Cement Asphalt Emulsion Mortar Composites

Subjects: Materials Science, Ceramics

Contributor: Hussaini Umar

CA mortar (sometimes abbreviated to CAM) is one of the major construction materials for slab ballastless track in high-speed railways; it is an intermediate layer flung within the space between the track slab and the trackbed (as depicted in) of CRTS I and CRTS II. Cement and asphalt mortar is an organic–inorganic composite material primarily composed of asphalt emulsion, cement, sand, water, and other chemical admixtures. This composite material possesses fascinating properties that are different from both concrete and asphalt material alone because it couples the strength of cement as well as the flexibility of asphalt material.

damping performance | asphalt to cement ratio (A/C) | demulsification of emulsified asphalt

1. Introduction

With the design of high-speed rail, there has been an increasing demand for a high-quality railway system that includes railway tracks, communication, and a signal system, etc. Non-ballasted slab track is one of the foremost vital innovations created for high-speed railways. It is adopted all over the world due to the advantages it offers to the system over the ordinary ballasted track that includes reduced structural height, fewer maintenance requirements, durability, high lateral track resistance, which gives room for future speed increments, and no churning up of the ballast [1][2][3][4][5]. In mainland China, the China Railway Track System (CRTS), categorized into CRTS I, CRTS II, and CRTS III, are the main types of ballastless track systems adopted in recent decades.

CA mortar (sometimes abbreviated to CAM) is one of the major construction materials for slab ballastless track in high-speed railways; it is an intermediate layer flung within the space between the track slab and the trackbed (as depicted in **Figure 1**) of CRTS I and CRTS II Cement and asphalt mortar is an organic–inorganic composite material primarily composed of asphalt emulsion, cement, sand, water, and other chemical admixtures [1][3][6]. This composite material possesses fascinating properties that are different from both concrete and asphalt material alone because it couples the strength of cement as well as the flexibility of asphalt material [7]. CA mortar is produced by mixing its components using different mix proportions; its properties are mainly controlled by the proportion of asphalt to cement (A/C ratio), which is the ratio of the content of asphalt to the content of cement by mass or by volume; sometimes expressed as the ratio of asphalt emulsion to cement (AE/C).

