Advances in Materials
2019; 8(2): 48-55
http://www.sciencepublishinggroup.com/j/am
doi: 10.11648/j.am.20190802.12
ISSN: 2327-2503 (Print); ISSN: 2327-252X (Online)

Evaluation of the Effect of Polystyrene on the Performance of Asphalt Mixes

Aftab Akbar[1, 2, *], Kashif Akbar[3], Naveed Khan[3, *], Afaq Ali[3], Abdul Karim[3], Fayaz-ur-rehman[3]

[1]Civil Engineering from Department of Civil Engineering, Sarhad University of Science & Information Technology, Peshawar, Pakistan
[2]Transportation Engineering, Sarhad University of Science and Information Technology, Peshawar, Pakistan
[3]Department of Civil Engineering, Sarhad University of Science and Information Technology, Peshawar, Pakistan

Email address:
Engraftab123@gmail.com (A. Akbar), Engrkashif0@gmail.com (K. Akbar), Engrnaveedkhan01@gmail.com (N. Khan), afaqali888@yahoo.com (A. Ali), Kareem4some1@gmail.com (A. Karim), Fayazktk1993@yahoo.com (Fayaz-ur-rehman)

[*]Corresponding author

To cite this article:
Aftab Akbar, Kashif Akbar, Naveed Khan, Afaq Ali, Abdul Karim, Fayaz-ur-rehman. Evaluation of the Effect of Polystyrene on the Performance of Asphalt Mixes. *Advances in Materials*. Vol. 8, No. 2, 2019, pp. 48-55. doi: 10.11648/j.am.20190802.12

Received: November 7, 2018; **Accepted**: December 28, 2018; **Published**: April 26, 2019

Abstract: Asphalt, sometimes known as Bitumen is a sticky, black and highly viscous liquid or semi-solid form of petroleum. It is mainly found in natural deposits or may be a refined product. The primary use (70%) of asphalt/bitumen is in road construction, where it is used as the glue or binder mixed with aggregate particles to create asphalt concrete. The reason for its extensive use is that asphalt is exceptionally rigid and durable; it flings sufficient flexibility to fit defect in underlying surfaces. Replacement/reprocessing and removal of damaged asphalt is a simple and comparatively easy operation. The asphalt is also a hundred percent recyclable product. Ordinary asphalt pavement has a limited amount of stress bearing capacity. Asphalt pavements are also affected by the surroundings and climate. The usual pavement distresses include: cracking; disintegration, distortion, skidding hazards; and surface treatment distresses. In this modern age, civil engineering constructions have their own structural and durability requirements, every structure has its own intended purpose and hence to meet this purpose, modification in traditional asphalt has become mandatory. It has been found that different types of additives added in specific percentage to asphalt improves the physical properties i.e. resistance of cracking and strengthening of asphalt. In this project, we have carried out test on asphalt with Polystyrene as an additive to check the influence of these additives on strength of Asphalt. According to various research papers, it has been found that addition of Polystyrene gives strength to asphalt. Hence, in this project we were interested in finding out the optimum quantity of polystyrene required achieving the maximum strength. From the exhaustive and extensive experimental work it was found that with increase in Polystyrene content in asphalt mix up to a limit, there was a tremendous increase in strength. At 5% Polystyrene content maximum stability achieved was 10.41 KN and flow was 3.46 mm, but as the percentage of Polystyrene increased, a decrease in the strength occurs. Hence the optimum amount of Polystyrene is 5%.

Keywords: Bitumen, Reclaimed, Pavement, Distresses, Polystyrene, Modifiers, Bearing Capacity

1. Introduction

Hot mix asphalt (HMA) is the combination of two materials: asphalt binder and aggregate. Aggregate is composed of 94% of the total mix by weight, and the remaining 4% by weight of the mix consists of the asphalt binder. In spite of the fact percentage of the asphalt binder is comparatively small and the asphalt binders mostly affect pavement performance more than the aggregate because of the environmental element, like sun radiation and heat, affect the asphalt binder more than aggregate.

