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EFFECT OF ASPHALT-TO-CEMENT RATIO ON STRENGTH OF CEMENT ASPHALT MORTAR USED IN HIGH-SPEED RAILWAY

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Abstract. The ballastless track structure (slab track) structure is commonly used in high-speed railway construction today. For this type of railway structure, the cement asphalt mortar polymer (CAM) layer plays an important role in damping, creating smoothness, reducing noise and ensuring simultaneous operation of the structure. Therefore, the CAM layer needs to be designed and manufactured to ensure ease of construction, strength and integrity for the entire slab track structure. This paper presents the initial experimental research results on the technology of CAM layer materials. The experimental studies were evaluated based on mixtures with asphalt/cement (A/C) ratios varying from 0.3, 0.4, 0.5, 0.6, and 0.7, respectively. The results of the research showed that, when the ratio of A/C increased, the flow time, flexural strength and compressive strength decreased. This trend of results was also completely consistent with the results of microstructural analysis by scanning electron microscope of mortar samples at 7 days of age.

Keywords: High speed railway, ballastless track, slab track, cement asphalt mortar, microstructure, scanning electron microscope.

1. INTRODUCTION

The ballastless track structure made of concrete (slab track) is an advanced railway track system with several outstanding features, such as low maintenance requirements, high durability, and reduced total thickness of the railway substructure [1]. This type of structure was first studied and applied by the Japanese National Railways in 1965 [2, 3]. Currently, slab track structures are widely used in high-speed railway construction in various countries, such as France, Germany, China, India, and South Korea [4, 5]. There are several different slab track systems, among which the Shinkansen and Bögl slab track systems utilize a Cement Asphalt Mortar (CAM) layer beneath the slab track [4]. The CAM layer serves to connect the slab track and the concrete base layer below to maintain the geometric integrity of the rail structure and absorb vibrations caused by train movement [6, 7].

Depending on different usage purposes, a type of CAM with a low elastic modulus is often used in the Shinkansen slab track system in Japan, whereas a type with a high elastic modulus is applied in the Bögl slab track system in Germany.

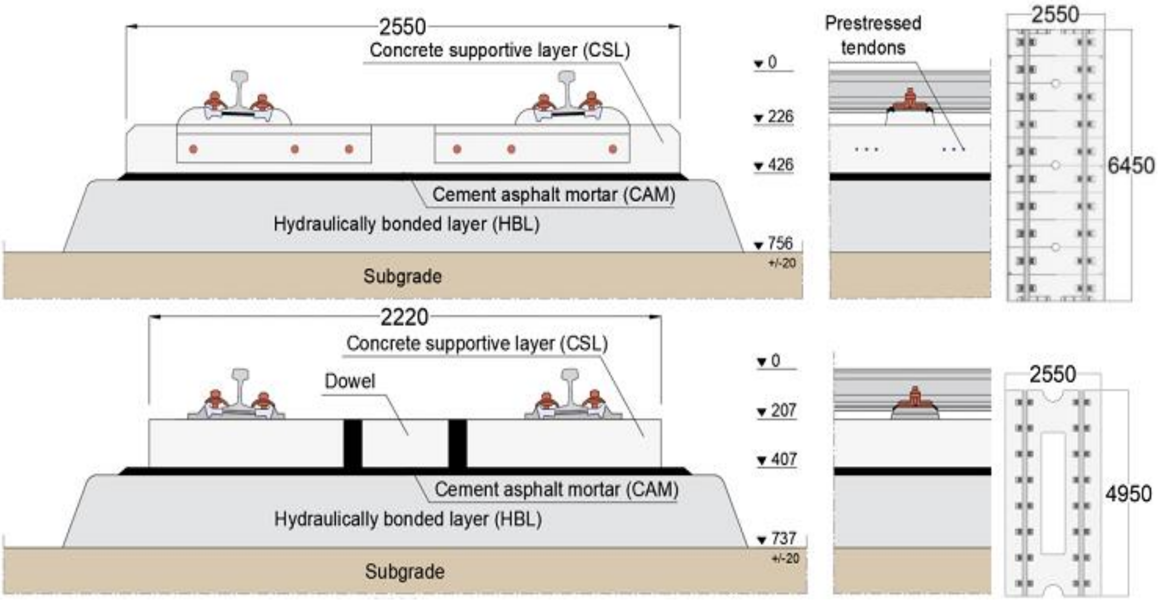


Figure 1. Slab track: (a)-Bögl, (b)-Shinkansen [4].

