# Impact of recycled rubber and PVC on mechanical properties of modified asphalt mixtures

## Impacto del caucho reciclado y PVC en las propiedades mecánicas de mezclas asfálticas modificadas

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**[1]Diego Ivan Quimbiulco-Rosero, [2]Mayra Paola Tacuri - Diaz,**
**[3]Francisco Roberto Ortiz-Navas, [4]Verónica Valeria Yépez Martínez**
[1]Universidad Politécnica Salesiana. dquimbiulcor@est.ups.edu.ec. ORCID: 0009-0006-3129-1287
[2]Universidad Politécnica Salesiana. mtacurid@est.ups.edu.ec. ORCID: 0009-0003-1664-7327
[3]Universidad Politécnica Salesiana. fortizn@ups.edu.ec. ORCID: 0000-0003-1071-3955
[4]Universidad Politécnica Salesiana. vyepez@ups.edu.ec. ORCID: 0000-0003-2790-7211

***Abstract***:

*When modifying asphalt mixtures with rubber powder and polymers such as blister-type PVC, the aim is to improve certain properties such as durability and maintenance time, thereby reducing costs. Additionally, it could be also benefit from an extended lifespan. Indirectly, this would contribute to the reduction of plastic and rubber waste, which currently lack proper management and are highly polluting to the environment. This article presents the results of research utilizing recycled rubber from used tires and blister-type PVC derived from waste produced by factories that market compounds of this material for various applications. When determining the Marshall properties for the asphalt-rubber mixture, percentages of 1 %, 2 %, and 3 % of rubber powder in relation to the asphalt aggregate were used. The same was done with the asphalt-PVC mixture, using percentages of 0.5 %, 1%, and 1.5 % of blister-type PVC. The results obtained show that rubber powder exhibits significantly lower stability and flow values compared to blister-type PVC, suggesting that PVC greatly enhances the asphalt mixture compared to rubber powder. To compare the modified asphalt, tests were also conducted for maximum theoretical specific gravity, obtaining the density of the asphalt mixture (Rice method), bulk density (unit weight), and percentage of voids in compacted or loose aggregates. These results provide valuable insights for future research on the benefits of asphalt modified with rubber powder and blister-type PVC.*

***Keywords***: *Modified asphalt, blister, rubber, bulk density, RICE method, Marshall properties.*

**Resumen**:

Al modificar las mezclas asfálticas con polvo de caucho y polímeros como el PVC tipo blíster, se busca mejorar ciertas propiedades en los pavimentos como su durabilidad, la disminución de tiempos para ejecutar mantenimientos, y extender su vida útil. Indirectamente, se contribuirá en la reducción de desechos plásticos y de caucho que no cuentan con un correcto manejo y son muy contaminantes para el medio ambiente. Este artículo muestra resultados de una investigación donde se emplea el caucho reciclado de neumáticos usados y el PVC tipo blíster que proviene de desechos de fábricas que comercializan compuestos de esta materia para diversas aplicaciones. Al determinar las propiedades Marshall para la mezcla de asfalto - caucho se utilizaron porcentajes de 1 %, 2 % y 3 % de polvo de caucho en relación con el asfalto. Lo mismo se hizo con la

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mezcla de asfalto - PVC usando porcentajes de 0.5 %, 1 % y 1.5 % de PVC tipo blíster. Los resultados que se han obtenido muestran que el polvo de caucho presenta valores de estabilidad y flujo muy inferiores con respecto al PVC tipo blíster, lo que sugiere que el PVC mejora de gran manera la mezcla asfáltica con respecto al polvo de caucho. Para realizar la comparación del asfalto modificado también se hicieron pruebas de gravedad específica máxima teórica, obtención de la densidad de la mezcla asfáltica (método Rice), densidad bulk (peso unitario) y porcentaje de vacíos de los agregados compactados o sueltos. Estos resultados son un aporte importante para futuras investigaciones sobre los beneficios del asfalto modificado con polvo de caucho y PVC tipo blíster.

**Palabras claves**: asfalto modificado, blíster, caucho, densidad bulk, método RICE, propiedades Marshall.

## 1. INTRODUCTION

In recent decades, waste management has become a major challenge due to the large increase and generation of waste, especially those made of polymers. The accumulation of these materials that are not biodegradable in the short term poses environmental problems such as soil or water pollution. Thus, the revaluation of waste results in a basic strategy to promote sustainability, where waste from one industry can become raw material for another.

The construction industry is an industry that has incorporated waste in the manufacture and construction of new infrastructure, allowing the reuse of discarded materials and reducing the dependence on non-renewable natural resources. Thus, applications have been developed where waste such as rubble (Ma et al., 2020), polymeric waste (Saikia & De Brito, 2012), glass (Mohajerani et al., 2017) and metals (Yellishetty et al., 2008) are incorporated into composite materials such as hydraulic or asphalt concrete.

The incorporation of waste into asphalt concrete is an innovative solution to improve the mechanical properties of pavements, converting them into modified asphalt. This technique involves the incorporation of a variety of materials, such as glass fibres, steel, organic compounds, rubber fibres, rubber powder, among others. The use of rubber from tires in pavements is a technique used for more than 100 years, with the first application reported in 1840 (Heitzman, 1992). However, it is from the 1950s that interest in the subject becomes more relevant (Alfayez et al., 2020). It has demonstrated a potential material to improve deformation, performance and even noise reduction in vehicle-pavement contact. This incorporation can be done either through a dry process, where the rubber replaces part of the aggregates (Takallou & Takallou, 1991), or through a wet process, where the rubber is diluted in the asphalt by heat.

