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The Effect of Recycled Material and Buton Granular Asphalt (BGA) on Asphalt Concrete Mixture Performance

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Abstract

Pavement recycling is an appropriate technology for constructing and restoring road pavement structures due to the limited supply and high cost of pavement materials. This study aims to improve the recycled mix's performance by replacing the fine aggregate in the recycled mix for road pavement with Buton Granular Asphalt (BGA). The percentage of recycled material (Reclaimed Asphalt Pavement/RAP) in the mixture was limited to 20% and 30% by weight of the total mixture. BGA was added by 3%, 6%, and 9% in each mixture with the RAP variation. Mixture performance was obtained through Indirect Tensile Strength (ITS) testing. The ITS test results showed that the ITS value of the mixture with RAP and BGA increased by an average of 4.7–15% compared to the mixture without RAP and BGA. The Toughness Index (TI) value increased by 3.5–19.8% with the addition of RAP. With the addition of 3% BGA, the TI value tends to increase and subsequently decrease up to 9% BGA levels. The result indicated that adding 30% RAP and 3% BGA to the mixtures improved pavement performance and could be a solution to increase the elasticity and fracture resistance of the mixture.

Keywords: Reclaimed Asphalt Pavement (RAP); Buton Granular Asphalt (BGA); Asphaltic Concrete Wearing Course (AC-WC); Hot Mix Asphalt (HMA); Indirect Tensile Strength (ITS); Stress; Strain; Toughness.

1. Introduction

Recently, sustainable construction has been an important issue in construction engineering. Environmentally friendly, safe, and efficient road construction has become the hope and concern for the road pavement industries around the world [1, 2]. Sustainable construction has become important due to the increasingly limited availability of resources in construction [3, 4], especially road construction [5]. On the other hand, the need for road materials is increasing every year for the construction and maintenance of roads [6]. One alternative solution that fits the context of sustainable road construction is pavement recycling [7, 8].

The residual scraping/peeling material from the old road pavement, composed of asphalt and aggregate, is used to recycle road pavement; this material is commonly referred to as reclaimed asphalt pavement (RAP) [9]. The utilization of RAP is part of green construction because it reduces the use of aggregate and asphalt and reduces energy use, which contributes to lowering road construction costs [10, 11]. Researchers today aim to maximize the use of RAP to produce a sustainable and highly durable pavement structure. Research on the conservation, reuse, and recycling of building materials is conducted to maximize the mechanical qualities of recycled materials, notably road pavement materials. The quality of this RAP material has undoubtedly declined throughout its service life, as evidenced by changes in gradation [12–15], asphalt aging, and mix fatigue [16]. For this reason, modifications are needed so that it can be reused as a material for constructing new road pavements [17]. Mixtures that use recycled asphalt can be a good alternative for

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road construction, especially if rejuvenating materials are used to reduce production temperatures and improve the performance of the mixture [18]. According to the Asphalt Institute (1993), the use of RAP in hot mix asphalt is around 10%–35% for metered production units, while for drum-type production units, the practical quantity is around 10%–50% [19]. According to Valdes et al., a recycled combination should contain 10% and 50% recycled material, with a 40% RAP mixture within the permissible range. A 60% RAP mixture exceeds the specified restrictions [20]. In hot mix asphalt, the permissible percentage of RAP is below 30% for the wearing course [21].

Recent studies have established that RAP addition in the hot mixture can also provide satisfactory results in mechanical properties [15, 16, 22]. Bethary et al. studied the influence of adding RAP and slag to the AC-Binder Course mixture. The tests occurred with RAP amounts of 10%, 20%, and 30% of the total mixture weight. The study found that Marshall stability values tend to increase with the addition of RAP. The optimum performance of the mixture is seen in the 30% RAP content [16]. Teherkani et al. investigated the impact of adding waste oil as a rejuvenator on certain engineering properties of asphalt concrete containing RAP. The percentages of RAP utilized are 25%, 50%, and 75%, based on the total weight. The ITS value of asphalt mixtures increased as the percentage of RAP increased [23].

On the other hand, Indonesia is one of the world's largest natural asphalt-producing countries. Indonesia has natural asphalt known as Asbuton (Buton natural asphalt) because the location of the Asbuton deposit is on the island of Buton, Southeast Sulawesi. A naturally occurring hydrocarbon substance is asbuton. Bitumen content in asbuton ranges from 10 to 40%; the remaining proportion is mineral [24]. With a capacity of over 600 million tons, the Asbuton deposit is considerable. The Asbuton deposit is thought to contain 24 million barrels of bitumen [25–27]. Apart from the availability of many Asbuton in Indonesia, other advantages of Buton granules include a high asphalt content and a constant moisture content below 2%.

Numerous research results indicate that the use of Buton asphalt (Asbuton) or Buton Granular Asphalt (BGA) as a partial substitution material for oil asphalt, besides being able to utilize Indonesia's natural wealth, is also able to increase the value of stability and can improve the performance of asphalt mixtures [28–30]. Mabui et al. discovered that indirect tensile strength values in asphalt mixtures containing Buton asphalt and plastic waste show an increase in Indirect tensile strength values up to 2% of plastic waste [31]. Mahyuddin et al. obtained the same results that the tensile strength value in the AC-WC mixture showed an increase with the addition of BGA up to 7.5% [32].

There has been enormous research conducted on the mechanical performance of the RAP and BGA mixtures independently. However, neither research combines using both RAP and BGA in hot asphalt mixtures, and the stress-strain concept approach needs to provide an explicit explanation of tensile strength, tensile modulus, and toughness index. Considering the positive outcomes and experiences of using Hot mix Asphalt with RAP or BGA inclusion, this technology could apply to developing nations such as Indonesia. In this regard, the combination of RAP and Indonesian natural asphalt is expected to reduce the use of new materials in the AC-WC hot mix asphalt, contribute to sustainable construction, and provide better mixture performance.

In addition to the previously mentioned aspects, the objective of this research is to figure out the effect of adding recycled material (RAP) and Buton Granular Asphalt (BGA) on the performance of the asphalt concrete wearing course (AC-WC). One indicator of the susceptibility of asphalt mixtures is their tensile strength. As a pavement layer that directly receives traffic loads, it is necessary to know its performance, especially its mechanical strength. The performance of asphalt mixtures that will be studied in this research focuses on the stress-strain relationship, indirect tensile strength (ITS), the tensile modulus of elasticity (Et), and toughness index (TI).

