

Lecture Notes in Networks and Systems 1070


Isak Karabegovic
Ahmed Kovačević
Sadko Mandzuka *Editors*

New Technologies, Development and Application VII

Advanced Production Processes and
Intelligent Systems, Volume 2

 Springer

Series Editor

Janusz Kacprzyk , *Systems Research Institute, Polish Academy of Sciences, Warsaw, Poland*

Advisory Editors

Fernando Gomide, *Department of Computer Engineering and Automation—DCA, School of Electrical and Computer Engineering—FEEC, University of Campinas—UNICAMP, São Paulo, Brazil*

Okyay Kaynak, *Department of Electrical and Electronic Engineering, Bogazici University, Istanbul, Türkiye*

Derong Liu, *Department of Electrical and Computer Engineering, University of Illinois at Chicago, Chicago, USA*

Institute of Automation, Chinese Academy of Sciences, Beijing, China

Witold Pedrycz, *Department of Electrical and Computer Engineering, University of Alberta, Alberta, Canada*

Systems Research Institute, Polish Academy of Sciences, Warsaw, Poland

Marios M. Polycarpou, *Department of Electrical and Computer Engineering, KIOS Research Center for Intelligent Systems and Networks, University of Cyprus, Nicosia, Cyprus*

Imre J. Rudas, *Óbuda University, Budapest, Hungary*

Jun Wang, *Department of Computer Science, City University of Hong Kong, Kowloon, Hong Kong*

The series “Lecture Notes in Networks and Systems” publishes the latest developments in Networks and Systems—quickly, informally and with high quality. Original research reported in proceedings and post-proceedings represents the core of LNNS.

Volumes published in LNNS embrace all aspects and subfields of, as well as new challenges in, Networks and Systems.

The series contains proceedings and edited volumes in systems and networks, spanning the areas of Cyber-Physical Systems, Autonomous Systems, Sensor Networks, Control Systems, Energy Systems, Automotive Systems, Biological Systems, Vehicular Networking and Connected Vehicles, Aerospace Systems, Automation, Manufacturing, Smart Grids, Nonlinear Systems, Power Systems, Robotics, Social Systems, Economic Systems and other. Of particular value to both the contributors and the readership are the short publication timeframe and the worldwide distribution and exposure which enable both a wide and rapid dissemination of research output.

The series covers the theory, applications, and perspectives on the state of the art and future developments relevant to systems and networks, decision making, control, complex processes and related areas, as embedded in the fields of interdisciplinary and applied sciences, engineering, computer science, physics, economics, social, and life sciences, as well as the paradigms and methodologies behind them.

Indexed by SCOPUS, INSPEC, WTI Frankfurt eG, zbMATH, SCImago.

All books published in the series are submitted for consideration in Web of Science.

For proposals from Asia please contact Aninda Bose (aninda.bose@springer.com).

Isak Karabegovic · Ahmed Kovačević ·
Sadko Mandzuka
Editors

New Technologies, Development and Application VII

Advanced Production Processes
and Intelligent Systems, Volume 2

 Springer

Editors

Isak Karabegovic
Academy of Sciences and Arts of Bosnia
Sarajevo, Bosnia and Herzegovina

Ahmed Kovačević
City, University of London
London, UK

Sadko Mandzuka
Faculty of Traffic and Transport Science
University of Zagreb
Zagreb, Croatia

ISSN 2367-3370

ISSN 2367-3389 (electronic)

Lecture Notes in Networks and Systems

ISBN 978-3-031-66270-6

ISBN 978-3-031-66271-3 (eBook)

<https://doi.org/10.1007/978-3-031-66271-3>

© The Editor(s) (if applicable) and The Author(s), under exclusive license
to Springer Nature Switzerland AG 2024

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

If disposing of this product, please recycle the paper.

Contents

Automation, Advanced Control, Digital Technologies and Intelligent Transport in Production Processes

Towards a Greener Future: Sensor-Based Material Characterization in Waste Sorting for a Sustainable Recycling Model	3
<i>Lejla Banjanovi-Mehmedovic and Nedim Dželilović</i>	
Optimized Digital Twin Networks	12
<i>Piercarlo Cattani and Francesco Villecco</i>	
Application, Challenges and the Future of NFT Technology	21
<i>Savo Stupar, Elvir Šahić, Mirha Bičo Ćar, and Maida Cico</i>	
Improving Passband in Cosine-Based CIC Decimation Filter with Improved Worst-Case Aliasing Attenuation	32
<i>Gordana Jovanovic Dolecek and Isak Karabegovic</i>	
Predicting Households' Short-Term Power Consumption Utilizing LSTM	39
<i>Grega Vrbančič, Vili Podgorelec, and Lucija Brezočnik</i>	
The Impact of Digital Transformation to the Criminal Law Assets	49
<i>Arben Prifti</i>	
Flexible and Transportable Illumination Control System for Machine Vision Applications	58
<i>Muhamed Gušić and Emir Sokić</i>	
Promising AI Applications in Power Systems: Explainable AI (XAI), Transformers, LLMs	66
<i>Oleh Lukianykhin, Vira Shendryk, Sergii Shendryk, and Reza Malekian</i>	
Developing E-mail Classification Model Using Sentiment Analysis to Improve Customer Support	77
<i>Emina Milanović Balić</i>	
Statistical Modeling of Ransomware Attacks Trends	87
<i>Milica Tufegdžić, Aleksandar Mišković, Predrag Dašić, and Vladimir Nedić</i>	

