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Preparation and Mechanical Properties of Dolomite Dust-Emulsified Asphalt Composites

Qun Liu [1], Weiqing Lin [2,*] and Fangyuan Zhou [3]

1 School of Architecture and Art Design, Hubei Communications Technical College, Wuhan 430079, China
2 School of Civil Engineering, Architecture and Environment, Hubei University of Technology, Wuhan 430068, China
3 School of Civil and Hydraulic Engineering, Huazhong University of Science and Technology, Wuhan 430074, China
* Correspondence: 2235429489@qq.com

Abstract: The dolomite dust-emulsified asphalt composite with excellent mechanical properties was successfully prepared using alkali activation. The effects of different alkali concentrations and emulsified asphalt contents on the mechanical properties of the materials were studied. The mechanical properties and microstructure of the composites were analyzed using compressive strength tests, bending strength tests, and SEM characterization. The experimental results show that the specimens have excellent mechanical properties: the 7-day compressive strength can reach 76.67 MPa, and the bending strength is about twice that of silicate-based geopolymer-emulsified asphalt composite. With an increase in emulsified asphalt content, the compressive strength of the samples decreases, while the bending strength increases first and then decreases. When the emulsified asphalt content is 1%, the bending strength of the sample is up to 28.81 MPa, which is 25% higher than that of the sample without emulsified asphalt. This indicates that an appropriate emulsified asphalt content can play a toughening role in the system, providing a new idea for designing high-toughness alkali-activated materials.

Keywords: waste dolomite dust; alkali-activated; emulsified asphalt; mechanical property

1. Introduction

Ecological and environmental protection is indeed an important aspect of healthy societal development. The 19th National Congress of the Communist Party of China has clearly pointed out that "We must establish and practice the concept that clear waters and lush mountains are mountains of gold and silver, and adhere to the basic state policy of conserving resources and protecting the environment."[1] In China's industrial field, 85% of the raw materials come from mineral products in mining production. The demand for mineral resources is growing, and the huge mining industry has brought a lot of tailings and waste dust storage[2]. Dolomite is a natural carbonate mineral with abundant reserves, accounting for about 1.7% of the total crust. It is widely used in the field of building materials and metallurgy, but high purity requirements for raw materials are necessary. For example, the MgO content of dolomite used in the metallurgical industry needs to be greater than 20%, and the SiO2 content cannot be greater than 3% [3]. Dolomite ore that does not meet the demand is difficult to use in the building materials and metallurgy industry, and the perennial accumulation has become a kind of solid waste that needs to be solved urgently. Therefore, using marginal dolomite as raw materials not only avoids raw material competition with these industries but also can realize the effective use of waste natural resources.

Alkali activation is considered an effective means of treating solid waste and producing green cementing materials. The product formed is called alkali-activated materials(AAM) or geopolymer, which not only has the same or even better mechanical properties as Portland cement, but also the production conditions are more mild [4,5]. Compared with the production process of Portland cement (two grinding and one burning), AAM greatly reduce carbon dioxide emissions and energy consumption. At present, the precursor of AAM is usually amorphous aluminosilicate calcined at high temperature, such as metakaolin, fly ash and slag [6–9]. In particular, the research of bulk solid waste mainly fly ash and slag as the precursor of AAM has become a research hotspot at home and abroad, showing great development potential [10,11]. However, the researches on the cheap natural carbonate minerals with huge reserves and the wastes in the mining process as the precursors of AAM is still limited. In current relevant studies, dolomite ($CaMg(CO_3)_2$) is generally considered to lack the gellability because it does not contain the tetracomorate Al of active aluminosilicate precursors, and the research in the field of AAM is very limited [12]. Although some scholars use dolomite as a raw material for the preparation of AAM, dolomite is often used only as an additive or replacement material for traditional aluminosilicate cementing materials. Yip et al. [13] added 17-35 mm fine limestone and dolomite powder to metakaolin-based geopolymer, respectively, and found that when the addition of limestone or dolomite powder was 20% of the total weight, the compressive strength of geopolymer increased, although it would shrink within 90 days of curing time. But, when the replacement weight is more than 20% of the total weight, the compressive strength decreases due to the interference of the powder on the geopolymer gel network. Szybilski and Nocun-Wczelik [14] found that the amount of cement hydration products increased with the increase of dolomite content in cement-based materials. This is due to the fine dolomite particles after crystallization and better water absorption. Mikhailova et al. [15] showed that the mechanical properties of the composite cementing material could be improved when fine dolomite was added to cement with 20%~25% mass fraction. There are fewer studies on using dolomite as the precursor of alkali excitation materials. Aizat et al. [16] studied the influence of different NaOH molar concentrations on the compressive strength of the dolomite base polymer and found that geopolymer obtained when NaOH is 20 M has the highest strength, but it is only 5 MPa, which is difficult to meet the application requirements in construction engineering. Yin Suhong [17] has deeply explored the properties and mechanism of alkali-activated carbonate ore cement grouting materials, but the strength of the materials is only 1-4 MPa, which is mainly used for the reinforcement and seepage prevention of sandy soft strata and has not been applied in civil engineering structural materials.

