EFFECT OF PLASTIC-COATED AGGREGATE (PCA) ON MARSHALL CHARACTERISTICS OF ASPHALT HOT MIX

Md. Mohayminul Islam[1], Md. Emtious Hossain[*2]

[1]*Lecturer, Department of Civil Engineering, Rajshahi University of Engineering & Technology, Bangladesh, e-mail:* mohayminul.islam37@gmail.com
[2]*Undergraduate student, Department of Civil Engineering, Rajshahi University of Engineering & Technology, Bangladesh, e-mail:* arifemtious010@gmail.com

***Corresponding Author**

ABSTRACT

The environment is a fragile ecosystem, continuously affected by human activities, and one of the biggest challenges that the environment is facing today is single-use plastic waste. It endangers both human and animals' health. Most of the plastic wastes are typically made from polyethylene (PE), Polyethylene terephthalate (PET), polypropylene (PP), and polystyrene (PS) materials, which are commonly found in household and commercial waste as water bottles, cold drink bottles, biscuit covers, plastic cups and foam etc. In this research, three primary categories of plastic waste are primarily employed, namely PET (used in water bottles and food packaging), PE (commonly found in plastic bags and trash bags), and PS (widespread use in foam cups and plates). The study focuses on the reuse of this plastic waste as a modifier in asphalt mix design. The coating over the aggregate was done using shredded plastics by heating at 110-180°C temperature. After curing, the PCA was utilized to prepare Marshall hot asphalt mix and investigate the properties such as Marshall stability, flow value, air void, and void filled with bitumen (VFB). Marshall mix design properties due use of PCA also show a phenomenal improvement in comparison to the asphalt concrete prepared using virgin aggregate. The study involved the use of three different mixes, namely Mix-I which is conventional mix, Mix-II and Mix-III, each containing, 1% and 2% of plastic coating over coarse aggregate. The results indicated that the optimal percentage of bitumen for Asphalt concrete was 4.73% for the conventional mix and 4.63% for the PCA Asphalt mix. The unit weight of the conventional mix is 2368 Kg/m^3, while Mix II (with 1% Plastic content) has a slightly higher unit weight of 2372 Kg/m^3. Mix III (with 2% Plastic content) has a different unit weight altogether.The experimental findings revealed that the Marshall stiffness values for the conventional mix, 1% and 2% plastic content were 6.07 kN/mm, 6.46 kN/mm and 6.22 kN/mm, respectively. This helps to have a better binding of bitumen with PCA due to increased bonding and area of contact between Polymers and Bitumen. Overall, this approach shows promise for mitigating the bad environmental influences of plastic waste while improving the properties of aggregate and bituminous concrete as well. The use of PCA in road construction can be a promising solution for environmental conservation as well as sustainable flexible pavement design.

Keywords: *Sustainability, PCA, flexible pavement, Marshall mix design, asphalt concrete.*

1. INTRODUCTION

In 2019, the world produced 380 million tons of plastic, and best 9% of that was recycled. The rest ended up in landfills, incinerators, or the surroundings. Bangladesh generates about 8000 tons of solid plastics waste each day from the six major cities (Dhaka, Chittagong, Khulna, Rajshahi, Barisal and Sylhet). (Abedin et. al.,2015)

The 21st century's safety- and environmental-conscious behaviours dictate that efforts must be made to minimize all behaviours that harm the environment in any way. Because of the increased amount of garbage brought on by the penetration of plastics, recycling, waste management, and environmentally friendly solutions should receive more attention (Shirin et al. 2020). The industry of plastic manufacturing is expanding significantly, particularly in the area of packaging production, and as a result, so is the quantity of plastic waste produced (Agnes et. al.,2016). Human behaviours in the twenty-first century is still increasing the number of activities that harm the environment. This necessitates the use of environmentally beneficial methods to cope with the growing volume of garbage, particularly plastics, such as recycling and waste handling. The industry that produces plastic materials is expanding, especially in the packaging industry. However, only a small portion of this waste gets recycled; the majority is destroyed and ends up polluting the environment (Adeniran et. al.,2022).

