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Araştırma Makalesi / Research Article

Effect of Polyolefin Modified Bitumen on Marshall Stability

M. Mevlüt AKMAZ[1*], Osman Nuri ÇELİK[2]

[1,2] *Konya Teknik Üniversitesi, Mühendislik ve Doğa Bilimleri Fakültesi, İnşaat Mühendisliği Bölümü, Konya.*

Sorumlu yazar e-posta: [1]mmakmaz@ktun.edu.tr , [1]ORCID ID: http://orcid.org/0000-0003-3558-7596
[2]oncelik@ktun.edu.tr , [2]ORCID ID: http://orcid.org/0000-0001-5368-0685

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Keywords
Stability; Pyrolysis; Polypropylene; Polyethylene; Modified bitumen.

Abstract

It is possible to improve the performance of the hot mix asphalt (HMA) by improving the properties of the materials (aggregate, bitumen) used in the HMA or by the addition of some special materials. In this study; polypropylene (PP) and high density polyethylene (HDPE) waste plastics were co–pyrolyzed at a temperature range of 300–350 °C. 2, 4, 5 and 6 % modified bitumen were made by using the solid product (char–additive) obtained from co–pyrolysis and pure 50/70 penetration grade bitumen. RV (rotational viscometer) tests were applied to pure and modified bitumens at different temperatures (60–165 °C) and the optimum rate of PP–HDPE additive was determined to be 5 %. Then; two different HMA sample series were prepared with Marshall apparatus using pure and 5 % PP–HDPE modified bitumen. For Marshall Mix design, sample series were formed at bitumen rates 3.5; 4; 4.5; 5 and 5.5 % and four HMA samples were produced at each bitumen rate. The samples were weighed in water, dry and saturated surface–dry. The heights of the samples were measured and the Marshall stability and flow values were determined by applying a load at a certain speed (50 mm/min). As a result; compared to the pure HMA, it was observed that the Marshall stability of the modified HMA increases between about 8.5 and 13 %.

Poliolefin Modifiye Bitümün Marshall Stabilitesi Üzerindeki Etkisi

Anahtar kelimeler
Stabilite; Piroliz; Polipropilen; Polietilen; Modifiye Bitüm.

Öz

Bitümlü sıcak karışımda (BSK) kullanılan malzemelerin (agrega, bitüm) özelliklerini iyileştirerek veya bazı özel malzemeler ilave ederek, BSK'nın performansını artırmak mümkündür. Bu çalışmada; polipropilen (PP) ve yüksek yoğunluklu polietilen (YYPE) atık plastikleri 300–350 °C sıcaklık aralığında birlikte piroliz edildi. Pirolizden elde edilen katı ürün (çar–katkı maddesi) ve saf 50/70 penetrasyon dereceli bitüm kullanılarak, % 2, 4, 5 ve 6 oranlarında modifiye bitümler yapıldı. Saf ve modifiye bitümlere, farklı sıcaklıklarda (60–165 °C) RV (dönel viskozimetre) testleri uygulandı ve PP–YYPE katkısının optimum oranı % 5 olarak belirlendi. Sonra; saf ve % 5 PP–YYPE modifiye bitüm kullanılarak, Marshall aparatı ile iki farklı BSK numune serisi hazırlandı. Marshall karışım tasarımı için, % 3,5; 4,0; 4,5; 5,0 ve 5,5 bitüm oranlarında numune serileri oluşturuldu ve her bir bitüm oranında 4 BSK numunesi üretildi. Kuru ve doygun yüzey–kuru olarak tartılan numuneler, su içinde tartıldı. Numunelerin yükseklikleri ölçüldü ve belirli bir hızda (50 mm/dakika) bir yük uygulanarak, Marshall stabilite ve akma değerleri belirlendi. Sonuç olarak; saf BSK ile karşılaştırıldığında, modifiye BSK'nın Marshall stabilitesinin yaklaşık % 8,5 ila 13,0 arasında arttığı gözlenmiştir.

1. Introduction

There are many features expected from the asphalt pavement. The most important of these are to ensure the comfort and safety of the road users and to ensure that the road is long–lasting and economical.

