Kufa Journal of Engineering
Vol. 16, No. 1, January 2025, P.P. 283-297
Article history: Received 9 July 2024, last revised 14 August 2024, accepted 16 August 2024

ENHANCING COLD MIX ASPHALT PERFORMANCE WITH GEOPOLYMER TECHNOLOGY

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https://doi.org/10.30572/2018/KJE/160117

ABSTRACT

Generally, Cold asphalt emulsion mixtures (CAEM) produced and compacted at ambient temperatures. The main objective of this study is to investigate the improvement of the performance for mixtures by the addition of geopolymers based on cementitious material by preparing the asphalt samples using three concentrations of geopolymer utilized as a substitute for limestone filler (LF),The mechanical properties of the mixtures were evaluated using the Marshall test, Indirect Tensile Strength (ITS) test, Kim test and Water sensitivity test TSR. The test results revealed that the concentration of (NaOH) has a substantial influence on the structure and characteristics of geopolymers, enhancing Marshall stability, ITS, and rut resistance. CAEM with geopolymer considerably improved Marshall stability and deformation resistance especially those containing fly ash.CAEM with geopolymer provides larger ITS conditioning and a TSR over 100% better than hot mix asphalt HMA. Furthermore, it is noteworthy to mention that the addition of geopolymer has somewhat improved the mechanical properties and durability characteristics of the CAEM.

KEYWORDS

Geopolymer Technology, Cold asphalt emulsion mixtures, Indirect tensile strength, Water sensitivity, Deformation Strength Test.

1. INTRODUCTION

In recent years, the issue of global warming has gained increasing importance and has been a major concern because of its environmental and economic impact (Shanbara et al., 2021). Institutions and researchers have shifted their focus towards the development and production of environmentally friendly and more sustainable building materials that do not consume fuel and use waste and by-product materials. Although cold asphalt mixtures have been around for a long time, they have not received the same attention as hot mixtures in terms of development and improvement, and they have always been thought traditional CAEM is less efficient than HMA. CAEM has three main disadvantages, including high air voids, poor early strength, and a long curing period to reach full strength(Herez et al., 2023) . These shortcomings played a role in CAEM's limited utilization in road construction.

Researchers accomplished various investigations to improve CAEM characteristics using various techniques. Waste Fly Ash (WFA) was utilized by (Al-Hdabi, 2014) to further enhance mechanical characteristics and resistance to moisture damage of cold-rolled asphalt (CRA) by substituting filler with WFA. Another by-product element that was utilized as a modifier for boosting the durability and mechanical features of CRA was silica fume (SF). The results indicated that besides improving resistance to moisture damage, there was a significant increase in stiffness modulus and performance in uniaxial creep test. (Dulaimi et al., 2017) observed that Using alkali-activated (NaOH solution) with cementitious filler-containing FA improves the mechanical characteristics and moisture resistance of CMA. The impact of adding pozzolanic materials to the cold mix without using the conventional filler is evident from the above. We will utilize these materials in this investigation along with a different approach involving the use of geopolymer.(Al Nageim et al., 2024) created a new cold mix asphalt by replacing traditional limestone fillers in conventional CMA made from new novel upgraded fly and bottom ashes from incinerated wastewater sludge, the results of moisture damage and ageing tests higher results compared with conventional HMA.

Geopolymers are non-crystalline inorganic materials synthesized by activating aluminosilicate precursors with hydroxides, carbonates, or silicates of alkali metals. They are considered environmentally helpful since they have lower carbon emissions. Geopolymers promote green, sustainable, and eco-friendly construction, minimizing the need for natural resources (Tang et al., 2018). Furthermore, recycling green material waste is highly important to civil engineers for sustainable development. There is growing interest among researchers in utilizing industrial by-products such as fly ash, blast furnace slag, and cement kiln dust for geopolymer production. Geopolymerization is a geosynthesis a chemical reaction that combines minerals. Exposing aluminosilicate materials like fly ash, blast furnace slag, or thermally activated substances to high-alkaline environments (hydroxides, silicates) results in the development of geopolymers. Geopolymers have two- to three-dimensional Si-O-Al structures. These materials constitute a new class of cementitious compounds capable of replacing typical cement materials(Petermann et al., 2010). Several investigations have explored the incorporation of various industrial by-products, such as blast furnace slag, fly ash, and glass powder, in the production of geopolymers due to their silicon and aluminium content. These geopolymers play a significant role in altering the rheological and physical characteristics of asphalt binders. Their integration can improve various aspects of asphalt mixture performance, including stability, fatigue resistance, resistance to rutting, and resistance to low-temperature cracking. (Rosyidi et al., 2020) investigated the strength, morphological, and adhesion qualities of geopolymer-modified asphalt binders prepared by mixing FA with alkaline solutions (sodium hydroxide (NaOH) and sodium silicate (Na2SiO3). Following the addition of the geopolymer, the modified bitumen had greater impact values than the base bitumen. Overall, it provided its best results, with the appropriate concentration for bitumen modification was 5% geopolymer. Research by (Ibrahim et al., 2016) shown that adding fly ash and 8 molary (M) alkali activator to virgin asphalt binder enhanced the asphalt binder's hardness and improved its resistance to permanent deformation.