2. Material and Research Method

2.1. Material

The materials used in this study are:

(1) Fresh Aggregate in the form of coarse aggregate, fine aggregate, and dust taken from the Bili-Bili River, Gowa Regency, South Sulawesi Province, Indonesia;

(2) Bitumen with a penetration of 60/70;

(3) Recycled material (RAP) comes from road pavement strips that were damaged by the earthquake in Balaroa Village, Palu City, Central Sulawesi Province, Indonesia;

(4) Asbuton/Buton Granular Asphalt (BGA) type 50/30 comes from Lawele, Southeast Sulawesi Province, Indonesia. The location of RAP and BGA is shown in Figure 1, and the visual description of RAP and BGA materials is shown in Figure 2.

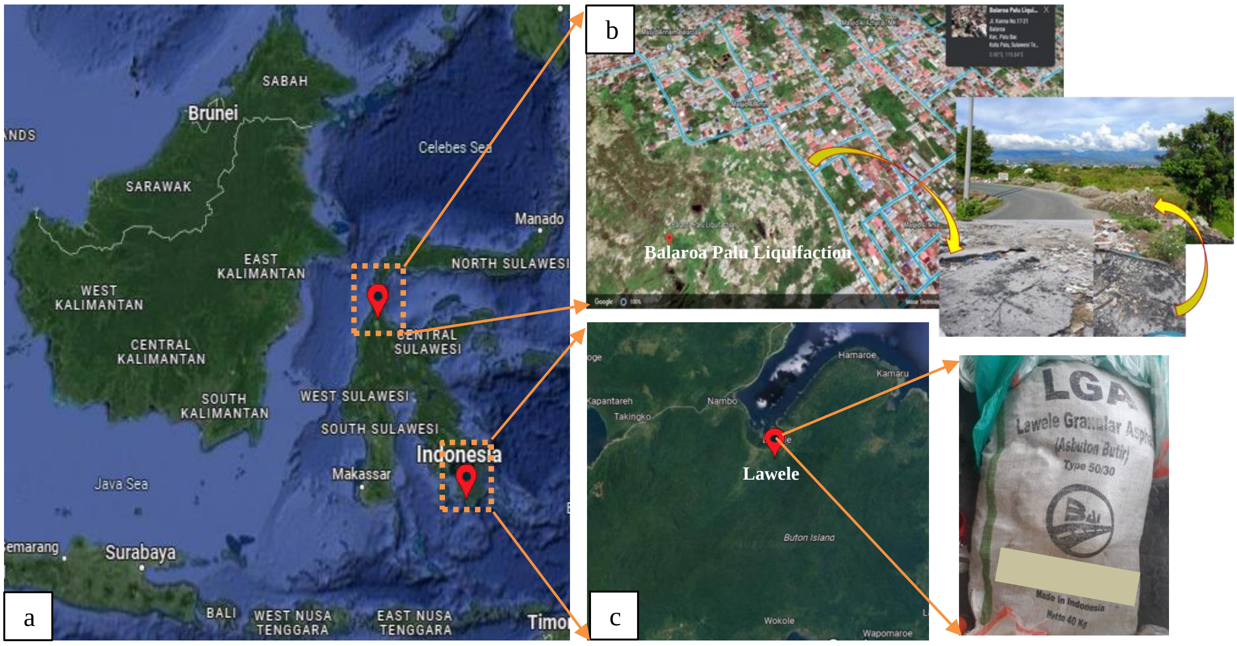

Figure 1. Location area of RAP dan BGA on satellite map (b) RAP material location (c) BGA material location

(a) (b)

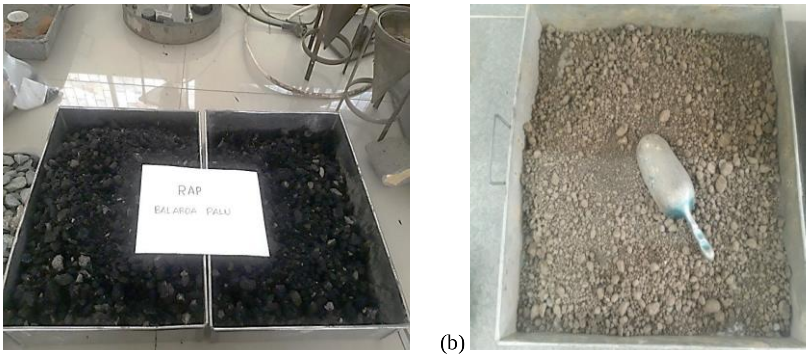

Figure 2. Research material (a) RAP material (b) BGA material

2.2. Research Method

The details of the research method can be seen on the flowchart in Figure 3. It is essential to test the properties of each component of the used material to determine its suitability for the AC-WC mixture. The initial tests carried out were asphalt extraction and recovery based on the ASTM method (Figure 4) on recycled materials (RAP) and Buton granules (BGA) to know the bitumen content of recycled materials and Buton granules [33, 34]. This information will be used in the mixed-design process. Furthermore, separate tests were carried out between bitumen and mineral extraction results to determine the physical properties of each. This material characteristic test was carried out on RAP, BGA, Fresh Aggregate and Fresh Bitumen. Then a mix design was carried out with variations in recycled material content (20% and 30%) based on the calculation results of the approximate bitumen content for each variation in the content of Buton granules used (3%, 6%, and 9%).

(a) (b)