In the asphalt pavement, cracks or deterioration occur after a period of time. Degradation of the pavements; generally, not enough quality materials are used, road infrastructure and superstructure is not built in accordance with the standards, or the number of project axle load repetition is exceed and road maintenance cannot be done well enough.

Therefore, the asphalt pavements are improved and higher strength is obtained by reducing the permanent deformations that occur under traffic load. Thus, the performance of the asphalt pavement is tried to be improved by modifying the bituminous binder. Because, the performance of the asphalt pavements greatly affects the quality of the bituminous binder used in the mixture.

Hınıslıoğlu and Ağar (2004) investigated the possibility of using various plastic wastes containing High Density Polyethylene (HDPE) as polymer additives to asphalt concrete. It was investigated that the influence of HDPE content on the Marshall stability, flow and Marshall Quotient (stability to flow ratio). HDPE modified asphalt concrete has been shown to provide a considerable increase in the Marshall Stability and Quotient values. Al–Hadidy (2006) investigated the potential use of pyrolysis polypropylene (PP) as modifiers in hot mix asphalt paving mixtures. Optimum bitumen content was obtained by Marshall Method and used in all the modified mixes. The results indicated that the inclusion of pyrolysis PP with asphaltic concrete mixtures gave a quite satisfactory result in terms of stability and other Marshall properties. Awwad ve Shbeeb (2007) determined the best type of polyethylene ((HDPE) and Low Density Polyethylene (LDPE)) to be used and its proportion. They were added to coat the aggregate. Marshall Mix design was used, first to determine the optimum bitumen binder content and then further to test the modified mixture properties. The results indicated that grinded HDPE polyethylene modifier provides better engineering properties. It was found to increase the stability, reduce the density and slightly increase the air voids and the voids of mineral aggregate. Tapkın (2008) manufactured asphalt concrete specimens with PP fibres at the optimum bitumen content. It was observed for fibre-reinforced specimens that the Marshall Stability values increased and flow values decreased in a noticeable manner. Attaelmanan al. (2011) blended different ratios of HDPE by weight of bitumen with 80/100 paving grade bitumen. The analyses of test results showed that the performance of HDPE-modified asphalt mixtures are better than conventional mixtures. A HDPE content of 5% by weight of asphalt was recommended similar to that investigated in this study. Abtahi al. (2011) selected PP fibres as modifier because of their low-cost and consistency with asphalt pavement. Asphalt specimens were made by a Superpave gyratory compactor (SGC), analyzed by both Marshall and Superpave methods and tested by Marshall Stability apparatus. The experimental results showed that adding PP fibre increases the Marshall stability and the air voids while reducing the flow properties. Qadir (2013) prepared two types of asphalt concrete samples namely control samples (without PP addition) and modified samples (with PP modification). Marshall Mix design was used for determining the optimum bitumen content for both sample types. The PP fibres were found to increase the Marshall Stability by almost 25%. Sadeque ve Patil (2014) evaluated the effect of waste LDPE, PP, crumb rubber obtained from waste tyre (CR) and nanoclay (MMT) on Marshall Stability. The result of experimental study showed that there is significant improvement in the Marshall Stability of bitumen due addition of waste polymer and nanoclay. Gibreil ve Feng (2017) investigated HDPE and crumb rubber powder (CRP) on the properties of hot mix asphalt. The results showed that using HDPE and CRP as modifiers improves the physical properties of asphalt and Marshall properties of HMA mixtures.

Some research on PP and HDPE is presented in the paragraph above. In this study; it is considered that plastic wastes (PP and HDPE) can be recycled with a different method as a result of the use in bitumen modification.

2. Material and Method

In this study; PP and HDPE waste plastics were co–pyrolyzed. The pyrolysis solid product was mixed with pure 50/70 penetration grade bitumen and modified bitumens were obtained. RV (rotational viscometer) tests were applied to pure and modified bitumens and the optimum rate of PP–HDPE additive was determined. Then; Marshall Mix Design was carried out using pure and 5 % PP–HDPE modified bitumen.