Integrated It Systems for the Management of Activities Related to Border Control at the Schengen Space	98
<i>Petrică Tertereanu, Aurel Mihail Țițu, Adrian Bogorin-Predescu, Vasile Gusan, Daniel Bâlc, and Alina Bianca Pop</i>	
The Impact of SMES Integration on the Power Grid: Current Topologies and Nonlinear Control Strategies	108
<i>Mohamed Khaleel, Ozan Gulbudak, Sadoon K. Ayed, Mustafa A. S. Mustafa, Hasan Shakir Majdi, Laith Jaafar Habeeb, and Monaem Elmnifi</i>	
Mobile Application mDating	122
<i>Suad Sućeska</i>	
Intelligent Traffic Safety Management on a Section of a Multi-lane Motorway	130
<i>Sadko Mandžuka, Krešimir Vidović, Goran Kos, and Luka Dedić</i>	
A Systematic Literature Review of the Urban Air Mobility Systems that Are Revolutionizing the Urban Transport	139
<i>Carlos Pérez Carrera, Ömer Ekim Genel, Maria Curcio, Carmine Maria Pappalardo, and Domenico Guida</i>	
Using Smart Solutions for Creating the Model of Urban Sustainable Mobility	150
<i>Arneta Mujić, Edin Gadžo, and Osman Lindov</i>	
Global Electric Car Market	158
<i>Branislav Dudic</i>	
Analysis of Opportunities of Software for Optimization of Transport Routes ...	165
<i>Maida Eljazović, Drago Ezgeta, Nedim Kamenjašević, and Mirzet Sarajlić</i>	
The Possibility of Implementing the A-CDM Concept at Smaller Airports up to 2 Million Passengers	172
<i>Damir Džubur, Muharem Šabić, and Denis Odić</i>	
Analyzing the Factors Influencing the Performance of Railway Infrastructure Managers	182
<i>Aida Kalem, Nedžad Branković, Nermin Čabrić, and Fadila Kiso</i>	
A Deep Learning Approach for Traffic Flow Prediction in City of Sarajevo	191
<i>Nedim Kamenjašević, Maida Eljazović, and Mirzet Sarajlić</i>	

Technological Inheritability of Parameters of Surface Engineering of Products After Vibrational-Centrifugal Hardening	198
<i>Yaroslav Kusyi, Andrii Kuk, Ivan Klymash, Nazarii Kusen, and Victor Vriukalo</i>	
Toward Complete Digitalisation of Postal Items Clearance in the Republic of Croatia	210
<i>Kljak Tomislav, Binički Marijan, Škorput Pero, and Vrkić Domagoj</i>	
Air Traffic Flow Analysis of Sarajevo Flight Information Region	218
<i>Lejla Nikšić</i>	
Barriers to Smart Mobility Implementation in Urban Context	228
<i>Bia Mandžuka, Krešimir Vidović, and Pero Škorput</i>	
Using Machine Learning to Predict Additional Taxi-Out Time as a Airport Key Performance Indicator in the Eurocontrol Zone	237
<i>Edvin Šimić, Muhamed Begović, Muharem Šabić, and Ermin Muharemović</i>	
Intelligent Vehicle Functions in Reducing the Uncertainty of the Driver's Environment and Reducing Risk	246
<i>Drago Ezgeta, Mustafa Mehanović, and Samir Čaušević</i>	
Advanced Business and Ecological functions in Production Systems	
Industry 4.0 in Micro, Small and Medium Sized Enterprises of the Sarajevo Canton	255
<i>Mirha Bičo Čar, Isak Karabegović, Munira Šestić, Elvir Šahić, Selma Hođžić, and Savo Stupar</i>	
Social Media and Marketing Worldwide	271
<i>Branislav Dudić, Alexandra Mittelman, and Jaroslav Vojtechovský</i>	
How is the Use of ICT Shaping Our Intended Effort for Learning?	279
<i>Fiser Zrinka</i>	
Contemporary Migrations and Development Dynamics	289
<i>Marija Orlandić, Marija Radunović, and Ivana Katnić</i>	
Using the Maximum Entropy Method for Effective Project Management	298
<i>Volodymyr Litvinov, Liubov Bovnegra, Andrey Pavlyshko, Alla Toropenko, and Yuliia Babych</i>	

