Effects of bentonite binder dosage on the properties of green limestone pellets

Vladimir Jovanović, Dinko Knežević, Živko Sekulić, Milan Kragović, Jovica Stojanović, Slavica Mihajlović, Dragana Nišić, Dragan Radulović, Branislav Ivošević, Milan Petrov

Effects of bentonite binder dosage on the properties of green limestone pellets | Vladimir Jovanović, Dinko Knežević, Živko Sekulić, Milan Kragović, Jovica Stojanović, Slavica Mihajlović, Dragana Nišić, Dragan Radulović, Branislav Ivošević, Milan Petrov | Chemical Industry | 2016 | |

10.2298/HEMIND160210023J

http://dr.rgf.bg.ac.rs/s/repo/item/0007347

Effects of bentonite binder dosage on the properties of green limestone pellets

Vladimir D. Jovanović[1], Dinko N. Knežević[2], Živko T. Sekulić[1], Milan M. Kragović[1], Jovica N. Stojanović[1], Slavica R. Mihajlović[1], Dragana D. Nišić[2], Dragan S. Radulović[1], Branislav B. Ivošević[1], Milan M. Petrov[1]

[1]*Institute for Technology of Nuclear and Other Mineral Raw Materials, Belgrade, Serbia*
[2]*University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbia*

Abstract

This paper presents the results of tests carried out to determine how the dosage of bentonite added as binder, affects the properties of green pellets made of the limestone fines that originate from Lithothamnium limestone processing. Bentonite was added to limestone in different mass fractions (1, 2.5, 5 and 10%), whereas all the other parameters of the pelletizing process remained constant. The aim of pelletizing was to consolidate limestone fines and form mechanically stable pellets, provided that all the other properties of limestone remain unchanged. The pellets formed in this way were analysed applying DTA/TG analysis and FTIR and SEM analyses. The results showed uniform distribution of bentonite in the pellets, demonstrated that the pellets are compact and there is no formation of new compounds. The pellets were tested for resistance to impact, compressive strength and abrasion resistance. Also disintegration tests were performed to determine the time required for the pellet to disintegrate completely in water. These mechanical properties are essential for transport, handling, storage and general use of pellets. The values of most of the parameters established for pellets with 5% bentonite, meet the standards required for use in agriculture for liming acid soils, however their application is limited because their impact resistance is unsatisfactory and the time required for their complete disintegration in water is extremely short. It should be noted that further increase of bentonite content (over 10%) will not improve the quality of green pellets. In view of the results obtained, it is necessary to introduce drying into the pelletizing process in order to bring the green pellets into solid state.

Keywords: lithothamnium limestone, bentonite, pelletizing, pelletizing plate, green pellet testing.

Available online at the Journal website: http://www.ache.org.rs/HI/

SCIENTIFIC PAPER

UDC 552.54:666.322:622.788

Hem. Ind. **71** (2) 135–144 (2017)

One of the most important parameters of soil fertility is **s**ubstitutional acidity. At the global level over 60% of the arable land can be classified as acid. This is due to the geological substrate and other natural factors, but it can also be attributed to industrial development and irresponsible attitude towards the environment [1]. In Serbia, without Vojvodina and Kosovo and Metohija, 13% of the land is extremely acidic (pH < 4), 17% highly acidic (pH 4–4.5), 30% medium (pH 4.5–5.5) and 22% is slightly acidic (pH 5.5–6.5), and only 18% has a neutral and an alkaline reaction [2]. In Vojvodina acid soils average is 14.2% and, depending on the area affected, acidity ranges from 1.9% (North Bačka) to 35.1% (South Srem) [3]. Soil pH value has a decisive impact on the dynamics of nutrients and heavy metals that are present in the soil. In acid environments, large quantities of heavy metals are liberated into the soil solution, which may be toxic to plants. This is the reason why in spite of larger investments in standard scientific farming methods it is impossible to achieve the desired results. The yield can be significantly increased by increasing the pH value to 6.5 with chemical ameliorating measures – adding calcium, which substantially reduces the heavy metal-induced toxicity. By adding limestone to the soil, calcium reacts with carbon dioxide and water from the soil, thereby forming calcium and magnesium carbonates. Further, this causes a reaction with the acidic colloidal complexes, wherein the calcium and magnesium replace hydrogen, and aluminium. These reactions produce carbon dioxide and increase the pH value of the soil to a satisfactory level [4].

Limestone has a very wide and varied use to raise the yield and product quality in all “acid” soils, in crop production, fruit growing, viticulture, horticulture and forestry. The aim is to achieve an optimum pH value of the soil (pH in a standard KCl solution ranges from 5 to 5.5) [5].

Bearing in mind that for such purposes mainly fine limestone, obtained from different filter plants, is used,

Correspondence: V.D. Jovanović, Institute for Technology of Nuclear and Other Mineral Raw Materials, Franše d’Eperea 86, 11000 Belgrade, Serbia.
E-mail: v.jovanovic@itnms.ac.rs
Paper received: 10 February, 2016
Paper accepted: 17 May, 2016
https://doi.org/10.2298/HEMIND160210023J

the biggest problem is its dissipation during transport and handling. Besides, this powdery material is also easily dispersed by wind from the land surface. On the other hand, limestone should be fine enough as to be dissolved by the impact of weathering and evenly spread on the soil.

In order to meet both requirements it is necessary to consolidate finer limestone grades. This is usually achieved by pelletization and briquetting, which provide appropriately sized material, suitable for transport, handling and use, but also fine enough to be dissolved under the influence of weathering and moisture from the soil and spread evenly on the soil.

The advantage of using pelletized limestone instead of crushed limestone fines consists in its easier use (no dusting, possible application in all weather conditions) and lower consumption of pellets (the ratio is 1:10 [6]).

