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M.Sc. in Civil Engineering

İBRAHİM SOYBAKIŞ

REPUBLIC OF TURKEY

GAZİANTEP UNIVERSITY

GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

INFLUENCE OF PET WASTE ON THE PROPERTIES OF ASPHALT CONCRETE

M.Sc. THESIS

IN

CIVIL ENGINEERING

BY

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Gaziantep University

Supervisor

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Co-Supervisor

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by

İbrahim SOYBAKIŞ

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İbrahim SOYBAKIŞ

ABSTRACT

INFLUENCE OF PET WASTE ON THE PROPERTIES OF ASPHALT CONCRETE

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As a result of the rapid growth of the world and the rapid development of technology, plastic materials which are easy to manufacture have become widely used. As a result of the use of plastics, the amount of waste has been greatly increased and these materials have been recycled. Plastic wastes can be reused in various sectors. PET bottles cause environmental pollution and do not dissolve in nature for a long time. Most of the roads in our country and in the world consist of bituminous pavements (bituminous hot mixture). Maintenance costs of these deteriorated roads are quite high. Bituminous mixtures containing waste plastic can solve this problem by extending the life of the roads. In this study, waste PET bottles were used in asphalt and their effects on asphalt were investigated. In order to remove plastic wastes from nature and recycle them, these wastes were added to asphalt concrete and the coating was thought to have better physical and mechanical properties. In the experimental study, the ground pet bottle wastes have been added to the asphalt mixture in the ratios determined as 0.3%, 0.4%, 0.5%, and 0.6% of the total mixture weight. Marshall Design method was used to find the optimum bitumen ratio with and without additives. Marshall Samples were prepared according to the binder layer aggregate gradation as specified in the Highways Technical Specification (KTŞ). In experiments, 50/70 penetrated bitumen was used at a mixture temperature of 145 °C. According to the test results, it has been observed that the use of PET bottle waste in asphalt mixtures improved the mechanical properties of the asphalt considerably.

Keywords: Waste PET Bottle, Marshall Mixture Design Method, Stability, Flow.

ÖZET

PET ATIKLARININ ASFALT BETONU ÜZERİNDEKİ ETKİLERİ

SOYBAKIŞ, İbrahim
Yüksek Lisans, İnşaat Mühendisliği
Danışman: Doç. Dr. Nihat ATMACA
İkinci Danışman: Doç. Dr. Adem ATMACA
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94 sayfa

Dünyanın hızla büyümesi ve teknolojinin hızlı bir şekilde gelişmesi sonucunda maliyet, üretim kolaylığı ve temin edilebilirliği kolay olan plastik maddeler günlük çok yaygın şekilde kullanılmaya başlanmıştır. Plastiklerin kullanılması sonucunda atık miktarı aşırı derecede artmıştır. Plastik atıklar çeşitli sektörlerde tekrar kullanılabilme özelliğine sahiptir. Çevre açısından uzun süre doğada kaybolmayan ve özelliklerini kaybetmeyen PET şişeler de bu kapsamda değerlendirilip tekrar kullanılabilmektedir. Ülkemizde ve dünyada yolların büyük bir bölümü bitümlü kaplamalardan (bitümlü sıcak karışım) oluşmaktadır. Bozulan bu yolların bakımı büyük bir ekonomik maliyet getirmektedir. Atık plastik içeren bitümlü karışımlar bu soruna bir çözüm yolların ömrünü uzatarak bu soruna çözüm getirebilir. Bu çalışmada atık pet şişelerin asfalt içerisinde kullanılarak asfaltın üzerindeki etkileri araştırılmıştır. Plastik atıkları hem doğadan yok etmek hem de yeniden değerlendirmek amacıyla asfalt betonun içine katılmış ve kaplamanın daha iyi fiziksel ve mekanik özelliklere sahip olması düşünülmüştür. Deneysel çalışmada öğütülmüş pet şişe atıkları, toplam karışım ağırlığının %0,3, % 0,4, %0,5 ve %0,6‘sı olarak belirlenen oranlarda asfalt karışımı üzerine uygulanmıştır. Katkılı ve katkısız en uygun bitüm oranının bulunması için Marshall Dizayn metodu uygulanmıştır. Marshall Numuneleri karayolları Teknik Şartnamesinde Belirtildiği (KTŞ) gibi binder tabakası agrega gradasyonu temel alınarak hazırlanmıştır. Yapılan deneylerde 50/70 pentrasyonlu bitüm 145 °C karışım sıcaklığında kullanılmıştır. Yapılan laboratuvar çalışmalarından elde edilen test sonuçlarına göre, atık pet şişe ilavesiyle katkılı asfalt karışımlarının mekanik özelliklerinde önemli ölçüde iyileşmeler gözlemlenmiştir.

Anahtar Kelimeler: Atık Pet Şişe, Marshall Karışım Dizayn Metodu, Stabilite, Akma.

''Dedicated to my family''

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LIST OF ABBREVIATIONS

ABC	Acrylonitrile Butadiene Styrene
ABC	Acrylonitrile Butadiene Styrene
KTŞ	T.C. Highway Technical Specification
ASMÜD	Asphalt Contractors Association of Turkey
ASTM	American Society for Testing and Materials
EN	European Norm
HMA	Hot Mix Asphalt
KGM	T. C. General Directorate of Highways
PA	Nylon
PC	Polycarbonate
PE	Polyethylene
PET(E)	Polyethylene Terephthalate
PLA	Polylactic Acid
PMMA	Acrylic
POM	Polyoxymethylene
PP	Polypropylene
PS	Polystyrene
PSW	Plastic Solid Waste
PVC	Polyvinyl Chloride
SMA	Stone Mastic Asphalt
TFOT	Thin Film Oven Test
TS	Turkish Standard
VFA	Voids Filled with Asphalt
VMA	Voids Mineral Aggregate

CHAPTER I

INTRODUCTION

1.1 Definition of the Problem

Plastic materials used in many different industries have become the main consumer of the society and the use of plastics results in excessive waste generation [1]. The limited storage area of the waste materials and unconsciously storing these materials causes environmental pollution. Only 9% of these plastic wastes are recyclable. Non-recyclable wastes cause pollution in land and oceans [2]. Therefore, plastic wastes need to be stored and recycled. The recycling of plastic wastes after consumption will help to conserve natural resources, prevent environmental pollution and save energy [3].

Recyclable wastes such as glass, metal, plastic and paper can be converted to a new raw material or product by physical and chemical processes [4]. Recycling is the use of these wastes as a second raw material after some processes. The main advantages of recycling plastics; reduction of the need for raw materials, preventing the natural balance of consumption resulting from population growth, preventing waste from polluting the environment, providing energy saving by using waste instead of producing new materials [5].

The most suitable plastics for recycling are PVC (Polyvinyl Chloride), PE (Polyethylene), PET (Polyethylene Terephthalate), PP (Polypropylene). Certain stages of the recovery of plastics solid wastes are collection of plastics from solid waste, if necessary, compacting and concentration of collected wastes, classification and processing of condensed waste plastics [6]. Some of the materials obtained from the recycling of plastic are: greenhouse cover, plastic bag in automotive sector, marley, waste water pipe, fiber and filling material, car spare parts making, detergent bottles, trash cans and similar products, rain water and waste water pipes, various plastic filling materials, various plastic toys and stationery supplies etc [7].

The negative effects of the asphalt roads that we use today and the effort to prevent the environmental pollution that surround the world have led to the development of a revolutionary project. The sustainable road project from recycled plastic was developed [8]. Most of the roads in Turkey and in the world consist of bituminous pavements (bituminous hot mixture). Maintenance of these deteriorated roads creates a great economic cost. Bituminous mixtures containing waste plastic can solve this problem by extending the life of the roads. In this study, the effect of granular PVC wastes on bituminous coating (bituminous hot mixture) was investigated.

1.2 Purpose and Scope of the Study

In this study, waste PET bottles were used in asphalt and their effects on asphalt were investigated. In order to remove plastic wastes from nature and recycle them, these wastes were added to asphalt concrete and the coating was thought to have better physical and mechanical properties.

1.3 Outline of the Thesis

This thesis consists of 5 chapters. The sections of thesis and contents of these sections are as follows:

In Chapter 1, main problems those led to this study are tried to be explained. Purpose and scope of the study are tried to be identified.

In Chapter 2, a detailed literature review and general background information about asphalt layers, types and history were presented. In addition, detailed information about the effect of PVC dust on asphalt road applications has been explained.

In Chapter 3, this chapter includes the information about the materials those are utilized in the study. Main properties of waste PVC samples, aggregates and bitumen were given. Also, test methods used in the study and their specifications were presented. Test methods include the tests applied to aggregates, bitumen and asphalt mixtures.

In Chapter 4, this chapter includes the results of aggregate tests, bitumen tests, Marshall Mix Design tests and wheel tracking test were explained.

In Chapter 5, the results of the study have been concluded and some inferences and suggestions have been done.

CHAPTER II

LITERATURE REVIEW

2.1 Asphalt

Asphalt is a mixture of dark bituminous pitch with sand or gravel, used for surfacing roads, flooring, roofing, etc. The use of asphalt type materials as building material has started as a result of the accumulation of bitumens on the lake floor and rocky ground (as a mixture of sand, lime and bitumen) [9]. In 526 BC, it was documented that Bitumen was used as a road construction material in the period of Nabopolassar, king of Babylon, and this is the first document recorded on the use of bitumen [10]. The ancient Greeks, who were familiar with the asphalt, used bitumen in aqueducts and the reservoirs those used to store water for the major cities and they called it as asphaltus. In the 16th century, bitumen was used to fill the pitch between the boards of the ships; in this way Venezuelans have formed a waterproof layer on outer part of the ships. Although bitumen has been used for many different purposes in Europe and USA, it has not been used as a paving material that improves the road conditions until the 18th century [9].

In 1870, the first asphalt pavement in America was laid in Newark, the largest city in New Jersey, by a Belgian chemist. In the same year, the first hot mix plant was established by a private company in the USA. With the increase in the popularity of the automobile in the first parts of the 1900s, the need for quality roads and innovations in the production of asphalt roads have become inevitable [11]. In 1910, asphalt became very common in the US. Until 1928, the asphalt was made by non-mechanically techniques. Increase in vehicle numbers and weights and increase in tire pressures triggered the development of asphalt design and construction stages [9]. Due to the reasons such as speed, quality, economy and worker safety, today almost all of the asphalt production consists of plant based production techniques which are mechanical methods. The technique for asphalt surfacing by hand has been substantially lost [12-14].

2.1.1 Asphalt Layers

For technical and economic reasons, asphalt pavements are usually divided into various layers [15] (Figure 2.1):

Figure 2.1 Asphalt layers

2.1.1.1 Asphalt Surface/Wear Layer

The top layer of asphalt, the wear layer, usually consists of 5 cm thick asphalt concrete. As top layer of the road, the asphalt surface is exposed to the traffic and weather directly. Due to the high mechanical and climatic stresses they must be replaced as a rule after 12 to 15 years. Particularly handy and wear resistant aggregates help to optimize their durability. Bituminous hot mixtures such as SMA-Stone Mastic Asphalt with high strength and high skid resistance are used in the state roads with very heavy traffic and the surface layer of the highways.

2.1.1.2 Asphalt Binder Layer

The binder layer applied on a bituminous foundation or granular foundation is generally formed by asphalt concrete with a thickness of 6-8 cm depending on the traffic load. The core function of binder is to quickly and effectively derive shear forces and vibrations from the road surface in the lower layers. Thus, it protects the outer layer particularly in high traffic and heavy braking from overloading and distortion.

2.1.1.3 Asphalt Base Layer

The bituminous base layer, which can be 8-18cm thick depending on the traffic load, consists of a bituminous hot mix with intensive grading on a generally unbonded granular base. The asphalt base layer serves to accommodate the high loads and to distribute them to the underlay. It is a uniform and stable surface for subsequent layers.The lowermost layer of asphalt comes to the really important role. With its coarse-grained rock mix it ensures the uniform distribution of the burden, thus increasing the load capacity of the road. If the road well maintained, a support layer can hold up to 50 years.

2.1.1.4 Asphalt Frost Protection Layer

The anti-frost protection layer is 30-35 cm thick. To prevent damage caused by frost, a frost protection layer is often used below the asphalt layers. The unbound gravel, sand or chippings are extremely resistant to heat, water penetration derive quickly and prevent awakenings due to frost in the upper layers of asphalt.

Depending on the thickness and position the different layers provide their contribution to the sustainability of road. For slightly polluted streets, paths and areas to apply the single-layer structure, which consists only of a base surface layer. In addition to standard of mix that meet the technical regulations of the asphalt road construction, there are also special asphalts as porous/whisper asphalt, semi-rigid layers etc.

2.1.2 Asphalt Mix Types

There are 4 main types of asphalt mixture according to the classification made by the Asphalt Contractors Association of Turkey [16]. They are bituminous hot mix asphalt, warm mixt asphalt, cold mix asphalt and foamed asphalt**.**

2.1.2.1 Bituminous Hot Mix Asphalt

Bituminous hot mix, also called hot mix asphalt, is obtained by mixing bitumen with heated mineral aggregate around 160 °C in asphalt plants. In the mixture, the aggregate is used in a ratio of 93-97% and bitumen in the range of 3% to 7%. Bituminous hot mixtures which should be used on roads with daily heavy vehicle traffic over 1000 are formed in 2 or 3 layers with different thicknesses depending on traffic.

2.1.2.2 Warm Mixt Asphalt

Warm mix asphalt is a bituminous mixture prepared to reduce the temperature of the bituminous hot mixture at least 20-30 ºC to save energy and reduce emissions. Reducing the temperature by 10 ºC during the preparation of the mixture causes 50% reduction of the emission. It is clear that this technology, which is not yet very common, will gain more importance in the future. Different mixing processes are applied to produce asphalt at low temperature. Paraffin is also used to reduce the viscosity of the bitumen.

2.1.2.3 Cold Mix Asphalt

On the roads with very low traffic, asphalt pavement roads are applied in the mix or on the road in order to provide roughness, sealing and surface smoothness. In cold mixtures, liquid petroleum asphalts or bitumen emulsion are used with crushed aggregates of certain sizes.

2.1.2.4 Foamed Asphalt

Foamed asphalt is formed by combining hot asphalt binder with small amounts of cold water. As the surface area of the foam bitumen is expanded and its viscosity is reduced, this bitumen has the optimum consistency to be mixed with the aggregate. Foam bitumen increases the strength of the aggregate and reduces moisture sensitivity. Foam asphalt is flexible and resistant to fatigue. Foam asphalt, an alternative to cold asphalt, is more economical as it requires less bitumen. In addition, since the aggregate does not need to be heated and dried, it provides great energy savings.

2.1.3 Hot Mix Asphalt Types

The most common type of flexible pavement surfacing in the world is Hot Mix Asphalt (HMA). It is also known as blacktop or bitumen, and sometimes just hot mix. Hot mix pavements are classified mainly as dense-graded mixes, stone matrix mixes, and open-graded hot mix asphalt.

2.1.3.1 Dense-graded mixes

This hot asphalt mix is the most common mix used because it can provide great impermeable characteristics allowing water to run away from the surface area. The name comes from the aggregate size used while mixing the raw materials to produce the asphaltic composition. It can also be subdivided as fine-graded or coarse-graded, depending on the majority of the aggregates in the final product. This type of asphalt is ideal for all traffic conditions and has great performance under structural conditions, friction, and for surfacing and repairing needs.

2.1.3.2 Stone matrix asphalt (SMA)

This mix was developed to maximize rutting resistance and to have great durability. Due to the process of production, this asphalt mix is more expensive than regular dense-graded mixes. Its design is based on higher asphalt content, modified asphalt binder, and fibers. This asphalt type has been used since the 1980s and can be used in numerous road and driveway applications.

Due to its high costs, it is recommended to be used on high volume interstate highways to get benefits from its durability and endurance. It will also increase the driver’s safety due to the impressive friction capabilities with tires; it will also minimize tire noise and will reduce reflective cracking.

Mineral fillers and additives are used to minimize asphalt binder drain-down during construction while increasing the amount of asphalt binder used in the mix and to improve mix durability.

2.1.3.3 Open-Graded Mixes

In this mixture, which is formed by uniform open grading materials, the coarse aggregate ratio is high but the ratio of fine aggregates and filler is low. Therefore, the void ratio of the mixture is high. Unlike dense-graded mixes and SMA, an open-graded HMA mixture is designed to be water permeable. The bituminous binder layer must be continuous and relatively thick in order to obtain asphalt with a long service life

2.2 Historical Development of the Asphalt in Turkey

Highways transportation, which was prominent in the 20th century, became very popular after the Second World War and became competitive with other transportation systems. After overcoming the energy crisis in the 1970s, road transportation continued its increasing trend and became the dominant transportation system in the developed and developing countries in 2000s. In our country, 97% of passenger transportation and 89% of freight transportation are carried out by road [17].

The Republic of Turkey was established in 1923 and has over 18 000 km long route (4000 km of these roads are in good condition). In the early years of the Republic of Turkey, Directorate of Bridges was responsible for doing work on the road, and priority is given to the railways in those years. After the Second World War, as in all the world countries, priority has been given to the highways in Turkey [17].

From 1923 to 1948, railroad policy was considered very important in terms of transportation. However, this situation changed in 1948 and reached a very important turning point on highways. In this period, with the increase in the financial resources, significant developments have taken place on the highways. The major development was recorded in 1948 with providing foreign aid, also known as the Marshall aid. After 1960, the transport system has spread all over the country in a balanced manner. In 1950, the Directorate of Bridges was restructured and the General Directorate of Highways (KGM) was established in order to be more efficient and modern methods [17].

At the end of the 1970s, multi-lane and divided roads were built. In these years, with the encouragement of KGM, many contractors have worked on the production and application of hot mix bitumen and started to produce asphalt. In the 1980s, rehabilitation projects were implemented to raise the standards of the existing road network. The development of the motorway network in Turkey has been initiated. With the new highway projects, the Turkish asphalt industry has developed significantly and the transfer of new technologies, knowledgeable manpower and increasing production has survived [18].

The importance given to the highways in the planned period has increased and the Bosporus Bridge and express roads have been constructed to meet the transportation needs of the country. Since 1980, the physical and geometrical capacity increasing facilities of the existing state and provincial roads have continued, and the construction of a state full access controlled highways has been accelerated. In the 2000s, the standard of highways was increased [17].

According the data of KGM the lengths of provincial roads according to surface are shown in Table 2.1. Data shows that the length of the asphalt road in Turkey has been increased with a high acceleration from 1998 to 2017. When the data from 1967 to 2017 are examined, it is observed that the production of stabilized roads decreased and asphalt pavement roads were preferred. Lengths of state highways according to surface types and road network according to surface type's according the data of KGM are shown respectively in Table 2.2 and Table 2.3.