Effects of Work Digitalization and Hybridization Within the Tax System of Bosnia and Herzegovina	306
<i>Elvir Čizmić, Elvir Karajbić, Đevad Šašić, and Rifet Đogić</i>	
Contemporary Management Techniques in the Function of Work Improvement in Primary Schools of Canton Sarajevo	315
<i>Elvir Čizmić, Dženita Čehajić-Kulo, Zijada Rahimić, and Munira Šestić</i>	
Roots of the New Development Trends in Europe	325
<i>Marija Radunovic, Marija Orlandić, and Ivana Katnić</i>	
Competencies for the 21st Century: Is Education Keeping up with Industry 4.0?	335
<i>Zrinka Šimunović and Višnja Vekić-Kljaić</i>	
Homo Deus: Technoskepticism/Techno-Optimism - Slipping into the Technosphere	344
<i>Abdel Alibegović, Dina Radeljaš, Omar Tahirović, and Alen Arnautović</i>	
Technology and Temporality - Accelerated History of the World	354
<i>Halima Sofradžija, Abdel Alibegović, Amina Hodžić, and Miroslav Pisarević</i>	
Economic Power: Security, Military and Political Resource	361
<i>Ivan Jovetic and Ivana Katnić</i>	
B2B E-commerce in Europe	370
<i>Branislav Dudić and Velibor Spalević</i>	
Analytical Review of the Current State of the Russian Economy and Its Various Industries	376
<i>Irina Somina and Maxim Kondakov</i>	
Use of Artificial Intelligence in the Formation of the Marketing Strategy of the Enterprise	387
<i>Chukurna Olena, Tardaskina Tetiana, Alkhimova Violeta, Kofman Viktorija, and Pankovets Leonid</i>	
Major Challenges in the Construction Industry	396
<i>Ivana Domljan and Vjekoslav Domljan</i>	
Effects of Binary Similarity Metrics in Recommender Systems for Jester Jokes Dataset	404
<i>Edip Senyurek and Jasmin Kevric</i>	

Application of New Technologies in Social Media Analytics: Enhancing User Engagement at Global Universities	413
<i>Mersid Poturak, Engin Obucic, Dino Keco, and Ensar Mekic</i>	
Digital Technologies in the BiH Banking Industry – State and Perspective	423
<i>Adem Abdić, Adnan Rovčanin, Ademir Abdić, and Fahir Kanlić</i>	
The Potential of the Green Economy as a Means of Financial and Promotion Green Innovation. Albania’s Predicament	432
<i>Adriana Xhuveli and Aelita Mani</i>	
Investment Decision Making Using Fuzzy Logic and Ahp	445
<i>Lucas Matheus Ribeiro and Selma Regina M. Oliveira</i>	
Industry 4.0 Within Postgraduate Business Education in Bosnia and Herzegovina: Overview and Recommendations	455
<i>Munira Šestić, Mirha Bičo Ćar, Sabina Alibegović Donlagić, and Dženan Kulović</i>	
Big Data Analytics in Government Organizations in an Emerging Economy	462
<i>Giulliano Delgado and Selma Regina M. Oliveira</i>	
Sustainable Peacebuilding and Responsible Use of Technology as Means and Consequences of Armed Conflicts in International Humanitarian Law	473
<i>Pjereta Agalliu</i>	
Development of New Sensors for Use in Smart Clothing	480
<i>Amra Bratovcic and Isak Karabegovic</i>	
Riverine Biodiversity: Threats and Challenges of Conservation on the Example of the Una River	489
<i>Vildana Alibabić, Amarildo Mulić, and Haris Hadžihajdarević</i>	
Antioxidative Activity of Selected Bosnian Mushrooms	501
<i>Aida Šapčanin, Ekrem Pehlić, Belma Pehlivanović-Kelle, and Gordan Jančan</i>	
Chemical Characterization and Potential Health Benefits of Wild Mushrooms from Eastern Bosnia	510
<i>Aida Šapčanin, Ekrem Pehlić, Gordan Jančan, and Alija Uzunović</i>	
Anthropogenic Impact on Organic Matter Pollution of the Bregava River	519
<i>Dalila Ivanković Memić, Almir Šestan, Aldina Kesić, and Aida Crnkić</i>	

Environmental Flow – Osanica River	526
<i>Mujčić Mirza and Hadžić Emira</i>	
Monte Carlo Simulation in Health Risk Assessment of Sulfur Dioxide Exposure – A Pivotal Factor for Future Air Quality Regulation	537
<i>Maida Šljivić Husejnović, Alija Uzunović, Medina Husanović, and Emira Mlivo</i>	
Harmonizing Neurotherapeutics -the Union of Non-invasive Brain Stimulation, EEG, and Artificial Intelligence	549
<i>Amina Radončić</i>	
Carbon Plastics for Structural Purposes Based on Aromatic Polyamide Phenylone C-2	556
<i>Olga Chihvintseva, Iryna Rula, Yulia Boyko, and Dragoljub Mirjanić</i>	
Magnetically Assisted Electrocoagulation Combined with Zeolite: Opportunities and Challenges in Compost Wastewater Treatment	564
<i>Nediljka Vukojević Medvidović, Ladislav Vrsalović, Sandra Svilović, Senka Gudić, and Silvia Bućma</i>	
An Integrated Health Risk Assessment Approach to the Study of Carbonated Water Spring from Tuzla Area, Bosnia and Herzegovina	575
<i>Maida Šljivić Husejnović, Almedina Palavrić, Azra Suljić, and Emira Mlivo</i>	
The Quantum-Chemical Aspects of Structuring for Some Aramide-Type Polymer Systems with Hetaryl Fragments	589
<i>Andrey Tokar, Olga Chihvintseva, and Dragoljub Mirjanić</i>	
Research on the Use of Tuff and Similar Inorganic Materials in Wildfire Fighting	597
<i>Mario Krzyk and Darko Drev</i>	
Seismic Actions on Buildings According to the National Regulations and Eurocode 8 for Bosnia and Herzegovina	606
<i>Faruk Avdic, Sanin Dzidic, Emir Hodzic, and Amir Causevic</i>	
Comparison of Wind Actions According to JUS Standards and BAS EN 1991-1-4 in Bosnia and Hercegovina	620
<i>Emir Hodžić and Sanin Džidić</i>	
Mortars with Marble Powder as Partial Replacement for Cement	628
<i>Armina Breščić, Marko Čećez, Merima Šahinagić-Isović, and Fuad Čatović</i>	

