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Review Article

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Evaluation of Molasses in Civil Engineering Works: A Review

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ABSTRACT

In this review study, the potential for the use of molasses in civil engineering work was investigated in detail. Molasses material is used in a wide range of industries, such as pharmaceuticals, chemicals, paper, and fertilizers. The increasing population and growing construction sector gradually increase the demand for raw materials. In addition, molasses produced during the sugar production process increases environmental pollution and operating costs. The aim of this study is to explain that molasses material can be used as an alternative raw material source in the construction industry. In this study, literature studies on molasses-containing asphalt, construction materials, ground works, and cementitious materials were reviewed. As a result of the study, it was found that molasses was generally used as a replacement material in place of synthetic and petroleum-based materials. Accordingly, molasses material can be a valuable source of raw materials for the construction sector of countries that are foreign-dependent, especially in terms of crude oil and chemical materials. In addition, molasses has been found to reduce construction costs and improve material properties. This situation provides a significant competitive advantage to the construction sector. Additionally, sustainable environmental protection can be achieved by using molasses in the production of eco-friendly construction materials. Molasses is suggested to be used in civil engineering works in terms of cost and material performance.

Keywords: Molasses, Construction Materials, Ground Work, Asphalt, Cementitious Materials

Melasın İnşaat Mühendisliği İşlerinde Değerlendirilmesi: Bir İnceleme

ÖZ

Bu inceleme çalışmasında, melasın inşaat mühendisliği işlerinde kullanım potansiyeli detaylı olarak araştırılmıştır. Melas malzemesi; ilaç, kimya, kâğıt ve gübre gibi çok çeşitli sektörlerde kullanılmaktadır. Artan nüfus ve büyüyen inşaat sektörü hammadde ihtiyacını giderek arttırmaktadır. Ayrıca şeker üretimi sürecinde ortaya çıkan melas, çevre kirliliğini ve işletme maliyetlerini de arttırmaktadır. Bu çalışmanın amacı, melas malzemesinin inşaat sektöründe alternatif bir hammadde kaynağı olarak kullanılabileceğini açıklamaktır. Bu çalışmada, melas içeren asfalt, yapı malzemeleri, zemin çalışmaları ve çimentolu malzemeler ile ilgili literatür çalışmaları incelenmiştir. Çalışma sonucunda, genellikle melasın sentetik ve petrol esaslı malzemelerin yerine ikame malzemesi olarak kullanıldığı tespit edilmiştir. Buna göre, melas malzemesi özellikle petrol ve kimyasal malzeme açısından dışa bağımlı ülkelerin inşaat sektörü için değerli bir hammadde kaynağı olabilir. Öte yandan, melasın inşaat maliyetini azalttığı ve malzeme özelliklerini arttırdığı belirlenmiştir. Bu durum, inşaat sektörüne, rekabet açısından oldukça önemli bir avantaj sağlamaktadır. Ayrıca, çevre dostu yapı malzemesi üretiminde melasın kullanılması sayesinde sürdürülebilir bir çevre korunumu sağlanabilir. Melasın, inşaat mühendisliği işlerinde maliyet ve malzeme performansı açısından kullanılması önerilmektedir.

Anahtar Kelimeler: Melas, Yapı Malzemeleri, Zemin Çalışması, Asfalt, Çimentolu Malzemeler

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1. INTRODUCTION

Molasses is a fluid and dark-brown colored industrial by-product consisted during the evaporation of concentrated sugar cane or sugar beet juice during the raw sugar manufacturing process (Mordenti et al., 2021; Eliodório et al., 2023). Generally, ~40 kg of molasses is obtained from 1 ton of processed sugar beet and ~45 kg from 1 ton of sugar cane (Nguyen & Gheewala, 2008; Isler-Kaya & Karaosmanoglu, 2022). The main chemical components of both cane molasses and beet molasses are ~30~35% sucrose, ~10~25% fructose and glucose, ~2~3% non-sugar components (minerals and moisture), and ~45~55% fermentable sugar (Jamir et al., 2021). Sugar purification process, plant type, and boiling temperature are the basic factors affecting molasses components and characteristics (Zhang et al., 2021). Molasses is used in various sectors because it is cheap and has a high sugar concentration (Kabeyi & Olanrewaju, 2022). Generally, molasses is used as an additive in the production of ethanol, citric acid, alcohol, baker's yeast, pharmaceuticals, sweeteners, animal feed, fertilizers, paper, biogas, bioplastics, and cement additives (Jamir et al., 2021; Mustafa et al., 2023; Acharya & Gyawali, 2024). Industrial use of molasses is increasing due to its low-cost and easy storage (Geremew Kassa et al., 2024). Figure 1 shows the total amount of molasses production worldwide between 2019 and 2025.

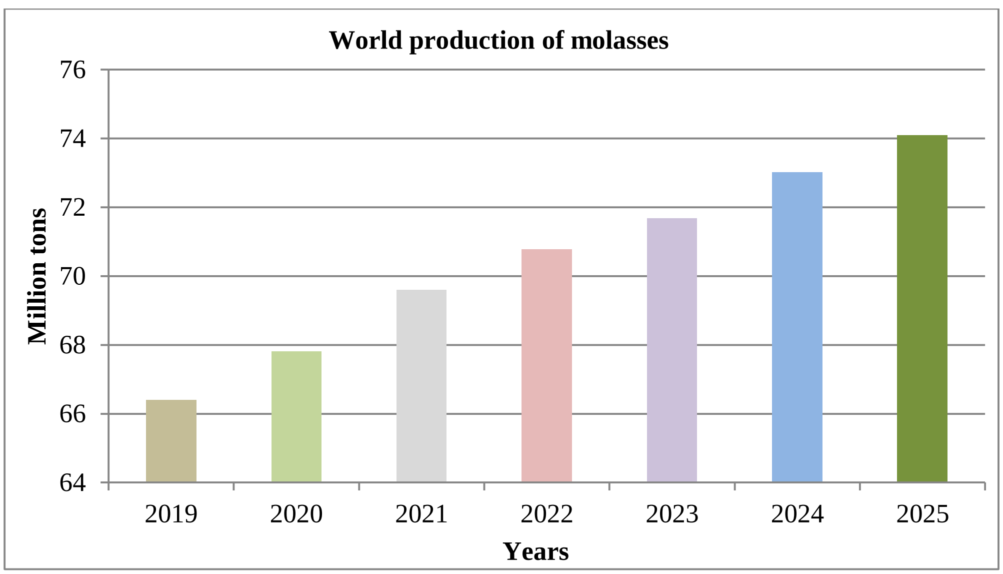

Figure 1: The total annual molasses production amount worldwide (OECD Report, 2024).