The methods for material consolidation can be widely used and therefore this area is the matter of interest of numerous researchers [7–10]. The goal of controlled consolidation of fine materials is to improve the product quality. In general, the agglomerates are produced to improve the physical properties: density, homogeneity, strength, compressive resistance, shape, appearance, etc.

The required values are determined by standards or other norms. Methods are selected depending on the type of material to be consolidated an on desired properties of the agglomerate; briquetting (consolidation under pressure), sintering (thermal consolidation) or pelletizing (consolidation by rotation). The adhesion forces between the particles forming the agglomerate have a decisive role and determine the strength of the agglomerate [11].

Sastry and Fuerstenau [12] have performed a comparative analysis of the mechanisms of adhesion. Given that the adhesion forces are different, at sufficiently large separating forces (*e.g*., elastic reactive forces, flow forces, friction-induced or shock-induced forces) the forming of the agglomerate is possible only when the adhesion forces are at their peak.

In case of consolidation by rotation, *i.e*., pellet forming on a rotating plate or disk (which is the case here) the particles accumulate in spherical agglomerates. The pellets so formed are dried in order to achieve the necessary strength. Usually, the quality of pellets is determined depending on their use [13] and typically the following properties are tested: shape size, mechanical strength, porosity and surface area.

In order to obtain agglomerates (pellets and briquettes), which are formed from Lithothamnium limestone it was necessary to conduct a series of tests. This paper presents the results of tests that were performed to analyse the formation of pellets that involved addition of bentonite as a highly viscous material. Bentonite is clay which has high viscosity and at the same time the presence of this material has no negative effects on soil properties. [14].

EXPERIMENTAL

Initial samples

For these tests the researchers used lithothamnium limestone from the deposit Dobrilovic near Loznica. The bentonite, used as binder is from the deposits Sipovo.

Testing methods

The atomic absorption spectrophotometer Perkin Elmer"-Analyst 300 was used to determine the chemical composition (Al_2O_3, Fe_2O_3, MgO, Na_2O and K_2O). Volumetric method was applied to determine CaO content, while SiO_2 content and a loss on ignition (900 °C) were determined by the gravimetric method (SRPS.B.B8. 070).

The mineralogical analysis of limestone was performed on a Carl Zeiss, model JENAPOL-U, polarisation microscope in reflected and transmitted light by the immersion method (immersion xylene) with qualitative identification of present minerals. The magnification of the objective lens ranges from 3.2 to 50×.

Particle size distribution was determined mechanically by dry sieving on a series of screens.

The NETZSCH 409 EP was used for thermal analysis of samples. To be able to compare quantitatively the mass loss, the samples were first dried for 2 h at 60 °C and then kept in a desiccator for 24 h at an air humidity of 25%. After that the samples were thermally treated at temperatures ranging between 20 and 1000 °C and at the heating rate of 10 °C/min. The experiments were conducted in an air atmosphere and the mass of each sample was 100 mg.

Infrared spectroscopic tests were performed with the Thermo-Fisher Scientific Nicolet IS-50. Prior to measurement, the samples were dried in an oven at 110 °C for 24 h. The attenuated total reflectance (ATR) technique was used for measurements in the range between 4000 and 400 cm^{-1} with 32 scans at a resolution of 4 cm^{-1}. When measurements had been completed it was necessary to make two corrections; the atmospheric correction for the removal of gas signals (CO_2 and H_2O) and automatic baseline correction.

SEM analyses were performed with the JEOL JSM--6610LV scanning electron microscope equipped with INCA energy dispersive X-ray spectrometer (EDS) and with a 20-kV electron gun. The samples were immersed in gold (layer thickness – 15 nm, density – 2.25 kg/m^3).

Pelletizing equipment

Toni Technik planetary-motion mixer was used to homogenize limestone samples with the binder. Lime-

stone pelletizing was conducted on Eirich TR 04 laboratory pelletizing plate, (plate diameter 40 cm, edge height 10 cm, possible adjustment of plate inclination angle from 30 to 90°, variable speed from 0 to 90 min^{-1}). RETSCH vibratory feeder was used to simulate continuous dosing of homogenized material on the pelletizing plate.

Description of the pelletizing process

In order to be prepared for the pelletizing process, the initial samples must be homogenized. This is a precondition that must be met in order to obtain pellets of uniform composition during pelletizing. Limestone is homogenized with the required amount of bentonite, without adding any water. After that, the homogenized sample is by means of the RETSCH vibratory feeder continuously fed on to the pelletizing plate, where the necessary amount of water is added using sprayers. During pelletizing experiments, the measured water content in all 4 samples was the same, *i.e*., 80 ml per sample.

The plate inclination angle (50°) and the number of revolutions (40 min^{-1}) were constant, while the quantity of the binder varied. Formed "green" pellets were stored for 24 h at room temperature.

Test methods for mechanical properties of pellets

Tests for pellet mechanical properties include; impact resistance, compressive strength, abrasion resistance and the time required for the pellet to disintegrate completely in water.

Impact resistance is tested by dropping a 100-g pellet sample 25 times from the height of 457 mm on to a 9-mm thick steel plate, after which the sample is sieved on a 2-mm mesh screen, whereat the mass of screen undersize should not exceed 5% (more rarely 10%) of the total mass of the sample [4].

Compressive strength is tested on 10 pellet samples using a standard laboratory hydraulic press in order to determine the maximum pressure that the pellet can withstand without breaking. With many years of experience in limestone agglomeration, the company Mars Minerals, obtained results, which therefore may be deemed as reliable, showing that pellets are able to withstand a minimum of 0.5 kg, which is considered as satisfactory for further handling [4].