Table 2.1 Lengths of Provancial Roads According to Surface Types [33]

Years	Asphaltic Concrete (km)	Surface Treatment (km)	Stone Block (km)	Stabilized (km)	Earth (km)	Primitive (km)	Total Length (km)
1967	30	682	58	13 058	7 315	2 958	24 101
1968	46	898	53	13 496	7 384	2 381	24 258
1969	62	1 530	58	13 469	7 381	1 890	24 390
1970	81	1 853	78	14 149	6 602	1 674	24 437
1971	84	1 990	77	14 446	6 239	1 615	24 451
1972	69	2 197	73	14 585	6 037	1 482	24 443
1973	79	2 534	68	15 021	5 570	1 192	24 464
1974	59	2 834	76	15 511	4 912	1 189	24 581
1975	135	4 211	88	15 210	4 719	944	25 307
1976	188	5 091	86	15 324	4 736	990	26 415
1977	251	5 942	74	14 981	4 386	1 272	26 906
1978	242	7 677	73	14 132	4 231	1 134	27 489
1979	267	9 306	60	12 768	3 967	1 483	27 851
1980	251	10 427	70	13 041	3 821	1 175	28 785
1981	259	11 196	65	12 495	3 475	1 334	28 824
1982	242	12 058	60	11 815	3 464	1 362	29 001
1983	242	12 951	69	10 854	2 701	1 270	28 087
1984	248	13 840	75	10 309	2 329	1 329	28 130
1985	172	14 724	77	10 104	2 035	1 193	28 305
1986	178	15 749	85	9 311	1 692	1 138	28 153
1987	196	16 565	125	8 528	1 409	1 030	27 853
1988	196	16 885	136	8 224	1 335	1 076	27 852
1989	117	17 398	94	7 684	1 154	1 057	27 504
1990	124	18 429	92	7 065	1 279	990	27 979
1991	109	19 087	89	6 454	1 217	1 004	27 960
1992	113	19 285	87	6 659	1 395	960	28 499
1993	117	19 874	85	6 089	1 297	884	28 346
1994	127	20 486	82	5 583	1 212	953	28 443
1995	135	20 866	82	5 322	1 248	924	28 577
1996	141	21 621	68	4 995	1 095	893	28 813
1997	150	22 607	69	4 749	1 120	826	29 521
1998	309	23 607	75	3 523	1 141	885	29 540
1999	302	24 014	82	3 216	1 106	815	29 535
2000	374	24 731	82	2 639	1 056	811	29 693
2001	599	25 156	91	2 297	1 042	744	29 929
2002	795	25 274	84	2 303	0 964	630	30 050
2003	838	25 520	93	2 171	0 926	585	30 133
2004	872	25 763	94	1 976	1 128	535	30 368
2005	881	25 761	91	1 953	1 243	639	30 568
2006	867	25 768	92	1 895	1 140	667	30 429
2007	868	26 414	109	1 583	841	764	30 579
2008	1 094	26 431	108	1 443	758	878	30 712
2009	1 193	26 500	114	1 353	730	1 058	30 948
2010	1 439	26 783	137	1 152	735	1 144	31 390
2011	1 692	26 880	138	963	674	1 211	31 558
2012	1 910	26 831	183	957	637	1 362	31 880
2013	2 368	26 930	190	760	603	1 304	32 155
2014	2 476	26 862	201	824	570	1 541	32 474
2015	2 702	27 327	191	699	614	1 532	33 065
2016	3 070	27 054	230	553	503	2 103	33 513
2017	3 802	26492	248	632	520	2 202	33 896

Note: Values are given by the end of the year. (such as 31.12.1967)

Table 2.2 Lengths of State Highways According to Surface Types [34]

Years	Asphaltic Concrete (km)	Surface Treatment (km)	Stone Block (km)	Stabilized (km)	Earth (km)	Primitive (km)	Total Length (km)
1967	1 259	12 030	149	18 132	2 004	1 582	35 156
1968	1 337	13 195	151	17 305	2 038	1 240	35 266
1969	1 388	14 354	149	16 246	1 950	1 143	35 230
1970	1 453	15 628	133	14 750	1 915	1 137	35 016
1971	1 621	16 526	127	13 804	1 726	1 214	35 018
1972	1 670	17 121	133	13 236	1 747	1 098	35 005
1973	1 622	17 924	123	12 499	1 631	1 016	34 815
1974	1 705	19 065	177	11 749	1 355	0 867	34 918
1975	1 757	19 198	117	10 823	1 160	0 707	33 762
1976	1 724	19 742	103	9 685	1 290	0 656	33 200
1977	1 745	20 862	80	8 086	866	0 862	32 501
1978	2 094	21 619	57	6 781	974	0 704	32 229
1979	2 440	22 049	56	5 977	988	0 698	32 208
1980	2 571	22 421	70	5 467	784	0 663	31 976
1981	1 641	22 888	52	4 763	678	0 866	30 888
1982	2 695	23 337	58	4 354	716	0 793	31 953
1983	2 694	23 571	59	3 861	630	0 395	31 210
1984	2 928	23 790	54	3 441	428	0 341	30 982
1985	3 196	24 060	48	2 915	405	0 373	30 997
1986	3 673	23 994	54	2 709	120	0 436	30 986
1987	3 776	24 465	52	2 239	101	0 429	31 062
1988	3 965	24 362	50	2 069	82	0 471	30 999
1989	4 011	24 640	50	1 874	80	0 393	31 048
1990	4 137	24 771	44	1 738	77	0 382	31 149
1991	4 305	24 787	45	1 596	110	0 418	31 261
1992	4 433	24 778	49	1 457	178	0 448	31 343
1993	4 488	25 086	43	1 263	128	0 416	31 424
1994	4 630	25 016	40	1 311	69	0 323	31 389
1995	4 700	24 983	39	1 230	82	0 388	31 422
1996	4 939	25 013	37	1 012	81	0 330	31 412
1997	4 986	25 077	38	825	81	0 313	31 320
1998	5 350	25 043	41	618	39	0 254	31 345
1999	5 450	25 040	50	545	89	0 214	31 388
2000	5 683	24 978	52	387	88	0 209	31 397
2001	5 853	24 872	48	318	71	0 214	31 376
2002	6 082	24 669	42	302	61	0 162	31 318
2003	6 092	24 698	39	270	92	0 167	31 358
2004	6 158	24 698	42	260	86	0 202	31 446
2005	6 199	24 541	42	254	86	0 249	31 371
2006	6 337	24 391	43	237	86	0 241	31 335
2007	6 538	24 205	49	213	106	0 222	31 333
2008	6 910	23 874	60	157	104	0 206	31 311
2009	7 488	23 282	66	137	53	0 245	31 271
2010	8 758	22 146	75	162	47	0 207	31 395
2011	9 869	21 032	74	114	47	0 236	31 372
2012	11 240	19 631	73	112	29	0 290	31 375
2013	12 502	18 364	71	92	29	0 283	31 341
2014	13 446	17 415	72	67	29	0 251	31 280
2015	14 393	16 399	71	45	17	0 288	31 213
2016	15 576	15 077	67	40	0	0 346	31 106
2017	16 991	13 691	66	36	0	0 282	31 066

Note: Values are given by the end of the year. (such as 31.12.1967)

Table 2.3 Road Network According to Surface Types [35]

Road Types	Asphaltic Concrete (km)	Surface Treatment (km)	Stone Block (km)	Stabilized (km)	Earth (km)	Primitive (km)	Total Length (km)
Motorways	2 157	--	--	--	--	--	2 157
State Highways	16 991	13 691	66	36	--	282	31 066
Provincial Roads	3 802	26 492	248	632	520	2 202	33 896
Total	22 950	40 183	314	668	520	2 484	67 119

Plastic materials used in many different industries have become the main consumer of the society and the use of plastics results in excessive waste generation [1]. The limited storage area of the waste materials and unconsciously storing these materials causes environmental pollution. Only 9% of these plastic wastes are recyclable. Non-recyclable wastes cause pollution in land and oceans [2]. Therefore, plastic wastes need to be stored and recycled. The recycling of plastic wastes after consumption will help to conserve natural resources, prevent environmental pollution and save energy [3].

Recyclable wastes such as glass, metal, plastic and paper can be converted to a new raw material or product by physical and chemical processes [4]. Recycling is the use of these wastes as a second raw material after some processes. The main advantages of recycling plastics; reduction of the need for raw materials, preventing the natural balance of consumption resulting from population growth, preventing waste from polluting the environment, providing energy saving by using waste instead of producing new materials [5].

The most suitable plastics for recycling are PVC (Polyvinyl Chloride), PE (Polyethylene), PET (Polyethylene Terephthalate), PP (Polypropylene). Certain stages of the recovery of plastics solid wastes are collection of plastics from solid waste, if necessary, compacting and concentration of collected wastes, classification and processing of condensed waste plastics [6]. Some of the materials obtained from the recycling of plastic are: greenhouse cover, plastic bag in automotive sector, marley, waste water pipe, fiber and filling material, car spare parts making, detergent bottles, trash cans and similar products, rain water and waste water pipes, various plastic filling materials, various plastic toys and stationery supplies etc [7].

The negative effects of the asphalt roads that we use today and the effort to prevent the environmental pollution that surround the world have led to the development of a revolutionary project. The sustainable road project from recycled plastic was developed [8]. Most of the roads in Turkey and in the world consist of bituminous pavements (bituminous hot mixture). Maintenance of these deteriorated roads creates a great economic cost. Bituminous mixtures containing waste plastic can solve this problem by extending the life of the roads. In this study, the effect of granular PVC wastes on bituminous coating (bituminous hot mixture) was investigated.

2.4. Plastic Wastes

The use of plastic packages and products has increased considerably over the last decade, due to the low prices and functional use of plastics. However, human beings are not fully aware of the environmental impact of these plastic wastes. It is also known that more than half of the plastics used are disposed as waste [21].

2.4.1 Plastic Waste Utilization in Asphalt Production

Since the asphalt roads have been constructed, many mix design studies have been carried out in order to increase pavement performance [22-24]. By adding different types of modifiers to the asphalt mixture satisfactory results have been obtained. These modifiers increased the adhesion strength between aggregate and bitumen and reduced the possibility of aggregate stripping [22-25]. Crumb rubber, extender, oxidant, filer, antioxidant, hydrocarbon, and polymers are the most preferred and studied modifiers [26].

Plastic polymers are obtained from materials such as used bags, pet bottles, and packaging waste. Plastic wastes, which have long years of dissolution in nature, cause very large environmental problems [27]. Therefore, these wastes must be disposed of. Recycled plastic wastes are very important in economic and environmental aspects.

In the 20th and 21st centuries, the use of Plastic Solid Waste (PSW) in recycling has gained importance [28]. Plastic wastes can be recycled in various ways. They can be used again after recycling and recovery processes. Plastic disposals can also be used in road construction [22]. The use of wastes in asphalt mixtures increases the performance parameters of the asphalt and contributes to the waste management [29].

Many studies have been carried out on the use of plastic wastes in asphalt mixtures and positive results have been demonstrated as a result of studies. Chen (2009) [30] used the plastic polymer as a binder modifier. According to this study, the modified asphalt mixture yielded better results in terms of permanent deformation resistance compared to the traditional asphalt mixture. Sasane et al. (2015) [31] used grinded plastic waste for asphalt pavement. In the mentioned study, it was observed that the binding forces between aggregate and bitumen increased and therefore the aggregate stripping rate decreased. Kalantar et al. (2009) [32] conducted a study on the use of PET bottles' particles as binder in asphalt. According to the result of the study, the resistance of the modified asphalt to flow and temperature changes was increased when compared with compared to the conventional asphalt.

CHAPTER III

MATERIALS AND TEST METHODS

3.1 Materials

3.1.1 Waste PVC Samples

In this study, Ground Pet Bottle wastes from a special trading company were used to get Bituminous Hot Mixtures (asphalt coatings). The aim of this study is to investigate the usage methods PVC wastes and to make positive contributions to the environment. PVC wastes with four different gradations are used in the present study (Figure 3.1). Gradation values and pictures of ground PVC wastes are given in the following tables (Table 3.1-3.4).

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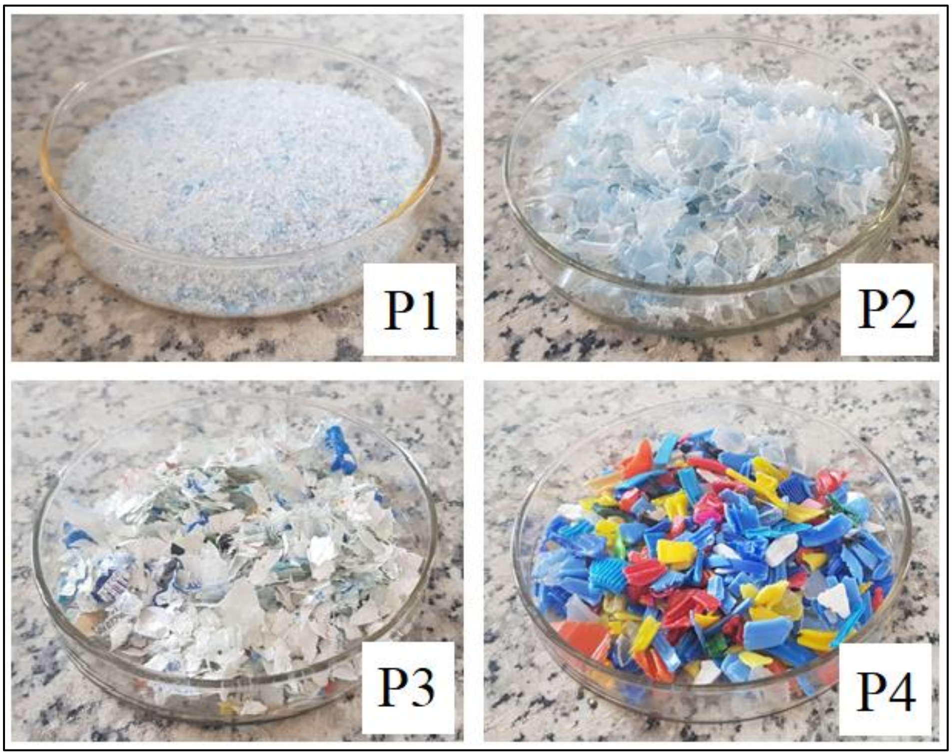

Figure 3.1 PVC test samples (P1-P2-P3-P4)

Table 3.1 Gradation values of the first PVC waste sample-1 (P1)

Sieve Size (mm)	Retained (%)	Cumulative Retained (%)	Cumulative Passing (%)
4.750	0	0	100
2.000	0	0	100
0.425	87.6	87.6	12.4
0.180	9.8	97.4	2.6
0.075	2.4	99.8	0.2
Pan	0.2	100	0

Table 3.2 Gradation values of the first PVC waste sample-2 (P2)

Sieve Size (mm)	Retained (%)	Cumulative Retained (%)	Cumulative Passing (%)
4.750	34.8	34.8	65.2
2.000	63	97.8	2.2
0.425	2	99.8	0.2
0.180	0.2	100	0
0.075	0	100	0
Pan	0	100	0

Table 3.3 Gradation values of the first PVC waste sample-3 (P3)

Sieve Size (mm)	Retained (%)	Cumulative Retained (%)	Cumulative Passing (%)
4.750	99.8	99.8	0.2
2.000	0.2	100	0
0.425	0	100	0
0.180	0	100	0
0.075	0	100	0
Pan	0	100	0

Table 3.4 Gradation values of the first PVC waste sample-4 (P4)

Sieve Size (mm)	Retained (%)	Cumulative Retained (%)	Cumulative Passing (%)
4.750	63.2	63.2	36.8
2.000	36.6	99.8	0.2
0.425	0.2	100	0
0.180	0	100	0
0.075	0	100	0
Pan	0	100	0

3.1.2 Bituminous

AC 50/70 bituminous binder was used as binder in the study. 50/70 Penetration Grade Bitumen is produced from the vacuum distillation of crude oil and is classified according to its penetration range. The properties of the bituminous binder used are given in the Table 3.5.

Table 3.5 Properties of the AC 50/70 bituminous binder

BINDER PROPERTIES	Requirements		Tets Methods
	Min	Max	
Before Ageing			
Penetration @ 25ºC/100g/5s, 1/10 mm	50	70	EN 1426
Softening point, ºC	46	56	ASTM D 36
Dynamic viscosity @ 60ºC, Pa.s	140	-	ASTM D 4402
Dynamic viscosity @ 135ºC, Pa.s	0.22	0.45	ASTM D 4402
After Ageing (RTFO)			
Mass change % m/m	-	0.3	ASTM D 2872
Dynamic viscosity @ 60ºC, % of original, Pa.s	-	300	ASTM D 4402
Softening point, ºC	48	-	ASTM D 36
Increase in softening point, ºC	-	7	ASTM D 36
Retained penetration, % of original	55	-	EN 1426
Spot test, % xylene	-	30	AASHTO T102

3.1.3 Aggregates

The aggregates used in the study were obtained from the limestone produced by Göngörler Stone Quarry near Yamaçoba Village in Şehitkamil District of Gaziantep. Four class aggregates taken from Güngörler quarry (1’’- 3/4’’, 3/4”-3/8”, 3/8”-No:4 , No:4-0)

3.2 Test Methods

3.2.1 Aggregate Tests

In order to use the aggregates in asphalt layers, the following properties should be known: abrasion resistance, freezing resistance, specific gravity, water absorption, affinity values, sieve analysis results, grain shapes, and resistance to varnishing due to friction effects.

3.2.1.1 Sieve Analysis Test (TS EN 933-1)

Sieve analysis test is carried out to determine the grain size distribution of the aggregate. Sieve analysis is performed by hand or sieving machine (Figure 3.2) and square mesh sieves are used for analysis. The number of sieves in the sieve series should be sufficient to give the necessary information about the material. The amount of sample to be analyzed using the sieve is selected according to the largest grain size to be used. The test sample is sampled by quaternary method or by a splitter in the amounts given below according to the maximum grain size of the aggregate. The sample is dried in an oven at 110° ±5 °C or in air. The material is sieved separately from all spans, starting from sieves through which 100% of the material passes. After the samples have been shaken for at least 2 minutes on the sieves, aggregate weights remaining on each sieve and passing through the sieve are determined.

Figure 3.2 Sieve Shaker Machine

Gradation obtained as a result of sieve analysis test is used for classification of aggregate, compliance of the dimensions of aggregates to the specification and calculation of aggregate mixing ratios. The amount of material passing through each sieve used in the experiment is calculated as a percentage of the total sample weight. In order to find the grain size distribution of the aggregates to be used in bituminous coatings, the square mesh sieve sizes given in Table 1 are used.

Table 3.6 Sieve sizes used in sieve analysis of aggregates

Sieve Designation	Sieve Opening (mm)
1.5 .inch	37.500
1 inch	25.400
¾ inch	29.100
½ inch	12.700
3/8 inch	9.520
No.4	4.750
No.10	2.000
No.40	0.420
No.80	1.177
No.200	0.075

3.2.1.2 Los Angeles Abrasion Test (TS EN 1097-2, AASHTO T96)

The Los Angeles Abrasion test is used for determination of abrasion that occurs in aggregate grains. In this experiment, aggregates having a grain size less than 75 mm are subjected to abrasion with a Los Angeles abrasion test machine (Figure 3.3) and the abrasion resistance of the aggregates is found. In the test, metal abrasive spheres are placed into the hollow, two-end cylindrical test machine together with the aggregate and the machine is operated at a certain speed. As a result of the test, the worn material is weighed. The weighed material is proportioned to the weight of the material taken at the beginning of the experiment. This ratio is called abrasion loss.

According to AASHTO T 96; the test sample and 11 steel spheres those have a total weight of 4584 ± 25 g are placed in the Los Angeles test machine. The machine makes a total of 500 cycles, with a speed of 30-33 revolutions per minute. After 500 cycles are completed, the sample is removed from the machine and sieved by washing through 1.70 mm (No.12) sieve. The material remaining on the 1.70 mm sieve is dried to a constant weight at 110 ± 5 ºC and weighed with a precision of 1 gram.

According to TS EN 1097-2; the test specimen and 11 steel spheres with a total weight of 4690 g to 4860 g are placed in the Los Angeles test machine. The machine performs a total of 500 cycles at a speed of 31-33 revolutions per minute. After the required number of cycles is completed, the sample is removed and washed by a 1.60 mm sieve. The material remaining on the 1.60 mm sieve is dried to a constant weight of 110 ± 5 ºC and weighed with a precision of 1 gram.

Figure 3.3 Los Angeles Abrasion Test Machine

The abrasion loss percentages according to AASHTO T 96 and TS EN 1097-2 are calculated by using Eqn 3.1 and Eqn 3.2 respectively.

$$Loss = \frac{M_{initial} - M_{final}}{M_{initial}} * 100 \quad \text{(AASHTO T 96)} \tag{3.1}$$

where;

Loss %: Abrasion loss percentage (%)

$M_{initial}$: Initial weight of sample (g)

M_{final}: Final weight of sample (g)

$$LA = \frac{5000 - m}{50} \quad \text{(TS EN 1097} - 2) \tag{3.2}$$

where;

LA: Abrasion loss percentage (%)

m: Material weight remaining on a 1.6 mm sieve (g)

3.2.1.3 Soundness Test (TS EN 1367-2, AASHTO T104)

This test is an expedited test used to measure the resistance of the aggregates under long-term weather effects to the freezing and thawing. In experiments conducted under laboratory conditions, saturated sodium sulphate or magnesium sulfate solution is used to obtain results in a short time. The pure and anhydrous sodium sulfate salt (Na_2SO_4. $10H_2O$) is added to water at 25-30 ºC and dissolved in water. At least 250 grams of sodium sulfate salt or 750 grams of crystallized sodium sulfate salt are added per liter of water. The solution can also be prepared with pure and anhydrous magnesium sulfate salt ($MgSO_4$) or crystallized magnesium sulfate salt ($MgSO_4.7H_2O$). In this case, 350 grams of anhydrous magnesium sulfate salt or 1400 grams of crystallized magnesium sulfate salt are added per liter of water.