The composition of CAM includes cement, asphalt emulsion, sand, water, and certain chemical additives [8, 9]. Portland cement is known as an inorganic material characterized by brittleness and rigidity, whereas asphalt emulsion is an organic material exhibiting viscoelastic properties. The combination of these two materials results in a composite that balances load-bearing capacity and deformation resistance. Depending on the type of asphalt emulsion, the asphalt content typically ranges from 50% to 65%, with the remainder consisting of water, emulsifying agents, and additives [10]. In some cases, the properties of asphalt emulsion need to be modified by adding polymer substances to enhance the performance characteristics of the CAM mortar [9, 11, 12].

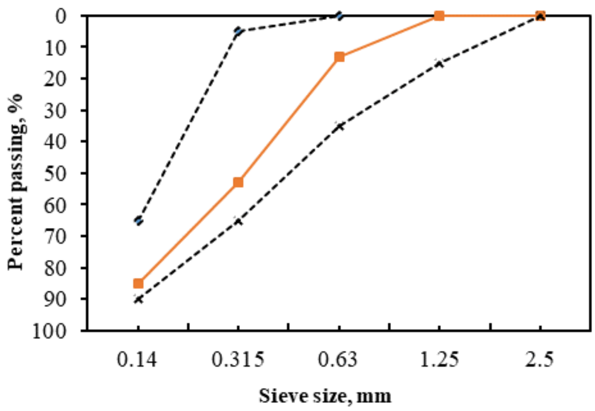
High fluidity and self-compacting capability are general requirements for CAM mortar mixtures, as CAM construction technology does not involve vibration compaction. Sand with a low fineness modulus can enhance the uniformity of CAM mortar; however, excessive fineness may negatively impact the fluidity of the CAM mortar [13]. The viscoelastic properties of CAM mortar require special attention when adjusting the asphalt-to-cement ratio (A/C). [14]. Wang et al. (2008a) investigated the effect of the A/C ratio on the setting time and rheological behavior of CAM mortar. Their findings indicated that a lower A/C ratio results in a faster setting process of the cement-asphalt paste [5]. When the water-to-cement ratio remains constant, the viscosity of CAM mortar increases proportionally with the A/C ratio. Therefore, it can be observed that although numerous studies have evaluated the properties of cement-asphalt emulsion mortar, few have focused on the strength formation mechanisms of CAM mortar when changing mixture proportions. This paper presents the results of an experimental research to determine the strength of cement mortar with varying A/C ratios, along with microstructural analyses, aiming to explain the mechanisms responsible for strength formation and development in different CAM mortar mixtures.

3. EXPERIMENTAL RESEARCH

3.1. Mix composition

Fine aggregate. The fine aggregate used was natural sand with a maximum particle size of 1.18 mm (Figure 1a). The particle size distribution and technical specifications are presented in Figure 2 and Table 1.

(a)



(b)

Figure 2. Fine aggregate: (a) Fine aggregate photo, (b) gradation plot of fine aggregate.

Table 1. Technical specifications of fine aggregate.

No	*Properties*	*Results*	*Criteria*
1	Fineness modulus	1.51	0.7-2.0
2	Impurities content (dust, silt, clay), %	0.96	Max 3.0
3	Specific gravity, g/cm3	2.654	-
4	Bulk density, g/cm3	1.432	-
5	Water absorption, %	0.73	-
6	Moisture content, %	0.1	

Asphalt emulsion. A slow-setting cationic asphalt emulsion was selected for use. The appearance of the emulsion and its technical specifications are shown in Figure 3 and Table 2, respectively.

Table 2. The properties of emulsion.

Sr.No	*Properties*	*Units*	*Test Procedures*	*Results*	*Specifications TCVN 8817-1:2011*
I	**Test on the emulsion:**				
1	Viscosity at 25 °C	s	TCVN 8817-2:2011	39	20 - 100
2	Storage stability, 24 hours	%	TCVN 8817-3:2011	0.5	≤ 1
3	Sieve test	%	TCVN 8817-4:2011	0.02	≤ 0.10
4	Particle charge		TCVN 8817-5:2011	positive	positive
5	Cement mixing	%	TCVN 8817-7:2011	1.0	≤2.0
6	Asphalt content	%	TCVN 8817-10:2011	63.3	≥ 57
II	**Test on the residue:**				
8	Ductility at 25 °C, 5 cm/min	cm	TCVN 7496:2005	>40	≥ 40
9	Penetration at 25 °C, 100g, 5 sec	0.1mm	TCVN 7495:2005	75	40 ÷ 90
10	Solubility test in trichloroethylene	%	TCVN 7500:2005	99.80	≥ 97.5

Cement. The study used ordinary Portland cement type PC40, meeting the requirements of AASHTO M85 (Figure 4). Some technical specifications of PC40 cement are presented in Table 3.

