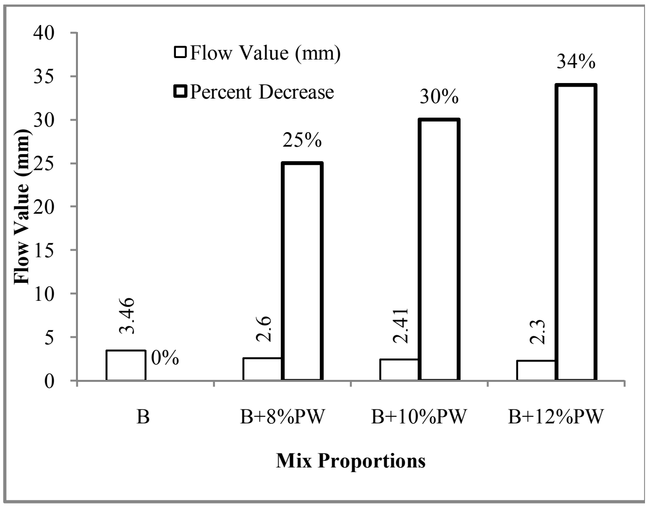

Fig. 2 Variation in Flow Values of Mixes with LDPE (PW)

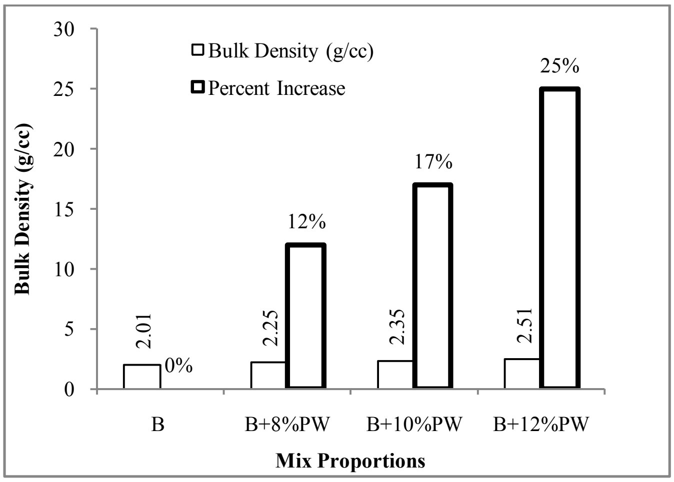

Fig. 3 Variation in Bulk Densities of Mixes with LDPE (PW)

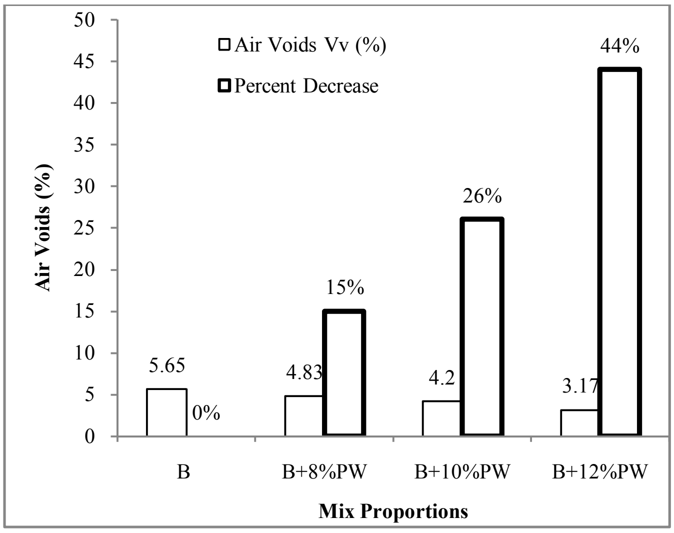

Fig. 4 Variation in Air Voids (Vv) of Mixes with LDPE (PW)

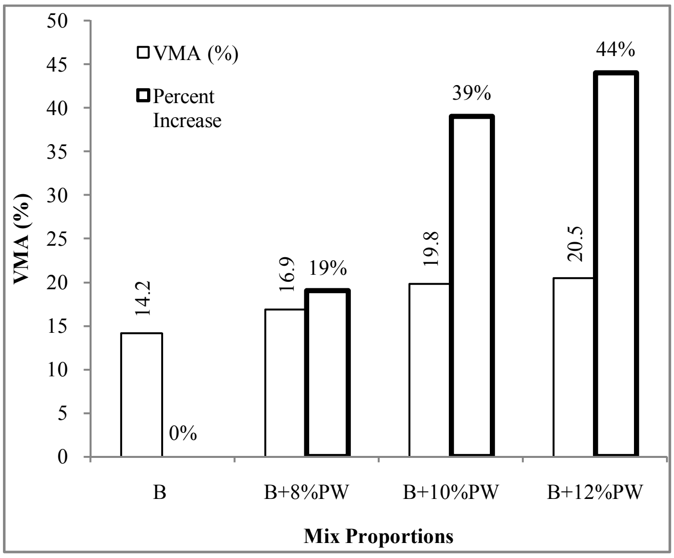

Fig. 5 Variation in VMA of Mixes with LDPE (PW)

