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on Renewable Electrical Power Sources**
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obnovljive izvore
električne energije
pri SMEITS-u**

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FOREWORD

Science, technology and industry accelerated development leads to improvements of human life, but also creates new risky situations. Humanity faces unprecedented risks. Global warming is an example. Although most experts in the field of climate change state that global warming is created by humans, some scientists do not agree. One of the main problems in these risky situations is – question of responsibility. The world governments should not leave all responsibility to scientists and experts. Authorities should consult experts to declare state of emergency. A strong political initiative is necessary to start dealing with serious ecological problems such as global warming or local environment pollution. Highest level political agreements achieved within the Kyoto Protocol are not enough to stop these phenomena. Clean technologies designed to provide superior performances at lower prices, with lowering losses of conventional offerings – have great chances to be the next driving force to ensure economy growth.

Science is the first to define problems of Earth and life survival. Science is trying to provide solutions, limited by political, social, economic and technology factors. Preservation of life on Earth is the common priority.

Science and technical and technology development can contribute in several fields:

- renewable power sources;*
- efficient energy usage;*
- waste reducing;*
- harmfulness of waste mitigation;*
- recycling;*
- soil, water and air purification;*
- residual waste neutralization.*

Important factor for political decisions making is the public opinion. Therefore, it is extremely important to raise awareness and widely educate population on necessary transition to renewable, ecologically acceptable power sources, which is one of long-term goals of this Conference.

For eight time, this international event is organized by the Society of Renewable Electrical Power Sources (DOIEE) within the Union of Mechanical and Electrotechnical Engineers and Technicians of Serbia (SMETS).

*Belgrade,
October 2020.*

PREDGOVOR

Ubrzani napredak nauke, tehnologije i industrije dovodi do poboljšanja kvaliteta ljudskog života, ali i do stvaranja novih rizičnih situacija. Čovečanstvo je suočeno sa rizicima kakvih u ranijoj ljudskoj istoriji nije bilo. Globalno zagrevanje je tipičan primer. Iako većina eksperata koji proučavaju klimatske promene tvrde da globalno zagrevanje postoji i da je čovek taj koji ga uzrokuje, postoje naučnici koji dovode u sumnju takve tvrdnje. Jedan od glavnih problema vezanih za nove rizične situacije jeste – pitanje odgovornosti. Vlade država u svetu ne smeju teret odgovornosti prepustiti isključivo naučnicima i ekspertima. Vlasti treba da se konsultuju sa ekspertima i da dobro procene kada treba proglasiti opasnost od rizične situacije. Potrebna je jaka politička inicijativa da bi se počeli rešavati ozbiljni ekološki problemi kao što je globalno zagrevanje, ali i lokalno zagađenje životne sredine. Politički dogovori na svetskom nivou koji su do sada postignuti u okviru Kjoto protokola, nedovoljni su za zaustavljanje ovog fenomena. Čiste tehnologije – tehnologije koje su dizajnirane da obezbeđuju superiorne performanse za nižu cenu dok istovremeno kreiraju manji gubitak od konvencionalnih ponuda – imaju velike šanse da budu sledeća motorna snaga koja će obezbediti ekonomski rast.

Nauka, naravno, pre svih uočava probleme opstanka planete i života na njoj. Ona takođe pokušava da ih reši i uspeva onoliko koliko je to realno moguće, imajući u vidu političke, socijalne, ekonomske i tehnološke faktore. Može se konstatovati da su praktično svi prioriteti posvećeni očuvanju života na Zemlji. Nauka i razvoj tehnike i tehnologije mogu tome doprineti u više segmenata:

- obnovljivi izvori energije;*
- energetska efikasnost;*
- smanjenje količine otpada;*
- smanjenje štetnosti otpada;*
- reciklaža;*
- prečišćavanje zemlje, vode i vazduha;*
- neutralizacija preostalog otpada.*

Bitan faktor za donošenje političkih odluka je i javno mnjenje. Zato je jako važno podizanje opšte svesti i što šira edukacija stanovništva o neophodnosti prelaska na obnovljive, ekološki prihvatljive izvore energije, što je jedan od dugoročnih ciljeva ove Konferencije.

Ovaj međunarodni skup po osmi put organizuje Društvo za obnovljive izvore električne energije (DOIEE) Saveza mašinskih i elektrotehničkih inženjera i tehničara Srbije (SMEITS).

*U Beogradu,
oktobra 2020.*

SADRŽAJ / CONTENTS

PREDGOVOR

Prof. dr Zoran STEVIĆ 7

1. Novi materijali i nove tehnologije u oblasti OIE

Plenarno predavanje – po pozivu

1. “SUPERALKALNI“ KLASTERI, PROIZVODNJA,
POTENCIJALNA PRIMENA KAO MATERIJAL
ZA SKLADIŠTENJE ENERGIJE
“SUPERALKALI” CLUSTERS, PRODUCTION, POTENTIAL
APPLICATION LIKE ENERGY STORAGE MATERIALS
Suzana VELIČKOVIĆ, Xianglei KONG 15

Redovna izlaganja

2. UPOTREBA NIKLA KAO MEĐUPREVLAKE U CILJU SMANJENJA
KONTAKTNE KOROZIJE NA ELEKTRIČNIM KONTAKTIMA AL-CU
USE OF NICKEL AS AN INTERMEDIATE COATING TO REDUCE
CONTACT CORROSION ON ELECTRICAL CONTACTS AL-CU
Silvana DIMITRIJEVIĆ, Zoran STEVIĆ, Aleksandra IVANOVIĆ,
Stevan DIMITRIJEVIĆ, Saša MARJANOVIĆ, Nikhil DHAWAN 23
3. SINTEZA SREBRNIH ČESTICA VELIČINE MIKROMETRA
PRIMENJIVE ZA DEBELO FILMNE KONTAKTE
NA SOLARNIM ČELIJAMA
SYNTHESIS OF MICRO-SIZED SILVER PARTICLES SUITABLE
FOR THICK FILM CONTACTS ON SOLAR CELLS
Stevan DIMITRIJEVIĆ, Silvana DIMITRIJEVIĆ,
Michele MILICIANI, Željko KAMBEROVIĆ,
Zara CHERKEZOVA-ZHELEVA. 29
4. SINTEZA I KARAKTERIZACIJA PREMAZA EPOKSIDNE SMOLE
SA POBOLJŠANOM OTPORNOŠĆU NA PLAMEN UPOTREBOM
MODIFIKOVANE TANINSKE KISELINE
SYNTHESIS AND CHARACTERIZATION OF EPOXY RESIN COATING
WITH IMPROVED FIRE RESISTANCE BY THE ADDITION
OF MODIFIED TANNIC ACID
Andreja ŽIVKOVIĆ, Nataša TOMIĆ,
Marija VUKSANOVIĆ, Aleksandar MARINKOVIĆ 35
5. PRIMENA KONCEPTA 3D ŠTAMPE BETONA
U IZRADI VETROGENERATORA
APPLYING CONCEPT OF 3D PRINTING CONCRETE
IN WIND TOWER CONSTRUCTION
Aleksandar SAVIĆ, Miša STEVIĆ, Sanja MARTINOVIĆ,
Milica VLAHOVIĆ, Tatjana VOLKOV HUSOVIĆ 43
6. TERMOVIZIJSKI MONITORING TOPLOTE HIDRATACIJE BETONA
THERMOVISION MONITORING OF CONCRETE HEAT OF HYDRATION
Aleksandar SAVIĆ, Zoran STEVIĆ, Sanja MARTINOVIĆ,
Milica VLAHOVIĆ, Tatjana VOLKOV HUSOVIĆ 47