Table 3. Properties of portland cement.

Fineness (% passing 0,08 mm sieve)	*Specific surface area(m2/kg)*	*Initial setting time, minute*	*Final setting time, minute*	*Compressive strength at 20 days, MPa*
94	331	160	225	50.4

Figure 3. Engineered asphalt emulsion.

Figure 4. PC 40 Portland cement.

Water. The water used was clean water that meets the requirements of TCVN 4506:2012.

Polymer additive. The additive used in this study was a polycarboxylate-based superplasticizer, with technical specifications meeting the requirements of ASTM C494/C494M.

CAM mortar mix propotion. The CAM mix had varying asphalt-to-cement ratios, with details presented in Table 4.

Table 4. CAM mix propotion.

Mix ID	*A/C*	*Cement, g*	*Emulsion, g*	*Water, g*	*Sand, g*	*Superplasticizer, g*
CAM-1	0.3	450	225	203	900	0.9
CAM-2	0.4	450	300	173	900	0.9
CAM-3	0.5	450	375	143	900	0.9
CAM-4	0.6	450	450	113	900	0.9
CAM-5	0.7	450	525	83	900	0.9

3.2 Sample and test preparation

Mixing procedure. The mortar mixture was prepared using a forced-action mixer operating at approximately 360 revolutions per minute (rpm). The temperature of both the materials and the mixer was controlled to maintain the mortar temperature at 20 ± 1°C. The mixing procedure included mixing water and asphalt emulsion at 60 rpm in 30 seconds; then, the dry powders were gradually added over 30 seconds while the mixer was running and the mixture was mixed at 120 rpm for a total of 120 seconds. Finally, the superplasticizer was added and mixed for an additional 30 seconds at 60 rpm.

Viscosity test. The viscosity test was conducted in accordance with ASTM C939-02, using a mortar sample volume of 1000 mL (Figure 5).

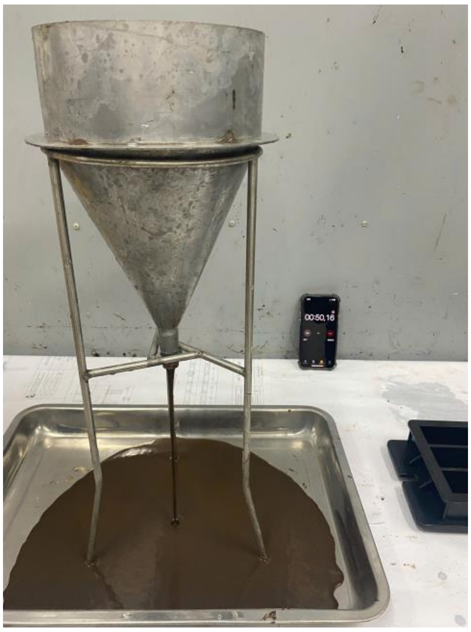


Figure 5. Flow time test.

Bending test and compression test. Mortar prisms with dimensions of 40 × 40 × 160 mm were prepared for testing, the number of replicate samples is 03 samples as specified in ISO 679:2009. After demolding at 24 hours, the specimens were initially cured at 20 ± 1°C and 95% relative humidity for one day, 7 days, followed by curing at 20 ± 1°C and 65% relative humidity for the remaining curing periods. The loading rate during the flexural tensile strength test and compressive strength test was 2.4 kN/s.

(a) (b)

Figure 6. Mortar compression testing: (a) bending test, (b) compression test.

Microstructural analysis. This study employed a Hitachi S-4800 scanning electron microscope (SEM) at the Institute of Materials Science – Vietnam Academy of Science and Technology (Figure 7) to perform microstructural analysis of 7-day hardened CAM samples through imaging techniques.

Figure 7. Microstructural analysis of cement-asphalt emulsion asphalt samples.