Fire Spalling of Concrete 637
Irfan Bidžević and Sanin Džidić

Preservation of Cultural Heritage Architecture by 3D Printing and Realistic
3D Models 646
Nedim Tuno, Admir Mulahusić, Jusuf Topolja, and Marko Savić

Analysis of Urban Layout and Architectural Configuration of Preschool
Facilities Built Until 1990: A Case Study in Sarajevo 654
*Nerma Smajlović Orman, Adnan Novalić, Maja Popovac,
and Ahmed El Sayed*

A Review on General Principles and Regulations of New Additions
in the Case of Architectural Heritage Protected Buildings 666
Yousef Zaarir, Adnan Novalic, and Ahmed Elsayed

The Relative Values of a Moisture Percentage in Building Envelopes:
Moisture’s Spots with a Moisture Meter 680
Jovana Jovanović and Ivan Stevović

How Well Does Bosnia and Herzegovina Follows the Regulations
for Planning Hydropower Plants in Relation to the EU and its Region? 690
Mirela Idrizović and Ahmed El Sayed

Author Index 699



Carbon Plastics for Structural Purposes Based on Aromatic Polyamide Phenylone C-2

Olga Chihvintseva¹ (✉), Iryna Rula¹, Yulia Boyko¹, and Dragoljub Mirjanić²

¹ Dnipro State Agrarian and Economic University, Sergiya Yefremova St., 25, Dnipro 49009, Ukraine
diso@i.ua

² Academy of Sciences and Arts of the Republic of Srpska, 8000 Banja Luka, Bosnia and Herzegovina

Abstract. For the purpose of creating a plastic for structural purposes, the aromatic polyamide phenylone C-2 was reinforced with chromium-containing carbon fiber in an amount of 17 wt. %. As a result of a set of studies of the structure, thermophysical, physico-mechanical and tribological properties, it was found that the reinforcement of aromatic polyamide makes it possible to obtain a material with improved performance characteristics. The engineered carbon fiber having high thermal resistance, thermal conductivity and wear resistance is characterized by a low linear expansion thermal coefficient and friction factor, is operable in a wide range of specific pressures and sliding speeds and can be used for products operating in friction units of movable joints of machines and machinery.

Keywords: aromatic polyamide · chromium-containing carbon fiber · carbon plastics · properties

1 Introduction

One of the priority areas of scientific studies in the field of polymer materials engineering is the development of functional structural materials with high thermal shock resistance, improved physico-mechanical and tribological properties, intended to be used in specific areas.

Phenylone C-2 (TU 6-05-221-226-72) is a high-quality structural material capable of being used for operation under the effect of large static and dynamic loads in the temperature range from -80 °C to $+200$ °C. Phenylone C-2 is well processed; its distinctive feature is the combination of high rigidity and strength with high fracture toughness [1, 2]. In terms of strength parameters, phenylone C-2 surpasses most of the known unfilled plastics and is second only to glass plastics [3, 4].

Despite the high physical and mechanical properties, phenylone C-2 has good performance capability only under conditions of lubrication (oil, water), while in the dry friction mode it has high friction factor values and a narrow range of the RV criterion, which significantly limits its operational capabilities.

One of the effective methods of improving the tribotechnical characteristics of polymers is the reinforcement of the polymeric matrix with carbon fibers (CF).

2 Computational Details

The carbon-fiber-based polymer composites – carbon plastics (CP) [5, 10] are characterized by high values of resistance to fatigue loads, damping capacity and vibration resistance, electrical conductivity and chemical stability; low thermal coefficient of linear expansion, which ensures an insignificant change in the product size when heating and cooling them.

Due to the high performance characteristics the carbon plastics have found wide application in various industry fields, ranging from rocket and space and aviation equipment, automotive engineering, shipbuilding to sports equipment and household appliances [6–8].

For the purpose of creating a new carbon plastics for structural purposes the aromatic polyamide phenylone C-2 was reinforced with chromium-containing carbon fiber (Cr-CF) in an amount of 17 wt. %.