7.	UTICAJ MEHANOHEMIJSKE AKTIVACIJE KOMPONENTI NA SINTEZU KORDIJERITNE KERAMIKE ZA PRIMENU U ELEKTRONICI INFLUENCE OF MECHANOCHEMICAL ACTIVATION OF COMPONENTS ON SYNTHESIS OF CORDIERITE CERAMICS FOR APPLICATION IN ELECTRONICS Nataša ĐORĐEVIĆ, Milica VLAHOVIĆ, Slavica MIHAJLOVIĆ, Sanja MARTINOVIĆ	51
8.	UTICAJ VREMENA RELAKSACIJE AKTIVIRANE SMEŠE NA SINTEZU KERAMIKE ZA NAMENU U ELEKTRONICI IMPACT OF RELAXATION TIME OF ACTIVATED MIXTURE ON CERAMICS SYNTHESIS FOR ELECTRONICS PURPOSES Nataša ĐORĐEVIĆ, Milica VLAHOVIĆ, Slavica MIHAJLOVIĆ, Sanja MARTINOVIĆ	57
2. Energetski izvori i skladištenje energije		
9.	POTENCIJAL POLJOPRIVREDNE BIOMASE U SISTEMIMA PROIZVODNJE BIOGASA U REPUBLICI SRBIJI POTENTIAL OF AGRICULTURAL BIOMASS IN BIOGAS PRODUCTION SYSTEMS IN THE REPUBLIC OF SERBIA Olivera EĆIM-ĐURIĆ, Dragan KRECULJ, Danijela ŽIVOJINOVIĆ, Miloš VORKAPIĆ	63
10.	GASIFIKACIJA OSTATAKA BIOMASE ZA POTREBE PROIZVODNJE ELEKTRIČNE ENERGIJE GASIFICATION OF BIOMASS WASTES AND RESIDUES FOR ELECTRICITY PRODUCTION Marta TRNINIĆ	71
11.	POBOLJŠANJE SVOJSTAVA BETONA DODATKOM LETEĆEG PEPELA IZ TERMOELEKTRANE ZA PRIMENU U GEOTERMALNIM SISTEMIMA ENHANCING PROPERTIES OF CONCRETE BY ADDITION OF FLY ASH FROM A THERMAL POWER PLANT FOR APPLICATION IN GEOTHERMAL SYSTEMS Milica VLAHOVIĆ, Aleksandar SAVIĆ, Sanja MARTINOVIĆ, Nataša ĐORĐEVIĆ, Zoran STEVIĆ, Tatjana VOLKOV HUSOVIĆ.	77
12.	PRIMENA OBNOVLJIVIH IZVORA ENERGIJE U ZGRADARSTVU APPLICATION OF RENEWABLE ENERGY RESOURCES IN BUILDINGS Njegoš DRAGOVIĆ, Milovan VUKOVIĆ, Igor UROŠEVIĆ	87
13.	EFIKASNA SINHRONIZACIJA DIZEL GENERATORA U USLOVIMA PROMENLJIVE FREKVENCIJE IMPROVED SYNCHRONIZATION OF DIESEL GENERATORS IN VARIABLE FREQUENCY CONDITIONS USING PREDICTIVE METHOD Zoran NIKOLIĆ, Dušan NIKOLIĆ	95
14.	KORIŠĆENJE OBNOVLJIVIH IZVORA – PRETVARANJE GEOTERMALNE ENERGIJE U ELEKTRIČNU UTILIZING RENEWABLE RESOURCES – CONVERTING GEOTHERMAL ENERGY TO ELECTRICITY Miljan VLAHOVIĆ, Milica VLAHOVIĆ, Zoran STEVIĆ	101
15.	OBNOVLJIVI IZVORI ENERGIJE, POTENCIJALI I PRIMENA U SVETSKIM OKVIRIMA I U SRBIJI RENEWABLE ENERGY SOURCES, POTENTIALS AND APPLICATIONS WORLDWIDE AND IN SERBIA Miomir MIKIĆ, Sanja PETROVIC, Zorica SOVRLIĆ, Daniela UROŠEVIĆ	111

16.	OCENA ŽIVOTNOG CIKLUSA BIOENERGETSKIH SISTEMA LIFE CYCLE ASSESSMENT OF BIOENERGY SYSTEMS Slobodan CVETKOVIĆ, Mirjana KIJEVČANIN.	119
3. Energija vetra		
17.	VETROTURBINE SNAGE PREKO 20 MW – TEHNOLOŠKA PERSPEKTIVA WIND TURBINE BEYOND 20 MW – TECHNOLOGY PERSPECTIVE Aleksandar SIMONVIĆ, Aleksandar KOVAČEVIĆ, Toni IVANOV, Miloš VORKAPIĆ	123
18.	NUMERIČKA PROCENA AERODINAMIČKIH PERFORMANSI ROTORA VETROTURBINE SA VERTIKALNOM OSOM OBR TANJA I KONCENTRATOROM NUMERICAL EVALUATION OF AERODYNAMIC PERFORMANCES OF VERTICAL-AXIS WIND TURBINE ROTOR WITH FLOW CONCENTRATOR Jelena SVORCAN, Ognjen PEKOVIĆ, TONI IVANOV, Miloš VORKAPIĆ	135
19.	UPRAVLJANJE PRETVARAČIMA U VETROTURBINAMA CONTROL OF CONVERTERS IN WIND TURBINES Stevan JOKIĆ, Zoran STEVIĆ	143
4. Solarna energija		
20.	NAPREDNI SOFTVERSKI SISTEM ZA MONITORING SOLARNOG NAPA JANJA ADVANCED SOFTWARE SYSTEM FOR MONITORING OF SOLAR PANELS Vuk JOVANOVIĆ, Ilija RADOVANOVIĆ, Zoran STEVIĆ.	155
21.	ANALIZA I POREĐENJE RAZLIČITIH METODA MPPT KOD PV SISTEMA NAPA JANJA ANALYSIS AND COMPARISON OF DIFFERENT MPPT METHODS IN PV POWER SYSTEMS Zoran STEVIĆ, Miša STEVIĆ, Ilija RADOVANOVIĆ	159
22.	SOLARNA ENERGIJA U SRBIJI SOLAR ENERGY IN SERBIA 163 Sanja PETROVIĆ, Mimir MIKIĆ, Daniela UROŠEVIĆ	163
23.	MOGUĆNOSTI IMPLEMENTACIJE FOTONAPONSKIH SOLARNIH PANELA U PODRUČJIMA NAMENJENIM VIŠEPORODIČNOM STANOVANJU POSSIBILITIES OF IMPLEMENTATION OF PHOTOVOLTAIC SOLAR PANELS IN MULTI-FAMILY HOUSING AREAS Borjan BRANKOV, Ana STANOJEVIĆ, Mila PUCAR, Marina NENKOVIĆ-RIZNIC	167
24.	PRIMENA SOLARNE ENERGIJE U FUNKCIJI ODRŽIVOG RAZVOJA U JP EPS, OGRANAK RB „KOLUBARA“ - ORG. CEL. PRERADA APPLICATION OF SOLAR ENERGY IN THE FUNCTION OF SUSTAINABLE DEVELOPMENT IN PC EPS, BRANCH OF RB „KOLUBARA“ - ORG. CEL. PROCESSING Momčilo MOMČILOVIĆ, Milisav TOMIĆ.	177