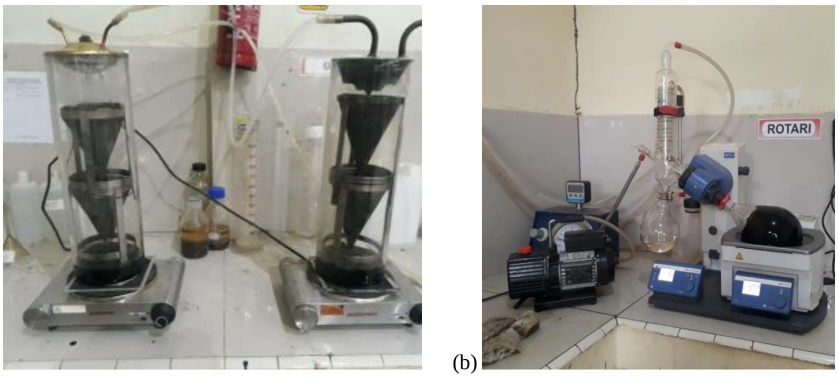

Figure 3. (a) Extraction test (b) Bitumen recovery test

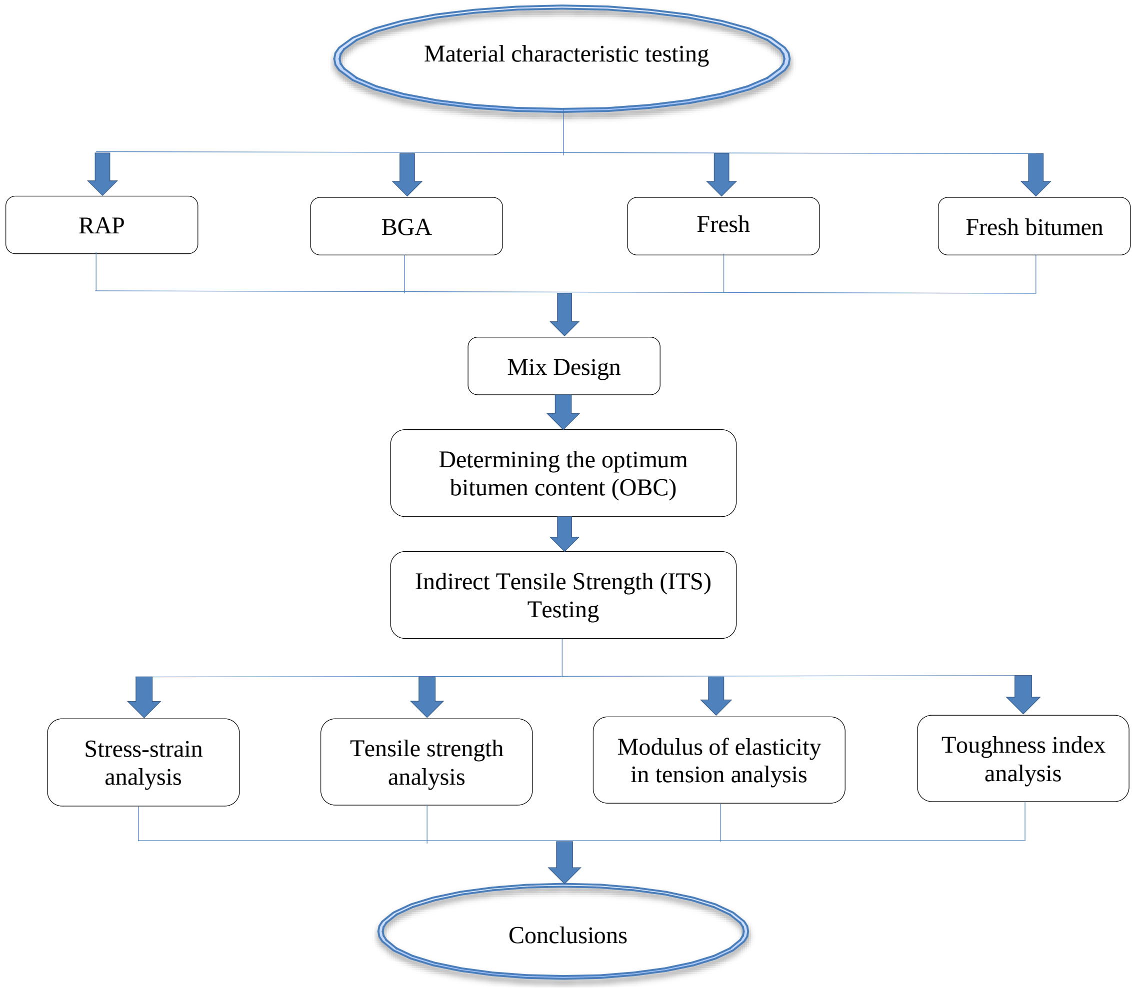

Figure 4. Research methodology

After the mix design process, samples in the form of briquettes were made to obtain the Optimum Bitumen Content for each variation of the mixture (Figure 5). Samples were prepared based on SNI 06-2489-1991 with different bitumen contents based on calculating the effective bitumen content. Samples were made using a binder in the form of bitumen with a percentage of 5%, 5.5%, 6%, 6.5%, and 7% by mass of the mixture to achieve the optimal bitumen content (OBC) value for each RAP percentage and BGA percentage. The test carried out to obtain the optimum bitumen content was the Marshall test based on SNI 06-2489-1991. Then ITS samples were made for each variation of the mix using the optimum bitumen content (OBC) that had been obtained. Furthermore, Figure 6 shows an indirect tensile strength test based on ASTM D 6931-12. The ITS test results were used to analyze the research parameters, which included the stress-strain value, indirect tensile strength, elastic tensile modulus, and toughness index of the mixture. Research parameters were determined to analyze the mechanical performance of the mixture. Stress-strain value and indirect tensile strength are related to mixture elasticity; elastic tensile modulus represents mixture modulus elasticity; and toughness index is related to mixture resistance to cracking and failure.

Figure 5. Samples making process

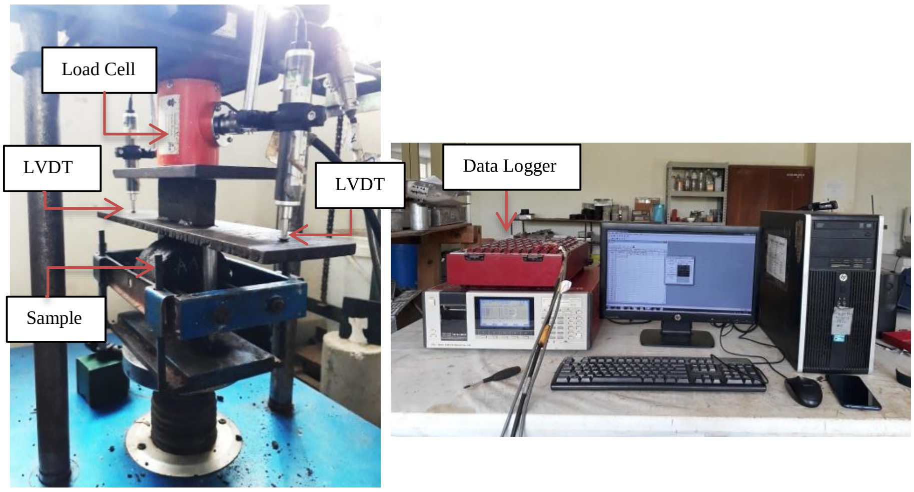

Figure 6. Indirect Tensile Strength (ITS) test

The indirect tensile test was conducted by increasing static force along the sample's diameter at 50 mm per minute. Load cells were utilized to gauge the load placed on the sample. Two linear variable differential transformers (LVDT) positioned vertically on the sample were used to monitor displacement. Computer-connected data loggers continuously monitor and record loads and displacements [35]. Equation 1 is used to determine the tensile strength value, where the ITS value is a function of P, the Vertical load applied (N), d, the Sample diameter (mm), and t, the Sample thickness (mm).

$$\text{ITS} = \frac{2P(1000)}{\pi\, d\, t} \tag{1}$$

The Toughness Index (TI) is a parameter that describes the characteristics of toughness, which, as determined by the stress-strain curve, is the mixture's capacity to absorb energy and deformation without collapsing in the post-ultimate stress region [36]. The ITS test results have been used in numerous studies [36–40] to calculate the toughness index (TI). TI is determined using Equation 2. The strain value calculated is the peak stress that occurs to the strain when the peak stress decreases to 80%. The post-ultimate stress behavior that leads to final failure can be described using TI values. TI represents the amount of stress-strain energy required to cause material failure.

$$\text{TI} = \frac{A\varepsilon - Ap}{\varepsilon - \varepsilon p} \tag{2}$$

where TI is toughness index, Aε is zones up to strain ε under the stress-strain curve, Ap is zones up to strain εp under the stress-strain curve, εp is compatible horizontal strain with the peak stress, and ε is horizontal strain precisely where it ought to be.

