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Fourier-Transform Infrared Spectroscopy Analysis of Mechanochemical Transformation Kinetics of Sodium Carbonate to Bicarbonate

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Abstract:

During mechanical activation, qualitative changes that can produce various phenomena occur in the material. In this study, anhydrous sodium carbonate was mechanically activated for 2, 7, 14, and 28 minutes in a vibro mill at a frequency of 3000 oscillations per minute. After activation, four series of activated samples were stored in the air at room conditions for 31 days (relaxation period). To monitor the kinetics of the transformation process of activated sodium carbonate samples, i.e. the mechanism of sodium bicarbonate formation during relaxation, Fourier-transform infrared (FTIR) spectroscopy analysis was used. FTIR testing was performed as a function of relaxation time for all four series of samples, with characteristic groups observed: CO_3^{2-} , HCO_3^- and OH . The obtained results provided kinetics parameters for the transformation of sodium carbonate into sodium bicarbonate due to the chemisorption of moisture and carbon dioxide from the atmosphere.

Keywords: Mechanical activation; sodium carbonate; Sodium bicarbonate; Mechanochemical transformation; FTIR.

1. Introduction

In the world, the activation of materials is widely used as a procedure for bringing energy to the system so that it begins to react in a controlled manner. This allows the system to skip over the "energy barrier" on the reaction path. Materials can be activated by chemical [1-3], thermal [4,5], radiation [6], mechanical [7-10], and similar treatments. Mechanical activation of powders is one of the frequently applied activation methods for modifying/ changing and regulating physico-chemical characteristics of materials by delivering mechanical energy to the system in various technical and technological ways, which leads to reducing the particle size and enlarging the intercontact surface between particles, creating plastic deformations and various types of defects as well as soft agglomerates. This method is becoming more and more topical [11-15]. With the development of this procedure, significant savings compared to classical methods of material activation have been achieved. Owing to provided energy excess

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that induces increased system's reactivity, many research fields related to obtaining new materials and monitoring the kinetics of the solid phase reactions have been opened [16-19].

Sodium carbonate is a compound that responds particularly well to mechanical activation. Namely, its chemical activity significantly increases owing to the weakening of the bonds in the crystal lattice. This enables using sodium carbonate in mechanochemical syntheses which can replace classical chemical processes in extreme operating conditions [20]. Also, its adsorption ability enhances by mechanical activation. It has been observed that activated sodium carbonate, when exposed to the air, adsorbs carbon dioxide and moisture, whereby the amount of adsorbed gases depends on its activation degree [21]. This is especially significant because of the increasing emission of carbon dioxide into the atmosphere. Numerous studies reported the attempts to improve the adsorption characteristics of sodium carbonate by various methods in order to adsorb carbon dioxide thus protecting the environment [22-25]. The results of monitoring the mass change of inactivated and activated sodium carbonate stored for 64 days (relaxation time) in three different media (vacuum, carbon dioxide, and air) at room temperature showed that only the masses of the samples in a vacuum did not change. The masses of the samples in carbon dioxide and especially in the air grew. The mass increase of activated samples was significantly higher than that of inactivated ones. This mass increase of activated samples during relaxation time is not only the result of enlarging the free surface of the samples but also of the crystal lattice disturbance and thus enhancing the total energy of the system whose relaxation would occur by binding the present reagents that can chemically bond to the investigated system. The reagents, carbon dioxide and moisture from the air, were chemisorbed on the activated sodium carbonate samples and the presence of sodium bicarbonate was confirmed during and after the relaxation period [21].

As a continuation of the research [21], it is important to determine the kinetics of the processes that took place on activated sodium carbonate during the relaxation period, which is precisely the goal of this paper. The kinetics of the transformation process on mechanically activated sodium carbonate, i.e. the mechanism of sodium bicarbonate formation from mechanically activated sodium carbonate during the relaxation period, was monitored by the Fourier-transform *infrared* (FTIR) spectroscopy analysis. The spectra were recorded for all series of activated sodium carbonate samples as a function of relaxation time.

2. Materials and Experimental Procedures

The sodium carbonate used in this study was anhydrous and in p.a. quality. According to the MERCK index 11.8541, the chemical composition of sodium carbonate is: 99.5% Na_2CO_3 , 0.002% Cl, 0.005% SiO_2 , 0.0005% Pb, 0.0005% Fe, 0.01% Al, 0.0005% Mg, 0.01% K, 0.005% SO_4^{2-} , 0.005% Ca, and 0.5% loss on drying at 180°C; specific mass 2500 kg m^{-3} ; decomposition temperature 851°C. Na_2CO_3 has a monoclinic crystal lattice ($a=8.907$, $b=5.239$, $c=6.043$); the bond energy values are: Na–O (364 kJ mol^{-1}), C–O (1076.4 kJ mol^{-1}), C=O (532.2 kJ mol^{-1}).

Sodium carbonate was mechanically activated in the high-energy mill KHD Humboldt Wedag AG. Samples in the amount of 50 g each were activated for 2, 7, 14, and 28 minutes (activation time) at a frequency of 3000 oscillations per minute thus obtaining four series for further investigation.

The mill consists of housing with a drive mechanism having an elastic shaft above which is horizontally placed a cylindrical vessel of small height with two massive ring working elements of a total weight of 3 kg, which occupy one third of the mill's working volume. The volume of the working vessel is 2 dm^3 , and the maximum amount of material that can be activated is 200 g. The eccentric flywheel and torsion springs convert the circular motion of the elastic shaft into the vibrating oscillatory motion of the working vessel. Engine

power is 0.8 kW. The device works discontinuously in an air atmosphere. Intensive movement of the working vessel with rings leads to its heating up to a temperature of 80°C.

After activation, the samples were stored at room conditions for 1, 6, 10, 24, and 31 days (relaxation time).