Asphalt is a major concrete binding material and has become the preferred material for modern expressways due to its improved driving comfort, safety, and service life of highway pavement [18]. Currently, asphalt is used in the form of hot asphalt, diluted asphalt, and emulsified asphalt. Compared to hot asphalt and diluted asphalt, emulsified asphalt can save 40% to 50% energy, improve construction conditions, reduce project costs by more than 20% to 30%, and effectively reduce excessive aging of asphalt caused by high temperature heating. It also reduces the amount of carcinogenic benzopyrazine that is released through volatilization [19]. But the general emulsified asphalt composite has the technical problem of insufficient strength in the early stage. Combining it with AAM can not only improve the shortcomings of low toughness and high brittleness of AAM, but also effectively solve the problem of low early compressive strength of general emulsified asphalt composites by taking advantage of the characteristics of high strength and early strength of geopolymer [20].

In this study, the abandoned dolomite dust from a quarry was used as the precursor of the consolidated phase (i.e., alkali-activated material). Emulsified asphalt was used as the toughening phase, while sodium hydroxide and sodium silicate were used as alkali-activated agents. The abandoned dolomite dust-emulsified asphalt composite material with excellent mechanical properties was prepared by compression molding. The effects of different alkali concentration and emulsified asphalt contents on the compressive strength and bending strength of the sample were investigated, and the different properties of the emulsified asphalt-silicate based AAM and the emulsified asphalt-dolomite based AAM were compared in order to provide a new idea for the preparation of AAM with high toughness.

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2. Materials and Methods

3.1. Materials

Researchers selected 70#A grade road asphalt from Sinopec Maoming Branch and JY-C2 cationic medium crack emulsifier from Jiangsu Jinyang New Material Technology Co., LTD. Dolomite powder with a particle size of 250 mesh was obtained from the abandoned dolomite powder produced during the mining operation in a quarry in Shiyan, Hubei, China. Its chemical composition was determined by X-ray fluorescence (XRF-1800, Shimadzu Company, Japan), and the results are shown in Table 1. Mineralogical analysis was carried out by X-ray diffractometer (Empyrean, Panaco, Netherlands), as shown in Figure 1. The main phases were dolomite, with some doped calcite and tremolite phases. The alkali activator consists of sodium hydroxide particles and liquid sodium silicate. The modulus of sodium silicate is 3.1, the content of silica (SiO_2) is 27.66%, and the content of sodium oxide (Na_2O) is 8.8%. Sodium hydroxide particles are analytically pure (AR) grade.

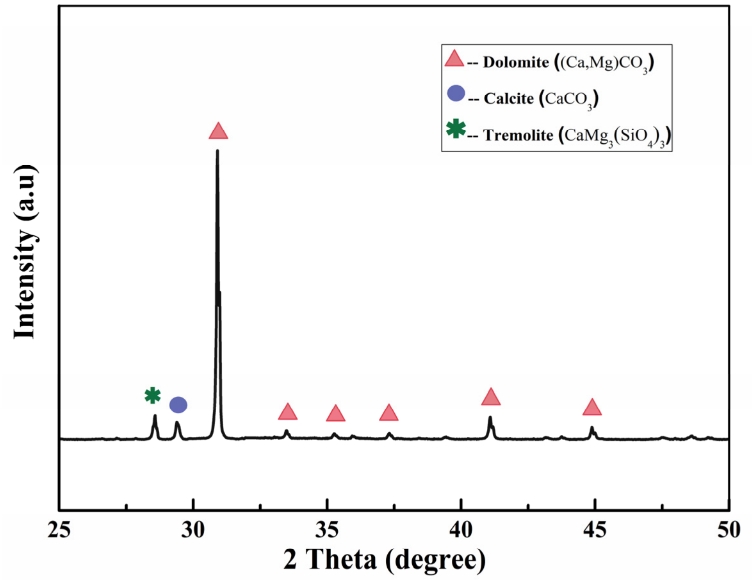

Figure 1. XRD pattern of waste dolomite dust.

Table 1. Chemical composition of waste dolomite dust (wt.%).