No post-ultimate stress load and fragile material are represented if the TI value is 0. In contrast, the TI value for an elastic, perfectly plastic material with no load-carrying capacity loss after peak load is 1. As seen in Figure 7, a typical stress-strain diagram provides the basis for determining TI values.

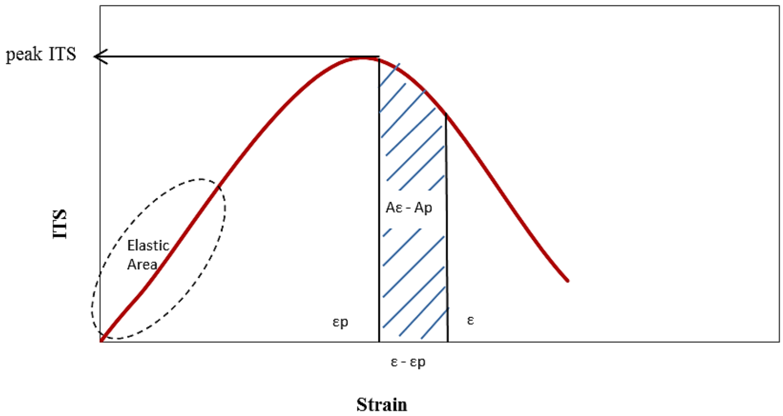

Figure 7. Correlation of ITS and strain values

Figure 7 also shows that the relationship between the indirect tensile strength (ITS) and strain forms a straight line up to 50% of the peak indirect tensile strength, indicating the material's elastic region. From this elastic area, the tensile modulus of elasticity ($E_{tensile}$) value can then be determined, which is the ratio between stress and strain in the elastic curve area [41].

3. Result and Discussion

3.1. Material Characteristics

RAP and BGA extraction results are shown in Figures 8 and 9. Table 1 displays the properties of RAP, BGA, Fresh Aggregate, and Fresh Bitumen. Based on the results of the material characteristics test, fresh aggregate and fresh bitumen appeared to meet all material characteristics criteria based on the Indonesian Ministry of Public Works and Public Housing, Revision Specifications 2 of 2018 [42]. Different things could be seen from the RAP Bitumen penetration value that did not meet the bitumen specifications of 60/70 penetration, so adding to the rejuvenation material was necessary. The rejuvenator used in this research was "*Reclamite*" at 22% of the RAP weight.

Table 1. Results of Material Characteristics Test

Test	Test Method	Requirements		Test Result					
		Min	Max	RAP		BGA		Fresh Aggregate	Fresh Bitumen
				Aggregate	Bitumen	Aggregate	Bitumen		
Bitumen Content (%)	ASTM D2172/ D2172M – 11	--	--	--	5.20%	--	23,04%	--	--
Aggregate Impact Value (%)	SNI 03-1996-1990	--	30%	6,90%			--	--	--
Abrasion (%)	SNI 2417-2008	--	40%	--	--	--	--	24.9	--
Coarse Aggregate									
Bulk Specific Gravity	SNI 03-1969-1990	2.5	--	2.67	--	--	--	2.57	--
Apparent Specific Gravity		2.5	--	2.74	--	--	--	2.68	--
Fine Aggregate									
Bulk Specific Gravity	SNI 03-1970-1990	2.5	--	2.63	--	2.508	--	2.52	--
Apparent Specific Gravity		2.5	--	2.7	--	2.587	--	2.66	--
Filler									
Specific Gravity	SNI 03-1970-1990	2.5	--	2.63	--	--	--	2.7	--
Coarse Aggregate Absorption (%)	SNI 03-1969-1990	--	3	1.03	--	--	--	1.5	--
Fine Aggregate	SNI 03-1970-1990			0.94	--	2.6	--	2.2	--
Penetration, 25°C (0.1 mm)	SNI 06-2456-1991	60	79	--	12.6	--	56.3	--	66.5
Softening Point, °C	SNI 06-2434-1991	48	--	--	72	--	53	--	49
Bitumen Specific Gravity	SNI 06-2441-1991	1	--	--	1.07	--	1.08	--	1.03

Figure 8. RAP before and after extraction

Figure 9. BGA before and after extraction

3.2. Mix Design

RAP material can be reused in a mixture of road pavement after going through the stages of improvement of its physical properties, considering that RAP material has experienced a decrease in performance from the previous due to the load received during the service period. Improvements have been made on RAP aggregates was gradation improvement by adding new aggregates so that the mixed gradation can meet the required AC-WC gradation range. In this research, two compositions between new aggregates and RAP aggregates were used, namely composition A (20% RAP + 80% new aggregate material) and composition B (30% RAP + 70% new aggregate material), and one composition without RAP material, namely composition C (new aggregate and BGA). In each composition (A, B, and C), the addition of BGA material was 0%, 3%, 6%, and 9%. The same gradation was used for the three compositions, as shown in Figure 10.