The effects of mechanical activation were monitored by FTIR spectroscopy analysis. FTIR spectroscopy is a very important non-destructive method, given the high sensitivity and precision of frequencies, excellent resolution, quick recording, and possibility to repeat recording as well as different ways to interpret the obtained data. It is used to identify compounds and qualitatively monitor the chemistry of various processes [26-32]. In this study, using FTIR spectroscopy, changes were observed on the characteristic groups: CO_3^{2-} , HCO_3^- and OH^- . FFT infrared spectra of the samples were recorded on a spectrometer Bomem-Hartman & Braun Michelson MB-100, in the wave numbers range of $4000\text{-}300\text{ cm}^{-1}$ and at a resolution of 2 cm^{-1} . Since sodium carbonate is very sensitive to the presence of moisture, samples were prepared in the form of a suspension using "Nujol". Changes in peaks' areas, as well as in peaks' widths at half-heights, were observed for the given ionic groups: CO_3^{2-} , HCO_3^{2-} and OH^- . The results are presented as a function of relaxation time for all four series, t.e. for different activation periods.

3. Results and Discussion

3.1 FTIR spectroscopy analysis of non-activated Na_2CO_3

FTIR spectrogram of the initial, non-activated sodium carbonate sample is presented in Fig. 1.

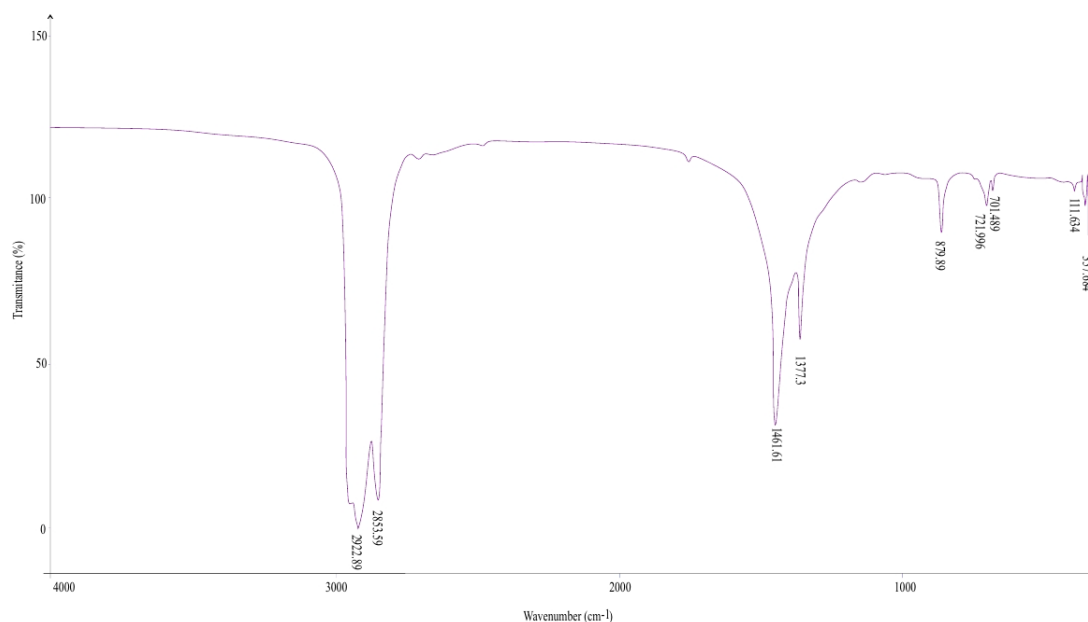


Fig. 1. FTIR spectrogram of non-activated Na_2CO_3 .

The wavelengths of the characteristic peaks monitored by FTIR spectroscopy in this study are given in Table I.

Tab. I Characteristic wavelengths monitored by FTIR spectroscopy.

Na_2CO_3	NaHCO_3	CO_3^{2-}	HCO_3^-	OH^-	$\text{CO}_2 + \text{H}_2\text{O}$
1775cm^{-1}	1800cm^{-1}	1461.61cm^{-1}	$1800\text{-}1980\text{cm}^{-1}$	$3500\text{-}3600\text{cm}^{-1}$	$2300\text{-}2400\text{cm}^{-1}$
1420cm^{-1}	1000cm^{-1}	1090cm^{-1}	1000cm^{-1}	1645cm^{-1}	
878cm^{-1}		874cm^{-1}		$590\text{-}720\text{cm}^{-1}$	
702cm^{-1}		725cm^{-1}			

3.2 FTIR spectroscopy analysis of activated Na_2CO_3 during relaxation at room conditions

Fig. 2 shows comparative FTIR spectrograms of all four series of sodium carbonate samples for different relaxation periods at room conditions.