This device offers a maximum resolution of up to 2 nm and a maximum magnification of 800,000 times. Additionally, it is equipped with an Energy Dispersive X-ray Spectrometer (EDX), specifically the EMAX ENERGY model from Horiba (UK), which allows for the analysis of the chemical elemental composition of the samples.

3.5 Test result and discussion

3.5.1. Effect of asphalt-to-cement ratio on viscosity

Flow time is the most critical parameter of the CAM mixture, as it ensures the self-flowing and self-compacting capability of the mortar. The flow time results of CAM mixtures with varying asphalt-to-cement ratios are presented in Figure 8.

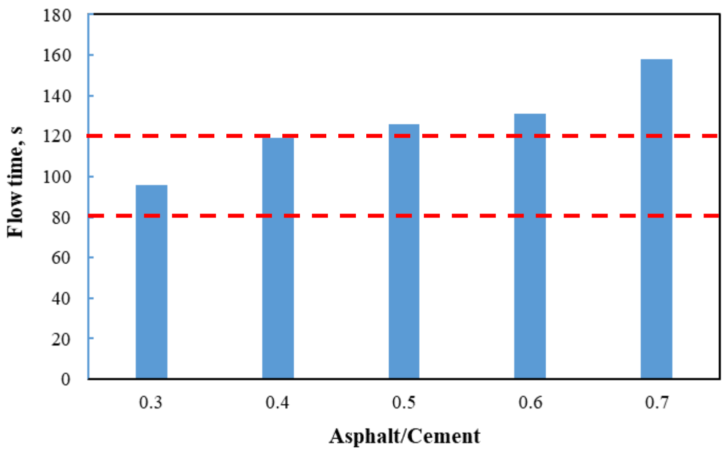
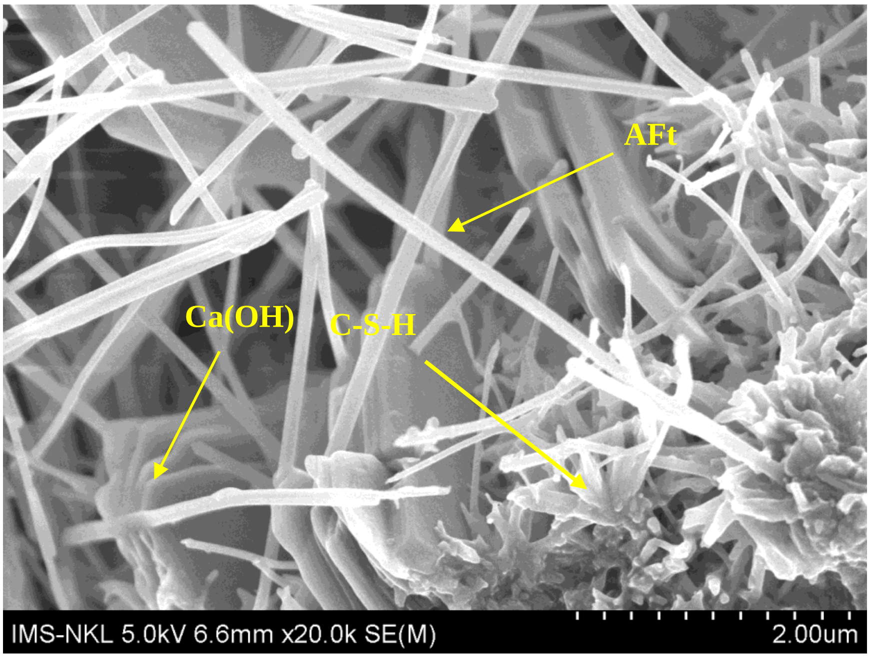


Figure 8. Flow time test result.

