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Effect of Different Filler Types on Mechanical Properties of CMA

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Abstract

Although conventional hot mix asphalt (HMA) has good performance, it has many drawbacks, such as gas emission into the environment, high energy for preparation and compaction, and difficulty controlling temperature for long transfer distances. Therefore, some sustainable technologies, such as cold-mix asphalt (CMA), are used. This study aims to develop cold mix asphalt (CMA) using by-products and waste materials. The methodology for this study included using four types of filler material: CKD (cement kiln dust), OPC (ordinary Portland cement), SF (silica fume), and RH (rice husk) as fillers. Laboratory tests were performed to assess the volumetric and mechanical characteristics of the modified mixture using Marshall test, indirect tensile strength, and retaining strength. The findings showed that CMA-CKD has significantly improved in mechanical characteristics. Also, other types of fillers, such as SF, and RH Ash, as activators of CMA-CKD, showed substantial enhancement in their mechanical properties. CMA- CKD -SF showed performance superior to other modified mixtures. It concluded that the updated CMA could be an alternative to the CMA-OPC to gain the required mechanical properties besides other benefits such as cost-effectiveness and environmental impact.

Keywords: HMA; CMA; Marshall; Retaining Strength; Indirect Strength; CKD; SF; RH Ash.

1. Introduction

One of the main concerns for researchers worldwide is the substitution of sustainable additional cold mix asphalt (CMA) for hot asphalt mixtures in building the surface layers of highways and roads. Energy savings, financial effectiveness, and environmental impact

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will all benefit from this reduction. Moreover, road and highway authorities are drawn to CMA because they make up a significant quantity of industrial trash that needs to be disposed of in virgin areas (Al-Hdabi et al., 2014; Al-Busaltan et al., 2012; Al Nageim et al., 2012; Abdel-Wahed and Al Nageim, 2016, Dulaimi et al., 2023, Ayar, 2018). Because of the advantages for the environment, researchers have made numerous attempts to improve the qualities of CMA. Adding fillers to the CMA gradation is one attempt at this. It influences the stiffness, resistance to permanent deformation, susceptibility to moisture, and resistance to fractures of the asphalt mix (Kim et al., 2008). Fly ash replaces conventional mineral fillers to modify CMA and improve their performance with a conventional hot asphalt mix (Al-Busaltan et al., 2012). Additionally, adding SF to CMA intended for surface courses improves its initial strength, durability, and long-term strength (Al-Hdabi et al., 2014). Treating CMA with 1-2% Ordinary Portland cement can improve mechanical performance and extend early strength compared to regular CMA. (Thanaya et al., 2009) .(Al Nageim et al., 2023) utilized a novel form of CMA that substitutes limestone and ordinary Portland cement with wastewater bottom ash (UBA) and sludge fly ash (UFA). The filler that was used was silica fume (SF). The findings indicated that at 3 days of age, CMA with 2.1% OPC + 3.9% UFA had ITSM values 11 times higher than conventional CMA, and at 28 days of age, ITSM values were five times higher for CMA with 2.1% OPC + 3.3% UFA + 0.6% UBA higher than traditional CMA. For both mixtures, SF-activated hydration significantly increased ITSM. (Head, 1974) reported that, compared to untreated mixtures, the Marshall stability is increased by 300% when 1% OPC is added as a modifier to CMA. Replacing SD with Rice husk ash(RHA) and FA Fly ash (FA) can improve the Marshall stability to 20.32% and 25.99%, respectively (Deb and Singh, 2023). The tensile strength and moisture susceptibility of mixes were also improved. The rutting deformation of the mix with SD is 16.57 mm, the highest among other filler mixes, and the resistance has increased to 1.66 % and 52.16% after the application of RHA and FA filler. Also, the stability responses and substantial up-grading durability by incorporating RHA in CMA. The tensile strength of CMA holding RHA is less in the initial days of curing compared to conventional stone dust (SD) filler mix(Deb and Singh, 2022). The experimental results show that the tensile strength and Marshall stability of CBEM increased drastically by replacing mineral fillers with waste rice husk ash and ordinary Portland cement. The moisture-induced damages are reduced due to the WRHA, and OPC is added to the CBEM. The tensile strength values and stability values of WRHA-modified CBEM are more optimistic than OPC-modified CBEM. The experimental results show that the tensile strength and Marshall stability of CBEM increased drastically by replacing mineral filler with waste rice husk ash and ordinary Portland cement. The moisture-induced damages are reduced due to the WRHA and OPC is added in the CBEM. As the tensile strength values and stability values of WRHA modified CBEM are more optimistic than OPC modified CBEM (Dash et al., 2022).

This research aims to show how waste or by-product materials might enhance CMA's properties. However, recycling waste materials reduces the impact of waste material on the environment, preserves natural materials, and minimizes the cost of pavement construction or maintenance.

2. Raw materials

To guarantee economic efficiency and assess the feasibility of utilizing the new mixture in local applications. Local materials were used in this study to the extent that they were accessible. Among these resources were:

2.1 Aggregate material

The local quarry in West Kerbala provided the aggregates used in this study. According to section R-9 of the Standard Specification of Road and Bridge, the materials gradation and other property requirements were met. Following the Iraqi criteria for binder course layers GSRB, R9 (GSRB, 2003b),), limestone aggregate was sieved, isolated, and graded. The study's aggregate material is shown in Figure 1.