CO_2	CaO	MgO	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	P_2O_5
45.22	24.31	24.11	5.58	0.53	0.19	0.03	0.02	0.01

Table 2. shows the raw materials used in emulsified asphalt. First, the asphalt was heated in an oven at 165°C until it was fully flowing. Meanwhile, the emulsifier and water mixture was heated and stirred on an induction oven until the emulsifier was completely dissolved in water. Then, preheat the colloidal mill and add the mixture of emulsifier and water. Start the colloidal mill for 15 s. After that, slowly pour the asphalt into the outlet of the funnel pipeline while constantly stirring it. Once all the asphalt is added, let the colloid mill continue to run for 40 s. Finally, filter the emulsified asphalt prepared by a screen with an aperture of 1.18 mm and store it for reserve.

Table 2. Raw material proportioning for emulsified asphalt (wt.%).

Name	Asphalt	Water	Emulsifier
JY-C2	48	51.10	0.90

3.2. Sample preparation

First, add X g of dolomite powder to a grinding bowl. Then, add 0.01X g, 0.015X g, 0.02X g, and 0.03X g of sodium hydroxide particles and 0.1X g of water glass to each experimental group and mix them evenly with the powder. When the powder is wet, add 0.01X g, 0.03X g, and 0.05X g of emulsified asphalt that has been prepared to each experimental group and mix them evenly. Fill the mixed powder into a special steel mold and press it under a load of 75 MPa for 1 minute to form it. The mold was removed to obtain the compressive strength sample with diameter of 10mm and height of 10 mm and the bending strength sample with diameter of 10 mm and height of 25 mm.

The annular test mold (inner diameter 60 mm, thickness 6 mm) was pre-wet with the lino felt base, the emulsified asphalt binder was poured in and scraped flat, and the specimen was slightly formed after being placed for 1 min for demounding. The specimen was maintained at 25°C and 95% humidity for 60 min, and two cohesion specimens were prepared for each mix ratio.

3.3. Test and characterization

The samples underwent compressive strength and bending strength tests using a universal testing machine (Matest Industrial Systems (China) Co., Ltd.). The loading method was displacement loading at a rate of 2 mm/min. The field emission scanning electron microscope (Nova NanoSEM 450, FEI, Netherlands) was used to obtain the microstructure of the sample at 0.5 nA using a scattered electron detector.

After the preparation of emulsified asphalt, the pH value was determined with a digital pH meter, and the samples were respectively tested by particle ion charge test, storage stability test and Angler viscosity test according to the asphalt related test procedures JTG E20-2011 T 0754-2011, to complete the performance analysis and determination of emulsified asphalt samples.

The cohesion test was carried out in accordance with the requirements of the specification JTG E20-2011 T 0754-2011. The cohesion test specimen was prepared after completing the repeatability test of the cohesion test instrument, and was placed for 1 min to make it slightly formed and then released for maintenance. The test was carried out after the specified time.

3. Results and Discussion

Table 3 shows the basic property parameters of the emulsified asphalt. The results indicate that the emulsified asphalt is cationic acidic emulsified asphalt with an Angler viscosity of 10.95 at 25°C and a storage stability of 0% at (15±1)°C for 24 h. These findings suggest that the emulsified asphalt has high viscosity and stable storage stability.

Table 3. Basic properties of emulsified asphalt.

Types	Ion Species	pH	Angler Viscosity	Storage Stability (%)	Cohesion (N·m)
Medium breaking	cation	2.98	10.95	0	1.28

Figure 2 shows that the compressive strength of the sample after 7 days increased initially and then decreased with the increase of alkali concentration. The compressive strength of the sample was highest at 76.67 MPa when the concentration was 1.5%, indicating that there is an optimal alkali concentration that makes the sample have more excellent mechanical properties. At the same time, when the alkali concentration was between 1% and 2%, the compressive strength of the sample after 7 days was not less than 65 MPa. This indicates that waste dolomite dust has good potential as an alkali-activated material precursor and can meet the mechanical performance requirements of most building materials. However, more and more attention has been paid to the toughness of building materials at this stage. To further improve the flexural performance of AAM is conducive to broadening its use range and increasing its safety factor. Therefore, the effect of emulsified asphalt and whisker toughening will be further discussed in the following sections.