Bitumen consists of viscous liquid essentially of mineral oil, hydrocarbon derivatives (such as Asphaltenes, Maltenes), which are soluble in carbon di-sulphide, and is considerably non-volatile and gradually soften by heating. It is either black or brown in color depending on its mode of derivation, possesses water-proofing and adhesive properties and has a variable hardness and volatility.

Temperature had an influence on pavement, it becomes soft when the temperature is high and when temperature is low it get cracked. Heavy loaded vehicles detoriate the road; hence it is essential to improve the standard asphalt by material which can play the part as binder to achieve the following properties:

1. Increase in Elasticity and viscosity.
2. Reduction of temperature responsiveness.
3. Aging resistance and higher softening point.

The Waste tires of vehicles represent a serious environmental problem that many countries are facing as they collect rapidly but are not easily disposed off. Many proposals have been thought of in recent past for treating and improving the conventional asphalts, such as the introduction of the additives in order to improve the properties of asphalt.

Polystyrene is a synthetic aromatic Polymer made from the monomer styrene. Polystyrene is one of the most widely used Plastics, the scale of its production being several billion kilograms per year. Polystyrene is very slow to biodegrade and is therefore a focus of controversy among environmentalists. It is increasingly abundant as a form of Litter in the outdoor environment, particularly along shores and waterways, especially in its foam form.

A dosage of Polystyrene modifier added to asphalt can increase asphalt's performance in stability, stability, viscosity, and resistance to aging. Better application performances of asphalt pavement are affected directly by proper polystyrene amending. This paper shows some research that confirms the relationship between the addition of Polystyrene with the structure and the properties of Polystyrene-modified asphalt. Polystyrene modified asphalt mixtures were prepared by means of Polystyrene latex adding to aqueous solution, and it is an energy-saving, ecologically safe material because it does not need any heating processes creating gas discharge and fire threat during its use.

Problem statement:

Many roads agencies have been experiencing problem of premature failure of pavements like potholes, corrugation, roughness, cracks and etc. Heavy loaded traffic damages the road earlier than usual design period which causes more expense on repairing and maintenance. On the other hand, the use of plastics, rubbers, etc. is increasing day by day. Waste like plastic bottles, polymers, waste tires cups, can be re-used as additives in bitumen in order to improve their properties. The use of Polystyrene in asphalt giving origin to the term asphalt plastics has been an alternative to minimize the environmental impact, and simultaneously to improve the mechanical properties of the asphalt mixture. This research has been conducted for investigating the effect of adding Polystyrenes in asphalt mix in different proportions to find out the optimum quantity of the additive that gives us the best results.

Scope:

1. Improve strength
2. Reduce the amount of Bitumen
3. Increase cohesion

Objectives:

To add varying amount of Polystyrene to the asphalt mix until the desired physical properties are achieved.

1. To check the effectiveness of Polystyrene as an additive of bitumen.
2. To find optimum percentage of Polystyrene
3. Sufficient workability
4. Enough strength to survive heavy weight load.

Modifiers:

Polystyrene

Polystyrene is a synthetic aromatic polymer made from the monomer styrene. Polystyrene can be solid or foamed. General-purpose polystyrene is clear, hard, and rather brittle. It is an inexpensive resin per unit weight. It is a rather poor barrier to oxygen and water vapor and has a relatively low melting point.[4] Polystyrene is one of the most widely used plastics, the scale of its production being several billion kilograms per year.[5] Polystyrene can be naturally transparent, but can be colored with colorants. Uses include protective packaging (such as packing peanuts and CD and DVD cases), containers (such as "clamshells"), lids, bottles, trays, tumblers, and disposable cutlery.

As a thermoplastic polymer, polystyrene is in a solid (glassy) state at room temperature but flows if heated above about 100 °C, its glass transition temperature. It becomes rigid again when cooled. This temperature behavior is exploited for extrusion (as in Styrofoam) and also for molding and vacuum forming, since it can be cast into molds with fine detail.