Upon reviewing Figure 1, it is seen that the annual production amount of molasses is gradually increasing. In 2023, ~71.7 million tons of molasses were produced worldwide. In addition, it is predicted that ~74.1 million tons of molasses will be produced worldwide in 2025. On the other hand, ~2% of the sugar produced globally is produced in Türkiye. In Türkiye, depending on the climatic conditions, sugar beet is mostly grown in Konya, Eskişehir and Yozgat provinces (TEPGE Report, 2023). Figure 2 shows the molasses silo and molasses material of the Eskişehir Sugar Factory. Figure 3 shows the total annual molasses production amount in Türkiye.

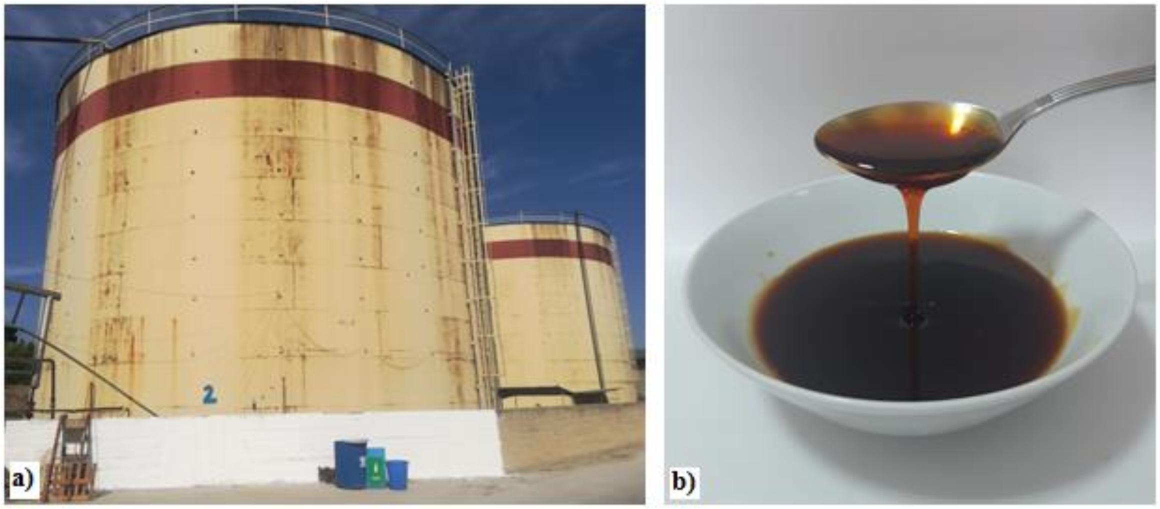

Figure 2: a) Sugar factory molasses silo, b) Molasses material.

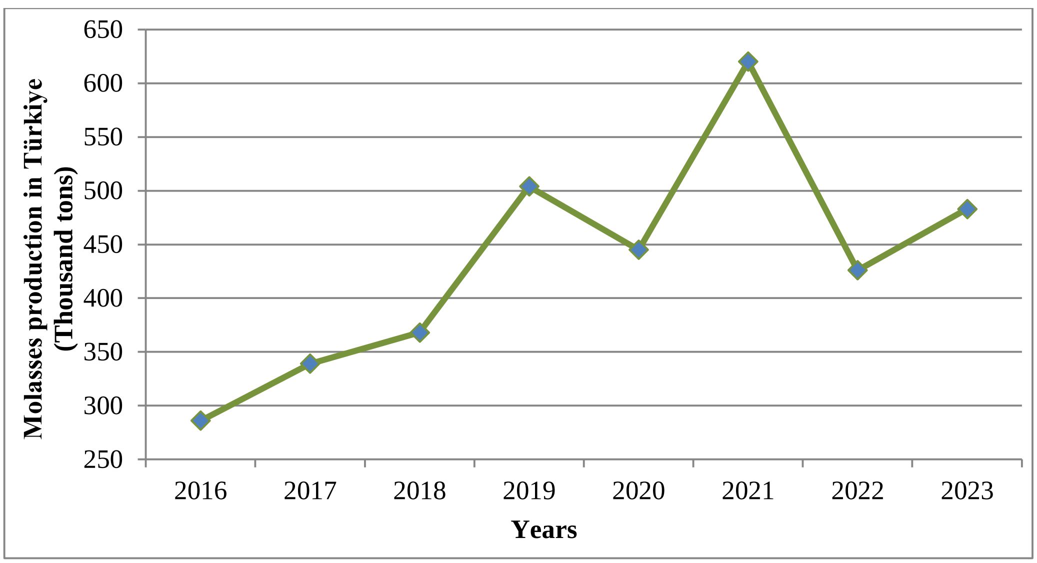

Figure 3: Türkiye's annual sugar beet molasses production amount (Thousand tons) (TEPGE Report, 2023).

According to Figure 3, the annually molasses production amount varies in Türkiye. However, it is understood that the amount of molasses production has generally increased. Although the amount of molasses is increasing both globally and in Türkiye, molasses also has some disadvantages. These are the risks of contamination of underground water, high storage operating costs, and high disposal costs (Wynne & Meyer, 2002; Klaver et al., 2023). In order to reduce the effects of these disadvantages of molasses, its use on a global or local scale is very important in terms of environmental conservation and economic factors (Parascanu et al., 2021; Stephen et al., 2024).

The aim of this paper is to use molasses in the construction industry and to establish a relationship between the construction industry and different industries, such as the sugar industry. In this respect, our study has an original subject. There is a gap in the literature regarding the use of molasses in the construction sector. In the light of the studies investigated in this study, researchers can use molasses material in the production of bituminous materials and asphalt pavements, construction materials, ground works, and cementitious materials. In addition, disposing of molasses in the construction sector will be very beneficial for the Türkiye's economy and the protection of the natural environment.

2. METHODOLOGY

Agricultural wastes (Agro-wastes) and by-products are used as alternative raw material sources in various sectors. One of these alternative raw material sources is molasses. In the introduction section, information is given about the definition of molasses, chemical components, its use in different sectors, and the annual production amount in the world and in Türkiye. For this literature review, various theoretical and experimental papers related to molasses and construction have been reviewed. The evaluation of molasses in the construction sector is explained in four main sections. In this study, firstly, papers on the use of molasses in bituminous materials and asphalt works were reviewed. Accordingly, the use of molasses for highway works in the construction industry has been evaluated. Secondly, the use of molasses in the production of various construction materials has been investigated. In the construction sector, molasses material can be considered to be used in the production of composite construction materials, especially for interior and exterior areas. Thirdly, different papers have been investigated regarding the use of molasses in ground-work to strengthen the ground by civil engineers. It has been explained that ground problems and construction costs can be reduced thanks to molasses. Fourthly, the use of molasses material in cementitious materials is examined. The effect of molasses on the characteristics and production costs of cementitious paste, mortar, and concrete is explained.

