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Article

Sustainable Use of Marble Dust and Silica Fume in the Asphalt Mix

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Abstract

Asphalt pavements are widely utilized in Pakistan due to their excellent smoothness, low noise levels, and ease of maintenance. However, issues such as rutting, cracking, shoving, and aging of the pavement surface result in significant maintenance costs. In today's era of globalization, the emphasis on sustainable development is increasingly critical, complementing traditional infrastructure growth. This study investigates the potential of using two industrial byproducts, marble dust and silica fume, as fillers to improve the performance of asphalt mixtures. Initially, the optimum bitumen content was determined to be 3.86%. Following this, varying percentages (2% to 10%, in 2% increments) of both marble dust and silica fume were incorporated into the asphalt mix by weight of the aggregate. The samples were tested for Marshall stability and flow values, with the results indicating that the incorporation of marble dust enhanced stability and reduced flow, with optimal performance observed at 8%. For silica fume, the highest stability and lowest flow values were obtained with a 6% addition. Future studies could explore additional properties of asphalt mixtures incorporating these fillers.

Keywords: Silica Fume, Marble Dust, Asphalt mix, Marshall Stability, Flow Value.

1. Introduction

Mobility is a fundamental human need, with transportation playing a crucial role in supporting economic activity. The efficiency, availability, and affordability of transportation systems directly influence a nation's economy. In the current era of globalization, the emphasis has shifted from traditional development to achieving sustainable development, which is now the primary focus. Research is actively being conducted to improve the quantity and quality of transportation services to meet the growing demands. Pavements are primarily categorized into two types: flexible and rigid. These pavement types exhibit distinct and contrasting characteristics. Flexible pavements are known for their superior serviceability, ride quality, cost-effectiveness in construction, and the ability to function without joints. Conversely, rigid pavements offer benefits such as enhanced durability, greater strength, resistance to oils and chemicals, and lower maintenance costs [1]. On the other hand, rapid population growth both globally and in Pakistan has led to an increased production of waste, including industrial byproducts. Unfortunately, large-scale recycling programs are not yet widespread, especially in developing countries like Pakistan. Consequently, landfills have become the primary method of waste disposal, which poses significant risks to human health and the environment. In the case of asphalt mixtures, incorporating marble dust as a filler an industrial waste product has been shown to positively affect the stability and rutting resistance of the mix, while also improving moisture resistance and reducing stability loss [2]. Marble dust is a product of the marble processing industry it contains mostly calcium carbonate and other mineral contents. Silica fume which is also a useful material, is a finely divided mineral byproduct obtained as a result of manufacturing alloys of silicon and ferrosilicon. Silica fumes have a high reactivity because of its ultrafine particle size and high surface area. It is effective when employed during construction in the filling of gaps when cement particles come to get in touch with each other and hence a compact and dense product is obtained which has greater compressive force and minimal permeability. Silica fume is also known to increase the asphalt mix performance most especially in the base course, which increases its durability and efficiency in use of fine aggregates. Also, the asphalt mixtures with the addition of silica fume will have an improved effect on the environment since asphalt production has an adverse environmental impact [3]. It is also found that marble dust may be also substituted partially in an asphalt mix to provide substantial enhancement in the asphalt mix properties [4]. Several advantages of the incorporation of marble dust in the asphalt pavements include improved stability and durability [5]. The paper seeks to investigate the possibility of mixing silica fume and marble dust as fillings in asphalt mixture respectively, thus enhancing the performance of the asphalt mix besides being environmentally friendly as relates to waste disposal.