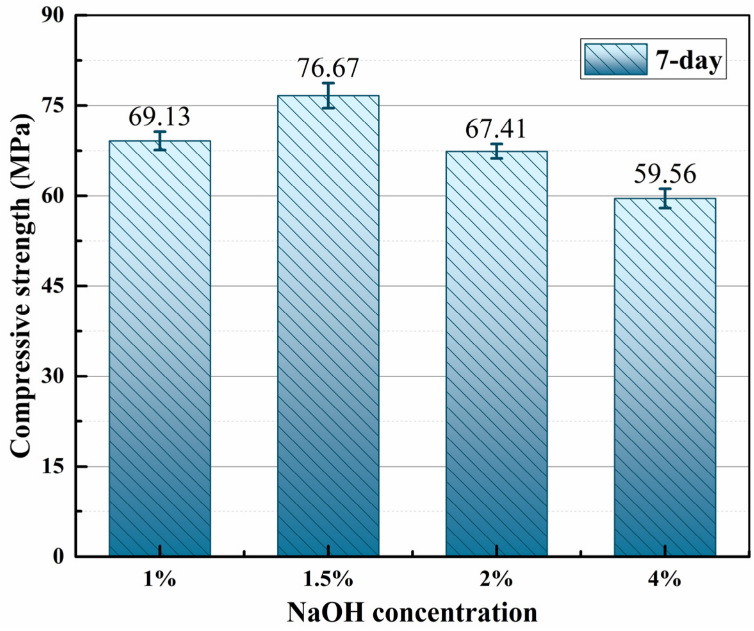

Figure 2. Effect of different alkali concentration on the compressive strength.

Figure 3 shows the relationship between the amount of emulsified asphalt added and the compressive strength of samples after 3 and 7 days. As the amount of emulsified asphalt added increases, the compressive strength of samples after 3 and 7 days shows a downward trend. This is because asphalt, as a toughening phase, is filled in the skeleton system of alkali-activated dolomite consolidated phase, and its contribution to the compressive strength of samples is weaker than that of gel produced in alkali-activated dolomite reaction. Therefore, as the amount of emulsified asphalt increases, the compressive strength of samples shows a downward trend. Comparing the strength of different asphalt contents after 3 and 7 days, it can be found that with the increase of emulsified asphalt content, the growth rate of sample strength with age increases. This indicates that the addition of emulsified asphalt slows down the reaction rate of alkali-activated dolomite and its strength development rate.

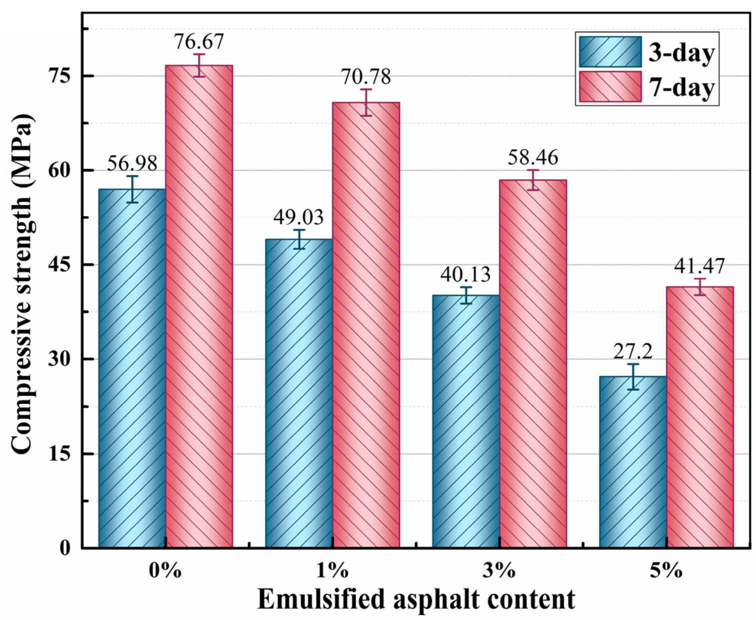

Figure 3. Effect of emulsified asphalt content on compressive strength.

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Figure 4 shows the influence of different emulsified asphalt contents on the bending strength of the sample. With an increase in emulsified asphalt content, the 7-day compressive strength of the sample first increased and then decreased. When the emulsified asphalt content was 1%, the bending strength of the sample was the highest, which was 25% higher than that of the sample without emulsified asphalt. This indicates that emulsified asphalt with an appropriate dosage plays a toughening role in alkali-activated dolomite consolidation systems and improves their fracture resistance. This provides a new idea for designing AAM with higher toughness in the future.

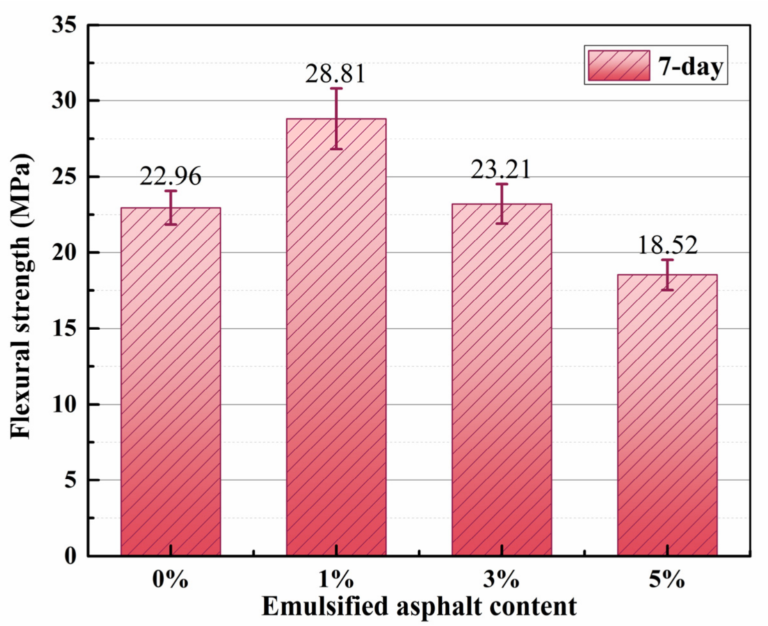

Figure 4. Effect of emulsified asphalt content on the bending strength.