Figure 1. Aggregate material used in the study.

Table 1. Results of gradation test aggregate according to Iraqi specification.

Sieve size	mm	Type I	Type II	Type IIIA	Type IIIB
		Base Course	Binder or Leveling Course	Surface or Wearing Course	
		% Passing by Weight of Total aggregate + Filler			
1 ½ in	37.5	100			
1	25.0	90-100	100		
¾	19.0	76-90	90-100	100	
½	12.5	56-80	76-90	90-100	100
⅜	9.5	48-74	56-80	76-90	90-100
No. 4	4.75	29-59	35-65	44-74	55-85
No. 8	2.36	19-45	23-49	28-58	32-67
No. 50	300 µm	5-17	5-19	5-21	7-23
No. 200	75 µm	2-8	3-9	4-10	4-10
Asphalt Cement (% weight of total mix)		3-5.5	4-6	4-6	4-6

Table 2 .Results of gradation test aggregate according to Iraqi specification.

Coarse Aggregate			
Property	**Value**	**Standard of Tests**	**GSRB Specification for Surface Course**
Bulk Density, gm /cm^3	2.543	C127 (ASTM, 2015b)	-
Apparent Density, gm /cm^3	2.634	C127	-
Water Absorption, %	1.36	C127	-
Percent Wear by Los Angeles Abrasion, %	9.1	C131(ASTM, 2014)	30% Max
Soundness (Loss by Sodium Sulfate), %	4.1	C88 (ASTM, 2013b)	12% Max
Clay Lumps, %	0.05	C142(ASTM, 2010)	-
Fine Aggregate			
Bulk Density, gm /cm^3	2.64	C128 (ASTM, 2015c)	-
Apparent Density, gm/cm^3	2.65	C128	-
Water Absorption, %	0.71	C128	-
Clay Lumps, %	1.9	C142	-
Passing Sieve No.200, %	3.52	C117(ASTM, 2013a)	-

2.2 Filler Material

This research utilized three fillers: cement kiln dust (CKD), Silica Fume, Ordinary Portland Cement, and Rice husk ash, as shown in Figure 2. CKD utilized is a waste material generated from the cement industry of Karbala Cement Plant. Typically, the CKD is landfilled in the nearby desert. Silica Fume was supplied from the local market. Rice husk ash was prepared from burning local rice husk. Karbala Cement Plant produces Ordinary Portland cement, and all its properties are satisfied according to Iraqi specifications for ordinary cement.

Figure 2 Cement kiln dust (CKD), Silica Fume, and Rice husk ash material used in the study.

Table 3. Morphology Properties of the Utilized Fillers.

Chemical Properties (XRF)				
Properties	**Filler Type**			
	CKD	**OPC**	**SF**	**RH**
SiO2	15.29	24.91	90.63	92.1
Al2O3	3.33	2.321	0.02	0.33
Fe2O3	2. 5	1.125	0.01	0.36
CaO	42.6	64.145	1.23	---
MgO	0.87	1.326	0.01	0.79
K2O	1.06	0.755	0.15	3.28
Na2O	0.2	1.719	0.25	0.12
SO3	---	---	---	1.24
P2O5	---	---	---	0.95

3. Test Methods

3.1 Marshal test

This test determines how resistant cylindrical specimens of asphalt mixture are to plastic flow when loads are applied perpendicular (load rate 50 mm/min) to their cylindrical axis. Following ASTM D6927 (ASTM, 2015a), the asphalt mixture preparation procedure is depicted in Figure 3. The curing system for the two types of mixture is shown below.

- For HMA, the curing duration is 24 hours at 25 ^{0} C.
- For CMA curing duration, 24 hours at 25 ^{0} C in mold plus 24 hours at 40 ^{0} C in water bath.

Figure 3. Preparation process for asphalt mixture.

3.2 Indirect Tensile test

A cylindrical specimen is loaded (load rate 50 mm/min) at its vertical diametric level at a test temperature and with a limited rate of deformation in order to evaluate the tensile characteristics of asphalt mixes. The maximum load at failure is noted and used to compute ITS for specimens. This test provides two indications for bituminous mixtures. The first indication is used to assess the cracking tendency of the bituminous mixture. Using the tensile strain at failure to estimate the likelihood of cracking is more helpful. It is more likely that a mixture will not crack if it must bear enormous forces before cracking. On the other hand, the second indication is used to evaluate the water susceptibility of bituminous blends. The ASTM D6931(ASTM, 2017)-compliant test method was finished. ITS is calculated using Equation 1.

$$\boldsymbol{ITS = \frac{2P}{\pi . D . t}} \qquad (1)$$

Where:

$ITS =$ indirect tensile strength, kPa

$P =$ maximum load, N

$t =$ specimen height immediately before test, mm

$D = specimen\ diameter$, mm

3.3 Retained Strength

The ability to withstand weathering and the abrasive effect of traffic is known as durability (Epps et al., 2000). Aging, deterioration, and disintegration are examples of how weathering affects the characteristics of asphalt mixtures (Grenfell et al., 2009). According to ASTM D 1074 (ASTM, 2017a), retained strength was used to investigate how various mixes resisted water damage. The test compares conditional and unconditional samples using indirect tensile or compressive strength tests. The ability of pavement materials to tolerate compressive forces that are oriented axially is known as their compressive strength. In order to characterize water damage, GSRB (General Specification for Roads and Bridges) requires compressive testing to be at least 70% (GSRB, 2003a). The compressive strength test is shown in Figure 4 below.