2. Literature Review

Several studies researching on the impact of silica fume as a filler material in asphalt mixtures have been conducted. In one study, effects of adding silica fume at proportions of 25 to 100 percent was added to asphalt and the Marshall stability and flow tests were used to determine properties of the mixture. The improvements in stability were highly processed based on the results, in which recycled asphalt pavements (RAP) recorded an upmost result of 31.02 kN (concentration 75 percent silica fume) [6]. Marble dust (MD) was also tested to replace mineral filler in hot mix asphalt (HMA) in a different research work. It was established through the study that the optimum bitumen content (OBC) could be identified where the Marshall mix design could be used and the perfect percentage of MD, according to the outcome obtained using Marshall stability tests, was 4%. Use of MD not only enhanced the stability and resistance to rutting of the asphalt mix but also enhanced the resistance of the mix to permanent deformation. But a more MD content decreased fatigue life of mixture. Peculiarly, MD is a good option to substitute the stone dust (SD) to enhance rut resistance during high temperatures productions [7]. In other studies, a 50 percent substitution of conventional filler by marble dust in asphalt mixes was observed to offer optimal rutting resistance and improved dynamic stability [8]. Addition of silica fume & fly ash as fillers, further influenced the viscoelastic behavior of asphalt mixes to a significant extent on enhancing their performance over conventional mix or mixes modified with fly ash [9]. Moreover, Asphalt mixtures were prepared with different percent of silica fume (0%-100%) and conditions like Flakiness Index, Elongation Index and L.A. Abrasion test indicated that silica fume had a great effect in improving the mechanical features of the mix [10]. In a different recent study by comparing marble dust and banana fiber as a filler, the addition of marbles dust showed an increase in compressive strength, tensile strength, and elasticity meaning that filling the asphalt with marble dust is beneficial to the properties of the asphalt [11]. The impact of several waste products such as waste glass powder (WGP), waste brick powder (WBP), rice husk ash (RHA) and stone dust as fillers in HMA was also investigated. Results showed that depending on the number of WGP and WBP in a mix its fatigue life would perform better than those of RHA mix and control mix (no significant difference in performance) [12]. Possibilities of the use of waste marble dust (WMD) as an HMA component were also investigated, and they revealed an increase in several important properties of the asphalt mixture including Marshall stability, tensile strength, and void qualities, when WMD is added to a

3 percent mixture of asphalt, which demonstrates the effectiveness of WMD as a mineral filler in an asphalt mixture [13]. Another study considered replacement of some of coarse aggregates with recycled PCBs and PVC component of e-waste and replacement of filler material with marble dust. Study showed that, with the increase in the percent of e-waste, Marco stability and flow value increased significantly. Moreover, such strategy increased the qualities of the mixture, as well as it lead to the recycling of waste and minimization of costs [14]. Silica fume was finally used in bitumen and trial was done using 2, 4, 6 and 8 percent concentration in the mixture and the results revealed that 6percent silica fume gave the optimum performance in enhancing the stability and strength of the mix as a whole [15].

3. Problem Statement

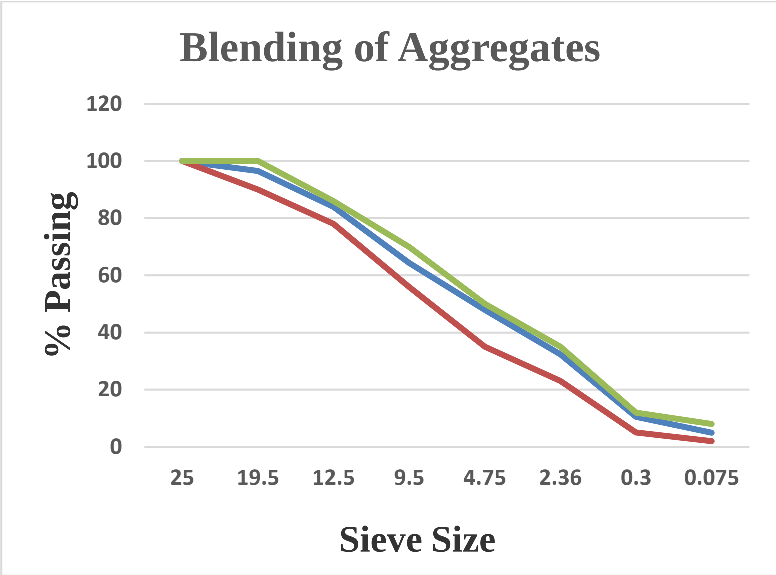
Pakistan is currently facing significant financial challenges, making it difficult to meet the increasing demands for infrastructure development. Pakistan is a developing country that needs to strengthen its economy especially by its preservation of both financial and natural resources. There is a frequent break down of pavements and roads in the country especially towards failure to perform optimally in a functional and structural capacity and high costs of repair and maintenance are thus incurred. Reusing and recycling the waste materials give an opportunity to save energy, effect the environment inflicting minimum harm on it, and save the environment qualities. Examples of environmental friendly practices, which reflect the goals of sustainable development, include recycling the construction and demolition wastes and use of industrial byproducts. When it comes to highway construction, especially in asphalt mixtures, an interest in applying marble dust as a filler and polymer waste materials as a modifier is on the increase. Also, inclusion of silica fume has demonstrated the likelihood of enhancing the rheological characteristics of asphalt more so, at low temperatures. The primary research question is to determine the possibility of using marble dust and silica fume in asphaltic concrete mixture. In particular, the scientific purpose of the study would be the estimation of the influence of these materials in the form of fillers on the performance and properties of asphalt mixtures to extend the life of such mixtures, their stability, and their sustainability in relation to the environment.