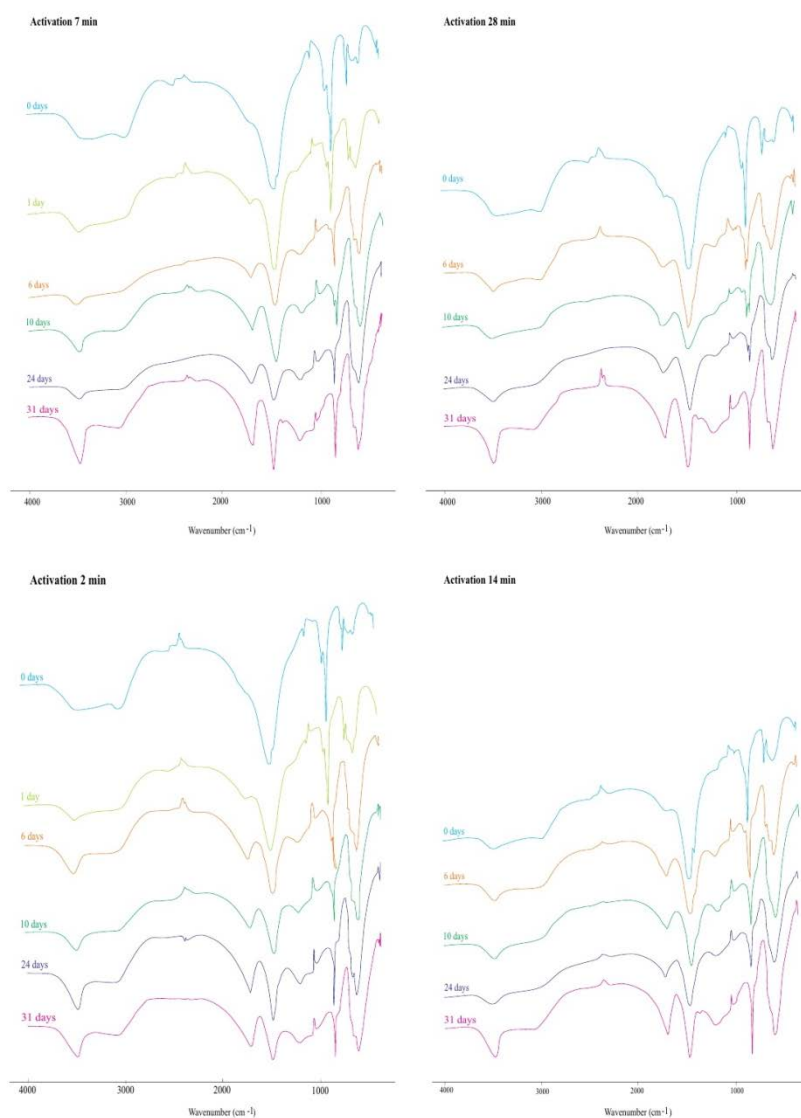


Fig. 2. FTIR spectrograms of Na_2CO_3 samples activated for 2, 7, 14, and 28 min during relaxation time (0, 1, 6, 10, 24, and 31 days) at room conditions.

When comparing the FTIR spectra of the samples mechanically activated for various periods, presented in the diagrams in Fig. 2, the differences in intensities and widths of the characteristic peaks are clearly noticeable. In all diagrams, gradual changes in the curves at certain wavelengths are observed. The initial curves (0 days of relaxation) for all four activation times, at a wavelength of 3500-3600 cm^{-1} , do not have clearly defined peaks, and with the increasing relaxation time, the peaks become more and more expressive. By analyzing the database, it was determined that this wavelength value refers to the OH⁻ group. The appearance of the OH⁻ group in the activated sodium carbonate sample, as well as changes in the area of the characteristic OH⁻ group peak, can be explained by the fact that the Na₂CO₃ sample, due to the energy obtained by mechanical activation and disturbed crystal structure had increased adsorption and chemisorption affinity to moisture from the atmosphere during relaxation. The valence OH⁻ groups bind to the crystal lattice of activated Na₂CO₃, and the diagrams show that the peak characterizing the OH⁻ group increases with the increasing relaxation time. A similar change is observed at a wavelength of 1645 cm^{-1} , and the database revealed that these changes are also related to the OH⁻ group.

At a wavelength of 1420 cm^{-1} , which characterizes Na₂CO₃, that is CO₃²⁻ ion, a tendency of peak decrease with the increasing relaxation time can be seen. Similar changes are observed at a wavelength of 873 cm^{-1} . This is a consequence of the conversion of carbonate to bicarbonate ion due to the absorption of moisture and carbon dioxide from the air. Parallely with this change, a peak characteristic for the bicarbonate ion at a wavelength of 1800 cm^{-1} appeared. This peak is more pronounced with the increasing relaxation time.

At wavelengths from 2300 to 2400 cm^{-1} , a peak that principally disappears gradually with the progress of relaxation time can be observed. These wavelengths are typical for adsorbed moisture and carbon dioxide. During relaxation, chemisorption of moisture and carbon dioxide occurs and the conversion of carbonate to bicarbonate, which explains the decrease and disappearance of this peak on the observed curves.

At wavelengths from 700 to 800 cm^{-1} , with emphasis on 725 cm^{-1} , a peak, whose both the intensity and the surface area are decreasing with the increasing relaxation time, can be observed. The analysis determined that it is a carbonate ion, whose amount decreases as a function of the relaxation time due to the process of chemisorption of moisture and carbon dioxide from the air. Parallely with this result, the peak characteristic for the HCO₃⁻ group increases, which is a consequence of the transformation of carbonate into bicarbonate.

In the discussion that follows, based on the obtained FTIR spectrograms of activated sodium carbonate, areas of peaks characteristic for ion groups CO₃²⁻, HCO₃⁻, and OH⁻, as well as peaks widths at half-height during relaxation time were estimated and graphically presented.

3.3 Changes in areas and widths at half-heights of peaks characteristic for CO₃²⁻, HCO₃⁻, and OH⁻ groups in activated Na₂CO₃ during relaxation at room conditions

Diagrams in Fig. 3 display changes of the areas of peaks characteristic for CO₃²⁻, HCO₃⁻, and OH⁻ groups as a function of relaxation time for all four series of activated sodium carbonate samples. As seen in Fig. 3a), the fastest and most significant changes took place in the period of the first ten days of relaxation. During this time interval, the area of the characteristic CO₃²⁻ group peak decreased by 55-70 % with regard to the initial value depending on the activation time of the samples; chemical transformation of carbonate occurred, whereby its amount in the sample decreased. A clearly expressed plateau for the relaxation interval from 10 to 25 days indicates stagnation, i.e. area of the characteristic CO₃²⁻ group peak remained unchanged. From 25th day until the end of the monitored relaxation time (31 days), the peak area of the observed group for samples activated for 7, 14 and 28 min changed again. The peak area of the sample activated for 2 min did not change from the 10th

day of the relaxation time, while the drop in peak area value was most pronounced for the sample activated for 28 min, slightly smaller for the sample activated for 14 min, and the smallest for the sample activated for 7 min. These changes are the result of disturbing the crystal lattice and raising the energy of the activated system, which facilitated the adsorption of moisture and carbon dioxide on the activated sample. The longer the sample was subjected to mechanical activation and thus the destruction of the crystal structure, the more exposed the sample was to modifications and adsorption of H₂O and CO₂ from the atmosphere.