Figure 4. Compressive strength test.

4. The research Results

4.1 The optimum binder content for HMA

The results showed that increasing the asphalt content significantly affects the volumetric properties of HMA ,as shown in Figures 5 to 8. As the asphalt content increases, the Density increases due to enhanced cohesion and reduced internal voids. A noticeable reduction in air voids is observed, reflecting better compaction and filling of internal spaces. The VMA initially declines with increasing asphalt content and stabilizes, indicating a balance between asphalt volume and available void space within the aggregate structure. Meanwhile, the VFB increases consistently, showing more efficient occupation of the voids by the asphalt binder. These trends highlight the importance of determining the optimum asphalt content that ensures high Density, appropriate air voids, and acceptable volumetric properties to achieve durable and high-performance asphalt mixtures, an optimum point of around 4.5%.

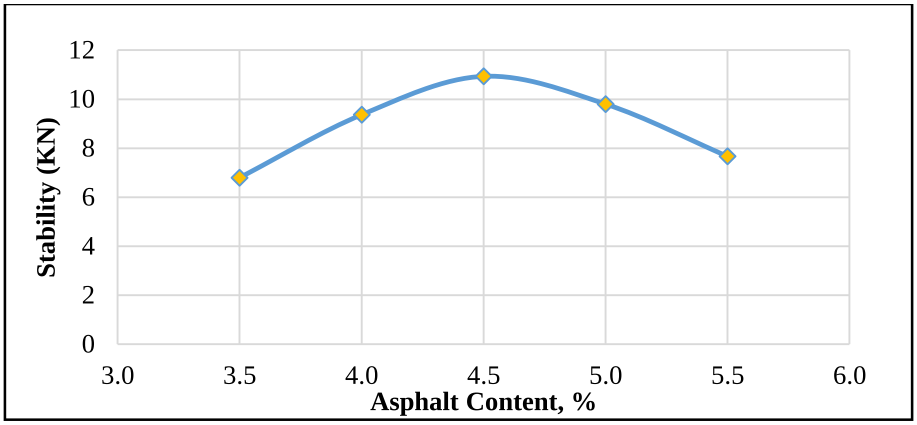

Figure 5. Marshal stability with the HMA's asphalt content.

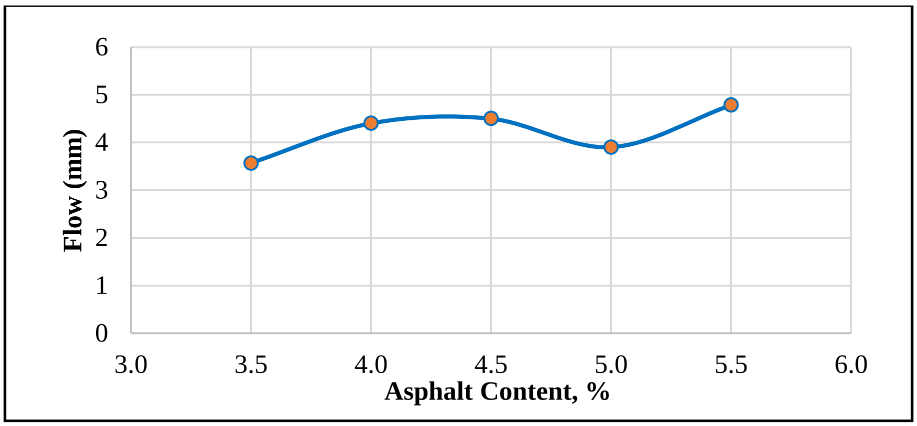

Figure 6. Marshal flow versus HMA's asphalt content.

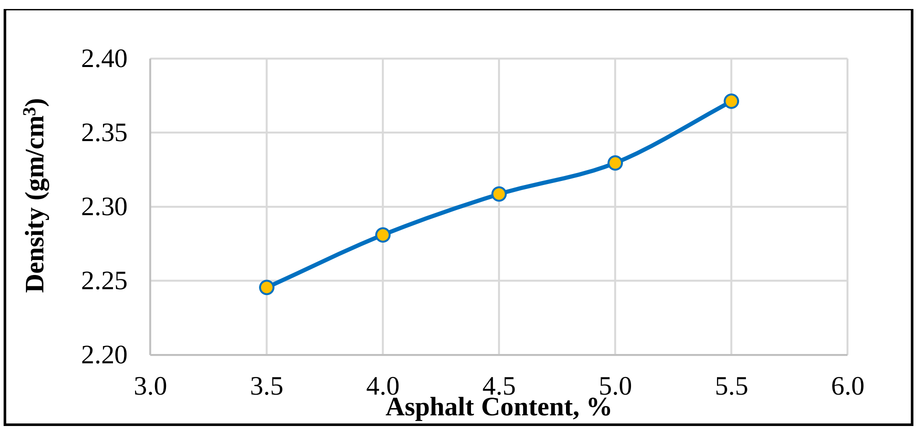

Figure 7. Density versus HMA's asphalt content.

