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Investigation of boron waste usage in civil engineering applications

İnşaat mühendisliği uygulamalarında bor atıklarının kullanımının araştırılması

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Abstract

Nowadays, limited natural resources and huge consumption leads to increase in production costs and energy usage. Increasing energy consumption causes environmental damages, which yield climate change. This situation increases the interest in sustainability along with the recycling of waste material in different areas. While sustainability awareness of society is tried to be created in different countries, research and development studies are also carried out on the other hand. Studies regarding sustainability in civil engineering include recycling and reuse of various wastes. Turkey has 73% of the boron reserves, and provides 50% of boron need in the world. The boron mine can be used in a wide variety of applications such as aerospace and aircraft industries and even in disinfectant production due to the Covid-19 pandemic. On the other hand, boron waste is expected to increase with the increase in production potential. The objective of this study is to introduce the potential of using boron wastes in civil engineering. Applications of boron waste in civil engineering have been researched in the literature and evaluated in detail. As a result of the study, possible boron waste assessment suggestions have been presented for Turkey.

Keywords: Boron waste, Civil engineering, Re-usage, Sustainability.

Öz

Günümüzde sınırlı doğal kaynaklar ve fazla tüketim, üretim maliyetlerinin ve enerji kullanımının artmasına neden olmaktadır. Artan enerji tüketimi, iklim değişikliğine neden olan çevresel zararlara neden olmaktadır. Bu durum, farklı alanlarda atık malzemelerin geri dönüşümü ile birlikte sürdürülebilirliğe olan ilgiyi artırmaktadır. Farklı ülkelerde toplumun sürdürülebilirlik bilinci oluşturulmaya çalışılırken bir yandan da araştırma geliştirme çalışmaları yürütülmektedir. İnşaat mühendisliğinde sürdürülebilirlik ile ilgili çalışmalar, çeşitli atıkların geri dönüştürülmesini ve yeniden kullanılmasını içermektedir. Türkiye bor rezervinin %73'üne sahiptir ve dünyanın bor ihtiyacının %50'sini sağlamaktadır. Bor madeni, havacılık ve uçak endüstrileri gibi çok çeşitli uygulamalarda ve hatta Covid-19 pandemisi nedeniyle dezenfektan üretiminde kullanılabilmektedir. Öte yandan, üretim potansiyelindeki artışla birlikte bor atıklarının da artması beklenmektedir. Bu çalışmanın amacı, bor atıklarının inşaat mühendisliğinde kullanım potansiyelini ortaya koymaktır. Bor atıklarının inşaat mühendisliğindeki uygulamaları literatürde araştırılmış ve detaylı olarak değerlendirilmiştir. Çalışma sonucunda Türkiye için olası bor atığı değerlendirme önerileri sunulmuştur.

Anahtar Kelimeler: Bor atığı, İnşaat mühendisliği, Yeniden kullanım, Sürdürebilirlik.

1 Introduction

Natural resources and raw materials have been used to produce whatever is needed by humanity especially after industrial revolution. Natural resource reserves decreased during this process. Population increases resulted mass production which increased demand for energy and workforce. Wastes are generated from process of production which cause environmental and storage problems. These wastes can reduce air quality, pollute water and soil, and damage food supply chains. Importance of recycling is increasing to limit effects of production to nature. Recycling may reduce environmental problems and contribute to the country's economy [1, 2].

Boron is one of the most important underground resources of Turkey, which has approximately 70% of the world's boron reserves. Some processes are required to obtain boron since boron is not found in pure form in nature. First of all, boron ore is removed from the soil and then goes through several stages such as crushing, sieving, washing and grinding, respectively. All these stages in the recover and condensation process of boron generate industrial wastes which have a negative impact on the environment and cannot be recycled by nature. Potential use of boron wastes in civil engineering projects may reduce environmental effects of boron production. In this study, the applications of boron wastes in civil engineering were investigated in the literature and evaluated in detail.