3. RESULTS AND DISCUSSION

3.1. Asphalt

Asphalt concrete is produced by appropriately combining aggregate grains with hot-bitumen binder material. Bitumen binder can be defined as a viscous Newtonian fluid obtained from the distillation process of crude oil. Bitumen material is mainly used in asphalt production (Caputo et al., 2020). The properties of the binder in asphalt mixtures directly affect the physical and mechanical properties of asphalt, such as creep, stability, void structure, and tensile strength (Gambalonga et al., 2023). Civil engineers and scientists are constantly improving the performance of asphalt concrete and asphalt pavements. Generally, the binder material is modified in asphalt mixtures (Abtahi et al., 2010). Additionally, scientists have been working to modify asphalt concrete due to the instability of crude oil production and oil prices. Figure 4 shows the global production amount and price of crude oil between 2017 and 2023.

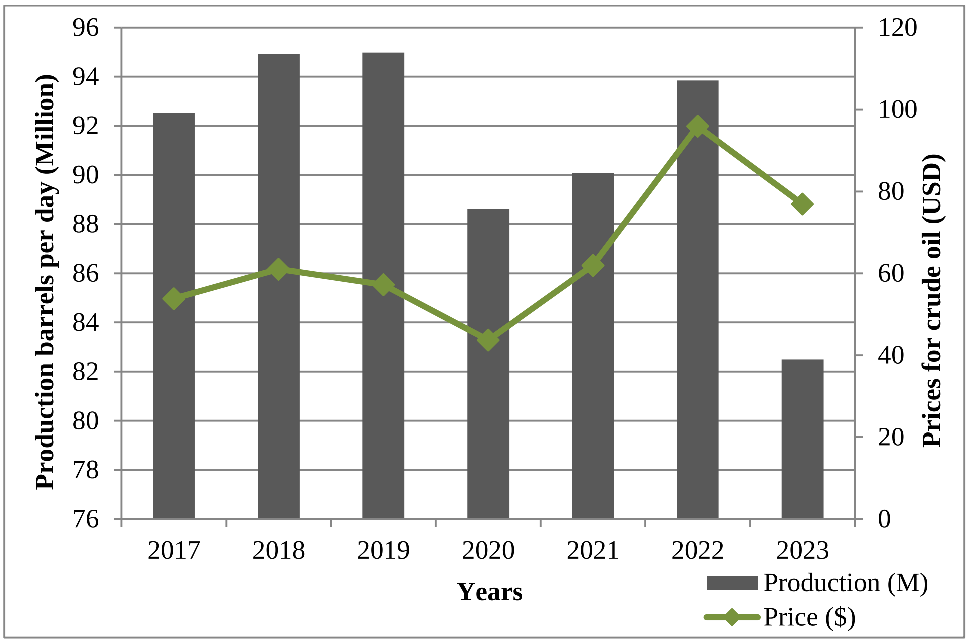

Figure 4: Globally, the amount of crude oil produced and the price of crude oil (between 2017 and 2023) (Businessinsider, 2024).

When Figure 4 is examined, the amount of crude oil production and the price of crude oil in the energy market vary considerably from year to year. Scientists are developing different methods to mitigate the impact of oil on asphalt production. One of these methods is to replace the traditional bitumen binder with molasses in asphalt mixtures. In this section, different experimental literature studies using molasses in asphalt production are investigated.

Prakash et al. investigated the characteristic properties of bitumen mixtures by adding up to 15% cane molasses to the bitumen mixtures. The highest Marshall Stability value was determined in bitumen mixtures containing 13% molasses. In addition, it has been stated that molasses reduces moisture absorption and oxidation by reducing the void rate of mixtures (Prakash et al., 2014).

Gürü et al. experimentally determined the effects of beet molasses and boron oxide on bitumen properties. In the study, it was found that when 5% molasses was added to bitumen mixtures, the viscosity and softening point of the bitumen mixture decreased. On the other hand, they observed that molasses increased the ductility and penetration of bitumen materials. Additionally, it has been explained that rutting resistance improves when bitumen mixtures are modified with molasses and boron oxide (Gürü et al., 2017).

Mose and Ponnurangam investigated the effect of cane molasses on bitumen performance. Asphalt mixtures were prepared by adding different amounts of molasses instead of bitumen. As a result, as the amount of molasses in the mixtures increased, the specific gravity, tensile strength, and ductility of the mixtures decreased. In addition, it was determined that the softening point values decreased in parallel with the increase in molasses content in all mixtures. The highest performance was obtained from mixtures containing 20% molasses. Additionally, a cost reduction of approximately 17% was calculated for 20% molasses-based bitumen mixtures (Mose & Ponnurangam, 2018).

Rangan et al. examined the use of cane molasses in asphalt concrete produced with coarse or fine aggregate. In the study, bitumen material was replaced with 4%, 8%, and 12% molasses in asphalt concrete prepared with 60/70 penetration. As a result, the highest Marshall value was obtained for the asphalt prepared based on 4% molasses in accordance with the relevant standards. It has been determined that the strength of asphalt concrete prepared with coarse aggregate is lower (Rangan et al., 2019).

Harerua and Ghebrab examined the rheological properties of hot asphalt mixtures modified with molasses. In the study, 5%, 10%, 15%, and 20% molasses were replaced instead of bitumen. As a result, it has been stated that water content of molasses negatively affects the rheological properties of bitumen mixtures. Additionally, it was determined that as the molasses ratio increased in bitumen mixtures, the carbonyl index decreased and the shear modulus value increased (Harerua & Ghebrab, 2020).

Le investigated the use of cane molasses as an alternative binder material in asphalt concrete mixtures. In the study, cane molasses was replaced in the bitumen mixture at a rate of 5%~25% of the asphalt weight. As a result, the most suitable molasses rate in the mixtures was determined as 10%. The highest tensile strength and rutting resistance were obtained in asphalt concrete prepared at this ratio. Additionally, it was emphasized that molasses could be a suitable alternative raw material source to reduce the cost of asphalt production (Le, 2021).

Saboo et al. investigated the addition of cane molasses at various rates (5%, 10%, 15%, 20%, 25%, and 30% by weight) as a replacement material to asphalt-based bitumen binder material. Due to the oil crisis and increasing environmental pollution problems, they suggested the use of waste materials in traditional bitumen mixtures. In the study, it was determined that 25% molasses was the most suitable ratio. According to the plain sample, it was stated that the moisture damage, permanent deformation, and fatigue resistance of the 25% cane molasses-based bitumen mixture comply with the relevant standards. They also calculated that the binder cost was reduced by 21% (Saboo et al., 2023).

Arslan et al. examined the use of beet molasses and fly ash (FA) in modifying bituminous mixtures. It has been stated that molasses components can improve the characteristic properties of bituminous mixtures due to their high sugar content. In the study, in bituminous mixtures modified with 3% molasses, the stability of the mixture increased by ~11%, peeling resistance by ~85%, and rutting resistance by ~42%. In addition, the produced molasses-fly ash-based bituminous mixture has been recommended to be used in regions with heavy rainfall (Arslan et al., 2024).