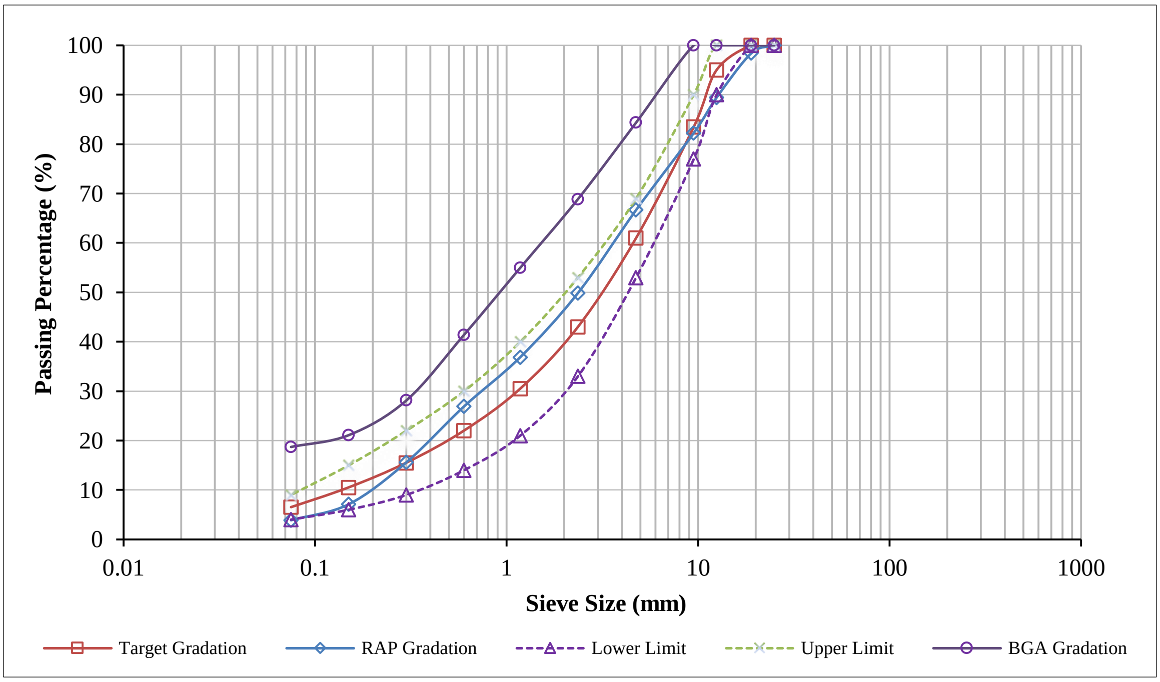

Figure 10. Mixture gradation

3.3. Stress-Strain

Indirect tensile strength testing (ITS) generates the asphalt mixture's stress and strain values. ITS testing was performed on three samples at each variation in the percentage of BGA. The correlation between stress and strain in the optimum binder content conditions is shown in Figures 11 to 13.

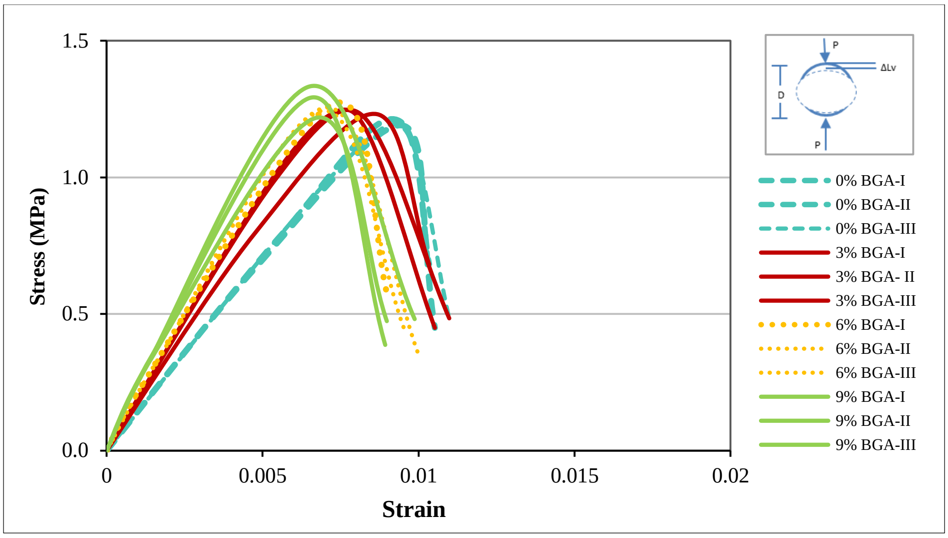

Figure 11. Comparison of the stress - strain in the mixture without RAP material

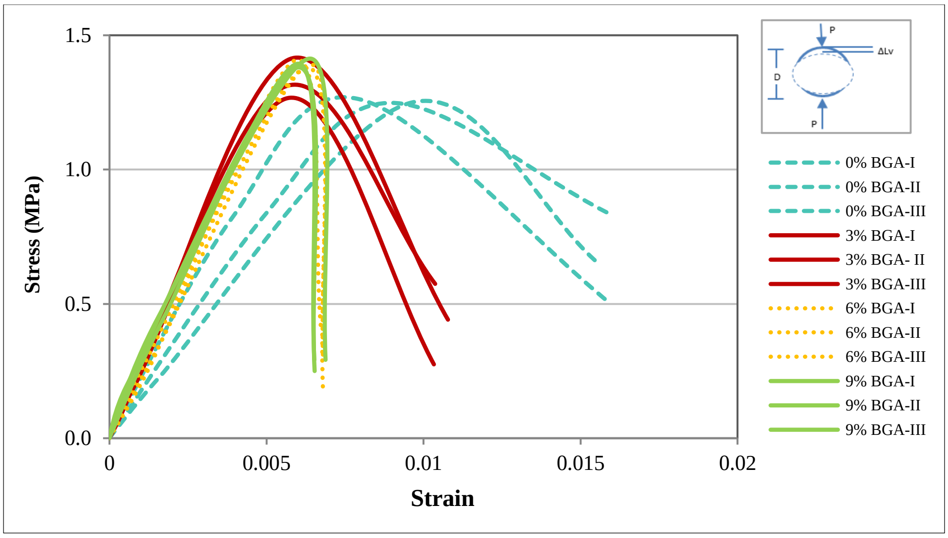

Figure 12. Comparison of the stress - strain in the mixture with 20% RAP material

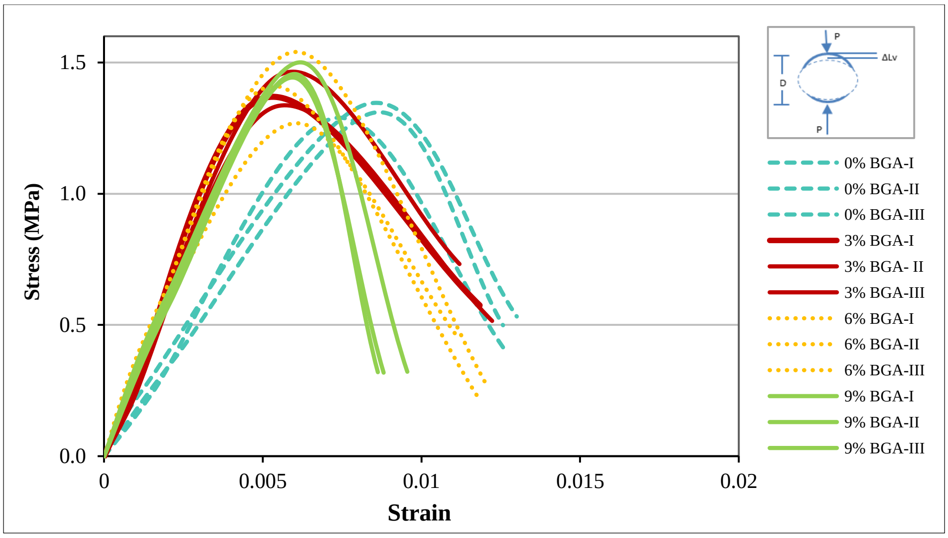

Figure 13. Comparison of the stress - strain in the mixture with 30% RAP material

Figure 11 represents the stress-strain relationship in the mixture without RAP. In Figure 11, the higher the percentage of BGA, the more stress that occurred would also tend to increase; a steeper curve indicated this compared to the mixture without BGA. According to the results in Figure 11, the percentage of 9% BGA generated the highest stress value compared to other mixtures. The increase in the stress value of the mixture containing BGA of 3%, 6%, and 9% found a straight line up to 3.2%, 5.3%, and 7.5%, respectively, compared to the stress in the conventional mixture. This phenomenon was due to the high BGA content, which would contribute to increasing the mixture stiffness because of the increasing number of fine materials in the mixture. As a result, the mixture's capability improved in receiving the load given, which was correlated with the minor strain that occurred.