Aggregates, which are sieved and dried in the oven at 110 °C, are put in certain amounts in permeable baskets and immersed into sodium sulfate or magnesium sulfate solution so that solution will exceed the upper aggregate level at least 2 cm and the container is covered. The aggregates are allowed to stand in the solution at a temperature of 21 °C for 16-18 hours. At the end of the immersion period, the aggregate sample is removed from the solution and allowed to drain for 5 min and dried to constant weight in oven at 110 °C. Aggregate sample is cooled down to room temperature. The procedure is repeated by dipping the sample into the solution for the second time. These dipping-drying processes are repeated 5 times, at the end of 5th cycle the sample is cooled and washed with water until the solution is completely cleaned. The samples are then dried to a constant weight of 110 °C and weighed. The difference between the weight of the sample remaining on the sieve after the experiment and the pre-test sample weight constitutes the loss of freezing. The freezing losses according to the grain size specified in the standard are converted according to the original gradation for the aggregate.

3.2.1.4 Specific Gravity and Absorption Test (TS EN 1097-6, ASTM C 127)

Coarse Aggregate

The purpose of this experiment is to determine the volume and weight relationship of the aggregate. Specific gravity experiments are performed for coarse (coarse), fine aggregates and filler. At least 2 kg of the material remaining on the 4 mm sieve is taken and washed. The weight of the sample in the oven, the weight of the saturated surface in the dry state and the weight in the water are determined. The dry and saturated surface dry volume specific gravity, apparent specific gravity and percentage of water absorption of the coarse aggregate are calculated (Eqn. 3.3-3.6).

Volume specific gravity (dry) (gr / cm^3)

$$\frac{A}{(B-C)*A} \tag{3.3}$$

Volume specific gravity (saturated surface, dry) (gr / cm^3)

$$\frac{B}{B-C} \tag{3.4}$$

Apparent specific gravity (gr / cm^3)

$$\frac{A}{A-C} \tag{3.5}$$

Absorption (%)

$$\frac{B-A}{A}*100 \tag{3.6}$$

where;

A: Weight of dried material (g)

B: Saturated surface dry material weight (g)

C: Weight of saturated surface material in water (g)

Fine aggregate

500 g of the washed and dried fine material is placed in the fine aggregate specific gravity pycnometer and weighed together with the pycnometer. Then the pycnometer is filled with distilled water for half an hour, after which the pycnometer is connected to the vacuum for 15-30 minutes and the air is absorbed. The pycnometer is disconnected from the vacuum and is expected to collapse on its own. When the water is completely clear at the top, it is filled with distilled water until the pycnometer is filled. The lid is closed in such a way that there is no air bubble and it

is left in a 25 °C water bath for 1 to 1.5 hours. The pycnometer is thoroughly weighed with a towel or filter paper and weighed on a 0.1 gram sensitive scale. Specific gravities and absorption percentages of fine aggregate are calculated by using Eqn. 3.7-3.10.

Volume specific gravity (dry) (gr / cm^3)

$$\frac{A}{B+D-C} \tag{3.7}$$

Volume specific gravity (saturated surface, dry) (gr / cm^3)

$$\frac{B}{B+D-C} \tag{3.8}$$

Apparent (apparent) specific gravity (gr / cm^3)

$$\frac{A}{A+D-C} \tag{3.9}$$

Absorption (%)

$$\frac{B-A}{A} * 100 \tag{3.10}$$

where;

A: Weight of dried material (g)

B: Saturated surface dry material weight (g)

C: Volumetric vessel + water + fine aggregate weight (g)

D: Water filled weight of the volumetric container (g)

Mineral filler

Filler material is the aggregate material that passes through a 0.075 mm sieve. Mineral fillers should have a uniform granulometric composition. Although mineral fillers constitute a very small percentage of the total aggregate, they play a role in the regulation of the properties of the mixture. Specific gravities of filler are calculated by using Eqn. 3.11.

Specific gravity (g / cm^3)

$$\frac{A}{A + C - D} \tag{3.11}$$

Where;

A: Sample weight (g)

B: Container weight (g)

C: Cap + water + sample weight (g)

3.2.1.5 Flakiness Index Test (TS EN 933-3)

This test method is used for the determination of flatness index of aggregates larger than 4 mm and smaller than 100 mm in accordance with TS EN 933-3. Square span sieve set and roller bar sieves are used in this test. The experimental steps are as follows: The test sample is washed and dried at 110 ± 5 °C in air circulation oven to a constant mass, cooled, weighed and sample mass is recorded. The grains passing through a 4 mm sieve are weighed and do not used for calculation. The sample between 4 mm and 100 mm is sieved and each grain size fraction (di / Di) is weighed and stored separately. Each grain size fraction (di / Di) is sieved by a bar sieve. Weigh the material in each grain size fraction passing through the roller bar sieves. The sum of all di / Di particle size fraction masses is calculated and recorded as M1. The total flatness index FI is calculated (Eqn. 3.12 and 3.13) and the value found is rounded to the nearest whole number and reported.

$$FI = \frac{M_2}{M_1} * 100 \tag{3.12}$$

where;

M_1: The total mass of the grains in each grain size fraction (g)

M_2: Total mass of grains passing through roller bar sieves (g)

$$FI_i = \frac{M_i}{R_i} * 100 \tag{3.13}$$

where;

Mi: The mass in each grain size fraction (g)

Ri: The mass of the grains passing through the bar sieve to which each grain belongs (g)

3.2.1.6 Affinity Test (TS EN 12697-11)

In the peel test, the reduction of adhesion between aggregate and bitumen is determined by the effect of water and temperature. The amount of peel depends on the type of aggregate used (such as limestone, basalt, etc.) and the type of bituminous binder. 600 g of crushed aggregate sample with a size of 6.3-10 mm is sieved through a 6.3 mm sieve and dried to a constant weight of 110 ± 5 °C. Washed and dried 150 aggregate samples and bituminous binder are heated in two different steel containers in accordance with the temperatures given in TS EN 12697-35. The bituminous binder used in the test must have the same properties as the bituminous binder to be applied to the road. After the aggregate sample is placed in the heated mixing vessel, the sample of the bitumen heated to an amount equal to 5% by weight of the aggregate is poured onto the aggregate. Aggregate and bitumen samples are mixed in a vessel until the aggregates are completely covered with bitumen. The sample is transferred to two flat-bottomed petri containers in equal amounts and the coated aggregates are placed in such a way that they are not touched. Petri container are incubated for 1 hour ± 5 min at laboratory temperature and immersed in a deep tray filled with distilled water. Samples are kept in a 60-degree oven for 24 hours. At the end of this period, the petri d container is taken out, its water is changed, it is visibly examined under a light from the side. At the end of the experiment, the ratio of the unpeeled surfaces of all aggregate grains (brownish, transparent parts are considered as unpeeled) to the whole surface is determined according to TS EN 12697-11 and rounded to the nearest 5% and expressed as resistance to peeling.

3.2.1.7 Methylene Blue Test (TS EN 933-9)

The methylene blue test set used to determine the clay content in the fine portions of the aggregates. The moisture content is determined before preparing the methylene blue solution. 5 g of methylene blue solution is weighted with a 0.01 g precision. The solution is brought to constant mass at 100 ± 5 °C. After cooling in desiccator, the dry weight of the solution is measured. The moisture content is calculated with Eqn. 3.14.

$$W = \frac{M_h - M_g}{M_g} * 100 \tag{3.14}$$

Where:

W: Moisture content (%)

M_h: Initial weight of methylene blue solution (g)

M_g: Oven-dry weight of the methylene blue solution (g)

Methylene blue is absorbed on clay surfaces by changing cations. Each clay group has a different cation exchange capacity. When the cation exchange capacity of the clay is exceeded, excess methylene blue is not absorbed on the clay surface. A mixture of aggregate (0-2mm) and pure water is prepared for the determination of methylene blue that can be retained on the surface. 5 ml solutions of methylene blue dye are added to the mixture, and after each addition a blot test is carried out on the filter paper to determine the presence of free dye. The methylene blue test result is calculated as a numerical value with the Eqn. 3.15.

$$MB = \frac{V}{M_1} * 10 \tag{3.15}$$

Where;

MB: Methylene Blue value

M_1: Mass of test sample (g)

V: Total volume of the added dye solution (ml)

3.2.2 Bitumen Tests

3.2.2.1 Needle Penetration Test (TS EN 1426)

The consistency or fluency of the bituminous binders is determined by the penetration test. Penetration is the length of penetration of a standard needle in the vertical direction to the bituminous binder under a specified load, within a specified time and at a certain temperature. The penetration unit is 0.1 mm. Bituminous binder sample that is subjected to penetration test is prepared according to TS EN 58. Penetration test machine is shown in Figure 3.4.

Figure 3.4 Penatration Testing Machine

In the first stage of the experiment, approximately 500 g of the bitumen sample is filled into a clean test sample container. The bitumen is heated in the oven (min. 130 ºC) to a temperature of 80 ºC - 90 ºC above the estimated softening point. The penetration device is activated and the bitumen penetration value is determined after 5 seconds. A minimum of 3 measurements are made at least 10 mm from the edges of the test specimen with three separate needles. Different and clean needles should be used for each measurement. In experiments on samples larger than 100, the needle used for each measurement should be left on the specimen. After three measurements have been completed, the needles should be removed and cleaned. The test is valid if the difference between the three measurement values does not exceed the limits specified in Table 3.7.

Table 3.7 The highest difference between penetration values

Penetration Value	<49	50-149	150-249	250<
The highest difference between maximum and minimum penetration values	2	4	6	8

The experiment is carried out in two samples and a total of 6 measurements are made. The arithmetic average of these measurements is taken and is rounded to the whole number and reported as the penetration value. If the maximum difference value is exceeded, the experiment is repeated with a second sample. Experiments are repeated until 3 valid measurements are obtained with the same test sample.

3.2.2.2 Softening Point Test (TS EN 1427)

Ring and ball method is used to measure the behavior of bituminous binders against temperature. The bitumen sample is heated to be fluid and mixed until there are no air bubbles. After applying an anti-sticking agent (such as Vaseline) on a brass plate, the rings are placed on the plate. The heated bitumen is placed in the test ring and allowed to cool to room temperature for at least 30 minutes. The test specimen, which is soft at room temperature, is cooled for at least 30 minutes at a temperature of at least 10 °C below the softening point. The experiment should be performed within a maximum period of 4 hours.

The portion of the test sample overflowing from the ring is cut off with a hot knife so that each test sample has a flat surface. The test set-up is placed on the automatic softening point device (Figure 3.5) and the test is performed. The average of the two results obtained for samples with softening point of 80 ºC or less is considered as the test result with a precision of 0.2 ºC. The average of the two results obtained for samples with softening point above 80 ºC is considered as the test result with a precision of 0.5 ºC.

Figure 3.5 Automatic softening point device

3.2.2.3 Thin Film Oven TFOT Test (TS EN 12607-2)

This test is used for determination of the resistance to hardening under the influence of heat and air for bitumen and bituminous by TFOT method. In this experiment, a 3.2mm thick bitumen film is heated for 5 hours at 163 °C and the loss of mass is determined. The changes in the penetration, softening point and ductility values of the bituminous materials with the effects of heat and air can be determined with this method. The sample to be used in the experiment must be absolutely anhydrous. 50 ± 0.5 g of the test sample are heated and mixed thoroughly and then poured into the sample cup. The temperature of the bitumen sample in the container is reduced to room temperature and weighed with a precision of 0.01 grams. After the Thin film oven test machine (Figure 5) is set to 163 ± 1 °C test temperature, 2 test samples are placed on the shelves of the oven. The shelves are rotated at a speed of 5-6 revolutions per minute. The test period starts as soon as the temperature reaches 162 °C. From this moment on, the sample is kept in the oven for 5 hours at 163 °C.

Figure 3.6 Thin film oven test machine

Weight losses in two samples are calculated. The average of the two values is found and the calculation is performed according Eqn. 3.16. Penetration, softening point and ductility tests are carried out after loss of heating.

$$Heating\ Loss\ (\%) = \frac{A - B}{A} * 100 \qquad (3.16)$$

where;

A: First weight of sample (g)

B: Weight of the sample after the experiment (g)

3.2.2.4 Flash and Fire Point Test (TS EN ISO 2592)

This test is used for determination of flash and fire points of petroleum products using the Cleveland open cup apparatus. It is applicable to petroleum products. This test is applied to petroleum products having open cup flash points between 79 °C and 400 °C. The flash point is the lowest temperature at which the sample flash, but does not continue to burn, as a result of contacting the test flame to the steam of the heated test sample. The flashpoints of petroleum products are very important for preventing hazards that may occur during the application of these products.

The bituminous material to be tested is heated to 140-160 °C and then filled to the test cup so that there is no air bubble on the surface. Firstly, the sample temperature increases by 14-17 °C per minute. Approximately 28 °C before the flash point, the temperature increases by 5-6 °C per minute. The diameter of the test flame must be 4 mm. The test flame must pass through the container for approximately 1 second. When ignition occurs at any point on the sample surface, the current temperature is recorded as flash point.

3.2.2.5 Solubility Test (TS EN 12592)

The solubility test is used primarily to restrict the amount of coke and/or mineral matter in bitumen. Firstly, 2 g of bitumen is weighed into the balloon flask and approximately 50 ml of toluene is added to dissolve the bitumen. To thoroughly dissolve the bitumen with toluene, the flask is placed in the heating assembly for 30 minutes and then the material is allowed to cool. In the meantime, the glass filter is washed with toluene and incubated in 140 °C for 2 hours. At the end of this period, the glass filter is placed in the desiccator, and allowed to cool for 20 minutes. The glass filter removed from the desiccator is weighed with 0.0001 precision. The bitumen which is allowed to cool is washed with toluene and subjected to filtration. After filtering is finished, the glass filter is heated to 140 °C for 2 hours. After 2 hours, the glass filter is kept in the desiccator for 20 minutes and then weighed. Result of solubility test is found by the Eqn. 3.17-3.19.

$$X\ (g) = M_2 - M_1 \tag{3.17}$$

$$Z\ (\%) = \frac{X}{Y} * 100 \tag{3.18}$$

$$R\ (\%) = 100 - Z \tag{3.19}$$

where;

M_1: The first weight

M_2: The last weight

X: Mass Difference:

Y: Amount of Bitumen (g)

Z: Insoluble Bitumen Percentage (%)

R: Soluble Bitumen Percentage (%)

3.3 Marshall Method of Mix Design

Mixtures prepared by mixing the aggregate and bitumen after heating both of them at different temperatures are called as bituminous hot mix or hot mix asphalt (HMA). The Marshall method is the most commonly used design method for mixing aggregates and bitumen in asphalt plants. In order to increase the workability of the aggregates and to ensure that the asphalt cement is in a suitable flow rate, heating is carried out prior to the mixture. The objectives of the mix design of asphalt coatings can be summarized as follows:

- For determination of the amount of bitumen required to obtain a stable superstructure,
- To provide sufficient strength that is not going to deform under traffic loads,
- To provide a gap that will provide a small amount of compression that can occur under traffic loads without a decrease in flow and stability. However, to ensure that there is not enough gap in the layer to contain moisture and excess air.
- To determine an economic mixture and aggregate gradation having a workability value that will provide suitable asphalt production without segregation.

The purpose of Marshall Method of Mix Design is to provide that the binder and aggregate types are properly mixed and reach the desired requirements in the standards and also is to create a, stable, impermeable, flexible, fatigue resistant, high slid resistance and economical mixture.

3.3.1 Design Stages

Marshall Mix Design stages are as follows:

- The volume specific gravity of the coarse and fine aggregate is calculated.
- The specific gravity of asphalt cement and mineral filler is determined.
- The volume specific gravity of the aggregate mixture in the coating mixture is calculated.

- The maximum specific gravity of the loose coating mixture is calculated.
- The volume specific gravity of the compressed coating mixture is determined.
- The effective specific gravity of the aggregate is calculated.
- Bitumen absorption of aggregate is calculated.
- The effective bitumen amount of the coating mixture is calculated.
- The percentage of voids between aggregates in the mixture of compressed .asphalt coating is calculated.
- The air gap in the compressed coating mixture is determined.
- The percentage of pores filled with asphalt is determined.

The above steps apply to all mixture analyzes. In the Marshall method, the necessary stability and flow tests are carried out after these stages. According to all test and measurement results in Marshall Mix Design, the following graphs (Figure 3.7) are plotted for each bitumen percentage.

Bitumen % – Density (kg/m^3)

Bitumen % – Stability (kN)

Bitumen % – Flow (in 0,25mm)

Bitumen % – Voids Mineral Aggregate, VMA (%)

Bitumen % - Voids Total Mix (%)

Bitumen % – Voids Filled with Asphalt, VFA (%)

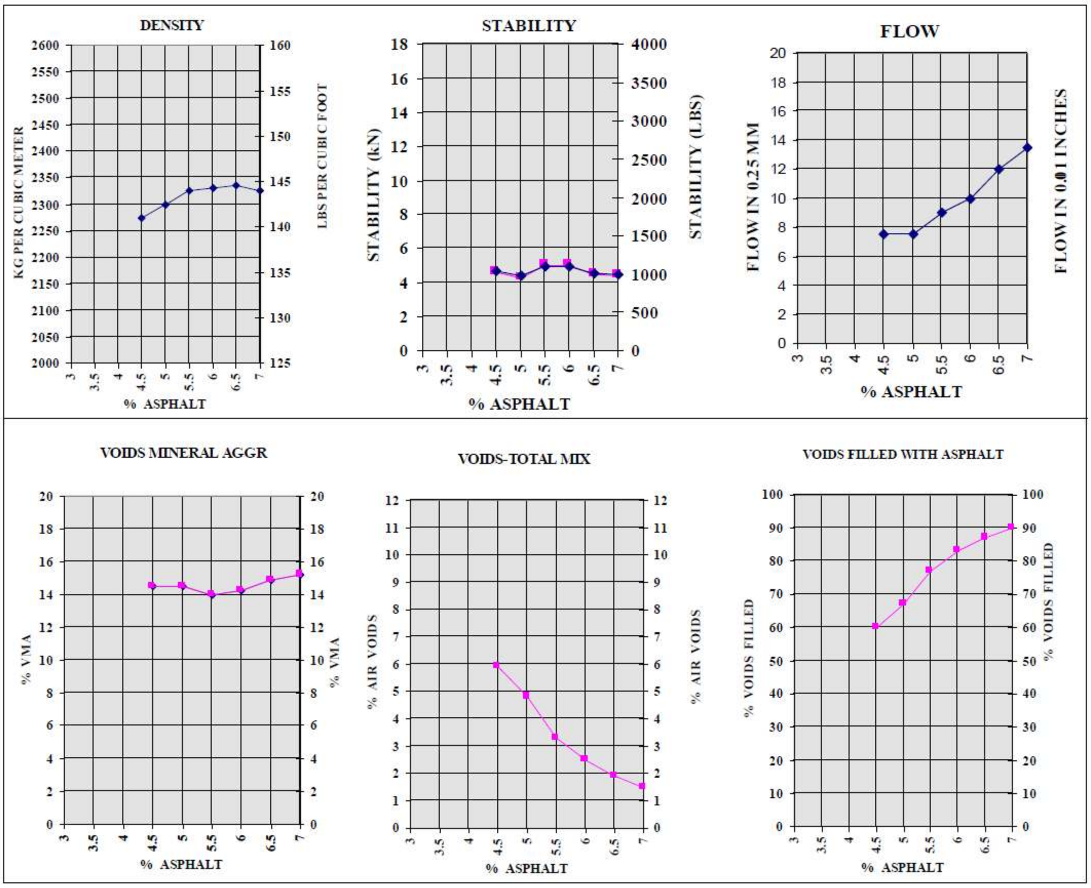

Figure 3.7 Marshall Mix Design graph examples

3.3.2 Design Procedure

In the Marshall Test method of mix design three compacted samples are prepared for each binder content. At least four binder contents are to be tested to get the optimum binder content. All the compacted specimens are subject to the following tests:

- Bulk density determination.
- Stability and flow test.
- Density and voids analysis.

3.3.2.1 Preparation of Test Specimens

The coarse-fine aggregate and the mineral filler material need be proportioned so as to fulfill the requirements of the desired standards. The required amount of the mixture is taken for producing compacted bituminous mix samples of thickness 63.5 mm. 1150 gram of aggregates and mineral filler are needed to get the desired thickness. The aggregates are heated to 175 °C - 190 °C the compaction mould assembly and rammer are cleaned and kept pre-heated to 100 °C - 145 °C. The bitumen is heated to 121 °C - 138 °C and the required amount of first trial of bitumen is added to the heated aggregate and thoroughly mixed. After all, the mixture is placed in a mould and compacted with number of blows specified. The sample is taken out of the mould after few minutes using sample extractor.