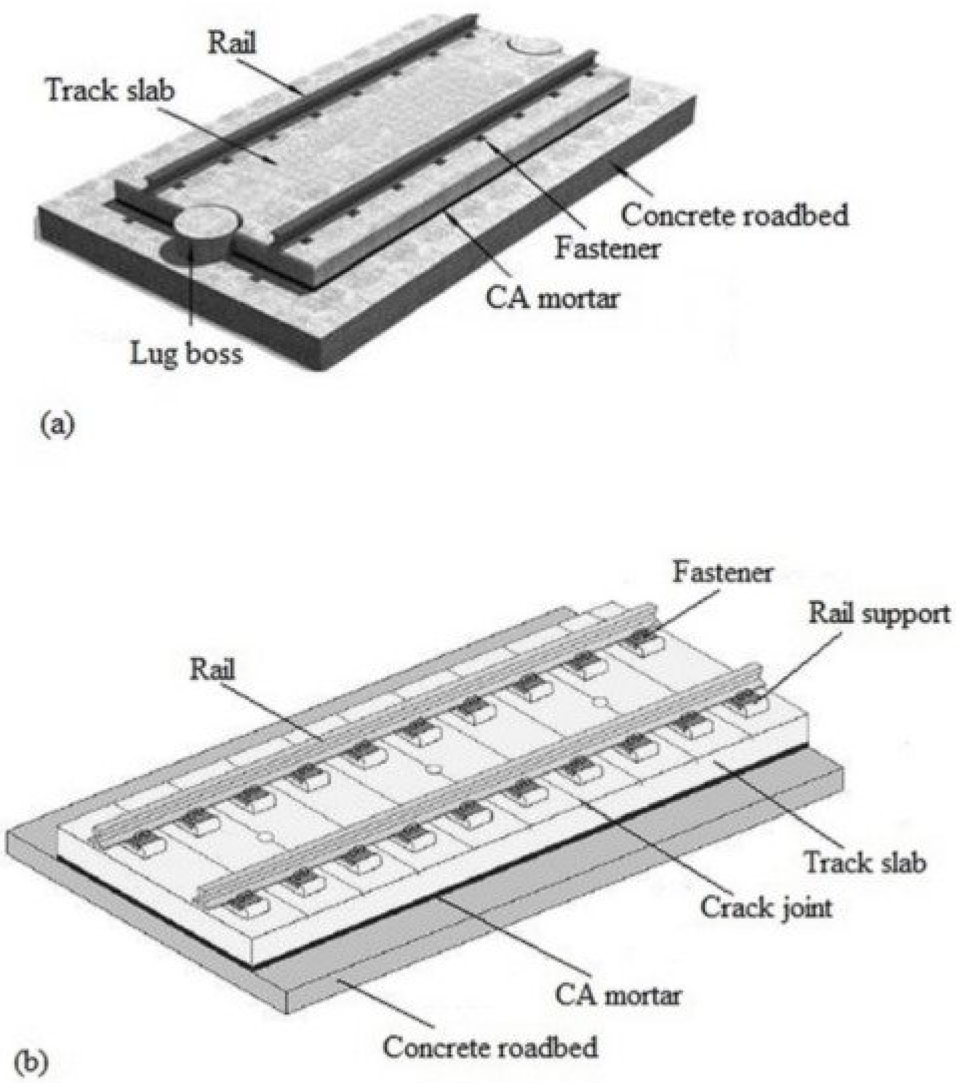

Figure 1. Structure of a slab ballastless track; (**a**) China Railway Track System (CRTS) I [8], (**b**) CRTS II [9]. CA: cement emulsified asphalt.

CAM I is mainly characterized by having high asphalt content, less cement, and a higher A/C ratio ranging between 0.6 to 1.2; contrarily, CAM II has a high cement content with less asphalt content and an A/C of about 0.2 to 0.6 [1]. Moreover, with the properties of asphalt being more influenced by temperature as compared to cement, the dynamic mechanical response of CA mortar under varied service temperatures may differ [10]. For instance, more asphalt (higher A/C) is required in CAM I when the railway structure requires more damping performance; whereas more cement (lower A/C) is included in CAM II if the railway structure needs more strength compared to the damping performance [11].

The interaction between the constituent materials of CA mortar influences its properties; the interactions between components of CA mortar include the impact of cement on the breakdown of emulsified asphalt and the effect of emulsified asphalt on the hydration process of cement [12][13]. Therefore, CA mortar does not combine only the advantages of cement and emulsified asphalt materials but also improves the shortcomings of the two materials. Properties of CA mortar such as the damping performance and strength characteristics are greatly affected by the amount of asphalt emulsion and cement. The damping performance and strength characteristics of CA mortar are determined by various parameters by engineers during design, which includes the type of railway track structure, load, environmental conditions, etc.

Currently, the incorporation of industrial by-products, naturally occurring minerals, and other supplementary cementitious materials (SCM) as a partial replacement of cement in the production of CA mortar has also been getting attention from researchers across the globe. [14] proposed a technique that assesses the plausibility of stabilizing the ballast using CA mortar, as an eminent solution to minimize losing the track quality as a result of particle abasement and ballast settlement. Based on the technique they proposed, pouring fresh CA mortar on the ballast layer will cause the CA mortar mixture to flow through the ballast system, thereby coating the ballast particles and creating strong inter-particle bonding [15]. Although the properties of asphalt material are delicate to climatic conditions such as moisture and temperature, in this technique, the incorporation of cement will mitigate this problem.

2. Preparation of CA Mortar

CA mortar is prepared using an appropriate mix proportion of constituent materials and depending on the type of CA mortar and where it will be used or applied, the proportion of materials varies. These proportions include the percentage by mass or volume of each of the constituent materials, as well as the various ratios such as A/C, ratios of sand to cement (S/C), water to cement According to the chosen mix proportions, the materials are then mixed using the designated method and apparatus. Consequently, in the construction of a non-ballasted plate track, CA mortar is grouted within the space between the bottom concrete trackbed and the top track slab with its gravitational force; thus, it needs to possess good properties to alter to such a technique [3][16][17], and to enhance the stability and comfort degree of the ballastless slab track structure [18].

To produce CA mortar with desirable mechanical properties, the air content should be within the range of 8% to 12%; and it was reported that mixing speed, mixing time, and fluidity had direct effects on the air content of CAM [19]. The mixing speed and defoaming agents influenced air content by affecting air bubble entrainment and retention. Defoamers or defoaming agents are used in CA mortar preparation to control the air content together with the appropriate mixing speed and mixing time. Concerning mixing speed, when the mixing speed is high, the defoamers also try to depress the air-entraining ability; but when the mixing speed is low, the defoamers may have a slight influence on air-entraining ability [19].