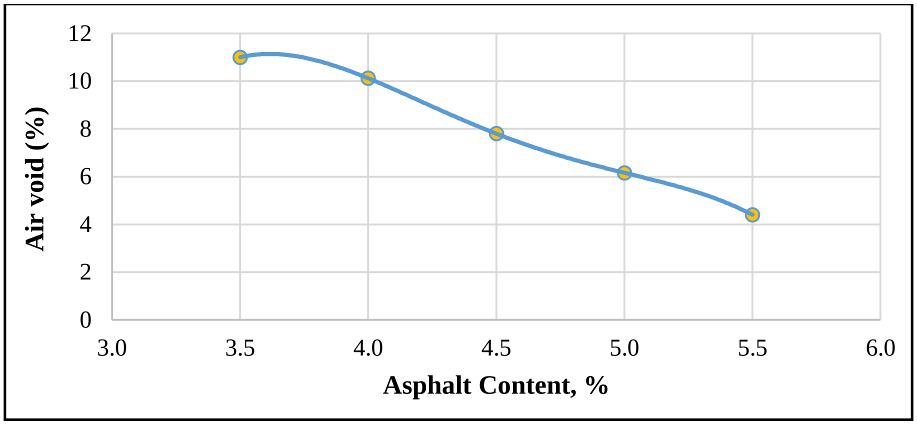

Figure 8. Voids in total mix versus HMA's asphalt content.

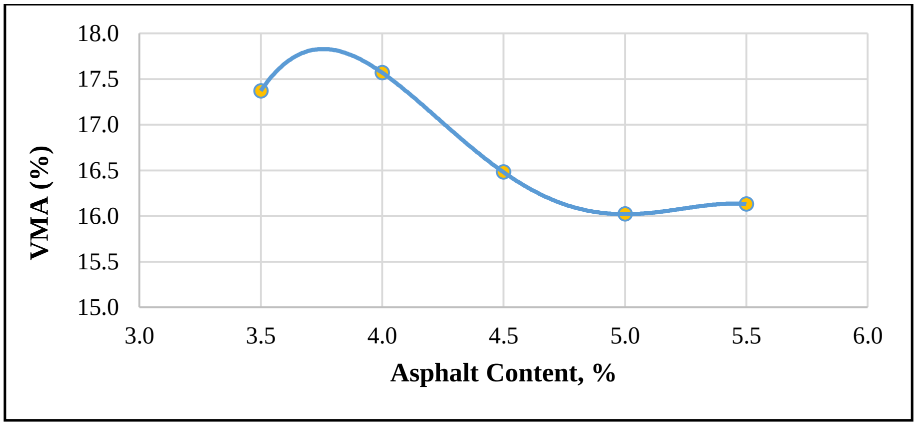

Figure 9. VMA versus HMA's asphalt content.

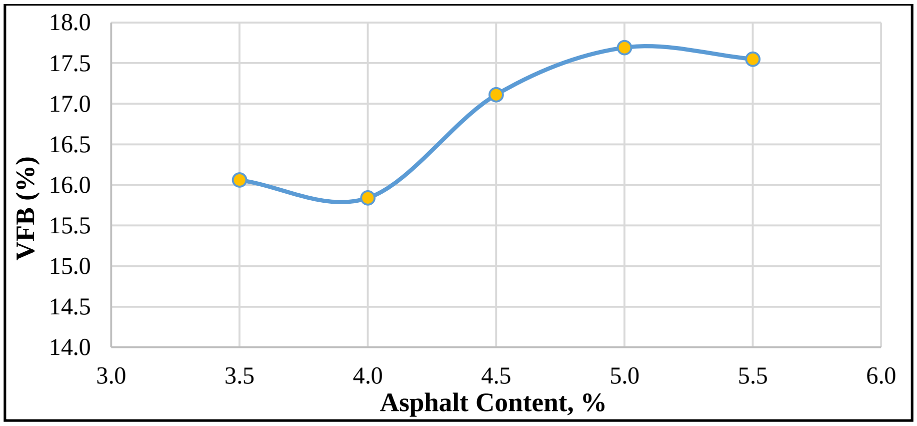

Figure 10. VFB versus HMA's asphalt content.

4.2 The optimum binder content for CMA

MS-14 (Asphalt Institute, 1989) states that the starting emulsion content is 10.5%. The optimum prewetting water content is then determined by comparing the initial emulsion content with several prewetting water contents. It was determined to be 4% based on the results shown in Figures 11-13. The result shows that stability decreases sharply (1.8 kN to 0 kN) as water content rises (2–8%). Excess water disrupts cohesion between aggregates and asphalt, acting as a lubricant and creating air voids, weakening structural strength and lowering Density. Also, Fig. 13 Marshall Flow rises with asphalt content, as higher binder content enhances flexibility. However, excessive asphalt risks over-softening the mix, necessitating a balance between deformation resistance and plasticity.

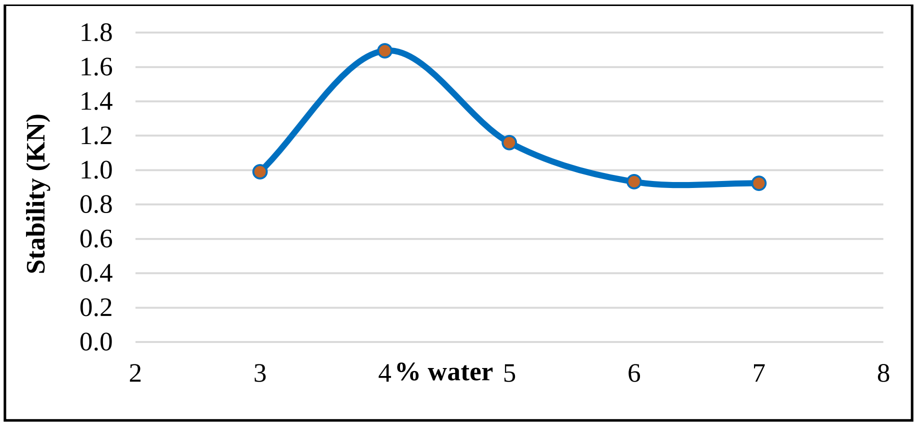

Figure 11. Marshall stability versus water content of CMA.