Formula: $(C_8H_8)_n$, IUPAC ID: poly (1-phenylethene-1,2-diyl)

Composition and Characteristics

Modified binders are divided into the subsequent 2 broad compositional groups:

1. Undiversified binders, which are outlines as a mix of a chemical compound and hydrocarbons wherever two distant phases can't be detected on a microscopic level. or where two phases are interlocking to such an extent that the fabric behaves as a single-phase material from small. The examples of homogenous binders are SBR, EVA and SBS polymer modified binder
2. Non-homogenous binders are wherever there are 2 distinct, detectable phases and wherever there will be localized variations in properties relying at what stage a test is performed. Bitumen rubber falls into this class because it consists of rubber crumbs partially dissolved in a bitumen matrix.

In chemical terms, polystyrene is a long chain hydrocarbon wherein alternating carbon centers are attached to phenyl groups (the name given to the aromatic ring benzene). Polystyrene's chemical formula is $(C_8H_8)_n$ it contains the chemical elements carbon and hydrogen.

General Applications of polystyrene:

Packaging, Appliances, Consumer electronics, Medical.

Types of Polystyrene

1. Solid Foam
2. Extruded Foam
3. Copolymers

2. Materials and Methods

2.1. Asphalt Cement

The bitumen used in this test was of penetration grade 60/70 brought from Attock Refinery KPK.

2.2. Course Aggregate

The course aggregate used in preparation of samples are 3/4" (inch) downgraded and were brought from Margalla (KPK). Sieve analysis was done in university.

2.3. Filler

The filler material used by Author in this project was STONE DUST.

2.4. Polystyrene Polymer

The polystyrene polymer were brought from Karachi, Pakistan (AHMAD CHEMICAL CO PVT LTD). Polystyrene is an inexpensive and hard plastic, and probably only polythene is more common in your everyday life.

2.5. Tests on Aggregate

1. Sieve Analysis (Gradation Test)

A sieve analysis (gradation test) is a practice or procedure commonly used in civil engineering to assess the particle size distribution (also called gradation) of a granular material. The size distribution is often of critical importance to the way the material performs in use.

Figure 1. *Sieves.*

Figure 2. *Gradation of Course Aggregate.*

Result: Total amount of Aggregate = 1200 gm.

Table 1. *Gradation of Sieve Analysis.*

Sieve Size	Weight of Aggregate Retained (grams)	Percentage of Weight Retained (%)
19	0	0
12.5	277.2	23
9.5	162	13.5
4.75	291.6	24.3
2.36	144	12
1.18	129.6	10.8
0.6	72	6
0.3	27.6	2.3
0.15	27.6	2.3
0.075	19.2	1.6
Pan	49.2	4.1

2. LOS Angeles Abrasion Test:

The Los Angeles test is a measure of degradation of mineral aggregates of standard grading's resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum containing a specified number of steel spheres. The Los Angeles abrasion test is a common test method used to indicate aggregate toughness and abrasion characteristics. Aggregate abrasion characteristics are important because the constituent aggregate in HMA must resist crushing, degradation and disintegration in order to produce a high quality HMA.

Result: Loss Angeles Abrasion test = 30%

Figure 3. *LOS Angeles Abrasion Test on Aggregates.*

3. Water Absorption Test:
Formula used is Water absorption = [(A – B)/B] x 100%.
Result: Water Absorption value = 0.8%
Specific Gravity = 2.7 Specific Gravity = 2.7

Figure 4. *Water Absorption Test on Aggregate.*

2.6. Tests on Bitumen

1. Penetration Test:
The penetration test is an empirical method to measure the consistency of the bitumen. Penetration is defined, as the distance a standard needle loaded with a 100g weight will penetrate into a bitumen sample for 5 seconds. Usually penetration is measured at 250C.
Result:
Penetration of Bitumen = 74 mm