5. Energetska efikasnost

25. **ENERGETSKA EFIKASNOST U SEKTORU JAVNIH ZGRADA NA TERITORIJI GRADA KRAGUJEVCA – STUDIJA SLUČAJA OŠ „MILUTIN I DRAGINJA TODOROVIĆ“**
ENERGY EFFICIENCY IN THE PUBLIC BUILDINGS SECTOR IN THE TERRITORY OF THE CITY OF KRAGUJEVAC – CASE STUDY OF “MILUTIN AND DRAGINJA TODOROVIĆ” ELEMENTARY SCHOOL
Ana RADOJEVIĆ, Aleksandar NEŠOVIĆ,
Jasmina SKERLIĆ, Dušan GORDIĆ, Danijela NIKOLIĆ 189
26. **SIMULACIJA INVERTORA ZA INDUKCIONO GREJANJE**
SIMULATION OF INVERTERS FOR INDUCTION HEATING
Biljana BAKOVIĆ, Zoran STEVIĆ. 199
27. **PRIMENA SUPERKONDENZATORA U ELEKTRIČNIM VOZILIMA**
APPLICATION OF SUPERCAPACITORS IN ELECTRIC VEHICLES
Zoran STEVIĆ, Ilija RADOVANOVIĆ, Miša STEVIĆ 207
28. **ENERGETSKI EFIKASAN SISTEM ZA STERILIZACIJU DRVETA**
ENERGY EFFICIENT SISTEM FOR WOOD STERILIZATION
Miloš MARJANOVIĆ, Miša STEVIĆ, Miloš MILEŠEVIĆ,
Žarko ŠEVALJEVIĆ, Sanja PETRONIĆ, Marta TRNINIĆ, Zoran STEVIĆ. 211

6. Aplikacije i usluge

29. **KOJE VEŠTINE SU POTREBNE U PROIZVODNJI LITIJUM-JONSKIH BATERIJA ZA ELEKTRIČNA VOZILA**
WHAT SKILLS ARE NEEDED IN PRODUCTION OF LITHIUM-ION BATTERIES FOR ELECTRICAL VEHICLES
Zoran KARASTOJKOVIĆ 217
30. **PRIMENA LASERA U AUTOMOBILSKOJ INDUSTRIJI**
APPLICATION OF LASERS IN AUTOMOTIVE INDUSTRY
Milesa SREĆKOVIĆ, Nenad IVANOVIĆ, Stanko OSTOJIĆ,
Aleksander KOVAČEVIĆ, Nada RATKOVIĆ KOVAČEVIĆ,
Zoran KARASTOJKOVIĆ, Sanja JEVTIĆ 223
31. **RASTVARANJE KATODNOG MATERIJALA IZ LIB U SUMPORNOJ KISELINI U PRISUSTVU AZOTA**
DISSOLUTION OF LIBS CATHODE MATERIAL IN SULFURIC ACID IN THE PRESENCE OF NITROGEN
Dragana V. MEDIĆ, Snežana M. MILIĆ, Slađana Č. ALAGIĆ,
Zoran M. STEVIĆ, Boban R. SPALOVIĆ, Maja M. NUJKIĆ, Ivan N. ĐORĐEVIĆ. 241
32. **INTEGRACIJA DISTRIBUIRANIH PV SISTEMA U PAMETNIM SREDINAMA KORISTECI FOG COMPUTING ARHITEKTURU**
INTEGRATION OF DISTRIBUTED PHOTOVOLTAIC SYSTEMS IN THE SMART ENVIRONMENT THROUGH FOG COMPUTING ARCHITECTURE 247
Ilija RADOVANOVIĆ, Ivan POPOVIĆ. 247
33. **PRIMENA METODOLOGIJE PAMETNIH MREŽA U DISTRIBUCIJI ELEKTRIČNE ENERGIJE**
SMART GRID TECHNOLOGY IN POWER DISTRIBUTION SYSTEMS
Ivan POPOVIĆ. 251
34. **MOGUĆNOSTI PRIMENE IIOT PLATFORME U ELEKTROENERGETSKIM SISTEMIMA**
POSSIBILITIES OF IIOT APPLICATION PLATFORMS IN THE ELECTRICAL POWER SYSTEMS 255
Vojkan NIKOLIĆ, Zoran STEVIĆ, Stefana JANIĆIJEVIĆ, Dragan KRECULJ 255