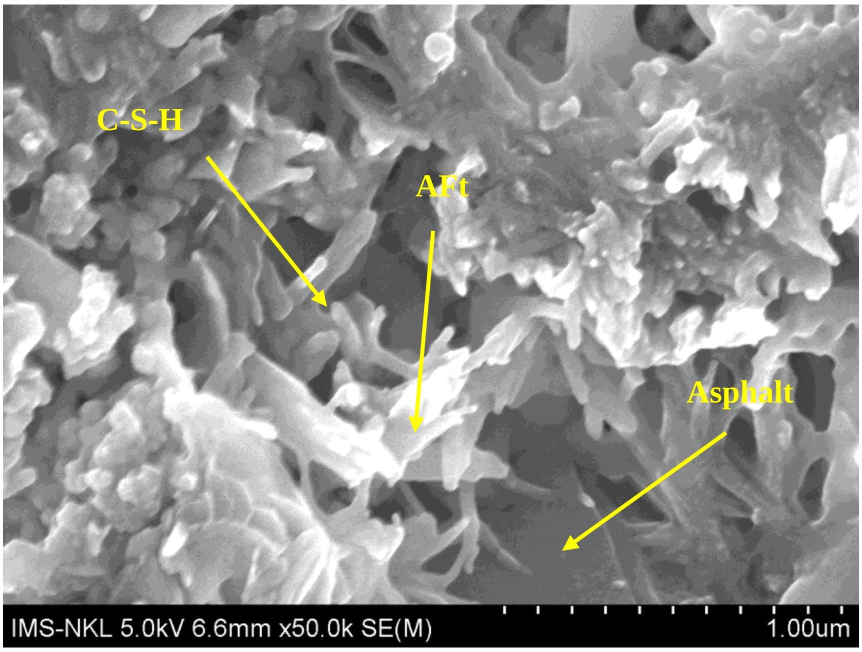
With constant cement-to-sand and water-to-cement ratios, an increase in the asphalt-to-cement ratio results in higher viscosity. This increase is attributed to the retention of free water and the agglomeration of asphalt emulsion droplets and cement particles, which in turn raises the viscosity. The workability of the cement–asphalt emulsion mortar mixture is determined by its plastic viscosity and yield stress [15]. The plastic viscosity of the CAM mixture significantly affects the flow time, while the yield stress has a greater impact on the slump flow. When the asphalt-to-cement (A/C) ratio is low, the asphalt phase in the CAM mixture is relatively small, resulting in low viscosity at that point. As the A/C ratio increases, its effect on the viscosity of the mixture is relatively minor, while it more noticeably reduces the yield stress of the CAM mixture. If the acceptable flow time range is set between 80–120 seconds [16, 17], then the mixtures with an A/C ratio of 0.3 and 0.4 meet the requirement.

3.5.2. Effect of asphalt-to-cement ratio on mortar microstructure

Figure 9 shows SEM images of mortar samples with asphalt-to-cement (A/C) ratios of 0.3, 0.5, and 0.7. It can be observed that asphalt films, C–S–H gel fibers, and AH_3 are present in the images. The performance of the mortar primarily depends on the density of hydration gels (C–S–H and AH_3) and the presence of ettringite formed during cement hydration. The hydration products of cement can penetrate through the fine asphalt film and adhere to each other or bond tightly to the surface of the aggregate. The cement hydration process consumes a portion of water in the interfacial zone between the asphalt emulsion and sand, contributing to the hardening of the asphalt binder. However, as the A/C ratio increases, the amount of hydration products in the mortar decreases, leading to a weaker structural framework (Figures 9a and 9c). Additionally, the cement particles are coated by asphalt, which hinders further hydration of the cement. Some hydration products are unable to penetrate the asphalt film, preventing complete hydration of the cement. As clearly shown in Figure 9c, a large amount of asphalt appears on the surface of cement particles and hydration products. Due to the viscous nature of asphalt, this significantly reduces the hardening and reinforcing effect of the hydration products, leading to an overall decrease in density and structural integrity.



(a)