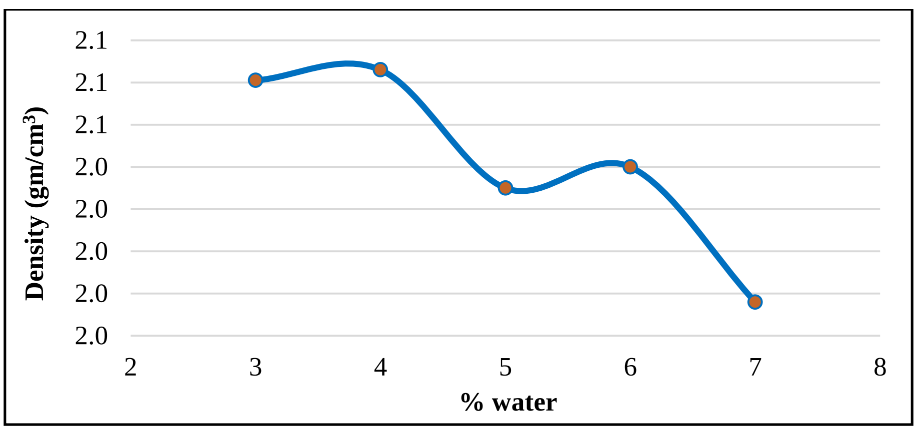

Figure 12. Density versus water content of CMA.

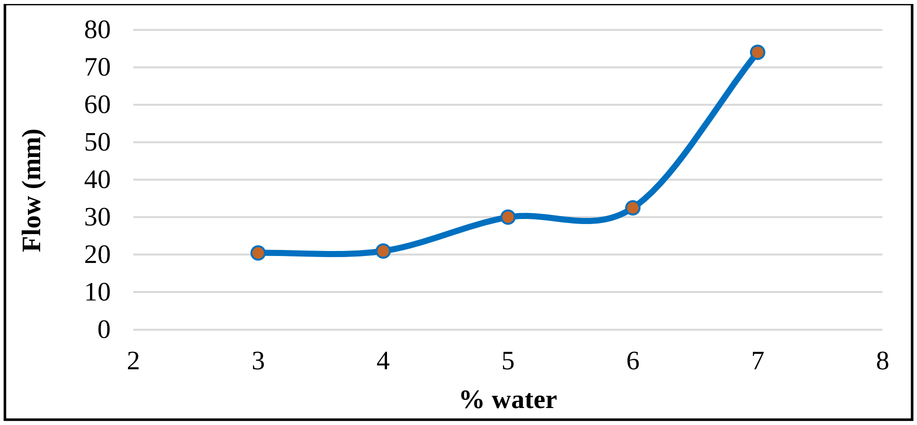

Figure 13. Marshall flow versus asphalt content of CMA.

Then, different emulsion content was used to determine the optimum emulsion content with the optimum prewetting water content. According to the results shown in figures 14-16, this value is 10%.

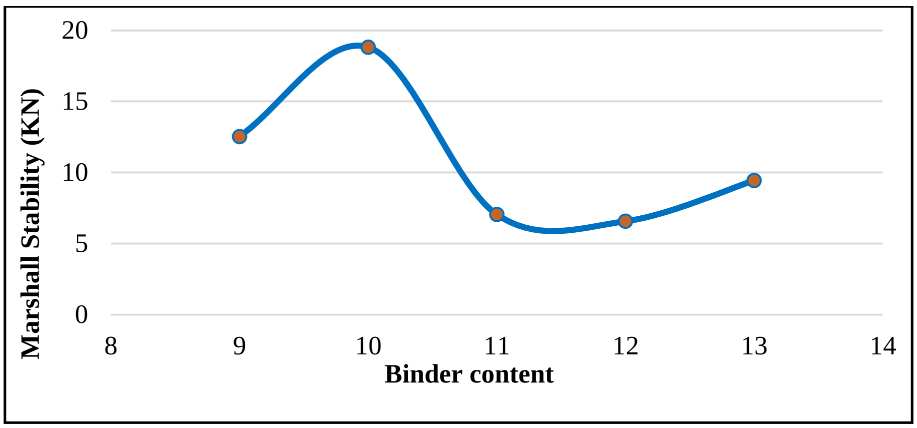

Figure 14. Marshall flow versus asphalt content of CMA.