35.	ISTRAŽIVANJE UTICAJA RELATIVNE VLAŽNOSTI I TEMPERATURE NA IOT REŠENJE ZASNOVANO NA JEFTINIM SENZORIMA ZA PRAĆENJE KVALITETA VAZDUHA INVESTIGATION OF THE INFLUENCE OF RELATIVE HUMIDITY AND TEMPERATURE ON THE IOT SOLUTION WITH LOW COST AIR QUALITY MONITORING SENSORS Ivan VAJS, Dejan DRAJIĆ, Ilija RADOVANOVIĆ.	261
36.	RAČUNARSKO UPRAVLJANJE ENERGETSKI EFIKASNIM SISTEMOM ZA STERILIZACIJU DRVETA COMPUTER CONTROL OF ENERGY EFFICIENT WOOD STERILIZATION SYSTEM Miša STEVIĆ, Miloš MARJANOVIĆ, Ilija RADOVANOVIĆ, Zoran STEVIĆ.	267
37.	VAŽNOST PRIMENE ANALIZE RIZIKA KOD OPREME POD PRITISKOM KOJA SE ISPITUJE PO POSEBNOM PROGRAMU IMPORTANCE OF APPLYING RISK ANALYSIS TO PRESSURE EQUIPMENT TESTED BY A SPECIAL PROGRAM Sanja PETRONIĆ, Marko JARIĆ, Katarina ČOLIĆ, Suzana POLIĆ, Dimitrije MALJEVIĆ.	271
38.	AUTOMATIZACIJA PROCESA PROIZVODNJE BAKARNE ŽICE METODOM LIVENJA U VIS – PODSISTEM ZA INDUKCIONO ZAGREVANJE AUTOMATION OF A COPPER WIRE MANUFACTURING PROCESS USING UP-CASTING METHOD – SUBSYSTEM FOR INDUCTION HEATING Nada RATKOVIĆ KOVAČEVIĆ, Misa STEVIĆ, Milos MILEŠEVIĆ, Srđan MAKSIMOVIĆ, Đorđe DIHOVIČNI, Zoran STEVIĆ.	279
39.	POVEĆANJE TOLERANCIJE GREŠKE ADC AD7799 INCREASING FAULT TOLERANCE OF ADC AD7799 Artem BASKO, Elena PONOMARYOVA.	287
40.	MOGUĆNOST KORIŠĆENJA KOŠTICA VIŠNJE KAO BIOGORIVA ZA DOBIJANJE TOPLOTNE ENERGIJE POSSIBILITY OF USING SOUR CHERRY PITS AS BIOFUEL FOR OBTAINING THERMAL ENERGY Milorad PETROVIĆ, Milan JOVANOVIĆ, Zoran ŠTIRBANOVIĆ, Jovica SOKOLOVIĆ, Vojka GARDIĆ.	295

UTICAJ MEHANOHEMIJSKE AKTIVACIJE KOMPONENTI NA SINTEZU KORDIJERITNE KERAMIKE ZA PRIMENU U ELEKTRONICI

INFLUENCE OF MECHANOCHEMICAL ACTIVATION OF COMPONENTS ON SYNTHESIS OF CORDIERITE CERAMICS FOR APPLICATION IN ELECTRONICS

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Kordijerit, $2\text{MgO}\cdot 2\text{Al}_2\text{O}_3\cdot 5\text{SiO}_2$, zbog svojih svojstava predstavlja izuzetno atraktivan keramički materijal koji se može primeniti u elektronici za različite namene. Kako je temperatura sinterovanja kordijerita veoma visoka ($1375\text{ }^\circ\text{C}$), svako sniženje temperature na kojoj se formira kordijerit donosi ekonomski benefit. Zbog toga je u ovom radu primenjena metoda mehanohemijske aktivacije smeše polaznih komponenti za sintezu kordijerita sa ciljem sniženja njegove temperature sinterovanja. Ispitivani su efekti mehanohemijske aktivacije na kordijeritnu smešu. Povećanje specifične površine aktiviranih polaznih komponenti je praćeno BET metodom. TG metoda i gubitak mase primenjeni su za praćenje promena uslovljenih temperaturom u analiziranom trokomponentnom sistemu. Na osnovu dobijenih rezultata, povećanja specifične površine i gubitka mase sa povećanjem vremena aktivacije, očekuje se sniženje temperature sinterovanja kordijerita.

Ključne reči: kordijerit; sinterovanje; mehanohemijska aktivacija; BET; TG

The properties of cordierite, $2\text{MgO}\cdot 2\text{Al}_2\text{O}_3\cdot 5\text{SiO}_2$, makes this ceramics nowadays an attractive material, which can be used for various applications in electronics. As the sintering temperature of cordierite is very high ($1375\text{ }^\circ\text{C}$), any decrease in the temperature at which cordierite is formed leads to economic benefits. Therefore, in this study, the mechanochemical activation of the initial components mixture for the synthesis of cordierite was applied with the aim to lower its sintering temperature. The effects of mechanochemical activation on the cordierite mixture were investigated. Changes in the specific surface area of the activated components were determined by the BET method. The TG method and mass loss were used to monitor the temperature-induced changes in the analyzed three-component system. Based on the obtained results, increase in specific surface area and weight loss with increasing activation time, a decrease in cordierite sintering temperature is expected.

Keywords: cordierite; sintering; mechanochemical activation; BET; TG

1 Introduction

Ceramics based on cordierite ($2\text{MgO}\cdot 2\text{Al}_2\text{O}_3\cdot 5\text{SiO}_2$) have excellent thermal shock resistance, low dielectric constant (~ 5) and low thermal expansion coefficient ($20\cdot 10^{-7}/^\circ\text{C}$). These properties make cordierite suitable for various microelectronic components, as well as in semiconductor production, for a wide range of high-temperature applications, and applications in mechanical engineering [1-4].

However, cordierite is difficult to sinter due to its very high and narrow range of sintering temperatures ($1300\text{-}1400^\circ\text{C}$). The thermodynamic principles of the kinetics of the syntheses of cordierite ceramics are given in the literature [5].

On the other hand, during the mechanochemical activation of the powders, their free surface increases and changes in the structure of the material are induced by the mechanical energy. These

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changes have a direct influence on material properties which depend on structure, mass transport and reactivity.

Mechanochemically activated samples have more accumulated energy compared to the inactivated. Bearing this in mind, it is important to analyze the possible chemical changes of the activated system after certain periods of time (relaxation period) as they can have further influence on the kinetics of the sintering process. The accumulated energy can induce surface and bulk chemisorption of components in the atmosphere. If no changes of an activated sample occur during the relaxation time, then a mechanochemically activated sample can be sintered after an unlimited period of time. FT IR spectroscopy is used to make evident changes in the samples occurring during the relaxation time [6-15].

In this work mechanochemical energy was used to activate initial cordierite mixtures containing MgO, Al₂O₃ and SiO₂ in the ratio 2:2:5 with the aim to decrease the sintering temperature of cordierite. The influence of mechanochemical activation on the initial cordierite mixture was examined and analysed.

2 Experimental

The following oxides of technical quality were used in this research: MgO (98.60 %), Al₂O₃ (99.19 %) and SiO₂ (96.10 %). A powder mixture composed of oxides MgO, Al₂O₃ and SiO₂ in the ratio 2:2:5 was prepared. The system 2MgO+2Al₂O₃+5SiO₂ was mechanochemically activated for 5, 15, 30, 60, 120 and 240 minutes (samples marked with A1-A6, respectively), in a laboratory cylindrical ceramic ball mill (VEB, model 13x10.5).

The effects of mechanochemical activation on this system were investigated by monitoring the specific surface area and mass changes during time.

The specific surface area was determined by BET method. The nitrogen adsorption isotherm was determined by a standard volumetric apparatus at a temperature of -196 °C. The samples were degasified at 110 °C for 3 hours. Specific surface area was calculated according to the Brunauer, Emmett, Teller method from the nitrogen adsorption isotherm, using values of 0.05 < p / p₀ < 0.3.

Mass was determined by non-isothermal thermogravimetry (TG) using a NETZSCH DTA instrument with defined operating conditions: temperature range from 20 to 1500 °C, at a heating rate of 10 °C/min.