Plastics are becoming a necessary component for everyday lives and are utilized in an increasing variety of applications worldwide. In India's cities and villages, plastic is used for a variety of purposes, such as carrying bags for groceries, drinking water bottles, furniture, kitchenware, and industrial chemical storage in plastic drums. Plastic utensils are also used domestically, among many other applications. Plastics that have been used will eventually end up in the trash, contribute to pollution since they contain hazardous chemicals, spread illness, and give rise to uncontrollable problems in society. The amount of plastic waste produced nowadays is growing daily, and managing this material is quite challenging. There aren't many techniques available for recycling plastic garbage. Recycling, landfilling, plastic coating on aggregate, incineration, gasification, and hydrogenation are a few examples (Awasthi et. al.,2017).

Plastic coating enhances road performance by increasing bitumen binding, reducing voids, preventing moisture absorption, and preventing bitumen oxidation. It also prevents rutting, revelling, and pothole formation, making roads more durable (Chavan, 2013). Waste plastic in road construction improves bitumen bonding, making roads more durable and able to handle heavy traffic. Flexible pavements with waste plastic show better results than regular ones. Marshall stability and flow tests show higher stability with 1% PET waste replacement, but decreases with 2% replacement (Dhodapkar et. al.,2008). Plastic waste, including Polyethylene, Polypropylene, and Polystyrene, can be used to create roads. When heated between 110-140°C, the plastic softens and forms a film-like covering. Plastics Coated Aggregates (PCA) are a suitable material for creating bendable roads. When mixed with heated bitumen, the PCA-Bitumen mix has better adhesion and less tendency to get wet. The roads have a higher load-bearing capacity, supporting twice as much weight as before. This method has been successful since 2002, benefiting the environment and saving money (Rajasekaran et al., 2013). The use of waste plastic in the coating of aggregates reduces the evaporation of moisture. Utilizing waste commodity plastics for binder modification offers a cost-effective, technologically advanced method of improving conventional binder performance, as well as an alternative approach to plastic waste management. This has further contributed to the reduction of plastic waste disposal, as it is an environmentally friendly technique (Sheriff et al., 2017, Islam et al., 2021).

Asphalt pavement is made by coating hot bitumen over hot stone aggregate and rolling it out. Bitumen acts like a glue, but when water gets stuck on the pavement, it can seep through and cause potholes, which are a bad spot on the road (Islam et al. 2019). Anti-stripping agents are only used for a short time and the process adds to the cost of road laying (Sulyman et al., 1987). Plastic waste in the form of flexible pavements could provide a solution to the problems associated with the disposal of plastic waste. A lot of work has been carried out in the field of using plastic waste in the construction of bituminous roads (Gautam et al., 2016). The Marshall sample was prepared without the addition of plastic waste, and the amount of plastic waste in the mix varied from 6% to 14% by weight. The results of the Marshall parameters obtained summarized the variations in stability, flow, bulk density, and air voids (VFB %) in bitumen (Rajput et al., 2016). By using plastic waste to cover the aggregates, the qualities of the aggregates were enhanced with various types of plastic waste. It performed better than regular aggregates. This means that if we use plastic to make changes, it can help make the bad quality of certain materials better. These improved materials can then be used for construction purposes. The ability to absorb water has reduced. As a result, there will be less empty space and it will resist water and water pooling more effectively. Plastic-coated aggregate shows positive results in tests measuring abrasion and impact (Hossain et al. 2023). Using new technology made road construction stronger and increased the lifespan of roads. It also helps the environment and creates money (Harnadh, 2015).

When there is more plastic waste mixed in with bitumen, it makes the aggregate and bitumen better (Islam et al. 2021). The best amount of plastic that can be used with bitumen is 12%, as determined by the Marshal Stability test. The changed bitumen performs well when compared to normal results. When binders are prepared with more waste plastic, the stickiness of the binders decreases, but their ability to withstand heat increases. Covering small stones with leftover plastic makes it harder for them to soak up water. Using waste commodity plastics in improving binders is advantageous because it is a low-cost and effective way to enhance the performance of traditional binders. It also provides an alternative method of managing plastic waste. This technique helps reduce the amount of plastic waste and is good for the environment (Ghalayan et al., 2017). To make flexible roads stronger and more stable. Therefore, plastic waste is applied to the aggregate and stone dust waste is added to the bitumen in order to improve the performance of the pavements. From the experiment, both Plastic Coated Aggregate and Stone dust waste made a stronger bond with Bitumen. Plastic Coated Aggregate can help reduce empty spaces. So, the roads can handle lots of cars and last longer. The test results showed that adding plastic waste and filler material to bituminous mixes makes them more stable (Rashid et al. 2020, Islam et al.2021). This shows that the aggregates have good resistances to properties such as weight, crushing, impact, and water absorption. It makes the mix better (Selvakumar, 2018). Using waste plastic in road construction improves how well the roads work. Because the plastic material and bitumen stick together more effectively, there are fewer empty spaces. This happens because the polymers and bitumen have a stronger connection and touch more areas. The roads can handle a lot of cars, so they last longer. Using new technology made road construction stronger and increased the lifespan of the roads. It will also help to make the environment better. Using waste plastic in flexible pavements works well compared to regular flexible pavements. In this project, metals are being used to replace some of the plastic waste in bitumen. The number of metals being used is either 1%, 2%, or 2. 75% of the total weight. According to tests on stability and flow, adding 1% PET waste can increase stability compared to the usual mixture. However, the flow value remains unchanged for both types of mixtures. Increasing the amount of PET waste that is replaced by 2% can make the stability and flow decrease (Alave et. al., 2018). In this study, three different types of plastic waste were utilized, resulting in varying percentages of plastic waste. This discrepancy sets it apart from other research studies which will be addressed through this research. The primary aim of this study is to examine the optimum percentage of bitumen in Asphalt concrete and analyse the Marshall properties of specimens as the plastic content increases.

