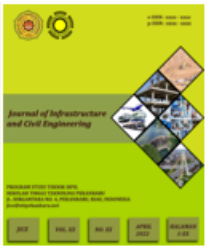
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Marshall Characteristics and Durability Values of AC-WC Asphalt Concrete Mixture with Blood Cockle Shell Waste as Filler Substitution

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Abstract

The utilization of blood cockle shell (Anadara granosa) waste from Dumai, Riau, as a substitute for stone dust filler in Asphalt Concrete Wearing Course (AC-WC) mixtures aims to reduce environmental waste and improve pavement performance. This study analyzes the effect of cockle shell powder content on Marshall characteristics and durability, evaluated against the General Specification of Bina Marga 2018 Revision II. Marshall specimens were prepared at an optimum asphalt content (OAC) of 5.39% with substitution levels of 0% and 12-20% of the filler weight (three specimens per variation). Parameters analyzed included stability, flow, density, VMA, VIM, VFWA, Marshall quotient (MQ), and durability expressed as the retained strength index (RSI). The highest stability, 5,819.47 kg, was obtained at 17%, but its flow (7.10 mm) exceeded the 2-4 mm limit. Considering the balance of Marshall parameters and durability, 14% showed the most balanced performance, with a stability of 5,018.25 kg, a flow of 3.10 mm, an MQ of 656.55 kg/mm, and the highest RSI of 124.01%, although its VIM (1.02%) and VMA (14.20%) fell outside the specification. All variations produced RSI values above 90%. These results indicate that blood cockle shell waste is a potentially viable eco-friendly filler for AC-WC mixtures.

Keywords: *Blood cockle shell, Durability, Marshall test, Substitution*

1. Introduction

Roads are land transportation infrastructure that play a strategic role in supporting community mobility, goods distribution, and regional economic growth. One of the pavement types commonly applied in inter-city and inter-provincial road projects is flexible pavement with asphalt concrete layers, particularly Asphalt Concrete Wearing Course (AC-WC). This layer serves as the road surface while protecting the underlying structure from vehicle loads and environmental conditions.

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In the composition of AC-WC mixtures, one of the essential constituent materials is filler. Filler fills the voids between aggregate particles, increases mixture strength, and improves pavement characteristics. Conventional fillers commonly used include stone dust and lime. However, the increasingly limited availability of natural materials necessitates the exploration of more sustainable alternatives.

Blood cockle shells are waste generated in large quantities from the seafood processing industry, particularly in coastal areas such as Dumai, Riau. This waste is generally not optimally utilized and causes negative environmental impacts. Research by Farida and Rachmadiba [1] showed that cockle shells contain up to 66.70% CaO compounds, which are chemically active and potentially improve asphalt mixture performance. The high calcium carbonate ($CaCO_3$) content makes cockle shells chemically similar to limestone, making them potentially usable as alternative filler. Previous studies have also examined cockle shell powder or ash as a filler or filler substitute in asphalt mixtures, both in AC-WC [2][3][4] and in AC-BC [5]. Other waste materials, such as fly ash and rubber waste, have likewise been explored in AC-WC mixtures [6].

This study aims to analyze the Marshall characteristics and durability values of AC-WC asphalt concrete mixtures with blood cockle shell waste filler substitution at levels of 0% to 20%, to determine the optimum content that meets the requirements of the General Specification of Bina Marga 2018 Revision II [7].

2. Literature Review

2.1. Flexible Pavement and AC-WC Mixture

Flexible pavement uses asphalt as a binding material that provides flexible characteristics and the ability to gradually distribute traffic loads to the underlying layers. Asphalt Concrete Wearing Course (AC-WC) is a surface layer composed of a mixture of coarse aggregate, fine aggregate, filler, and bitumen asphalt with specific gradation specifications. The quality of the AC-WC mixture is greatly influenced by the characteristics of its constituent materials, especially the filler, which plays a role in filling voids and improving the bonding between components.