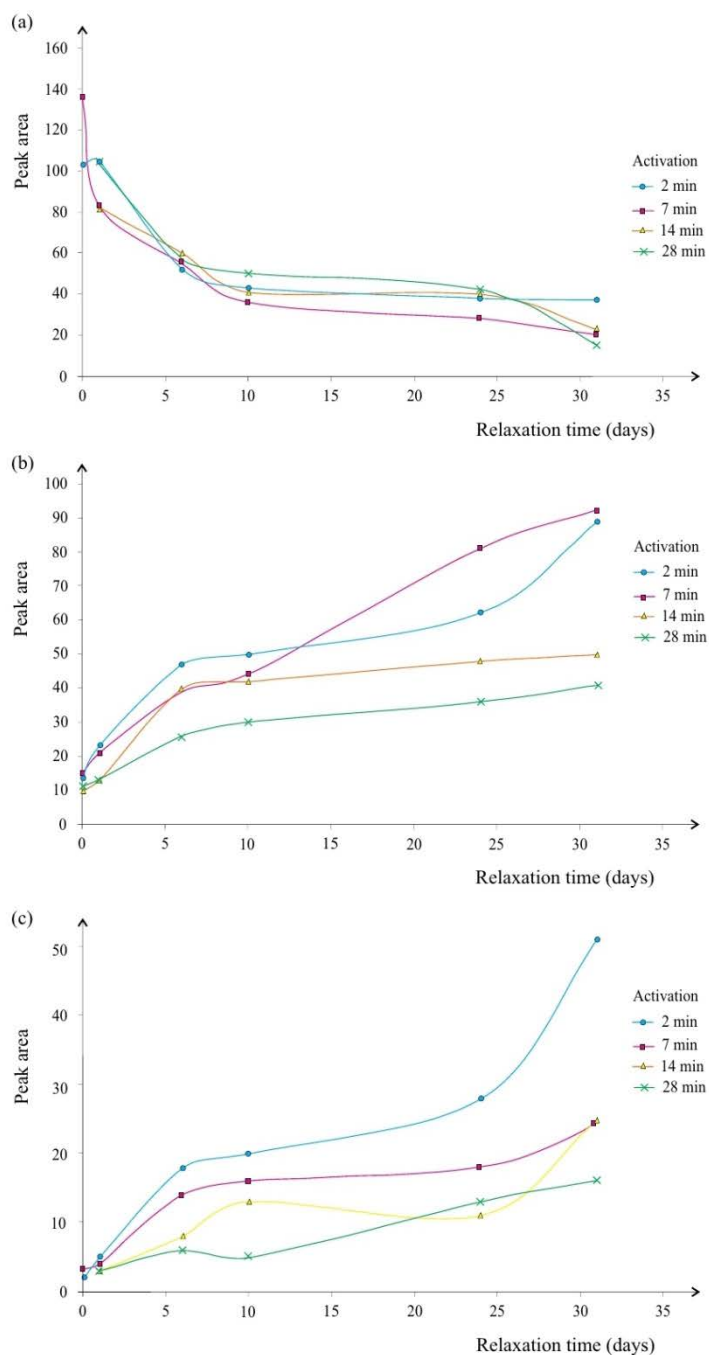


Fig. 3. Areas of peaks characteristic for ionic groups: a) CO₃²⁻, b) HCO₃²⁻, and c) OH⁻ as a function of relaxation time for Na₂CO₃ samples activated for 2, 7, 14, and 28 min.

This indicates that the sample activated for 28 min underwent the most significant modifications during mechanical activation and, furthermore, the degree of transformation of the sample was in accordance with the activation period.

According to the results of peak areas characteristic for the HCO_3^- ion group (Fig. 3 b)), it is evident that these values enhanced with the progress in relaxation time indicating that the amount of bicarbonate ion in the analyzed sample increased as a function of time of exposure to a given ambience.

This proves that the exposure of activated sodium carbonate to the air led to a qualitative change of the sample, i.e. to the adsorption/ chemisorption of CO_2 and moisture from the atmosphere, and thus to the conversion of sodium carbonate to sodium bicarbonate. Also, it can be seen that the most significant transformations in all series occurred during the first 5 days of relaxation and a bit milder in the period from 5 to 10 days. After 10th day, only samples activated for 14 and 28 min continue the similar trend of peak area increment until the end of the observed relaxation time. Samples activated for 2 min also maintained this trend, but only until the 25th day of relaxation and afterward a sharp increase in peaks' areas, i.e. in the rate of change or in the amount of HCO_3^- ions is evident. In samples activated for 7 min, such changes began from the 10th day of the relaxation period.

Based on the analysis of information obtained from IR spectra from the aspect of changes in carbonate and bicarbonate groups, it was concluded that Na_2CO_3 was converted to NaHCO_3 during the relaxation period.

In order to determine the mechanism of bicarbonate ion formation, qualitative changes in the samples were analyzed by monitoring the evolution of the OH^- group. It is known that there are two types of OH^- groups, valence and deformation, whereby a valence OH^- group is more important for the observed system.

It can be seen from Fig. 3c) that with the relaxation time progress, the amount of hydroxyl group increased, i.e. the peaks' areas enlarged. Since sodium carbonate, unlike bicarbonate, does not contain the hydroxyl group, this is the additional qualitative proof of the chemical transformation of activated sodium carbonate into sodium bicarbonate under conditions in which spontaneous conversion would not otherwise occur. As the Na–O chemical bonds were weakened due to mechanical activation, the sodium ion was replaced by a hydrogen ion during the relaxation period, whereby the OH^- group was formed. It can be concluded that the formation of sodium bicarbonate begins with the binding of the valence OH^- group to the activated crystal structure of sodium carbonate.

By comparative analysis of diagrams presented in Fig. 3, three time-intervals of changes of the observed system can be distinguished during the relaxation process. The first interval is up to 7 days of the relaxation period when the mechanism of moisture adsorption from the air and binding of valence OH^- groups to the crystal lattice of activated Na_2CO_3 dominate. The second is from the 7th to the 25th day of relaxation, when the balance between the formation of sodium bicarbonate from sodium carbonate is established, the so-called plateau effect, because there is still no critical mass of the OH^- group, i.e. of the hydrogen source for bicarbonate formation. The third interval is after the 25th day when the reaction of bicarbonate formation is intensified due to the existence of a sufficient amount of the OH^- group which directs the reaction towards the bicarbonate formation.