2. METHODOLOGY

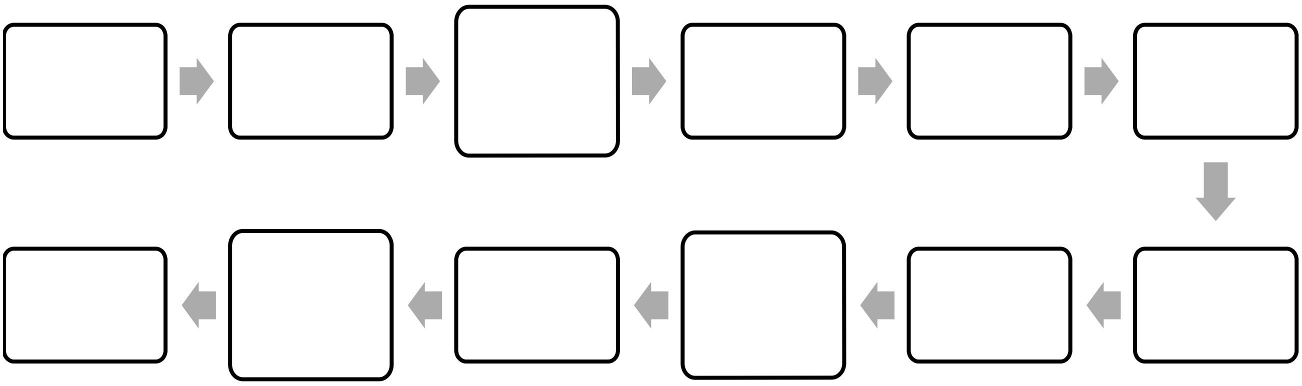

Figure 1: Overall procedure of the test

The preparation process for plastic-coated aggregate usually consists of a number of steps. The stages involved are shown in Figure 01, though the specifics may change based on the study or project. Waste plastics were gathered in first place. Waste plastics were cleaned and dried to get rid of any dirt or additional chemicals. Next, the spotless plastic bottle was cut into smaller pieces by shredding. The plastic particles have more surface area as a result of this procedure, which facilitates their adhesion to the aggregate. The plastic pieces ranged in size from around 3/4th to ½ inch. The plastic is allowed to melt and coat the aggregate's surface by heating it to between 200 and 220 degrees Celsius. One percent of the shredded plastic was gradually and constantly added to the heated aggregate while maintaining this temperature. To produce a homogenous mixture, the aggregate was constantly churned throughout this procedure. The plastic melted as a result, covering the aggregate's surface. Plastic coated aggregate was allowed to cool and air cure at room temperature following the coating procedure. Then determine mechanical properties of PCA and prepare Marshall mould and test Marshall properties.

