

 **Processing '22**

ZBORNİK RADOVA

**35. Međunarodni kongres
o procesnoj industriji**

Holiday Inn, Beograd

1–3. jun 2022.



SET
SAMIT ENERGETIKE TREBINJE

ZBORNİK RADOVA

pisanih za 35. Međunarodni kongres o procesnoj industriji
PROCESING '22



2022

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Izdavač
Savez mašinskih i elektrotehničkih
inženjera i tehničara Srbije (SMEITS)
Društvo za procesnu tehniku
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PREDGOVOR

Od preko 50 radova prijavljenih za ovogodišnji Procesing, za izlaganje je prihvaćeno 47 radova autora iz zemlje i inostranstva.

Zbornik celih radova će u režimu slobodnog pristupa biti objavljen na sajtu www.izdanja.smeits.rs. Kao integralni dokument biće dostupan na sajtu www.smeits.rs

Međunarodni karakter Procesinga '22 i ove godine ostvaren je inostranim učesnicima sa radovima, kao i članovima naučnog odbora. Zvanični jezici za izlaganje radova na kongresu su srpski i engleski.

Osnovni ciljevi kongresa su inoviranje i proširivanje znanja inženjera u procesnoj industriji, energetici, rudarstvu, komunalnom sektoru (vodovodima, toplanama) i podrška istraživačima u predstavljanju ostvarenih rezultata istraživačkih projekata.

Tematika Procesinga '22 obuhvata osnovne procesne operacije – mehaničke, hidromehaničke, toplotne, difuzione, hemijske i biohemijske, kao i procesna postrojenja i opremu (aparate i mašine).

Program Procesinga '22 obuhvata oblasti: procesne tehnologije; projektovanje, izgradnja, eksploatacija i održavanje procesnih postrojenja; inženjerstvo životne sredine i održivi razvoj u procesnoj industriji; energetska efikasnost u procesnoj industriji; procesi i postrojenja u pripremi i prečišćavanju vode u procesnoj industriji; modelovanje i optimizacija procesnih i termoenergetskih postrojenja; merenja i upravljanje u procesnoj industriji; menadžment kvaliteta i standardizacija u organizacijama.

Osim izlaganja radova, program Procesinga '22 obuhvata i dva okrugla stola na sledeće teme:

- Nova domaća zakonska regulativa u oblasti opreme pod pritiskom.*
- Savremeni postupci termičkog tretmana otpada. Iskustva u primeni biomase kao goriva.*

Procesing '22 organizuje Društvo za procesnu tehniku pri SMEITS-u, a u Naučnom i Organizacionom odboru prisutni su predstavnici svih Mašinskih fakulteta u Srbiji kao i Tehnoloških i drugih fakulteta u okviru kojih je oblast procesne tehnike zastupljena u nastavi.

Pomoć u organizovanju Procesinga '22 dali su članovi Katedre za procesnu tehniku Mašinskog fakulteta Univerziteta u Beogradu i mnogih drugih fakulteta iz Srbije.

Ovogodišnji skup završava se posetom novom Centru za upravljanje otpadom u Vinči.

*U Beogradu
juni 2022.*

SADRŽAJ

Procesne tehnologije

1. ISPITIVANJE MEŠLJIVOSTI SA VODOM
METANOLA KAO PETROHEMIKALIJE
Matilda LAZIĆ, Dragan HALAS, Duško SALEMOVIĆ, Aleksandar DEDIĆ 13
2. KONTROLISANO OTPUŠTANJE KOFEINA IZ TRODIMENZIONIH MREŽA
NA BAZI POLI(METAKRILNE KISELINE) I KAZEINA – ISPITIVANJE UTICAJA
KONCENTRACIJE KOFEINA NA PROCES OTPUŠTANJA
Maja D. MARKOVIĆ, Rada V. PJANOVIĆ,
Pavle M. SPASOJEVIĆ, Sanja I. SAVIĆ, Vesna V. PANIĆ 19
3. ISPITIVANJE ANTIMIKROBNIH SVOJSTAVA
NEKIH BIĐINELI-AZO PIRIDONSKIH BOJA
Julijana TADIĆ, Ivana GAZIKALOVIĆ, Jelena LAĐAREVIĆ,
Aleksandra MAŠULOVIĆ, Milica SVETOZAREVIĆ,
Slavica POROBIĆ, Dušan MIJIN 25
4. PROUČAVANJE A-CIJANOSTILBENA KAO
POTENCIJALNIH MOLEKULSKIH PREKIDAČA METODOM
LINEARNE KORELACIJE ENERGIJE SOLVATACIJE
Anita LAZIĆ, Nemanja TRIŠOVIĆ, Nataša VALENTIĆ 29
5. ISPITIVANJE ANTIOKSIDATIVNE AKTIVNOSTI AZO BOJA
NA BAZI 6-HIDROKSI-4-METIL-2-PIRIDONA
Aleksandra MAŠULOVIĆ, Jelena LAĐAREVIĆ, Julijana TADIĆ,
Vanja VERUŠEVSKI, Luka MATOVIĆ,
Milica SVETOZAREVIĆ, Dušan MIJIN 37
6. KOMPOZITNI MATERIJALI NA BAZI NEZASIĆENIH POLIESTARSKIH SMOLA
DOBIJENIH IZ BIOOBNOVLJIVIH IZVORA I OTPADNE KAFE
Olga PANTIĆ, Vesna PANIĆ, Sanja SAVIĆ, Maja MARKOVIĆ,
Melina KALAGASIDIS KRUŠIĆ, Pavle SPASOJEVIĆ 41
7. TERMIČKA OBRADA PREHRAMBENIH PROIZVODA POMOĆU
UHT (ULTRA HIGH TEMPERATURE) TEHNOLOGIJE U FABRICI POLIMARK
Lazar MANDIĆ 49
8. UTICAJ ČUVANJA U KONTROLISANOJ ATMOSFERI
NA KVALITET PLODOVA JABUKE
Snežana M. STEVANOVIĆ, Dragan MARKOVIĆ,
Uroš MILOVANČEVIĆ, Milena OTOVIĆ 55