Research on the use of geopolymer materials as a modifier for CMA is scarce, according to a survey of the literature. Therefore, the motive of this study is to investigate the strength, stiffness, moisture resistance and permanent deformation of CMA modified (FA) and (CKD) based geopolymer. Four types of fillers used instead of (LF) were mixed with 3 concentrations of alkaline solution and samples were produced and examined at three intervals: 7, 14, and 28 days. Mechanical property enhances were evaluated using the Marshall stability and Indirect Tensile Stiffness, while water sensitivity was assessed using the Indirect Tensile Strength Ratio (ITSR).

2. MATERIALS

Locally sourced materials from within Iraq were gathered. These materials' laboratory testing were carried out as shown below.

2.1. Asphalt materials

MA mixtures were prepared using asphalt cement that was obtained from the Al-Dourah refinery and had a penetration grade of (40–50). Table 1 displays the testing and physical characteristics of the employed asphalt cement. Asphalt emulsion was used in CMA type (Cationic Slow-setting). The supplies were from Setraco's Iraq Branch.

Table 1: Properties of Asphalt Cement

Property	Value	SCRB Specification
Penetration, 25°C (77°F), 100 g, 5 s	44	40-50
Ductility, 25°C (77°F), 5cm/min,cm	123	>100
Softening point (°C)	47	-
Viscosity, 135°C,cp	565	>400
Viscosity, 60°C,cp	183	4000
Specific gravity	1.103	-

Table 2: Properties of Asphalt Emulsion

Property	Value
Type	Cationc
Particle charge	Positive
Appearance.	Dark brown to black liquid
Penetration, 25°C (77°F), 100 g, 5 s	45
Residue by evaporation, %	58
Ductility, 25°C (77°F), 5 cm/min, cm	>100
Viscosity, Saybolt Furol at 25°C (77°F)	20
Relative Density at. 15 °C, g/cm3	1.105

2.2. Aggregate

The crushed limestone aggregates (coarse and fine) used in the study came from Thmuial quarry, which are situated south-west of Ramadi. The Roads Laboratory at the University of Anbar, College of Civil Engineering, conducted tests on the physical characteristics of both aggregates, which are shown in Table 2. As shown in Fig.1, aggregate gradation a type of binder layer commonly used in accordance with SCRB requirements section R9, 2003 was adopted in this study.

Table 3: Physical properties of the Aggregate

Material	Property	Value
Coarse Aggregate	Bulk specific gravity	2.573
	Apparent specific gravity	2.647
	Water absorption, %	1.089
	Percent Wear by Los Angeles Abrasion ,%	23.86
	Soundness Loss by Sodium Sulfate Solution,%	8.8
Fine Aggregate	Bulk specific gravity	2.424
	Apparent specific gravity	2.655
	Water absorption, %	3.6