Diagrams of changes in peak area values and changes in peak width values at half-height of sodium carbonate samples activated for 2, 7, 14, and 28 min as a function of relaxation time are illustrated in Figs 4-7.

Diagrams of changes in both peak area values and peak width at half-height values of sodium carbonate samples activated for 2, 7, 14, and 28 min as a function of relaxation time are illustrated in Figs 4-7.

Regarding the samples activated for 2 min, three domains of peak area changes depending on the relaxation time are noticeable on the curves in Fig. 4 a): from 0-7 days of exposure of activated samples to atmospheric conditions, that is to adsorption of moisture and

carbon dioxide; stagnation period (from 7 to 25 days); and again significant changes in all characteristic groups (from 25 to 31 days). The most significant changes can be seen in the CO_3^{2-} group, where a sharp peak area drop corresponds to the carbonate group loss from the analyzed sample. In the same period, a notable increase in the amount of bicarbonate ion is observed, as well as the rise in the amount of hydroxyl group present in the sample activated for 2 min.

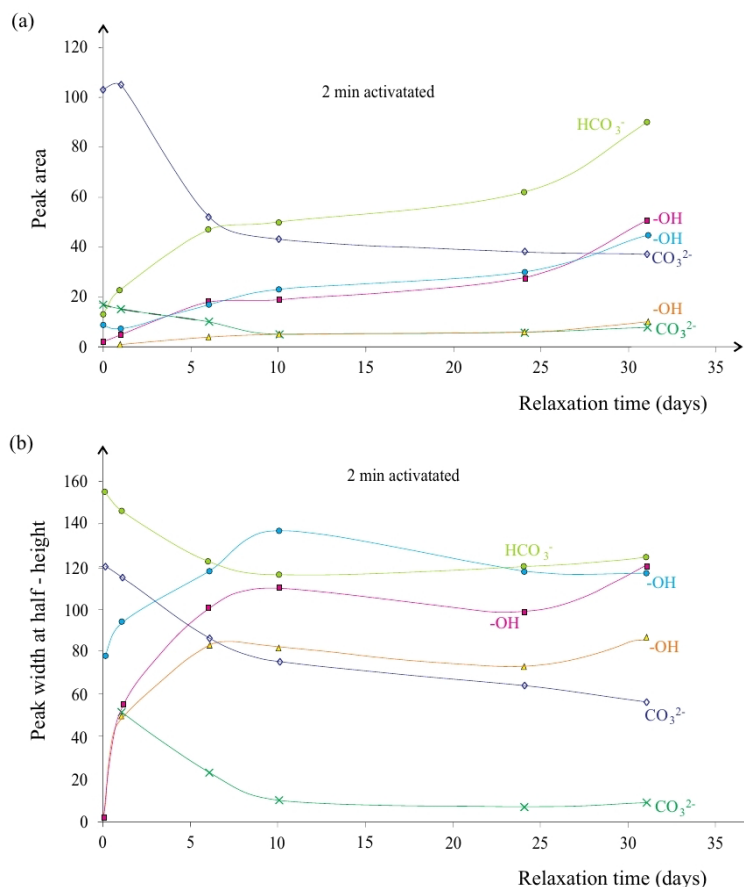


Fig. 4. a) Areas of peaks characteristic for ionic CO_3^{2-} , HCO_3^{2-} , and OH^- groups, b) Widths at half-heights of peaks characteristic for ionic CO_3^{2-} , HCO_3^{2-} , and OH^- groups in Na_2CO_3 sample activated for 2 min as a function of relaxation time.

The same regularity is evident in Fig. 4b) where the values of the *half-height peak width* for the CO_3^{2-} group decrease, while for the HCO_3^- and OH^- groups increase with the relaxation time progress.

The same regularity is evident in Fig. 4b) where the widths at half-heights of peaks characteristic for the CO_3^{2-} group decrease, while for the HCO_3^- and OH^- groups increase with the relaxation time progress.

As far as the samples activated for 7 min (Fig. 5a), the area of the characteristic CO_3^{2-} group peak decreases with the relaxation time progress, whereby this drop is sharp during ten days, especially on the first day of the sample aging. After that period, this tendency is slight until the end of the monitoring. The phenomenon can be explained by a significantly enhanced energy of just activated sodium carbonate due to the energy delivered to the system by mechanical activation as well as by the weakened bonds in the crystal. This caused the sudden adsorption of moisture and carbon dioxide from the air as well as the formation of a

bicarbonate ion, which is reflected in the increased width of the peak characteristic for the HCO_3^- ion.