Scholars have also studied the compressive and bending properties of silicate-based geopolymer-emulsified asphalt composites (SAC). In this paper, the properties of dolomite dust-emulsified asphalt composites (DAC) are compared with those of silicate-based geopolymer-emulsified asphalt composites, as shown in Table 4. It can be observed that for samples with similar compressive strength, the dolomite dust-emulsified asphalt composites prepared in this study has a significant advantage in bending performance. The bending and compressive strength ratio of dolomite dust-emulsified asphalt composite is nearly twice that of silicate-based geopolymer-emulsified asphalt composite. This is mainly due to differences in reaction mechanism and microstructure of reaction products between the two materials in alkali activator solution.

Table 4. Mechanical properties of two different emulsified asphalt composites.

	DAC			SAC [21]		
	Compressive Strength (C)	Bending Strength (F)	C/F Ratio	Compressive Strength (C)	Bending Strength (F)	C/F Ratio
Group 1	58.46	23.21	39.70%	58.7	11.8	20.10%
Group 2	60.35	23.61	39.12%	60.7	13.8	22.73%
Group 3	76.67	22.96	29.95%	76.9	10.5	13.65%

Silicate-based geopolymers dissolve and condense in alkaline environments, as shown in eqn. (1) and (2) [22,23]. The sample section's micro-morphology is uniform and continuous, as seen in Figure 5 (a) and Figure 5 (b) below.

$$(\mathrm{Si_2O_5,Al_2O_2})_n + n\mathrm{H_2O} \xrightarrow{\mathrm{NaOH}} n(\mathrm{OH})_3-\mathrm{Si}-\mathrm{O}-\mathrm{Al}^-(\mathrm{OH})_3 \quad (1)$$

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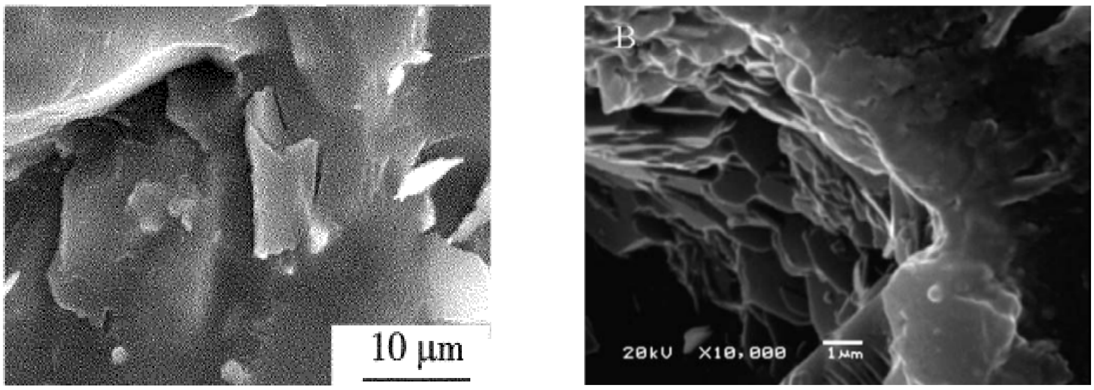
$$n(\mathrm{OH})_3-\mathrm{Si}-\mathrm{O}-\mathrm{Al}^{-}(\mathrm{OH})_3 \xrightarrow{\mathrm{NaOH}} \mathrm{Na}^{+}\left(\mathrm{SiO}_2,\mathrm{AlO}_2^{-}\right)_n+3n\mathrm{H}_2\mathrm{O} \tag{2}$$