Pellet abrasion resistance is tested by sieving a 100-g pellet sample on a laboratory mechanical device, *i.e*., a 2-mm mesh screen, for a period of 5 min. After that it was possible to determine that the mass fraction of 2-mm particle size should not exceed 5% of the total mass of the sample [4].

The disintegration of pellet in water is tested by immersing three pellet samples from each group into the water, at room temperature and measuring the time required for the pellet to completely disintegrate in water.

RESULTS AND DISCUSSION

Limestone pelletizing process, using bentonite as a natural, highly viscous binder is tested in order to determine the cost-effectiveness of green pellet production with properties that meet the agricultural requirements in terms of acid soils liming. Basic requirements are related to mechanical impact resistance (handling, loading/reloading), compressive resistance (transport and storage) abrasion resistance (transport) and slow disintegration of pellets in atmospheric conditions (rain, snow and humidity). Empirical literature was used for reference values [4].

Properties of initial samples

The chemical composition of limestone and bentonite samples is given in Table 1.

The mineralogical composition of limestone is as follows: calcite, quartz, clay minerals, and limonite. Calcite is of organogenic origin, mainly crypto-crystalline. Fragments of fossil remains appear with a minor presence of quartz. Limestone is poorly clayed and limonated. Based on the results of limestone chemical and mineralogical composition it may be noted that limestone is of organogenic origin, with the presence of clayey components. Precisely due to these properties, this specific type of limestone is suitable for use in agriculture, especially considering its solubility in water, as opposed to other types of limestone. [15].

In terms of size both samples are 100% finer than 100 μm.

Four composite samples were formed by mixing limestone as calcium fertilizer and bentonite as binder with the following limestone to bentonite mass ratio:

- Sample 1: 99:1%;
- Sample 2: 97,5:2,5%;
- Sample 3: 95:5%;
- Sample 4: 90:10%

The particle size distribution of pellets obtained by agglomeration on pelletizing plate is shown in Table 2.

The preferred size of limestone fertilizer pellet is 3–15 mm [11]. Tests were made with pellets larger

Table 1. Chemical composition of limestone and bentonite samples

Component	CaO	SiO_2	Al_2O_3	MgO	Na_2O	K_2O	Fe_2O_3	MnO	P_2O_5	TiO_2	LOI
Limestone, %	52.55	3.87	0.50	0.41	0.204	0.104	0.461	0.07	0.032	–	41.81
Bentonite, %	2.63	50.73	21.76	1.72	0.0027	0.265	5.76	–	–	0.675	16.40

Table 2. Particle size distribution of pellets (mass%)

Particle size range, mm	Sample 1	Sample 2	Sample 3	Sample 4
+15	2,09	0,00	17,73	0,00
-15+10	3,33	5,49	49,83	51,01
-10+5	23,29	10,63	24,53	15,13
-5+2	46,49	39,39	3,51	13,63
-2+0	24,81	44,49	4,40	20,23
Sum	100,00	100,00	100,00	100,00

than 2 mm and it was evident that pellets with 5% of binder have the smallest percent of the unfavourable particle size –2+0 mm.

The use of pellets made of limestone and bentonite as binder depend on their mechanical properties, which provide stability during transport, handling and storage and resistance to disintegration in water, thus ensuring its slow dissolution. At the same time, pelletizing should primarily change the particle size, but not the structural properties of limestone.

Control of homogeneity and structure of the limestone formed into pellets

For the formation of a usable pellet it is important to provide a uniform distribution of the binder within the material that is to be pelletized. In order to verify this it was necessary to perform microscopic tests. Scanning electron microscopy (SEM) analyses were conducted on samples with the lowest and the highest bentonite content (1 and 10%). The results of these analyses are presented in Figure 1, which also includes comparative SEM micrographs of the sample 1, with different magnifications: a) 400, c) 1000, e) 5000 and g) 10000×, and of sample 4 with the same magnifications.

At the comparatively displayed SEM micrographs of samples 1 and 4, it may be noticed that no macroscopic and microscopic difference is visible between those samples, although there is a big difference in the mass fraction of the binder. This can be explained by the fine size of the initial material and good homogenization of samples. In order to verify whether the homogenization process was carried out properly, as a precondition for quality palletizing, mapping was performed on the SEM device on the same pellet samples. Mapping included Al and Si, which are typical for the binder (bentonite). Their uniform distribution over the mapped area of the limestone pellet sample demonstrates sample homogeneity. Mapping results are comparatively shown in Figure 2.

Figures 2a and b represent SEM micrographs of the pellet surface of samples 1 and 4 that have been mapped for the above mentioned elements, while Figures 2c and e represent the mapping results of the pellet surface of sample 1, and Figure 2d and f of sample 4 for Al and Si.

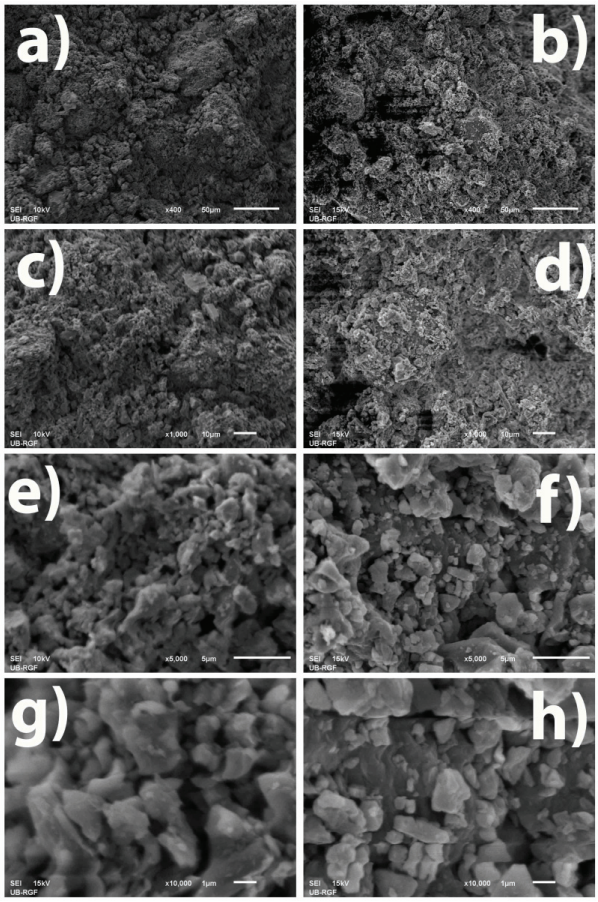

Figure 1. Micrographs of SEM samples 1 (left column) and 4 (right column) with different magnifications.