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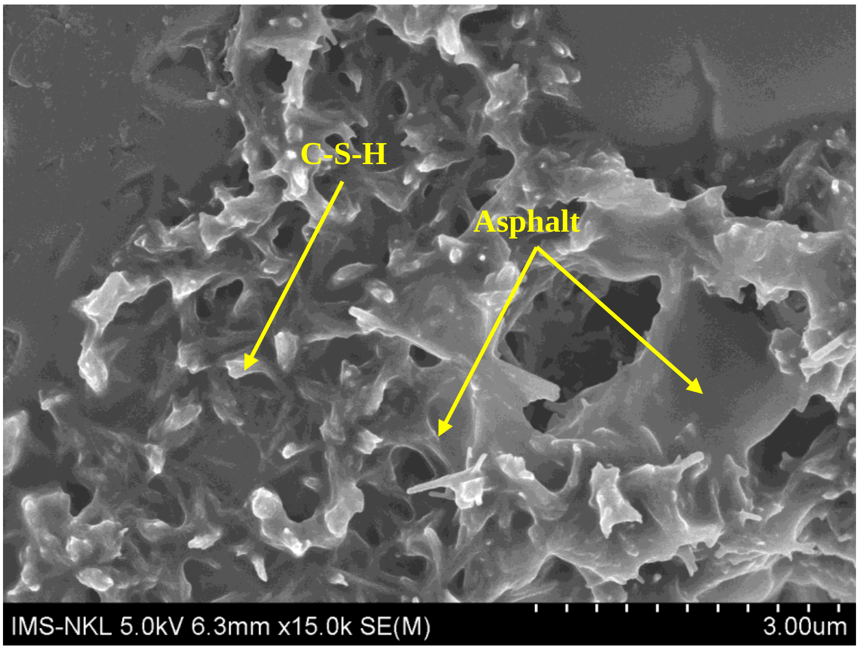

(c)

Figure 9. SEM image of 7-day mortar samples corresponding to different A/C:

(a) = 0.3; (b) = 0.5; (c) = 0.7.

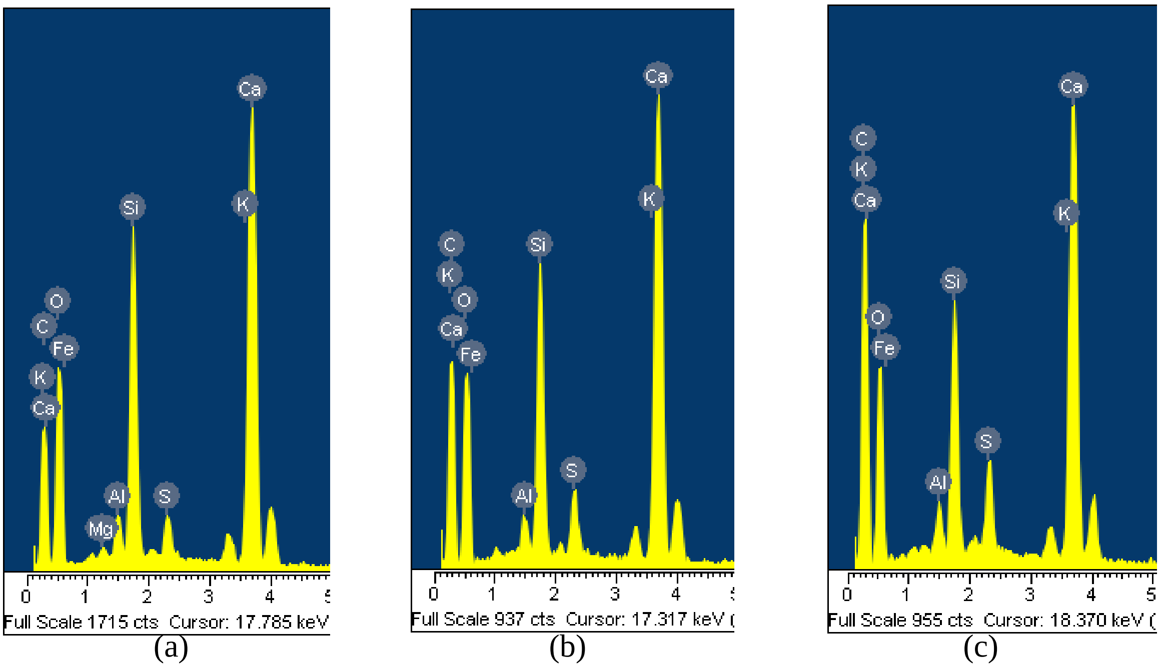

Figure 10. EDX image of 7-day mortar samples corresponding to different A/C ratios:

(a) = 0.3; (b) = 0.5; (c) = 0.7.

The EDX analysis of the samples corresponding to asphalt-to-cement ratios of 0.3, 0.5, and 0.6 revealed prominent peaks for the elements C (carbon), O (oxygen), Ca (calcium), Si (silicon), and Al (aluminum).