3 Results and discussion

Specific surface area values of the cordierite mixture during mechanochemical activation, obtained by the BET method, are presented in Figure 1.

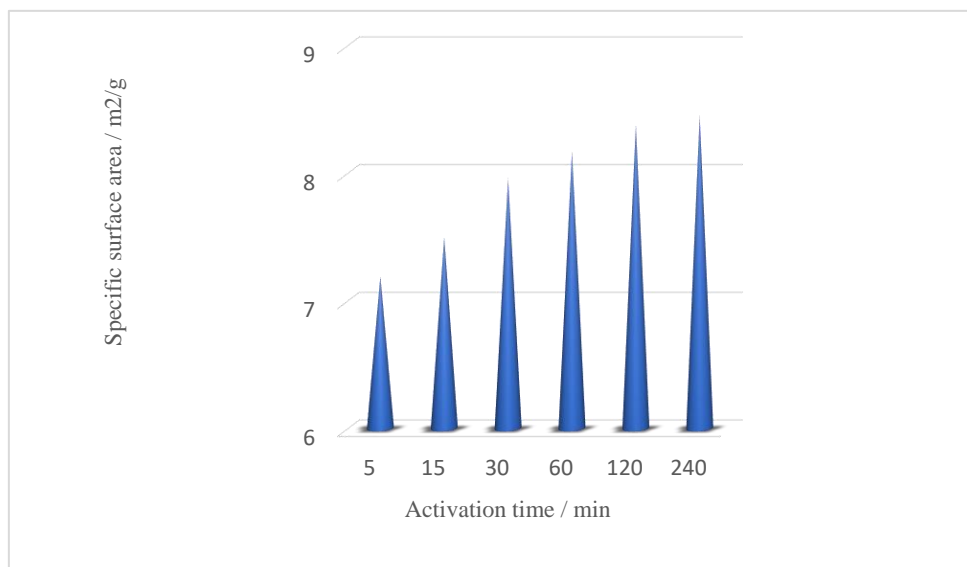


Figure 1. Specific surface changes of the cordierite mixture as a function of the time of mechanochemical activation

The results given in Figure 1 showed that the specific surface of the cordierite powder mixture ($2\text{MgO}+2\text{Al}_2\text{O}_3+\text{SiO}_2$) changed as a function of activation time in a way that longer activation time caused higher specific surface area values. The sample activated for 5 min had a specific surface area value of $7.19 \text{ m}^2/\text{g}$, while the sample activated for 240 min had a specific surface area of $8.45 \text{ m}^2/\text{g}$. This dependence is not linear but S-shaped, with a plateau from 0 to 50 minutes and another one from 120 to 240 minutes.

It can be concluded that the size of the particles decreased and therefore the specific surface of the activated powders increased with time of mechanochemical activation. These changes are especially pronounced during the first 120 minutes. Further activation resulted in only a small increase in the specific surface area.

The obtained experimental results of the changes in the specific surface area of the activated cordierite mixture can be expressed by the following kinetics equation (Eq. 1):

$$(S_\infty - S)/(S_\infty - S_0) = \exp(-kt) \quad (1)$$

where S , S_0 and S_∞ are the specific surface areas of the powder: after time t , the starting specific surface area (before mechanochemical activation), and the final specific surface area (at the end of mechanochemical activation), respectively, and k is the rate constant of the activation process, $k = 3.1 \cdot 10^{-2} \text{ s}^{-1}$.

The chosen samples, A1, A3, A5, and A6, activated for 5, 30, 120, and 240 minutes, respectively, were allowed to relax for 24 months.

Chemical analysis of mechanochemically activated samples showed the presence of magnesium hydroxyl carbonate after 24-month relaxation. This can be explained by the reaction of hygroscopic MgO from the activated cordierite mixture with humid air. In this case, the relaxation time should be minimal and the initial cordierite mixture should be activated just before the sintering process. It can be concluded that the relaxation time of the mechanochemically activated mixture should be minimal, that is the sintering process have to be performed immediately after activation.

Non-isothermal TG analysis showed that all these samples had a rapid loss of mass at a temperature of about $400 \text{ }^\circ\text{C}$ and that the mass loss increased with increasing the activation time, Figure 2.

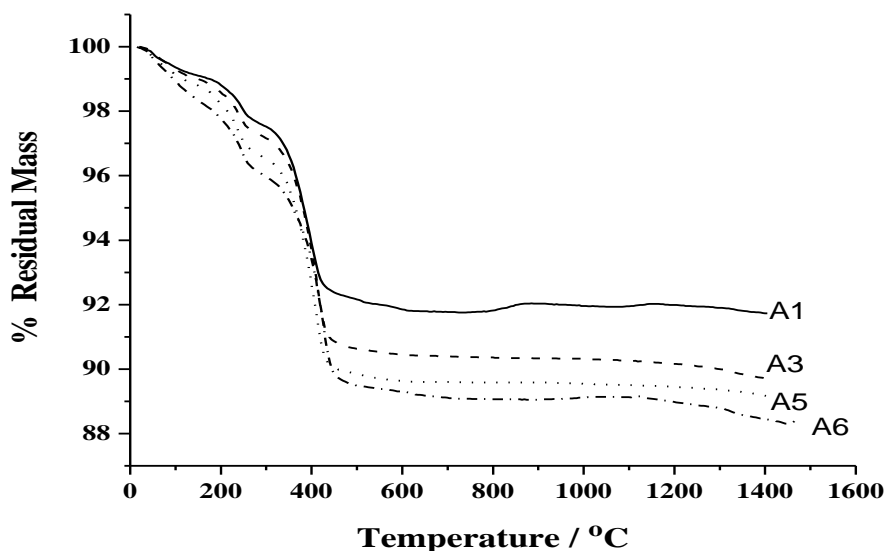


Figure 2. Non-isothermal TG curves of the cordierite mixture mechanochemically activated for different periods of time

Three mass loss steps are visible on the TG curves.

The first mass loss step occurred at temperatures up to $100 \text{ }^\circ\text{C}$, which indicates loss of humidity, amounting to a mass loss of $\sim 1 \%$ for all samples.

The second mass loss step occurred in the temperature range from 230 °C to 300 °C. Preliminary research showed that this mass loss corresponded to the dehydration of $\text{MgCO}_3 \cdot \text{Mg}(\text{OH})_2 \cdot 3\text{H}_2\text{O}$. The mass loss was in the range from 1 % to 3 %, depending on the activation time.

The third mass loss step is very rapid and represents the greatest mass changes in the system. It occurred in the temperature range from 390 °C to 420 °C, which corresponds to the temperature range of the decomposition of magnesium hydroxyl carbonate. The mass loss in this step was 4 % for the sample activated for 5 minutes and 6 % for the sample activated for 240 minutes.

The overall mass loss of the examined samples at a temperature of 400 °C as a function of the activation time is presented in Figure 3.