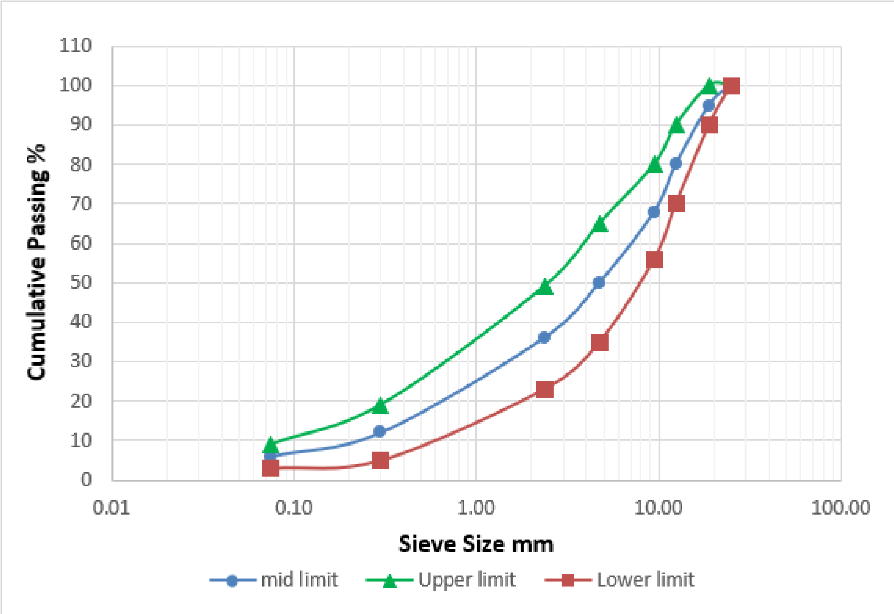

Fig. 1. Aggregate gradation of binder course

2.3. Fillers

Three mineral fillers were used in this study : Conventional Limestone Filler (LF), fly ash type F (FA), and Cement Kiln Dust (CKD). Usually, a control mixture (limestone filler, LF) was used to compare with other mixes, Fly ash (FA) was bought from a local market, while the by-product material (CKD) came from the Kubaisah cement factory. Table 4 shows the chemical composition of the applied fillers as determined by XRF analysis.

Table 4: XRF Analyze of the chosen filler materials

Properties	CaO	SiO2	Al2O3	MgO	Fe2O3	SO3	K2O	Na2O
LF	51.9	0.96	0.33	1.30	0.34	2.10	0.03	0.02
FA	9.840	46.97	28.56	1.254	4.132	1.412	0.689	0.738
CKD	59.8	14.8	3.76	2.41	3.6	2.45	1.73	0.01

3. SAMPLE PREPARATION

3.1. Design of Hot mix procedures

Marshall's design method was used to produce conventional hot mix asphalt (HMA) samples (ASTM, 2010)with five different asphalt content categories. As shown in Fig.1, the materials used for the binder layer were asphalt of grade 40-50 and aggregate gradation conforming to the Iraqi standard specification (SCRB, 2015).Tables 1 and 2 show the use of course and fine aggregates, respectively. Only limestone filler was used in the manufacture of HMA specimens. A Marshall Hummer was used to compact the area, with 75 blows each face. The specimens were then allowed to cool before being demolded. The optimum asphalt content was found to be 5%.

3.2. Design of Cold mix procedures

Asphalt Institute Marshall method for emulsified asphalt aggregate cold mixture design (Asphalt Institute MS-14, 1989) was followed in the preparation of cold mix asphalt specimens, with certain modifications based on the Iraqi standard CSRB comply to the subsequent actions: The binder layer's aggregate gradation selection, as indicated in Fig. 1 and adopted in (SCRB, 2015) Sec. R9. Calculate the Initial Residual Asphalt Content (IRAC) using the empirical Equation

$$P = (0.05A + 0.1B + 0.5C) * 0.7 \qquad (1)$$

Where P = is the percentage of emulsified asphalt based on the dry aggregate weight.
A = Aggregate retaining percentage on 2.36 mm (No. 8 sieve)

B = The percentage of aggregate that is retained on 75µm (No. 200 sieve) and passes 2.36 mm (No. 8 sieve).

C = Aggregate passing 75 µm (No. 200 sieve) as a percentage

Next, find the Initial Asphalt Emulsion Content (IEC) by dividing P by the percentage of residual asphalt content (X), as shown in the equation 2

$$\mathrm{IEC} = \mathrm{P} / \mathrm{X} \qquad (2)$$

To find the Optimal Asphalt Emulsion Content, numerous specimens varying in asphalt emulsion contents were produced, with two increments above and two below the initial residual asphalt content (IRAC) computed using equation 1. Using the Marshall technique for pouring and compaction, as described above.Specimens were placed in the mold for 24 hours at lab temperature, followed by 24 hours in an oven at 40°C, before being measured using the Marshall apparatus to establish the average indirect tensile strength for each pair of specimens. The maximum ITS was used to determine the Asphalt Emulsion Content. Table 5 summarizes the Design procedure steps.