3.3.2.2 Bulk Density of the Compacted Specimen

The bulk density of the sample is usually determined by weighting the sample in air and in water. It may be necessary to coat samples with paraffin before determining density. The specific gravity G_{bcm} of the specimen is calculated by the Eqn. 3.20.

$$G_{\text{bcm}} = \frac{W_a}{W_a - W_w} \tag{3.20}$$

where;

W_a = weight of sample in air (g)

W_w = weight of sample in water (g)

3.3.2.3 Stability test

In conducting the stability test, the specimen is immersed in a bath of water at a temperature of 60° ± 1 °C for a period of 30 minutes. It is then placed in the Marshall Stability testing machine and loaded at a constant rate of deformation of 5 mm per minute until failure. The total maximum in kN (that causes failure of the specimen) is taken as Marshall Stability. The stability value so obtained is corrected for volume. The total amount of deformation is units of 0.25 mm that occurs at maximum load is recorded as Flow Value. The total time between removing the specimen from the bath and completion of the test should not exceed 30 seconds.

3.4 Wheel Tracking Test

Wheel Tracking Test is carried out according to TS EN 12697-22 standard.

3.5 Indirect Tensile Strength Test AASHTO T-283

Indirect Tensile Strength Test is used to determine the resistance of bituminous hot mixtures to harmful effects of water. This test is applied conditionally and unconditionally to the asphalt samples produced for the bituminous hot mixture layer. This test described in AASHTO T-283 covers the measurement of the tensile strength change due to the freeze-thaw effects of compacted bituminous mixtures in the laboratory. Conditional and unconditional sample groups are formed by using practical density (Dp) values. The selected conditional and unconditional samples are transferred to the Indirect Tensile Strength spreadsheet and the amount of water required for the conditional samples to become saturated with water is calculated.

Unconditional samples should be kept at room temperature until the test and stored in sealed plastic bags. These samples are kept in a water bath at 25 °C for 2 hours and all unconditional samples are placed under the pressure plate respectively. When a maximum load value is reached, vertical crack formation is observed in the sample along the diameter. Then, indirect tensile strength is calculated.

The conditional samples are placed in a vacuum vessel with metal parts at the base. The vacuum cup is filled with water at room temperature so that it exceeds the sample surface by at least 25 mm. A partial vacuum such as 10-26 inch-Hg is applied for 5 minutes and the vacuum is interrupted. The sample is kept in water for 10 minutes to become saturated. 70-80% of the prepared samples are checked whether they become filled with water. Vacuumed samples are placed in bags containing 10 ml of water each and sealed in bags. The samples are stored in a deep freezer at 18 ° C for 16 hours, then removed and kept in a 60 ° C water bath for 24 hours. The samples are then removed and kept in a 25 ° C water bath for 2 hours. Finally, the indirect tensile strength values are calculated.

Indirect tensile strength ratios are calculated by proportioning the values of the conditional group to the values of the unconditional group. Indirect tensile strength calculations are performed as follows (Eqn. 3.21):

$$St = -\frac{2\ x\ P}{\pi\ x\ t\ x\ D} \tag{3.21}$$

where;

St = Tensile Strength, (psi)

P =Maximum load, (Ib)

T = Sample Thickness, (inch)

D: Numune Çapı, inch

CHAPTER IV

TEST RESULTS

4.1 Aggregate Test Results

Four class aggregates taken from Güngörler quarry (1’’- 3/4’’, 3/4”-3/8”, 3/8”-No:4 , No:4-0) and 50/70 penetrated bitumen were used in the study. In order to obtain the optimum gradation curve, aggregates of different sizes are used in certain percentages. For each aggregate (0-5mm, 5-10mm, 10-20mm, 20-25mm) size, one sieve analysis was performed per day for 15 days. The reason for choosing the 15-day period is to obtain the average aggregate values using different samples taken daily from the aggregate quarry. The preparation of the mixture gradation is based on the sieve analysis results given in the Table 4.1. The usage rates, design gradation and tolerance limits of the aggregates are shown in same table.

Table 4.1 Usage rates, design gradation and tolerance limits of the aggregates

Aggregate Usage Percentages (%)		**12 %**	**24 %**	**22 %**	**42 %**	**100 (Total %)**	**100 (Total %)**	**T. C. Highways Technical Specification Binder Section 407 Limits**			
Sieve Opening (mm)		(20-25) mm	(10-20) mm	(5-10) mm	(0-5) mm	**Gradation of Mixture**	**Corrected Design Gradation (2% Adhered Filler)**				
mm	inch	% Passing	% Passing	% Passing	% Passing			**Specification**		**Tolerance**	
37.5	1 1/2"	100	100	100	100	100	100	100	100	100	100
25.4	1"	100	100	100	100	100	100	100	100	100	100
19.1	3/4"	19.7	100	100	100	90.4	90.2	80	100	86.2	94.2
12.7	1/2"	0.3	43.2	100	100	74.4	73.9	58	80	69.9	77.9
9.52	3/8"	0.0	3.2	86.9	100	61.9	61.1	48	70	57.1	65.1
4.75	No.4	0.0	0.1	2.4	100	42.6	41.4	30	52	37.4	45.4
2.00	No.10	0.0	0.0	0.2	66.7	28.1	26.6	20	40	23.6	29.6
0.42	No.40	0.0	0.0	0.0	29.5	12.4	10.6	8	22	8	13.6
0.177	No.80	0.0	0.0	0.0	20.8	8.7	6.9	5	14	5	9.9
0.075	No.200	0.0	0.0	0.0	16.1	6.8	4.9	2	7	2.9	6.9
**** 2% Adhered Filler**											

The gradation curve (Figure 4.1) shows that the percentages of the aggregates used in total are within the specification values.

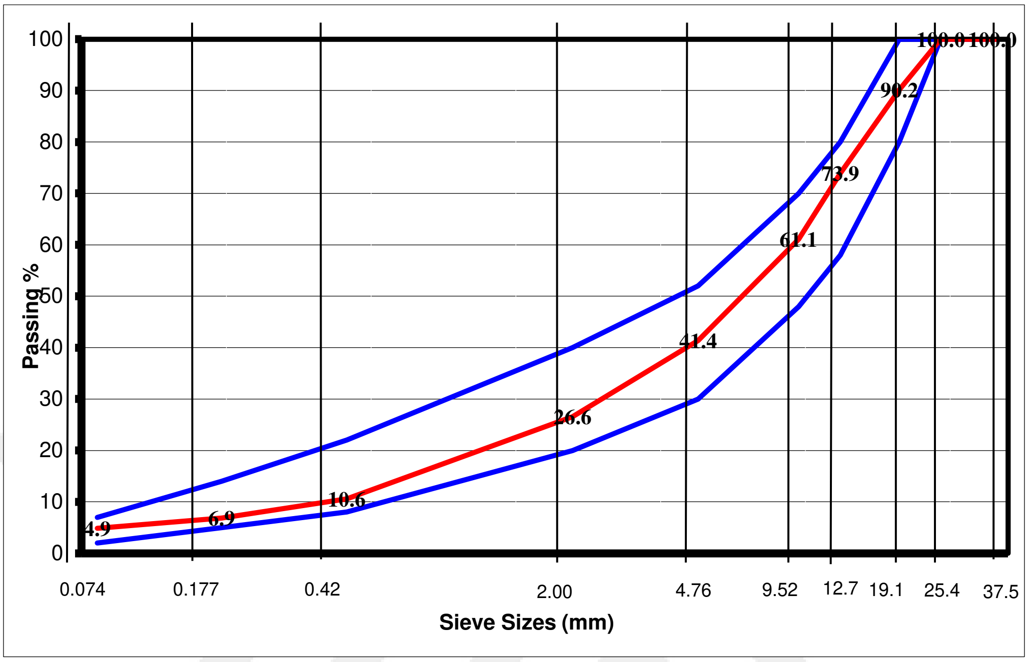

Figure 4.1 Gradation curve of aggregate

The test results of the aggregates prepared in accordance with the design gradation are shown in Table 4.2 and Table 4.3. The maximum water absorption percentage of coarse and fine aggregate should not exceed 3% (TS EN 1097-6). According to the test results, the water absorption percentages of the coarse and fine aggregate are 0.40% and 0.93% respectively.

Table 4.2 Quarry name, type, specific gravity and water absorption of aggregates

The name of the quarry		Güngörler		
Type of Rock		Limestone		
Type of Test	**Coarse Aggregate**	**Fine Aggregate**	**Filler**	**Test Standard**
Volume Specific Gravity	2.690	2.671		TS EN 1097-6
Apparent Specific Gravity	2.719	2.738	2.747	TS EN 1097-6
Absorption (%)	0.40	0.93		ASTM C 127 TS EN 1097-6

According to TS EN 1367-2 standard, the soundness test result of aggregate with the $MgSO_4$ solution should be maximum 18%. The soundness test result is in the desired range as 15%. According TS EN 933-9 standard, Methylene Blue test result should be equal or lower than 1.5%. Methylene Blue test result is in the desired range as 1.0%. According to AASHTO T-96 Los Angeles abrasion loss percentage should be maximum 30%. Los Angeles abrasion loss percentage of the aggregate is in the desired range as 22.3%. According to BS 812 Flakiness Index percentage should be maximum 30%. Flakiness Index test result is in the desired range as 27.3%. According to TS EN 12697-11 standard affinity test result should be higher than 60%. Affinity test result is in the desired range as 80-85%.

Table 4.3 Test results of aggregate mixture

Type of Test	Result	Test Standard
Effective specific gravity of the mixture (by experiment)	2.705	ASTM D-2041
Effective specific gravity of the mixture (by calculation)	2.706	ASTM D-2041
Soundness	15.00	TS EN 1367-2
Methylene Blue test result	1.000	TS EN 933-9
Los Angeles Abrasion Loss (%)	22.30	AASHTO T-96
Flakiness Index (%)	27.30	BS 812
Affinity (%)	80-85	KTŞ Section 403 Annex-A

4.2 Bitumen Test Results

Bitumen test results are shown in Table 6. According to TS EN 1426 standard bitumen penetration depth should be between 50-70mm. Penetration of 50/70 bitumen used in the study is 57 mm. According to TS EN 12607-2 TFOT test result of the bitumen should be 0.5%. According to TFOT test result mass loss found as 0.03%. According to TS EN ISO 2592 standard, the flash and fire point of the bitumen should be higher 230 ºC. According to TS EN ISO 2592 test result flash and fire point of the bitumen are 295 ºC and 295 ºC respectively. According to 12592 standard solubility of bitumen should be minimum 99%. Test result gives a solubility percentage of 99%. According to the TS EN 1427 test, softening point of bitumen should be between 46-54 ºC. Softening point of bitumen used in the study is 49 ºC.

Table 4.4 Bitumen test results

Type of Test	Result	Test Standard
Bitumen specific gravity	1.033	TS1087
Bitumen Penetration (dmm)	57	TS EN 1426
Thin film oven TFOT (%)		
Mass loss (%)	0.03	TS EN 12607-2
Softening point (^oC)	49.2	TS EN 12607-2
Permanent penetration (mm)	57.6	TS EN 12607-2
Flash Point (^oC)	295	TS EN ISO 2592
Fire Point (^oC)	295	TS EN ISO 2592
Solubility (%)	99	TS EN 12592
Softening point (^oC)	49	TS EN 1427
Bituminous binder	Refinery	-
	Type	Bitumen
	Class	B 50/70

4.3 Results of Marshall Method of Mix Design

In the first stage of the study, normal binder design was done and optium bitumen rate and other results were found (Table 4.5-4.6 and Figure 4.2), then the plastic wastes were added to the mixture at certain rates and experimental studies were continued and comparisons were made. As a result of the design with 2x75 hammer blow according to the Marshall Method, the optimum bitumen ratio was found to be 4.40% by weight of the dry aggregate. Other results obtained by using the optimum bitumen ratio are given in Table 4.5. Adhered filler mineral ratio was assumed to be 2%. Also, the tables of the following parameters were created.

Bitumen % – Density (kg/m^3)
Bitumen % – Stability (kN)
Bitumen % – Flow (in 0,25mm)
Bitumen % – Voids Mineral Aggregate, VMA (%)
Bitumen % - Voids Total Mix (%)
Bitumen % – Voids Filled with Asphalt, VFA (%)

Optimum bitumen ratio is obtained by using the graph of density-bitumen (Dp), stability-bitumen, total voids mix-bitumen and VFA-bitumen. Bitumen ratios corresponding to maximum density and stability values and bitumen ratios corresponding to the average voids total mix and VFA values in the specification are used to get optimum bitumen ratio.

Table 4.5 Hot Mix Design Data (Marshall Method)

	Results	**Specification**
Optimum bitumen ratio (%)	4.40	3.5-6.5
Practical specific weight	2.414	-
Stability (kg)	990	Min.750
Void ratio (%)	4.71	4-6
Voids filled with asphalt (VFA)(%)	66.1	60-75
Voids in the mineral aggregate (VMA) (%)	13.9	13-15
Yield (mm)	2.70	2-4

Table 4.6 Detailed Hot Mix Design Data (Marshall Method)

Bitumen Penetration	: 57	Volume Specific Gravity of Coarse Agg.,G_{k-h}	2.690	G_{ef}-experiment	: 2.705
Bitumen Specific Gravity,G_b	: 1.033	Apparent Specific Gravity of Coarse Agg.,G_{k-z}	2.719	G_{ef}-calculation	: 2.706
Bitumen Absorption of Aggregate P_{ba}	: 0.30	Volume Specific Gravity of Fine Agg.,G_{i-h}	2.671	Aggregate Mix.	: 1150 gr
Efficient Specific Weight of Agg.,G_{ef}	: 2.706	Apparent Specific Gravity of Fine Agg.,G_{i-z}	2.738	Stroke no	: 75
Agg. Volume Specific Gravity,G_{sb}	: 2.685	Apparent Specific Gravity of Filler,G_{f-z}	2.75	**%Va=Agg. Volume %**	**: 85.44**
Apparent specific gravity of agg.,G_{sa}	: 2.727			**%Vb=Bitumen Volume %**	**: 9.85**
				%Vh=Air Volume %	**: 4.71**

HOT MIX DESIGN DATA (MARSHALL METHOD)

No	BITUMEN Wa,%	BITUMEN g	Compact Temp. °C	Specimen Height,mm 1	2	3	avg.	Weight Dry in Air,g A	Weight In Water,g C	Weight S.S.D. B	Volume cm³ V	Volume Sp. Gr. Dp	Maks.Teo. Sp. Gr. Dt	% Void Vh	% V.M.A	V. F. A. Vf	Flow mm	Stability kg	Corr. Factor	Corrected Stability kg
1	3.50	40.25	142	64.3	64.5	64.4	64.4	1173.8	689.0	1187.0	498.0	2.357					1.81	901	0.978	881
2	3.50	40.25	140	65.0	64.9	65.0	65.0	1183.8	696.6	1197.7	501.1	2.362					2.20	1004	0.965	969
3	3.50	40.25	142	64.5	65.4	64.5	64.8	1176.9	691.5	1189.9	498.4	2.361					2.44	902	0.969	874
												2.360	2.566	8.01	15.08	46.9	2.15			908
4	4.00	46.00	142	64.9	64.2	64.9	64.7	1179.0	693.0	1190.2	497.2	2.371	i				2.22	1129	0.972	1097
5	4.00	46.00	143	64.6	64.8	64.6	64.7	1194.8	704.2	1202.3	498.1	2.399					3.20	1005	0.972	977
6	4.00	46.00	144	63.8	63.7	63.6	63.7	1179.2	694.8	1189.8	495.0	2.382					2.44	1024	0.994	1018
												2.390	2.548	6.17	14.41	57.2	2.82			997
7	4.50	51.75	142	63.7	63.6	63.5	63.6	1187.1	698.3	1197.3	499.0	2.379	i				2.35	923	0.997	920
8	4.50	51.75	141	63.5	63.6	63.6	63.6	1199.3	706.0	1203.8	497.8	2.409					2.53	925	0.997	923
9	4.50	51.75	140	63.9	63.8	63.6	63.8	1191.3	713.4	1207.7	494.3	2.410					2.71	925	0.993	918
												2.410	2.530	4.75	14.13	66.4	2.62			920
10	5.00	57.50	141	63.4	63.5	63.6	63.5	1201.9	708.7	1207.4	498.7	2.410	i				2.75	1020	0.999	1019
11	5.00	57.50	140	63.9	63.6	63.7	63.7	1199.7	710.4	1203.8	493.4	2.431					2.80	1085	0.993	1078
12	5.00	57.50	142	63.3	63.4	63.5	63.4	1206.6	715.3	1209.2	493.9	2.443					3.35	1021	1.002	1023
												2.437	2.513	3.00	13.56	77.9	3.08			1050
13	5.50	63.25	142	62.2	62.3	62.5	62.3	1198.0	704.5	1200.8	496.3	2.414					2.91	923	1.030	950
14	5.50	63.25	143	63.9	63.8	63.7	63.8	1214.1	715.6	1215.8	500.2	2.427					3.28	916	0.992	908
15	5.50	63.25	141	63.7	63.8	63.6	63.7	1196.9	705.2	1200.5	495.3	2.417					2.90	905	0.994	900
												2.419	2.496	3.06	14.61	79.0	3.03			919
16	6.00	69.00	141	63.3	63.2	63.4	63.3	1217.0	712.2	1220.0	507.8	2.397					3.67	881	1.004	885
17	6.00	69.00	143	62.2	63.2	63.6	63.0	1215.0	712.7	1219.0	506.3	2.400					3.13	834	1.012	844
18	6.00	69.00	142	63.5	63.4	63.5	63.5	1213.0	710.3	1218.0	507.7	2.389					4.88	803	1.000	803
												2.395	2.479	3.38	15.86	78.7	3.89			844
	4.40		OPTIMUM BITUMEN RESULTS (From Chart)									2.414	2.533	4.70	13.9	66.0	2.70	Fill/Bit	Stb/flow	990
	4.40		OPTIMUM BITUMEN RESULTS (Calculation Geff_ trial)									2.414	2.532	4.67	13.9	66.4	2.70			990
	4.40		OPTIMUM BITUMEN RESULTS (Calculation Geff_Calculation result)									2.414	2.533	4.71	13.9	66.1	2.70	1.10	367	990
			BINDER DESIGN CRITERIA											(4-6)	min13	(60-75)	(2-4)	max1.4		min750

$V=B-C$

$D_p=A/V$ $D_t=(100+W_a)/(100/G_{eff}+W_a/G_b)$

$V_h=(D_t-D_p)\times100/D_t$

$G_{sb}=100/(\%K/G_{k-h}+\%\dot{I}/G_{i-h}+\%F/G_{f-z})$

$G_{sa}=100/(\%K/G_{k-z}+\%\dot{I}/G_{i-z}+\%F/G_{f-z})$

$VMA=100-(D_p\times(100-W_a/(1+W_a/100))/G_{sb})$

$V_f=(VMA-V_h)\times100/VMA$

$P_b=100\times G_b\times(G_{ef}-G_{sb})/(G_{ef}\times G_{sb})$

1½"	100.0
1"	100.0
3/4"	90.2
1/2"	73.9
3/8"	61.1
No.4	41.4
No.10	26.6
No.40	10.6
No.80	6.9
No.200	4.9