2.1. Pyrolysis

The pyrolysis process of the wastes (polypropylene (PP) and high density polyethylene (HDPE)) was carried out in the pyrolysis test system in the Transportation Laboratory of Konya Technical University. This system is shown in Figure 1. This test system consists of three different units. These units are reactor (furnace), condensation (liquid product collection) and control unit. The solid, liquid and gas products were obtained from pyrolysis and the product yields were 56,04; 32,37 and 11,59 %, respectively.

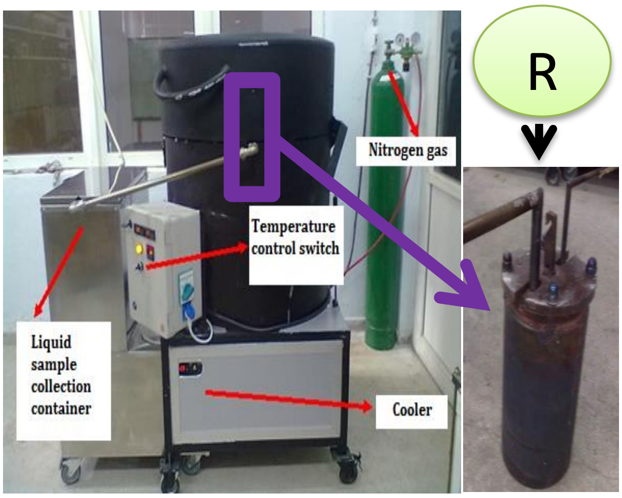

Figure 1. Pyrolysis test system and units

2.2. Modification

At the end of pyrolysis of PP–HDPE plastic mixture; the solid product was mixed with pure bitumen. Modified bitumen was obtained by adding 2, 4, 5 and 6 % of the bitumen weight to the pure bitumen. Modification parameters: 160–170 °C temperature, 15 min. 500 rpm pre–mixing and 45 min. 1300 rpm high mixing was determined. The same processes were applied for modified bitumens using a high shear polymer modified mixer.

2.3. RV (Rotational Viscometer) test

The viscosity values of the pure and modified bitumens were determined by using the test device described as "Brookfield Viscometer". Viscosity readings were made by using spindle number 27 and applying the necessary test conditions. Viscosity was performed at a temperature range of 60–165 °C and increasing temperatures every 15 °C. Based on the viscosity change of the each modified bitumen, the optimum rate of PP–HDPE additive was determined.

2.4. Marshall mix design

The Marshall method of mix design is for dense–graded HMA (hot mix asphalt) mixes. It is used almost everywhere in the world. For a single selected aggregate gradation, five different asphalt contents are tested for various volumetric and strength criteria to select the optimum binder content. The test results should always be reported as the average for three compacted, "identical" specimens (Anonymous 2014). For Marshall Mix design; aggregate gradation was determined, HMA sample series were produced using two different bitumen and the related test processes were applied to the samples.

2.4.1. Gradation

It has long been established that the gradation of the aggregate is one of the factors that must be carefully considered in the design of asphalt paving mixtures (Anonymous 2014). The amount of each aggregate size fraction required to produce a batch of one sample (about 1200 g.) will result in a height of 2.5 ± 0.1 inches (63.5 ± 2.5 mm) (ASTM 2016). The aggregate gradation criteria given in Table 1 should be considered in the design of the HMA.

Table 1. Aggregate gradation design (selected) and criteria (Anonim 2013) for HMA Design

Size fraction mm (inç., No.)	Type–1 (Passed %)		Design (selected) gradation (%)
	Lower limit	Upper limit	
19,0 (3/4")	100		100
12,5 (1/2")	88	100	93
9,5 (3/8")	72	90	78
4,75 (No. 4)	42	52	47
2,0 (No. 10)	25	35	33
0,425 (No. 40)	10	20	15
0,180 (No. 80)	7	14	11
0,075 (No. 200)	3	8	6

Thus, taking into account the aggregate gradation criteria within the scope of Marshall Mix design, aggregate groups consisting of 1200 g. were formed for the HMA samples. Table 1 shows the aggregate gradation design (selected) and criteria and Figure 2 shows the gradation curve.