Mehta and Saboo examined the physical and rheological properties of molasses-based bio-asphalt. Bio-asphalt mixtures were prepared by modifying the molasses ratios to 10%, 20%, and 30%. As a result, the penetration of the mixtures decreased as the molasses content increased. It has also been stated that molasses content has no effect on the workability of asphalt concrete. On the other hand, it has been determined that all molasses-based asphalt mixtures have suitable thermal storage stability for transportation, storage, and laying. In addition, in the cost analysis, it was calculated that a 30% molasses additive reduces the cost of asphalt by approximately 20~30% (Mehta & Saboo, 2024).

Based on the various literature studies reviewed, it has been concluded that molasses can be an alternative raw material source in asphalt production. In addition, it appears that the molasses-based asphalt material produced complies with the relevant standards. On the other hand, it was stated that the properties of the bituminous mixture improved thanks to the sugar content of molasses. It has been reported that the stability, peeling resistance, rutting resistance, ductility, penetration, tensile strength, and shear modulus of asphalt increase when bitumen is replaced by molasses in the asphalt mixture. On the other hand, molasses decreased the void ratio, moisture absorption, oxidation, carbonyl index, penetration, specific gravity, and softening point values in asphalt mixtures. Scientists and civil engineers have also found that environmental pollution and asphalt costs are reduced by using molasses in asphalt production.

3.2. Construction materials

Agro-wastes are widely used in the production of construction materials. Researchers are investigating the use of agro-waste in construction materials to improve the properties of materials or reduce the cost of production. In this section, the effect of molasses on the properties of construction materials was investigated through various experimental studies.

Benk and Coban studied the usability of pumice and molasses in the production of lightweight thermal insulation bricks. In the study, brick materials were produced with 82.5% and 95% doses of pumice and 12.5% molasses at temperatures between 200 °C and 850 °C. As a result, it was determined that the density and tensile strength values of molasses based brick samples produced with high heat treatment at

850 °C increased. In this case, it has been stated that molasses could potentially be an alternative binder material to cement or plaster in brick production (Benk & Coban, 2012).

Cuervo studied the effects of gypsum and beet molasses on the compressive strength of adobe bricks. In the study, bricks were produced with a combination of molasses and gypsum at the ratios of 2.5%, 5%, 10% and 15%. As a result, it has been reported that the compressive strength values of adobe bricks produced with 2.5% molasses and 2.5% gypsum increased by ~9% compared to the control brick. Furthermore, it has been determined that if high amounts of molasses are used in brick production, the compressive strength of the bricks decreases significantly. Additionally, it has been stated that agro-wastes such as molasses can be used to improve the mechanical properties of construction materials (Cuervo, 2020).

Chantit et al. examined the usability of bagasse, bagasse ash and molasses in earth block production. In the study, earth blocks were produced by adding 4%, 8%, and 12% molasses and different amounts of bagasse and bagasse ash (15% and 25%) to the samples. According to experimental results, the highest compressive strength (~4.60 MPa) was obtained in 12% molasses-based 14, 21, and 28-day earth blocks. In addition, it has been stated that the thermal properties of bloks improve as the molasses and bagasse content in the blok increases. Additionally, it has been explained that cheaper and more eco-friendly construction materials can be produced if the sugar industry and the construction industry merge (Chantit et al., 2022).

Syahfitri et al. investigated the physical and mechanical properties of lightweight composite tiles produced with sorghum bagasse and molasses. Composite tile samples were produced with 5%, 10%, 15% and 20% molasses content. As the molasses content increased in the tile samples, the water absorption and thickness swelling values of the samples decreased, while the internal bonding and screw holding capacity values increased. The density of all samples was determined to be below 0.8 g/cm^3. In addition, 20% molasses composite tiles were determined to be the most suitable samples in terms of relevant standards (Syahfitri et al., 2024).

Dabakuyo et al. studied the mechanical properties of metakaolin and cane molasses-based geopolymer soil blocks. In the study, soil blocks were produced with 5% metakaolin and different amounts of molasses (2~8%). As a result, they determined that the most suitable molasses ratio was 4%. As the molasses ratio increased in soil block mixtures, the compressive strength of the blocks increased. The compressive strength of 4% molasses-based soil blocks was determined to be ~4.20 MPa. In addition, it has been explained that since molasses reduces the porous structure of soil blocks, the water absorption ratio also decreases. The produced soil blocks are suggested for use in wall applications (Dabakuyo et al., 2022).

Şahinöz et al. investigated the usability of beet molasses as a binder material in the production of polymer composite panels. In the study, panel samples were prepared by adding molasses up to 35% by weight instead of synthetic adhesives. As a result, the flexural strength of 35% molasses-based composite panels was determined to be 16 MPa. It was therefore declared that the composite panels produced comply with the load-bearing wood board standards. The molasses-based panels produced can be considered to be used as construction materials such as fences, wall coverings, concrete moulds, and office dividers (Şahinöz et al., 2022).

Sutiawan et al. examined the use of non-toxic citric acid, maleic acid and molasses instead of synthetic binder materials in wood panel production. They stated that panel construction products such as plywood have negative effects on humans and the environment because synthetic binders contain formaldehyde gas. In the study, plywood panels could be produced with these three types of binders. However, since acid-based binders contain higher cross-links than molasses, the highest physical and mechanical performance was achieved in acid-based panels (Sutiawan et al., 2023).

Cai et al. investigated the production of composite wood panels with a binder mixture prepared only with molasses and curing agent. In the study, shear strength of 1.20 MPa was obtained from panel samples. In addition, it has been stated that molasses-based panel materials can be produced more easily with the hot-pressing method. The panels produced are suggested for use in humid environments (Cai et al., 2023).

Şahinöz et al. examined the physical and mechanical properties of eco-friendly composite construction panels produced from plant waste and beet molasses. It has been stated that the panels are both safe for human health and low-cost because they are made from waste materials. In the study, it is expressed that molasses has a good binding performance by creating cross-linking due to its sugar content. In addition, they suggested that the produced construction panels be used indoors and outdoors for general use (Şahinöz et al., 2023).

Djonga et al. researched the production of a new composite rice husk and molasses binder-based insulation panel. In the study, different amounts of cane molasses (12~30%) were used instead of thermoset synthetic resin in the production of composite insulation panels. In the results obtained, it was determined that as the molasses content of composite panels increased, the volumetric mass, thermal conductivity, flexural and compressive strength values of the panels increased, and the density and water absorption ratios decreased. Additionally, it has been stated that it is possible to produce panels in accordance with standards by substituting cane molasses instead of synthetic resin (Djonga et al., 2024).

According to the literature reviewed, molasses is generally used in the production of bricks, tiles, soil blocks, and composite panels. It has been determined that molasses added to construction materials at the most suitable ratio increases the density, thermal properties, internal bonding, flexural and compressive strength values of the materials. In addition, it has also been determined that molasses reduces the water absorption rate, pore amount, and thickness swelling values of construction materials. Especially in composite panel production, cheap and eco-friendly materials are produced by using molasses instead of toxic synthetic binders. In addition, thanks to molasses, some construction materials can be produced at lower temperatures for indoor and outdoor environments. This is very important in terms of reducing the production costs of the material in the construction sector. Additionally, the protection of the natural environment can be achieved by disposing of waste materials in the production of construction materials.