2 Boron minerals and utilization in Turkey

Boron, which is not found as a free element in natural conditions, exists as boron oxide compound. Boron minerals are classified according to their calcium, sodium and magnesium elements composition. The economic value of minerals is determined by the ratio of boron oxide (B_2O_3) in compound [3].

There are more than 230 boron minerals in nature and the most commercially important boron minerals are tincal, colemanite, kernite, ulexite, pandermite, boracite, szaybelite

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and hydroboracite (Table 1). The most abundant boron minerals in Turkey from the point of reserves are tincal and colemanite. Tincal deposits in Turkey are located in Kırka-Eskişehir, colemanite deposits are located in Emet- Kütahya, Bigadiç- Balıkesir and Kestelek- Bursa. Furthermore, ulexite reserves are available in Bigadiç- Balıkesir, and ulexite is obtained from time to time as a by-product in Kestelek-Bursa. The main boron minerals are converted into high value-added products at international quality standards by Eti Maden are colemanite (76%), tincal (22%) and ulexite (2%) (Table 1). The products derived from those ores are concentrated tincal, borax pentahydrate, borax decahydrate, anhydrous borax, boric acid, sodium perborate, etidot-67, boron oxide, zinc borate, calcined tincal, ground colemanite and ground ulexite. Most of the production is exported. Eti Maden Operations General Directorate in Turkey provides the world's 47% boron demand. Boron minerals made valuable by Eti Maden using various mining methods; it is enriched by subjecting it to physical processes and turns into concentrated boron products. Boron products in Turkey are mostly used in glass and ceramic fields at a rate of 36% and 31%, respectively [4].

The production of concentrate boron in Turkey is carried out in the Emet-Kütahya, Bigadiç-Balıkesir, Kırka-Eskişehir, and Kestelek-Bursa enterprises owned by Eti Holding Eti Bor A.Ş. Concentrated boron production in these facilities is based on the removal of clayey material as a result of dispersion and classification at the end of the washing process. Etibank Kırka Borax Factories produce approximately 3 million tons of tincal per year [4]. Borax pentahydrate, borax decahydrate, concentrated tincal, anhydrous borax and calcined tincal are obtained from tincal. During production, 120,000 tons of clay waste is generated annually in the concentrated tincal unit and borax pentahydrate unit. This waste containing approximately 8-22% B_2O_3 is emptied into the facility area. These wastes contain a very high concentration of B_2O_3, therefore it is an environmental pollution problem as far as an economic loss [5].

3 Review of literature

Developing world countries consume large amounts of energy and resources, and produce waste. Environmental pollution resulting from waste leads to the deterioration of the ecological balance. For this reason, studies have focused on the usability of recyclable wastes instead of raw materials. The evaluation of waste materials and by-products prevents the destruction of nature by reducing the use of limited natural resources, and also minimizes the problems that will occur in the environment as a result of the storage of materials. However, not all wastes can be used as raw materials or additives, so detailed research is required. In addition, studies on the evaluation of wastes, which are seen as a secondary raw material source that can be an alternative to existing raw material sources, have come to the fore.

The minerals found in Turkey given in Table 1 are the most important boron minerals used in the production of boric acid and various borates. In these production processes, wastes containing boron are formed, polluting the environment and making storage a big problem. In recent years, the use of waste generated as a result of increased boron production in the construction industry has been investigated.

3.1 The use of boron waste in cement and building materials

Boron has been used in production of cement for a time. Researchers have determined that using B_2O_3 in cement production resulted significant improvements in cement's properties. When the studies done so far are examined, it has been seen that boron residues with the same B_2O_3 percentage were added to the cement in different weight ratios. Strength and durability tests were carried out on the cements containing B_2O_3. Such studies have been carried out throughout the world. It has been determined that minerals such as colemanite and boron wastes may be suitable for cement production. Boron wastes are generally used as glaze and tile paste in the ceramic industry; in floor and wall tiles; in the production of cement and brick; as a lightweight concrete and lightweight construction element; and as a raw material or additive in the field of glass and enamel. 24% of boron waste is used in the cement sector and 30% in the brick sector as can be seen in Figure 1. The literature studies on the usability of boron waste in cement and building materials are examined in this section.