Chromium-containing carbon fiber that contains chromium oxide Cr_2O_3 , at a heat treatment temperature of 800–900 °C it catalyzes the formation of a phase of nanoscale lattice-ordered carbon, the structural element whereof are graphene layers. The presence of nanoscale phases of metal and lattice-ordered carbon in the micron-scale Cr-CF structure (fiber diameter is about 6–8 microns) gives the fiber filler a set of new properties characteristic for nanoscale objects and opens up wide opportunities for their practical application, in particular, for the manufacture of parts for structural purposes [9, 11].

2.1 Results and Discussion

As previously conducted scientific studies have shown, the introduction of metal into the carbon fiber structure improves its wetting property with polymer binders and affects the interaction between the polymer and the filler at the interface of phases, which improves the carbon fiber strength properties [12].

At the initial stage, structural studies of the binder and carbon plastic based thereon were carried out. IR-spectral analysis of plastics was performed using the X-29 spectrophotometer. The preparation of study samples was performed by pressing the substance into a potassium bromide tablet: about 50 mg of the sample was ground into 600 mg of potassium bromide, then subjected to significant compression in a metal mold.

As a result of the study, it was found that the carbon plastic IR-spectrum in general outline reproduces the phenylone C-2 spectrum (Fig. 1). A wide band (almost from 4000 to 1800 cm^{-1}) with weakly pronounced maxima was observed in the area of stretching vibrations of hydrogen atoms. It is the result of overlapping bands of bound and free amide NH-groups, the maxima in the area of 3250 and 3050 cm^{-1} refer to stretch vibrations of hydrogen-bonded NH-groups. The intense absorption bands typical for aromatic polyamides and characteristic for phenylone C-2 were appeared in the area of 1700–1200 cm^{-1} .

These are the Amide I, Amide II and Amide III bands in the region of 1660, 1550 and 1245 cm^{-1} and narrow intense bands corresponding to the fluctuations of aromatic fragments (1605, 1530 and 1480 cm^{-1}). In the area of 1200–400 cm^{-1} , less intense absorption bands appeared, among which a note should be made of the deformation

bands of hydrogen atoms of aromatic fragments 860 cm^{-1} and a number of bands 780 , 719 and 683 cm^{-1} related to vibrations of amide groups.

Despite the fact that the carbon plastic spectrum is generally similar to the phenylone C-2 spectrum, some differences are observed therein. In particular, in the spectrum of carbon plastic, the Amide III band is expanded in the high-frequency direction, which results in shifting of its maximum to 1248 cm^{-1} . The spectrum also contains extra bands near Amide I at $1640\text{--}1650\text{ cm}^{-1}$ (here in the phenylone C-2 spectrum only a relatively weak shoulder was observed). A note should be made of the notable expansion of the 781 cm^{-1} band and the strengthening and expansion of the 1080 cm^{-1} band. The latter leads to the fact that in the carbon plastic range it appears to be shoulder-like.

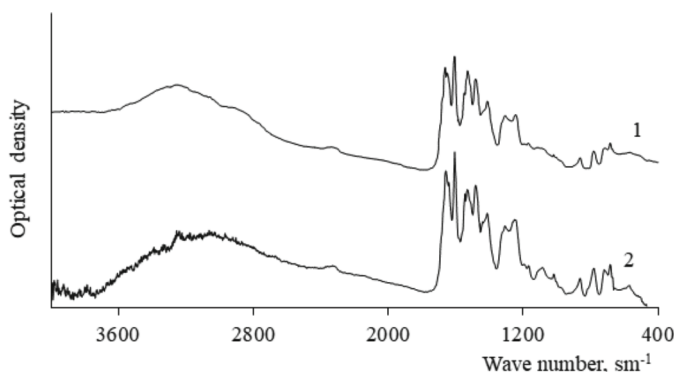


Fig. 1. IR absorption spectra of phenylone C-2 (1) and carbon plastic on its basis, reinforced with 17 wt. % Cr-CF

Since all these features refer to changes in amide-fragment-related bands, it may be concluded that the fibrous filler affects the polyamide matrix structure, whereby this effect relates specifically to amide groups.

The X-ray diffraction analysis was carried out using the Dron-2.0 unit in copper radiation with a nickel filter. A set of experimentally obtained maxima on diffraction patterns was described by two characteristics: scatter angle 2θ and relative intensity.

The X-ray diffraction studies have made it clear that a wide intense peak in the area of the scatter angle $2\theta = 22.6$ rad, characteristic of phenylone C-2, was also appeared on the carbon plastic diffractogram as well (Fig. 2). On the carbon plastic diffraction pattern the amorphous ring on the curves in the area of Wulf-Breg angles $2\theta = 20\text{--}30$ rad significantly decreased, which was illustrative of a more crystalline carbon plastic structure as compared to the polymer binder.

One of the effective methods for predicting the behavior of polymer composites in high temperature conditions is thermal analysis allowing to note changes occurring when heating of the material with subsequent release or absorption of heat [12].