Table 5: Results of Design of Cold mix procedures

According to MS-14 steps	Value
The Initial Residual Asphalt Content (P %)	6.44
The Initial Asphalt Content in Emulsion (IEC)=(P/0.58 %)	11.10
The Optimum Pre-Wetting Water Content (OPWC) (%)	3.5
The optimum total liquid content at compaction (%)	13.6
The Optimum Asphalt Emulsion Content (OAEC) (%)	10.1

To incorporate geopolymer into mixtures by modifying the process. At first an alkali activator solution was used instead of ordinary pre-wetting water. The investigation's alkali solution was made by mixing a 1:1 ratio of sodium hydroxide (NaOH) and sodium silicate solution (Na2SiO3). The NaOH solution was made by dissolving 98% pure NaOH pellets at various concentrations in distilled water. The alkali solution was produced 24 hours in advance to guarantee full reaction while mixing. Secondly, mixtures were created by substituting mineral limestone filler with various types of fillers, specifically FA and CKD, in varied quantities to produce geopolymers. The alkali activator utilized in this research is a combination of sodium hydroxide (NaOH) and sodium silicate (Na2SiO3). NaOH was made at 2, 5, and 8 M concentrations. A series of samples were obtained by slowly mixing the aggregates and different fillers with an alkali activator for 60 seconds. The emulsion was then added to the others and well stirred for 90 seconds. The mixture was then place in a Marshall mold and compacted using a Marshall Hammer, with 75 blows to each face. Both the mixing and compaction operations were carried out at laboratory temperatures (25°C). After preparation, all specimens were kept in the molds for 24 hours at the same laboratory temperature. They were then extruded out of the molds and wrapped in thick nylon for additional testing. Following that, all specimens had been left to cure for 7, 14, and 28 days at laboratory conditions (25°C). Samples were then kept in the oven for 24 hours at 40°C to prepare them for testing. Table 6 presents the mix proportions and abbreviations utilized in this study.

Table 6: Details about the mix proportions

ID	Mixture types	Filler types	Asphalt Emulsion %	Alkali solution%
CM1	Control mixtures	LF (6%)	10.1%	3.5%-water
CM2	FA + CKD	FA(4%)+CKD(2%)	10.1%	3.5%
CM3	Full CKD	CKD(6%)	10.1%	3.5%
CM4	Full FA	FA(6%)	10.1%	3.5%
CM5	Full FA	FA(6%)	10.1%	3.5%(NaOH Solution only)
HMA	Hot mix	LF (6%)	5% Asphalt binder 40/50	-

LF: Limestone filler FA: Fly Ash type F CKD: Cement Kiln Dust

4. TESTING PROGRAM

The performance of the developed Cold mixes with geopolymer was assessed using a range of laboratory experiments. To evaluate the primary properties of stiffness, resistance to moisture damage, and rutting resistance, three basic tests were carried out: the Marshall test, the ITS test, and the Kim test.

4.1. Marshall Test

This test was performed in accordance with ASTM (D1559) by Marshall device. The same procedure was followed for both HMA and CMA, with the exception of curing protocols, in which HMA specimens were allowed to cool at lab temperature for 24 hours before being placed in a water bath for 30 minutes at 60°C, whereas CMA specimens were kept in the lab temperature and tested at 7, 14, and 28 days before they were placed in an oven for 2 hours at 60°C. After that, they were tested with the Marshall device, and the applied load rate of (50.8) mm per minute, the Marshall flow was measured at the maximum value of load Marshall stability.