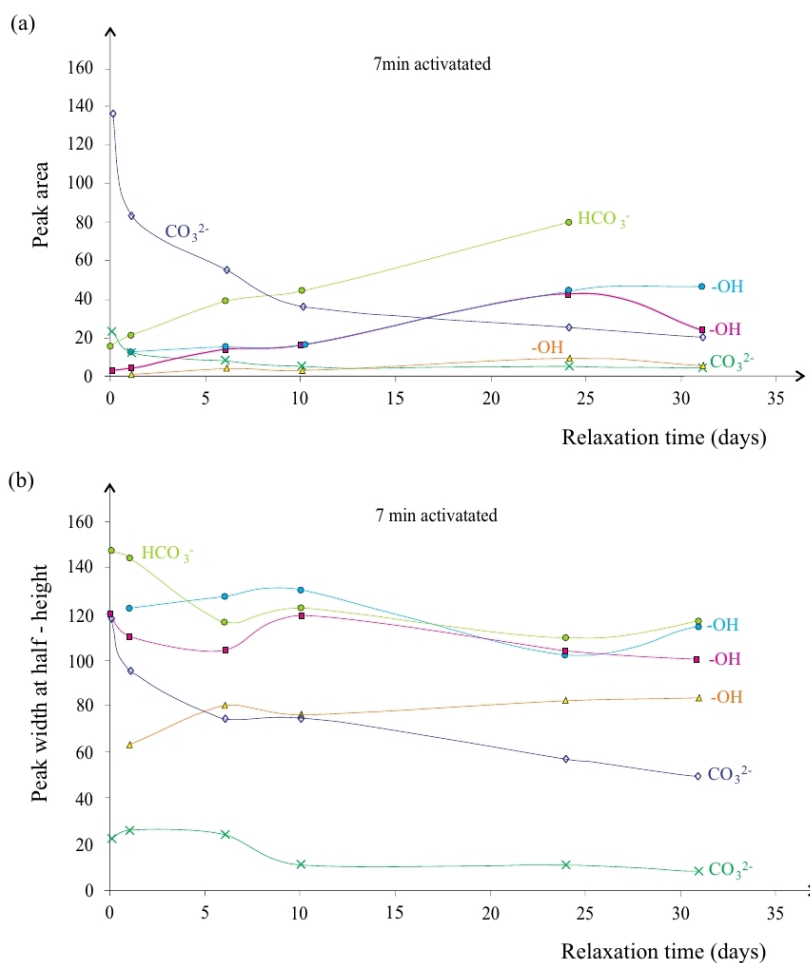


Fig. 5. a) Areas of peaks characteristic for CO_3^{2-} , HCO_3^{2-} , and OH^- ionic groups, b) Widths at half-heights of peaks characteristic for ionic CO_3^{2-} , HCO_3^{2-} , and OH^- groups in Na_2CO_3 sample activated for 7 min as a function of relaxation time.

A similar trend of corresponding changes in peaks widths' at half-heights can be seen in the diagram shown in Fig. 5 b). The reduced width at half-height of the peak characteristic for the CO_3^{2-} group is considerable. The most significant changes for all ions occur in the first 10 days of relaxation time.

Unlike the sample activated for 7 min, the one activated for 14 min shows a tendency for a slightly slower change in the peak areas of the characteristic ions (Fig. 6a). Thus, a significant decrease in the area of the characteristic CO_3^{2-} group peak also occurs in the first 10 days of the relaxation time. Until the 25th day, the peak area remains unchanged, while during the last 7 days of monitoring it additionally falls. The increase in the value of the area of the characteristic HCO_3^- group peak is in accordance with the decrease in the area of the characteristic CO_3^{2-} group peak (converting carbonate to bicarbonate).

The diagrams of the change in the widths at half-heights of peaks characteristic for CO_3^{2-} , HCO_3^{2-} , and OH^- groups show the tendency of converting carbonate to bicarbonate in the sodium carbonate sample activated for 14 minutes (Fig. 6b). The figure shows significant and harmonized changes in the *peak width at half-height* as a function of relaxation time, whereby reducing energy of the system occurred as a result of the carbonate to bicarbonate

conversion by adsorption of moisture and carbon dioxide from the air. Due to the longer mechanical activation time of the samples, the delivered energy is higher, which is reflected in faster chemical changes in the sample (converting carbonate to bicarbonate). The reduction of the carbonate ion amount in favor of bicarbonate happened in the first 5 days of the relaxation time, and then the curve of changes became milder in accordance with the decrease in the total energy of the system.

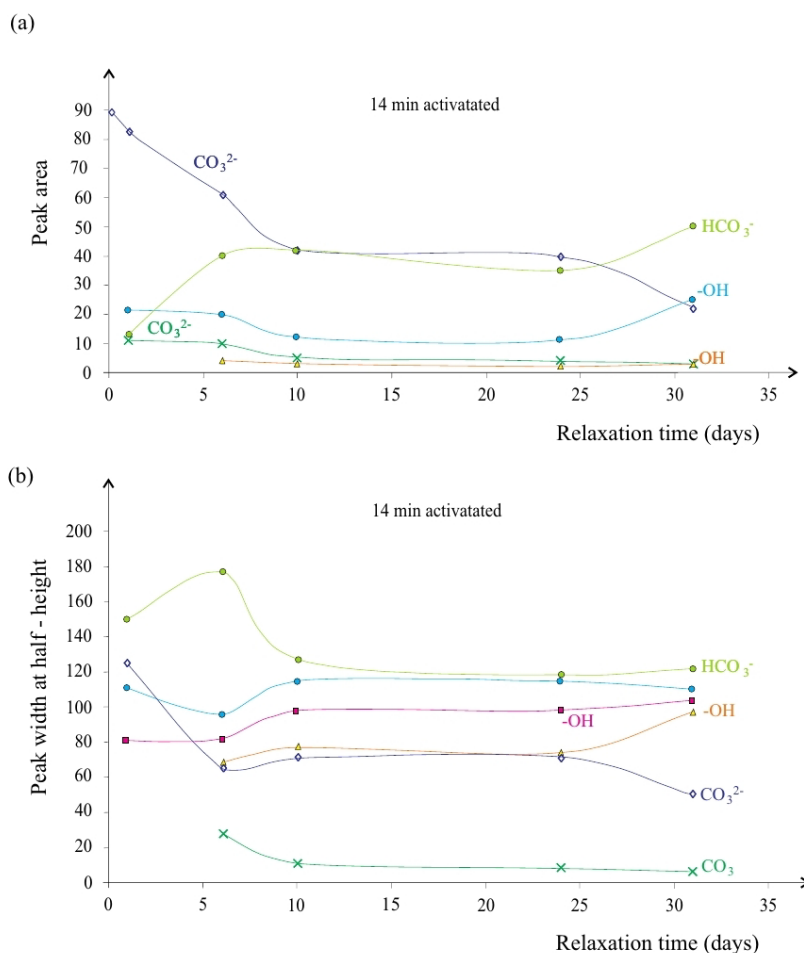


Fig. 6. a) Areas of peaks characteristic for CO_3^{2-} , HCO_3^{2-} , and OH^- ionic groups, b) Widths at half-heights of peaks characteristic for CO_3^{2-} , HCO_3^{2-} , and OH^- ionic groups in Na_2CO_3 sample activated for 14 min as a function of relaxation time.

After the 25th minute, there are slight changes again. The widths at half-heights of peaks characteristic for CO_3^{2-} group decline, while those for HCO_3^- and OH^- groups increase. These results are also in accordance with the previous ones, which describe the mechanism of chemisorption of moisture and carbon dioxide chemisorption from the air on activated sodium carbonate samples.