The data of the thermogravimetric analysis of Cr-CF were indicative of the high thermal resistance of the fiber: in the temperature range of $300\text{--}423\text{ K}$, a gradual reduction in mass of the reinforcing filler ($0.4\text{--}4.2\%$) was observed due to the moisture removal from the samples and only at a temperature of 1073 K the fiber began losing 9% of the

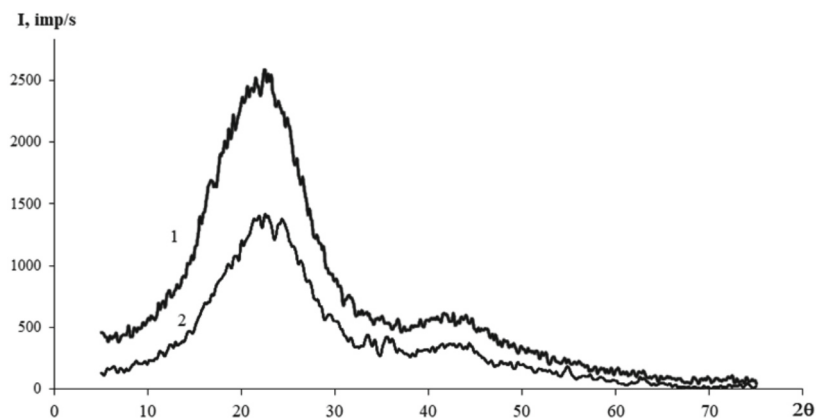


Fig. 2. Diffraction patterns of phenylone C-2 and carbon plastic based thereon, reinforced with 17 wt.% Cr-CF

mass. Therefore, it is quite predictable that the reinforcement of phenylone C-2 Cr-CF allowed increasing its thermal resistance (Fig. 3, Table 1). In particular, the temperature at which 10, 20 and 30% mass loss of carbon plastic samples was observed was 19, 22 and 35 °C higher, respectively, than for the initial polymer.

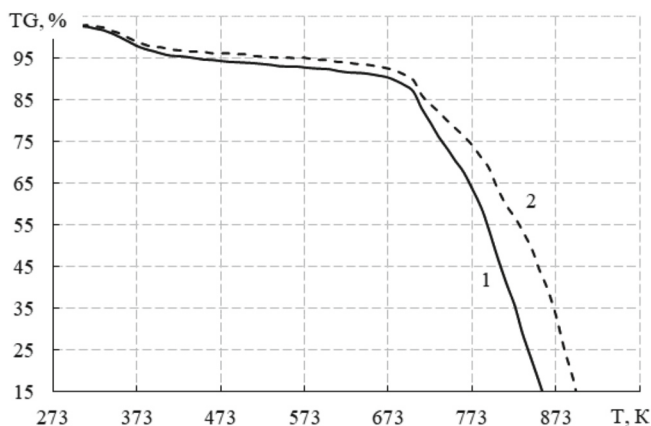


Fig. 3. Curves of thermogravimetric analysis of phenylone C-2 (1) and carbon plastic based thereon, reinforced with 17 wt. % Cr-CF (2)

The data of thermal studies showed that intensive destruction of materials, accompanied by a significant mass loss, began to appear at temperatures above 873K. On the curve of differential thermal analysis, an exothermic peak revealed in this area, characterizing the decomposition process of the polymer binder [2], whereby while its value for carbon plastic was greater as compared to phenylon C-2, which is indicative of a more intensive decomposition process of carbon plastic [13, 14].

Table 1. Thermal resistance of phenylone C-2 and carbon plastic based thereon

Material	Temperature, K		
	T ₁₀	T ₂₀	T ₃₀
C-2	680	725	755
C-2 + 17 wt. % Cr-CF	699	747	790

T₁₀, T₂₀, T₃₀ are the temperatures of 10, 20 and 30% mass loss, K.

Along with an increase in thermal resistance, the developed carbon plastic showed better improved thermophysical and physico-mechanical characteristics (Table 2). The specific heat capacity of carbon plastic in the temperature range of 173–498 K was on average 15% lower than that of phenylone C-2; the drop in the linear expansion thermal coefficient as a result of measurements in the temperature range of 298–558 K varied from 20 to 60%, and the thermal conductivity coefficient and strength parameters increased [13].

Table 2. Thermophysical and physico-mechanical parameters of phenylone C-2 and carbon plastic based thereon

Parameters	Phenylone C-2	Phenylone C-2 + 17 wt. % Cr-CF
Thermal conductivity coefficient λ , W/m · K at a temperature of 323 K	0.27	0.52
Temperature linear expansion thermal coefficient, $\alpha \cdot 10^{-6}$, K ⁻¹ in the temperature range of 298–558 K	43.2	17.6
Ultimate compressive strength $\sigma_{\text{compr.}}$, MPa	361	368
Compression yield strength σ_{st} , MPa	202	221
Compression elasticity modulus E, MPa	3314	3438
Surface hardness after abrasive friction testing Ra, μm	5.8	3.6

The study of tribological properties of aromatic polyamide and carbon plastic based thereon in the dry friction mode was carried out on a disc friction machine. The sample wear was evaluated according to the disk scheme (steel 45, HRC₃ 50, Ra = 0.08) – a carbon plastic sample (\varnothing 10 mm, height 10 mm) at specific loads $P = 0.2\text{--}0.8$ MPa, sliding speeds $v = 1, 1.5, 2.0$ m/s, the friction path was 1000 m. The wear of samples was determined using the analytical scales VLR-200 with an accuracy of 0.0002 g.