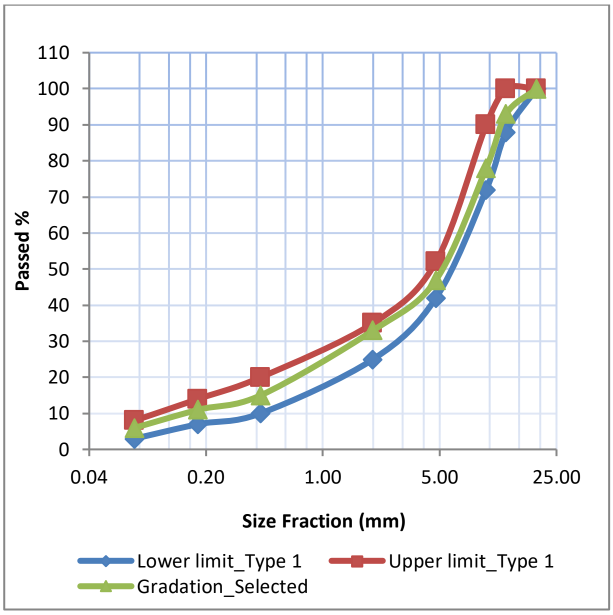

Figure 2. Aggregate gradation curve

2.4.2. HMA sample preparation

The asphalt binder used in preparing the HMA samples must be heated to the range of mixing temperatures recommended for manufacturer / supplier or must be heated to the range of mixing and compaction temperatures to produce a viscosity of 170 ± 20 cP (170 ± 20 mPa.s) and 280 ± 30 cP (280 ± 30 mPa.s), respectively (ASTM 2016). As a result of the viscosity (RV) measurements, the mixing temperature ranges of pure and 5 % PP–HDPE modified bitumen are in the range of 156–162.5 and 157–163.5 °C, respectively; the compaction temperature ranges are in the range of 144.5–149 and 146–150 °C, respectively. These temperatures were taken into account in the production of HMA samples. In the Marshall Mix design, sample series were formed at bitumen rates 3.5; 4; 4.5; 5 and 5.5 % and four HMA samples were produced at each bitumen rate.

2.4.3. Marshall stability and other processes

A minimum of three specimens of a given mixture shall be tested. The specimens should have the same aggregate type, quality, and grading; the same mineral filler type and quantity; and the same binder source, grade and amount. In addition, the specimens should have the same preparation, that is, temperatures, cooling, and compaction. Specimens should be cooled to room temperature after compaction. During cooling they should be placed on a smooth, flat surface. Bulk specific gravity of each specimen shall be determined and thickness of each specimen shall be measured (ASTM 2015). For bulk specific gravity; the specimen is immersed in a water bath at 25 °C. The mass under water is recorded, and the specimen is taken out of the water, blotted quickly with a damp cloth towel, and weighed in air (ASTM 2017). Then, the Marshall stability and flow values were determined by applying a load at a certain speed (50 mm/min). Figure 3 shows the HMA samples and the situation after the stability measurement.

Figure 3.a. HMA samples for one serial

Figure 3.b. The situation after the stability measurement

3. Results

3.1. RV tests and optimization

The results of RV tests of pure and modified bitumens are given in Table 2. Viscosity measurements were made in the temperature range of 60 to 165 °C.

Table 2. Viscosity values (60–165 °C)

Temperature ºC	Viscosity values (cp = mPa.s)				
	Pure 50/70	2 % Pp-Hdpe	4 % Pp-Hdpe	5 % Pp-Hdpe	6 % Pp-Hdpe
60	262.500	379.466,7	426.000	477.500	497.500
75	41.230	53.890	58.900	71.253,3	74.170
90	9.536,7	11.096,7	11.820	12.880	13.376,7
105	2.897	3.156	3.208,7	3.358	3.471
120	1.084	1.115,7	1.141	1.176	1.204,7
135	474,2	487,5	500	512,1	518,8
150	241,2	242,5	244,2	250,9	255,9
165	130,9	132,1	135	137,1	137,5

The optimum rate of PP–HDPE additive was investigated. For this purpose, viscosity values given in Table 2 were used. The lowest additive rate that creates the most behavioral changes when added to the bitumen was investigated and it was assumed that this rate was the optimum amount to be added to the bitumen for that additive. In determining the optimum amount, the changes in bitumen viscosity for the unit change in the amount of additive added to the bitumen were calculated proportionally (Arslan 2010).