Figure 5. *Performing Penetration Test.*

Table 2. *Comparison of % of Polymer with Penetration value.*

% of Polystyrene in Bitumen	Penetration Value
0	84
3	65
5	59
10	42

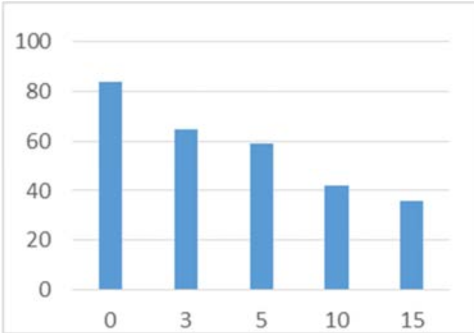


Figure 6. *Comparison of % of Polymer with Penetration value.*

2. Softening Point Test:
RESULT:
Softening point of Bitumen = 63

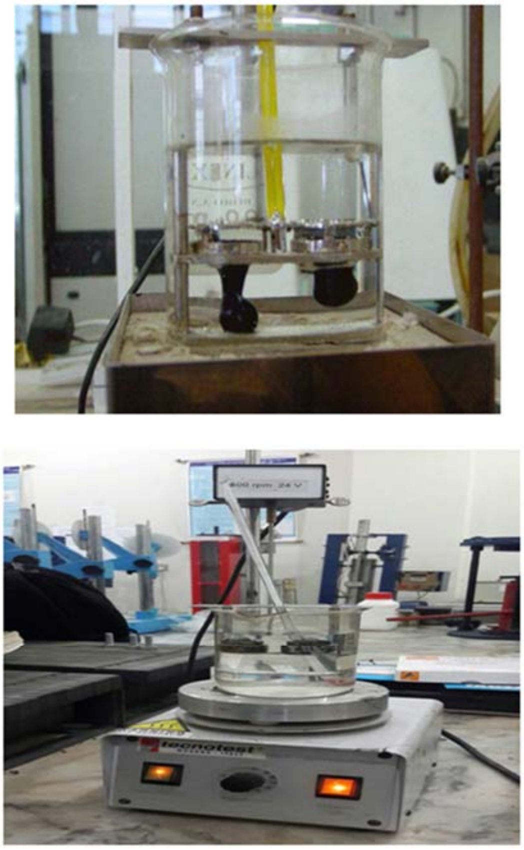


Figure 7. *Performing Softening Pont Test on Bitumen.*

Table 3. *Comparison of % of Polymer with Softening Point Value.*

% of Polymer in Bitumen	Softening Point (c°)
0	63
3	65
5	68
10	69

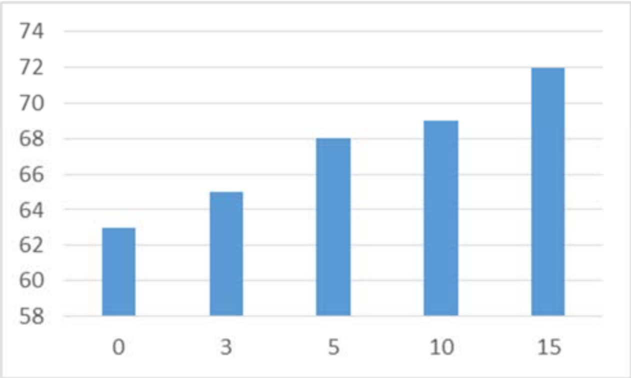


Figure 8. *Comparison of % of Polymer with Softening Point Value.*

3. Flash and fire point test:

Flash Point:

The flash point of a material is the lowest temperature at which the Vapors of bitumen catch fire in the form of a flash under specified conditions of the test.

Fire Point:

The fire point is the lowest temperature at which the bitumen burn for at least 5 seconds under specified conditions of the test.

Result:

Table 4 Flash and fire point result

% of polymer in bitumen	Flash point C°	Fire point C°
0	240	250
3	272	280
5	276	284
10	278	290

Flash point of Bitumen = 203°C

Fire point of Bitumen = 221°C

4. Determintion of ductility:

The ductility of bituminous material is the distance in centimeters to which it will elongate before breaking when a briquette specimen of the materials is pulled at a specified speed and at specified temperature.