If limestone structure changes during palletizing, the pellet can become useless so, to determine and avoid this occurrence, additional (DTA, TG, FT-IR and SEM) analysis of previously described samples were conducted.

The results of differential thermal analysis (DTA) of initial limestone and bentonite samples, and of the limestone pellet samples with different contents of bentonite (1, 2.5, 5 and 10%) are shown in Figure 3 while the results of the thermos-gravimetric (TG) analysis are shown in Figure 4.

DTA curve of the initial bentonite sample illustrates the peaks characteristic for bentonite from the deposit Sipovo. The endothermic peak with a minimum at 136°

is related to dehydration and loss of adsorbed water and water that coordinates exchangeable cations in the interlayer. This process entails a mass loss of 15% (Figure 4) occurring within the temperature interval of 20––300 °C. Endothermic peak with a minimum at 529° is the result of dehydroxylation and loss of structural water. This process entails a mass loss of ~4% occurring in the temperature interval of 300–600° (Figure 4).

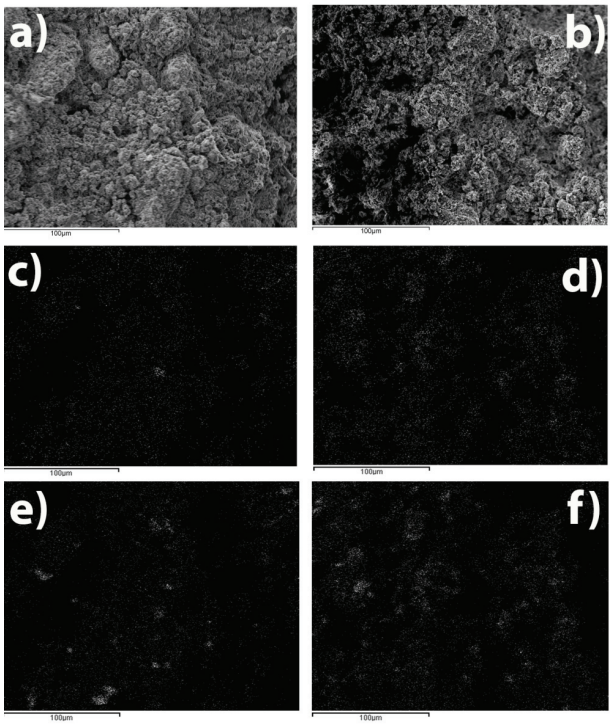

Figure 2. Results of sample mapping 1 and 4.

The endothermic peak with the minimum at 742° results from the presence of carbonates, while the mass loss from 600 to 1000° is due to their combustion. Endothermic–exothermic peak at 871 and 888° is characteristic of bentonite and originates from phase bentonite transformation. This process does not entail a change in the TG diagram. In the DTA curve of the initial limestone, it is possible to observe an endothermic peak of high intensity with a minimum at 894° and it originates from the oxidation of carbonates. This process entails a mass loss of ~44% (Figure 4). The DTA curves of pellets with different bentonite content, show peaks typical for limestone, without major displacement. Increased bentonite content tends to decrease the peak intensity typical for limestone. The peaks typical for bentonite were not observed in samples 1 to 4, due to low bentonite content and significantly decreased intensity of peaks. Besides, due to a relatively low mass fraction of bentonite, the results of TG analysis show no major difference in mass change, compared to the initial limestone sample.

The results shown in Figures 3 and 4 lead to the conclusion that the addition of bentonite as binder to limestone in the pelletizing process and the increase of its mass fraction have no impact on the thermal properties of the initial limestone sample.

The results of FTIR (Fourier-transform infrared spectroscopy technique) analysis of initial limestone and bentonite samples and of limestone pellet samples with different bentonite contents are shown in Figure 5.

The graphic display of FTIR band of the initial bentonite sample contains peaks typical for bentonite from Sipovo deposit. The band with maximum at 3382 cm^{-1}