The same phenomenon was also seen in the mixture with 20% RAP (Figure 12) and 30% RAP (Figure 13). The higher the percentage of BGA and RAP, the more stress that occurs, which also tends to increase. In addition, it was also seen that the lowest stress and the most prominent strain were given by a mixture without BGA, indicated by a gentler curve than a mixture with BGA. Compared to other mixtures, the percentage of 9% BGA results in the highest stress value, as shown in Figure 12. The increase in stress value of the 20% RAP mixture with the addition of 3%, 6%, and 9% BGA was 6.1%, 11.2%, and 11.3%, respectively, compared to the stress in the mixture without BGA. Figure 13 shows the same result for a mixture containing 30% RAP, and it is clear that adding BGA increased the stress value from 5.4% to 11.4% compared to the mixture without BGA. It occurred because the high BGA and RAP content affected the increasing amount of fine material in the mixture and increased the stiffness. As a result, the strain was minor, increasing the mixture's ability to receive the given load. The results obtained are in agreement with other studies outcomes [23, 32].

3.4. Indirect Tensile Strength (ITS)

The value of indirect tensile strength (ITS) at the optimum bitumen content with variations of RAP and BGA material is shown in Table 2 and Figure 14. Indirect tensile strength was obtained at the maximum stress and strain that occurred during the maximum stress from the indirect tensile strength test, then calculated based on Equation 1.

Table 2. Mixture performance based on indirect tensile test result

RAP	BGA	ITS (MPa)	$\varepsilon_{Ultimate}$ mm/mm	$\varepsilon_{Fracture}$ mm/mm	$E_{tensile}$ (MPa)	Toughness Index
0%	0%	0.938	0.0101	0.0103	931	0.5522
	3%	0.968	0.0083	0.0091	1173	0.7049
	6%	0.988	0.0071	0.0078	1396	0.7046
	9%	1.008	0.0066	0.0074	1521	0.5368
20%	0%	0.982	0.0088	0.0121	1121	0.6613
	3%	1.043	0.0057	0.0072	1818	0.7693
	6%	1.086	0.0062	0.0064	1744	0.7296
	9%	1.102	0.0062	0.0063	1789	0.6158
30%	0%	1.051	0.0081	0.0095	1306	0.6736
	3%	1.106	0.0054	0.0076	2068	0.8238
	6%	1.111	0.0060	0.0075	1864	0.7593
	9%	1.159	0.0061	0.0069	1888	0.6889

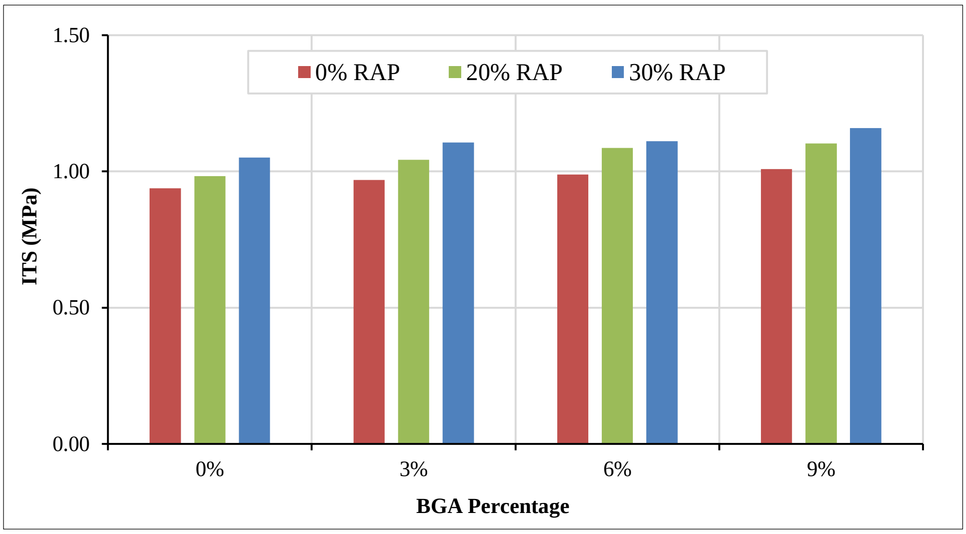

Figure 14. Comparison of indirect tensile strength (ITS) to the percentage of BGA

According to Figure 14 and Table 2, ITS generally increased with the addition of BGA and RAP materials. The increase in the ITS compared to the mixture without BGA was 2.5% for the AC-WC conventional mixture, 4.1% for the AC-WC mixture containing 20% RAP, and 3.4% for the mixture containing 30% RAP. Based on these results, the AC-WC mixture of 20% RAP gave the highest percentage of ITS increases of 4.1%.

However, the highest ITS was produced in a mixture with 30% RAP, which was 12%–15% greater than the mixture without RAP, while the 20% RAP mixture was only 4.7%–9.9% greater than the mixture without RAP. It happened because the mixture containing RAP produced a mixture that had high interlocking. After all, the void in the RAP aggregate mineral had been filled by RAP bitumen, which had a low penetration value and produced more stable aggregate granules with increased indirect tensile strength. In addition, the high proportion of BGA contributes to a stiffer mixture due to the abundance of fine minerals in the mixture. Similar to previous research, the addition of RAP to hot asphalt mixtures will improve the properties and performance of the mixture [23, 43]. Mahyuddin et al. discovered that using asbuton in the porous asphalt mixture increases ITS [32]. However, these previous studies only used RAP and BGA in separate mixtures, not in one mixture.

