

REOLOGIJA POLIMEROV

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Reologija polimerov
Course title:	Rheology of polymers
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski	Mehanika (smer)	2. letnik	1. semester	obvezni

Univerzitetna koda predmeta/University course code:	0566906
Koda učne enote na članici/UL Member course code:	6042-M

Predavanja /Lectures	Seminar /Seminar	Vaje /Tutorials	Klinične vaje /Clinical tutorials	Druge oblike študija /Other forms of study	Samostojno delo /Individual student work	ECTS
30		30			65	5

Nosilec predmeta/Lecturer:	Lidija Slemenik Perše
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Izvajalci predavanj:	
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	
Izvajalci praktičnega usposabljanja:	

Vrsta predmeta/Course	Obvezni strokovni predmet na smeri Mehanika, ki je
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type:

izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Mechanics, which is an elective specialised course in other fields of study.

Jeziki/Languages:

Predavanja/Lectures:	Slovenščina
Vaje/Tutorial:	Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:**Prerequisites:**

Izpolnjevanje pogojev za vpis v Magistrski študijski program II. stopnje Strojništvo - Razvojno raziskovalni program.

Meeting the enrollment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Vsebina:**Content (Syllabus outline):**

1. Vsebina 1. Predavanja: UVOD
Osnovni reološki pojmi in količine, Materialne funkcije v časovnem in frekvenčnem prostoru, Osnovni tokovni režimi, Vpliv molekulske mase na mehanske in reološke lastnosti
2. Vsebina 2. Predavanja: REOMETRIJA
Instrumenti za merjenje reoloških lastnosti, Geometrije senzorskih sistemov, Metode za določevanje reoloških lastnosti talin oziroma trdnih snovi, Izračun reoloških fizikalnih parametrov na podlagi vnešenih količin
3. Vsebina 3. Predavanja: MEJNA NAPETOST
Inženirski primeri polimerov z mejno napetostjo, Enačbe za opis reološkega obnašanja materialov z mejno napetostjo, Določevanje in napovedovanje obnašanja polimerov z mejno napetostjo
4. Vsebina 4. Predavanja: VISKOELASTIČNOST
Lezenje in relaksacija - zveze med

1. Content of Lecture 1: INTRODUCTION
Basic rheological parameters, Material functions in time and frequency domain, Basic flow regimes, Effect of molecular weight on mechanical and rheological properties
2. Content of Lecture 2: RHEOMETRY
Instruments for determination of rheological properties, Geometries of sensor systems, Methods for determination of rheological properties of melts and solids, Calculation of rheological parameters
3. Content of Lecture 3: YIELD STRESS
Engineering examples of polymers with yield stress, Equations for rheological behaviour of materials with yield stress, Determination and prediction of the behaviour of polymers with yields stress
4. Content of Lecture 4: VISCOELASTICITY
Creep and relaxation - relation between stress and strain, Energy absorption, Mechanical models for prediction of viscoelastic behaviour during creep and relaxation, Explanation of the general

napetostjo in deformacijo, Absorpcija energije, Mehanski modeli za napoved viskoelastičnega obnašanja pri lezenju in obnovi, Popis splošnega napetostno-deformacijskega stanja viskoelastičnih materialov z uporabo materialnih funkcij

5. Vsebina 5. Predavanja: LINEARNA TEORIJA VISKOELASTIČNOSTI
Linearno in nelinearno vedenje materialov, Praktični pomen teorije linearne viskoelastičnosti, Določanje napetostne limite
6. Vsebina 6. Predavanja: ČASOVNA ODVISNOST MEHANSKIH LASTNOSTI
Relaksacijski čas, Tiksotropija, Fizikalno staranje, Mehanski spekter
7. Vsebina 7. Predavanja: VPLIV TEMPERATURE NA REOLOŠKE in MEHANSKE LASTNOSTI POLIMEROV
Temperaturni testi, Določanje faznih prehodov na podlagi dinamičnih modulov, Degradacija
8. Vsebina 8. Predavanja: REOLOŠKE MERITVE POLIMERNIH MATERIALOV
Izbira ustrezne reološke metode, Interpretacija rezultatov reoloških meritev, Povezava reoloških lastnosti s strukturo polimera
9. Vsebina 9. Predavanja: POMEN REOLOŠKIH LASTNOSTI POLIMERNIH MATERIALOV PRI RAZVOJU PRODUKTOV IN NAČRTOVANJU PROCESOV
Povezava reoloških lastnosti taline s procesnimi parametri izdelave polimernega produkta, Vpliv viskoelastičnih lastnosti na polimerni produkt pri predelavi (»Dye swell« efekt, Weisenbergov efekt, trganje taline, mejna napetost, ...), Vpliv časovno odvisnih lastnosti na delovanje (mehanske lastnosti) in življenjsko dobo polimernih izdelkov (zobniki, tesnila, ventili, ...)

stress-strain state of viscoelastic materials using material functions

5. Content of Lecture 5: LINEAR THEORY of VISCOELASTICITY

Linear and non-linear behaviour of materials, Practical meaning of linear theory of viscoelasticity, Determination of stress limit

6. Content of Lecture 6: TIME DEPENDENCY of MECHANICAL PROPERTIES

Relaxation time, Thixotropy, Physical aging, Mechanical spectra

7. Content of Lecture 7: EFFECT of TEMPERATURE on RHEOLOGICAL and MECHANICAL PROPERTIES of POLYMERS

Temperature tests, Determination of phase transitions with dynamic moduli, Degradation

8. Content of Lecture 8: RHEOLOGICAL MEASUREMENTS of POLYMER MATERIALS

Selection of the proper rheological method, Interpretation of the results of rheological measurements, Relation of rheological properties with the structure of polymer

9. Content of Lecture 9: The IMPORTANCE of the RHEOLOGICAL PROPERTIES of POLYMER MATERIALS in RESEARCH and DESIGN

Relation of the rheological properties of melt with process parameters of polymer processing, Influence of viscoelastic properties on the polymer product during processing (Dye swell effect, Weisenberg effect, melt fracture, yield stress, ...), Influence of time dependent properties on the performance (mechanical properties) and life-time of polymer products (gears, seals, valves, ...)