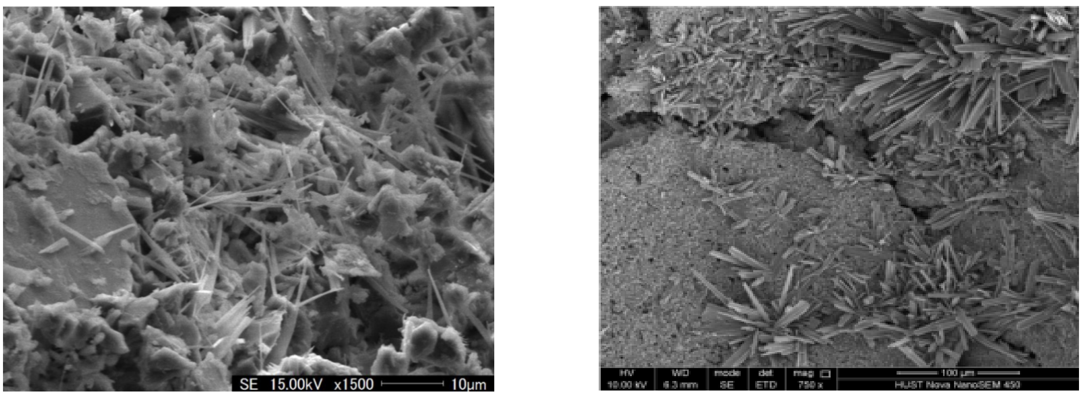
(a) (b)

Figure 5. SEM diagram of silicate-based geopolymers: (a) Slag-based geopolymer[24]; (b) Metakaolin-based geopolymer[25]

According to previous studies [26,27], dolomite dust mainly undergoes dedolomitization reaction (eqn. 3) and ion crosslinking reaction (eqn. 4) in an alkali environment. This includes a reaction process of dissolution and precipitation, during which the dolomite forms calcium carbonate in clusters of crystals, as shown in Figure 6 (a) and 6 (b) below. Unlike the homogeneous and continuous product obtained in Figure 5, the calcium carbonate obtained in the form of clusters of crystals enables more micropores to be formed in the alkali-activated dolomite sample than in the silicate-based geopolymer. The micropores of these reaction products provide a larger specific surface area for the demulsification of emulsified asphalt so that the asphalt can be more closely coated on the surface of inorganic particles, forming a ductile interpenetrating bond inside the skeleton. The microstructure diagram of two different emulsified asphalt-AAM composite materials is shown in Figure 7. It can be seen that the DAC samples have more complex morphology of micro-reaction products, and the emulsified asphalt is interwoven in the acicular whisker. The whisker and emulsified asphalt act as a toughening agent together. Therefore, under the same compressive strength, dolomite dust-emulsified asphalt composites show better bending performance.

$$\mathrm{CaMg(CO_3)_2}+2\mathrm{NaOH}=\mathrm{CaCO_3}\downarrow+\mathrm{Mg(OH)_2}\downarrow+\mathrm{Na_2CO_3} \tag{3}$$

$$\mathrm{(Ca,Mg)CO_3}+2\mathrm{NaOH}+\mathrm{H_4SiO_4}=\mathrm{(Ca,Mg)H_2SiO_4}+\mathrm{Na_2CO_3}+2\mathrm{H_2O} \tag{4}$$



(a) (b)

Figure 6. SEM diagram of dolomite-based geopolymers: (a) compression molding[16]; (b) casting molding.

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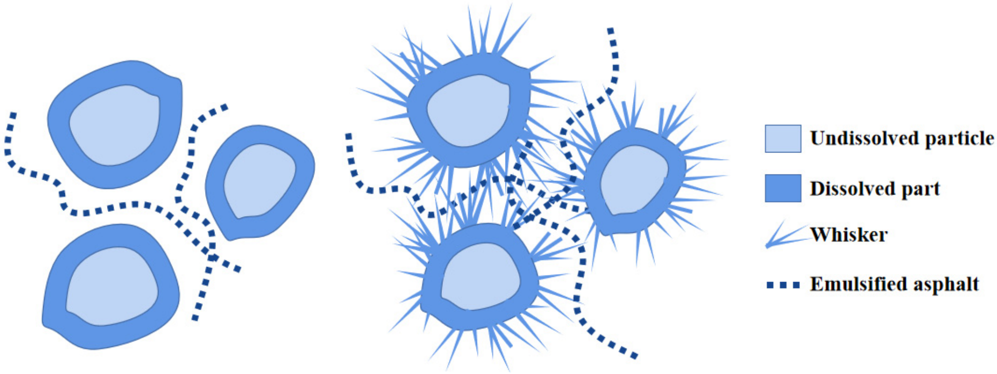

(**a**) SAC (**b**) DAC

Figure 7. Microstructure diagram of two different emulsified asphalt-AAM composites.