Table 1. Boron minerals' B_2O_3 ratios (%) [4]

Structure	Mineral Name	Formula	B_2O_3 % ratio	Location
Sodium Borate	Tincal	$Na_2B_4O_7.10H_2O$	36.6	Kırka, Emet, Bigadiç, USA
	Kernite	$Na_2B_4O_7.4H_2O$	51.0	Kırka, USA, Argentina
Calcium Borate	Colemanite	$Ca_2B_6O_{11}.5H_2O$	50.8	Emet, Bigadiç, USA
	Pandermite	$Ca_4B_{10}O_{19}.7H_2O$	49.8	Sultançayır, Bigadiç
Sodium-Calcium Borate	Ulexite	$NaCaB_5O_9.8H_2O$	43.0	Bigadiç, Kırka, Emet, Argentina
	Probertite	$NaCaB_5O_9.5H_2O$	49.6	Kestelek, Emet, USA
Magnesium-Calcium Borate	Hydroboracite	$CaMgB_6O_{11}.6H_2O$	50.5	Emet

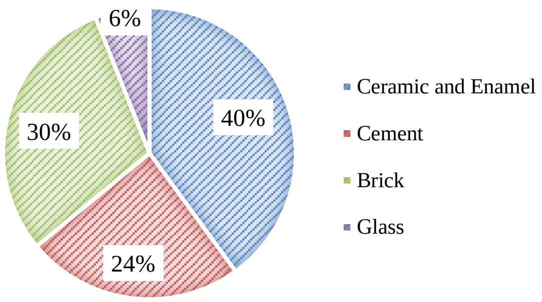

Figure 1. Distribution of boron wastes by sector [6]

The use of boron and boron waste in the production of cement and building materials has been considered by many researchers and experimental studies have been carried out. Industrial-scale cement production was carried out in Denizli and Göltaş cement factories with the joint efforts of BOREN National Boron Research Institute and Turkish Cement Manufacturers' Association [7].

Özdemir and Öztürk (2003) [5] examined the use of boron-containing clay wastes in cement production. The mechanical and chemical properties of cement prepared by adding boron waste to clinker and gypsum was investigated. When the acquired results were compared with the Portland cement properties and Turkish standards, it was specified that boron waste could be used as a cement additive up to 10%.

Kavas and Emrullahoğlu (2005) [8] produced high quality bricks with high strength and low water absorption by mixing Seydişehir red mud and Kırka boron waste clays at different rates. Kavas (2006) [9] investigated the use of boron waste up to 15% in brick production. As a result of mineralogical and mechanical experiments, it has been found that the use of boron waste is possible. It has been shown that the use of 15% boron waste results in a significant reduce in brick firing temperature and increase in mechanical performance.

Demir and Keleş (2006) [10] investigated the radiation transmission of concrete samples containing borogypsum and colemanite concentrator waste for 59.54 and 80.99 keV gamma rays. Borogypsum is one of the wastes produced in boric acid production. It has been shown that boron waste is effective in producing gamma ray shielding material and preventing radiation transmission.

Batar and Köksal (2009) [11] used waste calcined tincal to develop a new environmentally friendly plaster material. When the plaster consisting of 3% perlite, 1.5% waste paper and 7.1% waste calcined tincal is compared with the plaster available in the market, its heat permeability resistance increased by 26% and its strength value increased by 31%.

Davraz (2010) [12] examined the mechanism of action of boron mineral on cement hydration in his study. It has been stated that the boron compound slows down the hydration and prolongs the setting time depending on the boron oxide concentration it contains.

Kavas et al. (2011) [13] investigated four different types of waste containing boron for the production of artificial lightweight aggregates. Two different types of waste (SBW (sieve boron-containing waste) and DBW (dewatering boron-containing waste)) have properties close to pumice. The best results were obtained with a mixture of 20% clay, 35% SBW, 35% DBW and 10% quartz sand. Flash heating of the dry pellets at 760 °C for 5 minutes resulted in porous LWA with a bulk density of 0.97 g/cm^3.