Coarse %= 58.6
Fine % = 36.5
Filler % = 4.9

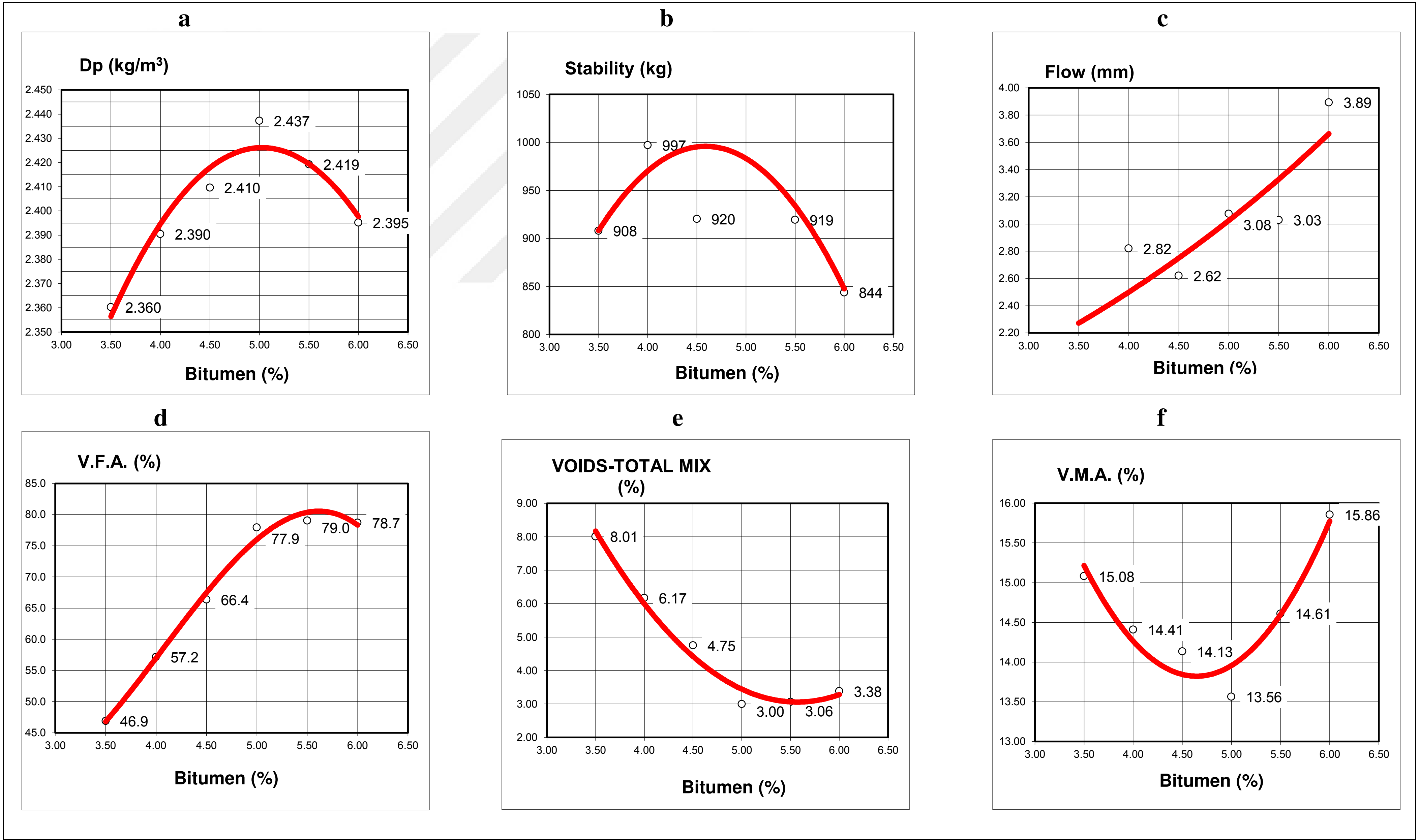

Figure 4.2 Marshall Mix Design results: **a)** Bitumen % – Density (kg/m^3) **b)** Bitumen % – Stability (kN) **c)** Bitumen % – Flow (in 0,25mm) **d)** Bitumen %– Voids Filled with Asphalt, VFA (%) **e)** Bitumen % - Voids Total Mix **(%)** **f)** Bitumen % – Voids Mineral Aggregate, VMA (%)

In the first stage of the experimental study, binder design was made without additive. Thus, optimum bitumen ratio and other Marshall Design parameters (stability, flow, VFA, VMA, etc.) were found (Table 4.5-4.6). Then, plastic wastes were added to the mixture in certain ratios and experimental studies were continued. In this study two methods were followed in asphalt mixtures produced using ground waste PET bottles. Firstly, the effect of ground PET bottle on bitumen was investigated. For this purpose, 50/70 penetrated bitumen was heated at 150 °C and ground pet bottle (10% of bitumen) was added to the heated bitumen. Bitumen and ground PET bottle wastes were mixed with a baguette and the wastes were expected to melt in the bitumen. However, since there was no melting at 150 °C, the bitumen was first heated to 175 °C and then to 190 °C. Since there was no melting at 190 °C, the ground PET bottle was added to the aggregate mixture.

After finding the optimum bitumen rate, bitumen rate was kept constant as 4.4% and ground PET bottle wastes in 4 different gradations were added to the 1150 g. aggregate mixture that is prepared according to the Highways Technical Specification (KTŞ) Binder Layer Type-II gradation, at the rate of 0.3%, 0.4%, 0.5% and 0.6%. Marshall control samples were prepared for each plastic waste sample. Totally, 48 Marshall control samples were prepared (Table 4.7).

Table 4.7 Number of samples

Weight of Mixture: 1200.6 g					
PVC Usage (%)	**PVC Amount (g)**	**Number of Samples**			
		P1	P2	P3	P4
0.3	3.6	3	3	3	3
0.4	4.8	3	3	3	3
0.5	6	3	3	3	3
0.6	7.2	3	3	3	3

Finally, the plastic rate was kept constant and the effect of bitumen was investigated. A total of 72 samples were formed with a bitumen rate of 3.5%, 4.0%, 4.5%, 5.0%, 5.5% and 6% (Table 4.8).

Table 4.8 Number of samples (weight of aggregate 1150 g)

Wa %	Bitumen (g)	Plastic (g)	Number of Samples			
			P1	P2	P3	P4
3.5	40.3	4.76	3	3	3	3
4.0	46.0	4.78	3	3	3	3
4.5	51.8	4.81	3	3	3	3
5	57.5	4.83	3	3	3	3
5.5	63.3	4.85	3	3	3	3
6	69.0	4.88	3	3	3	3

In Table 4.9, the amount of plastic sample P1 was kept constant as 6 grams and Marshall Parameters were examined according to bitumen rate (Figure 4.3). As a result, the highest stability value was reached with bitumen ratio Wa = 5.0% and stability started to decrease for higher bitumen ratios. Stability values of all studied bitumen ratios remained within the Highways Technical Specification (KTŞ) range. The graph below shows the stability changes.

Table 4.9 Detailed Hot Mix Design Data (Marshall Method) P1 (6 gram)

HOT MIX DESIGN DATA (MARSHALL METHOD)

No	BITUMEN		Comapct Temp.	Specimen Height,mm				Weight Dry in Air,g	Weight In Water,g	Weight S.S.D.	Volume cm³	Volume Sp. Gr.	Maks.Teo Sp. Gr.	% Void	%	V. F. A.	Flow	Stability	Corr. Factor	Corrected Stability
	Wa,%	g	°C	1	2	3	avg.	A	C	B	V	Dp	Dt	Vh	V.M.A	Vf	mm	kg		kg
1	3.50	40.25	142	65.2	66.3	65.0	65.5	1183.7	683.0	1189.8	506.8	2.336					2.17	1500	0.954	1431
2	3.50	40.25	140	64.0	64.4	65.1	64.5	1176.0	682.6	1184.3	501.7	2.344					2.10	1455	0.975	1419
3	3.50	40.25	142	64.5	65.4	64.5	64.8	1176.9	691.5	1189.9	498.4	2.361					1.98	1525	0.969	1477
												2.347	2.542	7.66	14.69	47.9	2.08			1442
4	4.00	46.00	142	64.9	66.4	65.1	65.5	1186.3	690.0	1193.7	503.7	2.355					2.68	1625	0.954	1551
5	4.00	46.00	143	65.3	65.1	66.5	65.6	1194.8	704.2	1202.3	498.1	2.399					2.68	1645	0.951	1564
6	4.00	46.00	144	65.5	65.4	65.6	65.5	1187.3	694.8	1189.8	495.0	2.399					2.44	1701	0.954	1622
												2.384	2.524	5.54	13.76	59.7	2.60			1579
7	4.50	51.75	142	64.5	64.7	65.8	65.0	1185.3	684.8	1192.3	507.5	2.336					2.06	1665	0.964	1606
8	4.50	51.75	141	65.7	64.4	66.2	65.4	1193.0	691.5	1198.3	506.8	2.354					2.39	1700	0.955	1624
9	4.50	51.75	140	65.0	65.2	65.4	65.2	1191.3	689.5	1196.2	506.7	2.351					2.30	1648	0.960	1582
												2.347	2.507	6.38	15.51	58.9	2.25			1604
10	5.00	57.50	141	65.3	65.8	63.7	64.9	1216.5	705.1	1219.5	514.4	2.365					2.31	1809	0.966	1747
11	5.00	57.50	140	64.8	64.1	62.8	63.9	1195.7	695.4	1198.2	502.8	2.378					2.25	1813	0.989	1794
12	5.00	57.50	142	64.3	64.0	63.5	63.9	1206.6	715.3	1209.2	493.9	2.443					3.35	1755	0.989	1735
												2.395	2.490	3.79	14.18	73.2	2.64			1759
13	5.50	63.25	142	62.3	62.7	63.6	62.9	1207.5	708.7	1208.1	499.4	2.418					3.00	1252	1.015	1271
14	5.50	63.25	143	64.2	62.8	63.9	63.6	1193.5	692.8	1194.7	501.9	2.378					3.99	1485	0.996	1479
15	5.50	63.25	141	63.7	63.8	63.6	63.7	1196.9	705.2	1200.5	495.3	2.417					2.90	1310	0.994	1302
												2.404	2.473	2.79	14.27	80.4	3.30			1351
16	6.00	69.00	141	63.6	64.4	63.1	63.7	1203.6	700.9	1204.5	503.6	2.390					3.77	1229	0.994	1222
17	6.00	69.00	143	64.1	63.0	64.4	63.8	1181.7	683.3	1183.4	500.1	2.363					3.13	1140	0.991	1130
18	6.00	69.00	142	63.5	63.4	63.5	63.5	1213.0	710.3	1218.0	507.7	2.389					3.88	1150	1.000	1150
												2.381	2.457	3.11	15.51	80.0	3.59			1167
	4.40		OPTIMUM BITUMEN RESULTS (From Chart)									2.414	2.510	4.70	13.9	66.0	2.70	Fill/Bit	Stb/flw	990
	4.40		OPTIMUM BITUMEN RESULTS (Calculation Geff_ trial)									2.414	2.510	3.81	13.0	70.7	2.70			990
	4.40		OPTIMUM BITUMEN RESULTS (Calculation Geff_Calculation result)									2.414	2.510	3.83	13.0	70.6	2.70	1.10	367	990
			BINDER DESIGN CRITERIA											(4-6)	min13	(60-75)	(2-4)	max1.4		min750

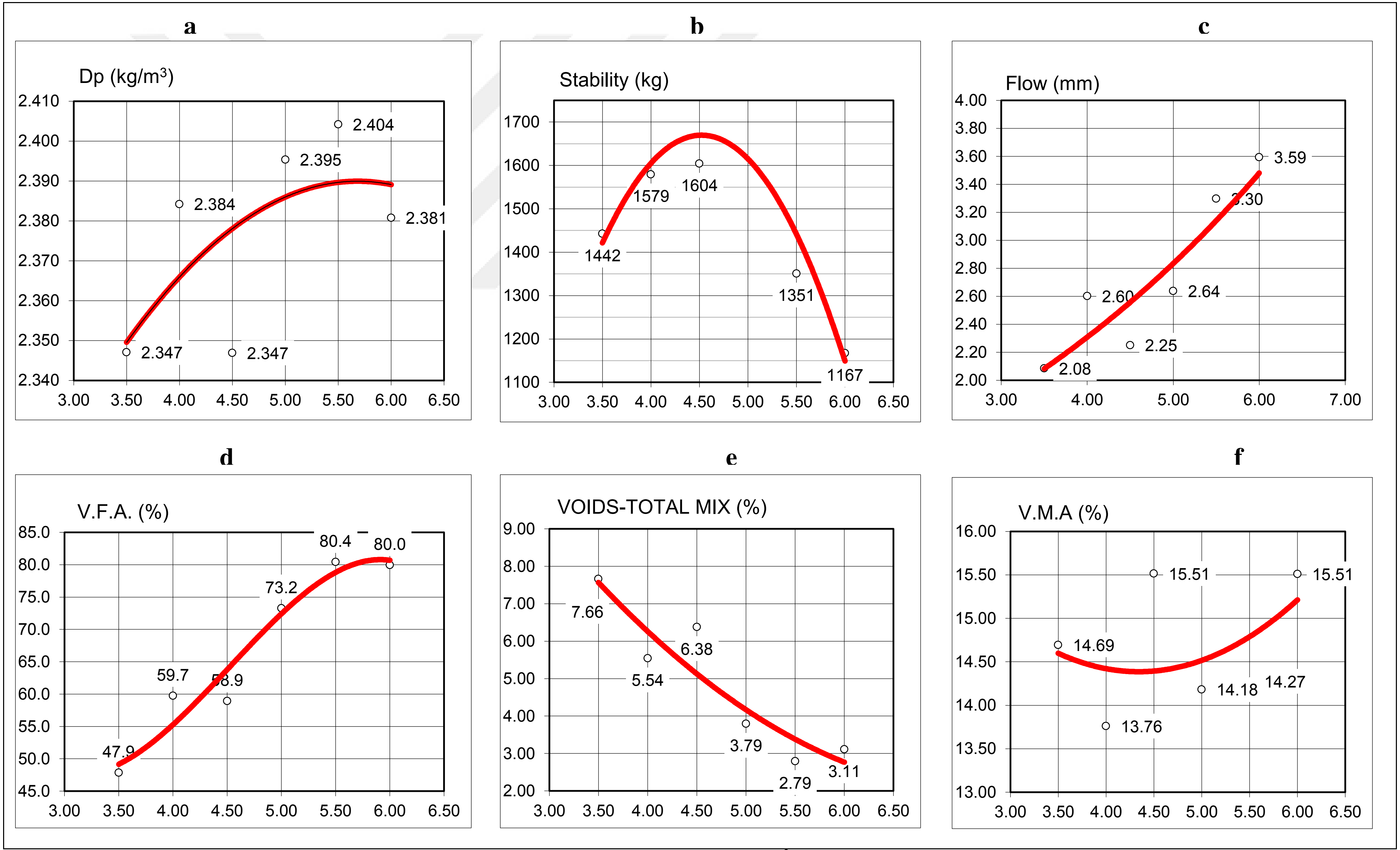

Figure 4.3 Marshall Mix Design Result P1 6g: **a)** Bitumen % – Density (kg/m^3) **b)** Bitumen % – Stability (kN) **c)** Bitumen % – Flow (in 0,25mm) **d)** Bitumen % – Voids Filled with Asphalt, VFA (%) **e)** Bitumen % - Voids Total Mix (%) **f)** Bitumen % – Voids Mineral Aggregate, VMA (%)

In Table 4.10, the amount of plastic sample P2 was kept constant as 6 grams and Marshall Parameters were examined according to bitumen rate (Figure 4.4). As a result, the highest stability value was reached with bitumen ratio Wa = 5.0% and stability started to decrease for higher bitumen ratios. Stability values of all studied bitumen ratios remained within the Highways Technical Specification (KTŞ).

Table 4.10 Detailed Hot Mix Design Data (Marshall Method) P2 (6 gram)

No	BITUMEN		Comapct Temp.	Specimen Height,mm				Weight Dry in Air,g	Weight In Water,g	Weight S.S.D.	Volume cm³	Volume Sp. Gr.	Maks.Teo Sp. Gr.	% Void	%	V. F. A.	Flow	Stability	Corr. Factor	Corrected Stability
	Wa,%	g	°C	1	2	3	avg.	A	C	B	V	Dp	Dt	Vh	V.M.A	Vf	mm	kg		kg
1	3.50	40.25	142	66.4	66.1	66.9	66.5	1196.0	690.8	1208.3	517.5	2.311					6.68	1249	0.933	1166
2	3.50	40.25	140	66.5	66.9	65.4	66.3	1189.2	685.0	1198.6	513.6	2.315					2.07	1326	0.938	1243
3	3.50	40.25	142	66.3	66.5	66.0	66.3	1192.1	690.0	1202.0	512.0	2.328					2.00	1265	0.938	1186
												2.318	2.543	8.85	15.80	44.0	3.58			1198
4	4.00	46.00	142	65.7	65.2	65.1	65.3	1199.8	695.2	1206.0	510.8	2.349					2.65	1427	0.957	1366
5	4.00	46.00	143	64.8	66.0	65.0	65.3	1194.4	692.0	1200.7	508.7	2.348					2.42	1359	0.959	1303
6	4.00	46.00	144	65.3	65.8	65.0	65.4	1196.2	694.8	1206.2	511.4	2.339					2.35	1400	0.957	1339
												2.345	2.526	7.14	15.23	53.1	2.47			1336
7	4.50	51.75	142	64.7	65.0	65.6	65.1	1191.6	688.6	1198.2	509.6	2.338					1.98	1409	0.962	1356
8	4.50	51.75	141	64.8	65.8	66.6	65.7	1186.2	684.7	1195.6	510.9	2.322					1.75	1238	0.949	1175
9	4.50	51.75	140	64.7	65.4	66.0	65.4	1189.0	686.0	1196.2	510.2	2.330					1.86	1356	0.957	1297
												2.330	2.508	7.10	16.18	56.1	1.86			1276
10	5.00	57.50	141	65.2	65.7	64.0	65.0	1195.6	696.0	1207.0	511.0	2.340					1.95	1452	0.965	1401
11	5.00	57.50	140	64.6	64.3	63.8	64.2	1190.0	695.4	1202.5	507.1	2.347					2.10	1356	0.982	1331
12	5.00	57.50	142	64.9	64.5	64.1	64.5	1194.0	701.0	1205.0	504.0	2.369					1.65	1365	0.975	1331
												2.352	2.491	5.60	15.80	64.5	1.90			1355
13	5.50	63.25	142	62.8	62.7	63.4	63.0	1202.0	705.0	1213.5	508.5	2.364					1.55	1325	1.013	1342
14	5.50	63.25	143	64.1	62.9	63.9	63.6	1194.5	693.5	1206.2	512.7	2.330					2.65	1365	0.996	1359
15	5.50	63.25	141	63.9	63.8	63.7	63.8	1198.0	698.5	1210.3	511.8	2.341					2.00	1300	0.992	1289
												2.345	2.475	5.25	16.45	68.1	2.07			1330
16	6.00	69.00	141	64.6	64.4	63.1	64.0	1201.0	695.8	1212.3	516.5	2.325					1.56	1256	0.986	1239
17	6.00	69.00	143	64.5	63.5	64.3	64.1	1198.0	686.5	1204.6	518.1	2.312					1.65	1280	0.985	1260
18	6.00	69.00	142	63.6	63.5	63.8	63.6	1205.8	708.0	1217.8	509.8	2.365					2.10	1005	0.996	1001
												2.334	2.459	5.06	17.22	70.6	1.77			1167
	4.40		OPTIMUM BITUMEN RESULTS (From Chart)									2.414	2.512	4.70	13.9	66.0	2.70	Fill/Bit	Stb/flw	990
	4.40		OPTIMUM BITUMEN RESULTS (Calculation Geff_ trial)									2.414	2.510	3.81	13.1	70.9	2.70			990
	4.40		OPTIMUM BITUMEN RESULTS (Calculation Geff_Calculation result)									2.414	2.512	3.89	13.1	70.2	2.70	1.10	367	990
			BINDER DESIGN CRITERIA											(4-6)	min13	(60-75)	(2-4)	max1.4		min750