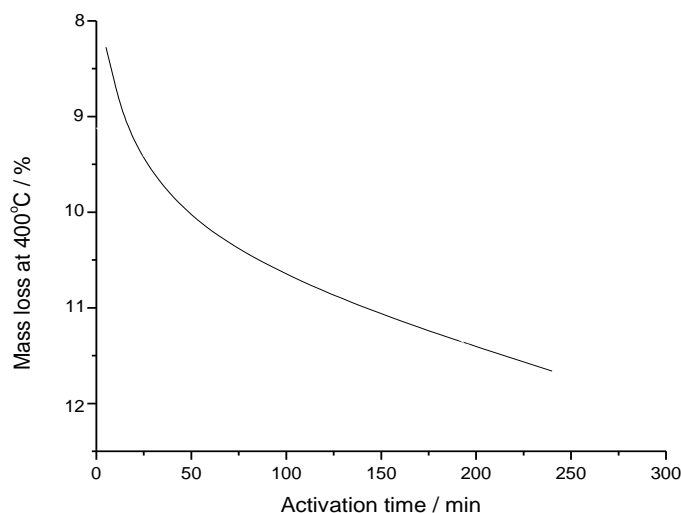


Figure 3. Total mass loss at 400 °C as a function of activation time

As seen in Figure 3, TG analyses of the cordierite mixture activated from 5 to 240 minutes exhibited a total mass loss from 8 to 12 % at 400 °C in a way that mass loss is increasing for longer activation times.

4 Conclusions

The results of an investigation of the mechanochemical activation effects on a powder mixture initially consisting of $\text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2$ in the ratio 2:2:5 have been presented. According to the obtained BET method results, with increasing duration of mechanochemical activation, the value of the specific surface area of the samples increased from 7.19 m^2/g for the sample activated 5 minutes to 8.45 m^2/g for the sample activated for 240 minutes. The mass loss, determined by TG method, after relaxation period of 24 months, occurred in three stages: at temperatures up to 100 °C, due to humidity loss; at temperatures about 240 °C, as a result of dehydration; and at temperatures around 400 °C owing to decomposition of the formed hydroxymagnesite. The total mass loss at a temperature of 400 °C increased from 8 to 12 % with increasing the activation time. Based on the obtained results, using mechanochemically activated cordierite mixture, lowering the sintering temperature of cordierite can be expected. Recommendation is to sinter the mixture as soon as possible after the activation to avoid moisture absorption by MgO.

Acknowledgments

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UTICAJ VREMENA RELAKSACIJE AKTIVIRANE SMEŠE NA SINTEZU KERAMIKE ZA NAMENU U ELEKTRONICI

IMPACT OF RELAXATION TIME OF ACTIVATED MIXTURE ON CERAMICS SYNTHESIS FOR ELECTRONICS PURPOSES

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Zahvaljujući svojim svojstvima, kordierit, $2\text{MgO}\cdot 2\text{Al}_2\text{O}_3\cdot 5\text{SiO}_2$, danas je atraktivan keramički materijal za razne primene, ali sa vrlo visokom temperaturom sinterovanja. Mehanohemijaska aktivacija smeše početnih komponenti izvedena je da bi se snizila temperatura sinterovanja. DTA metoda je korišćena za praćenje temperaturnih promena u analiziranom trokomponentnom sistemu. Kako je ranijim istraživanjima utvrđeno da vreme relaksacije može da utiče na aktivirane komponente u smislu hemijskih promena i stepena aktiviranosti, bilo je značajno utvrditi ima li uticaj i na posmatrani aktivirani system. Uticaj vremena relaksacije na smešu aktiviranih komponentata analiziran je FT IR spektroskopijom i početnih komponenti i aktivirane smeše nakon 24h i 24 meseca perioda relaksacije.

Ključne reči: kordierit; sinterovanje; mekanohemijaska aktivacija; DTA; FT IR

Due to its properties, cordierite, $2\text{MgO}\cdot 2\text{Al}_2\text{O}_3\cdot 5\text{SiO}_2$, is nowadays an attractive ceramic material for various applications but with very high sintering temperature. Mechanochemical activation of the initial components mixture was performed in order to decrease the sintering temperature. DTA method was used to monitor the temperature induced changes in the analyzed three-component system. Since previous research has pointed out that the relaxation time can influence the activated components in terms of chemical changes and the activation degree, it was important to determine whether it has an impact on the observed activated system. The influence of the relaxation time on the activated components mixture was analyzed by FT IR spectroscopy of both the initial components and the activated mixture after 24h and 24 months relaxation periods.

Key words: cordierite; sintering; mechanochemical activation; DTA; FT IR

1 Introduction

Cordierite, one of the most important phases of the $\text{MgO}\text{-SiO}_2\text{-Al}_2\text{O}_3$ system, has a low thermal expansion coefficient, excellent thermal shock resistance, low dielectric constant, high volume resistivity, high chemical durability, and relatively high refractoriness and mechanical strength. This ceramic material is widely used in electronics, for honeycomb-shaped catalyst carriers in automobile exhaust systems, substrate material in integrated circuit boards, and also as a refractory material, owing to its stability at high temperatures [1–3].

Cordierite ceramics can be prepared by conventional sintering methods, but it is difficult to sinter cordierite because of the narrow and sintering range (1300–1400 °C) just below its incongruent melting point [4–6]. The preparation of a homogeneous and fine cordierite powder that can be produced without sintering aids is considered to be highly desirable, due to the limiting factors of additives [7–15]. The thermodynamic principles of the kinetics of the syntheses of cordierite ceramics are given in the literature [5].

Mechanochemically activated samples have more accumulated energy compared to the inactivated initial components. Bearing this in mind, it was important to analyze the possible chemical changes of the activated system after certain periods of time (relaxation period) as they can have an

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influence on the kinetics of the sintering process. The accumulated energy can induce surface and bulk chemisorption of components in the atmosphere. If no changes of an activated sample occurred during the relaxation time, then a mechanochemically activated sample can be sintered after an unlimited period of time.

The aim of this research is to decrease the sintering temperature of cordierite by mechanochemical activation of the initial mixture (caoline (Al_2O_3), quartz (SiO_2), and alkali magnesium carbonate). The free surface of the initial powders increases during the mechanochemical activation and changes in the structure of the material are induced by mechanical energy. The influence of the relaxation time of this mechanochemically activated mixture on the sintering of cordierite ceramics was investigated.

2 Experimental

In this research the next initial raw materials of technical quality were used: MgO (98.60%), Al_2O_3 (99.19%) and SiO_2 (96.10%). The mixture composed of powdered MgO , Al_2O_3 and SiO_2 in the ratio 2:2:5 was mechanochemically activated for 5, 15, 30, 60, 120 and 240 minutes (samples marked with A1-A6, respectively), in a laboratory cylindrical ceramic ball mill (VEB, model 13x10.5). Non-isothermal thermogravimetry (TG) and differential thermal analysis (DTA) were used to monitor the influence of mechanical activation on the samples. For this purpose, a METZSCH DTA instrument was employed in the temperature range 20 to 1500°C, at a heating rate of 10°C/min.