4. Materials and Methodology

The materials and methodology used in the preparation of both conventional and modified asphalt specimens are outlined below:

4.1 Aggregates

Aggregates are defined as hard, inert minerals that are used to create the mix of particles. In asphalt mixtures, aggregates typically make up 75-78% by volume and 90-95% by weight. As aggregates bear the load on the pavement surface, their quality is crucial for ensuring the structural integrity of the asphalt. In this study, aggregates sourced from a crushing plant at Kot Bungalow, Khairpur Mir's, Sindh, Pakistan, were used. The gradation of these aggregates was selected according to the job mix formula. The blending of aggregate was performed by the trial and error method, and the optimum blending of aggregate was achieved as 15:37:48 corresponding to the sieve sizes of 25mm -19mm: 19mm-4.75mm: 4.75 mm- 0.075 mm. The blending of the aggregate chart is shown in Graph 1, where the blue curve indicates the target line, the green line indicates the upper limit, and the red line indicates the lower limit. The Aggregate Bulk Specific Gravity (Avg.) was measured as 2.656 and Apparent Specific Gravity (Avg.) as 2.710.



Graph 1: Blending of aggregate chart for Job Mix Formula

4.2 Bitumen

For the asphalt mixtures, bitumen of grade 60/70 was used, sourced from a batching plant in Hyderabad, Sindh, Pakistan. This bitumen was used for all the specimens, both conventional and modified (with silica fume and marble dust).

4.3 Silica Fume

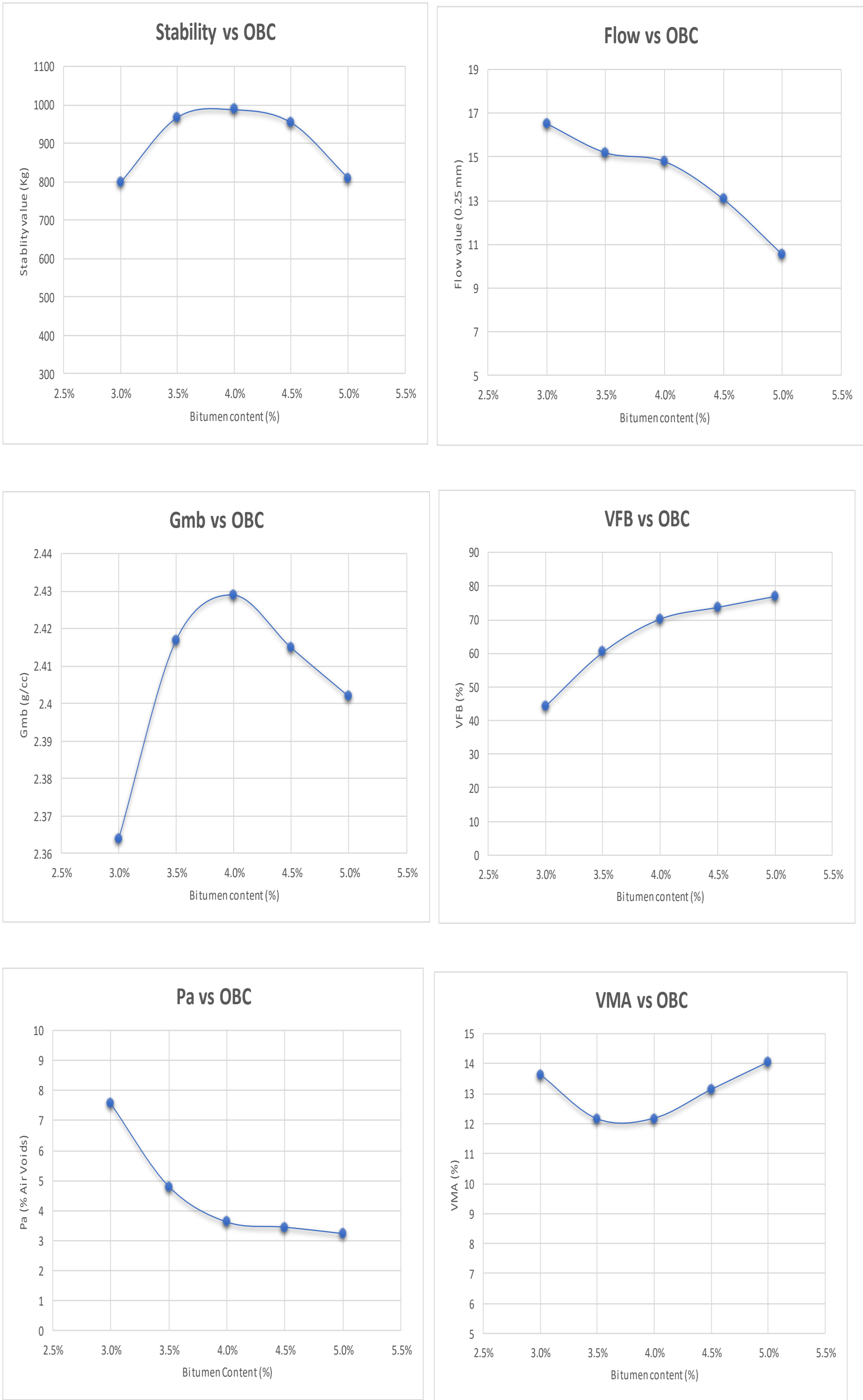
Silica fume, or micro silica, is a byproduct of producing silicon metal or ferrosilicon alloys. It is a fine material that significantly improves the compressive strength, durability, permeability, and chemical resistance of asphalt mixtures [16]. Despite being a byproduct, silica fume is widely valued in construction for its effectiveness as a filler. Due to the fine particle size of silica fume, it was used as a filler material to replace aggregate in the mix, with the particles passing through a 300 µm sieve and retained on a 0.075 µm sieve.