Other benefits of including rubber in asphalt reported in the literature are improved resistance to deformation of the asphalt pavement during traffic actions (Mashaan, 2012), prevent fatigue cracking on pavements (Moreno-Navarro et al., 2016), improves adhesion between the aggregates and the asphalt, improve its stability and resistance under greater traffic load (Wulandari & Tjandra, 2017). As a negative point, according to (Mohammed et al., 2021), the addition of crumb rubber reduces indirect tensile strength up to 30 %.

The use of polymers such as PVC (polyvinyl chloride) in the modification of asphalt mixtures has generated increasing interest in the field of pavement engineering due to its potential benefits in mechanical, economic and environmental performance. This approach aligns with the concept of circular economy, which promotes the use of plastic waste to mitigate environmental pollution and improve the properties of materials used in road construction.

Concerning to use of PVC in asphalt pavements, (Xu et al., 2022) highlights that the addition of recycled polymers such as PVC significantly improves the thermal and mechanical performance of pavements by reducing permanent deformations and increasing resistance to oxidative aging. Likewise, the authors point out that the use of physical and chemical modification techniques can optimize the interaction between asphalt and polymers, achieving better long-term performance.

Another relevant aspect is the variability in the properties of PVC and its compatibility with asphalt. According to (Li et al., 2022), the PVC incorporation method, its particle size, and the mixing conditions, such as temperature and stirring speed, significantly influence the final properties of the mixture. The experiments carried out showed that modified PVC significantly improves the stiffness of asphalt at high temperatures and maintains good flexibility in cold climates.

In addition, research (Jwaida et al., 2023) underlines the importance of evaluating the environmental and economic effects of using recycled PVC. These studies conclude that PVC recycling not only helps reduce the accumulation of plastic waste in landfills, but also decreases the need for virgin polymers, thus promoting more sustainable road construction

On the other hand, the work of (Fakhri et al., 2022) investigated the use of recycled PVC particles, specifically from water pipes and candy wrappers, in Stone Mastic Asphalt (SMA) mixes. Their mechanical properties were evaluated by testing for moisture resistance, shear strength, and crack resistance. The results showed that these particles increased asphalt stiffness, load deformation resistance, and fracture energy at intermediate and low temperatures. However, they also reduced skid resistance (BPN). It was concluded that recycled water pipe particles significantly improved mechanical properties more than those from candy wrappers, with an optimal content of 5% being recommended to optimize real traffic conditions.

Similar benefits were observer by (Ziari et al., 2019) that analyzed the impact of electric arc furnace dust (EAFD) and recycled PVC as additives in asphalt mixtures, evaluating their influence on resistance to aging, permanent deformation, moisture sensitivity and fatigue. Both materials were found to improve stiffness, rutting resistance and durability under repetitive loads, as well as reducing moisture sensitivity. In particular, EAFD showed a greater improvement in aging and moisture resistance, while PVC excelled in rutting resistance.

Table 1 presents some of the studied published in literature where PVC was added in asphalt mixtures. As it can be seen, most of the percentages used of PVC are over 2 % while particle sizes in some cases are not specified and in others is over 2 mm. Thus, the studies analyzed do not explore PVC particle sizes smaller than 1 mm.

*Table 1. Summary of the use of PVC in previous studies*

| Study | Type of PVC | Percentage of PVC | Size of PVC | Method of Introduction | Tests Conducted |
|---|---|---|---|---|---|
| (Nobinur Rahman et al., 2013) | Waste PVC | Up to 7.5 % | 2-3 mm | Shredded and mixed with bitumen | Marshall Stability, Flow, and Voids Characteristics |
| (Behl et al., 2014) | PVC Pipe Waste | 3 % and 5 % | 2-4 mm | Chemically treated, blended with bitumen | Visco-elastic properties, Rutting resistance, Fatigue life |
| (Rasel et al., 2011) | Waste PVC | 2.5 % to 20 % | Not specified | Mixed with bitumen | Marshall Stability, Flow, Stiffness, Void Characteristics |

| | | | | | |
|---|---|---|---|---|---|
| (Fakhri et al., 2022) | Recycled PVC (pipes, candy wrappers) | 2% , 3.5 %, 5 % | Passed No. 50 sieve | Mixed with bitumen using high shear mixer | Static creep test, ITS test, Rutting resistance, Skid resistance, SCB fracture test |
| (Ziari et al., 2019) | Waste PVC | Not specified | Not specified | Powder added to asphalt binder | FTIR, SEM, LAS, MSCR, Tensile strength, Rutting resistance |