When cement and asphalt emulsion form a mixture, cement hydration and the demulsification of emulsified asphalt begin to take place; the asphalt droplets usually form asphalt film after demulsification and cement grains are hydrated out–in, which consumes the water and increases the solid contents [3]. The structural development of CA mortar is associated with the change of state of the mixture of cement and asphalt emulsion from flow paste to a solid or hardened mortar. This mixture changes from flow or liquid state to plastic state and then to the solid-state; this process can be divided into four major phases or states: the dispersion state, the phase of interaction between emulsified asphalt with cement, the asphalt film structural formation phase, and structural development of solid mortar [3].

In the dispersion state, cement particles and asphalt emulsion droplets disperse independently within the fresh CA paste [3].**Figure 2** illustrates the dispersion state in the structural development of CA mortar.

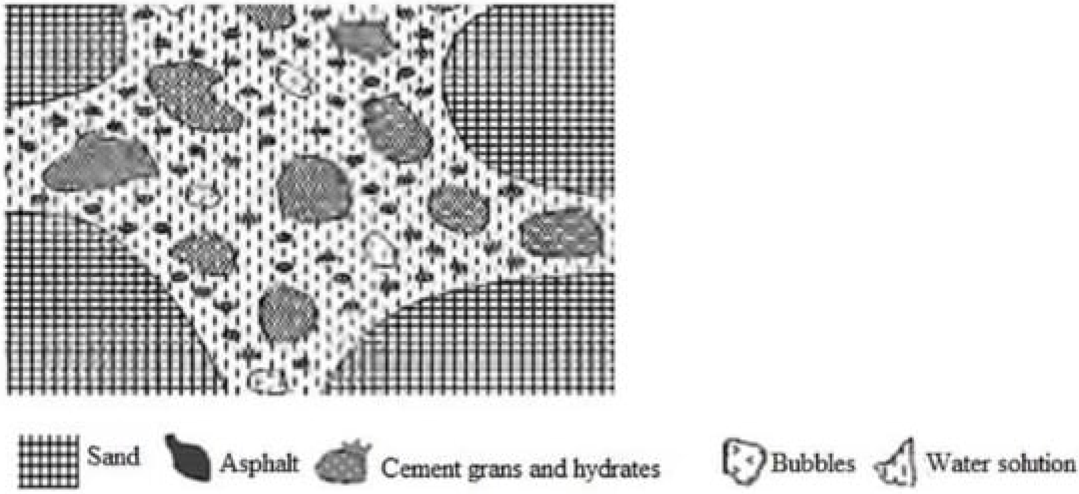

Figure 2. Dispersion state [3].

When asphalt emulsion and cement are mixed, they interact with each other in such a way that the consumption of water due to the hydration of cement accelerates the breakdown of emulsified asphalt; likewise, the adsorption of asphalt droplets on the surface of cement grains slows down the cement hydration process [1][20][21]. $Ca(OH)_2$ from the hydration of cement neutralizes the acid in emulsified asphalt, as such, hydration product begins to form when the $Ca(OH)_2$ concentration is saturated. At the same time, an asphalt emulsion is absorbed onto the cement grains and cement hydration products [3]. The interaction among cement and emulsified asphalt are usually represented experimentally by two aspects: the acceleration of asphalt emulsion breakdown due to the process of hydration of cement, and the retarding effect on cement hydration caused by the adsorption of asphalt droplets on the surface of cement grains [1], as illustrated in **Figure 3**.