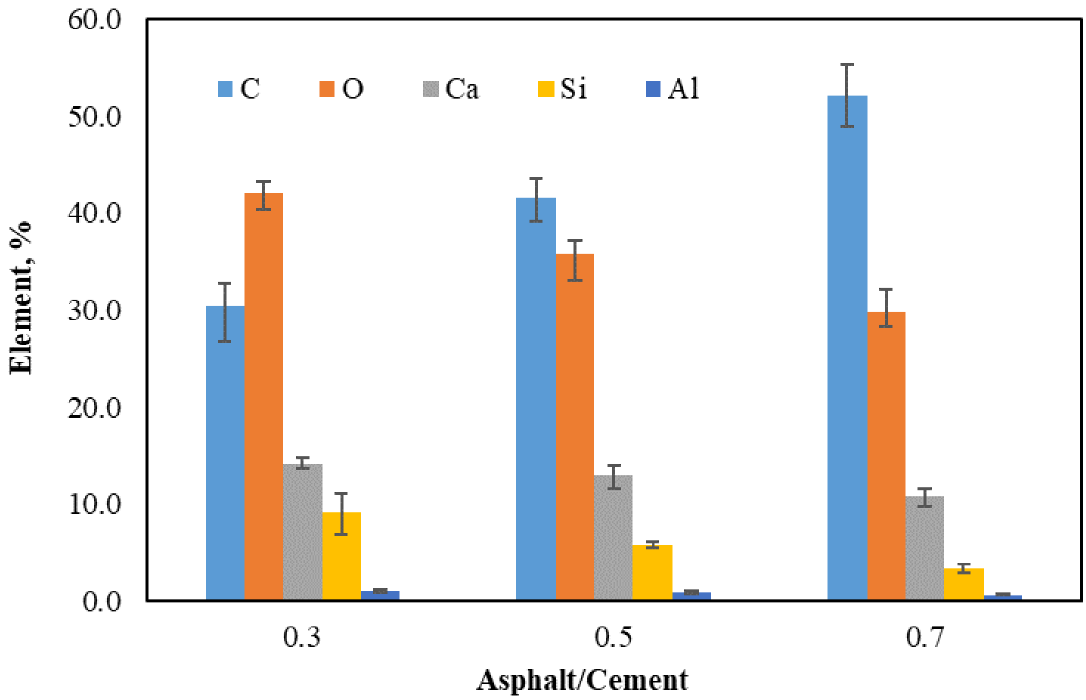

Figure 11. Element composition ratios in mortar samples

Carbon (C) is associated with the asphalt material, and the results shown in Figure 11 indicate that as the asphalt-to-cement ratio increases, the carbon content also increases, the elements Ca, Si, and Al are typically present in cement hydration products such as $3CaO.2SiO_2.3H_2O$ (C-S-H), $Ca(OH)_2$ and ettringite (AFt). The EDX analysis results show that the contents of Ca, Si, and Al tend to decrease as the asphalt content increases.

3.5.3. Effect of asphalt-to-cement ratio on flexural tensile strength

The flexural tensile strength test results of the mortar samples with varying asphalt-to-cement ratios are presented in Figure 12.

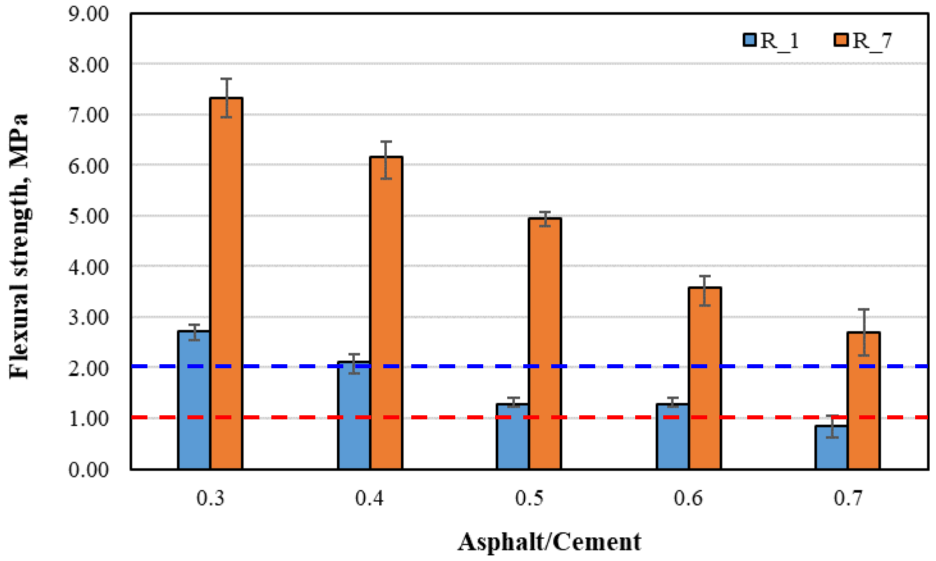

Figure 12. Flexural tensile strength test result.