4.4 Marble Dust

Marble dust also known as marble powder is a fine by-product of the marble processing industry. It mainly contains calcium carbonate besides other minerals that are found in the marble stone [17]. In the following work, we took marble dust as a filler substance, managing to substitute the aggregate in the mixture with the particles that passed through a sieve with 300-micro meter holes and were collected by a sieve with 0.075-micro-meter openings.

4.5 Sample Preparation

The job mix formula (based on trial and error with consideration of the given limits of the particle size distribution curve) was implemented in order to represent the optimum bitumen content (OBC). The variations were made in the bitumen content between the range of 3 and 5 percent (0.5 percent at a time). The OBC was computed as an average of the stability, unit weight (Gmb), and the percentage of air voids (Pa) with a result of 3.86 percent as it was shown in Graph 2. Conventional bitumen/asphalt mixture specimens were then created for comparison with modified asphalt mixtures, where silica fume (SF) and marble dust (MD) were used as fillers. To prepare these mixtures, silica fume and marble dust were mixed separately with hot aggregate at 160°C, ensuring an even coating on the aggregate surface. Hot bitumen (60/70 grade) was then added and thoroughly mixed to create the final asphalt sample.



Graph 2: Graphs of Bitumen contents versus different asphalt mix parameters

The optimum bitumen content (OBC) was determined using three different criteria: Bitumen-1: The bitumen content corresponding to maximum stability was 4.00%.
Bitumen-2: The bitumen content corresponding to maximum density (Gmb) was 3.80%.
Bitumen-3: The bitumen content corresponding to 4% air voids was 3.78%.