Projektovanje, izgradnja, eksploatacija i održavanje procesnih postrojenja

9. DODATNA ZAŠTITA OD KOROZIJE KULA ZA HLAĐENJE VODE
Nemanja STOJANOVIĆ, Mirko DIMITRIJEVIĆ, Martin BOGNER 61
10. ANALIZA I PRORAČUN GMRS I PRIMARNE GASNE DISTRIBUTIVNE MREŽE
U URBANOJ SREDINI – STUDIJA SLUČAJA KUČEVO
Aleksandar MADŽAREVIĆ, Pavle JANKOVIĆ 67
11. OSNOVNI ASPEKTI ODRŽAVANJA, EKSPLOATACIJE
I PROJEKTOVANJA NAFTOVODA
Jasna TOLMAČ, Slavica PRVULOVIĆ,
Saša JOVANOVIĆ, Milan MARKOVIĆ 89

12.	ANALIZA KORELACIJA ZA PRORAČUN KOEFICIJENTA TRENJA ZA FORMIRANJE NUMERIČKOG MODELA ZA PRORAČUN PADA PRITISKA ZA SLUČAJ PNEUMATSKOG TRANSPORTA LETEĆEG PEPELA LIGNITA U TERMOENERGETSKIM POSTROJENJIMA Nikola KARLIČIĆ, Marko OBRADOVIĆ, Dušan TODOROVIĆ, Milan M. PETROVIĆ, Dejan RADIĆ, Aleksandar JOVOVIĆ	99
13.	UTICAJ SADRŽAJA VLAGE U DRVNOJ SEČKI NA GUBITKE SA DIMNIM GASOVIMA I EFIKASNOST KOTLA Marko OBRADOVIĆ, Nikola KARLIČIĆ, Dušan TODOROVIĆ, Dejan RADIĆ, Aleksandar JOVOVIĆ	101
14.	FAKTOR SAGOREVANJA I NJEGOVA PRIMENA U PROCENI OTPORNOSTI NA POŽAR Ivan ARANĐELOVIĆ, Branislav GAJIĆ, Filip JEKIĆ	103
15.	OTPORNOST PREMA POŽARU NOSEĆE KONSTRUKCIJE OBJEKTA KOTLARNICA NA ČVRSTO GORIVO Marko SAVANOVIĆ, Ivan ARANĐELOVIĆ, Nikola TANASIĆ, Radenko RAJIĆ	107
16.	GLAVNO PROVETRAVANJE JAMA PODZEMNIH RUDNIKA UGLJA U SRBIJI Dejan DRAMLIĆ, Vladica RISTIĆ, Dragan ZLATANOVIĆ, Duško ĐUKANOVIĆ	113
17.	ZNAČAJNO POVEĆANJE INDEKSA TROŠKOVA PROCESNIH POSTROJENJA I OPREME TOKOM 2021. Srbislav GENIĆ, Branislav JAČIMOVIĆ, Vladislav STANKOVIĆ, Branislav GAJIĆ	115
18.	POVEĆAN HIDRAULIČKI OTPOR U CEVIMA JEDNOPROTOČNOG PARNOG KOTLA USLED ZAPRLJANJA: STUDIJA SLUČAJA NA PARNOM BLOKU SNAGE 650 MWE NA LIGNIT Vladimir D. STEVANOVIĆ, Sanja MILIVOJEVIĆ, Milan M. PETROVIĆ, Milica ILIĆ	117
19.	INVESTIGATION OF THERMAL AND DIMENSIONAL BEHAVIOR OF 3D PRINTED MATERIALS USING THERMAL IMAGING AND 3D SCANNING Zorana GOLUBOVIĆ, Milan TRAVICA, Isaak TRAJKOVIĆ, Aleksandar PETROVIĆ, Nenad MITROVIĆ	131

Inženjerstvo životne sredine i održivi razvoj u procesnoj industriji

20.	MAGNEZIJUM I HIPERTENZIJA U PROCESNOJ INDUSTRIJI Nikolina BANJANIN	133
21.	UPOTREBA MIKROREAKTORSKIH SISTEMA U PROCESIMA PREČIŠĆAVANJA OTPADNE VODE Ana DAJIĆ, Marina MIHAJLOVIĆ, Milica SVETOZAREVIĆ	137
22.	IMOBILIZACIJA PEROKSIDAZE IZ KROMPIROVIH LJUSKI U OBLIKU UMREŽENIH ENZIMSKIH AGREGATA ZA „ZELENU“ RAZGRADNJU ANTRAHINONSKE BOJE Milica SVETOZAREVIĆ, Nataša ŠEKULJICA, Ana DAJIĆ, Marina MIHAJLOVIĆ, Zorica KNEŽEVIĆ-JUGOVIĆ, Dušan MIJIN	141
23.	BIOSORPCIJA NIKLA IZ OTPADNIH VODA KORIŠĆENJEM EGZOPLOISAHARIDA IZOLOVANOG IZ BAKTERIJSKOG SOJA KLEBSIELLA OXYTOCA J7 Verica LJUBIĆ, Jovana PERENDIJA, Slobodan CVETKOVIĆ, Mina POPOVIĆ	147