Result:

Ductility of Bitumen = 100cm

Temperature = 27°C

Figure 9. *Performing Ductility Test.*

Table 5. *Comparison of % of Polymer with Ductility Value.*

% of polymer in Bitumen	Ductility
0	100
3	98
5	94
10	81
15	69

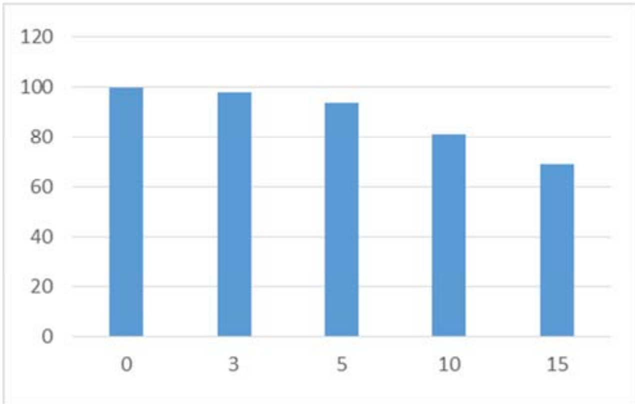


Figure 10. *Comparison of % of Polymer with Ductility Value.*

Table 6. *Values of tests on bitumen without polystyrene.*

TESTS	ACTUAL VALUE	SPECIFICATION
Penetration value	74	60-70
Softening point	65°C	43°C Min
Flash point	246°C	232°C Min
Fire point	250°C	242°C Min
Ductility	100 cm	100cm Min

3. Results of Experimental Work

Tests on asphalt and aggregate:

Table 7. *Results Of test on Asphalt and Aggregates.*

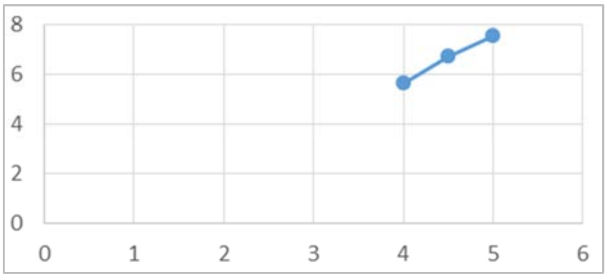
TEST NAME	Results
Penetration test	60/70
Softening point test	65°c
Flash Point test	203°c
Fire point test	221°c
Ductility test	100 cm
TEST NAME	Results
LOS Angeles abrasion test	30%
Water absorption test	0.8%

Results for stability of control samples

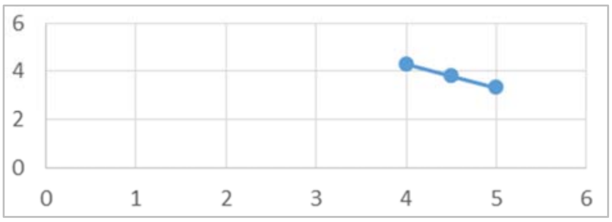
Table 8. *Results of control sample for stability.*

Results of Control Samples				
Sample Name	**Bitumen Content**	**No. of Samples**	**Stability (KN)**	**Flow (mm)**
Sample C11	4%	3	5.635	4.3
Sample C12	4.5%	3	6.72	3.8
Sample C13	5%	3	7.53	3.31

Figure 11. *Bath Tub.*



Comparison of % of Bitumen Content with Stability Value



Results for Stability of Polystyrene

Figure 12. *Comparison of % of Bitumen Content with flow Value.*

Table 9. *Stability for 5% Bitumen and variable Polystyrene.*

Bitumen and polystyrene					
Sample Name	**Bitumen Content**	**Polystyrene Content**	**No. of Samples**	**Stability (KN)**	**Flow (mm)**
Sample C21	5%	3%	3	7.51	3.21
Sample C22	5%	5%	3	10.41	3.46
Sample C23	5%	10%	3	8.32	3.15
Sample C24	5%	15%	3	8.38	2.98