2.1 Materials properties

Coarse aggregate is defined as those aggregates which are retained on the 2.36 mm sieve according to the Asphalt Institute. Generally black stone is used as coarse aggregate in sample preparation. In this research, used aggregate retained through 12.5 mm,9.5mm,4.75 mm,2.36 mm standard sieve. Fine aggregates are defined as those that are maintained on a 0.075 mm sieve after passing through a 2.36 mm sieve. Used sands retained on conventional sieves measuring 0.6mm, 0.3mm, 0.15mm, and 0.075mm in this investigation. Mineral Filler are those which are obtained after passing through the 0.075 mm sieve. These were obtained by shaking the fine aggregates mechanical sieve. According to ASTM specification D 946-74, the penetration value for bitumen with an 85-100 penetration grade used in pavement construction is between 85 and 100. Additionally, according to ASTM regulation, the minimum ductility value is 100 cm, the minimum solubility in CCl_4 is 99.0 percent, and the minimum flash point is 232°C**.**

2.2 Mix types

The following bituminous mixes were chosen for this investigation's specimen preparation:

Mix I (Conventional Mix): Coarse aggregate+ Coarse sand + Fine sand (filler) + Pure bitumen
Mix II: (Coarse aggregate + 1% Plastics) + Coarse sand + Fine sand (filler) + Pure bitumen
Mix III: (Coarse aggregate + 2% Plastics) + Coarse sand + Fine sand (filler) + Pure bitumen

Specimen prepartion and testing

3. RESULT AND DISCUSSION

Figure 2 showing the unit weight rises as the bitumen content rises, but after reaching a maximum value, it falls as bitumen content rises. Also figure 2 shows a unit weight of 2368 Kg/m^3 for the conventional mix with an optimum bitumen content of 4.73. Additionally, for Mix II (1% Plastic content), the unit weight is recorded as 2372 Kg/m^3, while for Mix III (2% Plastic content), the unit weight is measured at 2374 Kg/m^3, both with an optimum bitumen content of 4.63. Because there is an increase in lubricating action as bitumen content rises, aggregates densify under load to a certain extent. Because extra bitumen takes up space after a certain point, the mix's density declines. The ideal bitumen content is the limit mentioned above. Bitumen's unit weight increases as a result of the modification.

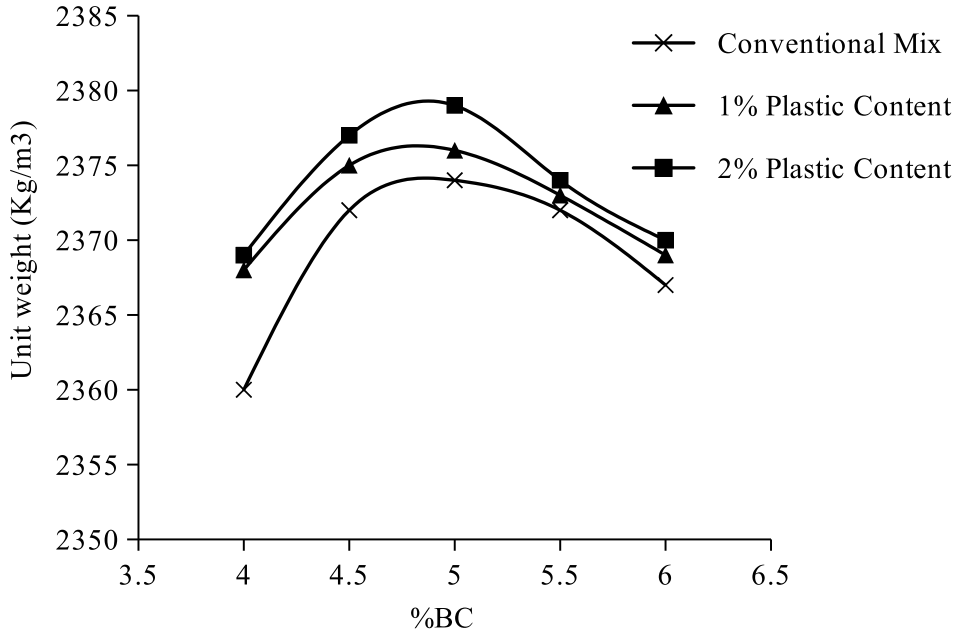

Figure 2: Variation of Unit weight (Kg/m^3) with respect to the Bitumen Content

Figure 3 shows when the bitumen content reaches a maximum value, the Marshall Stability rises with it. Also figure 3 displays the highest Marshall Stability value of 19.84 KN achieved at an optimal bitumen content of 4.63 for Mix II, which contains 1% plastic content. Additionally, the Marshall Stability values for conventional and Mix III, which contain 0% and 2% plastic content respectively, are 18.56 KN and 19.21 KN. With further bitumen content increases, Marshall Stability falls. Because bitumen content increases, blends lose density. Less loads can be supported by the surplus bitumen content than by aggregates, which takes up more space. The Marshall Stability therefore declines.