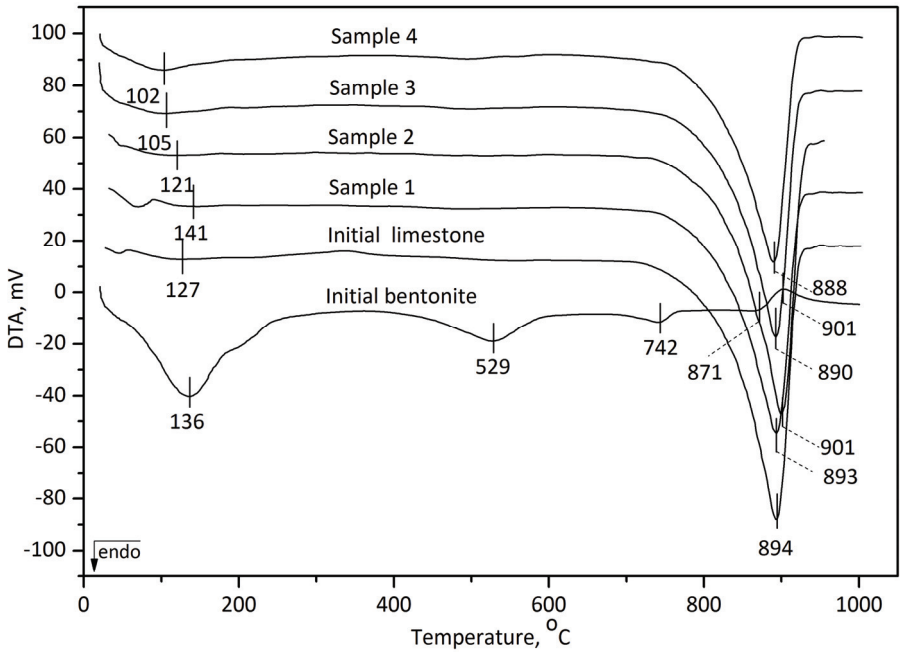

Figure 3. Results of DTA analysis of limestone, bentonite and their mixtures.

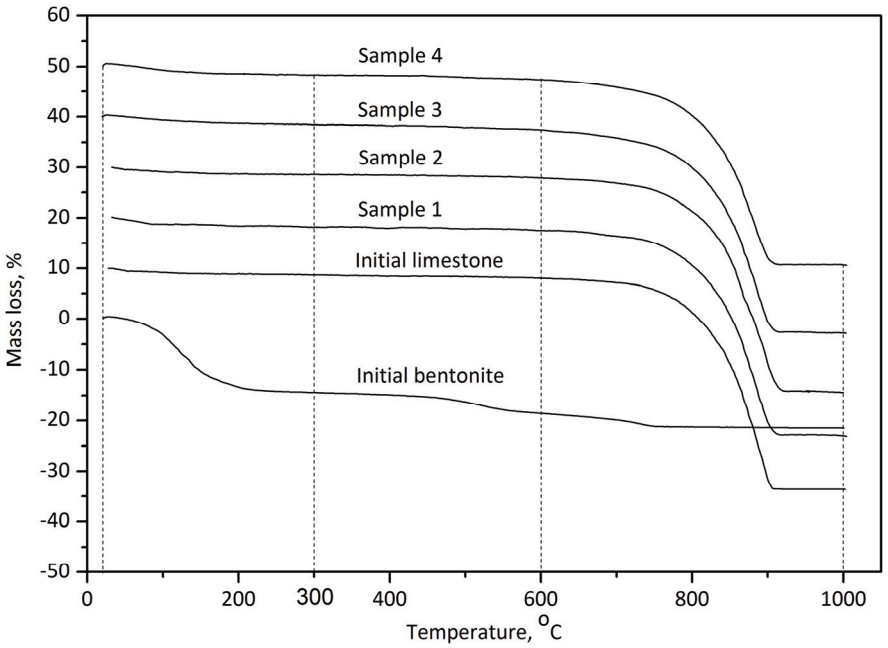

Figure 4. Results of TG analysis of limestone, bentonite and their mixtures.

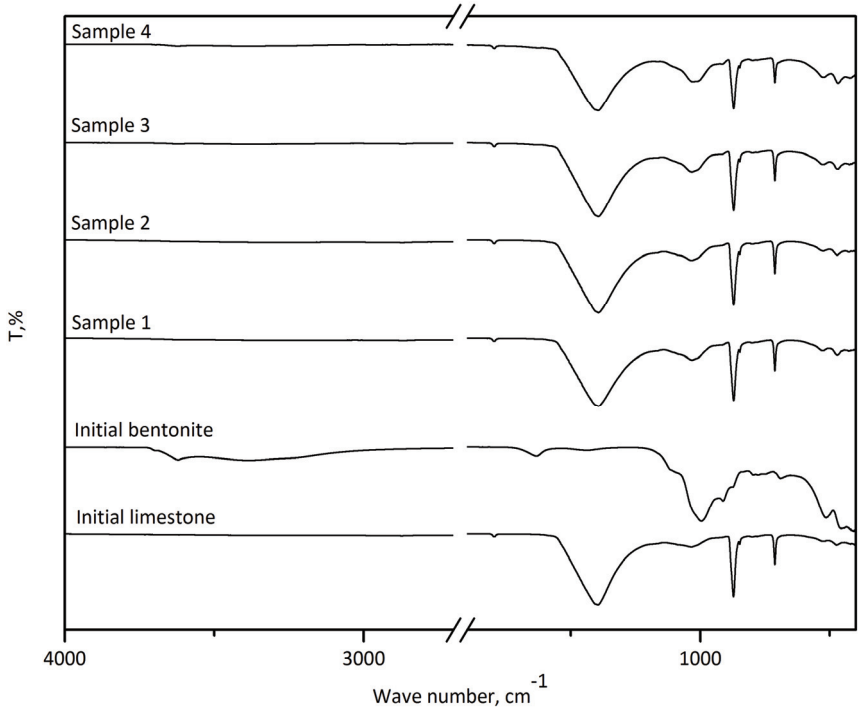

Figure 5. Results of FTIR analysis.

results from vibrations of OH group in Si–OH or of Al–OH group. The band at 994 cm^{-1} derives from asymmetric stretching vibrations in T-O group (T=Si or Al), in Si–O–Si and/or Al–O–Al, bands in the interval of 994––908 cm^{-1} derive from stretching vibrations Si–O in Si–OH or Al–O in the Al–OH group. The band at 785 cm^{-1} results from bending vibrations in Si–O–Si group, while bands at 519 and 457 cm^{-1} result from a symmetrical bending vibration of Si–O–Si and Al–O–Al group, while the band at 1637 cm^{-1} originates from vibrations of the OH group in T–OH.