Unlike previously analyzed diagrams of samples activated for 7 and 14 min, most of the changes in the sample activated for 28 min occurred during the first 5 days of the relaxation period (Fig. 7). This can be explained by the fact that owing to a longer activation period, maximum changes in the crystal structure and energy increase in this sample took place, as well as the practically complete adsorption of CO_2 and H_2O in the first 5 days of relaxation time.

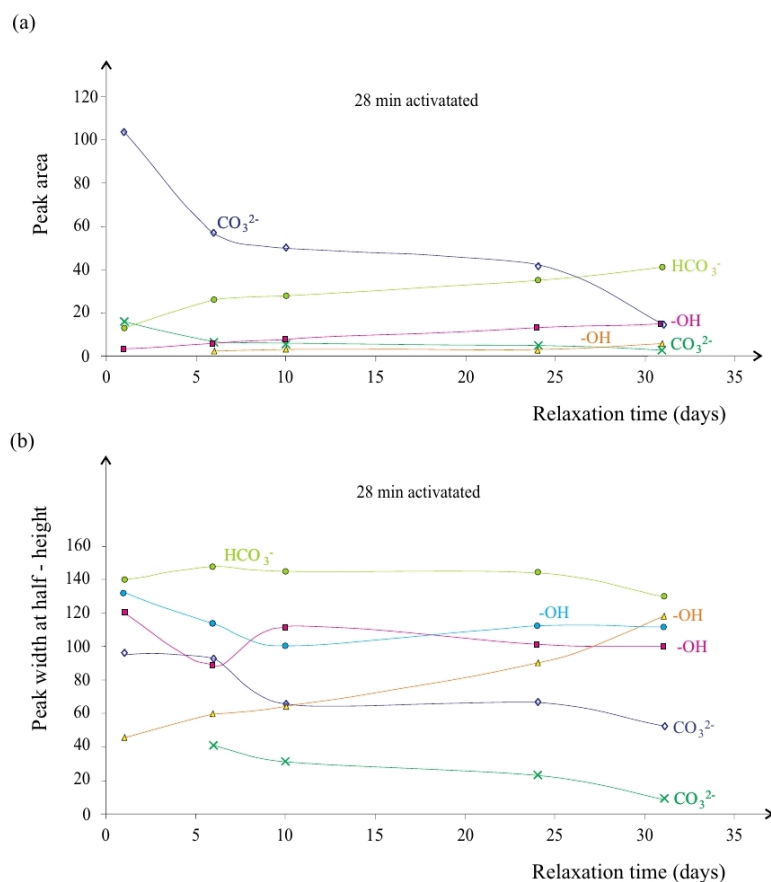


Fig. 7. a) Areas of peaks characteristic for CO_3^{2-} , HCO_3^{2-} , and OH^- ionic groups, b) Widths at half-heights of peaks characteristic for CO_3^{2-} , HCO_3^{2-} , and OH^- ionic groups in Na_2CO_3 sample activated for 28 min as a function of relaxation time.

After stagnation between the 5th and the 25th day of the relaxation period when the OH^- group was formed, there is a critical accumulation and transition to the bicarbonate ion, which is observed by a further change of peak area and peak width at half-height at given wavelengths.

Fig. 4 shows that the carbonate content decreases significantly with the relaxation time progress, while the amount of bicarbonate increases, which is a consequence of chemisorption of carbon dioxide and moisture from the atmosphere over the entire volume of activated sample, i.e. conversion of Na_2CO_3 to NaHCO_3 .

The curves shown in Figs 4-7 show a parallel process of changes occurring on the characteristic groups of activated sodium carbonate and its conversion to bicarbonate as a function of the relaxation time.

Tab. II Relative change in the areas of peaks characteristic for CO_3^{2-} , HCO_3^{2-} , and OH^- ionic groups (ΔS) as a function of the relaxation time.

Activation time	Area (ΔS)				
	CO_3^{2-} (I)	CO_3^{2-} (II)	HCO_3^{2-}	OH^- (I)	OH^- (II)
2 min	-62	-13	81	46	48
7 min	-117	-21	64	28	29
14 min	-57	-9	38	18	19
28 min	-86	-16	27	16	16

Relative change in the areas of peaks characteristic for CO_3^{2-} , HCO_3^{2-} , and OH^- ionic groups (ΔS) as a function of the activation time is presented in Table II.

Based on the previous diagrams for changes in the peaks' areas and peaks' widths at half-heights for the given ionic groups, it can be concluded that all the results indicate significant changes depending on the activation time of the starting sodium carbonate.

4. Conclusion

The FTIR spectroscopy analysis of four series of sodium carbonate samples mechanically activated for different intervals (2, 7, 14, and 28 min) in a high-energy mill with torsion springs and ring operating elements, and then stored at room conditions during 31 days (relaxation period), provided kinetics parameters for the transformation of sodium carbonate into sodium bicarbonate due to chemisorption of moisture and carbon dioxide from the atmosphere. Although sodium carbonate is a good sorbent, the results showed a gradient of changes in the analyzed samples during relaxation depending on the activation time. The changes in terms of reducing the number of carbonate ions in all four series of samples in favor of the formation of HCO_3^{2-} ions during the relaxation period are clearly noticeable. The key moment in the transformation process is the weakening of the Na–O chemical bond, where during the relaxation time the Na^+ ion was replaced by the H^+ ion, thus forming the OH^- group. The formation of sodium bicarbonate began by bonding the valence OH^- group to the activated crystal lattice of sodium carbonate. This transformation was taking place after the 25th day of the relaxation period owing to the existence of a sufficient amount of the OH^- group which directed the reaction towards the bicarbonate formation.