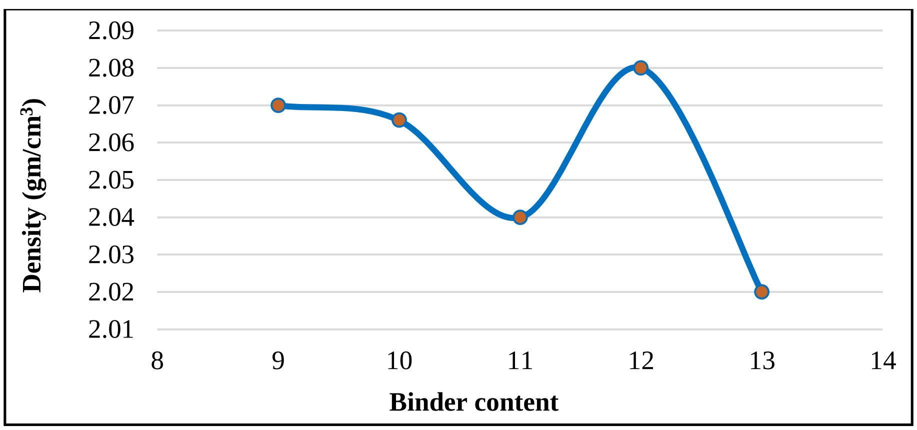

Figure 15. Density versus asphalt content of CMA.

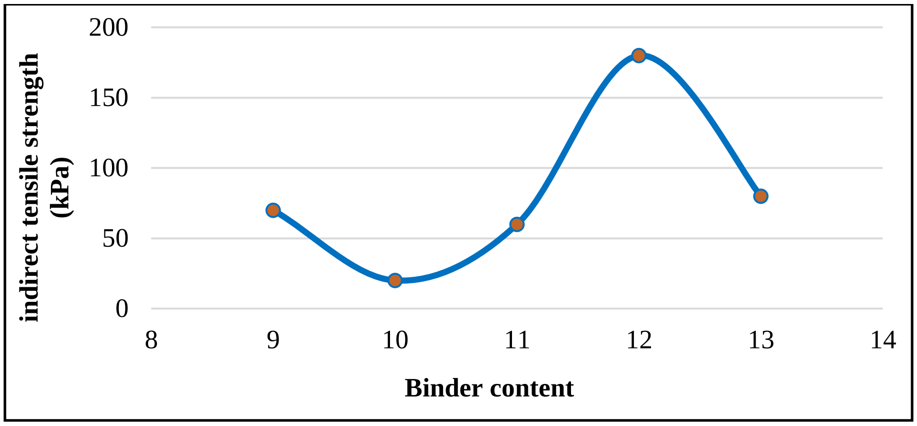

Figure 16. Marshall flow versus asphalt content of CMA.

4.3 The Result for Modified CMA

Results shown in Fig 17 illustrate that the Density of CMA has the same trend as the HMA density but with lower values. This can be because of the filler's particle size distribution. Also, the rheological properties of the emulsion bitumen used in CMA are recognized by lower viscosity and bonding strength compared to the binder in HMA. Consequently, these properties contribute to the lower overall Density of the mixture.

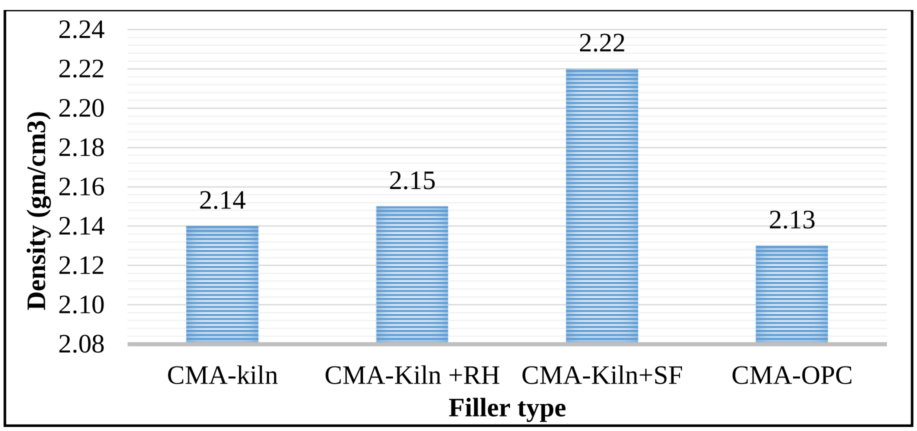

Figure 17. Density versus type of filler in CMA.

The results in Figure 18 show that CMA+ CKD+SF shows the highest Marshall stability. This enhanced performance is primarily attributed to the combined effects of improved densification and the formation of additional cementitious hydration products within the mix. CKD, a by-product rich in calcium oxide (CaO), undergoes a pozzolanic reaction with the amorphous silica (SiO_2) present in silica fume in the presence of moisture. This reaction produces secondary calcium silicate hydrate (C-S-H) gels, the principal binding phases responsible for strength development in cementitious systems. The formation of C-S-H not only fills micro-voids but also establishes strong chemical bonds with aggregate surfaces, improving the internal structure of the mix. Furthermore, due to its ultra-fine particle size and high surface area, silica fume acts as a filler and a reactive pozzolan. Its particles fill the voids between larger aggregate grains, enhancing the packing density and reducing total porosity. This microstructural refinement increases mix density, directly contributing to greater load distribution and improved resistance to permanent deformation. Figure 19 illustrates that the marshal flow of CMA with (kiln +SF) has the smallest values because the C-S-H gels and dense packing restrict the movement of particles under load, reducing the ability to deform plastically. The mix becomes more rigid, so it does not flow as much when applying pressure.