In the infrared spectrum of the initial limestone sample it is possible to observe bands typical for calcite. In the wave numbers field from 3000 to 700 cm^{-1} there are bands of varying intensity. In calcite, the carbonate functional group is linear (space group D_{3h}), and non-linear with the number of atoms N = 4 with 3N–6 = 6 basic vibrations, of which N–1 = 3 have valence. The

symmetrical valence vibration $\tilde{\nu}_1$ is infrared inactive. The wide and strong band at approx. 1430 cm^{-1} is attributed to the asymmetrical valence vibration $\tilde{\nu}_3$, which is doubly degenerated ($\tilde{\nu}_{3a}$ and $\tilde{\nu}_{3b}$). The sharp band at 873 cm^{-1} belongs to deformation vibration $\tilde{\nu}_2$ of the linear carbonate group. The $\tilde{\nu}_4$ is per deformation type, a doubly degenerated vibration ($\tilde{\nu}_{4a}$ and $\tilde{\nu}_{4b}$), for which within the spectrum, the band at 709 cm^{-1} is typical. In the infrared spectrum of the pellet samples 1–4 in addition to the spectral lines characteristic of limestone, of unchanged intensities and positions there are also lines typical for bentonite, whose intensity increases with increasing bentonite content in the samples. The results presented in Figure 5 indicate that during the pelletizing process that produced samples 1–4, there are no significant changes in the structural properties of initial limestone and bentonite samples.

Mechanical properties of pellets

Once the tests confirm that limestone and bentonite are sufficiently well-mixed and homogenous, and that the pelletizing process and binder had no impact on limestone structural properties, all the conditions have been met to test the mechanical resistance of the formed pellets. All the formed pellets contain different limestone to bentonite ratios and the results obtained after testing the impact resistance of pellets are shown in Figure 6.

Obviously, none of the samples satisfied the set standard, since the quantity of screen undersize after 25 free drops was far above the required 5–10%. This data suggests that handling (loading, shipping) green pellets will represent a problem, *i.e*., pelletizing could not be considered as the most suitable method of consolidation in cases that involve multiple loading and reloading of pellets.

The results of specific compressive strength tests are presented in Figure 7.

The results presented in Figure 4 show that the average values for compressive strength (kg/pellet) grow almost linearly, from samples with 1% (0,507 kg/pellet) to samples with 5% of binder (1,511 kg/pellet). After that point, this value decreases, so that in case of the sample with 10% of bentonite it amounts to 0,589 kg/pellet. Based on the results presented herein, it is possible to conclude that the samples meet the requirement for a minimum compressive strength of 0.5 kg/pellet and that 95:5 has proven to be the best limestone to bentonite mass ratio. Good compressive strength indicates that there will be no problems with the storage of green pellets.

The graphic display of the results obtained after testing the pellet abrasion resistance is presented through the content of the –2+0 mm particle size, and it is given in Figure 8.

The results shown in Figure 8 clearly suggest that the best abrasion resistance is obtained if the content of bentonite in pellets is 5%, however pellets with 10% demonstrate lower abrasion resistance. Bearing in mind that the mass of 2-mm screen underflow should range from 3 to 5%, it can be concluded that samples with 5 and 10% of bentonite meet the requirements, whereas the samples with low binder content are at the very threshold in terms of abrasion resistance.

Graphical display of test results that show the dissolution of pellets in water is given in Figure 9. Tests have established the time required for complete disintegration in water depends on binder content.

The results indicate that the pellets obtained from Lithothamnium limestone with bentonite as binder, regardless of the mass fraction of the binder, will dis-

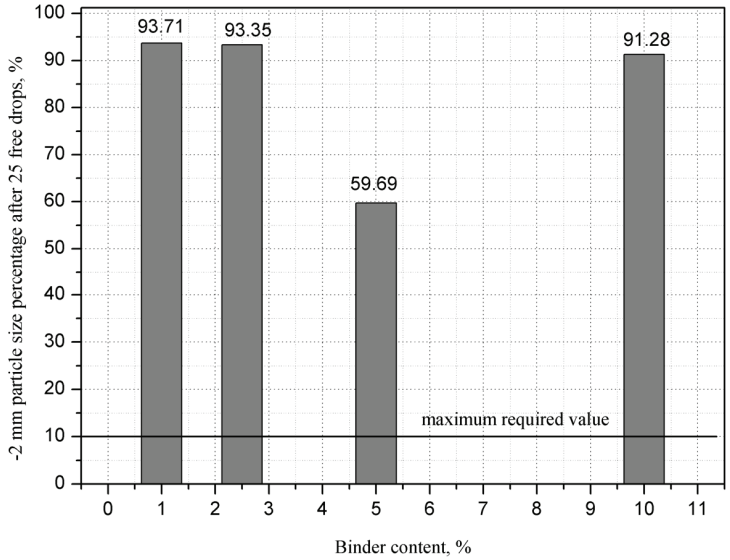

Figure 6. Dependence of –2 mm particle size percentage on binder dosage after 25 free drops.