Akyıldız (2012) [14] researched the availability of boron wastes as a pozzolanic material in concrete production. Strength and durability tests were carried out on concrete containing 3-12% boron waste. It was determined that the 56-day compressive strength of the 3% additive increased by 88% to 25.73 MPa according to 7-day compressive strength. In addition, according to the cost analysis, it has been revealed as a result of the calculations that boron wastes will save at least 10 times more when used instead of Portland cement.

Eyyüboğlu (2013) [15] produced 13 different cements by adding boron wastes with different B_2O_3 ratios up to 10% by weight to clinker and gypsum. Different B_2O_3 ratios did not reveal significant differences in the experimental results. The compressive strengths of cements with boron waste added and samples produced with CEM I cement in the high temperature test (at 900 °C) are approximately 17 MPa and 6.5 MPa, respectively. The reason for the decrease in strength of concrete at high temperatures was considered to be the deterioration of adherence, the deterioration of the structure of calcium silica hydrate gels in the cement paste and the thermal expansion differences in the aggregate.

Murathan et al. (2013) [16] aimed to produce a building material by using some environmental wastes together with boron waste. Due to the high content of calcium oxide in the boron waste, the water absorption values were high. As a result, it was determined that the produced composite material should not be used in construction materials in contact with water.

Kılıçarslan et al. (2013) [17] researched the effect of adding boron waste in the range of 5-20% on brick production by physical, mechanical and durability experiments. It has been concluded that the use of 20% boron waste improves the properties of red brick and it can be used in this industry.

Binici et al. (2014) [18] examined the mechanical and radiation impermeability properties of mortars produced by using colemanite waste. They stated that all samples with 0.75% colemanite additives had higher compressive strengths than that of the reference group. It was determined that the use of higher colemanite disrupted the concrete setting. According to their findings, barite, colemanite and blast furnace slag wastes have been appeared to be effective in preventing radiation transmission and promising materials for gamma ray shielding in mortars.

Mutuk and Mesci (2014) [1] investigated the use of up to 5% boron waste and up to 15% rice husk ash separately and together. The compressive strength of the samples containing 10% rice husk ash increased to 56.48 MPa, while that of the samples containing 5% boron waste increased to 46.10 MPa. Despite this, both results meet the Turkish

Standard (42.5-62.5 MPa). According to the results, boron waste could be used up to 5% in cement.

Kunt et al. (2015) [19] investigated the properties of cement mortar by adding up to 7% calcined/uncalcined borogypsum to the clinker. The usage of 3% calcined/uncalcined borogypsum was determined as the optimum value, and the compressive strengths are 48.00 MPa and 45.70 MPa, respectively. According to another research, the evaluation of this waste material with high boron content was determined that borogypsum could be used as an alternative material in cement bodies instead of other gypsum [20].

Koumpouri and Angelopoulos (2016) [21] investigated the effects of boron waste and boron oxide addition on low-energy belite cements by preparing three types of clinker. The usage of 6.5% boron waste by weight boron waste has been reduced the clinker temperature. As a result, it shows that the use of boron oxide, pure or produced from boron wastes, in certain amounts could be beneficial in the production of belite cement.

Erdoğan (2016) [22] aimed to produce two different insulation materials from carpet and boron wastes that are low in cost, have high heat and sound insulation values, and comply with the standards with their physical and mechanical properties. Comparisons were made with other insulation materials used in the industry. It has been determined that the produced HALIBOR-1 has a density of 185 kg/m^3, a thermal conductivity of 0.035 lW/(mK), and the obtained product is resistant to burning (B1-Difficult burning) due to the mineralogical advantages of boron.

Öztürk and Sevim (2016) [23] added up to 20% colemanite concentrator waste (borogypsum) to cement clinker in order to decrease the energy costs of cement production and improve the mechanical properties of cement. It was determined that the mechanical properties of the samples containing 5% borogypsum were similar to the reference sample.