2.2. Blood Cockle Shell as Alternative Material

Blood cockle shells (Anadara granosa) are biological waste containing calcium minerals in the form of $CaCO_3$ and CaO in high proportions. According to [1], the CaO content in cockle shell ash is quite dominant, making it a potential adsorbent as well as void filler in asphalt mixtures. The chemically active calcium content can strengthen the bond between asphalt and aggregate, slow down the aging process of asphalt, and increase the resistance of the mixture to permanent deformation (rutting) and moisture damage.

2.3. Filler and Blood Cockle Shell

Filler is a fine-grained material passing through sieve No. 200 (0.075 mm). Based on the Bina Marga 2018 Revision II Specification [7], filling materials must be dry, free of lumps, and contain material passing sieve No. 200 of not less than 75% by weight. Blood cockle shells contain $CaCO_3$ that is chemically similar to limestone, with a calcium (Ca) content reaching 99.228% based on XRF testing. The high CaO content acts as a stiffening agent that increases the stiffness and adhesion of the mixture [4].

2.4. Marshall Test Parameters

The Marshall test is a standard method for evaluating the performance of hot mix asphalt [9]. Parameters analyzed include:

a. Stability – the ability of the mixture to withstand loads without permanent deformation;
b. Flow – an indicator of mixture flexibility;
c. VIM (Void in Mix) – the percentage of air voids in the mixture;
d. VMA (Void in Mineral Aggregate) – voids between aggregate particles;
e. VFWA (Void Filled with Asphalt) – voids filled with asphalt;
f. Marshall Quotient (MQ) – the ratio of stability to flow as a measure of mixture stiffness.

2.5. Asphalt Mixture Durability

Durability refers to the resistance of the pavement layer to weather, water, and repeated traffic loads. The parameter used in this study is the Retained Strength Index (RSI), which is the ratio of stability after 24-hour immersion to stability after 30-minute immersion at 60°C, expressed as a percentage. Based on the General Specification of Bina Marga 2018 Revision II [7], the minimum required RSI value for AC-WC mixtures is 90%.

3. Research Methodology

This study used a quantitative method with an experimental approach, where data are presented in numerical form describing the values of variables tested in the laboratory, then analyzed and compared against the General Specification of Bina Marga 2018 Revision II [7].

The aggregate was supplied by PT Riau Mas Bersaudara and the Pen 60/70 asphalt by PT Lutvindo Wijaya Perkasa. Blood cockle shell waste was collected directly from the coastal area of Dumai, Riau, and all tests were carried out at the Highway Laboratory, Universitas Lancang Kuning, Pekanbaru. The combined aggregate gradation of the AC-WC mixture, based on a total aggregate weight of 1,200 g, is presented in Table 1 and lies within the gradation limits of the General Specification of Bina Marga 2018 Revision II [7].

Table 1. Combined Aggregate Gradation of the AC-WC Mixture

Sieve size (mm)	ASTM	Specification (% passing)	Target (% passing)	Retained (%)	Weight (g)
19	3/4"	100	100.00	-	-
12.5	1/2"	90-95	95.00	5.00	60.00
9.5	3/8"	77-83	83.50	11.50	138.00
4.75	No. 4	53-61	61.00	22.50	270.00
2.36	No. 8	33-53	43.00	18.00	216.00
1.18	No. 16	21-40	30.50	12.50	150.00
0.6	No. 30	14-30	22.00	8.50	102.00

Sieve size (mm)	ASTM	Specification (% passing)	Target (% passing)	Retained (%)	Weight (g)
0.3	No. 50	9-22	15.50	6.50	78.00
0.15	No. 100	6-15	10.50	5.00	60.00
0.075	No. 200	4-9	6.50	4.00	48.00
<0.075	Pan	-	-	6.50	78.00
Total				**100.00**	**1,200.00**

Cockle shells were processed through stages of cleaning, drying, crushing using a hammer mill, and sieving with sieve No. 200 (0.075 mm).