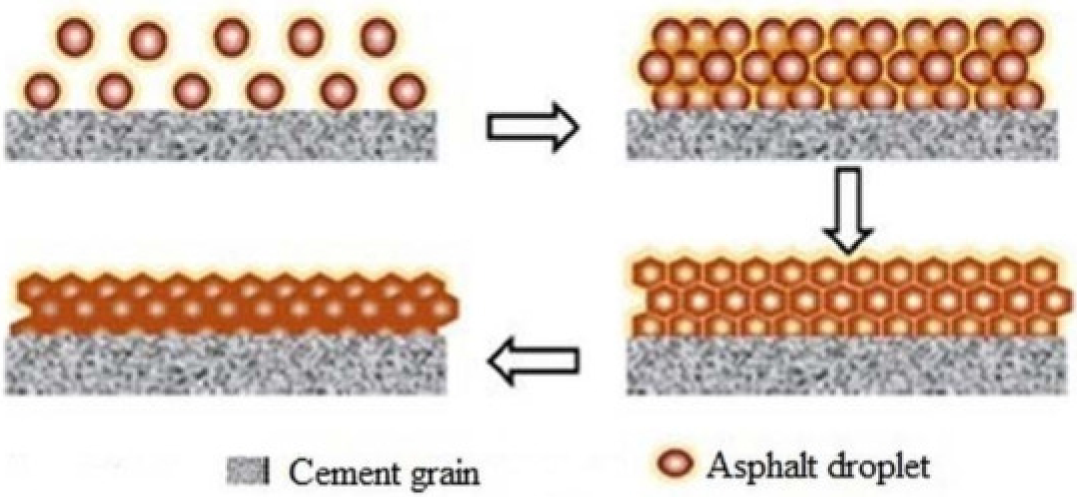

Figure 3. Schematic representation of asphalt net formation on cement grain [20].

[22] reported that emulsified asphalt affects both the rate of cement hydration and the degree of hydration, stating that emulsified asphalt retarded the rate of the hydration of cement but did not change the composition of cement hydrates. The degree to which asphalt emulsion affects the hydration process relies on the type or class of emulsified asphalt used. Nevertheless, the incorporation of anionic emulsified asphalt into cement causes a remarkable delaying effect than cationic emulsified asphalt [20]. [23], when emulsified asphalt and cement are blended, no chemical reaction could be detected except for the cement hydration process.

Once in contact with water, Portland cement begins to hydrate, set, and then hardens due to the number of chemical reactions among different chemical substances and water [24]. Emulsified asphalt, on the other hand, is formed by the process of dispersing small beads of asphalt or bitumen in water. Emulsified asphalt can be solidified or demulsified by flocculation and coalescence of asphalt droplets [1][25], as illustrated in **Figure 4**.

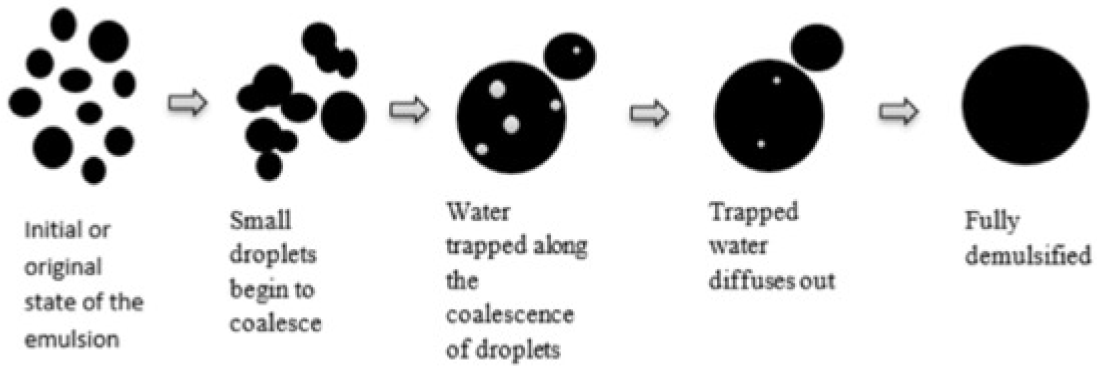

Figure 4. Stages in the breakdown or demulsification of asphalt emulsion [26].

As soon as cement and emulsified asphalt are mixed, cement consumes water from emulsified asphalt, and this consequently decreases the distance between asphalt droplets. As a result, asphalt droplets make contact and coalesce and finally form a continuous asphalt film, as illustrated in **Figure 3**.

The consumption of water by cement promotes the breakdown of emulsified asphalt, and the continuous hydration process brings about the rapid consumption of free water from emulsified asphalt and the absorption of asphalt droplets on the surface of cement grains. Meanwhile, asphalt particles coalesce together to form a membrane around the surface of hydration products, fine aggregates, and non-hydrated cement particles. At last, the asphalt membrane gets stuck to the surface of the hydration products and forms a spatial network structure, and then fine aggregates and cement hydration products fill the asphalt net structure as a filler [3][27][28]. Asphalt droplets split gradually, and its membrane sticks to cement hydrates (as depicted in **Figure 3**) to try and stop further cement hydration.

The results of their study indicated that emulsified asphalt slows down early cement hydration, and the asphalt membrane negatively influenced further hydration of cement. They reported that for CAM-II, which possesses a lower A/C and a high elastic modulus, hardened cement paste is the essential structural skeleton that influences strength development. While for CAM-I, which has a higher A/C and low elastic modulus, the framework formed by the asphalt film membrane and the framework formed by hardened cement paste are responsible for the strength development [28]. Their study clearly shows that the A/C ratio plays a vital role in determining the properties of CA mortar, but no detailed explanation was found in their study as to the effect or contribution of using different types or classes of emulsified asphalt on the strength development of fresh and hardened CA mortar.