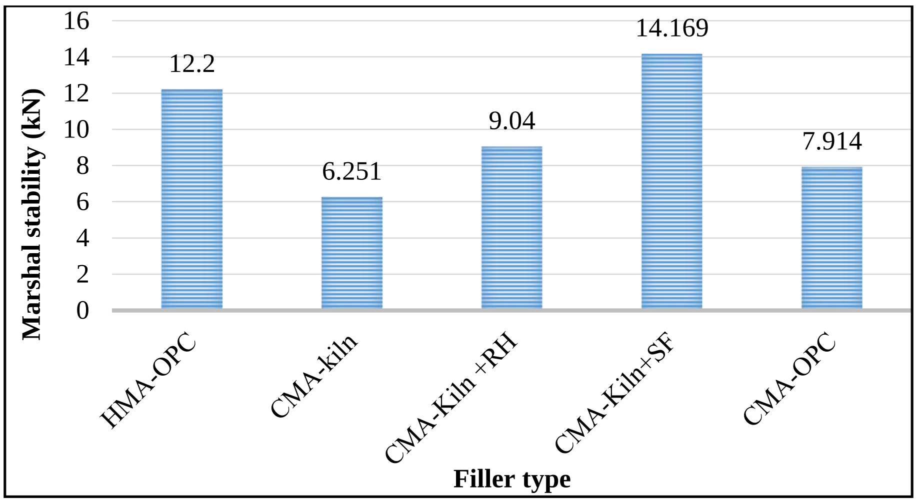

Figure 18. Marshall stability versus the type of filler in CMA.

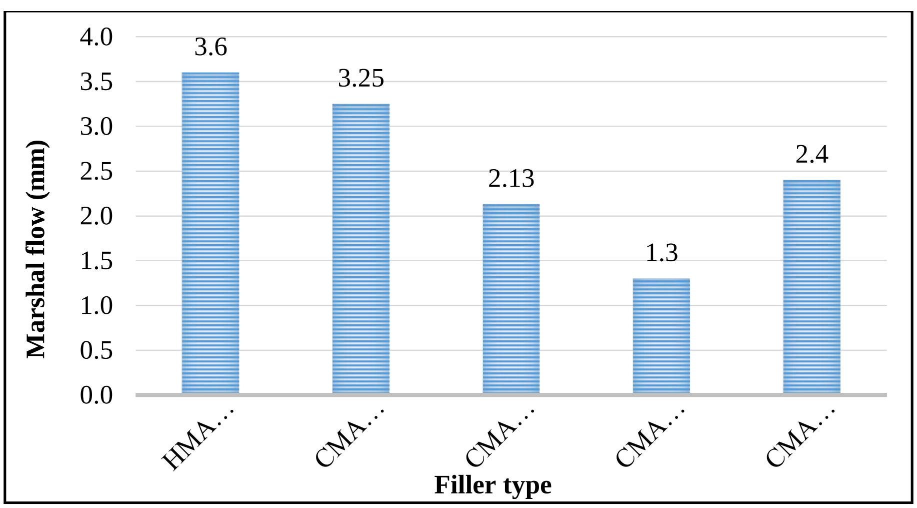

Figure 19. Marshall flow versus type of filler in CMA.

As can be seen in the results in Figure 20, CMA with (kiln +SF) has the highest retention strength. The distribution of filler and hydration product particle sizes for the conditional samples may cause this. Meanwhile, SF reacts with calcium ions (e.g., from cementitious additives or aggregates) to form calcium silicate hydrate (C-S-H) gels. These gels act as a secondary binder, chemically reinforcing the asphalt-aggregate interface and improving resistance to water-induced binder stripping. C-S-H gels create a hydrophobic (water-repellent) layer around aggregates, reducing water affinity. The hybrid Min+SF system achieves near-zero interconnected voids, minimizing water penetration and internal pore pressure. Low porosity limits water retention, preventing long-term weakening of the mix.

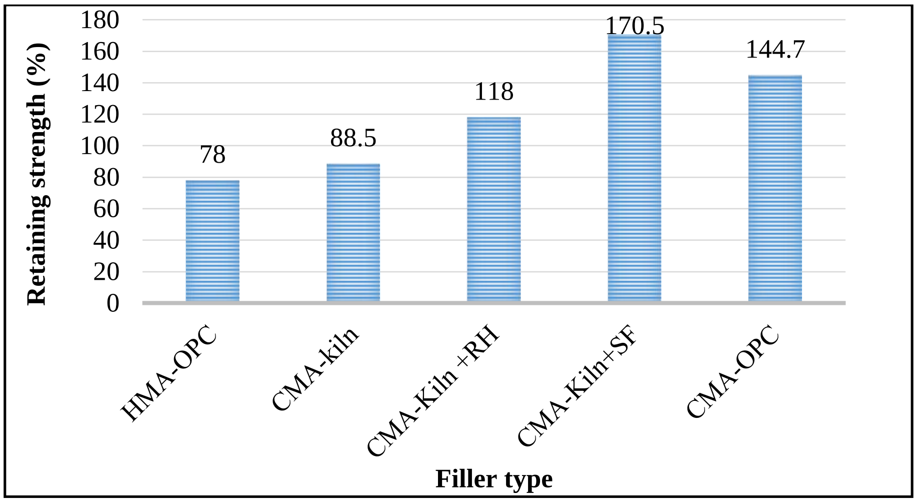

Figure 20. Retaining strength versus type of filler in CMA.