4.2. Moisture Damage Test

The indirect tensile strength test is employed to assess moisture damage in pavements. Put simply, the Marshall specimen is exposed to compressive loading by two strips positioned across its diameter until failure occurs, following the guidelines outlined in (ASTM D 6931, 2012). This standard employ equation (3) for the calculation of the Indirect Tensile Strength (ITS) value.

$$\mathrm{ITS} = \frac{2\mathrm{P}}{\pi \mathrm{Dt}} \tag{3}$$

Where ITS = Indirect tensile strength, kPa.
P = Maximum load, KN
D = Sample diameter, m
t= Sample hight ,m

Tensile strength ratio (TSR) was determined in accordance with (ASTM D1075, 2007) to evaluate moisture damage. In this test procedure, two sets of compacted specimens are used: one group consists of dry samples, known as unconditioned samples, and the second group consists of wet samples, known as conditioned samples.Curing techniques for conditioned and unconditioned specimens were adopted by Al-Busaltan et al.(Al-Busaltan et al., 2012) and Al-Hdabi et al. (Al-Hdabi and Al Nageim, 2017).The dry group (unconditioned) was left for 24 hr in a mold at lab temperature, then demolding and left the curing time at lab temperature, followed by 24 hr in an oven at 40°C. The wet group (conditioned) was left in the mold at lab temperature for 24 hours before being demolded and curing for 24 hr in an oven at 40°C, followed by 24 hr in a water bath at 60°C. The two group were then tested for ITS (as per ASTM D 6931). Moisture damage was subsequently assessed through the calculation of the TSR ratio for the samples using the following Equation :

$$TSR = \frac{St.con}{St.dry} * 100 \tag{4}$$

Where: TSR = tensile strength ratio, %

$S_{t.con}$= Indirect tensile strength of conditioned subset, kPa.

$S_{t.dry}$= Indirect tensile strength of dry subset, kPa.

4.3. Deformation Strength Test (Kim's Test)

The permanent deformation of asphalt pavement is a significant form of distress, with the resistance of asphalt to such permanent deformation being a crucial factor affecting the overall performance of asphalt pavements. A quick and easy test could be used to measures the resistance of asphalt mixtures to deformation under load. This technique called deformation strength denoted as SD which is developed by Kim et al.(Kim et al., 2004, Kim et al., 2011). It is highly correlated with rutting resistance, meaning the mixtures with higher SD values were found to show shallower rut depth in wheel tracking test (Doh et al., 2007). In 2017, it was included as one of the four criteria for Korean mix design(Kim et al., 2020).The specimen is cured in an oven at 60°C for 2 hr, then the SD test is done by placing a specimen into the specified rig as shown in Fig.2-a , and a static load is applied vertical at rate 50.8 mm/min to the top of the specimen via a loading head using a Marshall apparatus. Fig.(2-b) is illustrated a load-deformation curve represents the relationship between two variables peak load, P, and vertical deformation, v at P. The SD value was calculated using a newly developed equation:

$$S_D = \frac{0.32P}{\left[10+\sqrt{20y-y^2}\right]^2} \qquad (5)$$

`when S_D = deformation strength (Mpa), y = deformation (mm), and P = maximum load (P).