Över Kaman et al. (2017) [24] researched the effects of up to 25% boron waste heat-treated at 600°C on cement mortar. 90-day compressive strength was found to be 52 MPa in the use of 5% boron waste while the reference mortar was 51 MPa. As the boron waste increased, the compressive strength decreased. However, according to the test results, up to 25% boron waste could be used in the production of cement mortar.

Çiçek et al. (2018) [25] investigated the properties of ceramic wall and floor tiles containing 1–6% boron waste (1-33% B_2O_3). As a result of the study, a product that encourages production at lower temperatures, environmentally friendly and zero waste economy was obtained. The floor tile containing approximately 5.65% boron waste showed 65 °C lower sintering temperature, while the sintering temperature of the wall tile has been reduced by 70 °C.

Yıldırım and Derun (2018) [26] examined the mechanical and thermal properties of mortars using two different boron wastes up to 3% and CuO (copper oxide) nanoparticles up to 4%. The addition of borogypsum to the mortar composition improved its mechanical properties and resistance to water absorption compared with borax waste. It has been stated that 0.5–1% and 2% nano-CuO could be used optimally for mortars containing borax waste and borogypsum, respectively.

Mancı and Sarıışık (2019) [27] carried out a study to determine the effect of 1% tincal waste on early strength in lightweight concrete with pumice aggregate. In accordance with the obtained results, it was designated that the early strength increased in concretes with tincal waste added with the use of 176 kg/m^3 cement amount.

Çelik et al. (2019) [28] determined the physical, mechanical and chemical properties of pumice bricks produced using up to 8% colemanite and tincal, and up to 20% boron waste. The best results were obtained from bricks using 6-8% boron waste, according to the thermal conductivity coefficient (0.1504-0.1739W/mK), water absorption (32%), porosity (37.1%) and strength values (3.63-3.33 Mpa).

Evcin et al. (2019) [29] investigated the use of boron wastes up to 90% and marble wastes up to 20% in brick production. The flexural strength of the bricks using 85% boron waste and 5% marble waste, sintered for 4 hours at 1050 °C, was determined approximately 25 MPa.

Tokgöz et al. (2019) [30] researched the effects of the use of colemanite powder, a boron waste, in the range of 1-5%, on the acid resistance of mortars. In the case of using 1%, it was determined that a reduction of up to 36.73% in weight losses was achieved, and an increase of 15.50% and 18.10% occurred in compressive and flexural strengths, respectively. When the mechanical properties and acid effect of the mortars were examined, it was seen that the optimum use was 1%.

Çelen et al. (2019) [31] examined the physical properties and usability of barite as a radiation shielding material with the addition of up to 50% boron waste. According to the experimental results, as the amount of borogypsum increased the porosity percentage and water absorption percentage decreased. Additionally, the attenuation coefficients decreased and showed less efficient gamma ray shielding.

Sevim et al. (2019) [32] researched the usability of borogypsum up to 15% as a mineral additive in mortars by physical and mechanical experiments. It has been determined that as the amount of waste used increases, the workability is adversely affected, the use of 3% reduces capillarity and shrinkage, the use of 5% reduces the depth of carbonation and increases the compressive and flexural strength.

Aldakshe et al. (2020) [33] studied the use of boron wastes as aggregate in lightweight concrete production. Boron waste was used as aggregate at 1-9% ratios of pumice. It was found that the properties of the material improved with the enhance in the use of waste, the capillary water absorption amount decreased, and the compressive strength of 19.3 MPa was obtained with 9% boron waste substitution.

Öztürk et al. (2020) [34] researched the mechanical properties, electromagnetic and shielding performances of concrete samples containing boron wastes. While the mechanical properties of concretes containing boron mineral/waste were adversely affected, shielding performance was 3.16 to 100 times better than the reference sample.