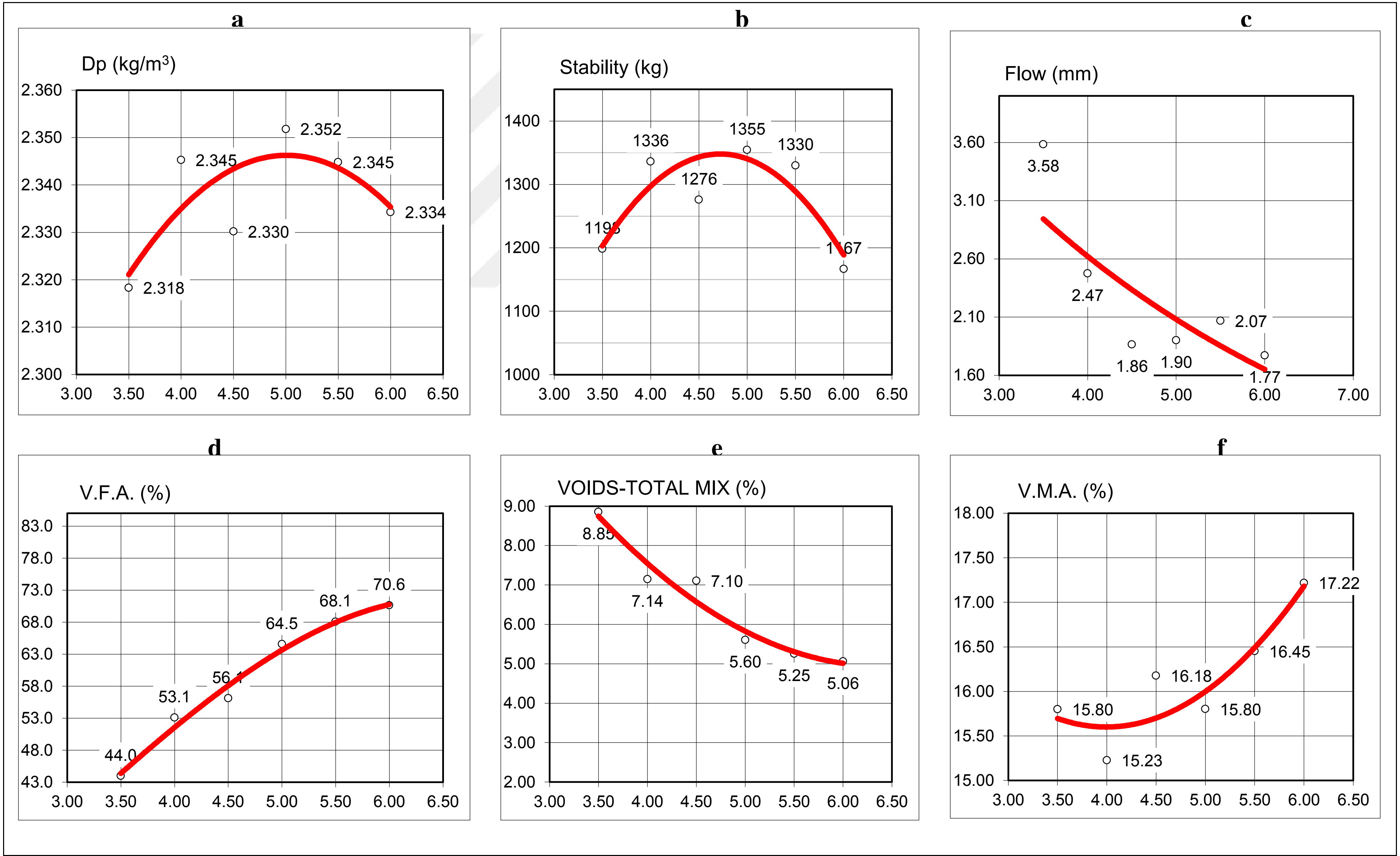

Figure 4.4 Marshall Mix Design Result P2 6g: **a)** Bitumen % – Density (kg/m^3) **b)** Bitumen % – Stability (kN) **c)** Bitumen % – Flow (in 0,25mm) **d)** Bitumen % – Voids Filled with Asphalt, VFA (%) **e)** Bitumen % - Voids Total Mix **(%)** **f)** Bitumen % – Voids Mineral Aggregate, VMA (%)

In Table 4.11, the amount of plastic sample P3 was kept constant as 6 grams and Marshall Parameters were examined according to bitumen rate (Figure 4.5). As a result, the highest stability value was reached with bitumen ratio Wa = 5.0% and stability started to decrease for higher bitumen ratios. In some bitumen ratios, stabilty values did not meet the specification criteria. In addition, the obtained Vh, VFA and flow values did not meet the specification criteria.

Table 4.11 Detailed Hot Mix Design Data (Marshall Method) P3 (6 gram)

No	BITUMEN Wa,%	BITUMEN g	Comapct Temp. °C	Specimen Height,mm 1	2	3	avg.	Weight Dry in Air,g A	Weight in Water,g C	Weight S.S.D. B	Volume cm³ V	Volume Sp. Gr. Dp	Maks.Teo Sp. Gr. Dt	% Void Vh	% V.M.A	V. F. A. Vf	Flow mm	Stability kg	Corr. Factor	Corrected Stability kg
1	3.50	40.25	142	65.6	64.3	65.8	65.2	1193.4	689.8	1199.6	509.8	2.341					0.85	1422	0.959	1364
2	3.50	40.25	140	64.1	65.3	65.0	64.8	1184.5	686.0	1191.5	505.5	2.343					1.35	1281	0.969	1241
3	3.50	40.25	142	64.4	63.9	63.4	63.9	1200.4	697.0	1203.0	506.0	2.372					0.95	1542	0.989	1526
												2.352	2.543	7.52	14.57	48.4	1.05			1377
4	4.00	46.00	142	63.4	62.5	64.4	63.4	1194.2	691.0	1199.2	508.2	2.350					1.25	1500	1.001	1501
5	4.00	46.00	143	62.4	62.6	62.1	62.4	1186.0	685.9	1191.2	505.3	2.347					1.34	1325	1.029	1363
6	4.00	46.00	144	63.1	63.6	63.5	63.4	1192.0	687.0	1195.2	508.2	2.346					1.20	1455	1.002	1457
												2.348	2.526	7.05	15.15	53.4	1.26			1440
7	4.50	51.75	142	66.4	65.8	66.4	66.2	1190.0	683.7	1200.0	516.3	2.305					1.45	1095	0.939	1028
8	4.50	51.75	141	65.4	66.1	65.2	65.6	1192.0	689.0	1201.0	512.0	2.328					1.65	1485	0.952	1414
9	4.50	51.75	140	65.4	66.0	64.5	65.3	1186.2	684.0	1188.0	504.0	2.354					1.80	1116	0.958	1069
												2.329	2.508	7.16	16.22	55.9	1.63			1171
10	5.00	57.50	141	65.7	65.5	65.6	65.6	1189.0	700.5	1192.0	491.5	2.419					1.65	1505	0.952	1432
11	5.00	57.50	140	66.2	65.4	65.5	65.7	1189.0	698.2	1191.5	493.3	2.410					1.75	1469	0.950	1395
12	5.00	57.50	142	65.8	65.4	64.6	65.3	1195.0	699.0	1197.5	498.5	2.397					1.50	1565	0.959	1500
												2.409	2.491	3.31	13.76	75.9	1.63			1442
13	5.50	63.25	142	63.8	63.4	63.5	63.6	1197.0	703.0	1200.5	497.5	2.406					1.85	923	0.997	921
14	5.50	63.25	143	64.8	64.5	63.8	64.4	1213.5	710.0	1214.0	504.0	2.408					2.00	916	0.978	896
15	5.50	63.25	141	63.8	63.7	63.9	63.8	1195.7	701.5	1199.0	497.5	2.403					1.90	905	0.992	897
												2.406	2.475	2.79	14.28	80.4	1.92			905
16	6.00	69.00	141	64.2	64.3	63.9	64.1	1216.0	712.2	1220.1	507.9	2.394					1.80	881	0.984	867
17	6.00	69.00	143	63.9	63.0	63.5	63.5	1214.5	712.7	1221.0	508.3	2.389					1.50	834	1.000	834
18	6.00	69.00	142	63.6	63.7	64.2	63.8	1212.8	710.3	1219.5	509.2	2.382					1.65	803	0.991	796
												2.388	2.459	2.86	15.30	81.3	1.65			832
	4.40		OPTIMUM BITUMEN RESULTS (From Chart)									2.414	2.512	4.70	13.9	66.0	2.70	Fill/Bit	Stb/flw	990
	4.40		OPTIMUM BITUMEN RESULTS (Calculation Geff_ trial)									2.414	2.510	3.81	13.1	70.9	2.70			990
	4.40		OPTIMUM BITUMEN RESULTS (Calculation Geff_Calculation res									2.414	2.512	3.89	13.1	70.2	2.70	1.10	367	990
			BINDER DESIGN CRITERIA											(4-6)	min13	(60-75)	(2-4)	max1.4		min750

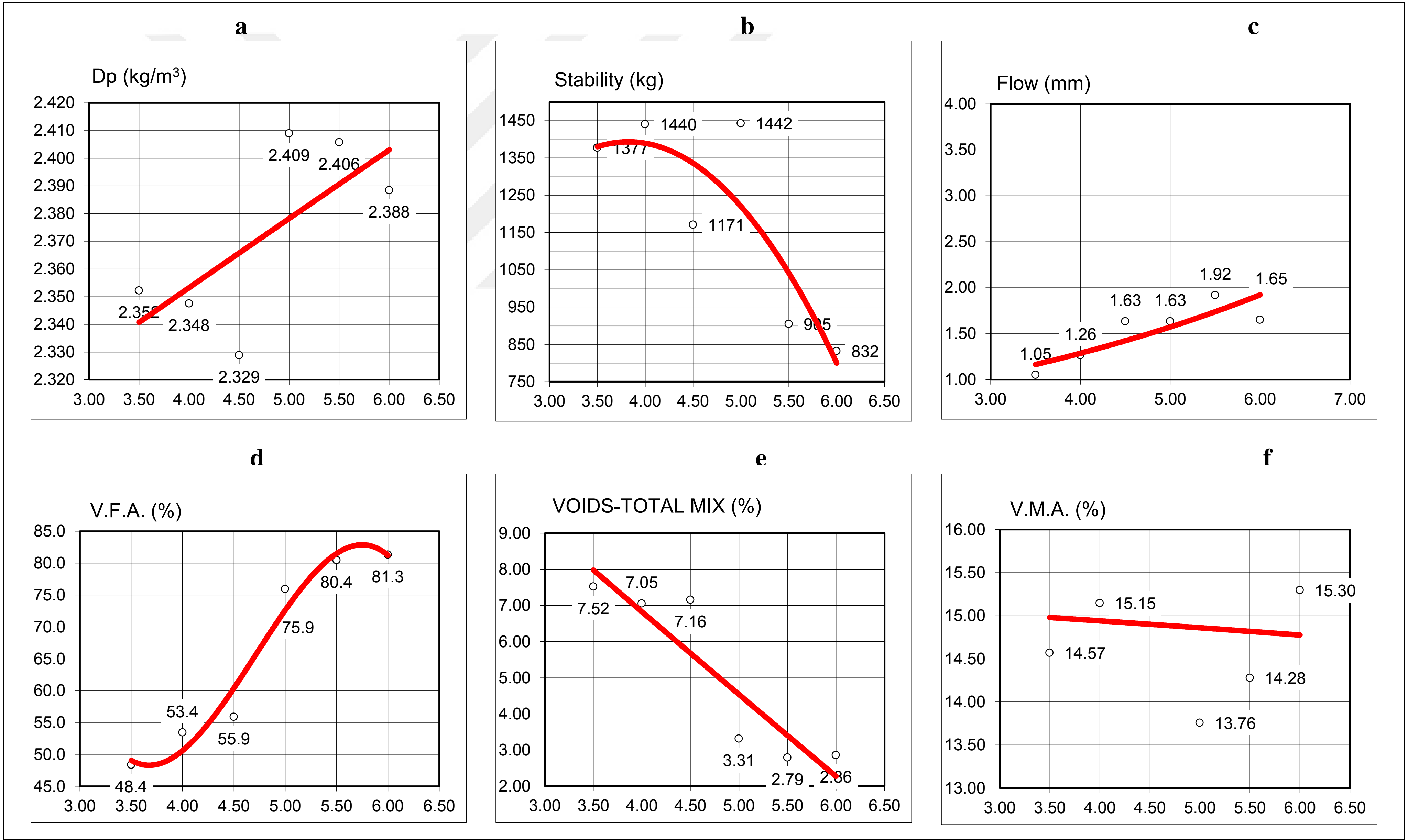

Figure 4.5 Marshall Mix Design Result P3 6g: **a)** Bitumen % – Density (kg/m^3) **b)** Bitumen % – Stability (kN) **c)** Bitumen % – Flow (in 0,25mm) **d)** Bitumen % – Voids Filled with Asphalt, VFA (%) **e)** Bitumen % - Voids Total Mix (%) **f)** Bitumen % – Voids Mineral Aggregate, VMA (%)

In Table 4.12, the amount of plastic sample P4 was kept constant as 6 grams and Marshall Parameters were examined according to bitumen rate (Figure 4.6). As a result, the highest stability value was reached with bitumen ratio Wa = 4.5% and stability started to decrease for higher bitumen ratios. In some bitumen ratios, stabilty values did not meet the specification criteria. In addition, the obtained Vh, VFA and flow values did not meet the specification criteria.

Table 4.12 Detailed Hot Mix Design Data (Marshall Method) P4 (6 gram)

HOT MIX DESIGN DATA (MARSHALL METHOD)

No	BITUMEN Wa,%	BITUMEN g	Comapct Temp. °C	Specimen Height,mm 1	2	3	avg.	Weight Dry in Air,gn A	Weight in Water,g C	Weight S.S.D. B	Volume cm³ V	Volume Sp. Gr. Dp	Maks.Teo Sp. Gr. Dt	% Void Vh	% V.M.A	V. F. A. Vf	Flow mm	Stability kg	Corr. Factor	Corrected Stability kg
1	3.50	40.25	142	64.9	63.4	64.8	64.4	1190.6	691.3	1195.2	503.9	2.363					1.50	1450	0.978	1419
2	3.50	40.25	140	63.9	65.2	65.0	64.7	1185.4	690.0	1191.0	501.0	2.366					1.35	1400	0.971	1359
3	3.50	40.25	142	64.0	63.9	63.8	63.9	1201.4	698.0	1206.9	508.9	2.361					1.65	1355	0.989	1341
												2.363	2.543	7.09	14.17	50.0	1.50			1373
4	4.00	46.00	142	66.0	65.3	64.9	65.4	1193.0	696.0	1199.0	503.0	2.372					1.35	1400	0.956	1338
5	4.00	46.00	143	64.7	64.9	65.1	64.9	1190.0	692.5	1197.0	504.5	2.359					1.20	1365	0.967	1319
6	4.00	46.00	144	64.1	63.7	63.8	63.9	1188.0	691.2	1195.0	503.8	2.358					1.30	1368	0.990	1354
												2.363	2.526	6.45	14.59	55.8	1.28			1337
7	4.50	51.75	142	65.2	64.5	64.6	64.8	1208.0	703.4	1213.0	509.6	2.370					1.65	1490	0.970	1445
8	4.50	51.75	141	65.4	65.8	64.8	65.3	1195.2	694.0	1199.3	505.3	2.365					1.75	1485	0.957	1422
9	4.50	51.75	140	63.9	65.1	64.3	64.4	1185.3	689.0	1189.6	500.6	2.368					1.65	1498	0.977	1463
												2.368	2.508	5.60	14.82	62.2	1.68			1443
10	5.00	57.50	141	65.1	65.6	65.2	65.3	1203.1	696.0	1208.5	512.5	2.348					1.60	1299	0.958	1244
11	5.00	57.50	140	65.2	65.6	65.9	65.6	1203.0	699.2	1207.5	508.3	2.367					1.65	1300	0.952	1238
12	5.00	57.50	142	65.8	65.3	65.2	65.4	1205.7	698.2	1212.2	514.0	2.346					1.54	1368	0.955	1307
												2.353	2.491	5.54	15.75	64.8	1.60			1263
13	5.50	63.25	142	62.5	62.9	62.5	62.6	1196.0	704.5	1201.5	497.0	2.406					2.00	1000	1.021	1021
14	5.50	63.25	143	63.8	63.7	63.9	63.8	1213.1	715.6	1218.2	502.6	2.414					2.20	985	0.992	977
15	5.50	63.25	141	63.9	63.5	63.7	63.7	1195.5	705.2	1201.4	496.2	2.409					2.40	1100	0.994	1094
												2.410	2.475	2.63	14.13	81.4	2.20			1031
16	6.00	69.00	141	63.4	63.5	63.4	63.4	1216.0	712.2	1221.2	509.0	2.389					2.60	965	1.001	966
17	6.00	69.00	143	63.0	63.1	63.5	63.2	1215.0	712.7	1220.1	507.4	2.395					2.50	895	1.007	901
18	6.00	69.00	142	63.6	63.5	63.9	63.7	1199.0	704.0	1204.0	500.0	2.398					2.35	925	0.995	920
												2.394	2.459	2.63	15.10	82.6	2.48			929
	4.40		OPTIMUM BITUMEN RESULTS (From Chart)									2.414	2.512	4.70	13.9	66.0	2.70	Fill/Bit	Stb/flw	990
	4.40		OPTIMUM BITUMEN RESULTS (Calculation Geff_ trial)									2.414	2.510	3.81	13.1	70.9	2.70			990
	4.40		OPTIMUM BITUMEN RESULTS (Calculation Geff_Calculation res									2.414	2.512	3.89	13.1	70.2	2.70	1.10	367	990
			BINDER DESIGN CRITERIA											(4-6)	min13	(60-75)	(2-4)	max1.4		min750

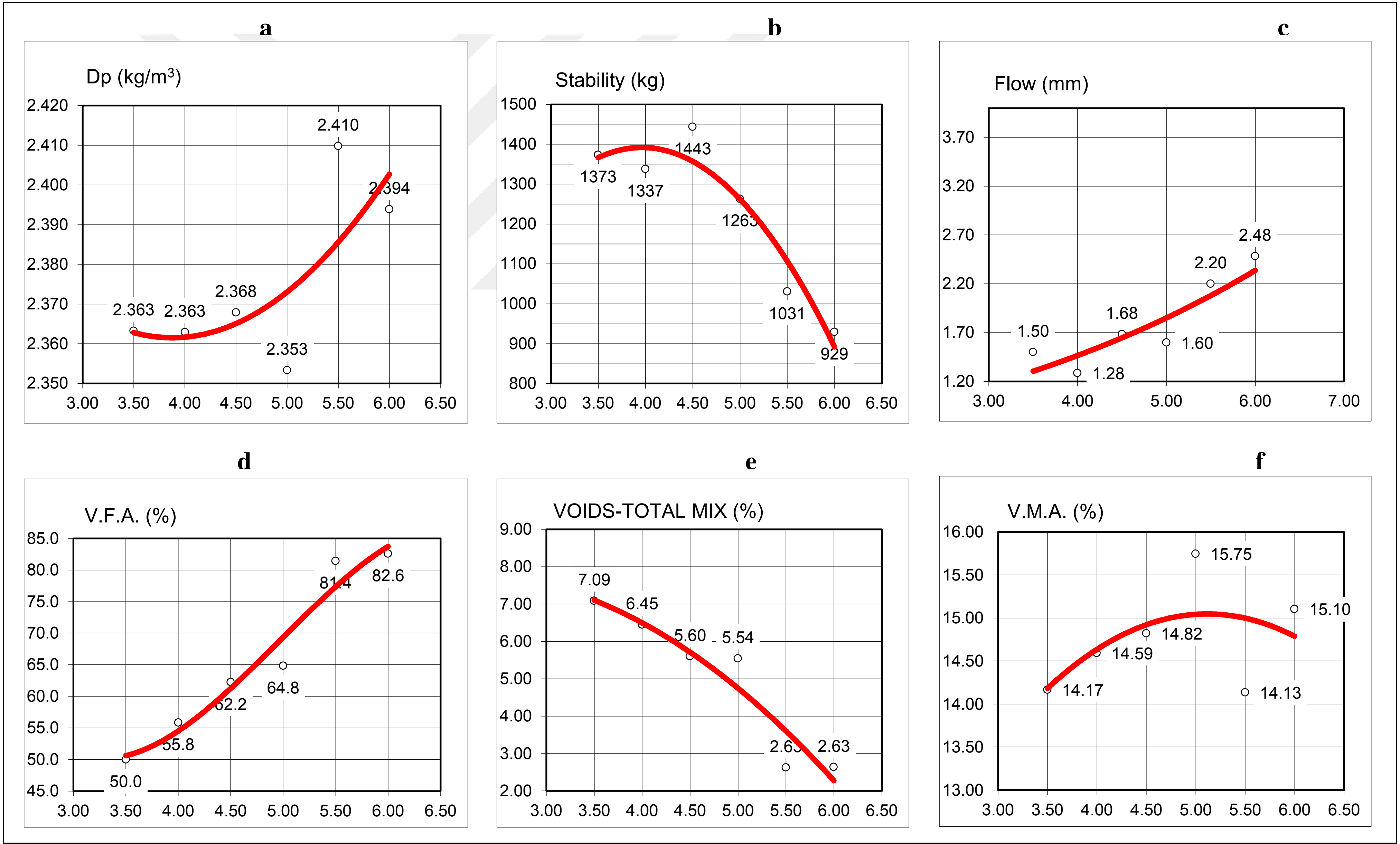

Figure 4.6 Marshall Mix Design Result P4 6g: **a)** Bitumen % – Density (kg/m^3) **b)** Bitumen % – Stability (kN) **c)** Bitumen % – Flow (in 0,25mm) **d)** Bitumen % – Voids Filled with Asphalt, VFA (%) **e)** Bitumen % - Voids Total Mix **(%)** **f)** Bitumen % – Voids Mineral Aggregate, VMA (%)

In the experimental study using the P1 sample, the bitumen rate was kept constant Wa = 4.4% and the changes according to the changing plastic ratios were examined (Table 4.13, Figure 4.7). It was found that it does not provide specification values when the plastic ratio is 0.6% (7.2 g.) The highest stability value was reached when the plastic ratio was 0.5%.