The calculation intervals and the calculation method used in these intervals for the optimum rate of PP–HDPE additive are shown in Table 3. Considering the situation mentioned in Table 3, the viscosity change (%) formed by the addition of additive is shown in Table 4. Table 4 shows that the highest change (%) with the addition of 5 %. Thus, the optimum rate of the PP–HDPE additive was determined to be 5 %.

Table 3. Calculation intervals and calculation method used in these intervals (Arslan 2010)

Calculation intervals	Calculation method
0 % – 2 %	(Proportional change between viscosity of pure and 2% modified bitumen) / 2
2 % – 4 %	(Proportional change between viscosity of 2 % and 4 % modified bitumen) / 2
4 % – 5 %	Proportional change between viscosity of 4 % and 5 % modified bitumen
5 % – 6 %	Proportional change between viscosity of 5 % and 6 % modified bitumen

Table 4. Viscosity change with additive

Temperature ºC	Viscosity change of the each calculation intervals (%)			
	0 % – 2 %	2 % – 4 %	4 % – 5 %	5 % – 6 %
60	**22,28**	6,13	12,09	4,19
75	15,35	4,65	**20,97**	4,09
90	8,18	3,26	**8,97**	3,86
105	4,47	0,83	**4,65**	3,37
120	1,46	1,14	**3,07**	2,44
135	1,40	1,28	**2,42**	1,31
150	0,26	0,35	**2,73**	1,99
165	0,47	1,10	**1,56**	0,29

3.2. Marshall mix design results

The Marshall Mix design was conducted to evaluate the effect of the PP–HDPE additive on the stability of the HMA. In addition, the optimum bitumen rate in the HMA was determined by the Marshall Mix design. Within the scope of the design, the maximum load to which each cylindrical HMA sample can resist and the flow values corresponding to this load were measured. At the same time, heights and weights of each sample were measured and density and volume calculations were made before stability and flow measurements. Table 5 and 6 shows stability (kg.), flow (mm) and mixture bulk specific gravity (G_{mb}) values of the each HMA series.

Table 5. Results of Marshall mix design made with pure bitumen (50/70)

Bitumen rate (%)	Bulk specific gravity (G_{mb})	Marshall stability (kg.)	Flow (mm)
3,5	2,410	1.272,61	3,47
4,0	2,439	1.406,99	3,79
4,5	2,451	1.266,51	3,92
5,0	2,459	1.174,01	4,66
5,5	2,453	1.108,09	5,19

When the tables 5 and 6 are examined, it is seen that the stability of the HMA samples produced with 5 % PP–HDPE modified bitumen is increased compared to the HMA samples produced with pure (50/70) bitumen. Table 7 shows this increase in stability values proportionally (percentage change).

Table 6. Results of Marshall mix design made with 5 % PP–HDPE modified bitumen

Bitumen rate (%)	Bulk specific gravity (G_{mb})	Marshall stability (kg.)	Flow (mm)
3,5	2,409	1.436,44	3,32
4,0	2,439	1.548,95	3,70
4,5	2,451	1.373,56	4,02
5,0	2,459	1.289,26	4,33
5,5	2,454	1.213,12	4,95

Table 7. Increased Marshall Stability (%)

Bitumen rate (%)	Increased stability (%)
3,5	12,87
4,0	10,09
4,5	8,45
5,0	9,82
5,5	9,48