Christogerou et al. (2021) [35] aimed to determine the mechanical and frost resistance properties of 8% boron waste in clay roof tiles. Boron-containing samples fired at 1000 °C were able to successfully withstand extreme freezing conditions (>400 freeze/thaw cycles). These samples fired at 1030 °C had a higher flexural strength of approximately 9.3%.

3.2 The use of boron waste in asphalt and road construction

In recent years, due to the expansion of the usage areas of boron minerals, significant boron waste piles are formed. In addition, the warehouses built for the generated wastes occupy an important place. Significant amounts of aggregate are also needed in road construction. The literature on the availability of boron waste in asphalt and road construction are examined in this section.

Kütük-Sert and Kütük (2013) [36] investigated the utilizability of boron wastes as filler material in asphalt concrete mixtures. Two groups produced hot mix asphalt for the experiments. They used limestone aggregate as filler material in asphalt concrete in the first group, and boron waste as mineral filler material in the second group. It has been concluded that the use of boron wastes as an alternative filler in asphalt pavements may be suitable for the binding layer of pavements exposed to hot climate regions and/or heavy traffic potential.

Terzi et al. (2013) [37] researched the effect of using colemanite waste as filler on the physical and mechanical properties of asphalt mixtures. Asphalt concrete with colemanite filler was prepared by using five different filler ratios according to the optimum bitumen value determined. As a result, it has been stated that colemanite waste is included in the specification where it gives values close to limestone and could be used as an alternative filler material instead of limestone in areas close to the areas where colemanite is extracted.

Gürer and Selman (2016) [38] carried out a Marshall design using boron waste fillers in the range of 4-8% by weight, and the conclusions were compared with the results of the limestone-based sample. The best values were obtained as a result of the use of boron waste filler at the rate of 5.7%. It has been determined that boron waste could be used as a filler in medium and low traffic asphalt concrete pavements in wear layers.

Oruç et al. (2016) [39] examined the rheological properties of 4 different boron minerals and boron modified bitumen and it was stated that the minerals formed electrostatic chemical bonds with the bitumen. Bitumen modification with boron; penetration values decreased, softening point and flash point values increased. As a result, an improvement was observed in the stiffness values.

Keskin and Karacasu (2019) [40] examined the use of boron wastes in asphalt concrete production and its sustainability performance. Marshall Design and creep tests were carried out on the samples produced by adding up to 15% of Crushed Boron Waste, and up to 10% of Borax pentahydrate and Anhydrous Borax. Borax pentahydrate and Anhydrous Borax added samples had the lowest stability values, but the highest deformations were observed in these samples. As a result, the samples with the longest service life and more resistant to rutting are the samples with crushed boron waste.

Kara (2021) [41] aimed to expand the use of boron wastes in road construction. In his study, stone mastic asphalt and concrete pavement were produced with [0,1–1.0] mm, [0–4] mm, [4–8] mm and [8–16] mm boron wastes, relevant tests were carried out and the current standard compared with samples. It has been found that boron waste is not suitable for use as aggregate in stone mastic asphalt. For concrete pavements, in order to obtain high strength, steel fibre should be used in the mixture and the concrete should be subjected to combined curing (3 Days Water + 2 Days 200 ^{0}C Oven Cure).

3.3 The use of boron waste in soil stabilization

Civil engineers are studying to find safe and economical solutions in design and construction steps. The soil conditions of the project site have a great effect on the design and construction methods in civil engineering applications. Problematic soil conditions can cause important problems therefore; soil conditions should be improved. The two main methods of soil stabilization are mechanical and chemical stabilization used depending on the construction process. The main objectives are reducing the compressibility, and maximizing its strength [42]. Waste materials used in soil stabilization are beneficial because they are much more economical than that of other materials and contribute to waste management. The literature on the usability of boron waste in soil stabilization are examined in this section.

Çoruh et al. (2013) [43] examined the availability of borogypsum waste as a stabilization material in the subbase layer of the road pavement. In addition, a cost calculation has also been made. It was determined that the most optimum use was the mixture containing 50% borogypsum. It was found that the layer thickness decreased from 35 cm to 30 cm as a result of sub-base construction with the optimum mixture, and the road construction cost was reduced by 12% for the whole road and 50% for subbase due to the 43% reduction in the amount of aggregate used.