The Optimum Asphalt Content (OAC) was first estimated using the formula Pb = 0.035(CA) + 0.045(FA) + 0.18(FF) + K, where Pb is the asphalt content (% by weight of total mixture); CA, FA, and FF are the percentages of the coarse aggregate, fine aggregate, and filler fractions relative to the total aggregate weight; and K is a constant (1 for asphalt concrete). These fractions were obtained from the combined gradation in Table 1: CA (aggregate retained on sieves 1/2" to No. 4) = 468 g/1,200 g = 39.00%, FA (retained on sieves No. 8 to No. 200) = 654 g/1,200 g = 54.50%, and FF (passing sieve No. 200) = 78 g/1,200 g = 6.50%. Thus, Pb = 0.035(39.00) + 0.045(54.50) + 0.18(6.50) + 1 = 5.99%, rounded to a theoretical OAC of 6.0%.

To determine the laboratory OAC, Marshall specimens were prepared at five asphalt contents around the theoretical value, namely Pb-1, Pb-0.5, Pb, Pb+0.5, and Pb+1 (5.0%, 5.5%, 6.0%, 6.5%, and 7.0%), with three specimens for each content (15 specimens in total). The Marshall parameters (VIM, VMA, VFWA, stability, flow, and MQ) were plotted against asphalt content, and the OAC was taken as the midpoint of the asphalt content range that satisfied all specification limits, which yielded a laboratory OAC of 5.39%.

A total of 60 specimens were prepared (30 for 30-minute immersion and 30 for 24-hour immersion) with cockle shell filler content variations of 0%, 12%, 13%, 14%, 15%, 16%, 17%, 18%, 19%, and 20% of the total filler weight of 78 grams. Compaction temperature was maintained at 135°C for all variations. Durability testing was performed by calculating the IKS using the formula IKS = $(S_2/S_1) \times 100\%$.

4. Results and Discussuion

4.1. Material Testing Results

The test results for all materials are presented in Table 1. All materials meet the Bina Marga 2018 Revision II Specification [7]. XRF testing of blood cockle shells confirmed the dominance of $CaCO_3$/CaO compounds with a Ca content of 99.228%.

Table 2. Material Testing Results

Parameter Uji	Hasil	Spesifikasi
Specific Gravity of Coarse Aggregate	2,92	≥ 2,50
Los Angeles Abrasion (%)	21%	Max. 40%

Specific Gravity of Fine Aggregate	2,56	≥ 2,50
Sand Equivalent (%)	94,11%	Min. 50%
Specific Gravity of Asphalt	1,003	0,95–1,05
Asphalt Softening Point (°C)	55,5°C	48–58°C
Asphalt Penetration (0.1 mm)	64,3	60–70
Ca Content – XRF (%)	99,228%	–

4.2. Marshall Characteristics

A summary of Marshall test results for all variations is presented in Table 2. All variations produced stability values well above the minimum threshold of 800 kg.

Table 3. Summary of Marshall Test Results

Content (%)	Density (g/cc)	Stability (kg)	Flow (mm)	VIM (%)	VMA (%)	VFWA (%)	MQ (kg/mm)	IKS (%)
0	2,42	3.278,99	3,70	3,15	15,96	80,24	790,85	90,27
12	2,41	3.731,96	3,54	3,17	15,98	84,48	834,27	90,91
13	2,36	4.550,48	3,49	3,60	17,07	82,26	942,28	113,36
14	2,45	5.018,25	3,10	1,02	14,02	92,08	656,55	124,01
15	2,45	4.384,82	4,70*	0,87	13,98	91,86	707,50	98,23
16	2,46	4.996,04	4,30*	0,39	13,40	97,94	797,76	91,41
17	2,41	5.819,47	7,10*	3,51	15,62	88,24	810,62	97,15
18	2,38	4.659,12	3,98	3,19	15,97	79,58	1.289,86	95,03
19	2,38	5.188,80	3,23	3,73	15,61	77,32	1.171,17	95,70
20	2,35	4.280,66	3,00	3,88	16,74	70,37	970,67	91,02
Spec.	**>2,0**	**≥800**	**2–4**	**3–5**	**≥15**	**≥65**	**≥250**	**≥90**

4.2.1 Density

Figure 1 shows the relationship between blood cockle shell filler content and mixture density. Density increased with increasing filler content, reaching a maximum of 2.46 g/cc at 16%. The very fine $CaCO_3$ particles passing sieve No. 200 effectively filled the voids between aggregates, resulting in a denser and more compact mixture. All density values were above the minimum specification threshold of 2.0 g/cc.