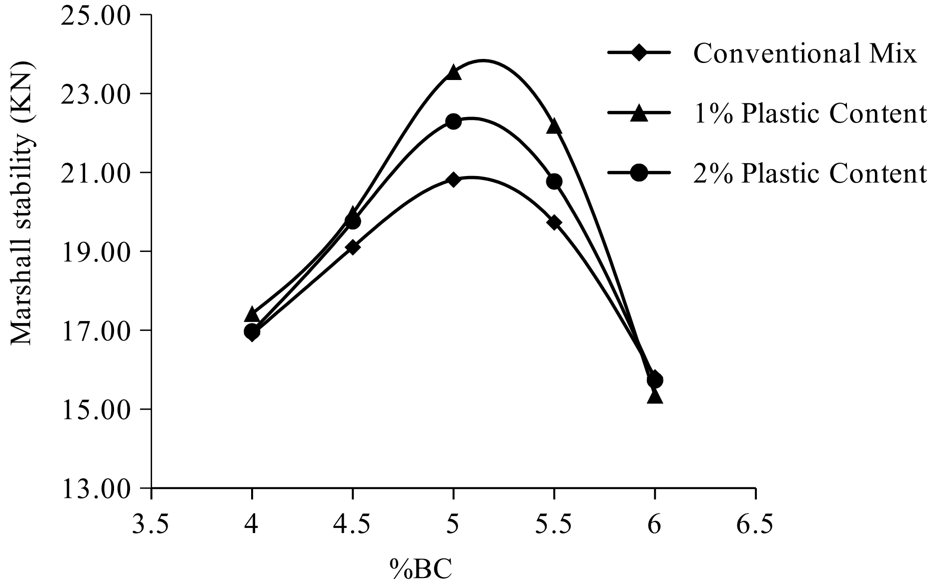

Figure 3: Variation of Marshall stability (KN) with respect to the Bitumen Content

Figure 4 indicates with an increase in bitumen content, the flow value rises. A coating of bitumen is created around the aggregates as bitumen concentration increases, creating an enduring connection between the aggregates. Also figure 4 illustrates the attainment of a maximum flow value of 12.36mm, corresponding to an optimum bitumen content of 4.63, specifically for Mix III with a plastic content of 2%. Additionally, it is observed that flow values for the conventional mix and Mix II (1% Plastic content) are 12.23mm and 12.28mm, respectively, at their respective optimum bitumen contents. As the bitumen content rises further, extra bitumen is stored around the aggregates. Less loads can be supported by the aggregates due to the additional bitumen's lubricating effect. Consequently, bitumen content increases along with flow value.

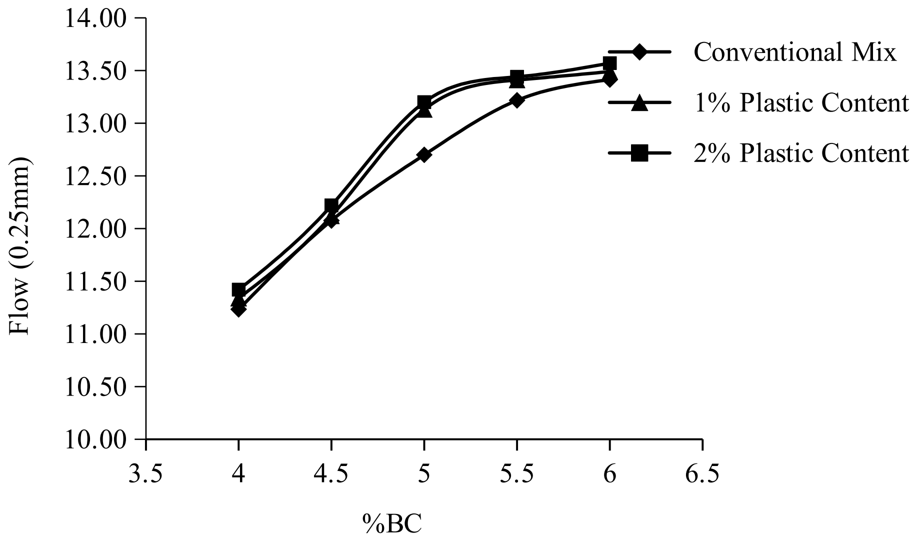

Figure 4: Variation of Flow value with respect to the Bitumen Content

Figure 5 represents with an increase in bitumen content, the proportion of air void reduces. The air void is smaller as a result of the increased bitumen penetrating it and filling the space that was previously empty of air. The air void progressively gets smaller. Also figure 5 illustrates that the maximum air void is 7.7 for the optimum bitumen content of 4.73 in the conventional mix.