Zhang et al. (2016) [44] aimed to reuse boron waste as an additive in road base material. The performances of lime and lime-cement stabilized boron waste mixtures were investigated by various experimental methods. Lime-cement and stabilized boron waste mixture had the highest compressive and tensile strengths. Due to the low frost resistance of the boron waste mixture stabilized with lime, it is recommended to be used in frost-free regions.

Zorluer and Gücek (2017) [45] tried to provide soil stabilization with 3 different mixtures using fly ash and slime waste boron. The mixture containing 10% boron waste and 20% fly ash was determined as an optimum mixing ratio.

Okur and Akıncı (2018) [46] investigated the dynamic behaviour of the use of 2-8% powdered boron wastes in soft subsoils. It was observed that the dynamic properties of kaolinite and montmorillonite clays treated with boron waste, which were subjected to resonance column and dynamic torsional shear tests, were improved. Montmorillonite clay behaved almost three times more rigid from the point of initial shear modulus. It has been observed that the effect of boron waste on kaolinite was less compared to montmorillonite.

Zorluer and Gücek (2020) [47] conducted an experimental study by mixing boron wastes with different industrial wastes such as marble dust at different rates. While the highest strength was observed in the 5GD–10FA sample in granite dust (GD) – fly ash (FA) mixtures, the highest strength was observed in the 10BR–20FA sample in the boron waste dust (BR) – fly ash (FA) mixtures. CBR values slightly increased in BR-FA mixtures. At the end of the freeze-thaw cycles, minimal weight loss was determined in the marble dust (MD)-FA mixture and the BR-FA mixtures. Additionally, they stated that boron waste can be used for soil stabilization but is not very influential.

4 Conclusion and recommendation

In order to expand the usage of boron products, several researches have been carried out. Further research is planned to increase the use of boron products in space and aircraft, nuclear electronic and communication, automotive, energy, metallurgy and construction industries. Some of that research is about using boron in development of military vehicles, as additive to fuels, production of polymeric materials and nanotechnologies. The more boron is used during production; the more boron waste will be produced.

In recent years, the use of boron added products has become widespread in the civil engineering sector with innovative approaches. Use of boron in building materials; it increases strength, provides resistance to high temperatures, ensures that boron wastes are brought into production, prevents the formation of bacteria and fungi, reduces harmful gas emissions to the environment during the production phase, and provides energy savings. Due to these properties, boron is used in the building materials industry in civil engineering; cement, brick, plaster, wood, insulation material, glass, ceramic etc. used in the fields. It has been stated that which types of boron wastes are used in the field of civil engineering according to the years in Table 2.

The construction sector is one of the most favourable sectors that can be used to decrease the environmental impressions of large amounts of boron wastes and to bring them into the economy. It is one of the sectors with the highest need for raw materials. The results of the studies in the literature encourage the use of boron minerals in the construction industry. It is seen that a significant part of the studies on boron waste is related to its use in cement or building materials. In the literature, there are limited studies on the use of boron waste in asphalt modifications and soil stabilization.

When the studies are evaluated, the utilize of boron/boron waste as an additive in cement production can provide properties such as superior fire resistance and radiation impermeability to cementitious composites. However, since the cost arising from transportation will also be reflected in cement production, it would be more beneficial to evaluate each waste in the region where it is located. The absence of any harmful component in boron's structure that may adversely affect the cement properties provides a great advantage for use of boron wastes in cement production. Using boron wastes in new production areas will decrease environmental damage and will provide additional income to the country's economy.

