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Lightweight aggregates coated with colemanite

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Abstract. Technological advancements in the field of building materials are achieved day by day. In this study, a new lightweight concrete aggregate is produced by mixing certain rates of colemanite (0%, 7.5%, 12.5%, 17.5%), cement and coating the surface of pumice aggregate with this mixture. Thin aggregate sections are analyzed with specific gravity, unit weight, water absorption, impact, and crushing experiments. In this way, the production of cement and cement+colemanite coated lightweight concrete aggregates is investigated and an opinion on the likely behavior of these concrete types is provided.

Keywords: aggregates/recycled aggregates; cement; construction materials; strengthening; admixtures

1. Introduction

In recent years, major developments in the field of construction have been achieved. These developments require building materials to have superior technical properties as well as paving the way for the utilization and application of many new building materials (Gündüz *et. al.* 2001).

Pumice stone is identified as "natural lightweight aggregate" in the technical terminology. The different sized grains obtained by crushing and sieving the pumice stone is defined as "pumice aggregate" (Gündüz 2005). Pumice stone is an extremely porous rock that is formed as a result of the rapid cooling of lava and gas exsolution during volcanic activities (Müller and Linsel 2005). Pumices have low density and high porosity due to their porous structure (Kogel *et al*. 2006, Artuso and Wargo 1998).

Boron, on the other hand, is another important mineral which has been known and used for a very long time (Yenmez 2009) and contains different ratios of boron oxide (B_2O_3). About 230 kinds of boron can be found in nature (www.enerji.gov.tr 2011). High concentration boron (colemanite) beds in economic sizes and boron compounds bound to oxygen are located mainly in the dry, volcanic, and hydrothermal regions of Turkey and the USA (DPT 2008). 90% of the boron used in the construction sector throughout the world is comprised of sodium based tincal, calcium based colemanite, and sodium+calcium based ulexite (www.minerals.usgs.gov 2012). In order to use these minerals, first they are primarily enriched via physical procedures in the industry and then transformed into various boron chemicals by refining (www.enerji.gov.tr 2011).

In the studies on the use of colemanite admixture cement and concrete; Binici *et al*. (2014), Yaltay *et al*. (2015) and Oto *et al*. (2013) have determined that concretes containing colemanite have better radiation protection. Aksoğan *et al*. (2016) have specified that 1% colemanite additive instead of fine aggregate, provide positively to the compressive strength of concrete samples. On the other hand Gencel *et al*. (2010) have determined that, using colemanite ranging from 10 up to 50% as aggregate in concrete has a negative effect, in respect to both physical and mechanical properties. In addition, in the studies conducted with colemanite coated aggregates; have been found to contribute positively to the pressure, permeability, high temperature and adherence properties of concrete produced with 12.5% colemanite+cement coated aggregates (Bideci 2016, Beycioğlu *et al*. 2015, Bideci *et al*. 2015).

In the present study, a mixture for coating aggregates is prepared by adding granular colemanite into different ratios of cement by weight (0-Control, 7.5%, 12.5%, and 17.5%). The obtained mixture was used for coating pumice and physical, chemical, mechanical, and contexture examinations were conducted. Also Scanning Electron Microscope analyses of samples were performed.

2. Material and method

2.1 Material

In this study, the pumice aggregate obtained from the furnace of Metaş Mining Ltd. Co., which is located in the Çardak village of Nevşehir is used. In studies conducted by the General Directorate of Mineral Research and Exploration (MTA), it has been reported that the high-quality pumice located in the mentioned area has a proven reserve of 82.612.500 m^3, a probable reserve of 87.592.000 m^3, and a possible reserve of 68.445.000 m^3

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Table 1 The chemical analyses of pumice aggregate and boron (granular colemanite)

Chemical Composition	B_2O_3	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	As_2O_3 (ppm)	As (ppm)	Loss on Ignition
Pumice	-	74.10	13.45	1.40	1.17	0.35	4.10	3.70	-	-	-	1.54
Colemanite	40.09	4.98	0.15	0.029	26.95	2.37	-	0.09	0.26	15	11.36	0.27

Table 2 Physical analysis of colemanite and results of the compressive and flextural strength experiments

Physical Analysis	Density (g/cm^3)	2.50
	Specific Surface (cm^2/g)	3839
	Over 40μ Sieve Residue (%)	21.8
	Over 90μ Sieve Residue (%)	0.2
Compressive Strength (MPa)	7 Days	4.1
Flextural Strength (MPa)		1.25

(www.mta.gov.tr). The granular colemanite, which is replaced for cement by weight, is obtained from the Directorate of Eti Mine, Bigadiç Boron Works (Eti Colemanite Analysis Report 2011). The chemical analyses of the pumice and colemanite obtained from the Directorate are shown in Table 1.