3.3. Ground work

Weak soil strength of the ground of the engineering structure is a very important problem for geotechnical or civil engineers. Mechanical methods or chemical stability methods (additives such as cement, lime, and mortar) are applied to increase soil stability (Archibong et al., 2020). Recently, organic-based materials have been commonly used to increase soil stability (Raheem et al., 2020; Shivhare & Mohanan, 2023). In this section, the effect of molasses on soil stability was investigated.

Ndegwa examined the effect of cane molasses on the stability of expansive clay soil. In the study, molasses was added to clay soil at ratios ranging from 4% to 14% by weight. As a result, the highest California bearing ratio (CBR) value was obtained from 8% molasses-based samples. It has been stated that molasses increases the load bearing capacity of expansive clay soil and reduces the swelling ratio. However, segregation of clay grains was observed when high amounts of molasses were used in clay soil. Accordingly, they suggested using molasses combined with lime for soil stability (Ndegwa, 2011).

Taye and Araya investigated the use of cane molasses and Portland cement combinations to improve the stability of clay soil. In the study, 4%, 8%, and 12% molasses and the same ratios of cement were added to the clay soil. As a result of the study, it was determined that swelling and plastic index values decreased in soil samples containing only molasses. Compared to the control sample, the CBR value of 4% molasses and cement-based soils increased from 1% to 64%, while the swelling value decreased by ~10% and the plastic index decreased by ~30% (Taye & Araya, 2015).

Mamuye et al. studied the improvement of the properties of low-quality gravel used in the foundation sub-base layer with the combination of molasses and lime. In the study, molasses was added to gravel-based samples at different ratios (2~10%). As a result, it was determined that as the molasses percentage increased in gravel-based mixtures, the CBR value increased from 28% to 37%, and the swelling ratio increased by ~2%. However, they found that samples prepared only with molasses did not comply with the relevant standards. On the other hand, it was detected that gravel samples blended with 50% molasses and 50% lime met the limit values of the relevant standards. The 3-day CBR value of molasses-lime based samples was determined to be 81% (Mamuye et al., 2018).

Vinodhkumar et al. studied the effect of molasses on the properties of expansive clay soil called black cotton soil. In the study, molasses was added to the soil at the ratios of 5%, 7.5%, 10%, 12.5% and 15%. The samples were kept under fixed curing conditions for 0, 7, and 14 days. As a result, the highest unconfined compressive strength was obtained in 14-day-old samples based on 12.5% molasses. On the other hand, it was stated that the liquid limit value decreased from 40% to 32%. They also suggested using molasses material for soil modification (Vinodhkumar et al., 2018).

Nabeel et al. examined the effect of ground granulated blast furnace slag (GGBS) and cane molasses on clay soil stability. The experimental studies were continued with the combination of clay soil, GGBS, and molasses in the ratio of 0~15%. In the study, 8% molasses was determined as the most suitable ratio. It has been stated that in clayey soil, the Atterberg limit, specific gravity, and plastic index values decrease with increasing molasses content up to 8%. On the other hand, the highest triaxial test result value in 8% molasses-based soils was determined to be 380 kPa, and the CBR value was ~15%. Additionally, it has been stated that environmental protection can be achieved by using waste in soil stabilization applications (Nabeel et al., 2019).

Bhardwaj and Sharma attempted to construct the subgrade design of flexible pavement with molasses, lime and foundry sand. Clay soil was blended with 5%, 10%, 15% and 20% molasses and different amounts of lime and foundry sand. According to the test results, it was determined that the differential free swell and consistency limit values of the clayey soil decreased and the CBR value increased with the optimum ratios of 10% molasses, 20% foundry sand and 9% lime. They determined that the designed subgrade met the required standards and the total construction cost is reduced by ~36% with the optimum mixture (Bhardwaj & Sharma, 2022).

Karimi et al. examined the effect of sugar cane molasses on the shear strength of plastic loamy soils. In the study, different amounts of molasses (2~12%) were mixed into soils containing 10%, 15% and 20% clay. As a result, it was observed that molasses addition in all mixtures improved the engineering properties of the soil, and the clay grains absorbed the molasses significantly. According to shear test data, the highest shear strength was obtained from samples containing 10% molasses. In addition, it has been analyzed that as the ratio of molasses in the soil mixture increases, the cohesion coefficient and internal friction angle curves increase (Karimi et al., 2022).

Jiménez et al. investigated the production of composite soil with cane molasses, waste rubber fiber and kaolin clay. In the study, soil samples were prepared with clay soil containing different amounts of molasses (0~12%), 0.1% fiber and 35% water. As a result, a more ductile fracture behaviour was observed in the soil samples as the percentage of molasses in the soil increased. The highest unconfined compressive strength (~2.1 MPa) was obtained in samples produced with 2% molasses. In addition, according to SEM analysis, it was observed that molasses and fiber formed a good link in 2% molasses-based samples. On the other hand, they explained that a very high ratio of bacteria occurred in the composite soil due to the molasses material (Jiménez et al., 2022).

Sadique and Sivanarayana studied the reinforcement of the expansive clay soil-based coating subgrade layer with molasses and jute fiber. Different amounts of jute fiber and molasses, ranging from 5% to 15% were added to the soil. As a result, the most suitable mixture ratio in the samples was determined as 12% molasses and 1.5% jute fiber. At this ratio, the plastic limit decreased by ~21% and the moisture content decreased by ~30% compared to the control sample. On the other hand, it was stated that the CBR value increased by 62%, and in addition, the cost of road construction could be reduced thanks to industrial wastes such as molasses (Sadique & Sivanarayana, 2023).

Ouedraogo et al. examined the use of the combination of laterite plastic clay and sugarcane molasses in the road sub-base layer. In the study, experimental studies were continued by mixing laterite clay with 0%, 2%, 4% and 6% molasses by weight. As a result, it was determined that CBR values increased as the molasses ratio increased in the samples after 24 hours, and the compressive strength values of the 21-day samples increased in parallel with the increase in molasses. It has been explained that a 2% molasses ratio can be used in the road sub-base layer as the most optimum value. In addition, they suggested the use of a molasses-based laterite clay road sub-base layer in areas not exposed to precipitation (Ouedraogo et al., 2023).

According to the experimental studies reviewed, molasses material is generally used to increase soil stability. The bearing capacity, compressive strength, cohesion and shear strength values of soil containing a certain amount of molasses increase. On the other hand, molasses reduces the swelling ratio, consistency limits, specific gravity and moisture content of the soil. Additionally, construction costs can be reduced by using molasses in ground works. However, in some studies, it is suggested to use molasses combined with materials such as lime, cement, and GGBS to increase the strength of the soil. There are not many studies on the effect of molasses on increasing soil stability. It is estimated that the use of molasses to improve soil stability in the construction sector will increase in the future.