24. PRIPREMA KOMPANIJE ELIXIR GROUP ZA UVOĐENJE PREKOGRANIČNOG MEHANIZMA ZA PRILAGOĐAVANJE UGLJENIKA NA GRANICAMA (CBAM)
Alija SALKUNIĆ, Nikola BELOBABA, Bajro SALKUNIĆ,
Ljiljana STANOJEVIĆ, Slavica BOGDANOVIĆ 155

Energetska efikasnost u procesnoj industriji

25. UTICAJ RADNIH FLUIDA ZA ORC NA EFIKASNOST
KOMBINOVANOG SISTEMA INTEGRISANOG SA GORIVOM ČELIJOM,
GASNOM TURBINOM, ORGANSKIM RANKINOVIM CIKLUSOM
I PARNOM TURBINOM
Nurdin ČEHAJIĆ, Jasmin FEJZIĆ 165
26. MOGUĆNOSTI UŠTEDE VODE I ISKORIŠTENJA
OTPADNE TOPLOTE IZ PROCESA ODMULJIVANJA
I ODSOLJAVANJA INDUSTRIJSKIH PARNIH KOTLOVA
Jasmin FEJZIĆ, Indira BULJUBAŠIĆ, Nurdin ČEHAJIĆ 183
27. POTENCIJAL KOGENERATIVNIH POSTROJENJA
NA BIOMASU U POSTIZANJU KLIMATSKE NEUTRALNOSTI
BIH DO 2050.GODINE
Azrudin HUSIKA, Nurin ZEČEVIĆ, Ejub DŽAFEROVIĆ 195
28. METODOLOGIJA AEROAKUSTIČNE ANALIZE
TROKRAKE H-DARIJUS VETROTURBINE
Boško RAŠUO, Marta TRNINIĆ, Mirko DINULOVIĆ 205
29. EKSPERIMENTALNA I CFD ANALIZA TURBULATORA
U OBLIKU OPRUGE KOD KOTLOVA NA BIOMASU
Đorđe A. NOVČIĆ, Miloš V. NIKOLIĆ, Dušan M. TODOROVIĆ,
Rade M. KARAMARKOVIĆ, Marko O. Obradović 215
30. PRODAJA ELEKTRIČNE ENERGIJE IZ KOGENERACIONIH POSTROJENJA, NA
ORGANIZOVANIM TRŽIŠTIMA
U JUGOISTOČNOJ EVROPI
Zorana BOŽIĆ, Dušan DOBROMIROV 217

Procesi i postrojenja u pripremi i prečišćavanju vode u procesnoj industriji

31. DEFINSANJE POTROŠNJE VAZDUHA U PROCESU BIOLOŠKE OBRADE
SANITARNIH OTPADNIH VODA U SEKVENCIJALNOM ŠARŽNOM
REAKTORU (SBR) NA PRIMERU POSTROJENJA KAPACITETA 1000 ES
Ognjen ĐORĐEVIĆ, Nikola KARLIČIĆ, Miroslav STANOJEVIĆ 219
32. PRIMENA KOMPOZITNOG GRAĐEVINSKOG OTPADA
U PREČIŠĆAVANJU INDUSTRIJSKIH OTPADNIH VODA
Ivana JELIĆ, Dragi ANTONIJEVIĆ,
Marija ŠLJIVIĆ-IVANOVIĆ, Slavko DIMOVIĆ 225
33. KVALITET OTPADNIH VODA MLEKARA
NA TERITORIJI CENTRALNE SRBIJE
Radmila LIŠANIN, Čedo LALOVIĆ 227

Modelovanje i optimizacija procesnih i termoenergetskih postrojenja

34. MODELIRANJE SAGOREVANJA PREDMEŠANOG CH₄/VAZDUH PLAMENA
PRI RAZLIČITIM TURBULENTNIM REŽIMIMA STRUJANJA
Andrijana STOJANOVIĆ, Srđan BELOŠEVIĆ, Nenad CRNOMARKOVIĆ,
Ivan TOMANOVIĆ, Aleksandar MILIĆEVIĆ 237

35. PIROLIZA STABLJIKE KUKURUZA U ŠARŽNOM REAKTORU:
UTICAJ PARAMETARA PROCESA NA PRODUKTE
Biljana MILJKOVIĆ 239

Merenja i upravljanje u procesnoj industriji

36. ZAKONSKA REGULATIVA I STANDARDIZACIJA
U OBLASTI MERENJA PRIRODNOG GASA
Mileva CVETKOVIĆ 255
37. ISPITIVANJE OTPORNOSTI PREMA POŽARU
POŽARNO OTPORNIH KLAPNI
Aleksandar KIJANOVIĆ,
Milica MIRKOVIĆ MARJANOVIĆ, Snežana ILIĆ 257