The fine structure of a material as revealed by microscopy is the microstructure of that material. Scanning electron microscopy (SEM) image analysis and mercury intrusion porosimetry (MIP) are among the techniques commonly used to study the microstructure of CA mortar. The microstructure of CA mortar reveals the fine structure of cement hydration products bind together with the asphalt membrane structure, the combination of which is referred to as cement asphalt binder (CAB). Cement asphalt binder is characterized by a two-phase system, including the asphalt binder phase and the hardened cement paste (hcp), which are produced from the demulsification of asphalt emulsion and cement hydration, respectively [1].

When cement and emulsified asphalt are mixed, cement consumes water, and cement hydrates such as calcium silicate hydrate (C-S-H), calcium hydroxide (CH), and ettringite are produced. Furthermore, at the end of the cement hydration, the porous C-S-H gel takes up a large volume of hardened cement paste and forms a compound microstructure [1]. With regards to asphalt binder, being an organic material, asphalt binder has a complex microstructure which is decided by its chemical components; asphalt binder is generally regarded as having a colloidal system, and therefore, at a macroscale level it can be regarded as one continuous phase [1][29][30].

At 6 h after mixing, some cement hydrates could also be observed but in a limited amount, as shown in **Figure 5**c; this indicated that cement hydration is in the acceleration period, so many products are produced at 6 h after mixing [31]. At 24 h after mixing, as depicted in **Figure 5**e, a large amount of cement hydration products with ahigh consumption of free water resulted in emulsion splitting that consequently resulted in the formation of the asphalt membrane. When the demulsification of emulsified asphalt was completed, the asphalt membrane gets attached to the surface of cement hydrates. It can be observed in **Figure 5**f that at 28 days, a permeating network of cement hydration products and asphalt membrane had been formed [31].