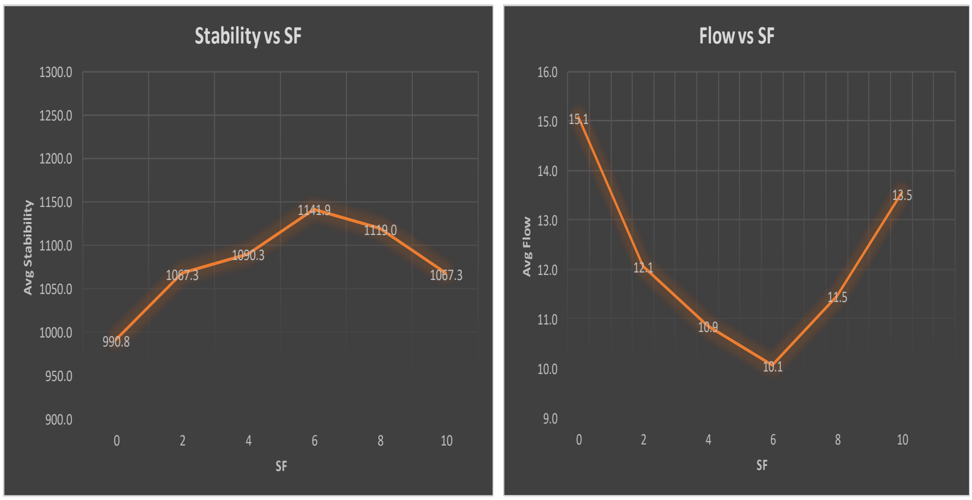
Optimum bitumen content (OBC)= (B-1+B-2+B-3)/3 = (4.00+3.80+3.78)/3

Optimum bitumen content (OBC)= 3.86%

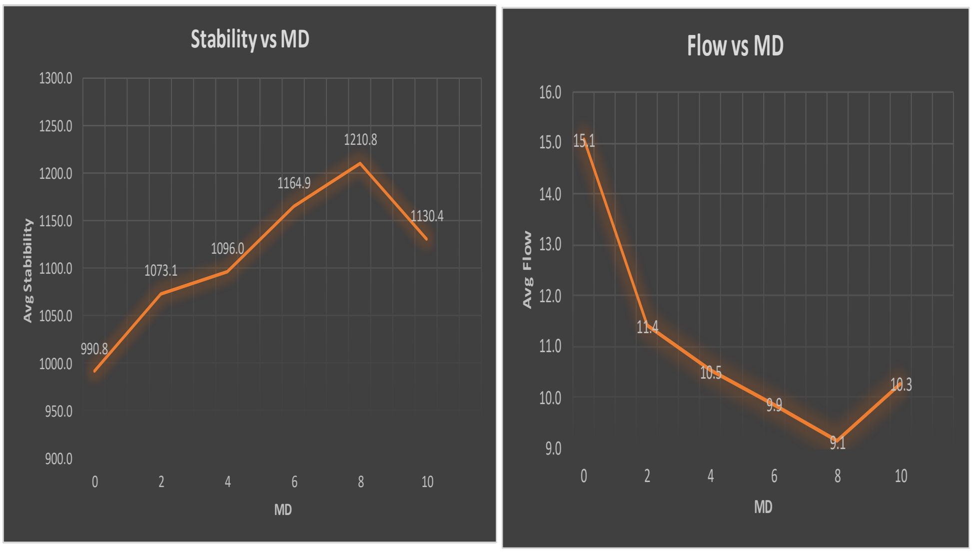
Pakistan is currently facing significant financial challenges, making it difficult to meet the increasing demands for infrastructure development. Pakistan is a developing country that needs to strengthen its economy especially by its preservation of both financial and natural resources. There is a frequent break down of pavements and roads in the country especially towards failure to perform optimally in a functional and structural capacity and high costs of repair and maintenance are thus incurred. Reusing and recycling the waste materials give an opportunity to save energy, effect the environment inflicting minimum harm on it, and save the environment qualities. Examples of environmental friendly practices, which reflect the goals of sustainable development, include recycling the construction and demolition wastes and use of industrial byproducts. When it comes to highway construction, especially in asphalt mixtures, an interest in applying marble dust as a filler and polymer waste materials as a modifier is on the increase. Also, inclusion of silica fume has demonstrated the likelihood of enhancing the rheological characteristics of asphalt more so, at low temperatures. The primary research question is to determine the possibility of using marble dust and silica fume in asphaltic concrete mixture. In particular, the scientific purpose of the study would be the estimation of the influence of these materials in the form of fillers on the performance and properties of asphalt mixtures to extend the life of such mixtures, their stability, and their sustainability in relation to the environment.