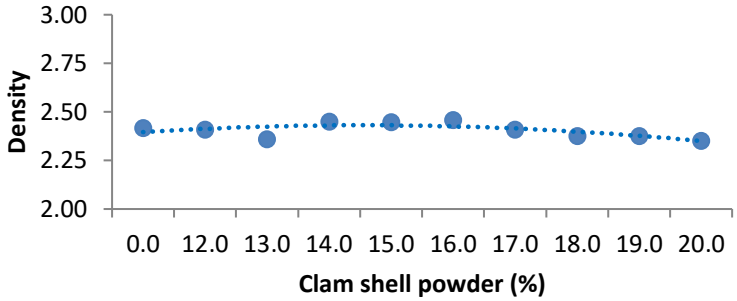


Figure 1. Relationship between Clam Shell Powder Content and Value Density

4.2.2 VFWA (Void Filled with Asphalt)

Figure 2 shows that VFWA values increased from 12% to a maximum of 97.94% at 16%, then decreased at 17%–20%. All VFWA values were above the minimum specification of 65%. The very fine cockle shell powder particles reduced the empty space in the mixture and facilitated asphalt filling of available voids. However, excessively high VFWA values (>95%) indicate a risk of bleeding at high temperatures [10].

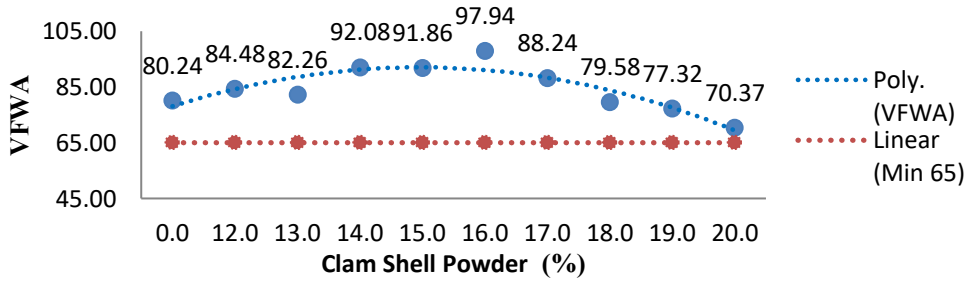


Figure 2. Relationship between Clam Shell Powder Content and Value VFWA

4.2.3. VITM (Void In The Mix)

Figure 3 shows that VITM values decreased from 12% to a minimum of 0.39% at 16%, then increased again at 17%–20%. At 0%–13%, VITM values were within the specification range of 3%–5%. The drastic decrease at 14%–16% indicates that air voids were almost entirely filled by a combination of asphalt and cockle shell powder particles. Very low VIM content may cause plastic fatigue and mixture instability under heavy load conditions.

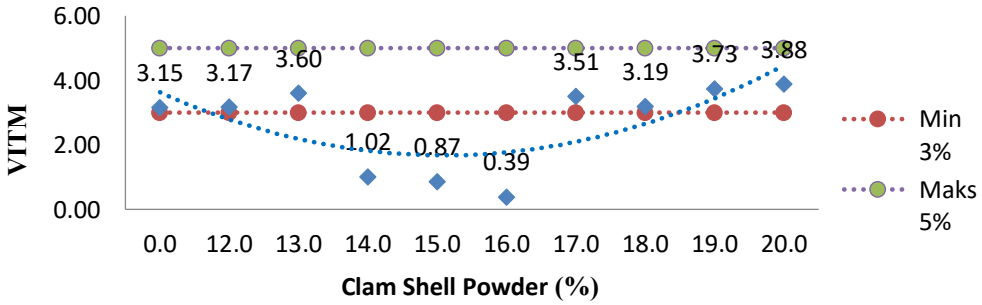


Figure 3. Relationship between Clam Shell Powder Content and Value VITM

4.2.4 VMA (Void Mineral Aggregate)

Figure 4 shows that VMA values decreased at 14%–16%, with a minimum of 13.40% at 16%, below the minimum specification of 15%. This decrease was caused by the very fine $CaCO_3$ filler particles filling almost all voids between aggregates, drastically reducing the volume of voids in the mineral aggregate. At 17%–20%, VMA values recovered and met the specification as filler particle distribution shifted.