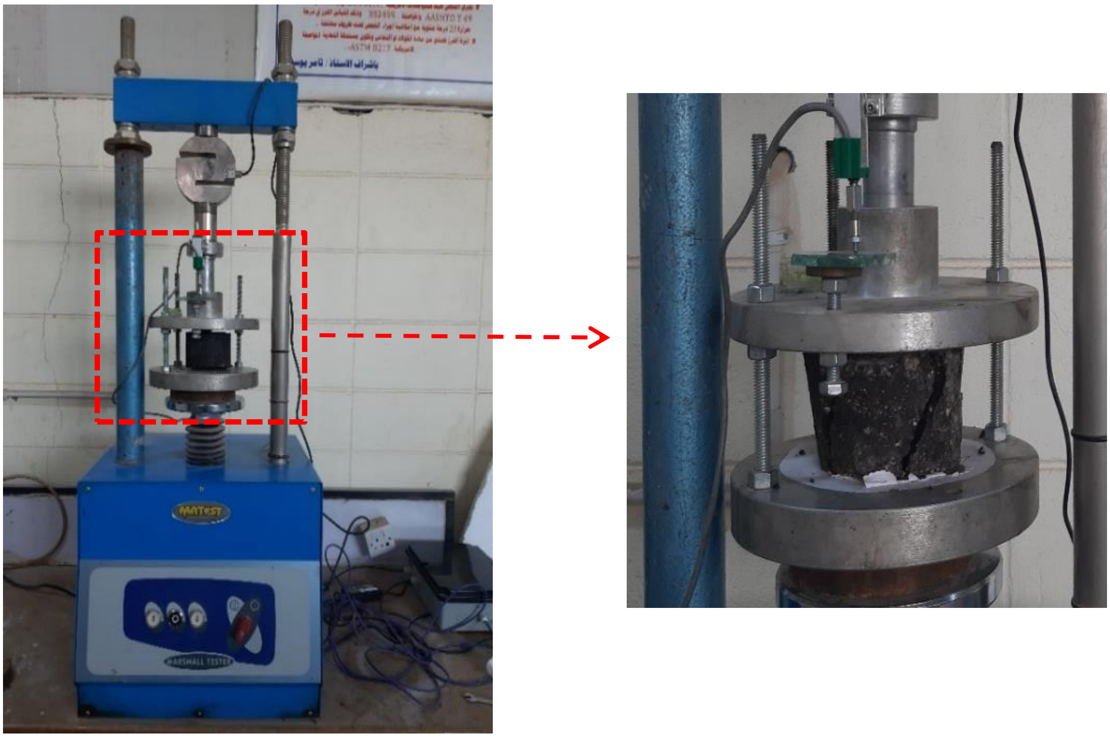

Fig. 2-a . Kim test for deformation strength

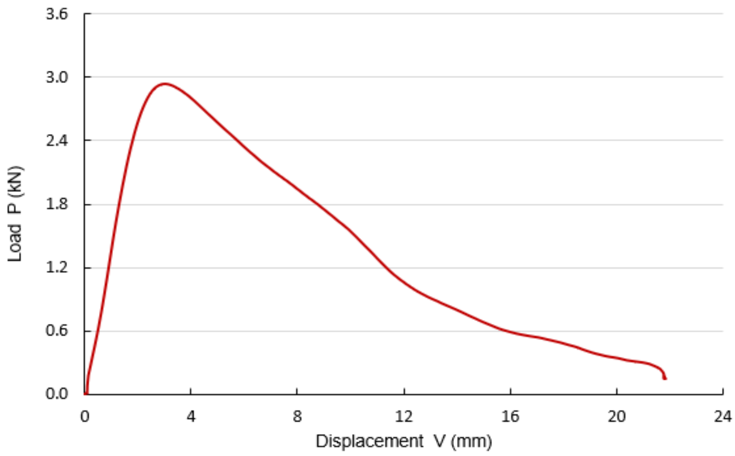

Fig. 2-b. A typical relationship for load – displacement from Kim test

5. RESULTS AND DISCUSSION

5.1. Performance of CMA in Marshall Test

According to the (ASTM D1559, 1989) test all specimens were tested at 7,14,28 days for assess the using Geopolymer at different concentrations in CMA. as shown in Fig. 3. It is obvious that the stability of the CM1 mixture is weak when compared to HMA, which is around 2.5 times greater than CM1, While the mixes to which the Geopolymer was added increased significantly, we have seen that increasing the concentration of the Geopolymer increased stability in all types of mixtures. At 2 molary shows that all of the mixtures exceeded (7KN) the minimum stability required for the binder course according to Iraq's specifications, whereas concentrates of 5 and 8 molarity increased in stability value and exceeded the stability of the HMA, especially at the age of 14, 28 days, and mixtures CM2 and CM4 exceeded the stability of the HMA for all curing periods 7, 14, and 28. Fig.4. shows flow results indicate that untreated CMA (6%LF) has a high flow value, which is unsatisfactory based on SCRB specifications. Other mixes flow values have improved in comparison to the control CMA.

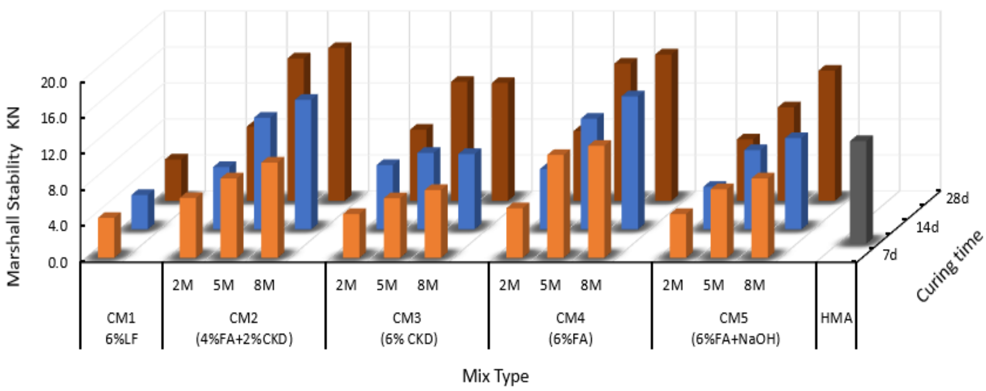

Fig. 3. Marshall stability for different CMA mixtures incorporated Geopolymer at 3 molarity and at 3 periods in comparison with HMA