Additionally, it is evident that the air void values for Mix II (1% Plastic content) and Mix III (2% Plastic content) with the optimum bitumen content are 5.8 and 5.9, respectively.

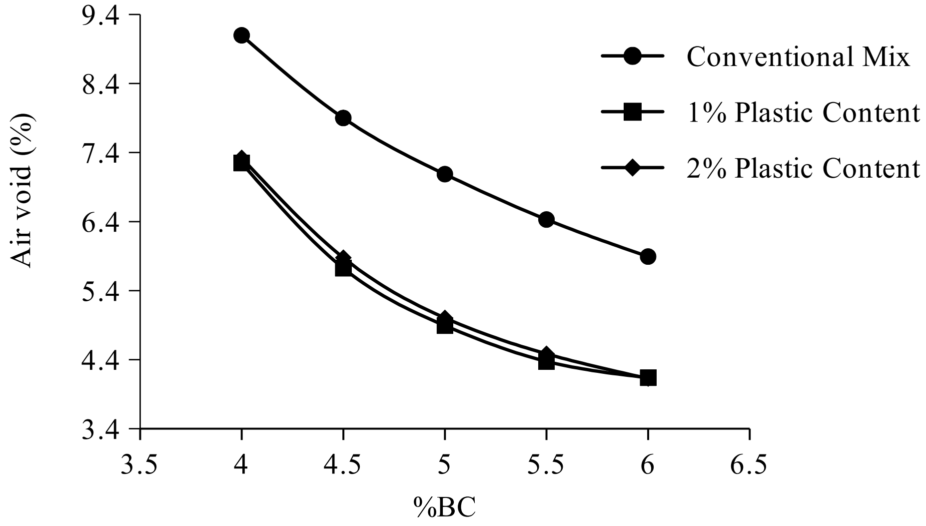

Figure 5: Variation of Air void with respect to the Bitumen Content

Figure 6 shows that after reaching a specific minimum value, the proportion of voids in mineral aggregate decreases with the addition of bitumen; however, as bitumen concentration increases, it increases. In the beginning, bitumen fills in the air space. The quantity of air void that bitumen removes from a space is smaller after mixing than the amount of bitumen that was injected. Therefore, as bitumen concentration rises, the amount of vacancy in the mineral aggregate also rises. A reflexive force rather than an attracting force is introduced among the aggregates as a result of the bitumen content's rising percentage of the mix's volume. This increases the percentage of void in the mineral aggregates. Also figure 6 shows that the Voids in Mineral Aggregate (%VMA) value is 14.8 for the optimal bitumen content of the conventional mix. Additionally, it is observed that the Voids in Mineral Aggregate (%VMA) values for Mix II (1% Plastic content) and Mix III (2% Plastic content) are 12.7 and 12.8, respectively, for the optimal bitumen content.