3.4. Cementitious materials

In the construction sector, chemical additives are widely used for the production of cementitious materials and ready-mixed concrete. Thanks to chemical additives, desired physical and mechanical properties can be obtained in cementitious or concrete materials (Pekmezci & Atahan, 2014; Tulga & Kılınç, 2018).

Figure 5 shows the annual production amounts of concrete chemical additives in Türkiye between 2015 and 2021.

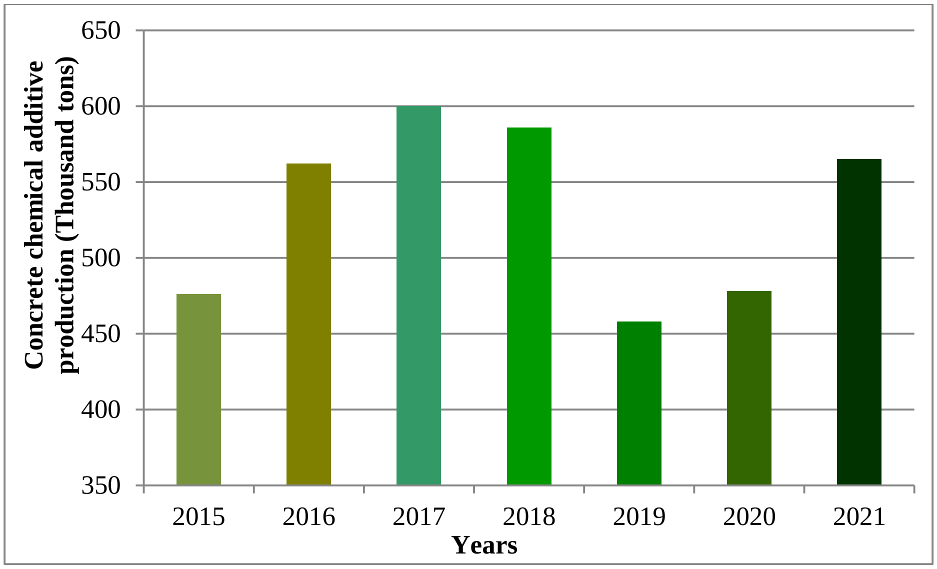

Figure 5: Türkiye concrete chemical additive production (Thousand tons) (2015~2021) (THBB Report, 2022).

When Figure 5 is examined, 565 thousand tons of concrete chemical additives were produced in Türkiye in 2021. Approximately 80% of the concrete chemical additives produced are water-reducing chemical additives. In Türkiye, the annual concrete chemical additive production amount varies. Additionally, Türkiye is Europe's largest concrete additive producer (THBB Report, 2022).

The production of chemical additives is both harmful to the environment and increases the cost of material production. In this study, it is suggested to use molasses in the production of cementitious materials instead of chemical additives. In this section, the effect of molasses on the properties of cementitious materials was investigated.

Acharya and Gyawali compared the effects of molasses and superplasticizer additives on the physical and mechanical properties of cement mortar. In the study, molasses and superplasticizer additives were added to the mortar mixtures at different ratios (0~1.2% by cement weight). As a result, the most suitable molasses ratio in the mortar was determined to be 87% less than in the superplasticizer. In addition, higher viscosity, compressive strength, and splitting tensile strength were detected in molasses-based mortars. Furthermore, it has been analyzed that molasses can reduce the use of cement in mortars, and thus cheaper and more eco-friendly concrete can be produced (Acharya & Gyawali, 2024).

Ali et al. examined the effect of cane molasses on the properties of recycled aggregate concrete (RAC) prepared at a w/c ratio of 0.45, 0.50, and 0.55. It has been explained that in concrete production, recycled aggregate has a higher water absorption capacity than natural aggregate, and therefore, the strength of concrete with recycled aggregate is generally lower. In addition, it has been stated that molasses can be used to reduce the water needs of concrete containing recycled aggregate. As a result, maximum compressive strength was obtained from concretes produced at 0.50 w/c and 0.25~0.50% molasses ratio.

It has also been analyzed that molasses improves the workability and fresh density properties of concrete and that the cost of concrete can be reduced by using molasses as a plasticizer additive in concrete (Ali et al., 2020).

Rashid et al. investigated the effect of molasses ratio on fresh properties of cement paste. In the study, concrete samples were prepared with recycled aggregate and 0.25~0.75% molasses by weight. As a result, the most suitable molasses ratio for cement pastes was determined as 0.25. It has been determined that up to this rate, the water need of the paste decreases and the setting times are increased, and also, the compressive strength of 365-day samples of 0.25 molasses-based concrete increases by ~15%. Furthermore, it is mentioned that using molasses and recycled aggregate combined can be a very important solution for a sustainable environment (Rashid et al., 2019).

Weifeng et al. researched the effect of cane molasses on the physical and hydration reaction properties of conventional Portland cement. In the study, molasses was added to cement paste and mortar samples at different ratios (0~0.05% and 1%). As a result, they determined that the setting time and fluidity of low-molasses-based samples increased. Additionally, it was determined that the formation of ettringite was rapid and the hydration of C_3S was delayed in samples containing high ratios of molasses (Weifeng et al., 2014).

Akar and Canbaz examined the effect of beet molasses on the properties of concrete in fresh and hardened states. In the study, concrete mixtures were prepared with 0.5% and 1% molasses and formaldehyde molasses additives. As a result, it was determined that the molasses additive increased the setting time of concrete samples and also increased the 28-day compressive strength of concrete by 20%. On the other hand, it was detected that the compressive strength of molasses-based concrete decreased by approximately 30% in sulphate and acidic environments. Additionally, they calculated that the cost of concrete could be reduced by ~3% by using molasses as a plasticizer in concrete (Akar & Canbaz, 2016).

Huang et al. investigated the usability of molasses as a plasticizer and retarder for calcium sulfoaluminate cement. In the study, molasses was added to cement pastes and mortars at the ratios of 0%, 0.25%, 0.5%, 0.75% and 1% by weight of the cement. As a result, it was determined that the initial 2-hour and 28-day unconfined compressive strengths of molasses-based samples were close to each other, and also, molasses increased the initial and final setting times of cementitious mortars. In addition, it has been observed that molasses delays the hydration reaction of mortars and increases the amount of porosity. Furthermore, they emphasized that molasses is a sustainable and suitable retarder/plasticizer additive for calcium sulfoaluminate cement (Huang et al., 2020).

Mohammed and Kadhim studied the usability of pumice stone and molasses in the production of lightweight concrete. In the study, molasses at the ratio of 0.2% of the cement weight and pumice stone at different ratios were added to the concrete samples. As a result, high-strength lightweight concrete was produced in accordance with the standards with 100% pumice stone and molasses. Thanks to molasses, the amount of mixing water and the production cost of concrete were reduced. Additionally, it is stated that molasses material improves the interface matrix between the aggregate and the cement (Mohammed & Kadhim, 2023).