The effect of relaxation, i.e. aging, of the activated cordierite mixture on the sintering processes was monitored by analyzing the mixture activated for 120 min using FT IR spectroscopy. FFT infrared spectra of the samples were recorded on an FFT IR spectrometer BOMEM-HARTMAN & BRAUN MICHELSON MB-100, in the range of wave numbers 4000-300 cm^{-1} at a resolution of 2 cm^{-1} . Since the samples are very sensitive to the presence of moisture, the method of making a suspension with "NuJol" was used to prepare the samples. The purpose of this analysis was to identify possible chemical changes on the activated surface of the components in the mixture as well as structural changes. A non-activated sample (zero sample) was also analyzed by the same chosen methodology [8] and the obtained results were compared.

3 Results and discussion

DTA method was used to investigate the changes in the activated cordierite system during the sintering process at temperatures up to 1600 °C. The samples activated for 5, 60 and 120 minutes were chosen for this examination.

The obtained DTA curves are presented in Figure 4.

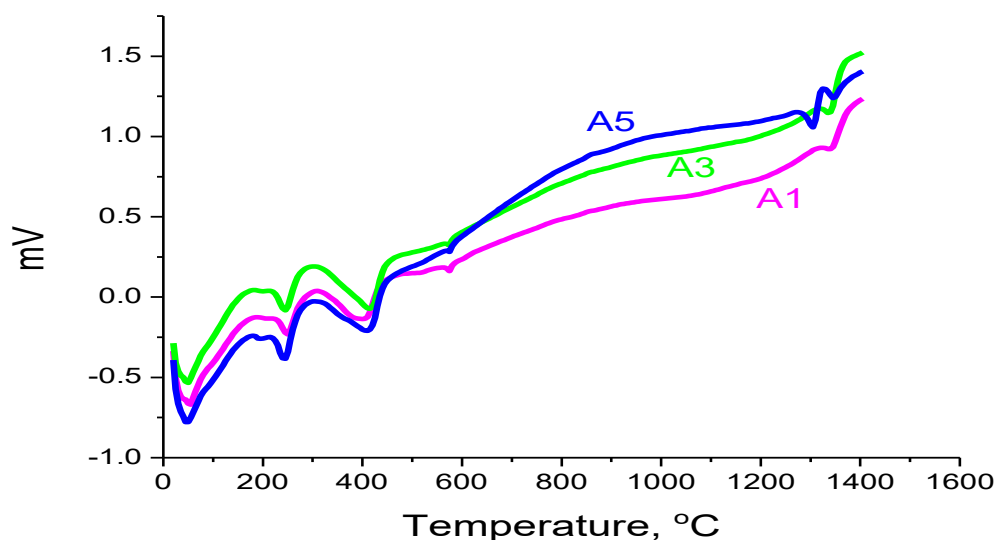


Figure 4. DTA curves of the cordierite mixture activated for 5, 60 and 120 minutes.

As seen in Figure 4, all investigated samples exhibit significant changes up to the temperature of 400 °C, while all the samples behaved quite similarly up to the temperature of 600 °C. Three characteristic peaks are visible: The first peak is up to 100 °C, resulting from loss of humidity. The second in temperature range from 230 to 300 °C which corresponds to the dehydration of $\text{MgCO}_3 \cdot \text{Mg}(\text{OH})_2 \cdot 3\text{H}_2\text{O}$, and the third peak in the range from 390 to 420 °C and it can be attributed to the decomposition of magnesium hydroxyl carbonate.

Indications of the commencement of cordierite formation were detected in the temperature range of 1200-1400 °C for the initial mixture. The corresponding endothermic and exothermic effects were shifted to lower temperatures with increasing duration of mechanical activation.

Derivative of the DTA curve of the sample activated for 5 minutes after a relaxation time of 24 months is presented in Figure 5.

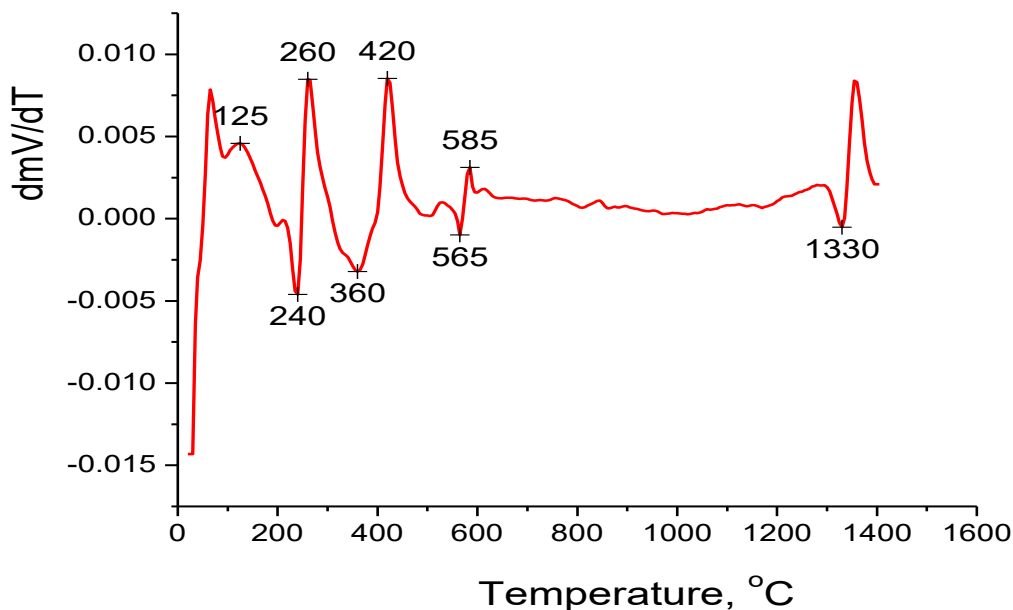


Figure 5. Derivative of the DTA curve for the sample activated for 5 minutes.

By analyzing the curve in Figure 5 it can be noticed that very rapid changes are taking place below the temperature of 600 °C. This indicates transformation reactions in the system at these temperatures. The clearly visible endothermic change at 1315 °C indicates the transformation temperature in the sintering process.

The temperature change of the endothermic effect in the cordierite sintering process from the initial cordierite mixture as a function of the mechanochemical activation duration is presented Figure 6.

As seen in Figure 6, the curve is S-shaped with two plateaus, which are separated by a region of significant changes in the system. The transformation model indicates that the temperature of cordierite sintering decreases with increasing activation time.

The first plateau lasts to 50 minutes of activation, indicating that the changes in the system in this time period were not pronounced enough to have any influence on the sintering process. From 50 to 160 minutes of activation, the changes in the reaction system cause decreasing the sintering temperature. In this range of activation times, it can be seen that the mechanochemical activation had an influence on the kinetics of cordierite sintering, i.e., the activity of the sample increased with increasing activation time. The mechanical energy was used not only for particle attrition but also for increasing the active surface of the particles. This accumulated energy has an influence on the affinity of the components to interact with each other at lower temperatures than in the non-activated systems.