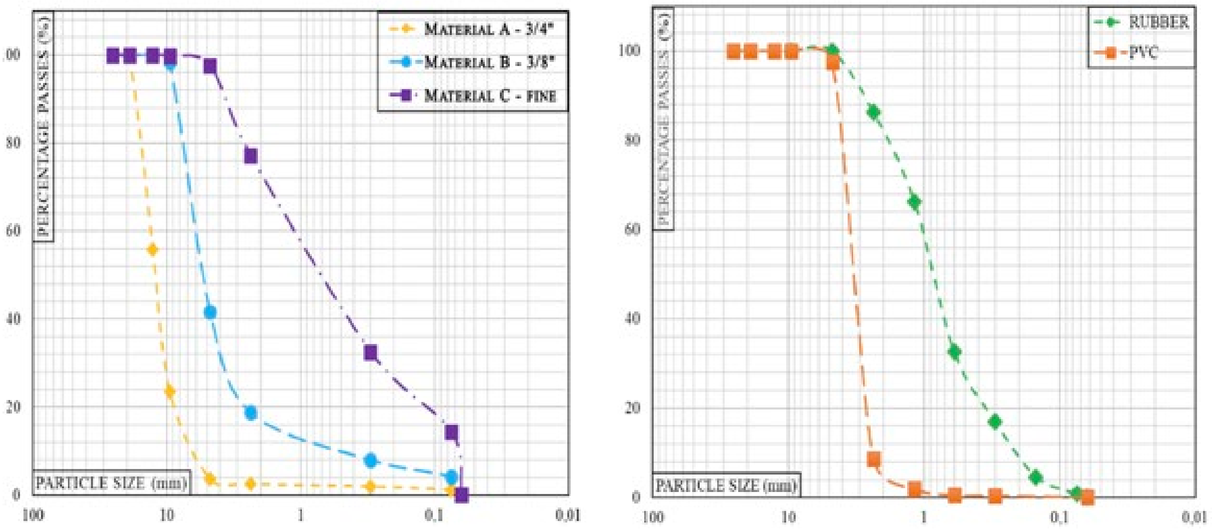
Within this context, the present investigation aims to investigate the use of rubber from used tires and blister-type PVC from factory incorporated to mix asphalt to evaluate the changes on main Marshal properties. For this, one size of rubber and three sizes of PVC are explorer as well as the manner of how these compounds are incorporated on mixtures.

## 2. MATERIALS

Two types of natural crushed limestone gravel and one type of sand were used, along with asphalt AC-20. Aggregates undergo a sieving process to obtain the required sizes for asphalt mixture design. The photograph in Fig. 1 shows how the material which are named as 3/4", 3/8", and sand.

A granulometric analysis was carried out based on INEN 696:2011 [8], evidencing a maximum particle size of 19.0 mm for 3/4" and 3/8” agreggate while maximum particle size of sand was 4.75 mm, as shown in Figure 2a.

Figure 1. Natural material for mix design



(a)

(b)

Figure 2. Granulometric curve of the aggregates, and polymers.

Being a material directly involved in the asphalt mix, the abrasion resistance of the aggregates was determined according to INEN 860:2011 [9] and resulted in 24.5 % for agreggate 3/4” and 30 % for aggregate 3/8”. In accordance with ASTM C127-15 [10] and ASTM C128-22 [11], the analysis of densities and the absorption percentage of each aggregate was performed, as shown in Table 1.

The crushed rubber powder was obtained from a company that processes used tires. The material obtained has different particle sizes since it is subjected to a shredding process of recycled tires. This does not provide uniformity in particle size, so it was necessary first to determine particle size distribution by granulometric process. Results can be seen in Fig. 2b. It is advisable for all rubber particles to have a size capable of passing through sieve No. 8 (2.36 mm), as established by the INEN 2680:2013 (NTE INEN 2680:2013, 2013) standard.

Rubber powder can be viewed as an additive to aggregates or as a partial replacement of a portion of the fine aggregates. According to (Cutucuamba & Fernández, 2024) it is observed that the fine rubber powder has a better workability than the coarse rubber powder since it adheres very well to the mixture unlike the other. This could be to its smaller size and larger specific surface area, ensures better dispersion within the asphalt mixture, leading to enhanced cohesion and homogeneity. It effectively modifies the rheological properties of the binder. Based on the previous observations, to incorporate rubber into the mixture design, the cumulative retained on sieve No. 30 (0.60 mm) was used as seen in Figure 2b.

On the other hand, the PVC used herein was a residue of manufacturing processes which is usually discarded. Similar than rubber, to know the particle distribution, a granulometric text was performed. Results are presented in Fig. 2b. The 97.40 % of the particles used in the mixture, presented a size between the N°4 sieve opening (4.75 mm) and the N°16 sieve opening (1.18 mm). So, in order to obtain the desired particle PVC sized, it was crushed to obtain smaller particles that could be incorporated more effectively into the mixture. A manual mill was used to achieve particle sizes of sieve No. 16 (1.18 mm), sieve No. 30 (0.60 mm), and sieve No. 50 (0.30 mm) to ensure better workability and achieve a uniform mixture.

## 3. TEST METHODOLOGY

### 3.1 Desing of control mix

In order to design the control mix of asphalt, the guides provided by (ASTM D6926-20, 2020) were followed. In the asphalt mixture design, once the aggregates to be used have been selected and the granulometric analysis has been conducted, a combination of materials is formulated based on the results obtained.

For the mixture, optimal percentages of each material size were determined, aiming to fall within the lower and upper limits of the specifications of the MOP-001-F-2002 (República del Ecuador, 2002) standard , for a nominal size of 3/4". (See Table 3).

*Table 2. Results of densities and absorption test in agreggate*

| Material | Mass specific gravity | Specific gravity SSS | Apparent specific gravity | % Absorption | Specific gravity of aggregates |
|---|---|---|---|---|---|
| A - 3/4" | 2.358 | 2.422 | 2.519 | 2.710 | 2.444 |
| B - 3/8" | 2.452 | 2.553 | 2.728 | 4.126 | |
| C - fine | 2.518 | 2.560 | 2.629 | 1.667 | |

*Table 3. Percentages of the combined mixture.*

| Material | % Optimum |
|---|---|
| A - 3/4" | 35 |
| B - 3/8" | 25 |
| C – fine | 40 |

It is worth mentioning that in order to verify the percentages, a granulometric curve must be constructed and superimposed with the curves generated by the limits of the aforementioned standard (See Figure 4).