Abalaka examined the effects of molasses and starch on the physical and mechanical properties of C35 concrete. In the study, concrete mixtures were prepared by adding both starch and molasses in different proportions (0~1%). As a result, it was determined that the compaction factor, workability, and initial setting time values of molasses-based concrete samples were lower than those of starch samples. In addition, although the early compressive strength was higher in molasses-based samples, it was stated that the compressive strength of starch-based samples was higher in 28 days samples. Furthermore, it is explained that the sugar content of molasses is very effective in improving the properties of concrete (Abalaka, 2011).

Jumadurdiyev et al. investigated the use of molasses as a water-reducing and retarder additive in concrete production. In the study, concrete samples were produced with three types of beet molasses (containing different ratios of sugar) and lignosulfonate additives. As a result, the setting time and workability of molasses-based samples were determined to be higher. It has been stated that the sugar content of molasses has little effect on setting time and workability. On the other hand, the compressive strength of molasses-based samples was determined to be higher at later ages. In addition, it has been determined that the shrinkage, carbonation, freeze-thaw, and expansion values of both molasses and lignosulfonate-based concretes are close to each other (Jumadurdiyev et al., 2004).

Kavas et al. investigated the effect of beet molasses on the setting time and compressive strength of borogypsum and FA based cementitious mortars. In the study, mortar samples were prepared with 2~10% borogypsum, FA and 0~0.1% molasses. As a result, it was determined that both molasses and borogypsum mortars increased the initial setting times, and the compressive strength values of 6% borogypsum and 0.1% molasses-based mortars after 7 days were higher than those of only borogypsum-based samples. In this case, it is suggested to use borogypsum and molasses combined in the production of cement mortar (Kavas et al., 2005).

Gao et al. examined the effect of beet molasses on the performance of blended cement containing high volumes of minerals. In the study, the blended cementitious mixture was prepared with 0.01~0.05% molasses and 41% mineral additive (FA+GGBS). As a result, according to SEM analysis, they observed that as the molasses ratio in the paste increased, the pore structure decreased and the microstructure improved. In addition, higher compressive strength was obtained in the 0.03% molasses-based paste compared to the control sample. Furthermore, it was mentioned that the negative effects of the sugar industry on the environment can be reduced by using molasses in the cement sector (Gao et al., 2011).

Zhang et al. investigated the usability of waste glycerin, lignin and molasses in the cement grinding process. In the study, glycerin, lignin and molasses were separately added to the blended cement at the ratios of 0~0.04% by weight of the cement. As a result, it was found that these three materials increased the mechanical properties, specific surface area, and density of the cement compared to the control sample. The highest mechanical strength was obtained in molasses-based paste. On the other hand, they determined that the 28 days compressive strength of 0.02% molasses-based paste was 10 MPa higher than the control sample. On the other hand, they determined that the 28 days compressive strength of 0.02% molasses-based paste was 10 MPa higher than that of the control sample and also explained that molasses improved the quality of cement (Zhang et al., 2016).

Li et al. examined the usability of cane molasses as an aid material in clinker production. In the study, molasses was added to the mixture containing ~97% clinker at the ratios of 0.01%, 0.02%, 0.04%, 0.08% and 0.1% (by clinker weight). As a result, according to the experimental data obtained, 0.04% was determined as the most suitable molasses ratio. It was determined that the setting time, compressive strength, density and workability of the samples increased up to 0.04% molasses ratio. On the other hand, it was stated that molasses is very effective in the clinker grinding process, provides energy savings, and reduces production costs in cement production (Li et al., 2015).

Al-Mamoori et al. studied the prevention of cold joint formation in the production of concrete elements with molasses material. It has been explained that the workability of concrete decreases due to evaporation in hot regions and that the long vibration process in concrete causes segregation. In the study, molasses was added to the concrete mixture at the ratios of 0%, 0.05%, 0.1%, 0.2% and 0.3% by weight of cement. As a result, they found that 0.2% molasses increased the compressive strength of concrete samples by ~11% and delayed the hydration reaction, increasing the setting time by 277 minutes. In this case, it is assessed that molasses can reduce the formation of cold joints in concrete, especially in hot regions (Al-Mamoori et al., 2018).

Mashtakov et al. investigated the production of a new plasticizer material based on beet molasses. In the study, molasses and alkali based fluid samples were prepared. The mechanical properties of concrete samples produced with this molasses alkali based mixture and two different commercial chemical plasticizers were compared. As a result, the highest compressive strength was obtained in concretes prepared with molasses-based plasticizer. It has been reported that the sugar content and pH value of molasses have an impact on the properties of concrete and that molasses can have a high potential to produce high-performance plasticizer (Mashtakov et al., 2018).

Jaramillo et al. demonstrated the effects of molasses dosage on the characteristic properties of concrete. In the study, molasses and a commercial plasticizer chemical material were added to the concrete samples separately at the ratios of 0%, 0.2%, 0.4%, 0.6%, 0.8% and 1.0% by volume. As a result, the 0.4% molasses ratio was determined to be the most suitable ratio compared to both control and plasticizer chemical-based samples. It was reported that at this ratio, the setting time, 28 days compressive strength, and workability of the samples increased. Additionally, according to SEM analysis, it was observed that microcrack formation was less in molasses-based samples. Moreover, they assessed that molasses could be a suitable alternative chemical material instead of retarder and plasticizer chemical materials (Jaramillo et al., 2022).

Pathan and Singh researched the combined use of cane molasses and treated waste water in concrete production. In the study, 0.40%, 0.60% and 0.80% molasses by weight of cement was added to the cementitious samples. As a result, 0.40 molasses ratio was determined as the most suitable ratio. It was detected that as the molasses content increased in the mixture, the setting time, workability, and splitting tensile strength values increased, and the amount of mixing water significantly decreased. In addition, it was explained that the use of molasses combined with treated waste water in concrete production is suitable and considerably reduces the concrete production cost (Pathan & Singh, 2017).

It has been found in the literature that molasses material increases the setting time, workability, fresh density, splitting tensile and compressive strength values, and reduces the water ratio, pore volume, and microcrack ratio in cementitious samples. According to the literature reviewed, molasses is used compatible with normal plasticizer, superplasticizer, and water-reducing additives. The sugar content of molasses positively affects the performance properties of plasticizers and water-reducing concrete admixtures. Thus, thanks to molasses, higher-quality cementitious materials can be produced with a low w/c ratio. In the construction industry, the production cost of cementitious material can be reduced by adding molasses as a replacement material to normal plasticizer, superplasticizer, and water-reducing chemical additives. In addition, compared to commercial chemical additives, molasses has a more positive effect on the properties of cementitious materials. Moreover, by using molasses as an aid grinding material in the production of cement clinker, energy savings can be achieved and environmental pollution resulting from cement production can be reduced. Additionally, it is suggested to use molasses material in the production of RAC and lightweight concrete. On the other hand, usability molasses combined with mineral-based materials such as pumice, FA, GGBS, and borogypsum is an important advantage. In the construction sector, the use of molasses in the production of cementitious materials can provide both an environmentally friendly building material and a sustainable environment. In this case, a strong commercial relationship can be established between the construction sector and the sugar sector.