The experiment regarding the pozzolanic activity of granular colemanite is conducted in accordance with the TS 25 standards. The results of conducted activity on colemanite are shown in Table 2 (Puzzolanic Activity Report of Colemanite 2012).

The CEM I 42.5/R cement, which was produced at the Kırklareli Limak Trakya Cement Factory according to TS EN 197-1, is used as binding material. The chemical and physical analysis of cement with standard boundary values is given in Table 3 (Cement Chemical Analysis Report 2012).

2.2 Method

Pumice aggregates are separated to range of grades with 4-8 mm and 8-16 mm for coating. Also pumice aggregates are kept in oven at 60℃ through 24 hours before coating. Coating machine (Complex stainless steel and is used homogeneously in the coating of chickpeas, roasted chickpeas, roasted chickpeas and dragee sugar products) used for covering process has 800 mm diameter, 1700 mm width and 1550 mm height with 1.85 kW-2.25 kW electric power. Surface has to be covered completely by spilling the cement and cement-colemanite grout on the aggregates put into the machines in two layers. In order to separate each layer, ground colemanite powder is spilled onto the aggregates. Aggregates are aimed to coated to have the same cover thickness (Beycioğlu *et al*. 2015). Two layers of cement or cement+colemanite putty is poured on the total surface of the aggregates placed in the coating machine. In order to divide each layer, granular colemanite dust is sprinkled on the aggregates.

The amount of colemanite in the aggregate coating (0%, 7.5%, 12.5%, and 17.5%). In a study by Sağlık *et al.* (2009), it is reported that the utilization rate of colemanite

Table 3 The chemical and physical analysis of CEM I 42.5/R cement

Component (%)	CEM I 42.5 R	TS EN 197-1	Physical Analysis			TS EN 197-1
CaO	63.92	C+S≥%50	Setting Time (Min.)	Start	145	min. 60
SiO_2	19.55			Finish	195	-
Al_2O_3	5.12	-	Density (g/cm^3)		3.11	-
Fe_2O_3	2.52	-	Specific Surface (cm^2/g)		3912	-
MgO	1.02	Lim.≤%5	Total Volume Expansion (mm)		1	max.10
SO_3	2.96	Lim.≤%4	Over 40μ Sieve Residue		23.1	-
Na_2O	0.27	-	Over 90μ Sieve Residue		2.4	-
K_2O	0.67	-	Compressive Strength (N/mm^2)	2 days	25.9	min. 20
Cl-	0.0089	Lim.≤%0.10		7 days	45.1	-
Loss on Ignition	4.08	Lim.≤%5		28 days	-	min. 42.5 max. 62.5
Res. Solution	0.36	Lim.≤%5				

Table 4 The codes of coated pumice aggregates

Colemanite Addition	Codes
---	Control
0%	0-CLM
7.5%	7.5-CLM
12.5%	12.5-CLM
17.5%	17.5-CLM

changed according to the B_2O_3 tenor it contains and that 2.5-3% of B_2O_3 in the clinker is optimal. Aggregates with grain sizes of 4-8 mm and 8-16 mm are coated with material that has the same thickness. Aggregate samples uncoated Control, coated with 0% of B_2O_3+cement are coded as 0-CLM, those coated with 7.5% of B_2O_3 as 7.5-CLM, those coated with 12.5% B_2O_3 as 12.5-CLM, and those with 17.5% B_2O_3 as 17.5-CLM (Table 4).

3. Results and discussion

3.1 The specific gravity, loose unit weight, and water absorption

The physical experiment results (specific gravity, loose unit weight, and water absorption) of the aggregates coated or uncoated with cement and cement+colemanite are shown in Table 5.