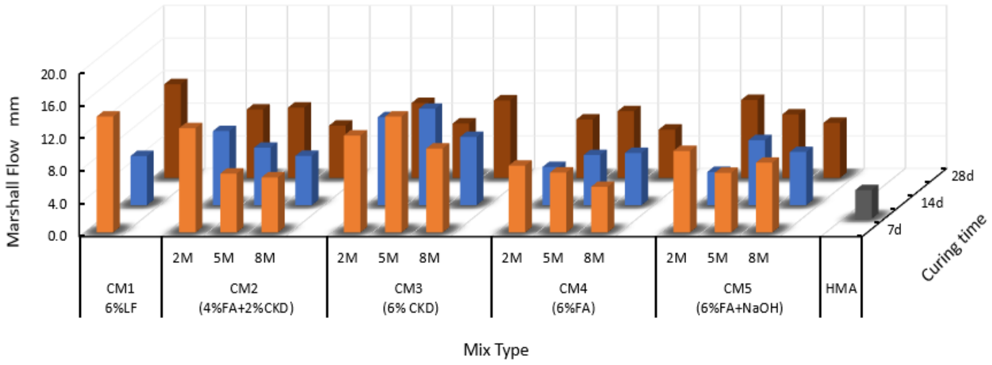

Fig. 4. Marshall flow for different CMA mixtures incorporated Geopolymer at 3 molarity and at 3 periods in comparison with HMA

5.2. Performance Moisture Damage

Moisture sensitivity is the main properties that characterize the durability of asphalt mixtures. It was determined by Tensile Strength Ratio TSR. Fig.5 displays the results of TSR for control mixtures, CAEM-G and HMA mixtures. While we see development when geopolymer is added, The greater the geopolymer concentration and the longer the curing period. It should also be highlighted that the mixes including Geopolymer had higher TSR values than the minimum values (70%) specified according to SCRB specifications, with many of them exceeding the TSR value for HMA because the ITS unconditioned value is larger than the ITS condition value, notably at 5molary, 8molary for mixtures CM2, CM4 and CM5.

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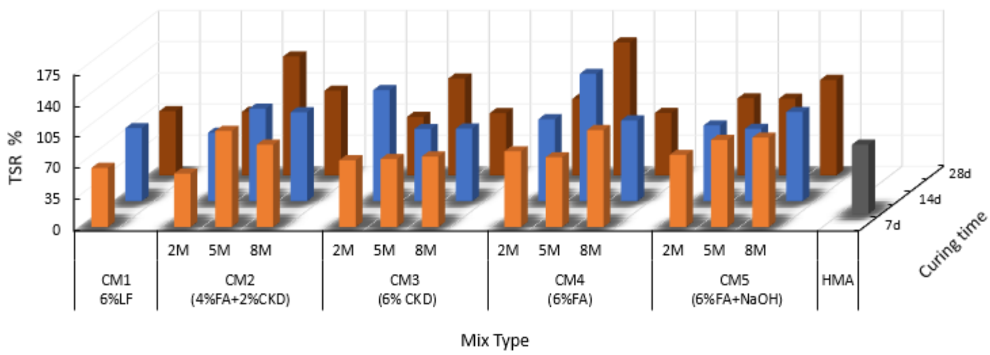

Fig. 5. TSR different CMA mixtures incorporated Geopolymer at 3 molarity and at 3 periods in comparison with HMA

5.3. Performance Deformation Strength

Fig. 6 shows the Strength against deformation results (SD) of control mixtures, mixtures containing geopolymer, and hot asphalt mixture. The specification limits of SD were a minimum of 3.2 MPa for HMA according to Korea Design criteria (MOLIT, 2017) (Kim et al., 2020). Results of SD follow the same trend of other tests, control mix lower value, HMA high value and the CMA boosted by geopolymer, its strength to deformation improves with higher concentration. Additionally, The SD values for mix CM2 were 2.5, 5.5, and 6.5 times higher than those for conventional CMA at 2M, 5M, and 8M. As with the CM4 and CM5 mixtures, the SD values followed the same trend., and their SD values neared those of the hot mix. It should be mentioned that the test was conducted at a temperature of 60°C, and it is well known that temperature has a significant impact on rutting resistance. These SD results indicate that these mixtures may be used on upper pavement courses for heavy traffic loads and diverse weather situations.