Menadžment kvaliteta i standardizacija u organizacijama

38. MODEL OPTIMANOG UPRAVLJANJA INTEGRISANIM KVALITETOM
U PROCESNOJ INDUSTRIJI
Mitar BIJELIĆ, Biljana MILANOVIĆ, Zdravko BIJELIĆ 259
39. ODNOS MENADŽMENTA KVALITETA I BLOKČEJN TEHNOLOGIJE
U LANCIMA SNABDEVANJA
Andrej POPADIĆ, Mladen ĐURIĆ, Luka POPADIĆ 261
40. ANALIZA STANDARDA ISO 30405 ZA REGRUTACIJU KADROVA
I NJEGOV ZNAČAJ U POSLOVANJU ORGANIZACIJA
Milica STOJILJKOVIĆ, Mladen ĐURIĆ, Jelena RUSO 285
41. PRELED STANDARDA ZA KOMPANIJE IZ
PREHRAMBENE INDUSTRIJE I NJIHOV LANAC SNABDEVANJA
Milena TOKIĆ, Mladen ĐURIĆ 295
42. PRELED STANDARDA ZA MENADŽMENT LJUDSKIH RESURSA,
UZ ANALIZU METRIKE KOJA SE KORISTI U NJIMA
Valentina MARKOVIĆ, Mladen ĐURIĆ 309

Oglasni deo

KOMPOZITNI MATERIJALI NA BAZI NEZASIĆENIH POLIESTARSKIH SMOLA DOBIJENIH IZ BIOOBNOVLJIVIH IZVORA I OTPADNE KAFE

BIOBASED COMPOSITE MATERIALS OBTAINED FROM UNSATURATED
POLYESTER RESINS AND WASTE COFFEE

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Upotreba bioobnovljivih monomera umesto stirena u proizvodnji nezasićenih poliestarskih (NZPE) smola, koje se u potpunosti dobijaju iz bioobnovljivih izvora predstavlja veliki izazov. Savremena istraživanja su ukazala da je stiren vrlo toksičan po ljudsko zdravlje i kategorizovan je kao potencijalno kancerogena supstanca. Upotrebom dimetil itakonata kao alternativnog rastvarača, koji se može dobiti iz obnovljivih izvora, obezbeđuje se niska viskoznost koja je neophodna za industrijsku primenu NZPE smola. U ovom radu je sintetisana NZPE smola na bazi ćilibarne kiseline, itakonske kiseline i propilen glikola, koja je zatim razblažena dimetil itakonom. S obzirom da NZPE smole imaju značajnu primenu u izradi kompozitnih materijala, u ovom radu su dalje ispitivana svojstva materijala pri različitim udelima otpadne kafe kao punioca (10, 20, 30 mas.%). Nakon sinteze određena je viskozimetrija, mehaničke karakteristike kompozitnih materijala, kao i sadržaj gel faze. Strukturna svojstva ispitana su primenom FTIR spektroskopije.

Ključne reči: materijali dobijeni iz bioobnovljivih izvora; otpadna kafa; itakonska kiselina; održivi razvoj

Replacing styrene with biobased monomers to produce fully biobased unsaturated polyester resins (UPRs) turned out to be quite a challenging task. Styrene has been recognized as a hazardous and a potentially carcinogenic substance for human health. Using dimethyl itaconate as an alternative reactive diluent to styrene, which can be obtained from renewable resources, enables low viscosity for easy manipulation of mentioned UPRs. Fully biobased UPRs in question were based on itaconic acid, succinic acid, and propylene glycol, which were then diluted with dimethyl itaconate. Having in mind that UPRs can be used as a matrix for composite materials, this paper examines the effect of different weight ratios of spent coffee grounds as a filler. To determine the application of thus obtained composite materials, characterization consisted of examining mechanical properties based on viscosity measurements, uniaxial stretching experiments, FTIR spectroscopy and gel content analysis.

Key words: biobased materials; waste coffee; itaconic acid; sustainable development

1 Introduction

At the level of policy generation, the principles embedded in the circular economy are now emphasized in process and product design. This has introduced several visionary concepts i.e., the bioeconomy, the biobased society and the green economy that are now redirecting the strategic planning of majority industrial sectors.

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Application of waste materials in polymer industry is quite challenging, however it can lead to lower energy consumption, reduced waste generation and it can change the overall effect that industrialization has on the environment. Therefore, the search for sustainable, cleaner technologies that utilize waste materials is very important.

Coffee is present in every culture around the world. The abundance in consumption with the constantly growing population results in large amounts of waste generated. Coffee beans' annual production in the 2019/2020 crop year exceeded 10 million metric tons [1]. Since coffee production doesn't have significant amounts of by-products, it is implied that waste from beverage consumption is almost equal to the initial mass obtained from coffee beans [2].

There are a lot of environmental issues arising from the inadequate disposal of this waste material [3]. Spent coffee grounds (SCG) is the final product after brewing. SCG contain large amounts of organic compounds (i.e. fatty acids, lignin, cellulose, hemicellulose, and other polysaccharides) that justify its valorization [4]. Because of many valuable compounds found in SCG, researchers have found various application options for this waste material. SCG is usually used as a natural amendment for farming purposes [5], but it is also used to produce biodiesel, biogas, bioethanol, and various extraction products for cosmetics and medical industry [6,7]. From the aspect of circular economy, SCG is a cheap raw material that can be used as a filler in composite materials [8].