After this period of change, a second plateau appeared when the reactivity of the system ceased to change. Further energy input due to mechanochemical activation results in no significant increase in the reactivity of the system and, hence, there was no further decrease in the cordierite sintering temperature. Thus, prolonging the milling would have no effect.

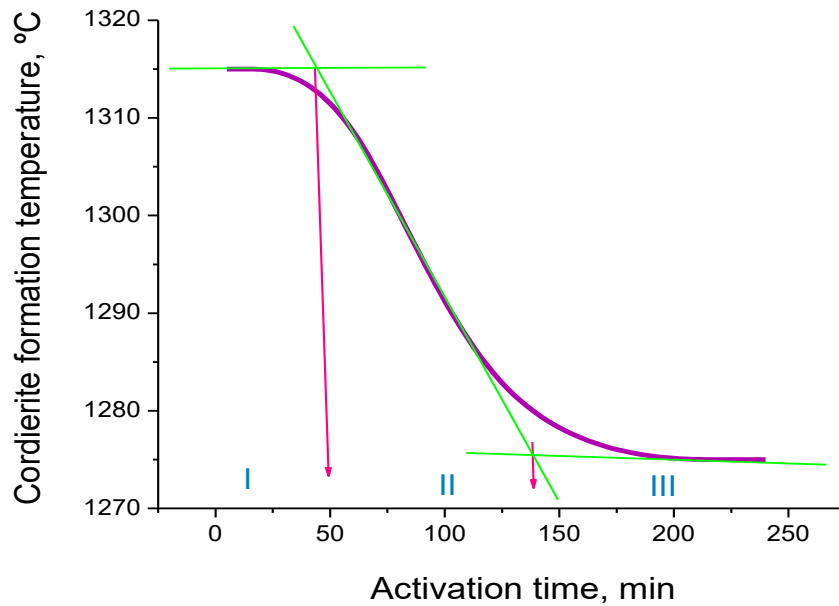


Figure 6. Temperature changes of the endothermic effect in the process of cordierite sintering as a function of the activation time

The temperature decrease of the endothermic and exothermic effects can be described by kinetic equations (Eq. 1):

$$(T_k - T_\infty) / (T_o - T_k) = \exp(-mt) \quad (1)$$

where T_k is the characteristic endothermic or exothermic temperature effect, m is the coefficient of the process, $m = 1.5 \cdot 10^{-2} \text{s}^{-1}$. The endothermic effect favors the transformation of β -quartz to α -quartz, while the exothermic effect results from solid-state reactions between MgO and SiO₂, resulting in the formation of forsterite.

FT IR spectroscopy was used to analyze eventual chemical changes of the activated cordierite mixture during the relaxation time (ambient conditions for up to 24 months). The IR spectra of a sample activated for 120 minutes after relaxation for 24 hours and after 24 months are shown in Figure 7.

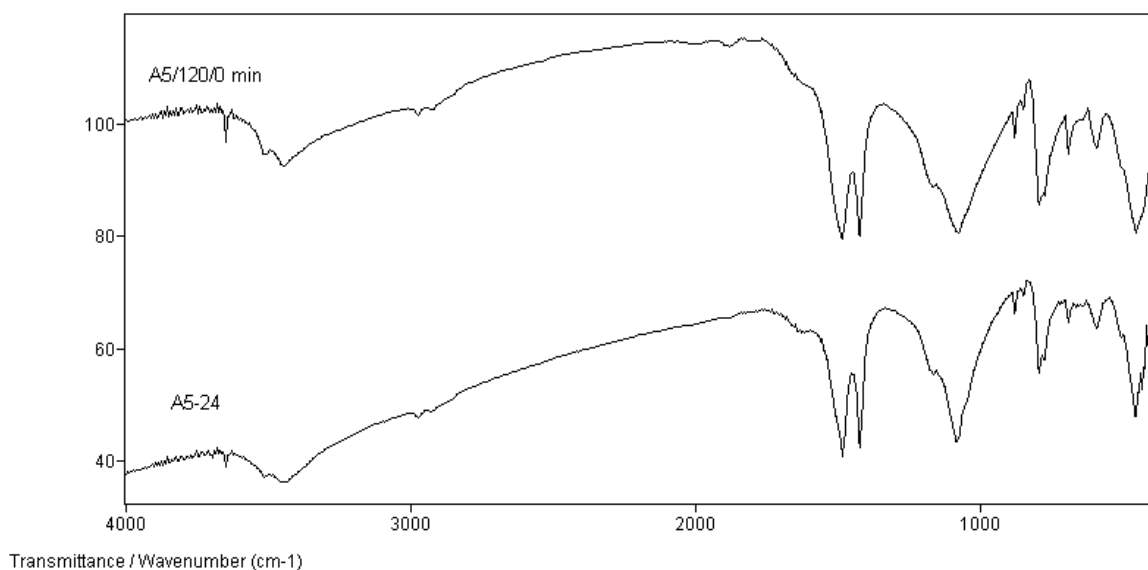


Figure 7. FT IR spectra of sample A5 after relaxation for 24 hours and 24 months.

From the spectra shown in Figure 7, it can be seen that hydroxyl- and carbonate- magnesium compounds were present as impurities in the mixture. The characteristic peaks of bound crystal water

are sharp at the wavenumbers 3445 cm^{-1} , 3512 cm^{-1} and 3649 cm^{-1} . The carbonates are visible at wavenumbers 1425 cm^{-1} and 1485 cm^{-1} , which indicates that the compounds are only impurities due to bound water and carbon dioxide, originating from the atmosphere. Since the initial components are well defined, it is supposed that this analysis proves surface adsorption of humidity and CO_2 from the atmosphere, which resulted in the formation of unstable compounds of hydromagnesite. The IR spectrum of Al_2O_3 shows the existence of $-\text{OH}$ groups at 3443 cm^{-1} , the origin of which originated is air humidity. These results are to be expected since in all experiments technical quality components were used. A relaxation period of 24 months had no influence on the sample since no noticeable changes were visible in the IR spectrum of this sample.

4 Conclusions

DTA proved that the influence of mechanochemical activation of the initial components was caused by an increase in energy of the initial cordierite mixture, which resulted in the endothermic and exothermic sintering reactions being shifted to lower temperatures. The decrease in these temperatures was about 100°C , depending on the activation time.

FT IR analyses showed that relaxation time had no influence on the activated mixtures. It can be concluded that the mechanochemically-activated samples did not change at all up to the moment of sintering, regardless of the activation time. The presented spectra explain the mass losses at the temperatures of 240 and 400°C , i.e., less-stable compounds (hydroxide and carbonate bonded to hydroxymagnesite) were generated during mechanochemical activation.

Acknowledgments

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