The condition after the indirect tensile strength test, as seen in Figure 15, illustrates the crack and failure pattern of the samples. The crack mechanism in all samples is the same, namely in the vertical direction of the sample's loading. Cracks occur primarily between the aggregate and the asphalt, with only a few cracks within the aggregate. It is influenced by the bitumen's adhesion and cohesion properties. The physical properties of RAP and BGA bitumen are very influential in the pattern of cracks that occur in mixtures with RAP and BGA. Figure 16 shows that the crack patterns in each sample are nearly identical. The failure pattern will be even more pronounced with the addition of RAP. RAP bitumen with low penetration means it has lost the maltene element in the bitumen. So that if the RAP bitumen fills the voids in the mineral aggregate, it will produce solid aggregate. However, RAP bitumen, which has lost its maltene element, will not cover the aggregate properly because its adhesion has decreased. The values of ITS and stress, which increase with the addition of RAP, further confirm this, indicating a stiffer mixture.

Due to the high content of fine minerals in BGA, which can potentially increase the mix's stiffness, adding BGA to recycled mixes typically yields the same results. It affects the mixture's flexibility when subjected to loads, which is reflected in the crack pattern that develops.

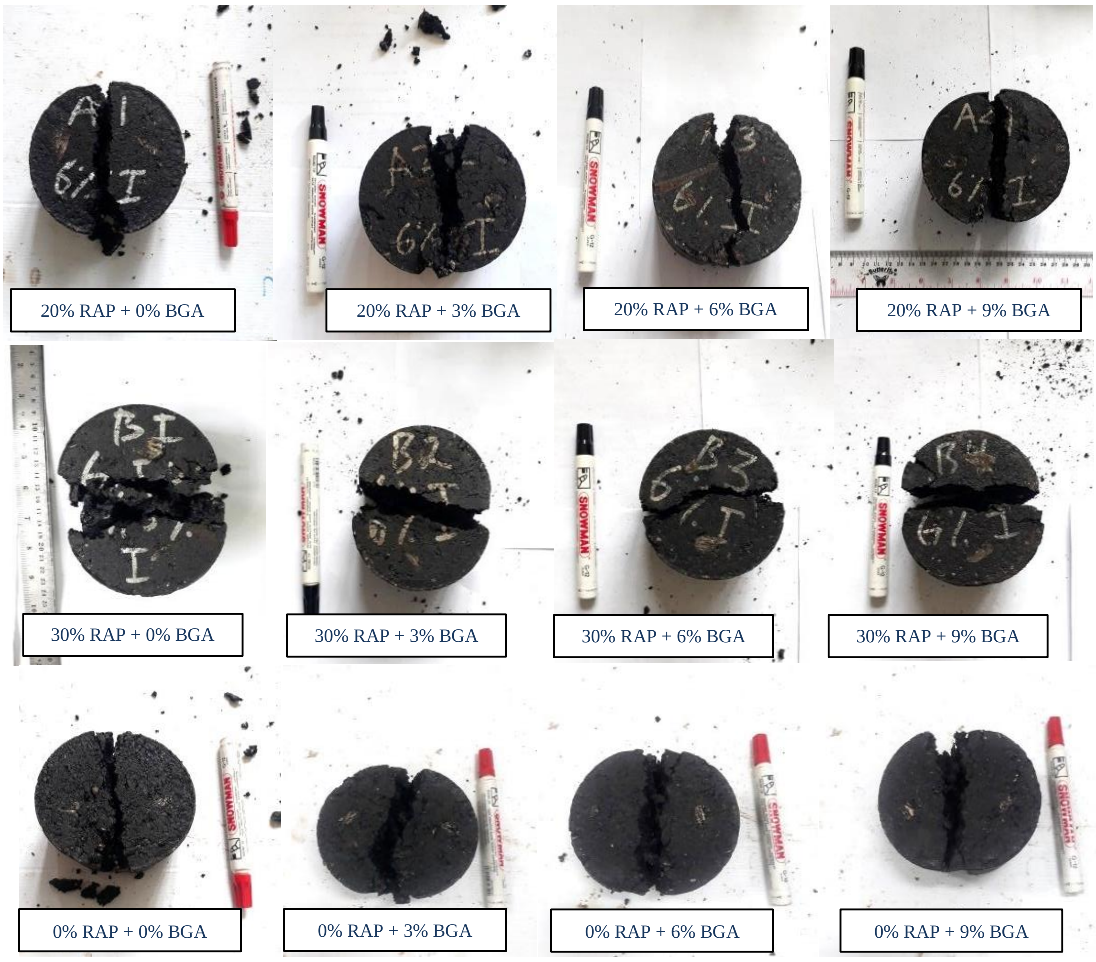

Figure 15. Sample condition after indirect tensile strength test

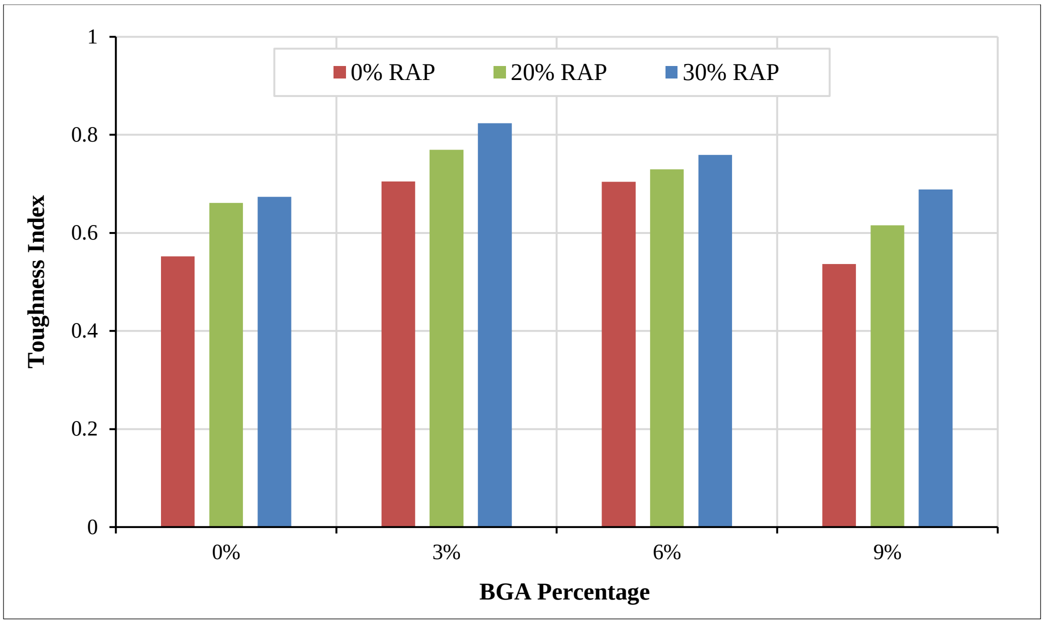

Figure 16. Comparison of the toughness index (TI) value to the percentage of BGA

3.5. Tensile Modulus ($E_{tensile}$)

The tensile modulus ($E_{tensile}$) illustrates the stiffness level of the mixture, which is a function of the optimum tensile stress and strain that occur at the elastic region of the stress-strain curve, as seen in Figure 7. Based on Figure 17, the tensile modulus increases by adding the percentage of BGA to 3% BGA, and then the $E_{tensile}$ tends to decrease. The $E_{tensile}$ value in the mixture with 20% RAP was 17.6%–55.2% greater than the mixture without RAP. While the 30% RAP mixture had an $E_{tensile}$ of 24.1% to 76.3% greater than the mixture without RAP.