The specific gravity experiment of the coated and uncoated pumice aggregates are conducted according to the principle regarding aggregate and water replacement by volume. "Pumice aggregates which will be used as lightweight aggregates should have minimum unit weight values of 2.1 g/cm^3".

The loose unit weight experiment is conducted according to the TS EN 1097-3, where it is observed that the loose unit weight of the aggregates by sieve sizes of 4-8 mm was 501-688 kg/m^3 and 401-621 kg/m^3 in aggregates by sieve sizes of 8-16 mm, respectively. These results are similar to the values reported in the literature (480-880 kg/m^3), except for the values pertaining to the uncoated

Table 5 The experiment results regarding the specific gravity, loose unit weight, and water absorption of the aggregates

Mixtures	Specific Gravity (g/cm^3)		Loose Unit Weight (kg/m^3)		Water Absorption Rates (%)	
	4-8 mm	8-16 mm	4-8 mm	8-16 mm	4-8 mm	8-16 mm
Control	1.05	0.96	501	401	27	38
0-CLM	1.44	1.30	688	621	13	16
7.5-CLM	1.44	1.32	673	613	14	17
12.5-CLM	1.46	1.34	656	615	13	19
17.5-CLM	1.44	1.39	640	619	15	17

Table 6 Physical test results of the coated and uncoated aggregates

Mixtures	Crushing Value (%)	Impact Value (%)
Control	63.0	51.4
0-CLM	67.2	40.0
7.5-CLM	64.3	53.2
12.5-CLM	42.9	46.6
17.5-CLM	49.8	49.8

pumice aggregates by sieve sizes of 8-16 mm in our study.

Water absorption percentages (24-hour) are conducted according to the TS EN 1097-6, it is observed that the control aggregates by sieve sizes of 4-8 mm had a water absorption rate of 27%. The water absorption percentages, compared to the control aggregate, decreased by 48% in 0-CLM aggregates, 52% in 7.5-CLM aggregates, 48% in 12.5-CLM aggregates, and 56% in 17.5-CLM aggregates. When we examined the aggregate groups with sieve sizes of 8-16 mm, it was found that the water absorption value of control aggregates was 38%, and the water absorption percentages decreased by 42% in 0-CLM aggregates, 45% in 7.5-CLM aggregates, 50% in 12.5-CLM aggregates, and 45% in 17.5-CLM aggregates.

During the investigation of water absorption percentages of the aggregates according to granule diameters, it is observed that the water absorption percentage of control aggregates also increased as granule diameters increased. However, the water absorption difference between the granules observed to be decreased after coating the aggregates with cement and cement+colemanite. Therefore, it is determined that granule size does not have a significant effect on water absorption after the coating procedure. It is found that the values in our study does not exceed the water absorption percentages provided in the literature (30-40%) (Newman and Owens 2003).

3.2 The crushing value of the aggregates

Aggregate crushing value (coefficient) is a relative measure of resilience against crushing under gradually increased pressure. In order to obtain the crushing value, the experiment cylinder is placed between the jaws of the compression machine. The rate of load increase in the experiment press is adjusted so that the load would reach 400 kN within 10 minutes. After the load is emptied, the aggregate mass is transferred to a clean container. At the end of the compression procedure, the material in the container is therefore, sieved with a 2.36 mm (BS) lool and the weight of the sieved material is determined (Sangari 1992).

As for the crushing coefficient crumble percentage values of uncoated, cement coated, and cement+colemanite coated aggregates, compared to control aggregates; it is observed that 7.5-CLM and 12.5-CLM aggregates showed a 32% and 21% decrease, respectively (Table 6). Shangari (1992) states that aggregate crushing coefficient crumble percentages of >30% are considered abnormal (Sangari 1992). According to the results, it is determined that the 12.5-CLM and 17.5-CLM coatings increased aggregate crushing strength.

3.2.1 The impact value of the aggregates

The "impact coefficient" which is a relative measure of aggregate resilience shock or impact is found for aggregate impact strength. The dry aggregates used in the experiment are weighted and placed in a steel cylinder container in 3 layers, and compressed by 25 impacts done with a poking stick on each layer. The impact hammer is dropped upon the aggregate in the container 15 times a second. At the end of the compression procedure, the material in the container is sieved with a 2.36 mm (BS) lool followed by the determination of the weight of the sieved material.