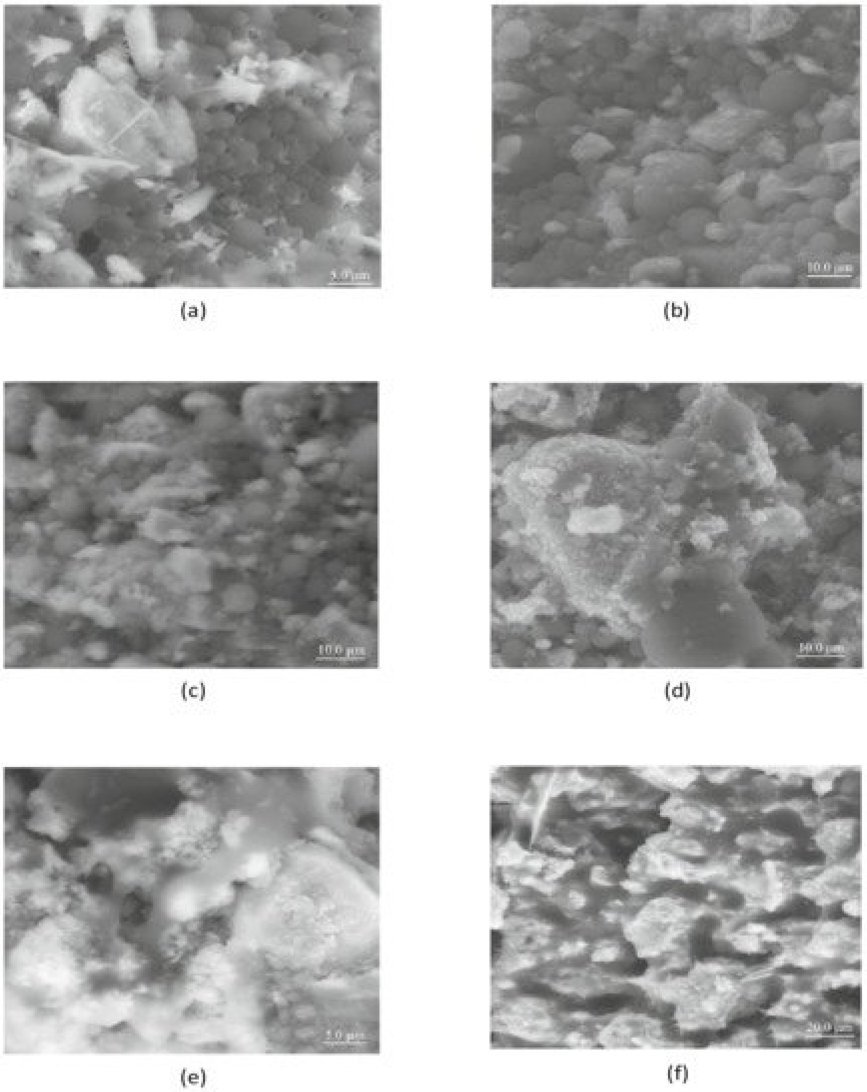

Figure 5. SEM images for the microstructure of CA paste hydrating at (**a**) 0 h after mixing (**b**) 3 h (**c**) 6 h (**d**) 12 h (**e**) 24 h (**f**) 28 days curing age [31].

The interaction between cement and emulsified asphalt ensures that after the process of cement hydration, cement hydrates provide strength to the CA mortar while emulsified asphalt provides toughness to the CA mortar after demulsification. , it was reported that the increase in the A/C improves the ability of CA mortar to resist deformation and also enhances its plasticity; increasing the A/C brings about an increase in the amount of asphalt, which significantly increases the amount of asphalt film that wraps the surface of cement hydrates; this consequently improves the damping ability of CA mortar. Therefore, the incorporation of rubber powder into the CA mortar can enhance its damping ability for good energy absorption and vibration dissipation. Similar conclusions have been made in the related literature [32], where it was documented that the incorporation of rubber powder or fiber can ameliorate the damping ability of cement mortar; nevertheless, the incorporation of fiber was found to be more efficient than RP in enhancing the damping ratio of cement mortar [32].

3. Compatibility between Major Constituent Materials of CA Mortar

In CA mortar preparation, the mixture of its constituents is generally associated with two major processes, i.e., the cement hydration process, and the breaking down of emulsified asphalt; these processes affect each other. Therefore, cement and emulsified asphalt should have an appropriate ratio in which the rate of hydration of cement will match the rate of demulsification of asphalt emulsion [3]. The compatibility between cement and emulsified asphalt is termed as having an appropriate proportion of cement and emulsified asphalt in which the cement hydration rate matches the emulsion breaking speed. CA mortar is a profoundly flowable grout made with different heterogeneous constituents of distinctive proportions, and thus, the compatibility among them is very imperative as they impact both fresh and hardened properties of CA mortar.

The hydration of cement affects the chemical stability of emulsified asphalt in different ways; the loss of water to cement hydration causes the spaces between the asphalt particles within the emulsion to collapse, and this increases the chances of the coalescence of asphalt micelles. [33] studied the effect of pH value, $Ca2^{+}$ concentration, and water loss due to hydration of cement on the chemical stability of asphalt emulsion. [21], the adsorption manners among emulsified asphalt and cement in CA mortar were studied, and it was reported that cement hydration speed up the demulsification of asphalt emulsion, which in return accelerated the adsorption of asphalt droplets onto the surface of cement grains, thus, increasing the particle size in the cement–asphalt emulsion (CAE) system. They used the filtration method to study the adsorption property of asphalt particles to the surface of cement grains, while the influence of adsorption behavior of asphalt droplets in the emulsion on the particle size of the CAE system was evaluated using a laser particle size analyzer.

[22] compares CA mortars prepared with two different asphalt emulsions with cement mortar in terms of the hydration process of cement, microstructure, compressive strength, and the chemical composition of cement hydrates. Additionally, their energy dispersion (EDS) and SEM analysis showed that asphalt emulsion retarded the rate of cement hydration but did not alter the chemical composition of cement hydrates. [34], the slow down effect of emulsifiers on cement hydration was evaluated by measuring the setting time of cement, cement hydration rate, and X-ray diffraction analysis. Besides, emulsifiers with a high slow down effect on the hydration of cement cause a loss in the hydration heat, cement hydrates, and also aborts hydration at an early age.

They reported that the incorporation of emulsified asphalt remarkably influenced the hydration of cement, and the total heat of hydration was found to decrease with an increase in the A/C. Furthermore, they also reported that the slow down effect on cement hydration due to anionic emulsion was more than that of the cationic emulsion—this was also reported in the related literature [20]—thus, anionic emulsion resulted in a lower hydration heat than cationic emulsion. Concerning workability, anionic emulsion enhanced the workability of CA mortar more than cationic emulsion [35]. This may be connected to the manner of their adsorption on the surface of cement grains, and since anionic emulsion retards the cement hydration process, the setting time of cement will also be prolonged; this helps in improving the workability of CA mortar made with anionic emulsion.