Figure 8 displays the micromorphologies of samples with different emulsified asphalt content at 500 and 1000 ratios. Samples without emulsified asphalt (a and b) have dense internal structures that include undissolved particles, flocculent gel on particle surfaces, and widely distributed acicular whiskers. The acicular whiskers grown on the surface of the particles are interwoven in the interstitial space between the particles and play a role in connection enhancement. It can not only improve the compressive strength of the sample, but also effectively improve the fracture toughness of the sample. In addition to particles, gels, and whisker components, samples (c and d) containing 1% emulsified asphalt also sporadically distribute demulsified asphalt internally. The demulsified asphalt covers some dolomite particles and plays a certain ductile connection role, resulting in better bending strength for the corresponding samples. However, with an increase in emulsified asphalt content to 5% (c and f), a large area of asphalt coating appears inside the sample, partially replacing the composition of particles, gels, and whiskers inside the sample. Loose pores caused by emulsified asphalt demulsification and water loss also appear around the asphalt-coated particles. This results in a decrease in macroscopic compressive strength and bending strength for the sample. The above results show that appropriate amount of emulsified asphalt and whisker can toughen together, which is conducive to the improvement of alkali-activated dolomite bending property.

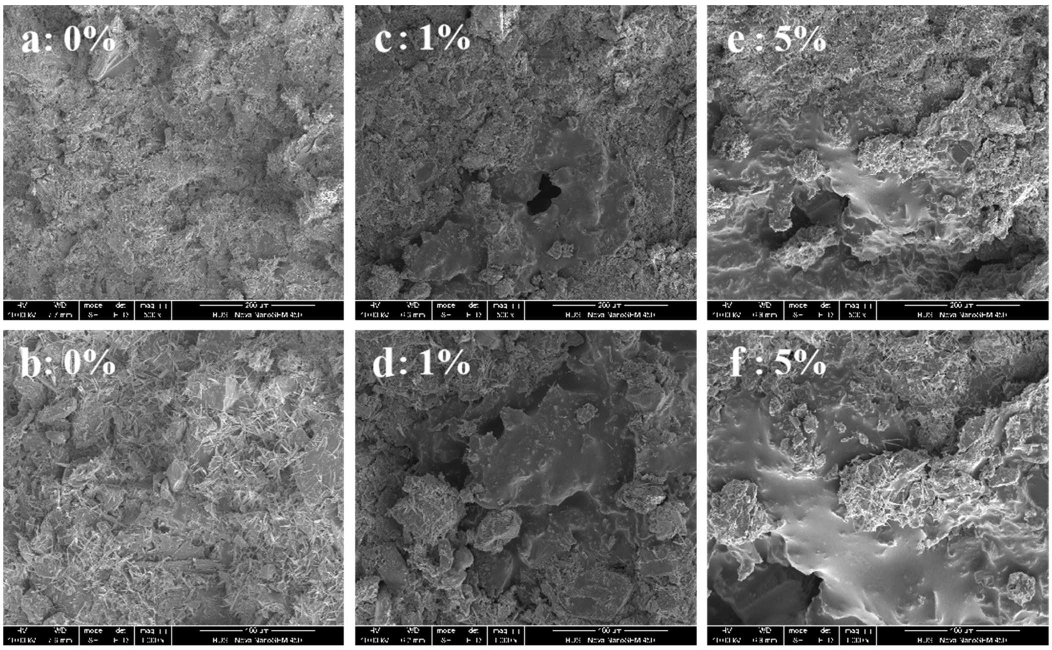

Figure 8. SEM diagram of samples with different emulsified asphalt content.

5. Conclusions

The dolomite dust-emulsified asphalt composite has excellent mechanical properties. It uses alkali-activated waste dolomite dust as the consolidation phase and emulsified asphalt as the toughening phase. The compressive strength of the consolidated phase of the composite is up to 76.67 MPa when the alkali concentration is 1.5%. With an increase in emulsified asphalt content, the compressive strength of the samples decreases while the bending strength of the samples increases first and then decreases. When the emulsified asphalt content is 1%, the bending strength of the sample is 28.81 MPa, which is 25% higher than that of the sample without emulsified asphalt. Compared with SAC, DAC has more excellent bending resistance while maintaining comparable compressive strength. This is mainly due to the formation of clusters of calcium carbonate crystals inside, which creates more micropores inside the sample. This results in a greater contact area between the asphalt and the surface of the skeleton particles, as well as more adequate demulsification and bonding of emulsified asphalt. This shows that emulsified asphalt with appropriate dosage can play a toughening role in alkali-activated dolomite consolidation systems and provides a new idea for designing AAM with high toughness.