The results of studies of operating modes affecting the tribological properties of samples indicated that with an increase in specific pressure and sliding speed, the carbon plastic coefficient of friction decreased (Fig. 4a).

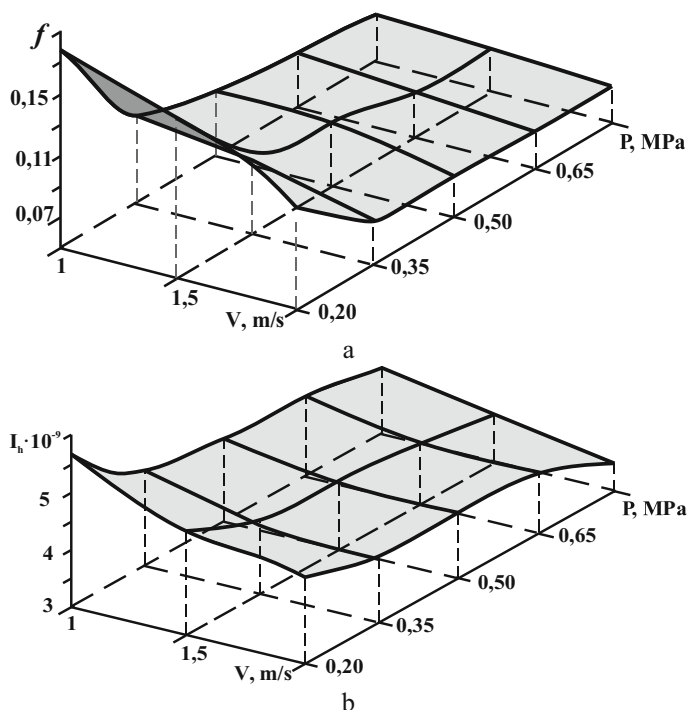


Fig. 4. Operating modes affecting the coefficient of friction (a) and the linear wear intensity (b) of carbon plastic based on phenylone C-2

In particular, in the course of operation of carbon plastic samples under sliding speeds of 1, 1.5 and 2 m/s with an increase in the specific load from 0.2 to 0.8 MPa, the carbon plastic coefficient of friction decreased by 42–56%, correspondingly. At the minimum specific pressure ($P = 0.2$ MPa) with an increase in the sliding speed from 1 to 2 m/s, the coefficient of friction decreased from 0.16 to 0.12, and at the maximum ($P = 0.8$ MPa) it was in the range of 0.08–0.07.

Along with a decrease in the coefficient of friction, the toughening of operating modes led to an increase in the carbon plastic wear resistance. With an increase in the specific pressure and sliding speed, the intensity of linear wear of carbon plastic decreased by more than 20%.

The coefficient of friction of phenylone C-2 under the study loads and sliding speeds varied from 0.13 to 0.18 and showed higher values as compared to carbon plastic, and the linear wear intensity with tightening of operating modes increased for the polymer from $6.5 \cdot 10^{-9}$ up to $1.5 \cdot 10^{-8}$.

In the event of friction of phenylone C-2 with low values of the thermal conductivity coefficient (Table. 2) localization and accumulation of heat occurs in the friction zone, which leads to an increase in the segmental mobility of macromolecules, an increase in adhesion, resulting in an increase in the coefficient of friction and damage to the friction surface of the polymer (Fig. 5a). The presence of strong adhesive bonding leads to the

destruction of the protective surface film formed on the counterbody in the course of the polymer wearing-in, the process of setting-up the polymer with the counterbody material begins to progress, therefore its friction factor and the linear wear intensity have high values.

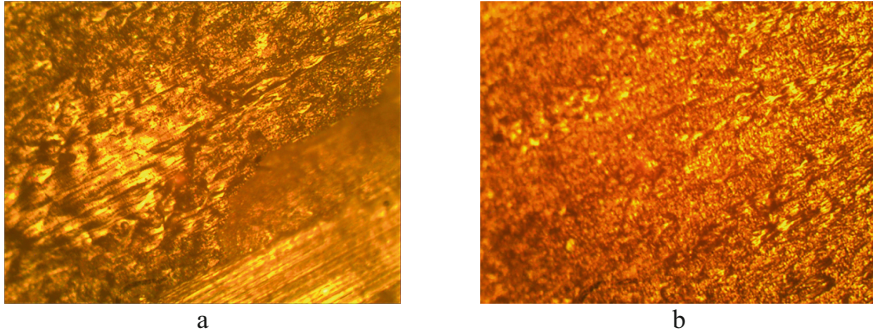


Fig. 5. The appearance of a sample of phenylone C-2 (a) and of carbon plastic based thereon (b) after studies in the dry friction mode under specific load of $P = 0.8$ MPa and sliding speed of $v = 2$ m/s

The performance capability criterion PV (the product of the specific pressure by the sliding speed) for phenylone C-2 was no more than 1.2 MPa · m/s. It probably has to do with the development of a high temperature on the steel counterbody surface, which caused the friction surface of the polymer sample to soften and for the material to lose its operability (Fig. 5a). The carbon plastic sample showed steady performance up to the maximum values of the operating modes, whereby the friction surface remained unchanged (Fig. 5b), the criterion for carbon plastic was 1.6 MPa · m/s.