5. Results

In this study, silica fume and marble dust were incorporated into the asphalt mixture at varying percentages ranging from 2% to 10%, with increments of 2%, based on the total weight of the aggregate mixture. The optimum bitumen content (OBC) was determined to be 3.86%. Following the preparation of the asphalt mixtures, Marshall stability tests were conducted to evaluate the behavior of the mixtures in terms of their stability and flow values. The results, which are illustrated in the graphs below, provide insight into how the incorporation of these materials affects the performance of the asphalt mix. The detailed Graphs are shown in Graph 3 (showing effect of adding different percentages of silica fume contents on the stability and flow value of silica fume modified asphalt mix) and Graph 4 (showing effect of adding different percentages of marble dust contents on the stability and flow value of silica fume modified asphalt mix).



Graph 3: Graphs showing Stability and flow values versus Silica Fume



Graph 4: Graphs showing Stability and flow values versus Marble Dust

The results indicate that incorporation of silica fume (SF) and marble dust (MD) into the asphalt mixtures played considerable role in both the values of stability and flow as presented by the data in the graphs 3 and 4. The higher the rate of silica fume, the more the stability of the asphalt mixture whereby the mixture was extremely stable when the content of silica fume was 6 %. But after this stability was reduced a bit. The flow value of the silica fume, however, reduced with higher content and the minimum flow value was observed with 1 % SF. This implies that the addition of silica fume enhances the resistance of the mix to deformation, making it more stable and decreasing its flow tendency under stress.

Equally, stabilization of the asphalt mixture with marble dust contributed to an increase in stability, and not exceeding 8 percent, after which it began to decline. The greatest stability reading of the marble dust was calculated at 8 percent mark, whereby there was an enhancement on the rutting resistance. Marble dust too reduced the flow values of the flow, as in the case of the lowest flow that was at 8% MD. This means that the marble dust when added to asphalt just as silica fume will improve the performance of the asphalt mixture by raising its stability and decreasing the flow and thereby by possibility improving on the generally overall performance and life expectancy of the pavement.

The results showed that both silica fume and marble dust proved to be good modifier materials in the asphalt mixture, and a 6% of SF and 8% of MD is the best performing percentage rates. Based on the results, it is possible to say that additional research regarding the usage of these materials at various percentages would bring quite valuable information about their future potential in terms of enhancing the work of asphalt pavements in diverse circumstances.

6. Conclusions and Recommendations

This study demonstrates that both silica fume (SF) and marble dust (MD) can be effectively utilized as modifiers for asphalt mixtures. The optimum bitumen content (OBC) determined for this research was 3.86%. When varying amounts of SF and MD, ranging from 2% to 10%, were incorporated into the asphalt mixture, it was found that increasing the percentage of these fillers led to higher stability values and lower flow values. Specifically, with silica fume, stability increased by 7.72%, 10.04%, 15.25%, 12.94%, and 5.41% at the 2%, 4%, 6%, 8%, and 10% replacement levels, respectively. Meanwhile, the flow values for SF decreased by 19.86%, 27.8%, 33.11%, 23.84%, and 10.59% at the corresponding percentages. For marble dust, stability values increased by 8.30%, 10.62%, 17.57%, 22.20%, and 14.09%, and flow values decreased by 24.50%, 30.46%, 34.44%, 39.73%, and 31.78% at the 2%, 4%, 6%, 8%, and 10% levels. The results from this research indicated that the highest stability and the lowest flow values were achieved when 6% silica fume and 8% marble dust were used as replacements, compared to the conventional asphalt mixture.

While this study used 60/70 grade bitumen, it is recommended that further research be conducted using other grades of bitumen to explore potential improvements in asphalt performance. Additionally, this study was limited to specific percentages of SF and MD; it would be valuable to explore other percentage combinations of these materials in future studies. Moreover, the current study used uncontrolled temperature conditions during sample preparation, and it is suggested that further research be carried out under controlled temperature settings to better assess the impact on the asphalt mixture's properties.

Author Contributions: The authors' contributions are as follows: Touqeer Ali Rind, Rafeeque Ahmed Kalhoro and Dildar Ali Mangnejo were responsible for the conceptualization, technical implementation, methodology, and drafting of the paper. Muhammad Farooque Panhyar and Muhammad Arsalan Khan contributed to data collection, compilation, and validation

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Conflicts of Interest: The authors declare that there is no conflict of interest regarding this study and affirm that the work is original, without any form of plagiarism. All sources of information have been properly cited and acknowledged.

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