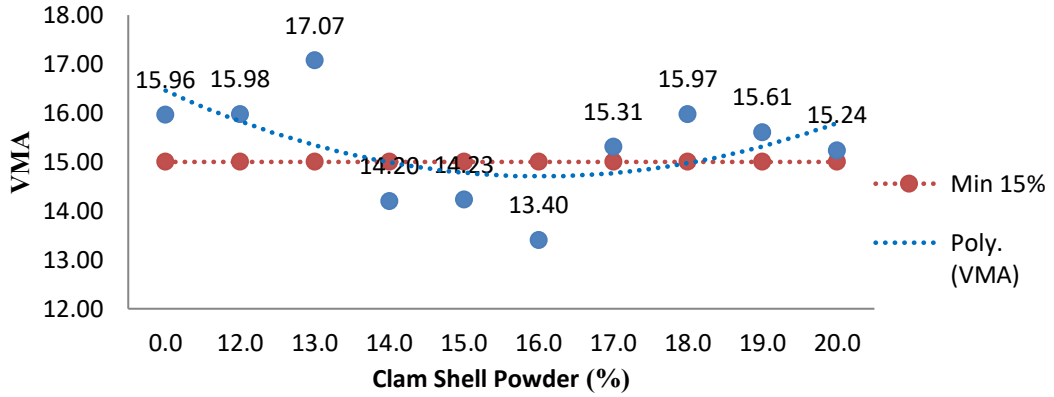


Figure 4. Relationship between Clam Shell Powder Content and Value VMA

4.2.5 Stability

Figure 5 shows that stability values for all variations far exceeded the minimum threshold of 800 kg. Stability increased from 0% (3,278.99 kg) to a maximum at 17% (5,819.47 kg). The high $CaCO_3$ content in blood cockle shells improved the bonding between asphalt and aggregate, making the mixture more resistant to permanent deformation. Although the highest stability was at 17%, the flow value at that content exceeded the specification limit (7.10 mm). Based on the balance of parameters, the 14%–16% range provided optimum stability of 4,384.82–5,018.25 kg.

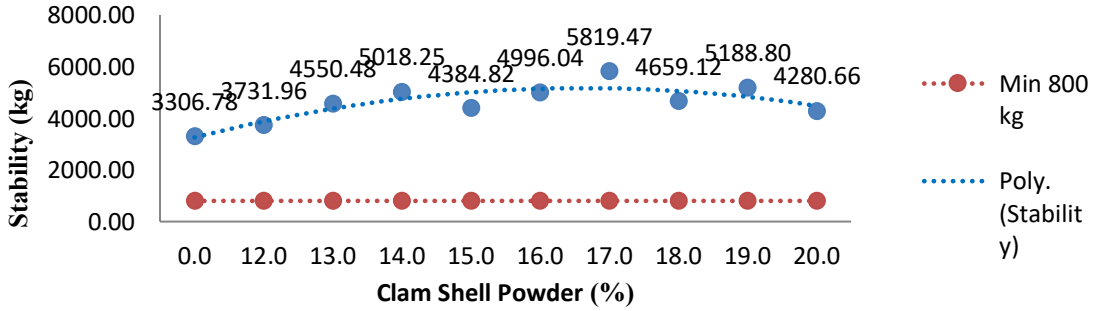


Figure 5. Relationship between Clam Shell Powder Content and Value Stabilitas

4.2.6 Flow

Figure 6 shows that flow values changed inconsistently with increasing cockle shell powder content. At 12%–14%, flow decreased to 3.54 mm, 3.49 mm, and 3.10 mm, all within the specification of 2–4 mm, indicating a sufficiently flexible mixture. At 15% and 16%, flow values of 4.70 mm and 4.30 mm exceeded the maximum

specification limit. A significant jump occurred at 17% (7.10 mm), indicating that excess $CaCO_3$ filler caused the mixture to become too plastic. At 18%–20%, flow values returned to near-specification ranges.