Regarding the aggregate impact coefficient crumble percentage values compared to control samples, it is observed that 0-CLM, 12.5-CLM and 17.5-CLM aggregates showed 22%, 9%, and 3% decrease, respectively; while the 7.5-CLM sample increased by 4% (Table 6). As mentioned before, aggregate impact coefficient crumble percentages of>30% are considered abnormal (Sangari 1992). In the literature, it has been stated that lightweight aggregates can be easily crushed during impact value experiments (Chandra and Berntsson 2003). According to the results, it is determined that 0-CLM, 12.5-CLM, and 17.5-CLM coatings increased aggregate impact strength.

3.3 Internal structures of coated and uncoated pumices

The thin section prepared for the petrographic investigation of rocks is identified by determining the acquired properties of heat passing through the section using a polarizing microscope (Erdoğan 2007).

3.3.1 Internal structure of uncoated pumice (control) aggregate

When we examine the thin section images of the pumice aggregate samples via microscope, it is observed that the majority of the rock is composed of volcanic glass with an amorphous structure. This volcanic glass, which constitutes clay, includes an abundant amount of opaque minerals (iron oxide-hydroxide). The amount of amorphous materials is approximately 4-5%. In addition, opal calsedon type SiO_2 compounds are observed in the rock. The amount of cavity

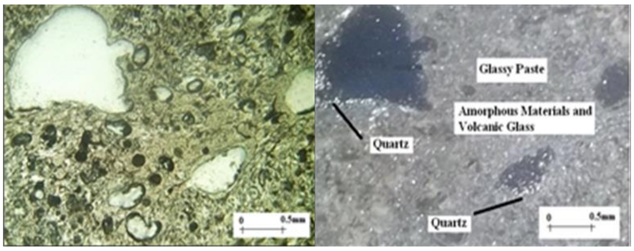

Fig. 1 The thin section images of uncoated pumice aggregate

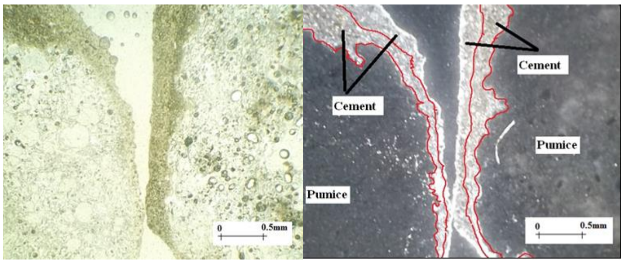

Fig. 2 The thin section images of cement coated pumice aggregate

in the rock is measured to be approximately 2-3% and the edges of the pores contained small amounts of crypto-crystalline quartz. Yield textures are also observed on the rock. Probable rocks transit to lava flows. It is determined that the rock was a product of dacidic magma (Fig. 1).

3.3.2 Internal structure of cement coated pumice (0-CLM) aggregate

It is observed that the first layer of coating in cement coated pumice aggregate is granolous, while the second layer is significantly thinner. Coating thickness is not homogenous due to section preparations and thichkness ranged between 0.3 and 1.8 mm (Fig. 2).

3.3.3 Internal structure of cement+colemanite coated pumice aggregates (7.5-CLM,12.5-CLM, 17.5-CLM)

The coating thickness of the cement+colemaite coated pumice aggregates was 0.6-1.0 mm in 7.5-CLM samples, 0.8-1.2 mm in 12.5-CLM, and 0.3-1.0 mm in 17.5-CLM. The thin section images of the aggregates are shown in Figs. 3, 4, and 5.

4. Conclusions

In this study, the contextures and physical properties of the uncoated, cement coated, and cement+colemanite coated pumice aggregate samples are evaluated by comparing to the properties of control samples. As a result, lightweight aggregates, which are improved via cement and cement+colemanite coatings, are produced.

• In the polarizing microscope studies of pumice aggregates obtained from the Çardak village of Nevşehir, it is determined that the pumice rock is an acidic magma product with dacid compounds.