Unsaturated polyester resins (UPRs) are a significant group of thermosetting polymers. Global production of UPRs is around 12 million metric tons a year, which makes them one of the mass-produced polymers. UPRs can have a wide range of properties due to the large number of materials that are used for their synthesis. They can be used as pure resins or reinforced with suitable fillers. Pure resins are used in production of decorative products, in polymer concrete, as a matrix in composite materials and as a binding agent for various types of coatings [9]. There is an extended supply of fillers that can be used as reinforcement. In this context, the use of natural fibers and particles, such as cotton, flax, or jute, for production of polymer based composite materials is especially appealing [10].

In general, UPRs consist of two main components: unsaturated polyesters (prepolymers) and reactive diluents (RD). In addition to the main components being obtained from petroleum, it has been found that the industrially used reactive diluent styrene poses a potential health risk and has a negative effect on the environment [11]. Constant oil price fluctuations caused by various socio-political events, the gradual depletion of fossil fuels and growing environmental issues have established new trends within the polymer industry. In the last decade, there are great efforts directed towards replacement of petroleum based raw materials with biobased raw materials and transitioning to cleaner technologies [12]. Under these circumstances it is important to find an adequate biobased alternative to styrene. *Cousinet et al.* investigated vinyl levulinate as a potential alternative to styrene, however, obtained UPR showed lower α relaxation temperature, elastic moduli at the rubbery plateau and mechanical properties determined by the three points bending tests [13]. Biobased butanediol dimethacrylate UPR has shown comparable properties to styrene cured UPR, but with poor ductility and resilience.

The use of itaconate based RDs turned out to be a good alternative. Itaconates are less toxic, and volatile compared to styrene without negative environmental effects. However, the mechanical properties of the UPRs with itaconate based RDs still need to be improved [14]. With this regard, to reduce the overall discrepancy in compared to commercial styrene based UPRs, the addition of different reinforcement fillers could be solution of choice.

In this paper a biobased UPR was synthesized as a matrix, with SCG as a biobased filler for a fully biobased composite material. UPR consisted of itaconic acid, succinic acid, propylene glycol with dimethyl itaconate as a RD, all derived from renewable resources. The obtained composite materials were characterized by uniaxial tensile testing, viscosity measurements, FTIR spectroscopy and gel content analysis.

2 Materials and methods

2.1 Materials

The itaconic acid, succinic acid, propylene glycol, hydroquinone and toluene were supplied from Acros Organics. The catalyst, FASCAT 4100 was procured from PMC Organometallics. The initiator, methyl ethyl ketone peroxide (MEKPO), activator, cobalt octoate, and reactive diluent, dimethyl itaconate (DMI) were all supplied by Sigma Aldrich. All chemicals were used as received.

2.2 Synthesis

UPRs are obtained by the polycondensation reaction between itaconic acid, succinic acid, and propylene glycol, by applying the mole ratio of 1:1:2.1, respectively. Toluene (0.5 wt.% based on monomers) was used to increase the rate of water removal. Hydroquinone (150 ppm) was added as a free radical scavenger and the components were mixed. The reaction was carried out in a three-neck round-bottom flask equipped with a stirrer, Dean-Stark and thermometer, and under nitrogen atmosphere. The temperature range was from 110 to 190°C and was raised by 10°C every hour. The reaction was carried out until the acid value reached 35. Obtained prepolymer was cooled to 90°C and diluted in dimethyl itaconate (30% w/w with respect to the prepolymer) which was used as a reactive diluent.

The prepared UPRs were mixed with MEKPO (2.5% w/w) and cobalt octoate (1% w/w), after which SCG was added in different weight ratios (10, 20, 30%). Previously, SCG was sifted through 200 µm sieves and dried in an air oven at 80°C for 5 hours. After homogenization, the mixtures were poured into Teflon molds, which were placed in an air oven for 24 hours at 60°C to cure. Additionally, all the samples were kept at 120°C for 2 hours to harden.

The acid value was defined as the number of milligrams of KOH needed to neutralize 1 g of resin and was measured according to ASTM D465-01. Around 0.5 g of resin was titrated with a KOH equimolar solution of toluene and isopropyl alcohol (0.3 mol/L).

2.3 FTIR spectroscopy

The Fourier Transform Infrared (FTIR) spectra of powdered samples were recorded in transmittance mode for the wavelength range of 600 – 4000 cm⁻¹ with a resolution of 4 cm⁻¹, using Nicolet™ iS10 FTIR Spectrometer.

2.4 Viscosity measurements

Viscosities were measured isothermally at 23°C using an Anthon Paar RheoCompass in Peltier plate geometry. The sample (around 5 mL) was loaded in a 20 mm 1° steel cone with a truncation gap of 25 µm. The shear rate was increased stepwise from 0.01 to 1000 s⁻¹, collecting 31 data points to observe any non-Newtonian behavior. At the given shear rate, the shear stress was measured every 2 s. The data were recorded when the shear rate was stabilized with up to 5% tolerance for three consecutive points. Different samples were measured in triplicate and the viscosities were averaged and reported.