The reinforcement of phenylone C-2 with chromium-containing CF almost doubled its thermal conductivity (Table 2); this contributes to better heat dissipation from the friction zone of the carbon plastic sample, which positively affects the change in its tribological properties.

As compared to the original polymer, the engineered carbon plastic showed a coefficient of friction lower more than by 2 times and a linear wear intensity by 2–35 times, which allows it to be used as a material of anti-frictional purpose for friction units of movable joints.

3 Conclusion

In general, the conducted set of studies testifies that the reinforcement of aromatic polyamide phenylone C-2 allows to significantly improve its performance characteristics. The developed carbon plastic shows improved thermal, thermophysical and physico-mechanical properties.

The study of the main regularities of the process of friction and wear of materials has shown that carbon plastic based on phenylone C-2 has anti-friction properties and

high wear resistance, which allows it to be recommended to be used as a material for the structural purpose of friction units of machines and machinery in order to increase the service life of products based thereon.

References

1. Sokolov, L.B., Gerasimov, V.D., Savinov, V.D., Belyakov, V.K.: Thermoresistant aromatic polyamides. *Khimiya*. P. 256 (1975)
2. Sokolov, L.B.: Thermoresistant and high-strength polymer materials. *Znanie*, p. 64 (1984)
3. Bueller, K.-U.: Heat- and thermoresistant polymers. *Trans. from German. Khimiya*, p.1056 (1984)
4. Katsnelson, M.Yu., Balaev, G.A.: Polymer materials. *Handbook. Khimiya*, p. 300 (1982)
5. Das, T.K., Ghosh, P., Das, N.C.: Preparation, development, outcomes, and application versatility of carbon fiber-based polymer composites: a review. *Adv. Compos. Hybrid Mater.* **2**(2), 214–233 (2019)
6. Kopei, B., Kopei, I., Kopei, V., Onysko, O., Mykhailiuk, V.: Comparison of the main parameters of the steel and carbon-fiber-reinforced plastic band traction units for long-stroke oil well pumps. In: Karabegovic, I., Kovačević, A., Mandzuka, S. (eds) *New Technologies, Development and Application VI. NT 2023. Lecture Notes in Networks and Systems*, vol. 687, pp.86–97. Springer, Cham (2023). https://doi.org/10.1007/978-3-031-31066-9_10
7. Li, Y.-M., Deng, C., Zhao, Z.-Y., Han, L.-X., Lu, P., Wang, Y.-Z.: Carbon fiber-based polymer composite via ceramization toward excellent electromagnetic interference shielding performance and high temperature resistance. *Compos. A Appl. Sci. Manuf.* **131**, 105769 (2020)
8. Molchanov, B.I., Chukalovsky, P.A., Varshavsky, V.Ya.: Carbon fibers. *Khimiya*, p. 208 (1985)
9. Safonova, A.M., Shpilevskaya, L.E.: Metal-carbon fiber fillers and polymer compounds based thereon. *Perspektivnye materialy*. **6**, 16–20 (2003)
10. Tokar, A., Chihvintseva, O., Milosavljević, M.: The quantum-chemical prediction for some NMR spectral parameters in systems based on aromatic polyamides. In: Karabegovic, I., Kovačević, A., Mandzuka, S. (eds.) *New Technologies, Development and Application VI: Volume 2*, pp. 236–241. Springer Nature Switzerland, Cham (2023). https://doi.org/10.1007/978-3-031-34721-4_26
11. Lysenko, O., Tetiana, K., Zagorulko, I., Dašić, P., Popil, O.: Simulation of the structure and formation kinetics of a metastable modification of cerium upon quenching from a liquid state. In: Karabegovic, I., Kovačević, A., Mandzuka, S. (eds.) *New Technologies, Development and Application VI: Volume 1*, pp. 112–122. Springer Nature Switzerland, Cham (2023). https://doi.org/10.1007/978-3-031-31066-9_12
12. Korshak, V.V.: Thermoresistant polymers, p. 25. Nauka, Moscow (1969)
13. Chigvintseva, O.P., Rula, I.V.: Carbon fiber for structural purposes on the basis of aromatic polyamide and metal-plastic carbon fiber. *Interacad. Coll. Vol. «Naukovi notatki»* (71), 157–162 (2021)
14. Chigvintseva, O.P., Rula, I.V., Boyko, Yu.V.: Study of thermal and tribiological properties of carbon fiber on the basis of phenylon C-2. *Interacademic Coll. Vol. «Naukovi notatki»* (75), 64–69 (2023)