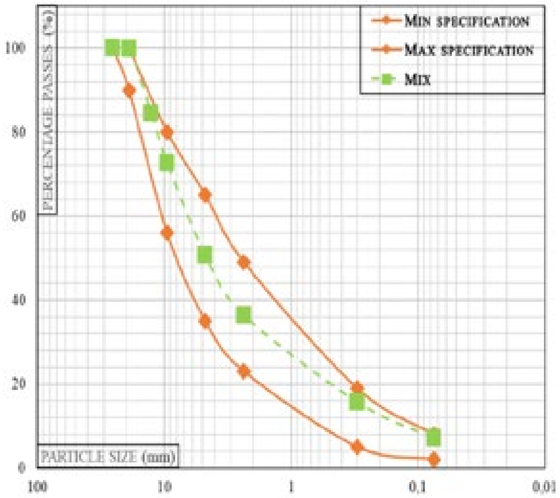


Figure 3. Granulometric curve of the mixture

Based on the initial asphalt content value obtained from the formula, briquettes are prepared with asphalt contents of 6.5 %, with an increase and decrease of 0.5 %.

Once the quantity of materials for the design is determined, the preparation and compaction of specimens according to (American Society for Testing and Materials, 2020) is carried out. A total of 15 specimens should be prepared, with 3 specimens for each asphalt content.

Each briquette is made with 1200 grams of granular materials plus the corresponding percentage of asphalt. The materials that are added to the mixture must be dried at a constant temperature ranging from 120 °C to 160 °C, then mixed in a pot until reaching a temperature of 130 °C to 150 °C for compaction.

Given that it is designed to withstand heavy traffic, it is recommended to apply 75 strokes to each briquette.

Tests are conducted on the samples with the aim of meeting the conditions established in ASTM D1559 and ASTM 2041 (American Society for Testing and Materials, 1989, 2010) standard, as detailed in Table 3.

*Table 4. Results of the volumetric and mechanical properties of the mixture*

| Asphalt (%) | Voids (%) | | | Stability (lbs) | Flow (1/100") | Bulk Specific Gravity (Gmb) | Rice Specific Gravity (Gmm) |
|---|---|---|---|---|---|---|---|
| | VAM | VFA | Vv | | | | |
| 5,0 | 15.06<br>(1.0 %) | 45.91<br>(1.2 %) | 8.14<br>(2.0 %) | 3433<br>(19 %) | 9<br>(6.7 %) | 2.185<br>(0.2 %) | 2.379 |
| 5,5 | 14.60<br>(0.4 %) | 61.85<br>(0.5 %) | 5.57<br>(1.1 %) | 3814<br>(10 %) | 10<br>(5.6 %) | 2.208<br>(0.1 %) | 2.339 |
| 6,0 | 14.04<br>(1.1 %) | 73.40<br>(1.3 %) | 3.74<br>(4.8 %) | 4022<br>(7.1 %) | 11<br>(5.1 %) | 2.235<br>(0.2 %) | 2.321 |
| 6,5 | 14.36<br>(0.8 %) | 77.58<br>(0.8 %) | 3.22<br>(3.6 %) | 3962<br>(5.4 %) | 12<br>(4.7 %) | 2.238<br>(0.1 %) | 2.313 |
| 7,0 | 14.40<br>(1.0 %) | 84.72<br>(1.2 %) | 2.20<br>(7.7 %) | 3715<br>(1.3 %) | 14<br>(4.2 %) | 2.249<br>(0.2 %) | 2.300 |

* Coefficient of variation in brackets

Based on the obtained data, the ideal amount of asphalt for the mixture is determined based on the 4 % voids percentage. (See Figure 4).

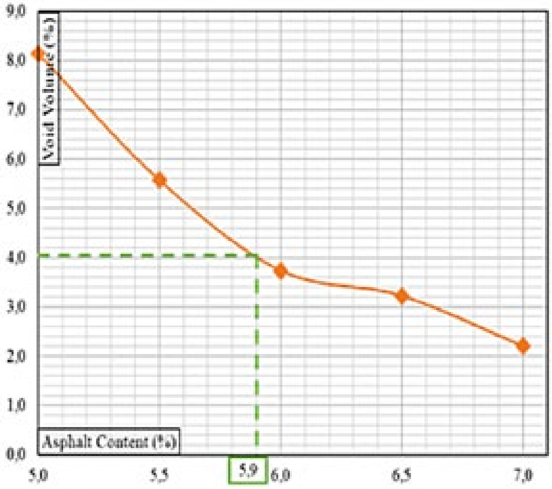


Figure 4. Void Volume vs Asphalt Content

Therefore, all analyzed properties are calculated and presented in Figure 5 considering this asphalt content.

As shown in Table 4, the volumetric and mechanical properties meet the requirements established by the MOP-001-F-2002 standard (República del Ecuador, 2002) for heavy traffic.

Upon obtaining an approximate optimal asphalt content of 5.9 % in the design, a verification was conducted with 3 additional specimens, resulting in values with which a comparison will be made with the different PVC and rubber mixtures.