Utilization of boron/boron waste in the civil engineering applications;

- It prevents the deformation of the material.
- It protects the material against the colour problem that occurs over time.
- It increases resistance to water and fire, radioactivity shielding performances.
- It provides features such as heat and sound insulation.
- Artificial lightweight aggregate can be produced by applying heat treatment to boron waste.
- When colemanite is added to the clinker at a rate of 8% in cement production, it reduces the firing temperature and this improves both the properties of the cement and saves energy.
- The addition of boron oxide compound to cement clinker prolongs the setting time.
- Boron added cements reduce the cooling requirement of mass concretes.
- It can be used as roofing, building coverings and cellulosic insulation.
- It can be used as aggregate in lightweight concrete production.
- It contains clay, which is the primary commodity of brick production, and the boron compounds in it provide fluidity.
- It can be used in asphalt concrete. Asphalt pavements prepared with 10% boron waste can recycle 86 tons of waste material for 1 km of road.
- It can be used for soil stabilization and road base materials.

Elements such as Lithium (Li) found in Kırka and Emet boron wastes can be reused. The most appropriate way to evaluate boron wastes is to evaluate the remaining clay contents after the recovery of valuable elements in the wastes in appropriate sectors. Furthermore, it is recommended that detailed chemical analysis should be made for the use of waste boron mixtures in soil stabilization and the effects of these wastes on soil and groundwater should be investigated. It is hoped that this study will shed light on the researches to be carried out by evaluating the boron minerals and wastes in civil engineering applications.

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Conflicts of interest

No conflict of interest was declared by the authors.

Similarity rate (Turnitin): %20

Table 2. Usage of boron waste in civil engineering applications by years

Applications	Boron Waste Type	Years	Reference
Production of cement	Boric acid wastes including reactor waste Borogypsum and sludges as well as colemanite concentrator waste Tincal concentrator waste Borax pentahydrate waste	2003	[5]
Bricks	Concentrator waste	2005	[8]
Bricks	Clay and fine waste from concentrator waste	2006	[9]
Production of gamma ray shielding material	Borogypsum Colemanite concentrator waste		[10]
Plaster material	Calcined borax waste	2009	[11]
Artificial lightweight aggregates	Sieve boron-containing waste Dewatering boron-containing waste	2011	[13]
Pozzolanic material in concrete	Boron waste found in Kırka	2012	[14]
Production of cement	Colemanite concentrator waste	2013	[15]
Building materials	Boron waste found in Emet		[16]
Bricks	Boron pond waste found in Kırka		[17]
Filler material in asphalt concrete	Borogypsum		[36]
Asphalt mixtures	Colemanite waste		[37]
Subbase layer of the road pavement	Borogypsum		[43]
Production of cement	Boron waste found in Kırka	2014	[1]
Radiation impermeability properties of mortars	Colemanite waste		[18]
Cement mortars	Calcined borogypsum Uncalcined borogypsum	2015	[19]
Production of belite cement	Boron waste found in Kırka	2016	[21]
Insulation materials	Colemanite waste		[22]
Production of cement	Colemanite concentrator waste		[23]
Asphalt concrete pavements	Boron waste found in Kırka		[38]
Road base material	Borax waste		[44]
Cement mortars	Boron derivative waste	2017	[24]
Soil stabilization	Slime waste		[45]
Ceramic wall and floor tiles	Boron-rich mining wastes	2018	[25]
Cement mortars	Borogypsum Borax waste		[26]
Dynamic properties of kaolinite and montmorillonite clays	Pulverized boron waste found in Kırka		[46]
Early strength of lightweight concrete	Tincal waste	2019	[27]
Pumice bricks	Boron waste found in Kırka		[28]
Bricks	Boron waste found in Emet		[29]
Cement mortars	Colemanite waste powder		[30]
Radiation shielding material	Borogypsum		[31]
Cement mortars	Borogypsum		[32]
Asphalt concrete production	Crushed boron waste found in Kırka		[40]
Lightweight concrete	Boron waste found in Kırka	2020	[33]
Shielding performance of concrete	Borogypsum Colemanite waste		[34]
Soil stabilization	Slime waste		[47]
Clay roof tiles	Boron waste found in Kırka	2021	[35]
Stone mastic asphalt and concrete pavement	Boron waste found in Bigadiç		[41]

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