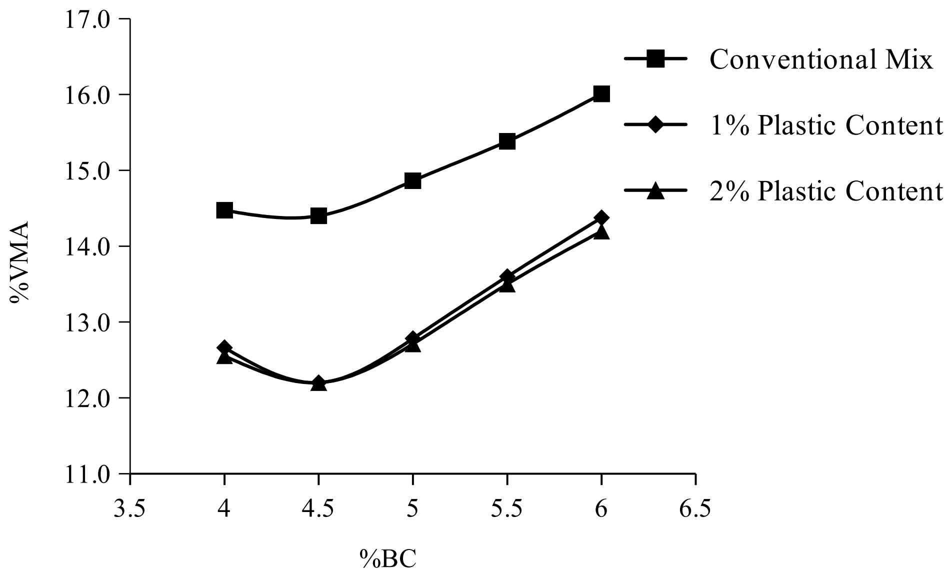

Figure 07 indicates that as the bitumen content rises, increases the percentage of voids filled by bitumen. Air from the spaces is eventually expelled when bitumen with increasing volume enters them. Hence the void occupied by the bitumen is increased. Figure 7 illustrates that the Percentage of Voids filled by bitumen (%VFB) is 47 for the optimal bitumen content of 4.73 in the conventional mix. Additionally, the %VFB values for Mix II (1% Plastic content) and Mix III (2% Plastic content) are 54 and 53 respectively, with an optimal bitumen content of 4.63.

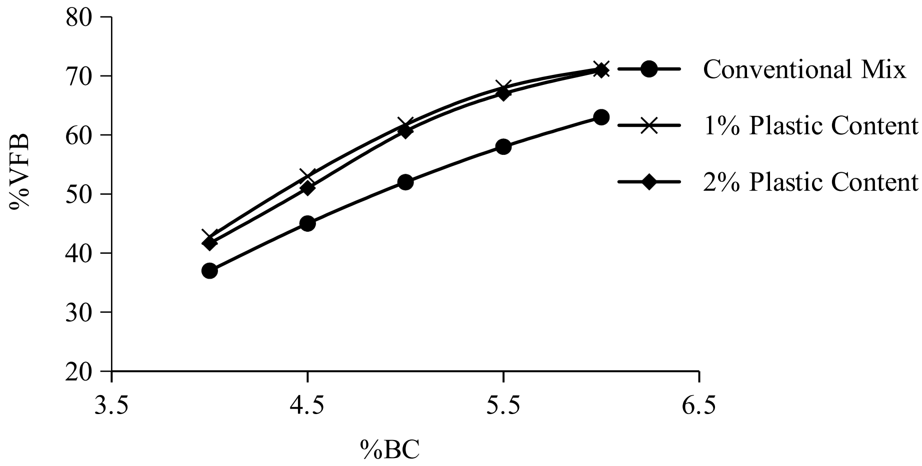

Figure 7: Variation of %VFB with respect to the Bitumen Content

4. CONCLUSIONS

The use of Plastic-Coated Aggregate (PCA) in asphalt mixes has demonstrated improvements in Marshall Properties compared to conventional asphalt mixes. Notably, there is an enhancement in unit weight and flow value, among other factors. For 1% of plastic waste on the aggregate surface is recommended for the best result. In terms of bitumen content, the conventional mix necessitates an optimum level of 4.73%, whereas the PCA mix requires a slightly lower content of 4.63%. This reduction in bitumen requirement is attributed to the plastic coating on the aggregate, which acts as a substitute. Consequently, at the optimum bitumen content, the unit weight for the conventional mix is measured at 2368 Kg/m^3, while the PCA mix registers a slightly higher value of 2372 Kg/m3. The Marshall Stability values also exhibit improvements, with the PCA mix achieving 19.84 KN compared to 18.56 KN for the conventional mix. Additionally, the percentage of air voids (%Va) is lower for PCA at 5.8%, as opposed to 7.7% for the conventional mix. The percentage of voids in the mineral aggregate (%VMA) is 12.8% for PCA and 14.8% for the conventional mix. Moreover, the percentage of voids filled with bitumen (%VFB) is 54% for PCA, indicating increased bonding and contact area between polymers and bitumen, while the conventional mix records a lower %VFB at 47%. In summary, the utilization of Plastic-Coated Aggregate contributes to better asphalt performance, showcasing enhanced properties such as unit weight, Marshall Stability, %Va, %VMA, and %VFB. The plastic coating not only reduces the bitumen requirement but also fosters improved binding with the aggregate, attributed to increased bonding and contact area between polymers and bitumen.

ACKNOWLEDGEMENTS

The author acknowledges the sacrifice of all teachers, Department of Civil Engineering, RUET that have enabled me to attain this level.