### 3.2 Rubber powder - Asphalt mixture

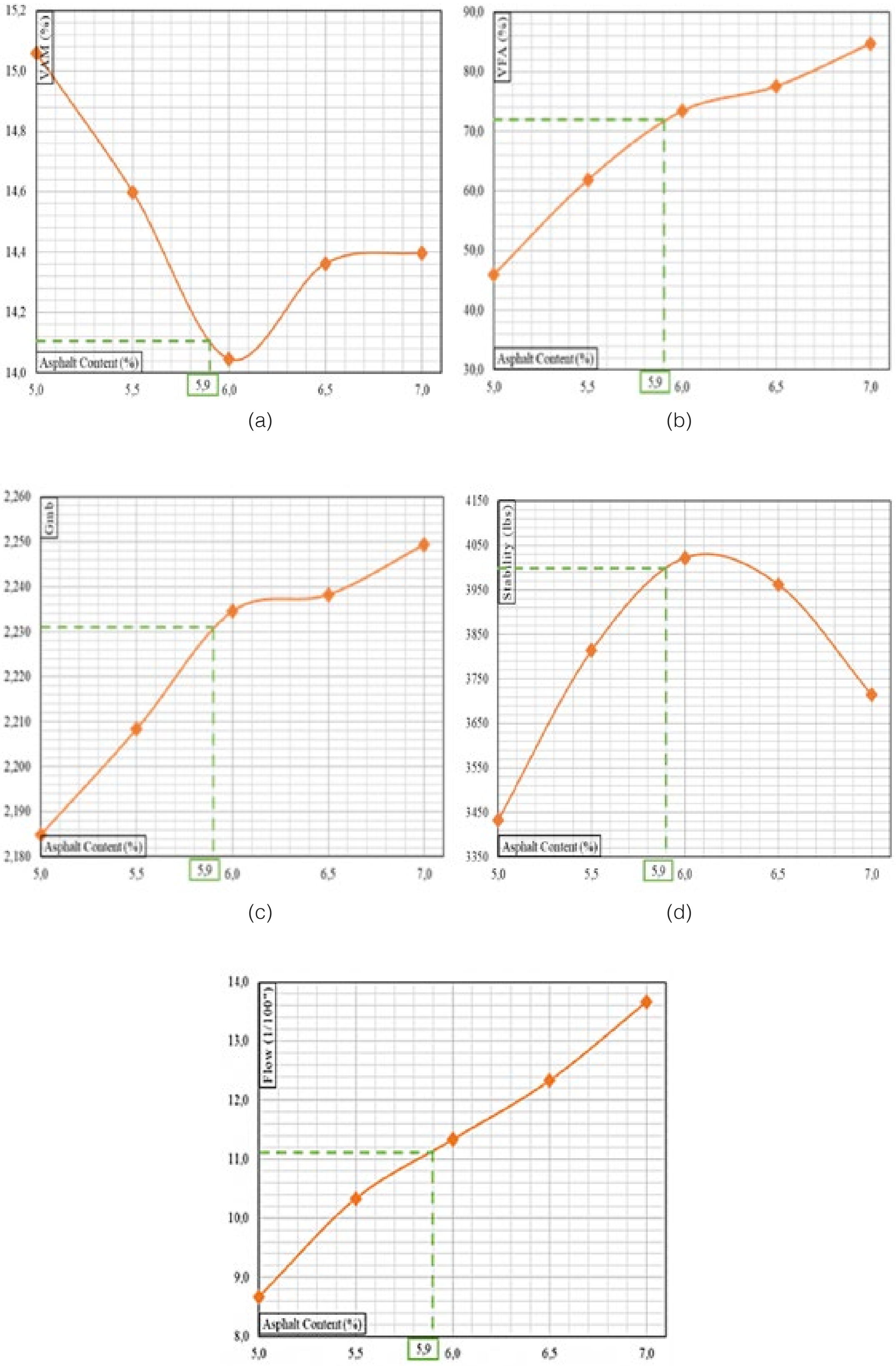
The rubber powder was used as an additive in the mixture, as an additional aggregate, and also as a replacement for a portion of the fine aggregate.

Before using the three percentages of rubber powder (1 %, 2 %, and 3 %), the preparation of 3 specimens with 2 % rubber was scheduled, considering the three ways it will be added to the mixture. This resulted in a total of 9 briquettes (3 briquettes with 2 % added as an additive, 3 briquettes with 2 % added as an additional aggregate, and 3 briquettes with 2 % added as a replacement in the fine aggregate). This was done to obtain values of the mechanical and volumetric properties of the mixture (see Table 5) to compare them and determine which method of adding rubber to the mixture might be the most effective.

*Table 5. Verification of established requirements of the Marshall test*

| Property | Value | Verification | Specification | Unit |
|---|---|---|---|---|
| Vv | 4 | 4.67 (2.95 %) | 3 - 5 | % |
| VAM | 14.10 | 14.31 (0.76 %) | > 13 | % |
| VFA | 72 | 67.36 (0.88 %) | 65 - 75 | % |
| Gmb | 2.231 | 2.225 | - | adim |
| Stability | 4000 | 4813 (8.66 %) | > 2200 | Lbs |
| Flow | 11.10 | 11 (5.34 %) | 8 - 14 | 1/100 in |
| Filler / bitumen | 1.12 | 1.12 | 0.8 - 1.2 | adim |

Figure 2. Granulometric curve of the aggregates, and polymers.



(a) (b)

(c) (d)

(e)

Figure 5. (a) VAM vs. Asphalt Content, (b) VFA vs. Asphalt Content, (c) Gmb vs. Asphalt Content, (d) Stability vs. Asphalt Content, (e) Flow vs. Asphalt Content.