It can be observed that increasing the asphalt-to-cement ratio leads to a decrease in flexural tensile strength at all curing ages. Specifically, as the A/C ratio increases from 0.4 to 0.5, 0.6, and 0.7, the flexural tensile strength decreases by 17.6%, 37.7%, 51.5%, and 64.7%, respectively. Additionally, the rate of flexural tensile strength gain from one to 7 days varies depending on the A/C ratio. The mixture with an A/C ratio of 0.5 showed the highest strength gain, increasing by a factor of 1.7. Assuming the minimum required flexural tensile strength is 1.0 MPa at one day and 2.0 MPa at 7 days [16, 17], the CAM mixture with an A/C ratio of 0.7 does not meet the performance requirements.

3.5.4. Effect of asphalt-to-cement ratio on compressive strength

The trend in compressive strength of the mortar samples at 1 day and 7 days, corresponding to different asphalt-to-cement ratios, is similar to that observed for flexural tensile strength (Figure 13).

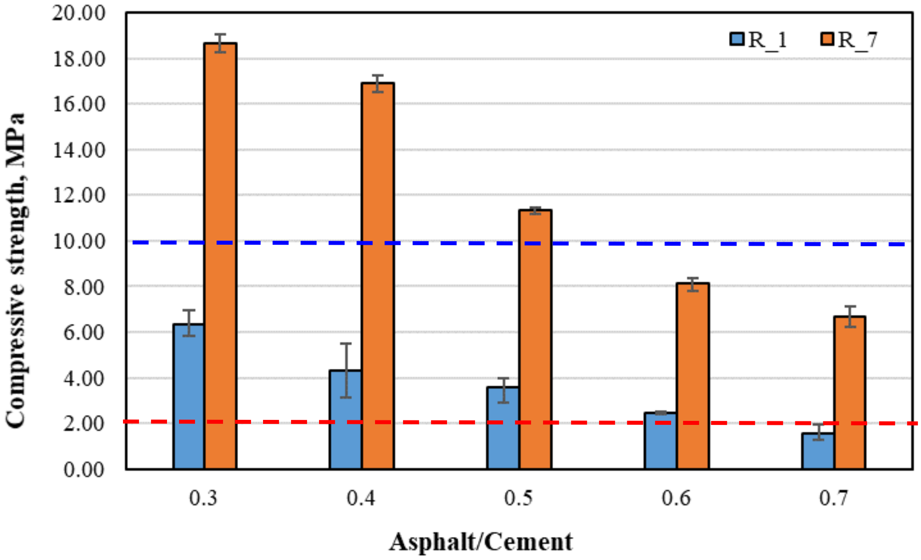

Figure 13. Compressive strength test.

It is evident that as the asphalt-to-cement ratio increases, the compressive strength of the samples at both 1 day and 7 days tends to decrease. Compared to the mixture with an asphalt-to-cement ratio of 0.3, the reduction in compressive strength is 15%, 40.3%, 57.5%, and 61.7% for ratios of 0.4, 0.5, 0.6, and 0.7, respectively. This decrease in compressive strength can be attributed to the formation of asphalt films during emulsion separation, which encapsulate the C–S–H products and hinder further hydration of cement particles, limiting the generation of additional C–S–H. This phenomenon is clearly observed in the SEM images in Figure 8 and the EDX analysis in Figure 9. Assuming a minimum compressive strength requirement of 2.0 MPa at 1 day and 10 MPa at 7 days [16, 17], the asphalt-to-cement ratio should not exceed 0.5.

4. CONCLUSION

Based on the experimental results evaluating the effect of the asphalt-to-cement (A/C) ratio on the microstructure and certain properties of CAM, the following conclusions can be drawn:

- As the A/C ratio increases, the flow time of the mixtures increases.
- The A/C ratio influences the hydration process of portland cement, higher A/C ratios reduce the extent of cement hydration.
- When the A/C ratio increases from 0.3 to 0.7, the flexural tensile strength and compressive strength of CAM decrease by 67.4% and 61.7%, respectively.

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