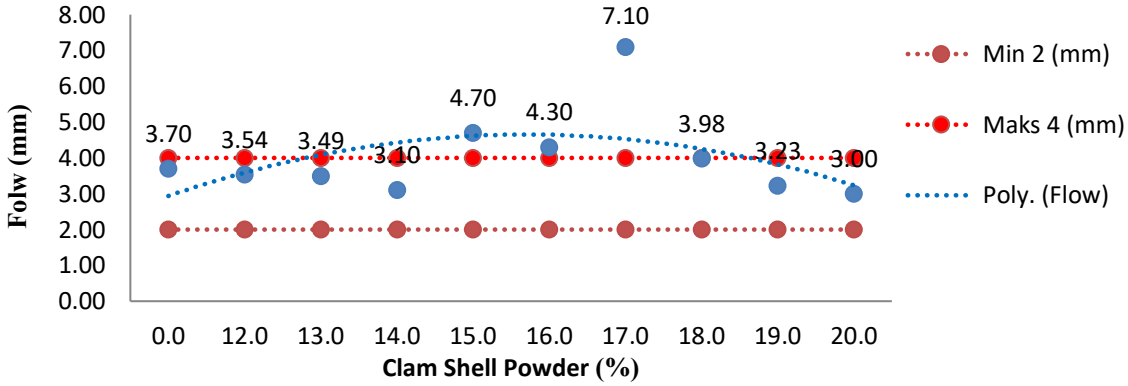


Figure 6. Relationship between Clam Shell Powder Content and Value Flow

4.2.7 Marshall Quotient (MQ)

Figure 7 shows that the highest MQ value was obtained at 18% content at 1,289.86 kg/mm. MQ is an indicator of mixture stiffness; the higher the MQ, the stiffer the mixture and the more susceptible it is to fatigue cracking from repeated loads. At 14%–16%, MQ values ranged from 656.55–797.76 kg/mm, indicating a balanced level of stiffness. All MQ values were well above the minimum specification of 250 kg/mm.

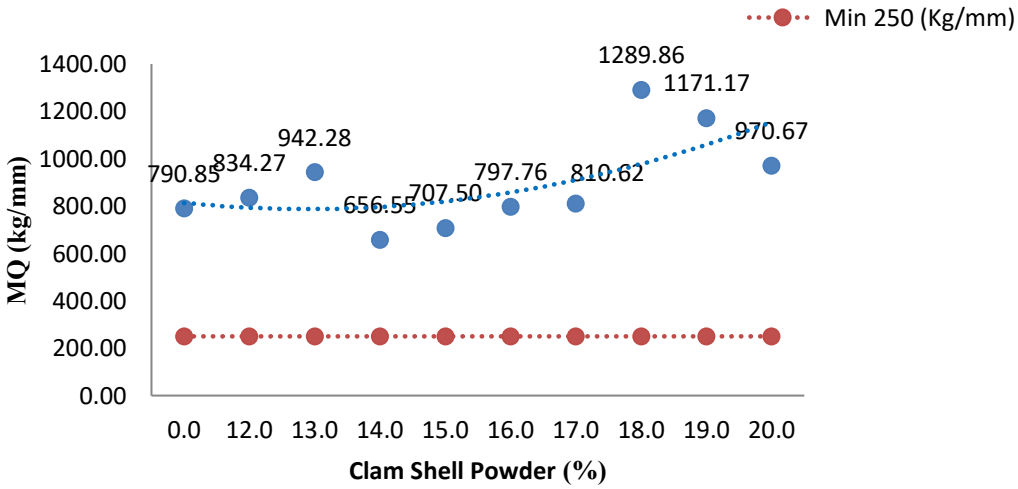


Figure 7. Relationship between Clam Shell Powder Content and Value MQ

4.3. Durability (IKS)

Table 3 and Figure 8 show the Retained Strength Index (RSI) test results for all variations of blood cockle shell filler content. All variations produced RSI values above 90%, meeting the Bina Marga 2018 Revision II Specification requirements.