Comparison of results with Marshal Mix Design Criteria

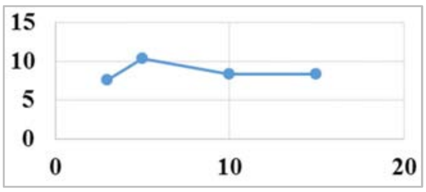


Figure 13. *Comparison of % of Polystyrene with Stability value.*

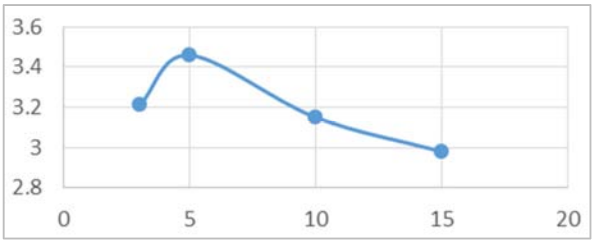


Figure 14. *Comparison of % of Polystyrene with Flow Value.*

Table 10. *Bitumen and polystyrene results with different percentages.*

Bitumen and polystyrene			
Bitumen Content (%)	**Polystyrene Content (%) of Bitumen**	**Stability (KN)**	**Flow #/ (mm)**
5	3	7.51	12 /3.21
5	5	10.41	10/2.61
5	10	12.12	8.48/2.12
5	15	14.56	7/1.76

Comparison of results with Marshal Mix Design Criteria.

Marshall Deign Criteria			
Light traffic Medium Traffic Heavy Traffic Esal <10x4 10x4<ESAL<10x4 ESAL>10x6			
Compaction	35	50	75
Stability	3336 (750)	5338 (1200)	8006 (1800)
Flow, 0.25mm (0.1in)	8 to 18	8 to 16	8 to 14

4. Analysis of Results

The value of Polystyrene at which the sample has maximum Marshall Stability value and maximum flow value is called as optimum Polystyrene content.

The optimum Polystyrene content is 5%.

From the figures above we concluded the with the further increased in Polystyrene content the value of Marshall Stability and Marshall Flow value decrease.

So it is clear that 5% is the optimum polystyrene content.

5. Conclusion

From the study of behavior of Polystyrene modified bitumen content it is found that modified mix possesses improved Marshall Characteristics as mentioned below;

It is observed that Marshall Stability increase with Polystyrene content up to 5%. At 15% Polystyrene content, flow value is low then the minimum criteria of Marshal Mix design. There is almost a 35% increases in the strength at 15% Polystyrene content which is a sign of good load bearing capacity of the asphalt.

We observed that further increase in Polystyrene content, the flow increases and stability decreases i.e. the resistances to deformation under heavy wheel load decreases. Asphalt-aggregate bonding is improved which will result in reduce stripping or moisture susceptibility. The adhesion between aggregate and asphalt binder is increased by coating polystyrene on aggregates which helps to reduce stripping. The Marshall Stability value is high as compared to ordinary bitumen mix. Marshall Stability value increases about 60%. The abrasion resistance of aggregates is improved which will result in the reduction of raveling. Mix has evolved better resistance to burning as Flash and Fire point increases with the addition of polystyrene. The polymer bitumen mix road surfaces will be less affected by Fire hazards. \

No toxic gas is produced. Dioxin is not formed during this process. Rutting results indicated that modified mixes containing polystyrene were less susceptible to deformation as compared to conventional bituminous mixes. Reduces consumption of bitumen by 8%. Reduces wear and tear and increases life of the Road.

Contributes for improved solid waste management. Use of Polystyrene in HMA is likely to cause considerable savings. In this study polystyrene addition as estimated to cause a saving of RS 35,000 per km of Road of 3.75 width. One of the major finding is that no toxic gas is produced by using polystyrene with bitumen. Waste plastics disposal is no longer a problem. Inclusive, the utilization of polystyrene in asphalt mixture decreases pavement deformation and increases the fatigue resistance and gives better bonding between aggregate and the asphalt.

6. Recommendation

It is necessary to work out a project proposal to carry out further studies on various aspects such as collection, processing and effective utilization of this waste material. To start with, such a study could be initiated, with the following components.

Methodology for collection and sorting out the useful components of the plastic wastes. Carrying out further laboratory investigations, construction of some test tracks and field studies on the performance of pavements using the modified bitumen. Identification of two or three construction companies who could incorporate appropriate mixing units in their bitumen boiler / hot mix plant to add and mix the required proportion of the processed plastic additive.