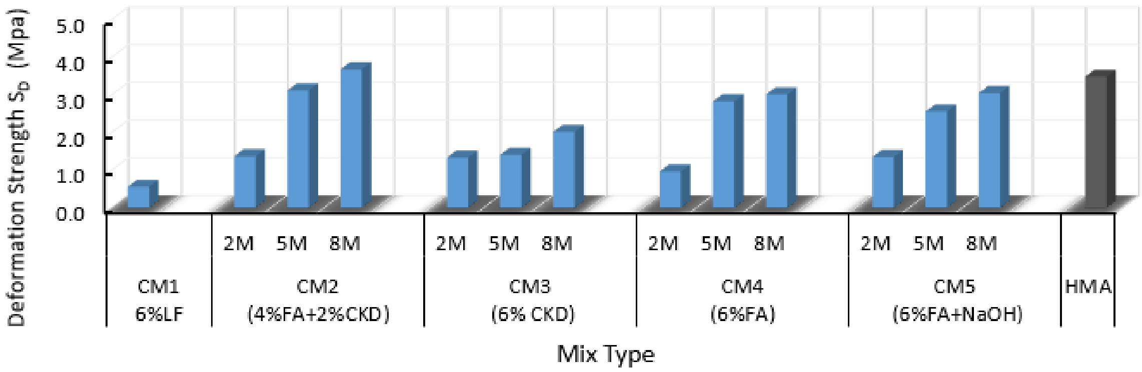

Fig. 6. Strength against deformation for different mixtures

6. SUMMARY AND CONCLUSION

This study used mechanical characteristics to evaluate the performance of cold asphalt concrete CMA with geopolymers, such as Marshall stability, indirect tensile strength (ITS), (TSR), and strength against deformation SD using different filler materials and geopolymer concentrations. Based on the testing program and the analysis of the results, the following conclusions may be drawn:

1. The major result is that the addition of geopolymer compounds had a significant effect on the specifications of cold mixes in comparison to traditional cold mix.

2. The concentration of NaOH has a significant effect on the structure and properties of geopolymers. With an increased in NaOH concentration, the Marshall stability, indirect tensile stiffness, and rut resistance improved resulting.

3. Study results indicated that conventional mixes are absolutely inappropriate for structural performance according to SCRB requirements and have limited and poor characteristics compared to hot mixtures.

4. The mechanical characteristics of CMA have improved by replacing limestone filler LF with FA. Furthermore, there has been no discernible increase in overall volumetric features.

5. Marshall stability of CMA increased significantly with adding Geopolymer to be more than the hot asphalt mixtures results at 5M and 8M, especially at 14, 28 days for CM2 and CM4.

6. At a concentration 2M, the mixtures achieved minimal stability according to SCRB specifications within 14 and 28 days, with CM2 achieving the lowest in 7 days. This is a crucial aspect of economics and sustainability.

7. CMA with geopolymer provides ITS conditioning that is larger than ITS unconditioned in terms of water susceptibility, and the results provide a TSR that is more than 100% better than the TSR for HMA.

8. According to the deformation resistance test, the best CMA mixtures are CM2, CM4, and CM5, which better than the control mix CM1.

In general, the following points are recommended:

1.For further study use potassium hydroxide (KOH) as alkali solution instead of sodium hydroxide (NaOH) in the future as activator for fly ash. Additionally, other pozzolanic materials that have cementitious properties, such as ground granulated blast furnace slag (GGBFS) or Paper Sludge Ash (PSA) or other should also be studied instead of fly ash.

2. Due to the good CM5 results in which NaOH is used alone without adding silicates Na2SiO3, researchers recommend using NaOH as solids in geopolymer synthesis and studying the influence on the properties and performance of CMA.

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