• It is observed that, compared to control aggregates, the specific gravity values of the aggregates with sieve sizes of

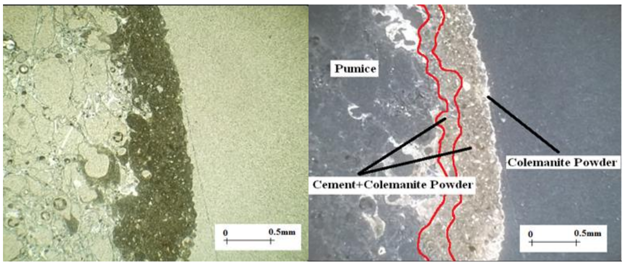

Fig. 3 The thin section images of 7.5-CLM coated pumice aggregates

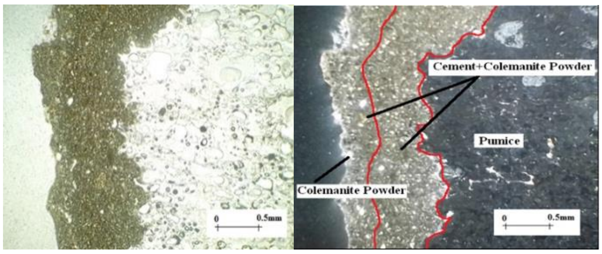

Fig. 4 The thin section images of 12.5-CLM coated pumice aggregates

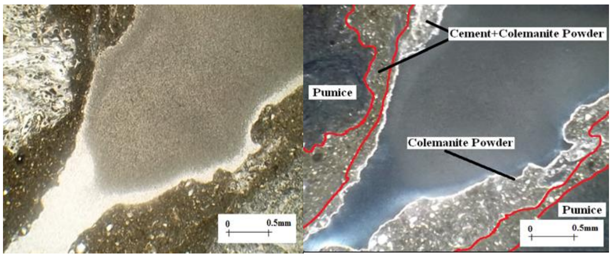

Fig. 5 The thin section images of 17.5-CLM coated pumice aggregates

8-16 mm increased with cement+colemanite coatings and that they are compatible with the specific gravity of the light aggregates used in concrete production, which is 2.1 g/cm^3 (Gündüz 2005).

• In the loose unit weight experiment results, it is seen that, compared to control aggregates, coated aggregates with sieve sizes of 4-8 mm has a 33% and those with sieve sizes of 8-16 mm has a 54% increase.

• Regarding water absorption percentages of the aggregates according to their granule diameters, it is found that the control aggregates has an increase in water absorption percentages as their granule diameters increase. However, the water absorption difference between the granules is decreased after coating the aggregates with cement and cement+colemanite. Therefore, it is determined that granule size does not have a significant effect on water absorption after the coating procedure. While the water absorption rate was 27-38% in uncoated aggregates, it was 13-19% in coated aggregates. Newman and Owens (2003) reported that water absorption rates of pumice are between 30-40%. The almost 50% decrease in water absorption would provide an increase in light concrete structures built with these aggregates.

Aggregate crushing values, impact values, and crumble percentage values are found to be higher than 30%. It has been stated in the literature (Chandra and Berntsson 2003) that light aggregates can be easily cracked in the impact test (Impact value). Compared to the control samples, the 12.5-CLM and 17.5-CLM aggregate samples have an increased crushing and impact strength.

In conclusion, it is demonstrated that the 12.5-CLM samples coated with colemanite containing cement had optimum values, and that lightweight concretes which will be produced with these aggregate samples may have high resilience, making it possible for the construction of higher lightweight concrete buildings.

References

Aksoğan, O., Binici, H. and Ortlek, E. (2016), "Durability of concrete made by partial replacement of fine aggregate by colemanite and barite and cement by ashes of corn stalk, wheat straw and sunflower stalk ashes", *Constr. Build. Mater.*, **106**, 253-263.

Artuso, J.F. and Wargo, G.R. (1998), *Concrete Construction Handbook*, 4th Edition, McGraw-Hill Handbooks, U.S.A.

Beycioğlu, A., Arslan, M.E., Sallı Bideci, Ö., Bideci, A. and Emiroğlu, M. (2015), "Bond behavior of lightweight concretes containing coated pumice aggregate: Hinged beam approach", *Comput. Concrete*, **16**(6), 909-918.

Binici, H., Aksoğan, O., Sevinç, A.H. and Küçükönder, A. (2014), "Mechanical and radioactivity shielding performances of mortars made with colemanite, barite, ground basaltic pumice and ground blast furnace slag", *Constr. Build. Mater.*, **50**, 177-183.