Table 4.13 Detailed Hot Mix Design Data (Marshall Method) P1 Wa 4.4%

HOT MIX DESIGN DATA (MARSHALL METHOD)

No	PET %	PET g	BITUMEN Wa,%	BITUMEN g	Comapct Temp. °C	Specimen Height,mm 1	2	3	avg.	Weight Dry in Air,g A	Weight In Water,g C	Weight S.S.D. B	Volume cm³ V	Volume Sp. Gr. Dp	Maks.Teo Sp. Gr. Dt	% Void Vh	% V.M.A	V. F. A. Vf	Flow mm	Stability kg	Corr. Factor	Corrected Stability kg
1	0.3	3.6	4.40	50.60	142	63.0	63.8	64.7	63.8	1197.3	701.5	1200.3	498.8	2.400					3.17	1226	0.991	1215
2	0.3	3.6	4.40	50.60	140	61.6	61.3	62.0	61.6	1179.3	692.2	1180.9	488.7	2.413					2.65	1509	1.049	1584
3	0.3	3.6	4.40	50.60	142	63.7	65.3	63.4	64.1	1203.3	702.9	1206.0	503.1	2.392					3.24	1313	0.984	1292
														2.402	2.512	4.38	13.52	67.6	3.02			1363
4	0.4	4.8	4.40	50.60	142	64.1	63.1	63.5	63.6	1187.8	694.4	1191.5	497.1	2.389					2.17	1233	0.997	1230
5	0.4	4.8	4.40	50.60	143	63.2	61.6	63.6	62.8	1189.8	698.3	1191.8	493.5	2.411					2.00	1519	1.017	1545
6	0.4	4.8	4.40	50.60	144	65.0	63.4	64.5	64.3	1192.6	697.2	1195.9	498.7	2.391					3.12	1377	0.980	1349
														2.397	2.512	4.56	13.68	66.7	2.43			1375
7	0.5	6.0	4.40	50.60	142	62.8	64.2	62.7	63.2	1191.0	695.2	1193.3	498.1	2.391					3.01	1478	1.006	1486
8	0.5	6.0	4.40	50.60	141	64.1	63.8	63.0	63.6	1200.9	702.2	1202.2	500.0	2.402					2.23	1660	0.996	1653
9	0.5	6.0	4.40	50.60	140	55.2	54.0	55.7	55.0	1004.3	584.5	1006.3	421.8	2.381					2.33	1500	1.278	1917
														2.391	2.512	4.80	13.90	65.5	2.52			1685
10	0.6	7.2	4.40	50.60	141	64.4	65.4	63.8	64.5	1190.0	693.2	1196.3	503.1	2.365					0.80	1090	0.975	1062
11	0.6	7.2	4.40	50.60	140	65.1	64.0	65.6	64.9	1202.8	700.2	1206.4	506.2	2.376					3.23	1255	0.967	1213
12	0.6	7.2	4.40	50.60	142	64.7	65.0	63.5	64.4	1198.8	697.0	1202.4	505.4	2.372					3.24	1578	0.978	1543
														2.371	2.512	5.60	14.62	61.7	2.42			1273
BINDER DESIGN CRITERIA																(4-6)	min13	(60-75)	(2-4)			min750

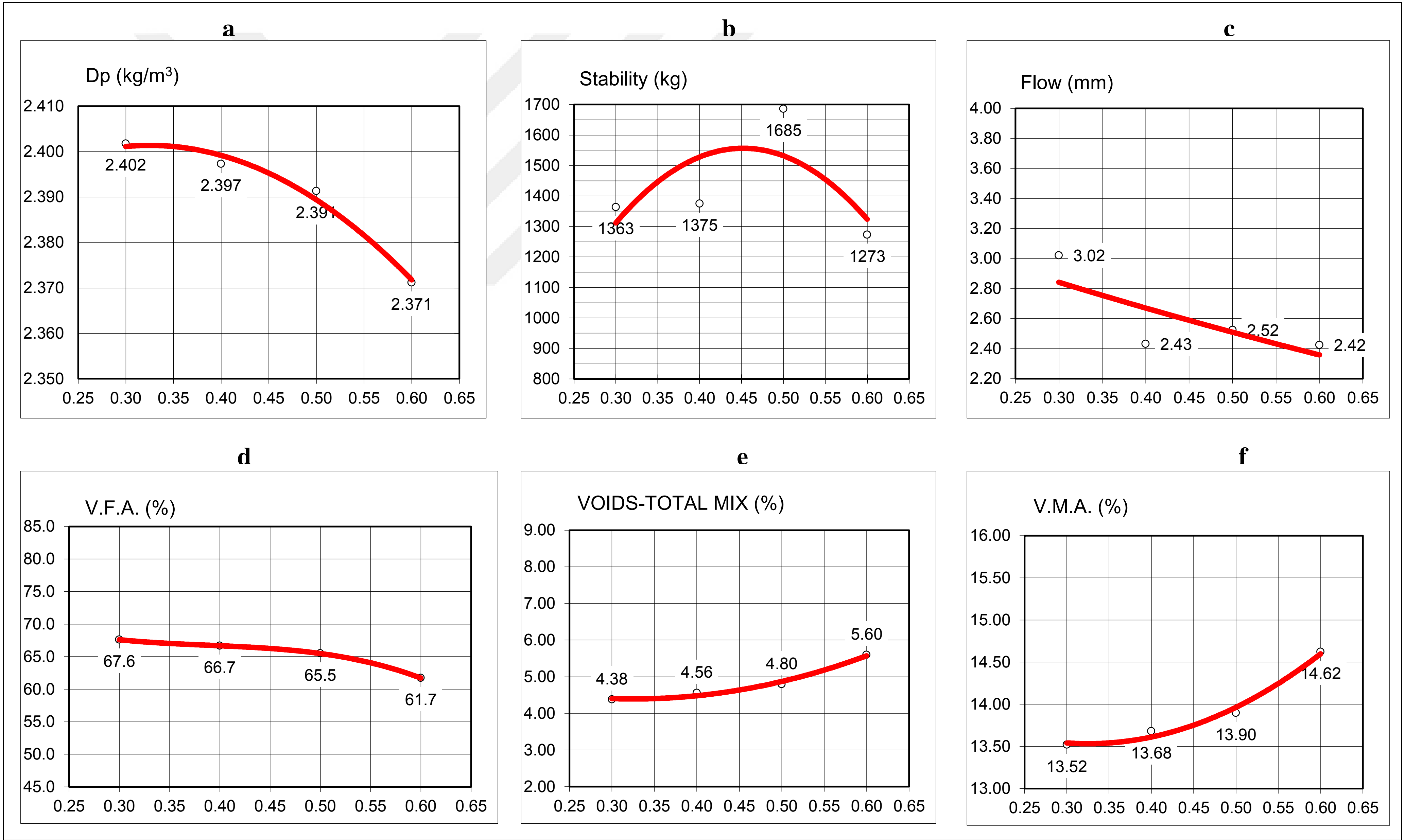

Figure 4.7 Marshall Mix Design Result P1 Wa=4.4%: **a)** PET % – Density (kg/m^3) **b)** PET % – Stability (kN) **c)** PET % – Flow (in 0,25mm) **d)** PET % – Voids Filled with Asphalt, VFA (%) **e)** PET % - Voids Total Mix **(%)** **f)** PET % – Voids Mineral Aggregate, VMA (%)

In the experimental study using the P1 sample, the bitumen rate was kept constant Wa = 4.4% and the changes according to the changing plastic ratios were examined (Table 4.14, Figure 4.8). The highest stability value was achieved when the plastic content was 0.6% (7.2 g.).

Table 4.14 Detailed Hot Mix Design Data (Marshall Method) P2 Wa 4,4%

HOT MIX DESIGN DATA (MARSHALL METHOD)

No	PET		BITUMEN		Comapct Temp.	Specimen Height,mm				Weight Dry in Air,g	Weight In Water,g	Weight S.S.D.	Volume cm³	Volume Sp. Gr.	Maks.Teo Sp. Gr.	% Void	%	V. F. A	Flow	Stability	Corr. Factor	Corrected Stability
	%	g	Wa,%	g	°C	1	2	3	avg.	A	C	B	V	Dp	Dt	Vh	V.M.A	Vf	mm	kg		kg
1	0.3	3.6	4.40	50.60	142	63.5	64.4	64.9	64.3	1187.3	691.5	1189.7	498.2	2.383					1.57	1169	0.981	1147
2	0.3	3.6	4.40	50.60	140	63.8	65.5	65.0	64.8	1188.4	693.0	1192.4	499.4	2.380					4.81	1281	0.970	1242
3	0.3	3.6	4.40	50.60	142	64.6	64.1	63.3	64.0	1203.4	703.5	1206.0	502.5	2.395					2.23	1542	0.987	1522
														2.386	2.512	5.01	14.09	64.4	2.87			1303
4	0.4	4.8	4.40	50.60	142	66.3	66.1	65.0	65.8	1198.0	695.2	1204.1	508.9	2.354					3.22	1269	0.947	1202
5	0.4	4.8	4.40	50.60	143	64.0	64.7	65.4	64.7	1190.7	690.7	1194.3	503.6	2.364					4.39	1182	0.971	1148
6	0.4	4.8	4.40	50.60	144	63.0	63.8	63.7	63.5	1185.7	689.8	1187.7	497.9	2.381					2.60	1469	0.999	1468
														2.367	2.512	5.78	14.78	60.9	3.40			1273
7	0.5	6.0	4.40	50.60	142	64.3	63.5	63.2	63.7	1202.0	699.3	1202.6	503.3	2.388					3.69	1095	0.995	1089
8	0.5	6.0	4.40	50.60	141	65.5	66.1	64.0	65.2	1196.2	695.5	1199.9	504.4	2.372					3.09	1485	0.960	1426
9	0.5	6.0	4.40	50.60	140	64.3	66.0	63.9	64.7	1185.2	685.0	1189.2	504.2	2.351					3.44	1116	0.970	1083
														2.370	2.512	5.64	14.66	61.5	3.41			1199
10	0.6	7.2	4.40	50.60	141	66.6	64.5	65.9	65.7	1205.3	699.0	1207.6	508.6	2.370					4.63	1481	0.950	1407
11	0.6	7.2	4.40	50.60	140	65.4	64.9	66.3	65.5	1204.6	698.1	1208.1	510.0	2.362					3.81	1361	0.953	1297
12	0.6	7.2	4.40	50.60	142	65.8	65.4	64.8	65.3	1201.5	695.2	1207.0	511.8	2.348					6.14	1477	0.957	1414
														2.360	2.512	6.05	15.03	59.7	4.86			1373
BINDER DESIGN CRITERIA																(4-6)	min13	(60-75)	(2-4)			min750

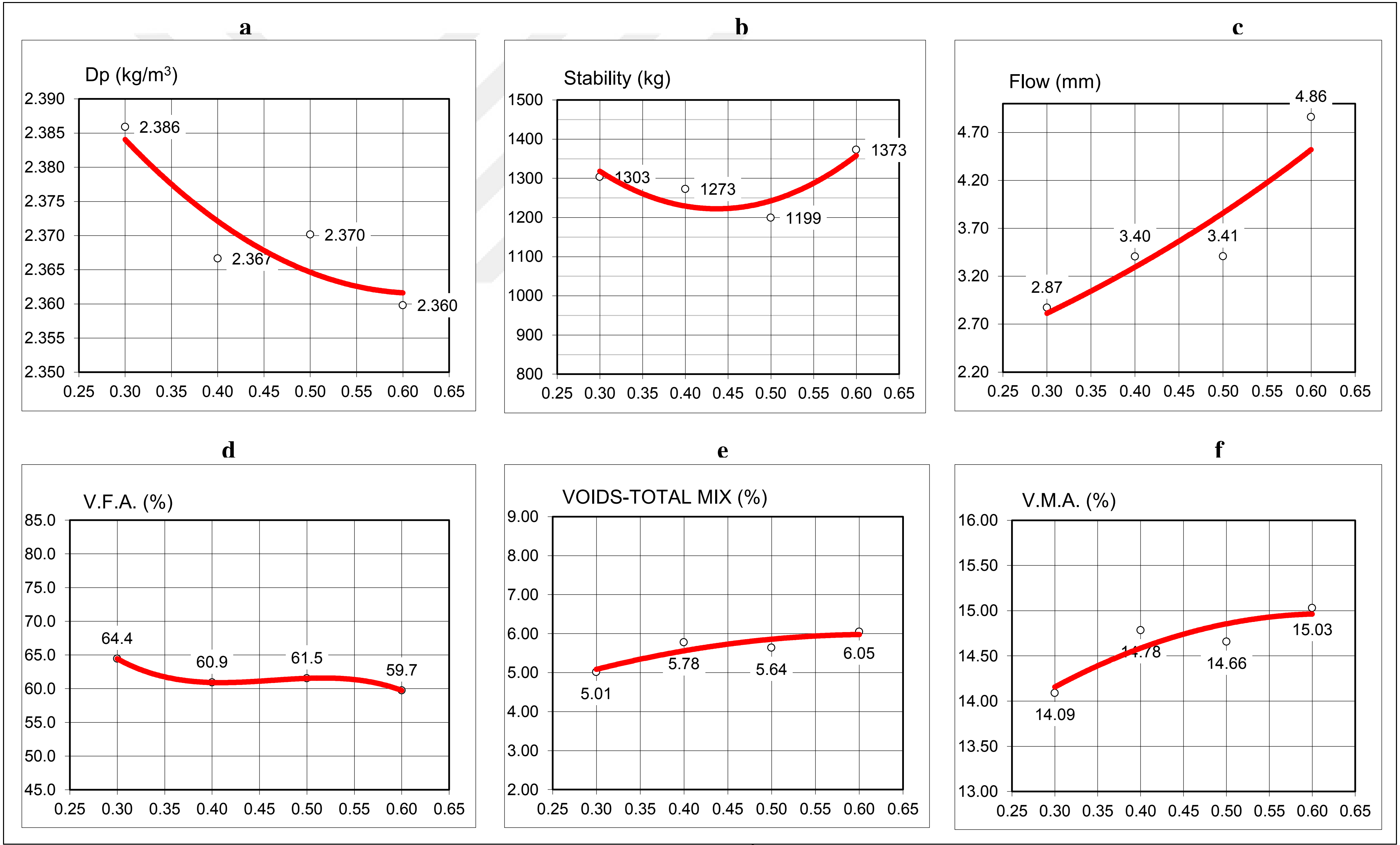

Figure 4.8 Marshall Mix Design Result P2 Wa=4.4%: **a)** PET % – Density (kg/m^3) **b)** PET % – Stability (kN) **c)** PET % – Flow (in 0,25mm) **d)** PET % – Voids Filled with Asphalt, VFA (%) **e)** PET % - Voids Total Mix **(%)** **f)** PET % – Voids Mineral Aggregate, VMA (%)

In the experimental study using the P1 sample, the bitumen rate was kept constant Wa = 4.4% and the changes according to the changing plastic ratios were examined (Table 4.15, Figure 4.9). In general, it has been found that it does not fully meet the TCK specification criteria (Marshall Strength values).

Table 4.15 Detailed Hot Mix Design Data (Marshall Method) P3 Wa 4,4%

HOT MIX DESIGN DATA (MARSHALL METHOD)

No	PET		BITUMEN		Comapct Temp.	Specimen Height,mm				Weight Dry in Air,g	Weight In Water,g	Weight S.S.D.	Volume cm³	Volume Sp. Gr.	Maks.Teo Sp. Gr.	% Void	%	V. F. A.	Flow	Stability	Corr. Factor	Corrected Stability
	%	g	Wa,%	g	°C	1	2	3	avg.	A	C	B	V	Dp	Dt	Vh	V.M.A	Vf	mm	kg		kg
1	0.3	3.6	4.40	50.60	142	65.7	64.2	65.7	65.2	1198.4	693.8	1203.6	509.8	2.351					0.73	1422	0.960	1365
2	0.3	3.6	4.40	50.60	140	63.9	65.5	65.0	64.8	1188.4	690.0	1195.0	505.0	2.353					1.10	1281	0.969	1241
3	0.3	3.6	4.40	50.60	142	64.2	64.1	63.4	63.9	1203.4	700.0	1207.0	507.0	2.374					0.95	1542	0.989	1526
														2.359	2.512	6.07	15.05	59.6	0.93			1377
4	0.4	4.8	4.40	50.60	142	63.2	62.7	64.3	63.4	1198.2	695.0	1203.2	508.2	2.358					1.15	1500	1.002	1502
5	0.4	4.8	4.40	50.60	143	62.3	62.5	61.5	62.1	1190.5	689.9	1195.1	505.2	2.356					1.00	1325	1.036	1373
6	0.4	4.8	4.40	50.60	144	63.0	63.5	63.6	63.4	1196.0	691.2	1199.0	507.8	2.355					1.20	1455	1.002	1458
														2.356	2.512	6.18	15.15	59.2	1.12			1444
7	0.5	6.0	4.40	50.60	142	66.3	64.9	66.3	65.8	1199.7	692.7	1207.2	514.5	2.332					1.00	1095	0.947	1037
8	0.5	6.0	4.40	50.60	141	65.5	66.0	65.0	65.5	1196.2	693.0	1203.1	510.1	2.345					1.35	1485	0.954	1416
9	0.5	6.0	4.40	50.60	140	64.4	66.1	64.4	65.0	1185.2	685.0	1189.2	504.2	2.351					1.80	1116	0.965	1077
														2.342	2.512	6.74	15.65	56.9	1.38			1177
10	0.6	7.2	4.40	50.60	141	65.6	64.5	64.9	65.0	1190.7	701.4	1191.7	490.3	2.429					1.43	1505	0.964	1451
11	0.6	7.2	4.40	50.60	140	65.2	64.5	66.2	65.3	1189.0	698.2	1190.0	491.8	2.418					1.60	1469	0.958	1407
12	0.6	7.2	4.40	50.60	142	64.7	65.3	64.3	64.8	1195.0	699.0	1197.0	498.0	2.400					1.50	1565	0.970	1517
														2.415	2.512	3.84	13.03	70.5	1.51			1459
					BINDER DESIGN CRITERIA											(4-6)	min13	(60-75)	(2-4)			min750
					AŞINMA DİZAYN KRİTERLERİ											(3-5)	min14	(65-75)	(2-4)	max1.5		min900
					BİNDER DİZAYN KRİTERLERİ											(4-6)	min13	(60-75)	(2-4)	max1.4		min750
					BİTÜMLÜ TEMEL DİZAYN KRİTERLERİ											(4-6)	(12-14,5)	(55-75)	(2-5)	-		min600
					SMA DİZAYN KRİTERLERİ											(2-4)	min16	-	(2-4)	-		min750