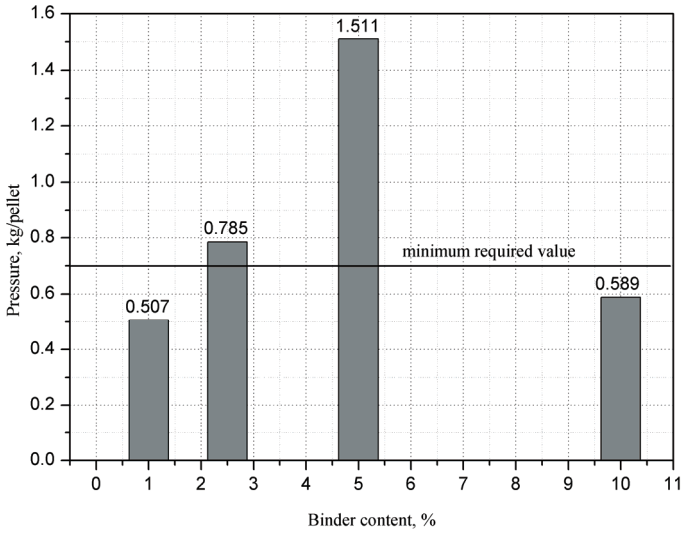

Figure 7. Dependence of average pellet compressive strength on binder content.

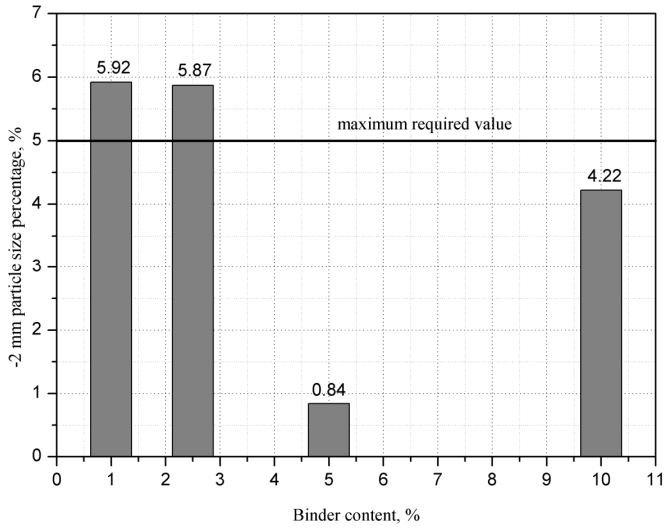

Figure 8. Dependence of pellet abrasion resistance on binder content.

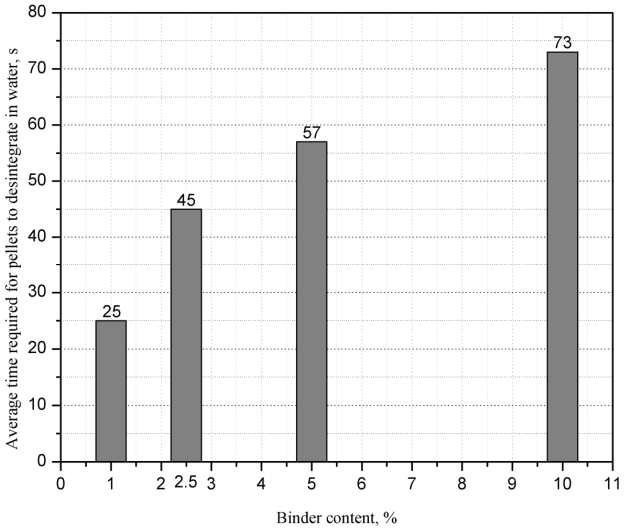

Figure 9. Average time required for pellets to disintegrate in water depending on binder dosage.

integrate rapidly in water, at room temperature. This practically means that limestone pellets spread over the field will dissolve after the first big rain or if the limestone is used to regulate pH values in fishponds it may be expected that the disintegration will be very quick.

The overall results obtained after testing the mechanical properties of "green" pellets are given in Table 3.

Table 3. Overall green pellet test results

Sample No.	CaO:binder ratio, %	Impact resistance –2 mm, %	Compressive strength kg/pellet	Abrasion resistance –2 mm, %	Time required for complete disintegration, s
1	99:1	93.71	0.507	5.92	25
2	97.5:2.5	93.35	0.785	5.87	45
3	95:5	59.69	1.511	0.84	57
4	90:10	91.28	0.589	4.22	73
Required values		Max. 5–10	Min. 0,5	Max. 3 do 5	As long as possible

Consequently, the green pellets obtained have a satisfactory compressive strength and abrasion resistance, but unacceptably poor properties in terms of impact resistance and time required for their disintegration in water, regardless of the binder fraction. Among analysed pellets, the best results are obtained if the limestone to bentonite mass ratio is 95:5. The practical applicability of so obtained green pellets is rather limited.

CONCLUSION

Experiments in pelletizing of lithothamnian limestone fines, with fractions 100% –100 μm, were carried out on a pelletizing plate in a continuous process, with the addition of bentonite as a highly viscous binder. The pellets obtained in this way were tested for impact resistance, compressive strength, abrasion resistance and time required for their complete disintegration in water. The pellets were then analysed applying DTA/TG analysis, FT-IR and SEM analyses.

DTA/TG analysis, FT-IR and SEM analyses conducted on formed pellets indicated that the structural properties of initial limestone and bentonite samples are slightly changed, that the distribution of bentonite in pellets is uniform, that the pellets are compact and there is no formation of new compounds. All the previous suggests that adhesion forces in this process were stronger than the flow and friction-induced or shock--induced forces and as a result the pellets obtained of lithothamnium limestone proved to be of desired quality.

Test results of the mechanical properties of pellets showed that the pellets obtained do not meet the usual standards required for pellets used in agriculture for acid soils liming. Among the specimens tested, the pellets with 5% bentonite gave the best results. Namely, the compressive strength of pellets with 5% bentonite was 1.511 kg/pellet (the minimum required is 0.5 kg/pellet), while the abrasion resistance was 0.84% (to a maximum of 5%).

Impact wear is 59.69%, which is several times more than the allowed maximum of 10%, the time required for disintegration in water is 57 s, which is very short. Tests proved that the mechanical properties of green pellets cannot be improved by increasing the share of bentonite. The tests showed that the mechanical properties of green pellets can be improved by drying, but this significantly increases the costs of the palletizing process.