*Table 6. Mechanical and volumetric properties of rubber powder.*

| **Rubber powder (%)** | **Voids (%)** | | | **Stability (lbs)** | **Flow (1/100")** |
|---|---|---|---|---|---|
| | **VAM** | **VFA** | **Vv** | | |
| 2% | | | | | |
| Additive | 20.62 | 50.50 | 10.21 | 1900 | 13 |
| Aggregate | 17.40 | 37.88 | 10.81 | 2768 | 13 |
| Replacement | 19.64 | 48.16 | 10.18 | 2434 | 12 |
| With Replacement of fine aggregate | | | | | |
| 1 % | 15.98<br>(7.5 %) | 56.99<br>(9.2 %) | 6.87<br>(11.2 %) | 3561<br>(2.9 %) | 10<br>(10.1 %) |
| 2 % | 19.64<br>(14.4 %) | 48.16<br>(18.5 %) | 10.18<br>(10.3 %) | 2434<br>(13.4 %) | 12<br>(7.1 %) |
| 3 % | 22.17<br>(2.3 %) | 47.52<br>(2.9 %) | 11.63<br>(5.0 %) | 1544<br>(7.0 %) | 16<br>(9.7 %) |

* Coefficient of variation in brackets

Taking into account the previous values (Table 5), the option of using rubber powder replacement in a small portion of the fine aggregate was considered. This is because it exhibits a lower voids percentage with better stability and flow compared to the other methods of adding rubber powder.

The briquettes were made with rubber percentages of 1 %, 2 %, and 3 % as a replacement for a small portion of the fine aggregate, resulting in 3 briquettes for each rubber percentage, totaling 9 briquettes. In Table 5, the variation in volumetric and mechanical properties obtained with respect to the different percentages and methods of adding rubber powder can be observed.

The incorporation of rubber powder into asphalt mixtures significantly influences pavement performance. As the air void content increases, from 4 % without rubber to values exceeding 10 % with rubber as an additive, aggregate, or replacement, the mixture's stability decreases, compromising its ability to resist deformation under load. Additionally, higher air void levels lead to increased susceptibility to water infiltration and oxidation, accelerating pavement aging and reducing durability. In other hand, 1 % of rubber added as replacement of fine agreggate increases, although not considerably, the volume of voids, also altering the stability and flow, although it keeps them within the specified limits.

### 3.3 PVC - Asphalt mixture

The blister-type PVC is added to the mixture as an additive, as an additional aggregate, and by replacing it as a percentage of the fine aggregate. Taking this into account, before making the briquettes with PVC percentages (0.5 %, 1%, and 1.5 %). Tests are conducted with 1 % PVC using the blister sizes retained on sieves; No. 16 (1.18 mm), No. 30 (0.60 mm), and No. 50 (0.30 mm), adding it as an additive to the mixture, resulting in 9 briquettes. Tests are conducted with 1 % PVC using the blister sizes retained on sieves; No. 16 (1.18 mm), No. 30 (0.60 mm), and No. 50 (0.30 mm), adding it as an additive to the mixture, resulting in 9 briquettes.

As observed in Table 6, the blister size that comes closest to optimal void values is sieve No. 30 (0.6 mm). With this blister size, briquettes are made, considering how the PVC will be added to the mixture, resulting in 18 briquettes (3 briquettes of 0.5 % added as an additional aggregate, 3 briquettes of 0.5 % added as a replacement in the fine aggregate; 3 briquettes of 1 % added as an additional aggregate, 3 briquettes of 1% added as a replacement in the fine aggregate; 3 briquettes of 1.5 % added as an additional aggregate, 3 briquettes of 1.5 % added as a replacement in the fine aggregate).

In Table 6 the difference in volumetric and mechanical properties of the modified mixture can be observed with respect to the different percentages and methods of adding blister-type PVC.

## 4. RESULTS Y DISCUSSION

### 4.1 Effect of rubber powder and PVC on the asphalt mixture

With the data obtained, it can be evidenced that the best way to incorporate rubber powder and blister-type PVC is by replacing a small portion of the fine aggregate, achieving more optimal values with 1 % rubber powder and 1 % blister-type PVC.

It is worth noting that a comparison was made with the control mixture, rubber mixture, and PVC mixture while maintaining the same asphalt percentage (5.9 %) and 1 % of each recycled element. As observed in Fig. 6 to Figure 10 where coefficient of variation (CV) is included. As it can be seen, The mixtures that present the greatest variability in the results are those that incorporate rubber, presenting a higher CV than the mixture without additions or those that include PVC. Nevertheless, in all cases except two, the CV is under 10 %, which gives an indicative the results could be considered consistent.