2.5 Gel content

The gel content was calculated by extraction in tetrahydrofuran (THF). The cured samples were cut into rectangular shapes, with dimensions of 40 × 10 × 4 mm, and their weight was determined (W_i). Such prepared samples were immersed into THF for 28 days at room temperature. The insoluble fractions, which correspond to the inflated polymer network, were filtered, carefully dried under vacuum, and then measured (W_{sol}). The gel content was calculated as follows:

$$GC (\%) = W_{sol} / W_i \times 100$$

2.6 Uniaxial tensile testing

The uniaxial tensile mechanical properties of the investigated UPR samples were evaluated using the Shimadzu Autograph AGS-X servo-hydraulic testing machine, equipped with a 1 kN load cell at ambient temperature according to ASTM D638. Four measurements were performed for each UPR sample at a testing rate of 2 mm/min. The average values of the break stress and break stroke

strain, the standard deviations and Young's modulus were determined. Young's modulus was calculated by the software TRAPEZIUM X from the linear part of the stress–strain curve.

3 Results and discussion

SCG composition can vary depending upon the roasting and processing techniques but generally consist of more than 50% carbohydrates that are mainly hemicellulose and cellulose that include their hydrolysis products, while the remaining part comprises lignin, lipids, proteins, minerals, and other substances [15]. Due to the heterogeneous nature of SCG, FTIR spectroscopy was used to determine its chemical structure. The FTIR spectra of SCG (Figure 1) shows a broad characteristic band at 3325 cm^{-1} which corresponds to –OH stretching vibrations. The double peaks at 2924 and 2850 cm^{-1} are related to C–H stretching. The characteristic band at 1656 cm^{-1} is attributed to coupling the C=O aldehyde and the C=C axial deformation, while the characteristic band at 1061 cm^{-1} represents conjugated C–O–C and O–C–C bonds [16].

The chemical structure of both uncured UPR (u-UPR) and cured UPR (c-UPR) was analyzed by FTIR spectroscopy and corresponding spectra are shown in Figure 1. The spectra of u-UPR and c-UPR both show a band at 1720 cm^{-1} that corresponds to C=O stretching, that derives from itaconic acid and succinic acid, and indicates an ester bond forming between carboxyl and hydroxyl groups [17, 18]. Band at 1640 cm^{-1} originates from C=C bonds and decreases in intensity after curing but doesn't completely disappear, which indicated that not all bonds reacted during crosslinking. Bands at 2940 cm^{-1} and 2980 cm^{-1} found in both spectra correspond to C–H stretching vibrations. Bands from 1300 cm^{-1} to 1000 cm^{-1} are related to C–O–C and C–O vibrations of ester bonds.

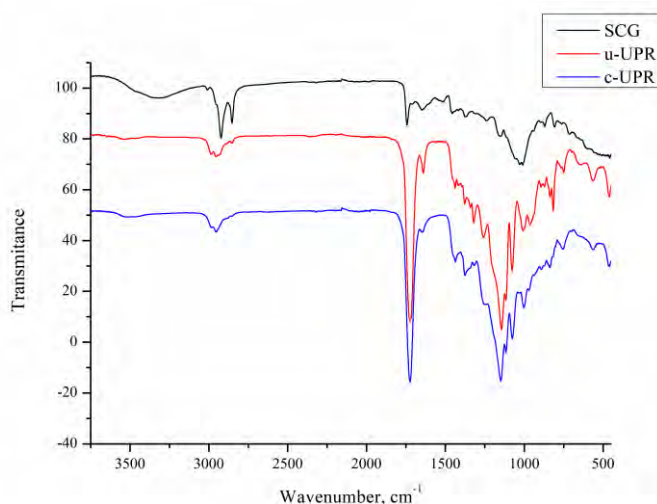


Figure 1. FTIR spectra of SCG, u-UPR and c-UPR.

The FTIR spectra of obtained composite material with different weight ratios of SCG are shown in Figure 2. Wide band at around 3300 cm^{-1} correspond to –OH stretching vibrations and it increases with increasing SCG ratio.

All the bands present in neat SCG spectra are also present in spectra of obtained composite materials. It is important to note that there are no strong interactions between these two materials. Based on these results it could be expected that incorporation of SCG will decrease mechanical properties of composite materials due to poor interaction between matrix and filler particles.

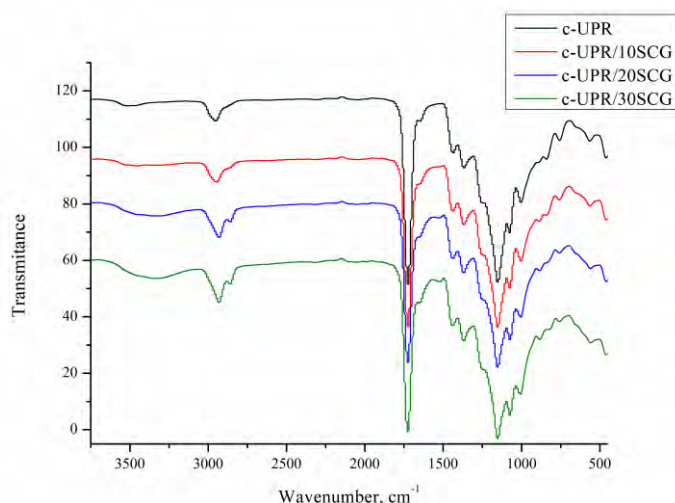


Figure 2. FTIR spectra of obtained composite materials.