When introduced or incorporated into cement mortar, emulsified asphalt generally has a negative influence on its strength and modulus of elasticity but improves its deforming ability [7][28][36][37]. Studies show that CA mortar with a higher A/C is associated with low strength and higher damping ability, while CA mortar with a lower A/C is associated with a higher strength but low damping ability. This is related to the increase in cement content and cement hydrates that is associated with a decrease in the A/C; cement possesses a higher elastic modulus than asphalt, so increasing cement content causes an increase in the elastic modulus of CA mortar; this is in line with some other results found in the related literature [37]. Therefore, increasing sand content leads to an increase in the elastic modulus of the CA mortar [38].

References

1. Liu, Y. Static, Dynamic Mechanical and Fatigue Properties of Cement-Asphalt Mortars; UCL (University College London): London, UK, 2018.
2. Markine, V.; Esveld, C. Assessment of High-Speed Slab Track Design. Eur. Railw. Rev. 2006, 12, 55–62.
3. Wang, F.; Liu, Y. The Compatibility and Preparation of the Key Components for Cement and Asphalt Mortar in High-Speed Railway. Reliab. Saf. Railw. 2012, 223–262.
4. Lei, X.; Zhang, B. Analysis of Dynamic Behavior for Slab Track of High-Speed Railway Based on Vehicle and Track Elements. J. Transp. Eng. 2011, 137, 227–240.
5. Esveld, C. Recent developments in slab track. Eur. Railw. Rev. 2003, 9, 81–85.
6. Zeng, X.; Xie, Y.; Deng, D.; Long, G. Vibration adsorption and separation capacities of CA mortar. J. Build. Mater. 2013, 16, 356–360.
7. Rutherford, T.; Wang, Z.; Shu, X.; Huang, B.; Clarke, D.R. Laboratory investigation into mechanical properties of cement emulsified asphalt mortar. Constr. Build. Mater. 2014, 65, 76–83.
8. Zeng, X.; Xie, Y.; Deng, D.; Wang, P.; Qu, F. A study of the dynamic mechanical properties of CRTS I type CA mortar. Constr. Build. Mater. 2016, 112, 93–99.
9. Zhang, Y.; Wu, K.; Gao, L.; Yan, S.; Cai, X. Study on the interlayer debonding and its effects on the mechanical properties of CRTS II slab track based on viscoelastic theory. Constr. Build. Mater. 2019, 224, 387–407.
10. Yuan, Q.; Liu, W.; Pan, Y.; Deng, D.; Liu, Z. Characterization of Cement Asphalt Mortar for Slab Track by Dynamic Mechanical Thermoanalysis. J. Mater. Civ. Eng. 2016, 28, 04015154.

11. Leiben, Z.; Wang, X.; Wang, Z.; Yang, B.; Tian, Y.; He, R. Damping characteristics of cement asphalt emulsion mortars. Constr. Build. Mater. 2018, 173, 201–208.
12. Song, H.; Do, J.; Soh, Y. Feasibility study of asphalt-modified mortars using asphalt emulsion. Constr. Build. Mater. 2006, 20, 332–337.
13. Issa, R.; Zaman, M.M.; Miller, G.A.; Senkowski, L.J. Characteristics of Cold Processed Asphalt Millings and Cement-Emulsion Mix. Transp. Res. Rec. J. Transp. Res. Board 2001, 1767, 1–6.
14. Le, T.H.M.; Park, D.-W.; Park, J.-Y.; Phan, T.M. Evaluation of the Effect of Fly Ash and Slag on the Properties of Cement Asphalt Mortar. Adv. Mater. Sci. Eng. 2019, 2019, 1–10.
15. D’Angelo, G.; Thom, N.; Presti, D.L. Bitumen stabilized ballast: A potential solution for railway track-bed. Constr. Build. Mater. 2016, 124, 118–126.
16. Zeng, X.; Xie, Y.; Deng, D.; Zheng, K.; He, Z. CA Mortar Construction of the Trial Section of Wuhan-Guangzhou Railway Passenger Dedicated Line. In Proceedings of the International Conference on Transportation Engineering 2009, Chengdu, China, 25–27 July 2009; pp. 4019–4024.
17. Zhang, Y. Construction Quality Control of Mortar Filling Layer of Ballastless Track of Hangzhou-Ningbo Passenger Dedicated Line. J. Railw. Eng. Soc. 2013, 30, 24–28.
18. Zhao, D.-T.; Wang, T.-C.; Liu, X.-Y.; Wu, L. Configuration and performance of CA mortar for ballastless slab track. J. Tianjin Univ. 2008, 41, 793–799.
19. Zeng, X.; Xie, Y.; Deng, D. A study of the mixing of cement and emulsified asphalt mortar. Mag. Concr. Res. 2013, 65, 1255–1264.
20. Zhang, Y.; Kong, X.; Hou, S.; Liu, Y.; Han, S. Study on the rheological properties of fresh cement asphalt paste. Constr. Build. Mater. 2012, 27, 534–544.
21. Hu, S.-G.; Wang, T.; Wang, F.-Z.; Liu, Z.-C. Adsorption behaviour between cement and asphalt emulsion in cement–asphalt mortar. Adv. Cem. Res. 2009, 21, 11–14.
22. Jing, X.; Jinxiang, H.; Jiaping, L.; Zhifei, L. Influence of asphalt emulsion on cement hydration in CA mortar. In International RILEM Conference on Advances in Construction Materials through Science and Engineering; RILEM Publications SARL: Hong Kong, China, 2011; pp. 982–989.
23. Yang, J.; Yan, P.; Kong, X.; Li, X. Study on the hardening mechanism of cement asphalt binder. Sci. China Ser. E Technol. Sci. 2010, 53, 1406–1412.
24. Neville, A. Properties of Concrete; Pearson Education Limited: London, UK, 2000.
25. James, A. Overview of Asphalt Emulsion. In Transportation Research Board; E-C102; Transportation Research Board of the National Research Council: Washington, DC, USA, 2006; pp. 1–15.