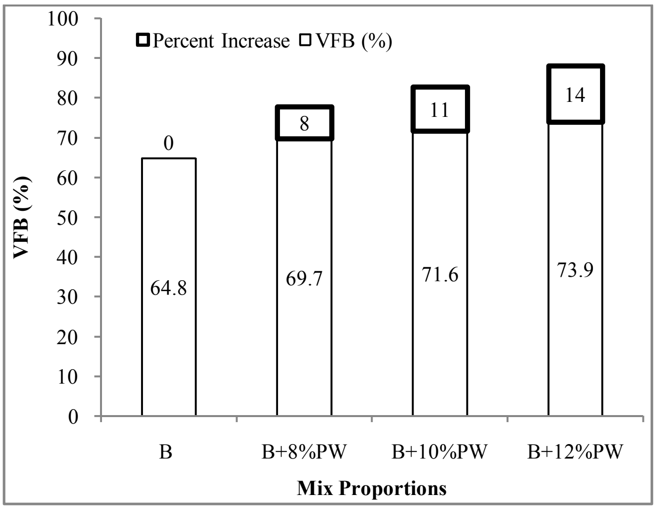

Fig. 6 Variation in VFB of Mixes with LDPE (PW)

Boiling Test

The test was carried out as per ASTM D-3625 1991. 250 gm of clean, oven dried aggregates passing 20 mm and retained on 12.5 sieves were heated to 160ºC and 14 gm of bitumen heated separately to 150ºC was mixed with aggregates. The mixture was allowed to cool down to 80ºC to 100ºC and then was added to boiling water. The content was boiled for 10 minutes (ASTM D3625, 1991). The average percent area of the aggregate surface stripped off bitumen was visually determined after the content of the beaker were allowed to cool to room temperature. There is significant improvement in the stripping characteristics by the use of plastics waste has been observed as shown in Table-8. There was no stripping observed for mixes after addition of waste plastics. From Table-8 it is evident that there was no stripping observed for the mix with addition of 10% and 12% waste plastics.

Table-8 Stripping Value of Control and Modified Bituminous Mixes

Mix	**Stripping Value (%)**	**Specifications as per MORT&H (2001)**
Mix without Plastics Waste (at 4.50%) bitumen content (Control Specimen)	2.5	Stripping Value (Average of percentage of area on aggregates surface stripped off from bitumen) should not be more than 5%
Mix with 10% LDPE (Modified Specimen)	0.0	
Mix with 12% LDPE (Modified Specimen)	0.0	

CONCLUSIONS

The result of present study clearly shows that the stability of DBM mixes was improved significantly on addition of plastic wastes to the mixes. The coating of the plastic modified bitumen was also improved significantly as compared to plain bitumen. Hence, the present study will result lesser road repairs and use of plastic wastes will help to utilize non biodegradable waste.

The addition of LDPE (PW) reduces the air voids which prevents the moisture absorption and oxidation of bitumen by entrapped air. This has resulted in enhancement of Marshall Stability value.

It has been observed that the stability values of mixes modified with plastic waste have been increased significantly upto the tune of 14% at 12% waste as comapred to mix prepared with plain bitumen. This shows the enhancement in strength of the mix due to addition of plastic waste which siginifies that the inclusion of plastic waste increases the density of the mix.

The flow value of mix was decreasing with increase in the waste content in the mix from 8 to 12%.

The bulk density of the mix was also increasing with increase in the plastic waste content. The most significant percenatge of waste is observed as 12% at which the density is maximium (2.51g/cc). Which is about 25% more than the density of the mix prepared with plain bitumen.

The decrement in the Vv values show that the stability of the mixes were improving on addition of plastic waste.

The VMA value of mix was increasing with increase in the waste content in the mix from 8 to 12%. However, the maximum increment in the VMA value is observed at 12% waste content which is about 44%.

It has been oberved that the decrement in the VFB values were observed at 10 and 12% waste content which are about 11 and 14% respectively.

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