In summary, the findings obtained from the literature studies investigated are given in Table 1. According to Table 1, the most suitable molasses ratio varies in different literature studies. Firstly, the most suitable molasses ratio in construction materials and construction works should be determined.

Table 1: Briefly, literature findings on the effect of molasses on construction materials and construction works.

Reference	Year	Determined most suitable molasses ratio	Remarks
Prakash et al.	2014	13%	The Marshall stability value of bitumen mixtures increased.
Gürü et al.	2017	5%	Molasses and boron oxide improved the rutting resistance of bituminous material.
Mose et al.	2018	20%	The cost of bituminous mixtures decreased by ~17%.
Rangan et al.	2019	4%	The Marshall value of asphalt concrete increased.
Harerua et al.	2020	5%	Hot-mix asphalt improved the rheological properties.
Le	2021	10%	Molasses improved the tensile strength of asphalt concrete.
Saboo et al.	2023	25%	The binder cost of the bitumen mixture decreased by ~21%.
Arslan et al.	2024	3%	The stability of bitumen mixtures increased.
Mehta et al.	2024	30%	Total asphalt costs decreased by ~20~30%.
Benk et al.	2012	12.5%	It was used as a binding material in brick production.
Cuervo	2020	2.5%	The compressive strength of adobe brick increased by 9%.
Chantit et al.	2022	12.5%	Earth block's thermal properties improved.
Syahfitri et al.	2024	20%	Lightweight composite roof tile was produced.
Dabakuyo et al.	2022	4%	The mechanical properties of the soil block improved.
Şahinöz et al.	2022	35%	It was used as a binder material in the production of composite panels.
Sutiawan et al.	2023	59% (concentrate ratio)	It was used in the production of eco-friendly wood panels.

Table 1: Continued.

Reference	Year	Determined most suitable molasses ratio	Remarks
Cai et al.	2023	2/1 (molasses/binder)	Composite panel production cost decreased.
Şahinöz et al.	2023	35%	Composite panel production cost decreased.
Djonga et al.	2024	12-30%	It was used instead of synthetic binders in the production of insulation panels.
Ndegwa	2011	8%	The CBR value of clay soil increased.
Taye et al.	2015	4%	The combination of molasses and cement reduced the swelling of clay soil by 10%.
Mamuye et al.	2018	50%	The combination of molasses and lime increased the base layer CBR value by 81%.
Vinodhkumar et al.	2018	12.5%	The liquid limit value of the expansive clay soil decreased.
Nabeel et al.	2019	8%	The highest triaxial test result value was obtained in clay soil.
Bhardwaj et al.	2022	10%	The mixture of molasses, lime and foundry sand reduced the construction cost by 36%.
Karimi et al.	2022	10%	The soil shear strength value increased.
Jiménez et al.	2022	2%	Molasses and rubber fiber increased the unconfined compressive strength value of clay soil.
Sadique et al.	2023	12%	Molasses and jute fiber reduced the plastic limit value of clay soil by 21%.
Ouedraogo et al.	2023	2%	The CBR value of laterite clay soil increased.
Ali et al.	2020	0.25-0.50%	RAC's water ratio has decreased.
Rashid et al.	2019	%0.25	The compressive strength of concrete increased by 15%.
Weifeng et al.	2014	1%	It delayed the hydration reaction of cement paste.
Akar et al.	2016	0.50-1%	Concrete cost decreased by ~3%.
Acharya et al.	2024	0.40%	It was used as a superplasticizer additive in the mortar mixture.
Huang et al.	2020	Unspecified	It was used as a retarder/plasticizer additive in cement mortars.
Mohammed et al.	2023	0.2%	The combination of molasses and pumice was used to produce high-strength lightweight concrete.
Abalaka	2011	0.05%	The physical and mechanical properties of concrete improved.
Jumadurdiyev et al.	2004	0.2%	The setting time and workability of concrete increased.
Kavas et al.	2005	0.1%	The combination of molasses and borogypsum increased the compressive strength of concrete.

Table 1: Continued.

Reference	Year	Determined most suitable molasses ratio	Remarks
Gao et al.	2011	0.03%	The combination of molasses and FA increased the compressive strength of cement mortar.
Zhang et al.	2016	0.02%	It was used as a grinding aid material in cement production.
Li et al.	2015	0.04%	It was used as a grinding aid material in cement clinker production.
Al-Mamoori et al.	2018	0.2%	The setting time of concrete increased.
Mashtakov et al.	2018	Unspecified	It was used as a high performance plasticizer for concrete.
Jaramillo et al.	2022	0.4%	It reduced the formation of microcracks in concrete.
Pathan et al.	2017	0.4%	It reduced the mixing water of concrete.

4. CONCLUSION

According to the literature studies reviewed, the evaluation of molasses in civil engineering works;

- Due to unstable oil production and prices, molasses is an excellent alternative raw material source to reduce the cost of asphalt production.
- Molasses improves the mechanical properties of asphalt material, such as stability, peeling resistance, rutting resistance, ductility, penetration, and tensile strength.
- When modifying asphalt, it is more suitable to use molasses combined with mineral-based binder materials such as fly ash and boron oxide.
- Molasses can be used as a binder in place of toxic synthetic binders used in the production of construction materials.
- Molasses improves the mechanical properties of construction materials (such as bricks, tiles, and composite panels), such as thermal properties, internal bonding strength, flexural and compressive strength.
- Thanks to the sugar content of molasses, the production of construction materials becomes easier.
- Molasses can be used to increase soil stability and road base load-bearing capacity.
- Molasses increases the bearing capacity, compressive strength, cohesion and shear strength of the soil and reduces the swelling ratio, consistency limits, specific gravity and moisture content.
- Molasses reduces the cost of road construction.
- Molasses should be used as a plasticizer, water reducer and retarder additive in cementitious materials.
- Compared to commercial chemical additives, molasses has a more positive effect on the properties of cementitious materials.

- It is more suitable to use molasses in RAC in combination with various mineral additives.
- It can be used as an aid grinding material in cement clinker production. Thus, energy savings can be achieved in cement production.

As a result, it is proposed that molasses be used in civil engineering, both to improve the properties of construction materials and to reduce costs. Molasses can contribute to the economy by being recycled in the construction sector. Thus, an economic relationship can also be established between different sectors, such as construction and the sugar sector. Molasses is a suitable raw material source for the production of cheap and eco-friendly construction materials for the construction sector and for reducing construction costs. By disposing of molasses in civil engineering works, CO_2 emissions can be reduced, and natural resources and the environment can be protected.

CONFLICT OF INTEREST STATEMENT

There is no conflict of interest among the authors.

CONTRIBUTIONS OF AUTHORS

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