4. Discussion and Conclusion

As a result of the RV and Marshall tests, the following determinations were reached:
- When Table 7 is examined; it is seen that the highest increase rate is 12,78 % (3.5 % bitumen), the lowest increase rate is 8,45 % (4.5 % bitumen) and stability increases between these two values.
- Table 4 shows that the highest change (%) with the addition of 5 %. Thus, the optimum rate of the PP–HDPE additive was determined to be 5 %.
- According to the RV test results given in Table 2, viscosity increases at all temperatures in modified bitumen, but this increase decreases at 150 and 165 °C and viscosity approaches to pure bitumen. Therefore, it has been found that the mixing and compaction temperatures are also close to each other. Although the workability of the mixture may be adversely affected by the increase in viscosity of the bitumen; it is believed that the PP–HDPE additive does not adversely affect the workability of the mixture due to the close temperatures. As a result of RV tests, the mixing temperature ranges of pure and 5 % PP–HDPE modified bitumen are in the range of 156–162.5 and 157–163.5 °C; the compaction temperature ranges are in the range of 144.5–149 and 146–150 °C, respectively. In addition, attention was paid to these temperatures in HMA samples produced with both modified and pure bitumen. That is, it can be said that all HMA samples are produced in the same viscosity state of the bitumen and the workability of the mixture is similar. In this case, the mixtures are expected to have close density. As shown in Tables 5 and 6, the bulk specific gravity (G_{mb}) values show affinity.

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5. References

Anonymous, 2014. MS–2 Asphalt Mix Design Methods, Seventh Edition, Asphalt Institute, USA, 77–88.

Abtahi, S.M., Ebrahimi, M.G., Kunt, M.M., Hejazi, S.M. and Esfandiarpour, S., 2011. Production of Polypropylene–reinforced Asphalt Concrete Mixtures Based on Dry Procedure and Superpave Gyratory Compactor. *Iranian Polymer Journal*, **20**, 813–823.

Al–Hadidy, A.I., 2006. Evaluation of Pyrolisis Polypropylene Modified Asphalt Paving Materials. *Al–Rafidain Engineering*, **14**(2), 36–50.

Anonim, 2013. Karayolu Teknik Şartnamesi. KGM (Karayolları Genel Müdürlüğü), Ankara, 407/1–18.

Arslan, D., 2010. Esnek üstyapıların performans özelliklerinin sentetik metal ve polibor katkı maddeleriyle geliştirilmesi. Doktora Tezi, Gazi Üniversitesi Fen Bilimleri Enstitüsü, Ankara, 298.

ASTM D 6926–16, 2016. Standard Practice for Preparation of Asphalt Mixture Specimens Using Marshall Apparatus.

ASTM D 6927–15, 2015. Standard Test Method for Marshall Stability and Flow of Asphalt Mixture.

ASTM D2726/D2726M−17, 2017. Standard Test Method for Bulk Specific Gravity and Density of Non−Absorptive Compacted Asphalt Mixtures.

Attaelmanan, M., Feng, C.P. and Al–Hadidy, A.I., 2011. Laboratory evaluation of HMA with high density polyethylene as a modifier. *Construction and Building Materials*, **25**, 2764–2770.

Awwad, M.T. and Shbeeb, L., 2007. The Use of Polyethylene in Hot Asphalt Mixtures. *American Journal of Applied Sciences*, **4**(6), 390–396.

Gibreil, H.A.A. and Feng C.P., 2017. Effects of high density polyethylene and crumb rubber powder as modifiers on properties of hot mix asphalt. *Construction and Building Materials*, **142**, 101–108.

Hınıslıoğlu, S. and Ağar, E., 2004. Use of waste high density polyethylene as bitumen modifier in asphalt concrete mix. *Materials Letters*, **58**, 267– 271.

Qadir, A., 2013. Rutting performance of polypropylene modified asphalt concrete. *International Journal of Civil Engineering, Transaction A: Civil Engineering*, **12**(3), 304–312.

Sadeque, M. and Patil, K.A., 2014. Marshall Properties of Waste Polymer and Nanoclay Modified Bitumen. *Architecture and Civil Engineering*, **12**(1), 1–9.

Tapkın, S., 2008. The effect of polypropylene fibers on asphalt performance. *Building and Environment*, **43**, 1065–1071.