Methodology for processing the plastic Bags as required for use in the preparation of modified bitumen, including cleaning, shredding and further processing of the plastic waste materials. Estimation of the types, quantity and useful components present in the waste plastic materialism the city and surrounding areas. Preparation of specifications and standards for the construction industry. It is hoped that an adoption of the utilization of polystyrene (PS) in HMA, the plastic waste materials will be put to effective use in Road construction industry, resulting in improved road pavements and also relief from the waste plastic materials being littered all around urban areas. Working out relative economics of using the modified bituminous mixes in road construction Works, considering the improved performance and increased service life of the pavement.

Acknowledgements

I am greatly thankful to Almighty Allah for his countless blessings. Beside this, I am deeply grateful to my supervisor Engr Abdurrahman for his able guidance, encouraging attitude and insightful comments during this work. I am also thankful and dedicate this work to my family members, specially my brother Danish Akbar.

Author’s Contribution

Aftab Akbar, Naveed Khan, KA, AK, AA, Conducted Experiments and arrange funds for the whole project and Aftab Akbar wrote the Manuscript.

References

[1] Fang, Changqing, Maorong Zhang, and Tiehu Li. "Combined Modification of Asphalt by Waste Polystyrene and Ethylene-Vinyl Acetate Packaging Materials." *Bioinformatics and Biomedical Engineering, 2008. ICBBE 2008. The 2nd International Conference on*. IEEE, 2008.

[2] Idris, Azni, Bulent Inanc, and Mohd Nassir Hassan. "Overview of waste disposal and landfills/dumps in Asian countries." *Journal of material cycles and waste management* 6. 2 (2004).

[3] Jennings, J.H. and Middleman, S. Homogeneous Nucleation of Vapor from Polymer Solutions Macromol. (1985) 18, 2274-2276

[4] Lynwood, Cole, ed. *Polystyrene: synthesis, characteristics, and applications*. Nova Science Publishers, Incorporated, 2014.

[5] *W. Guian, Vulcanization characteristics of asphalt/SBS blend in the presence of sulfur," Appl Polym & Sci, vol. 82, pp. 989-996, 2001.*

[6] Akmal, Naim, and Arthur M. Usmani. "CONFERENCE REPORT-Asphalt, Number One Thermoplastic Polymer." *Polymer News* 24.11 (1999): 396-397.

[7] Song, Hun, Jeongyun Do, and Yangseob Soh. "Feasibility study of asphalt-modified mortars using asphalt emulsion." *Construction and Building Materials* 20. 5 (2006): 332-337.

[8] N. Akmal and A.M. Usmani, "Asphalt Number One Thermoplastic Polymer", Polym. News, vol. 24, pp. 136-140, 2001.

[9] Cabeza, Luisa F., et al. "Experimental study on the performance of insulation materials in Mediterranean construction." *Energy and Buildings* 42.5 (2010): 630-636.

[10] Wen, Guian, et al. "Vulcanization characteristics of asphalt/SBS blends in the presence of sulfur." *Journal of applied polymer science* 82.4 (2001): 989-996.

[11] Ma, Z., and Y. Dai. "Recycling & disposal of discarded packaging." *Chongqing Environ. Sci* 20 (1998): 56-59.

[12] Poletto, M., H. L. Junior, and A. J. Zaterra. "Polystyrene: Synthesis, characteristics, and applications." *Polystyrene: Synthesis, Characteristics and Applications. New York: Nova Science Publishers* 303 (2014): 53-74.

[13] Rubinger, C. P. L., et al. "Sulfonated polystyrene polymer humidity sensor: synthesis and characterization." *Sensors and Actuators B: Chemical* 123.1 (2007): 42-49.

[14] Jabareen, Yosef Rafeq. "Sustainable urban forms: Their typologies, models, and concepts." *Journal of planning education and research* 26.1 (2006): 38-52.

[15] Fang, Changqing, et al. "Viscoelasticity of asphalt modified with packaging waste expended polystyrene." *Journal of Materials Science & Technology* 30. 9 (2014): 939-943.