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References

1. Xi Jinping. A Decisive Victory in Building a Moderately prosperous Society in all Respects and Striving for the Great Victory of Socialism with Chinese Characteristics for a New Era: A Report to the 19th National Congress of the Communist Party of China. Theoretical learning, 2017(12):4-25.
2. Hu Y, Li K, Zhang B, et al. Strength Investigation and Prediction of Superfine Tailings Cemented Paste Backfill Based on Experiments and Intelligent Methods. Materials, 2023, 16(11): 3995.
3. Cui Lisheng, Fu Ximing. Comprehensive development and application of dolomite ore. China Powder Industry, 2006, (2): 30-34.
4. Zhang T, Shi X, Wang Q, et al. Comprehensive Evaluation of the Performance and Benefits of SSA–GGBS Geopolymer Mortar. Materials, 2023, 16(11): 4137.
5. Panda B, Paul S C, Hui L J, et al. Additive manufacturing of geopolymer for sustainable built environment. Journal of Cleaner Production, 2017, 167: 281-288.
6. Kamal, Abdelli, Mahfoud, et al. Influence of the pozzolanic reactivity of the Blast Furnace Slag (BFS) and metakaolin on mortars. Energy Procedia, 2017.
7. Kathirvel P , Kaliyaperumal S . Influence of recycled concrete aggregates on the bending properties of reinforced alkali activated slag concrete. Construction & Building Materials, 2016, 102(JAN.15PT.1):51-58.
8. Han Dan, Che Yunxuan, Song Peng, et al. Preparation and mechanical properties of metakaolin base polymer. Sichuan Cement, 2014, 000(005):120-123.
9. Kong D, Sanjayan J G, Sagoe-Crentsil K. Comparative Performance of Geopolymers Made with Metakaolin and Fly Ash After Exposure to Elevated Temperatures. Cement and Concrete Research, 2007, 37(12):1583-1589.
10. Chindaprasirt P, Chareerat T, Sirivivatnanon V. Workability and strength of coarse high calcium fly ash geopolymer. Cement & Concrete Composites, 2007, 29(3):224-229.
11. Cheng T W, Chiu J P. Fire-resistant geopolymer produce by granulated blast furnace slag. Minerals Engineering, 2003, 16(3):205-210.
12. E. Cohen, A. Peled, G. Bar-Nes. Dolomite-based quarry-dust as a substitute for fly-ash geopolymers and cement pastes. Journal of Cleaner Production, 2019, 235: 910-9.
13. C. K. Yip, J. L. Provis, G. C. Lukey, J. S. Van Deventer. Carbonate mineral addition to metakaolin-based geopolymers. Cement and Concrete Composites, 2008, 30(10): 979-985.

14. M. Szybilski, W. Nocuń-Wczelik. The effect of dolomite additive on cement hydration. Procedia Engineering, 2015, 108: 193-198.
15. O. Mikhailova, G. Yakovlev, I. Maeva, S. Senkov. Effect of dolomite limestone powder on the compressive strength of concrete. Procedia Engineering, 2013, 57: 775-780.
16. E. Aizat, A. Al Bakri, Y. Liew, C. Heah. Chemical composition and strength of dolomite geopolymer composites. AIP Conference Proceedings. AIP Publishing LLC, 2017, 1885(1): 020192.
17. Yin Suhong. Study on alkali induced gelling and grouting materials of carbonate ore. Guangzhou: South China University of Technology, 2004.
18. Wang Jing, ZHANG Yaojun, Wang Yachao. Preparation of fly ash and slag base polymer toughened by asphalt and polypropylene fiber. Bulletin of the Chinese Ceramics, 2013, 32(007):1432-1437.
19. Wang Chang'an, Wu Yuliang, Guo Minyi, et al. Development and application of emulsified asphalt and its emulsifier. Guangzhou Chemistry, 2006, 031(001):54-60.
20. You Z, Mills J, Foley J M, et al. Nanoclay-modified asphalt materials: Preparation and characterization. Construction and Building Materials, 2011, 25(2):1072-1078.
21. Liu Leping, Cui Xuemin, Kuang Peizhang, et al. A geopolymer/emulsified asphalt composite and its preparation method, CN103232182A[P].
22. J. Davidovits. Properties of geopolymer cements. First international conference on alkaline cements and concretes. Kiev, Ukraine: Kiev State Technical University, 1994, 1: 131-149.
23. J. Davidovits. Geopolymers: inorganic polymeric new materials. Journal of Thermal Analysis and calorimetry, 1991, 37(8): 1633-56.
24. Liu Leping, Tan Hua, Deng Jiaxi, Kuang Peizang, He Yan. Properties and reaction mechanism of slag base polymer dry powder materials . Journal of Wuhan University of Technology,2014,36(06):36-40.
25. Wang H, Li H, Yan F. Synthesis and mechanical properties of metakaolinite-based geopolymer. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 2005, 268(1-3): 1-6.
26. Lin W, Zhou F, Luo W, et al. Alkali-activated dolomite and its outstanding mechanical strength. Materials Letters, 2020, 270:127682.
27. Lin W, Zhou F, Wenjun Luo, et al. Recycling the waste dolomite powder with excellent consolidation properties: Sample synthesis, mechanical evaluation, and consolidation mechanism analysis. Construction and Building Materials, 2021, 290:123198.