REFERENCES

Abedin, M. A., & Jahiruddin, M. (2015). Waste generation and management in Bangladesh: An overview. Asian Journal of Medical and Biological Research, 1(1), 114-120.

Adeniran, A. A., & Shakantu, W. (2022). The health and environmental impact of plastic waste disposal in South African Townships: A review. International Journal of Environmental Research and Public Health, 19(2), 779.

Agnes, N., & Rajmund, K. U. T. I. (2016). The environmental impact of plastic waste incineration. AARMS–Academic and Applied Research in Military and Public Management Science, 15(3), 231-237.

Alave, Y. B., Mahimkar, S. S., Patil, K. S., Gupta, J. J., & Kazi, A. (2021). Experimental Investigation of Plastic-Coated Aggregate. Int. J. Eng. Res. Tech, 9, 112-120.

Awasthi, A. K., Shivashankar, M., & Majumder, S. (2017, November). Plastic solid waste utilization technologies: A Review. In IOP conference series: Materials science and engineering (Vol. 263, No. 2, p. 022024). IOP Publishing.

Chavan, M. A. J. (2013). Use of plastic waste in flexible pavements. International Journal of Application or Innovation in Engineering and Management, 2(4), 540-552.

Dhodapkar, A. N. (2008). Use of waste plastic in road construction. Indian Highways, Technical paper, journal, P, (31-32), 8.

Gautam, P. K., Kalla, P., Jethoo, A. S., Agrawal, R., & Singh, H. (2018). Sustainable use of waste in flexible pavement: A review. Construction and Building Materials, 180, 239-253.

Ghalayan, P., & Rana, E. S. (2017). Partial replacement of bitumen by using plastic waste in bitumen concrete. International Journal of Latest Research in Engineering and Computing, 5(2), 7-12.

Harnadh, K. L. A. V., Kashyap, A. M. N., Gupta, C. L. K. M., & Sekhar, T. C. (2015). Experimental investigation on coarse aggregates by using waste plastics & polymers. Int. J. of Innovative Res. in Eng. & Manage, 2(3), 19-23.

Hossain, M. E., Islam, M. M. (2023). Application of Plastic-Coated Aggregate in the Construction of Flexible Pavement in an Eco-Friendly Way. International Conference on Planning, Architecture and Civil Engineering(ICPACE 2023), Rajshahi, Bangladesh.

Islam M.M., Islam M.S., and Rahman, F.I. (2019). A Brief Study on Capacity Loss at Major Rajshahi City Roads,Bangladesh. Proceedings of International Conference on Planning, Architecture and Civil Engineering(ICPACE), Rajshahi, Bangladesh.

Islam, M.M., Shirin, M.S., Tonoy, T.R., Sweet, S.A. (2021). Modification of Bitumen PropertiesUsing WastePolymer in Context of Bangladesh. International Journal of Mineral Processing and Extractive Metallurgy. Vol.6, No. 1, pp. 6-11

Rajput, P. S., & Yadav, R. K. (2016). Use of plastic waste in bituminous road construction. International Journal of Science Technology & Engineering, 2(10), 509-513.

Rajasekaran, S., Vasudevan, R., & Paulraj, S. (2013). Reuse of waste plastics coated aggregates-bitumen mix composite for road application–green method. American Journal of Engineering and Research, 2(11), 1-13.

Rashid, G.M.H., and Islam, M.M., (2020). A Review Paper on: Effect of Different Types of Filler Materials onMarshall Characteristics of Bitumen Hot Mix. International Journal of Materials Science and Applications.Vol. 9, No. 3, pp. 40-46.

Selvakumar, K., & Meenakshisundaram, O. (2019). Mechanical and dynamic mechanical analysis of jute and human hair-reinforced polymer composites. Polymer Composites, 40(3), 1132-1141.

Sheriff, K. M., Subramanian, N., Rahman, S., & Jayaram, J. (2017). Integrated optimization model and methodology for plastics recycling: Indian empirical evidence. Journal of Cleaner Production, 153, 707-717.

Shirin, M.S., Islam, M.M., Kumruzzaman, M., (2020). Stabilization of Coal Mine Waste and Its PracticalApplication as a Road Subgrade. American Journal of Traffic and Transportation Engineering. Vol. 5, No. 5,pp. 51-56.

Sulyman, M., Haponiuk, J., & Formela, K. (1987). Utilization of recycled polyethylene terephthalate (PET) in engineering materials: A review. International Journal of Environmental Science and Development, 7(2), 100.