The gel content analysis was used to assess the degree of crosslinking. Namely, unreacted monomers, oligomers and non-crosslinked polymer chains would dissolve in THF and leak from the samples. Thus, lower value of gel content indicates lower degree of crosslinking. This property is important for evaluation because it governs mechanical properties of cured resins. The obtained values of gel content are given in Table 1. There is a clear trend indicating that with increasing SCG ratio, the degree of crosslinking is decreasing. This trend showed that the presence of SCG interferes with the polymerization reaction, therefore resulting in lower crosslinking density. Considering the complex structure of waste coffee, several different scenarios may take place to interfere the radical polymerization. Numerous studies found various antioxidants substances in SCG, such as polyphenols, flavonoids, etc. [19, 20]. Most likely these components act as free radical scavengers and inhibit free radical polymerization leading to lower degree of crosslinking.

Table 1. Results of gel content analysis (GC) and uniaxial tensile testing.

Samples	GC, %	Young's modulus, MPa	Break stress, MPa	Break strain, %
c-UPR	98.58	304.55	22.13	13.40
c-UPR/10SCG	96.45	150.23	10.96	11.09
c-UPR/20SCG	92.08	75.06	7.18	10.76
c-UPR/30SCG	91.46	47.68	4.09	8.69

The mechanical properties of obtained composite materials as well as of neat UPR were examined by uniaxial tensile test. The obtained results are summarized in Table 1 and Figure 3. The highest break stress was obtained for c-UPR, while this value decreased with increasing SCG content. Samples c-UPR/20SCG and c-UPR/30SCG had similar degrees of crosslinking, but there is a significant weakening of mechanical properties with increase in SCG content. This could be explained by poor interactions between resin and SCG. Basically, in this system two main factors affect mechanical properties – i.e., degree of crosslinking and interactions between filler and matrix. FTIR analysis showed weak interactions between SCG and UPR. Also, increase in SCG content led to the decrease in degree of crosslinking. Due to this increase in SCG content led to the significant decrease in mechanical properties. Sample with 10 wt.% of SCG (c-UPR/10SCG) showed satisfactory properties to be used in some application while samples with higher content of SCG could not be commercially used. To use higher amounts of SCG it is necessary to modify surface of SCG in order to both increase interaction between SCG and resin, and to decrease inhibition caused by SCG.

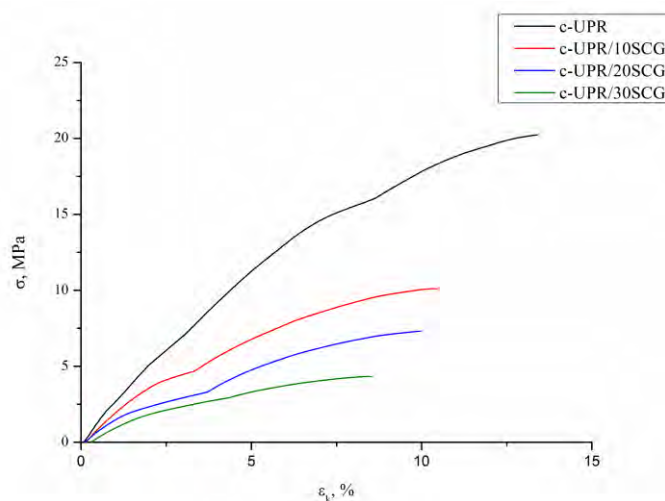


Figure 3. Stress – strain curve.

Shear rate dependance of viscosity of examined composite materials measured at 23°C is shown in Figure 4. Uncured UPR acts as Newtonian liquid showing no dependency on applied shear rate. Within the investigated shear rates, the UPRs with SCG added showed increase in apparent viscosity when compared with u-UPR. With increasing shear rate the slight viscosity decrease could be observed for u-UPR/10SCG and u-UPR/20 SCG. While viscosity of the sample with 30 wt.% of SCG (c-UPR/30SCG) plummeted in the shear rate range from 50 to 300 s⁻¹. This drop in viscosity found in c-UPR/30SCG can be assigned to clusters of SCG that further indicate that there are poor interactions between UPR and SCG.

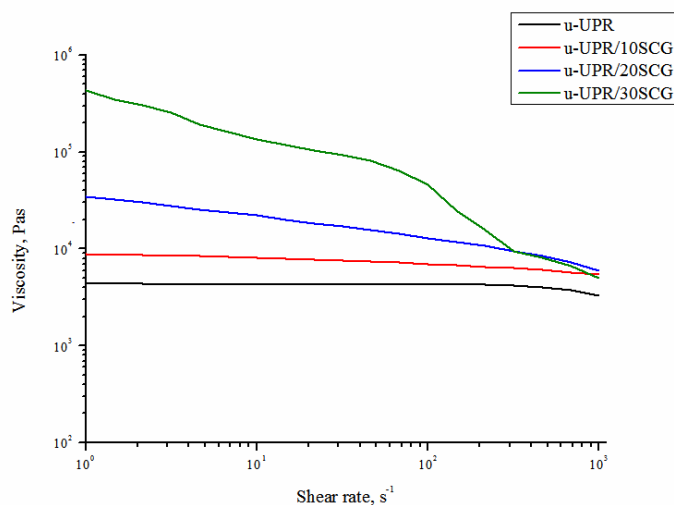


Figure 4. Viscosity as a function of the shear rate of the examined composite materials.