Acknowledgments

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5. References

1. F. Rodríguez-Reinoso, M. Molina-Sabio, *Carbon*, 30 (7) (1992) 1111.
2. J. Díaz-Terán, D. M. Nevskaja, J. L. G. Fierro, A. J. López-Peinado, A. Jerez, *Micropor. Mesopor. Mat.*, 60 (2003) 1.
3. D. Vamvuka, S. Troulinos, E. Kastanaki, *Fuel*, 85 (12-13) (2006) 1763.
4. J.M. Galligan, T. J. McKrell, *Physica B: Condens Matter.*, 291 (1-2) (2000) 131.
5. N. Obradović, V. Blagojević, S. Filipović, N. Đorđević, D. Kosanović, S. Marković, M. Kachlik, K. Maca, V. Pavlović, *J. Therm. Anal. Calorim.*, 138 (5) (2019) 2989.
6. I. Brissaud, P. Chevallier, C. Dardenne, N. Deschamps, J. P. Frontier, K. Gruel, A. Taccoen, A. Tarrats, J. X. Wang, *Nucl. Instrum. Methods Phys. Res. B*, 49 (1-4) (1990) 305.
7. Y. Wang, E.L. Botvinick, Y. Zhao, M.W. Berns, S. Usami, R.Y. Tsien, S. Chien, *Nature*, 434 (2005) 1040.
8. P. Baláž, *Int. J. Miner. Process.*, 72 (1-4) (2003) 341.
9. A. Castro, B. Jiménez, T. Hungri, A. Moure, L. Pardo, *J. Eur. Ceram. Soc.*, 24 (6) (2004) 941.
10. N. Obradović, W. G. Fahrenholtz, S. Filipović, D. Kosanović, A. Dapčević, A. Đorđević, I. Balać, V. Pavlović, *Ceram Int.*, 45 (9) (2019) 12015.

11. J. Živojinović, V. P. Pavlović, N. J. Labus, V. A. Blagojević, D. Kosanović, V. B. Pavlović, *Sci. Sinter.*, 51 (2) (2019) 199.
12. N. Obradović, N. Đorđević, S. Filipović, S. Marković, D. Kosanović, M. Mitrić, V. Pavlović, *J. Therm. Anal. Calorim.*, 124 (2) (2016) 667.
13. M. Pavlović, Lj. Andrić, D. Radulović, S. Drmanić, N. Đorđević, M. Petrov, *Sci. Sinter.*, 51 (1) (2019) 409.
14. N. Djordjevic, N. Obradovic, S. Filipovic, *Powder Metall. Met. Ceram.*, 51 (1-2) (2012) 83.
15. I. Tole, K. Habermehl-Cwirzen, A. Cwirzen, *Miner Petrol.*, 113 (2019) 449.
16. D. Kosanović, N. Labus, J. Živojinović, A. Peleš Tadić, V. Blagojević, V. Pavlović, *Sci. Sinter.*, 52 (4) (2020) 371.
17. D. Ramin, A. Mohammad, K. Arqavan, *Sci. Sinter.*, 52 (3) (2020) 245.
18. L. Smail, R. Djaida, S. Foudil, H. Menad, S. Nouari, *Sci. Sinter.*, 52 (2) (2020) 135.
19. N. Stojanović, A. Kalezić-Glišović, A. Janičijević, A. Maričić, *Sci. Sinter.*, 52 (2) (2020) 163.
20. A. R. Branković, V. M. Vidojković, S. Dj. Milošević, *J. Solid State Chem.*, 135 (2) (1998) 256.
21. N. G. Đorđević, S. R. Mihajlović, A. S. Patarić, *Sci. Sinter.*, 52 (4) (2020) 433.
22. S-W. Park, D-H. Sung, B-S. Choi, K-J. Oh, K-H. Moon, *Sep. Sci. Technol.*, 41 (12) (2006) 2665.
23. *Climate change 2014: Synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change, IPCC, Geneva, Switzerland. ISBN 978-92-9169-143-2.*
24. Y. Liang, *Carbon dioxide capture from flue gas using regenerable sodium-based sorbents, Master's Thesis, Louisiana State University, 2003.*
25. T. S. Ledley, E. T. Sundquist, S. E. Schwartz, D. K. Hall, J. D. Fellows, T. L. Killeen, *EOS*, 80 (39) (1999) 453.
26. A. Munajad, C. Subroto, S. Suwarno, *Energies*, 11 (2) (2018) 364.
27. T. Petit, Lj. Puskar, *Diam. Relat. Mater.* 89 (2018) 52.
28. V. Țucureanu, A. Matei, A. M. Avram, *Crit. Rev. Analyt. Chem.*, 46 (6) (2016) 502.
29. A. C. S. Talari, M. A. G. Martinez, Z. Movasaghi, S. Rehman, I. U. Rehman, *Appl. Spectrosc. Rev.*, 52 (5) (2017) 456.
30. V. Hospodarova, E. Singovszka, N. Stevulova, *Am. J. Analyt. Chem.*, 9 (6) (2018) 303.
31. X. Jiang, S. Li, G. Xiang, Q. Li, L. Fan, L. He, K. Gu, *Food Chem.* 212 (1) (2016) 585.
32. M. A. Mohamed, J. Jaffar, A. F. Ismail, M. H. D. Othman, M. A. Rahman, in: *''Membrane Characterization''*, Eds. N. Hilal, A. F. Ismail, T. Matsuura and D. Oatley-Radcliffe, Elsevier Inc., 2017, p. 3-29.

Сажетак: Током механичке активације у материјалу се јављају квалитативне промене које могу произвести различите појаве. У овој студији, анхидровани натријум карбонат је механички активиран током 2, 7, 14 и 28 минута у вибро млину при фреквенцији од 3000 осцилација у минути. Након активације, четири серије активираних узорака су чуване на ваздуху у собним условима 31 дан (период релаксације). За праћење кинетике процеса трансформације узорака активираног натријум карбоната, односно механизма формирања натријум бикарбоната током релаксације, коришћена је FTIR спектроскопска анализа. Испитивање је извршено у функцији времена релаксације за све четири серије узорака, посматрањем карактеристичних група: CO_3^{2-} , HCO_3^- и OH . На основу резултата, добијени су кинетички параметри трансформације натријум карбоната у натријум бикарбонат услед хемисорпције влаге и угљен-диоксида из атмосфере.

Кључне речи: *Механичка активација; натријум карбонат; натријум бикарбонат; механохемијска трансформација; FTIR.*

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