26. Ouyang, J.; Hu, L.; Li, H.; Han, B. Effect of cement on the demulsifying behavior of over-stabilized asphalt emulsion during mixing. Constr. Build. Mater. 2018, 177, 252–260.
27. Xie, Y.-J.; Fu, Q.; Zheng, K.-R.; Yuan, Q.; Song, H. Dynamic mechanical properties of cement and asphalt mortar based on SHPB test. Constr. Build. Mater. 2014, 70, 217–225.
28. Qiang, W.; Peiyu, Y.; Ruhan, A.; Jinbo, Y.; Xiangming, K. Strength Mechanism of Cement-Asphalt Mortar. J. Mater. Civ. Eng. 2011, 23, 1353–1359.
29. Lesueur, D. The colloidal structure of bitumen: Consequences on the rheology and on the mechanisms of bitumen modification. Adv. Colloid Interface Sci. 2009, 145, 42–82.
30. Loeber, L.; Muller, G.; Morel, J.; Sutton, O. Bitumen in colloid science: A chemical, structural and rheological approach. Fuel 1998, 77, 1443–1450.
31. Wang, Q.; Yan, P.; Kong, X.; Yang, J. Compressive strength development and microstructure of cement-asphalt mortar. J. Wuhan Univ. Technol. Sci. Ed. 2011, 26, 998–1003.
32. Tian, Y.; Lu, D.; Zhou, J.; Yang, Y.; Wang, Z. Damping Property of Cement Mortar Incorporating Damping Aggregate. Materials 2020, 13, 792.
33. Wang, F.; Liu, Y.; Hu, S. Effect of early cement hydration on the chemical stability of asphalt emulsion. Constr. Build. Mater. 2013, 42, 146–151.
34. Tan, Y.; Ouyang, J.; Lv, J.; Li, Y. Effect of emulsifier on cement hydration in cement asphalt mortar. Constr. Build. Mater. 2013, 47, 159–164.
35. Wang, Z.; Shu, X.; Rutherford, T.; Huang, B.; Clarke, D. Effects of asphalt emulsion on properties of fresh cement emulsified asphalt mortar. Constr. Build. Mater. 2015, 75, 25–30.
36. Kong, X.-M.; Liu, Y.-L.; Zhang, Y.-R.; Zhang, Z.-L.; Yan, P.-Y.; Bai, Y. Influences of temperature on mechanical properties of cement asphalt mortars. Mater. Struct. 2014, 47, 285–292.
37. Liu, B.; Liang, D. Effect of mass ratio of asphalt to cement on the properties of cement modified asphalt emulsion mortar. Constr. Build. Mater. 2017, 134, 39–43.
38. Fang, L.; Yuan, Q.; Deng, D.; Pan, Y.; Wang, Y. Effect of Mix Parameters on the Dynamic Mechanical Properties of Cement Asphalt Mortar. J. Mater. Civ. Eng. 2017, 29, 04017080.