As seen from the data in Figure 21, the indirect strength of CMA roughly corresponds to the trend of marshal stability. The results can be assessed with the same explanation.

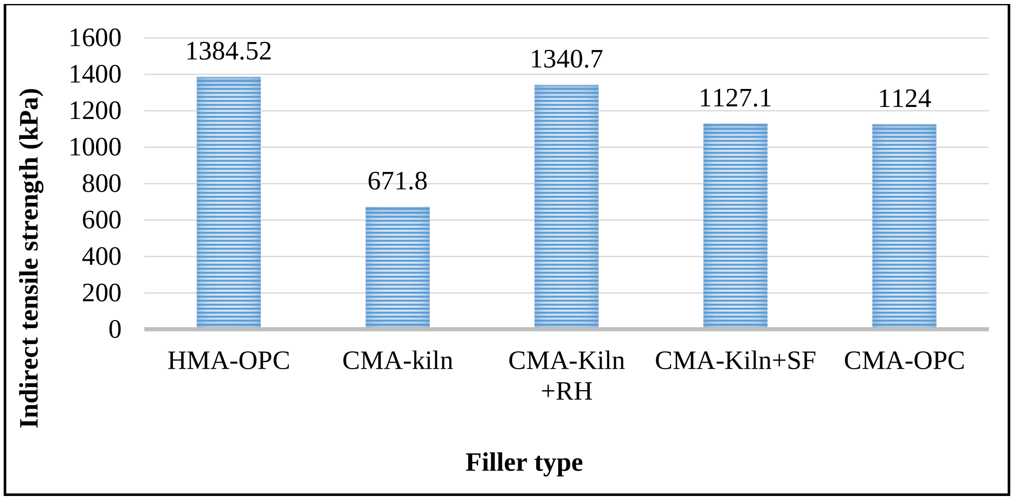

Figure 21. Indirect strength versus type of filler in CMA.

The results demonstrated that waste and by-product materials could be a viable substitute for OPC. Using such filler showed a significant modification in the mechanical properties of CMA. The only deficiency recognized was when using Kiln alone without an activator. However, from the results, it is clear that such an alternative adds value to the design of the highway pavement layer in terms of cost-effectiveness and environmental issues. Finally, it has to be said that the shortage of time was the reason for not checking the benefit of such material in the design parameters of highway pavement.

5. Conclusion

The conducted study successfully demonstrated OPC, which some agencies recommend, proves its validity as an active filler to gain the required engineering properties for a mixture used for highway pavement. Also, CKD improves the mechanical properties of CMA but requires activators for optimal performance. While, SF outperforms RH as an activator, offering superior stability and strength. The CMA+ CKD+SF have optimal mechanical performance and volumetric properties. Consequently, the use of waste materials reduces environmental impact and construction costs.

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تأثير انواع المواد المالئة (الحشوية) المختلفة على الخلطات الاسفلتية الباردة

الخلاصة:على الرغم من الأداء الجيد للخلطات الأسفلتية الساخنة التقليدية (HMA)، إلا أنها تعاني من العديد من العيوب مثل انبعاث الغازات إلى البيئة، واحتياجها إلى طاقة عالية للتحضير والرص، وصعوبة التحكم بدرجة الحرارة عند النقل لمسافات طويلة. لذلك ظهرت بعض التقنيات المستدامة مثل الخلطات الأسفلتية الباردة .تهدف هذه الدراسة إلى تطوير الخلطات الأسفلتية الباردة (CMA) من خلال استخدام المنتجات الثانوية ومواد النفايات. تضمنت منهجية الدراسة استخدام أربعة أنواع من المواد المالئة وهي: غبار أفران الأسمنت(CKD) ، والأسمنت البورتلاندي العادي(OPC) ، و السيليكا(SF) ، ورماد قشور الأرز (RH) كمواد مالئة. كما تضمنت الفحوصات المختبرية تقييم الخصائص الحجمية والميكانيكية للخلطات المعدلة باستخدام اختبار مارشال، واختبار الشد غير المباشر، واختبار القوى المتبقيه.أظهرت النتائج أن خلطة CMA المعدلة باستخدام CKD سجلت تحسنًا كبيرًا في الخصائص الميكانيكية. كذلك، أُضيفت أنواع أخرى من المواد المالئة مثل السيليكا(SF) ، وقشور الأرز، ورماد قشور الأرز كمواد منشطة لخلطةCMA-CKD ؛ وقد أظهرت هذه المنشطات تحسنًا ملحوظًا في الخصائص الميكانيكية للخلطة. وقد تبيّن أن الخلطة CMA-CKD-SF أظهرت أداءً متفوقًا مقارنةً مع الخلطات المعدلة الأخرى. وبناءً عليه، يمكن الاستنتاج أن الخلطة الأسفلتية الباردة المطورة يمكن أن تكون بديلًا فعالًا للخلطةCMA-OPC ، لتحقيق الخصائص الميكانيكية المطلوبة، إلى جانب مزايا أخرى مثل انخفاض التكاليف وتقليل الأثر البيئي.
الكلمات المفتاحية : الخلطات الاسفلتية الحارة , الخلطات الاسفلتية الباردة , فحص مارشال , فحص القوة المتبقية ,فحص الشد غير المباشر, غبار فرن الاسمنت ,دخان السليكا, رماد قشر الارز.