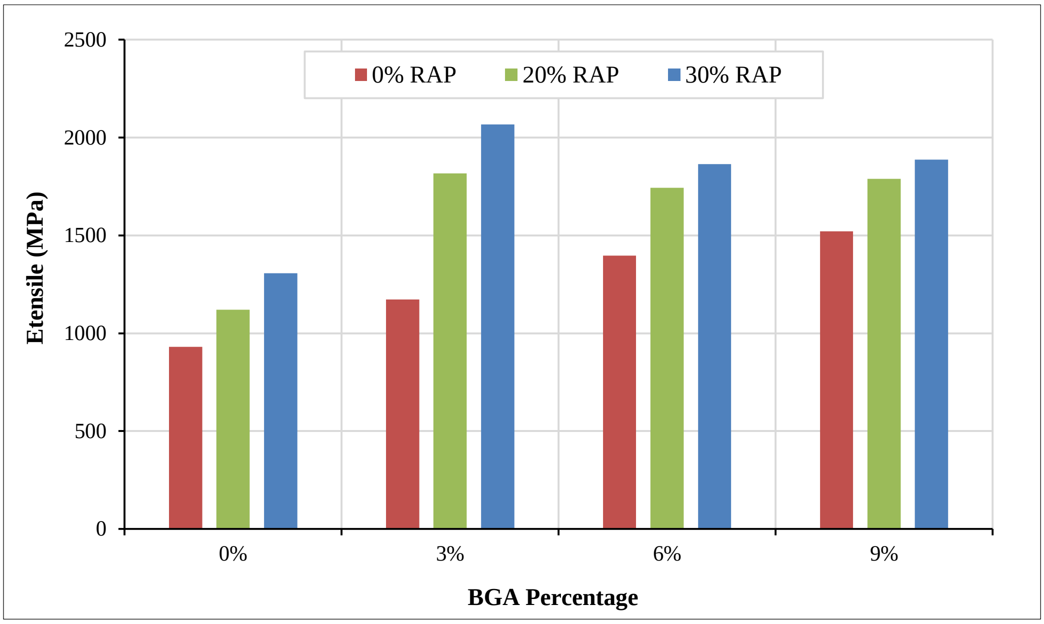

Figure 17. Comparison of tensile modulus elasticity ($E_{tensile}$) to the percentage of BGA

The mixture of 30% RAP with 3% BGA appeared to have a greater $E_{tensile}$ than other mixtures, namely 2068 MPa. This phenomenon occurred because the mixture had a smaller strain value than other variations, as seen in Table 2. The small value of the strain was caused by the addition of BGA up to 3%, which had been able to fill the void in the mixture and produce high interlocking and bonding strength to produce a mixture that tends to have high elasticity. The high elasticity value reduces the potential for deformation. Conversely, adding more than 3% BGA caused no more voids in the mixture to accommodate the addition of BGA, so the bond between grains weakens and reduces the value of mixture elasticity.

3.6. Toughness Index (TI)

The Toughness index (TI) in Figure 16 illustrates the capacity of the residual bond to sustain the tensile force until the collapse in the tensile stress after the peak. The TI value was calculated using equation (2), where the TI of the mixture with the RAP addition tends to be greater than the conventional mixture. The TI values of 20% RAP mixtures with 3%, 6%, and 9% BGA were found to be 19.1%, 3.5%, and 19.8% higher than the TI values of the conventional mixture, respectively. In the 30% RAP mixtures, adding 3%, 6%, and 9% BGA increased by 16.9%, 7.7%, and 28.4%, greater than the mixture without RAP and BGA, respectively.

The findings showed that the strength of the mixture containing RAP provided better resistance to the collapse than the mixture without RAP under tensile stress after the peak. This characteristic could be associated with aging, increased stiffness, and an increased asphaltene element in bitumen RAP. In connection with the percentage of BGA, the TI value tends to increase up to 3% BGA levels and subsequently decrease up to 9% BGA levels. This tendency was similar to the Tensile Modulus Elasticity ($E_{tensile}$) trend. These results show that the mixture with 30% RAP +3% BGA demonstrates the highest elasticity, while the conventional mixture shows the lowest. It showed that adding 3% BGA could increase the mixture's fracture resistance. A significant mechanical performance enhancement occurred in the mixture containing 30% RAP + 3% BGA. Therefore, it is the suggested amount to be used.

4. Conclusion

The result of this study proves that the inclusion of reclaimed asphalt pavement (RAP) and Buton granular asphalt (BGA) has a satisfactory effect on improving the mechanical performance of the asphaltic concrete wearing course (AC-WC) mixture. Adding RAP and BGA to the AC-WC mixture has increased ITS, $E_{tensile}$ and TI values compared to the conventional mixture. The ITS value of the recycled AC-WC mixture increased by 4.7%–15% compared to the conventional mixture. At the same time, the $E_{tensile}$ and TI values increased by 17.6%–76.3% and 3.5%–28.4%, greater than the conventional mixture. The increase in mechanical performance is likely due to the high interlocking and bonding strength from adding RAP and BGA. The relatively high content of fine minerals in BGA and solid minerals in RAP contributes to producing a high-stiffness mixture. As a result, the recycled AC-WC mixture becomes stiffer but retains adequate ductile properties. As a consequence of this, the mixture is capable of resisting loads without showing significant cracking.

Based on the elastic area and stiffness aspects, the research results showed that RAP and BGA could synergize well in a percentage of 30% RAP and 3% BGA to increase the elasticity of the mixture. This proportion provides optimal performance in the AC-WC mixture with an $E_{tensile}$ value of 2068 MPa and a TI value of 0.8238. As an outcome, RAP and BGA materials positively contribute to the performance of asphaltic concrete wearing course mixes and encourage sustainable construction.

5. Declarations

5.1. Author Contributions

Conceptualization, N.P. and M.W.T.; methodology, R.I. and I.R.R.; software, N.P.; validation, R.I., M.W.T., and I.R.R.; formal analysis, N.P.; investigation, N.P.; resources, N.P.; data curation, N.P.; writing—original draft preparation, N.P.; writing—review and editing, N.P.; visualization, N.P.; supervision, R.I., M.W.T., and I.R.R.; project administration, N.P.; funding acquisition, N.P. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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