Chandra, S. and Berntsson, L. (2003), *Lightweight Aggregate Concrete, Science, Technology and Application*, Noyes Publications, U.S.A.

DPT, Ninth Development Plan, 2007-2013 (2008), *Boron-Soda Ash, Chrome Chemicals Working Group Report*, Ankara, Turkey.

Erdoğan, Y. (2007), "Investigation of engineering properties of building materials made with acidic and alcaline pumice", Ph.D. Dissertation, Institute of Natural and Applied Science, Çukurova University, Adana, Turkey.

Eti Colemanite Analysis Report (2011), *Eti Maden Bigadiç Boron Works General Managment*, Colemanite Analysis Report, Balıkesir, Turkey.

Gencel, O., Brostov, W., Özel, C. and Filiz, M. (2010), "An investigation on the concrete properties containing colemanite", *J. Phys. Sci.*, **5**(3), 216-225.

Gündüz, L. (2005), "The construction sector pumice stone", Pumice Research and Application Center, Süleyman Demirel University, Isparta, Turkey.

Gündüz, L., Rota, A. and Hüseyin, A. (2001), "Material characteristics analysis of occurrence of pumice in Turkey and in the world", *Proceedings of the 4th Industrial Raw Materials Symposium*, Izmir, Turkey.

Kogel, J.E., Trivedi, N.C., Barker, J.M. and Krukowski, S.T. (2006), *Industrial Minerals and Rocks, Society for Mining*, Metallurgy and Exploration, Inc., U.S.A.

Limak Trakya Cement Factory (2012), *Cement Chemical Analysis Report*, Chemistry Lab Report, Kırklareli, Turkey.

Limak Trakya Cement Factory (2012), *Puzzolanic Activity Report of Colemanite*, Chemistry Lab Report, Kırklareli, Turkey.

Müller, H.S. and Linsel, S. (2005), "A new type of high-performance lightweight concrete", *Mater. Build. Struct.*, **6**.

Newman, J. and Owens, P. (2003), *Properties of Lightweight Concrete, Advanced Concrete Technology Processes,* Butterworth-Heinemann, Elsevier, Oxford.

Oto, B., Gür, A., Kaçal, M.R., Doğan, B. and Arasoğlu, A. (2013), "Photon attenuation properties of some concretes containing barite and colemanite in different rates", *Ann. Nucl. Energy*, **51**, 120-124.

Sağlık, A., Sümer, O., Tunç, E., Kocabeyler, M.F. and Çelik, R.S. (2009), *Axiom Active Boron Cement (BAB) and Applicability of ds Project*, DSI Technical Bulletin.

Sallı Bideci, Ö. (2016), "The effect of high temperature on lightweight concretes produced with colemanite coated pumice aggregates", *Constr. Build. Mater.*, **113**, 631-640.

Sallı Bideci, Ö., Bideci, A., Oymael, S., Gültekin, A.H. and Yıldırım, H. (2015), "Permeability features of concretes produced with aggregates coated with colemanite", *Comput. Concrete*, **15**(5), 833-845.

Sangari. (1992), *Concrete (Handbook of Building Materials of Construction Laboratory)*, Ankara, Turkey.

TS 25 (2008), *Natural Puzzolan (Trass) for Use in Cement and Concrete-Definitions, Requirements and Conformity Criteria*, Ankara, Turkey.

TS EN 1097-3 (1999), *Tests For Mechanical and Physical Properties of Aggregates-Part 3: Determination of Loose Bulk Density and Voids*, Ankara, Turkey.

TS EN 1097-6 (2002), *Tests for Mechanical and Physical Properties of Aggregates-Part 6: Determination of Particle Density and Water Absorption*, Ankara, Turkey.

TS EN 197-1 (2002), *Cement-Part 1: Compositions and Conformity Criteria for Common Cements*, Ankara, Turkey.

Yaltay, N., Ekinci, C.E., Çakır, T. and Oto, B. (2015), "Photon attenuation properties of concrete produced with pumice aggregate and colemanite addition in different rates and the effect of curing age to these properties", *Progr. Nucl. Energy*, **78**, 25-35.

Yenmez, N. (2009), "Boron minerals mining as a strategic importance for Turkey", *Geography J.*, **19**, 59-94.

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