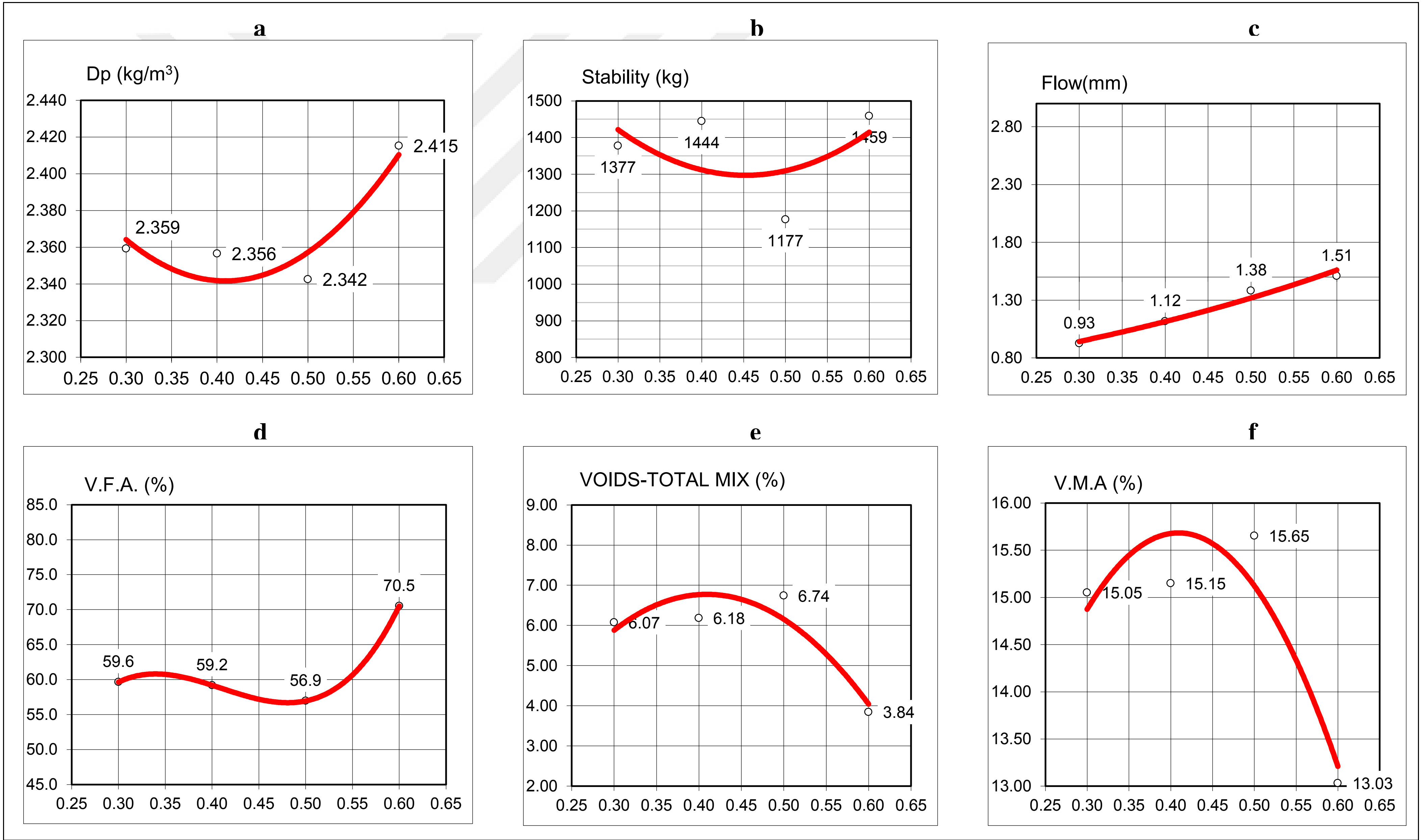

Figure 4.9 Marshall Mix Design Result P3 Wa=4.4%: **a)** PET % – Density (kg/m^3) **b)** PET % – Stability (kN) **c)** PET % – Flow (in 0,25mm) **d)** PET % – Voids Filled with Asphalt, VFA (%) **e)** PET % - Voids Total Mix (%) **f)** PET % – Voids Mineral Aggregate, VMA (%)

In the experimental study using the P1 sample, the bitumen rate was kept constant Wa = 4.4% and the changes according to the changing plastic ratios were examined (Table 4.16, Figure 4.10). In general, it has been found that it does not fully meet the TCK specification criteria (Marshall Strength values).

Table 4.16 Detailed Hot Mix Design Data (Marshall Method) P4 Wa 4.4%

HOT MIX DESIGN DATA (MARSHALL METHOD)

No	PET		BITUMEN		Comapct Temp.	Specimen Height,mm				Weight Dry in Air,g	Weight In Water,g	Weight S.S.D.	Volume cm³	Volume Sp. Gr.	Maks.Teo Sp. Gr.	% Void	%	V. F. A.	Flow	Stability	Corr. Factor	Corrected Stability
	%	g	Wa,%	g	°C	1	2	3	avg.	A	C	B	V	Dp	Dt	Vh	V.M.A	Vf	mm	kg		kg
1	0.3	3.6	4.40	50.60	142	65.0	63.5	64.9	64.5	1192.6	693.3	1197.2	503.9	2.367					1.74	1462	0.976	1427
2	0.3	3.6	4.40	50.60	140	63.8	66.2	65.0	65.0	1189.4	691.0	1195.0	504.0	2.360					1.50	1365	0.964	1316
3	0.3	3.6	4.40	50.60	142	64.1	64.0	63.7	63.9	1203.4	700.0	1207.0	507.0	2.374					1.85	1542	0.989	1524
														2.367	2.512	5.77	14.78	60.9	1.70			1423
4	0.4	4.8	4.40	50.60	142	65.9	65.2	65.0	65.4	1195.0	696.0	1201.0	505.0	2.366					1.25	1452	0.957	1389
5	0.4	4.8	4.40	50.60	143	64.6	64.8	65.2	64.9	1192.0	692.5	1198.0	505.5	2.358					0.80	1356	0.967	1312
6	0.4	4.8	4.40	50.60	144	64.0	63.8	63.9	63.9	1189.0	691.2	1197.0	505.8	2.351					1.60	1425	0.989	1410
														2.358	2.512	6.11	15.08	59.5	1.22			1370
7	0.5	6.0	4.40	50.60	142	65.3	64.6	64.5	64.8	1209.3	703.4	1211.7	508.3	2.379					1.59	1486	0.969	1440
8	0.5	6.0	4.40	50.60	141	65.6	65.9	65.0	65.5	1196.2	694.0	1198.0	504.0	2.373					1.62	1485	0.954	1416
9	0.5	6.0	4.40	50.60	140	64.0	65.2	64.4	64.5	1185.2	689.0	1188.0	499.0	2.375					1.50	1385	0.975	1350
														2.376	2.512	5.41	14.45	62.6	1.57			1402
10	0.6	7.2	4.40	50.60	141	65.2	65.7	65.1	65.3	1204.1	696.0	1209.5	513.5	2.345					1.80	1325	0.957	1268
11	0.6	7.2	4.40	50.60	140	65.1	65.7	66.0	65.6	1202.9	699.2	1206.2	507.0	2.373					1.65	1361	0.952	1295
12	0.6	7.2	4.40	50.60	142	65.9	65.2	65.4	65.5	1206.7	698.2	1211.1	512.9	2.353					1.95	1368	0.954	1305
														2.357	2.512	6.17	15.14	59.2	1.80			1289
BINDER DESIGN CRITERIA																(4-6)	min13	(60-75)	(2-4)			min750

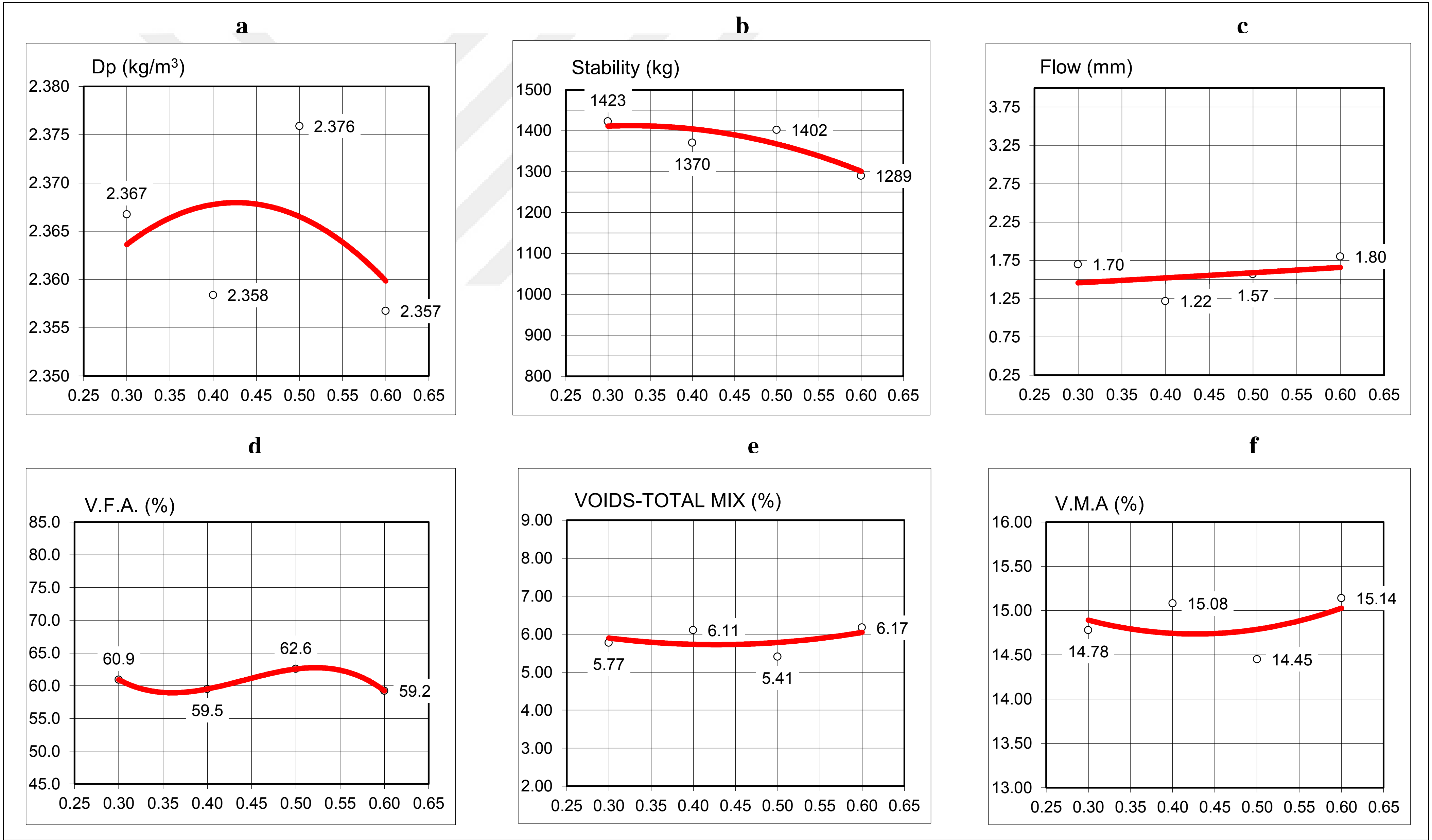

Figure 4.10 Marshall Mix Design Result P4 Wa=4.4%: **a)** PET % – Density (kg/m^3) **b)** PET % – Stability (kN) **c)** PET % – Flow (in 0,25mm) **d)** PET % – Voids Filled with Asphalt, VFA (%) **e)** PET % - Voids Total Mix **(%)** **f)** PET % – Voids Mineral Aggregate, VMA (%)

4.4 Results of Wheel Tracking Test

Wheel Tracking Test was performed on the samples prepared in accordance with wear Type 1 gradation. Experimental study results (Table 4.17) showed that the addition of plastic wastes to the bituminous hot mixture in certain proportions reduced the wheel track formation by approximately two and a half times compared to conventional mixtures. When the deformation results under repeated loads were examined, it was observed that asphalt concretes produced by adding 0.4% waste plastic particles gave positive results in terms of deformation. Plastic wastes show better binding function between aggregates. Waste plastics transfer their elasticity to the mixture. They can therefore dampen the effects of repetitive loads.

Table 4.17 Wheel Tracking Test Results (PRD)%

Test Method: TS EN 12697-22	
Mixture Type	**Wheel Tracking Test Results (PRD)%**
Waste PVC Powder Mixtures	2.57
Conventional Mixtures	6.00
Specification Limit	Maks 8%

4.5 Results of Indirect Tensile Strength Test

Samples without plastic waste and samples produced using P1 plastic waste were compared by using indirect tensile strength test (Table 4.18-4.19). Samples are divided into two as conditioned and unconditioned. Conditioned samples with PET waste additive have been observed to have approximately 79% greater direct tensile strength than samples without plastic waste. Unconditioned samples with PET waste additive have been observed to have approximately 61% greater direct tensile strength than samples without plastic waste (Figure 4.11). If the strength comparison is made in asphalt mixture without plastic, the ratio of conditioned to unconditioned strength will be found as 79.4%. If the strength comparison is made in asphalt mixture with PET waste additive, the ratio of conditioned to unconditioned strength will be found as 88.4% (Figure 4.11).

Table 4.18 Indirect Tensile Strength Test AASHTO T-283 (0 % PET)

Sample No	Conditioned		Unconditioned		Diff. %
	Load (kg)	Indirect Tensile Strength (kg/cm²)	Load (kg)	Indirect Tensile Strength (kg/cm²)	
1	517	5.10	1002	10.36	
2	784	7.89	934	9.45	
3	540	5.34	606	5.93	
4	597	5.77	479	4.63	
		6.03		7.59	79.4

Table 4.19 Indirect Tensile Strength Test AASHTO T-283 (0.5 % PET P1)

Sample No	Conditioned		Unconditioned		Diff. %
	Load (kg)	Indirect Tensile Strength (kg/cm²)	Load (kg)	Indirect Tensile Strength (kg/cm²)	
5	1069	10.73	1288	13.00	
6	1154	11.45	1220	12.10	
7	1094	11.01	1212	11.93	
8	1017	9.98	1181	11.82	
		10.79		12.21	88.4

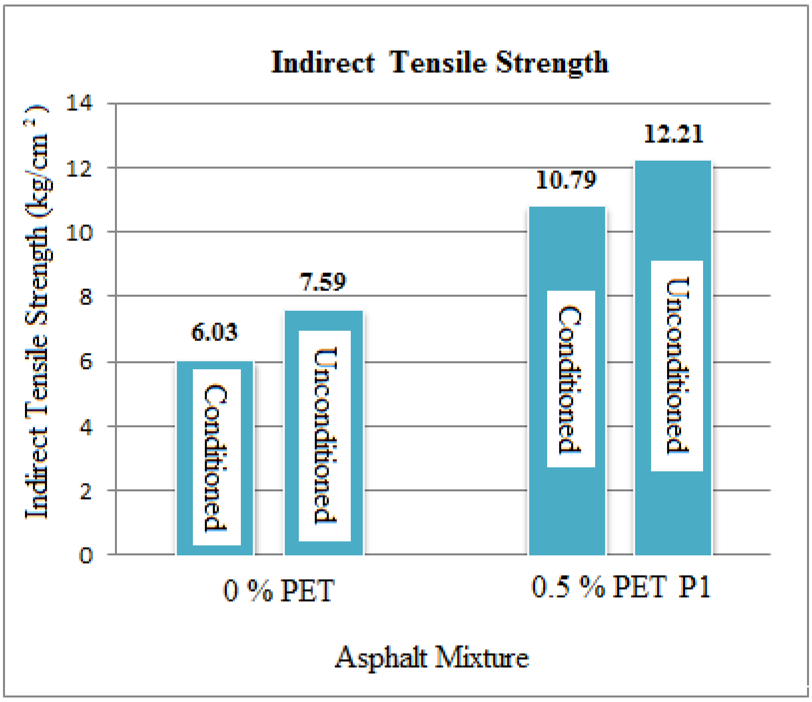

Figure 4.11 Indirect Tensile Strength Test Results of Conditioned and Unconditioned Asphalt Mixtures

CHAPTER V

CONCLUSION

There are some points to consider when investigating the usability of various wastes in asphalt concrete. The asphalt concrete produced by adding waste should have at least the performance values of the traditionally produced asphalt concrete.

Until recently, Marshall Design Method has been traditionally used around the world to evaluate the performance of asphalt concrete. Marshall Test parameters are an important criterion in asphalt experiments. On the other hand, practical specific gravity, total void ratio, bitumen filled void ratio and flow ratios are important parameter used to find asphalt quality.

The aim of this study is to use PVC wastes in asphalt. PVC wastes can be added to the mixture after being dissolved in bitumen or added directly into the mixture with aggregates. In this study, PVC wastes are added directly into the mixture with aggregates. Two methods were followed in asphalt mixtures produced using ground waste PET bottles. Firstly, the effect of ground PET bottle on bitumen was investigated. For this purpose, 50/70 penetrated bitumen was heated at 150 ° C and ground pet bottle (10% of bitumen) was added to the heated bitumen. Bitumen and ground PET bottle wastes were mixed with a baguette and the wastes were expected to melt in the bitumen. However, since there was no melting at 150 °C, the bitumen was first heated to 175 °C and then to 190 °C. Since there was no melting at 190 °C, the ground PET bottle was added to the aggregate mixture. After finding the optimum bitumen rate, bitumen rate was kept constant as 4.4% and ground PET bottle wastes in 4 different gradations were added to the 1150 g. aggregate mixture that is prepared according to the Highways Technical Specification (KTŞ) Binder Layer Type-II gradation, at the rate of 0.3%, 0.4%, 0.5% and 0.6%. Marshall control samples were prepared for each plastic waste sample.

The results of this study are listed below;

- In the experiments, different results were obtained according to the grading of the ground PET bottle waste. It has been observed that the smaller the particle size of PET waste, the better the results.
- The best result was obtained on the P1 sample and the comments were made on it.
- The test samples prepared with PET wastes added to the mixture in 0.3%, 0.4% and 0.5% ratios can provide Marshall strength values (700 kg, for the binder layer) given in KTŞ. However, when more than 0.5% PET waste is added to the mixture, the results do not provide the Marshall strength values given in the KTŞ. The best results were obtained from the samples produced using PET waste at the rate of 0.4% and 0.5%. For this reason, the studies were continued on 4% and 5% mixing ratios.
- With the addition of 0.4% of PVC wastes, asphalt concrete can be prepared in a way that can meet the requirements given in the KTŞ. According to Marshall Test results, asphalt concrete with waste plastic particles of 0.3% and 0.5% can be produced and applied.
- PVC wastes transfer their elasticity to the mixture. Therefore, they can dampen the effects of repetitive loads.
- The use of PET waste increases the workability and compressibility of the asphalt mixture. The resistance of the mixture to water increases.
- Wheel Tracking Test was performed on the samples prepared in accordance with wear Type 1 gradation. Experimental study results showed that the addition of plastic wastes to the bituminous hot mixture in certain proportions reduced the wheel track formation by approximately two and a half times compared to conventional mixtures. When the deformation results under repeated loads were examined, it was observed that asphalt concretes produced by adding 0.4% waste plastic particles gave positive results in terms of deformation. Plastic wastes show better binding function between aggregates. Waste plastics transfer their elasticity to the mixture. They can therefore dampen the effects of repetitive loads.

- The results showed that the addition of PET waste to the bituminous hot mixture reduced the wheel track formation by 40% and increased the strength of the asphalt mixtures by 77% compared to conventional mixtures.
- The large size of the PET wastes causes an increase in the amount of void in the asphalt mixture and thus leads to a decrease in strength. The performance of the asphalt wear layers should be high. Therefore, the asphalt concrete produced in the study should be evaluated in the binder layer which requires lower strength.
- Heat loss tests were also applied to the control samples. Asphalt, combined with plastic PET waste, loses its heat energy later than normal asphalt concrete. According to the measurements both inside the sample and on the sample surface, when the heat loss time is compared, the samples with PET waste additive cool down about 20 minutes later than the control samples. The temperature of asphalt concrete samples produced with PET waste drops from 160 °C to 40 °C 20 minutes later than the control samples. Therefore, PET-added asphalt absorbs the heat energy provided by the sun's rays during the day and provides important advantages especially in cold climate roads. This also means that asphalt concrete can be transported further distances.
- In our country, divided road investments are made every year. The total bitumen sale of TÜPRAŞ in 2018 is approximately 30 million tons. A significant amount of waste plastic can be used in the asphalt concrete produced using 4% PET waste (3 million tons). Such use of wastes will be beneficial for a sustainable life and national economy.
- According to the Ministry of Environment and Urbanization, Turkey's Waste Management Department data, 31 million tons of household waste are produced every year and 12 percent of it is composed of plastic waste.
- The use of plastic will contribute to the economy of the country by reducing bitumen utilization rate by approximately 6-8%. (about 2 million tons of bitumen approximately 2.186 * 2.000.000 = 4.372.000.000 TL)
- According to indirect tensile strength test, conditioned samples with PET waste additive have been observed to have approximately 79% greater direct tensile strength than samples without plastic waste. Unconditioned samples with PET waste additive have been observed to have approximately 61% greater direct tensile strength than samples without plastic waste.

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