It can be observed that the void volume (Vv) of the rubber powder and PVC dif-

*Table 7. Mechanical and volumetric properties of PVC*

| **Sieve** | **PVC (%)** | **Voids (%)** | | | **Stability (lbs)** | **Flow (1/100")** |
|---|---|---|---|---|---|---|
| | | **VAM** | **VFA** | **Vv** | | |
| Additive | | | | | | |
| No. 16 | 1.0 | 13.97 | 69.26 | 4.30 | 4255 | 11 |
| No. 30 | | 13.95 | 71.93 | 3.92 | 4268 | 11 |
| No. 50 | | 13.59 | 69.53 | 4.14 | 4513 | 9 |
| Aggregate + PVC | | | | | | |
| No. 30 | 0.5<br>(0.0 %) | 13.95<br>(1.7 %) | 67.47<br>(2.0 %) | 4.54<br>(5.9 %) | 4317<br>(11.4 %) | 14<br>(8.7 %) |
| | 1.0<br>(0.0 %) | 13.65<br>(2.0 %) | 71.19<br>(2.4 %) | 3.93<br>(7.9 %) | 4503<br>(18.4 %) | 13<br>(16.9 %) |
| | 1.5<br>(0.0 %) | 13.99<br>(1.7 %) | 69.16<br>(1.9 %) | 4.32<br>(6.0 %) | 5300<br>(12.0 %) | 12<br>(13.9 %) |
| Replacement of fine aggregate | | | | | | |
| No. 30 | 0.5<br>(0.0 %) | 15.56<br>(2.3 %) | 62.19<br>(2.8 %) | 5.88<br>(6.8 %) | 3641<br>(6.7 %) | 13<br>(7.1 %) |
| | 1.0<br>(0.0 %) | 13.96<br>(1.8 %) | 71.29<br>(2.1 %) | 4.01<br>(6.9 %) | 4465<br>(7.2 %) | 13<br>(6.5 %) |
| | 1.5<br>(0.0 %) | 14.45<br>(2.5 %) | 67.25<br>(2.9 %) | 4.73<br>(8.4 %) | 4491<br>(10.9 %) | 12<br>(10.7 %) |

* Coefficient of variation in brackets

fers greatly, as shown in Figure 6. Rubber powder exhibits a higher void volume compared to PVC and the control mixture. It is noticeable that the 1 % of rubber used in the mixture does not meet the minimum specifications ranging from 3 % to 5 %, as it presents 6.87 % void volume, unlike PVC which has a void volume of 4.1 %, being closer to the optimal value (4 %) and improving upon the control sample which started with a void volume of 4.67 %.

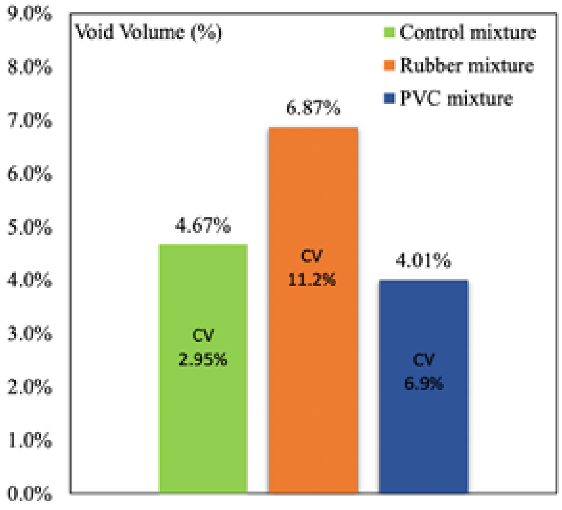


Figure 6. Void volume - Control mixture, rubber, PVC

In Figure 7, the voids in mineral aggregate (VMA) of the rubber powder (15.98 %) does not increase considerably compared to the VMA of the control mixture (14.31 %) and PVC (13.96 %). However, it is observed that the VMA of rubber is higher than both, and that the VMA of PVC is lower than that of the control sample. Additionally, it should be mentioned that the VMA in all three cases meets the minimum specifications, which require it to be greater than 13 %, as seen in Table 4.

When analyzing the voids filled with asphalt (VFA) with respect to the minimum specifications in Table 4, which indicate that VFA should be between 65– 75 %, it is observed that rubber powder has a lower value of 56.99 % and does not meet the minimum requirements, unlike PVC, which has 71.29 %, meeting the specifications