Acknowledgements

The results presented herein are part of the Technology Development Project no. TR-34013 for period 2011–2016 funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

REFERENCES

[1] H.R. von Uexküll, E. Mutert, Global extent, development and economic impact of acid soils, S. Afr. J. Plant Soil **171** (1995) 1–15.

[2] D. Vidojević, Report on the State Soil in Serbia, the Ministry of Environmental Protection and Spatial Planning, Belgrade, 2009 (in Serbian)

[3] S. Milić, Fertility of Privately Owned Land in Different Crop Growing Regions of Vojvodina, 45. Agronomist Conference, Zlatibor, 2001, www.nsseme.com/about/ /inc/SAS/45SAS/2011-02-04/3%Milic.pdf

[4] K.B. Albert, D. Langford, Pelletizing limestone fines, Mars Mineral, Mars, PA, 1998, pp. 12–29.

[5] B.C. Nyle, The Nature and Properties of Soils, 10th ed., Macmillan Publisher, London, 2000, pp. 232–235.

[6] Breaton stone, The Complete guide to agricultural lime, http://www.braenstone.com/wp-content/uploads/Ag–lime-Ebook-4.21.15

[7] Č. Jevremović, Pelletizing of Fly Ash from Power Plants and Environmental Protection, Faculty of Mining and Geology, Tuzla, 1988.

[8] P.C. Kapur, S.C.D. Arora, S.V.B. Subbarao, Water-bentonite interaction in balling of iron ores, Chem. Eng. Sci. (1973) 1535–1540.

[9] T. Gluba, The effect of wetting conditions on the strength of granules, Physicochem. Probl. Miner. Process. **36** (2002) 233–242.

[10] C. Schilling, J. S. Lee, B. Ghiasi, M. Tajilrou, M. Wöhler, C.J.Lim, X.T. Bi, A. Lau, S. Pelz, L. Tabil, S. Sokhansanj: Towards manufacturing the "ideal pellet", CSBE/SCGAB, Annual Conference, Edmonton, Alberta, Canada, 2015, Paper No. CSBE15-XXX.

[11] M. Petrović, Mineral Processing – Agglomeration Basics, Faculty of Mining, Geology and Civil Engineering, Tuzla, 2008, p. 288.

[12] K.V.S. Sastry, D.W. Fuerstenau, Kinetics of green pellet growth by the layering mechanism. Transact. AIME **262** (1977) 43–47.

[13] V.R. Sirisha K.K. Vijaya Sri, K. Suresh, G.K. Reddy, N. Devanna, A review of pellets and pelletization process - a multiparticulate drug delivery system, Int. J. Pharm. Sci. Res. **4** (2013) 2145–2158.

[14] E. Murad, The characterization of soils, clays and clay firing products. Hyperfine Interact. **111** (1998) 251–259.

[15] http://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1130447041&topicorder=9&maxto=10.

IZVOD

ISPITIVANJE KARAKTERISTIKA ZELENIH PELETA KREČNJAKA U ZAVISNOSTI OD KOLIČINE BENTONITA DODANOG KAO VEZIVA

Vladimir D. Jovanović[1], Dinko N. Knežević[2], Živko T. Sekulić[1], Milan M. Kragović[1], Jovica N. Stojanović[1], Slavica R. Mihajlović[1], Dragana D. Nišić[2], Dragan S. Radulović[1], Branislav B. Ivošević[1], Milan M. Petrov[1]

[1]*Institut za tehnologiju nuklearnih i drugih mineralnih sirovina, Franše d'Eperea 86, 11000 Beograd*
[2]*Rudarsko–geološki fakultet, Đušina 7, 11000 Beograd*

(Naučni rad)

Ovaj rad predstavlja rezultat ispitivanja uticaja sadržaja vezivnog sredstva na osobine peleta na osobine peleta dobijene od krečnjačke prašine nastale u postrojenju za preradu litotamnijskog krečnjaka „Zavoda za poljoprivredu Loznica". Eksperimenti peletizacije litotamnijskog krečnjaka frakcije 100% –100 μm su obavljeni na peletizacionom tanjiru kontinuiranim postupkom uz dodavanje bentonita kao visoko viskoznog sredstva. Peleti dobijeni na ovaj način su ispitivani na otpornost na udar, otpornost na pritisak, otpornost na abraziju i vreme potrebno za dezintegraciju peleta u vodi. Takođe, na peletima su urađene DTA/TG analiza, analiza FTIR i SEM analiza. Ispitivanja mehaničkih osobina peleta su pokazala da su vrednosti većine parametara kod peleta sa 5% bentonita zadovoljavajuće za primenu u poljoprivredi za kalcizaciju kiselih zemljišta. Naime, otpornost na pritisak je iznosila 1,511 kg/pelet, otpornost na abraziju je iznosila 0,84% i vreme dezintegracije u vodi je iznosilo 56,67 s. Dalje povećanje sadržaja bentonita na 10% nije potrebno jer ne utiče na povećanje ovih parametara peleta. DTA/TG analiza, analiza FTIR i SEM analiza na dobijenim peletima su pokazale da se strukturne osobine polaznih uzoraka krečnjaka i bentonite neznatno menjaju, da je raspodela bentonita u peletima ravnomerna, da su pelete kompaktne i da ne nastaju nova jedinjenja. To sve zajedno ukazuje da su sile adhezije u ovom postupku bile snažnije od strujnih sila i sila nastalih trenjem ili udarom i da su zbog toga dobijeni peleti litotamnijskog krečnjaka željenog kvaliteta.

Ključne reči: Litotamnijski krečnjak • Bentonit • Peletizicioni tanjir • Ispitivanje zelenih peleta krečnjaka