Table 3. Retained Strength Index (IKS) Values

CKD Level (%)	Stability 30 Minute (kg)	Stability 24 Hour (kg)	IKS Average (%)
0	3.278,99	2.949,23	90,27
12	4.157,39	3.760,63	90,91
13	3.630,84	3.691,90	113,36
14	4.504,96	4.866,04	124,01 ✓
15	3.914,28	3.710,96	98,23
16	5.492,15	4.940,96	91,41
17	5.162,21	4.551,24	97,15
18	5.158,14	4.825,00	95,03
19	4.588,87	4.011,43	95,70
20	5.609,57	5.137,68	91,02
Spek	**-**	**-**	**Min. 90%**

The highest IKS value was obtained at 14% filler content at 124.01%. The significant increase at 13%–14% was due to the ability of the $CaCO_3$-rich cockle shell filler to optimally fill voids between aggregates and strengthen the asphalt-aggregate bond, such that stability after 24-hour immersion was actually greater than stability after 30-minute immersion. At 15%–16%, IKS decreased to 98.23% and 91.41% due to the mixture becoming too stiff, weakening the asphalt-aggregate bond. At 17%–20%, RSI values ranged from 91%–97%, still meeting requirements but not exceeding performance at the optimum filler content.

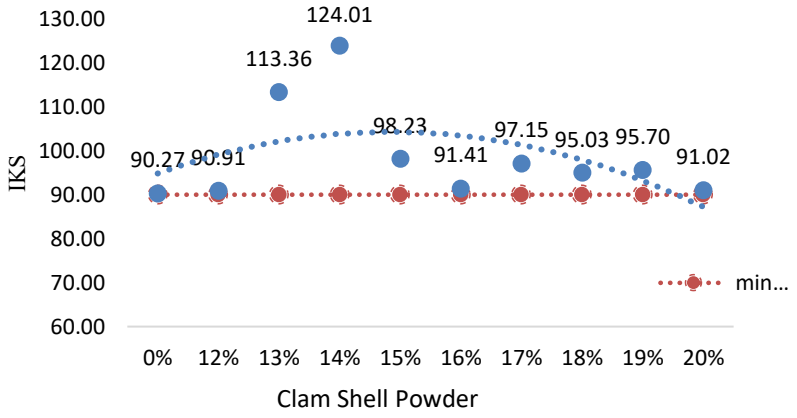


Figure 8. Relationship between Clam Shell Powder Content and Value IKS

5. Conlusion

Based on the research results and discussion, the following conclusions can be drawn:

a. Substitution of blood cockle shell waste filler significantly affected the Marshall performance and durability of the AC-WC mixture.

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b. The highest stability was obtained at 17% content (5,819.47 kg), far exceeding the minimum requirement of 800 kg. However, the flow at this content (7.10 mm) exceeded the specification limit of 2–4 mm, indicating an overly plastic mixture, so 17% was not selected as the optimum content.
c. The optimum filler content range was 14%–16%, with the most balanced performance at 14%. This content was selected because it combined high stability (5,018.25 kg), flow within the specification (3.10 mm), MQ above the minimum (656.55 kg/mm), and the highest RSI (124.01%). However, VIM (1.02%) and VMA at this content were outside the specification limits, so 14% should be regarded as the best compromise among the parameters rather than a fully compliant mixture.
d. All mixture variations produced RSI values above 90%, with the highest value of 124.01% at 14%, demonstrating excellent resistance to water damage.
e. Blood cockle shell waste is a viable eco-friendly substitute for stone dust filler in AC-WC mixtures to support sustainable road pavement construction.

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