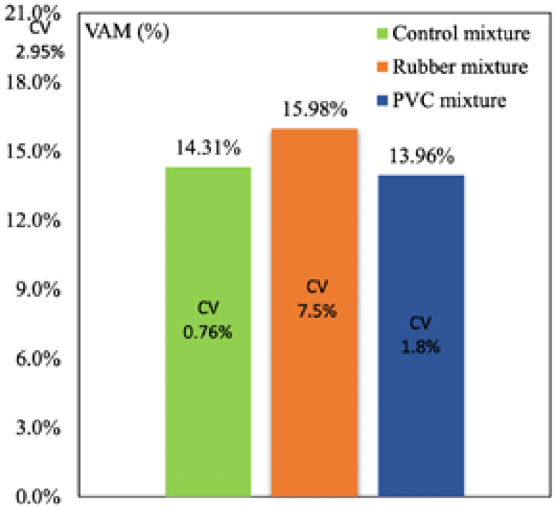


Figure 7. VMA - Control mixture, rubber, PVC

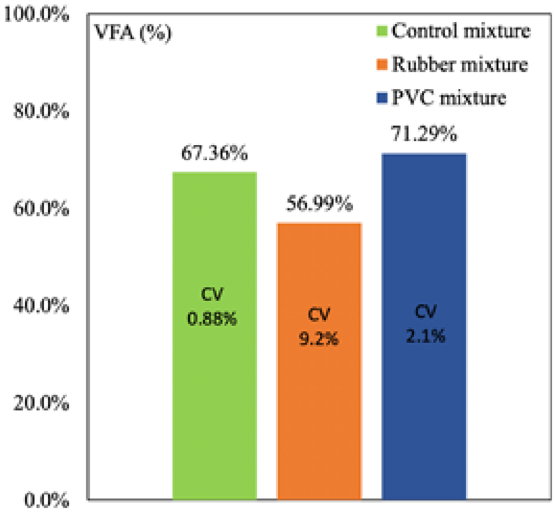


Figure 8. VFA - Control Mixture, rubber, PVC

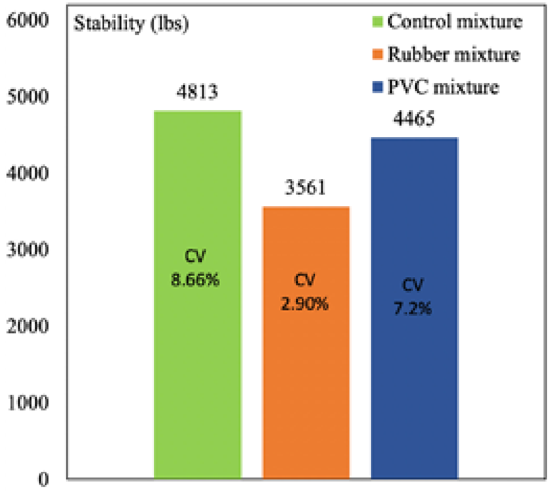


Figure 9. Stability - Control mixture, rubber, PVC

and improving upon the control sample, which started with 67.36 %. (See Figure 8).

The stability values for both are at the permitted limit as they exceed 2200 lbs, as shown in Table 4 This value is related to the mixture's ability to withstand deformations. It can be observed that the control sample has a value of 4813 lbs, which is higher than rubber (3561 lbs) and PVC (4465 lbs). Consequently, it is evident that the control sample significantly decreases its stability when rubber is added, and decreases slightly when PVC is added, but the difference in its value is not significant. (See Figure 9).

As seen in Figure 10 the flow of the control sample is 11 (1/100"), but when rubber powder is added, this value changes to 10 (1/100"), and when blister-type PVC is added, the flow value is 13 (1/100"). Comparing with the specifications in Table 6, which indicate that the flow should be in the range of 8-14, it can be concluded that the modified mixtures are within the allowable range.

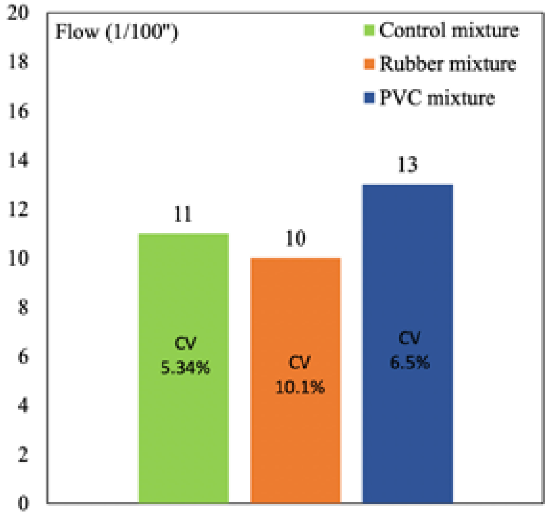


Figure 10. Flow - Control mixture, rubber, PVC

## 5. CONCLUSIONS

This article presents the incorporation of rubber powder and blister-type PVC in modified asphalt mixtures, aiming to evaluate which of these has a greater influence on the stability and flow of such mixtures, as well as to assess which one provides better workability and what percentage of these should be added to the conventional asphalt mixture to obtain optimal values. After conducting various tests, the following conclusions have been reached.

The modification of the asphalt mixture along with the addition of recycled PVC indicates better results in the tests than the modified mixture with rubber powder, both subjected to the same tests and with the same study variables. It can be evidenced that the best way to incorporate rubber powder and blister-type PVC is by replacing a small portion of the fine aggregate, achieving more optimal values with 1 % rubber powder and 1 % blister-type PVC

Rubber powder and PVC at different percentages respectively produced significant effects on the minimum specifications, both in the mechanical and volumetric properties of the hot mix asphalt design. Incorporate rubber in 1 % incremented the void volume of mixtures in 6.87 % which is over 5 % (maximum recommended value). In the other hand, 1 % of PVC allowed to slightly reduce the volume of voids. Raise the void volume could increase susceptibility to water infiltration and oxidation, accelerating pavement aging and reducing durability of mixture.

The stability in the asphalt mix design with rubber powder and blister-type PVC meets a minimum value for heavy traffic roads, of 2200 lbs, showing a decrease as the percentage of rubber powder increases; conversely, blister-type PVC shows an increase as the percentage increases.

Rubber powder requires a temperature equal to or higher than 175 °C before being incorporated into the conventional mixture, which hinders its workability. (Wang et al., 2020) affirm that temperature for crumb rubber-modified asphalt should not exceed 180 °C, as it ensures effective rubber swelling without significant degradation, enhancing the binder's mechanical properties and stability. In other hand, the AC-20 should not exceed its temperature of 150 °C. This necessitates that the rubber and aggregates be mixed before incorporation. In contrast, PVC can be added before the mixture of aggregates and AC-20 reaches 150 °C.

It is confirmed that blister-type PVC (1 %) proved to be better in the incorporation of the asphalt mixture with particle size from sieve No. 30 (0.60 mm) and added as a replacement for a portion of the fine aggregate. This has better workability when added to the conventional mixture and in the tests presents better values compared to rubber powder (1 %), which was added as a replacement for a portion of the fine aggregate.

The percentages of PVC and rubber powder used in general, and below the minimum specifications for the asphalt mixture design and the preliminary study of this research, indicate that the use of recycled materials presents better resistance to deformation in a flexible pavement.

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