4 Conclusion

In this paper we have investigated the potential use of SCG as a filler to produce a fully biobased composite material. As the matrix, a fully biobased UPR was prepared from itaconic acid, succinic acid, and propylene glycol. Several methods were applied for characterization. FTIR spectroscopy did not reveal any significant interactions between SCG and UPR. Furthermore, the results of gel content analysis indicated that SCG acts as an inhibitor and lowers the degree of crosslinking. As a result, obtained samples showed poor mechanical properties. Only the sample with 10 wt.% of SCG could be commercially used while samples with higher coffee content exhibited unsatisfactory mechanical properties for commercial usage. Viscosity measurements of composite materials further

avored the sample with 10 wt.% of SCG, since materials with high viscosity aren't commercially applicable.

To increase the compatibility between two main system components it is necessary to functionalize the surface of SCG. This could be the way to prevent the inhibition and therefore improve the interactions between SCG and UPR. Since SCG is categorized as a natural filler obtained from lignocellulose raw materials, it has hydrophilic properties. Increasing the compatibility between two main system components can be achieved by lowering the hydrophilicity of SCG. To achieve this objective several approaches can be used, such as selective surface modification of SCG, modification of the UPR matrix by additives and using compatibilizers to provide increased interactions among composite components.

5 Nomenclature

DMI – dimethyl itaconate
MEKPO – methyl ethyl ketone peroxide
RD – reactive diluent
SCG – spent coffee grounds
THF – tetrahydrofuran
UPR – unsaturated polyester resin

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7 References

- [1] **ICO, International Coffee Organization**, <https://www.ico.org/historical/1990%20onwards/PDF/1a-total-production.pdf>, accessed 14.4.2022.
- [2] **Blinová, Lenka, et al.** "Utilization of waste from coffee production." *Vedecké Práce Materiálovotechnologickej Fakulty Slovenskej Technickej Univerzity v Bratislave so Sídrom v Trnave* 25.40 (2017): 91.
- [3] **Lenoir, Dieter, Karl-Werner Schramm, and Joseph O. Lalah.** "Green Chemistry: Some important forerunners and current issues." *Sustainable Chemistry and Pharmacy* 18 (2020): 100313.
- [4] **Pujol, D., et al.** "The chemical composition of exhausted coffee waste." *Industrial Crops and Products* 50 (2013): 423-429.
- [5] **Morikawa, C. K., and M. Saigusa.** "Recycling coffee and tea wastes to increase plant available Fe in alkaline soils." *Plant and soil* 304.1 (2008): 249-255.
- [6] **Karmee, Sanjib Kumar.** "A spent coffee grounds based biorefinery for the production of biofuels, biopolymers, antioxidants and biocomposites." *Waste management* 72 (2018): 240-254.
- [7] **Ramirez, Nathalia, et al.** "Capacitive behavior of activated carbons obtained from coffee husk." *RSC Advances* 10.62 (2020): 38097-38106.
- [8] **Gaidukova, Gerda, et al.** "Spent coffee waste as a renewable source for the production of sustainable poly (butylene succinate) biocomposites from a circular economy perspective." *RSC Advances* 11.30 (2021): 18580-18589.
- [9] **Kalagasidis Krušić, M.** *Polymer coatings. Subject curriculum. Faculty of Technology and Metallurgy, Serbia, 2019.*
- [10] **Arrigo, Rossella, et al.** "Structure–property relationships in polyethylene-based composites filled with biochar derived from waste coffee grounds." *Polymers* 11.8 (2019): 1336.
- [11] **Li, Qiong, et al.** "Bio-based unsaturated polyesters." *Unsaturated Polyester Resins*. Elsevier, 2019. 515-555.
- [12] **Preradović, K.,** *Synthesis of composite materials based on unsaturated polyester resins and lignin.*, B.Sc. thesis, University of Belgrade, Faculty of Technology and Metallurgy, Serbia, 2018.

- [13]**Cousinet, Sylvain, et al.** "Toward replacement of styrene by bio-based methacrylates in unsaturated polyester resins." *European Polymer Journal* 67 (2015): 539-550.
- [14]**Panic, Vesna V., et al.** "Simple one-pot synthesis of fully biobased unsaturated polyester resins based on itaconic acid." *Biomacromolecules* 18.12 (2017): 3881-3891.
- [15]**Mata, Teresa M., António A. Martins, and Nidia S. Caetano.** "Bio-refinery approach for spent coffee grounds valorization." *Bioresource technology* 247 (2018): 1077-1084.
- [16]**Silva, Johny C., et al.** "Oil Spill Clean-Up Tool Based on Castor Oil and Coffee Grounds Magnetic Resins." *Macromolecular Symposia*. Vol. 380. No. 1. 2018.
- [17]**Brännström, Sara, Eva Malmström, and Mats Johansson.** "Biobased UV-curable coatings based on itaconic acid." *Journal of Coatings Technology and Research* 14.4 (2017): 851-861.
- [18]**Baharu, Mohd Najib, et al.** "Synthesis and characterization of polyesters derived from glycerol, azelaic acid, and succinic acid." *Green Chemistry Letters and Reviews* 8.1 (2015): 31-38.
- [19]**Panusa, Alessia, et al.** "Recovery of natural antioxidants from spent coffee grounds." *Journal of agricultural and food chemistry* 61.17 (2013): 4162-4168.
- [20]**Abdeltatif, Samar A., Khitma A. SirElkhatim, and Amro B. Hassan.** "Estimation of phenolic and flavonoid compounds and antioxidant activity of spent coffee and black tea (processing) waste for potential recovery and reuse in Sudan." *Recycling* 3.2 (2018): 27.