10. - 15 Content of Lecture 10 - 15: SPECIAL APPLICATIONS of RHEOLOGICAL PROPERTIES of POLYMERS in MECHANICAL ENGINEERING - examples

a) Thixotropy - oil industry - problems during drilling, the correct dimensioning of the pump with respect to time and

<p>10.- 15. Vsebina 10.-15. Predavanja: POSEBNE APLIKACIJE POMENA REOLOŠKIH LASTNOSTI POLIMEROV V STROJNIŠTVU - primeri:</p> <p>a) Tikotropija - naftna ind. - problemi pri črpanju nafte - pravilno dimenzioniranje črpalke glede na časovno in strižno odvisen odziv materiala</p> <p>b) Tribologija - pomen reoloških lastnosti pri mazivih (pomen viskoelastičnosti)</p> <p>c) Določanje življenjske dobe polimernih izdelkov (različne aplikacije termoplastov, elastomerov, termosetov, kompozitov)</p> <p>d) Reološke lastnosti posebnih polimernih materialov za različne aplikacije (fero in magneto reološki, kromogeni materiali, samozacelitveni polimeri, ...)</p> <p>e) Brizganje polimernih kompozitov z visoko koncentracijo trdnih delcev - tokovne lastnosti taline, najvišja sprejemljiva koncentracija trdnih delcev, vpliv strukture polimernega kompozita na tokovne lastnosti surovine za brizganje</p> <p>f) Vpliv različnih postopkov recikliranja na reološke in mehanske lastnosti polimernih materialov in kompozitov</p>	<p>shear dependent response of the material</p> <p>b) Tribology - the importance of rheological properties for lubricants (viscoelasticity)</p> <p>c) Determination of life-time for polymer products (different applications of thermoplasts, elastomers, thermosets, composites)</p> <p>d) Rheological properties of special polymer materials for various applications (ferro and magneto-rheological, chromogenic materials, self-healing polymers, ...)</p> <p>e) Injection moulding of highly filled polymer composites - flow properties of the melt, the highest possible concentration of the particles, the effect of composite structure on flow properties of the feedstock</p> <p>f) The effect of various recycling procedures on rheological and mechanical properties of polymers and composites</p>
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Temeljna literatura in viri/Readings:

1. Shaw M.T.: Introduction to Polymer Rheology, John Wiley & Sons, 2012, ISBN - 978-0-470-38844-0, [COBISS.SI-ID [127146755](#)]
2. Ferry J.D.: Viscoelastic Properties of Polymers, John Wiley & Sons, 1980, ISBN - 0-471-04894-1, [COBISS.SI-ID [139823](#)]
3. Osswald T.A., Rudolph N.: Polymer Rheology Fundamentals and Applications, Hanser Publishers, 2014, ISBN - 978-1-56990-517-3, [COBISS.SI-ID [100459267](#)]
4. Lakes R.S.: Viscoelastic materials, Cambridge University Press, 2009, ISBN - 978-0-521-88568-3, [COBISS.SI-ID [11300123](#)]
5. Ward I.M., Sweeney J.: Mechanical properties of solid polymers. John Wiley & Sons, 2012, ISBN - 0-471-91995-0, [COBISS.SI-ID [141289](#)]

Cilji in kompetence:

Objectives and competences:

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<p>Cilji:</p> <ol style="list-style-type: none"> 1. Cilj 1: spoznati pomen reologije pri polimernih materialih 2. Cilj 2: spoznati določevanje reoloških lastnosti in interpretacijo rezultatov 3. Cilj 3: spoznati različne primere aplikacije reoloških lastnosti v strojništvu 4. Cilj 4: spoznati pomen reoloških lastnosti polimernih materialov pri razvoju produktov in načrtovanju procesov 5. Cilj 5: spoznati znanstveno literaturo raziskav na področju reoloških lastnosti polimerov v strojniških aplikacijah <p>Kompetence:</p> <ol style="list-style-type: none"> 1. Kompetenca 1: aplikacija reoloških lastnosti pri uporabi polimernih izdelkov (S2-MAG, P1-MAG) 2. Kompetenca 2: sposobnost interpretacije in analize eksperimentalnih reoloških rezultatov (S2-MAG, P3-MAG) 3. Kompetenca 3: sposobnost uporabe reoloških lastnosti v posebnih strojniških aplikacijah (S7-MAG, S10-MAG, P2-MAG) 4. Kompetenca 4: sposobnost uporabe reoloških lastnosti pri razvoju produktov in načrtovanju procesov (S1-MAG, S2-MAG, P7-MAG) 5. Kompetenca 5: sposobnost analize objavljenih znanstvenih rezultatov (S5-MAG, S8-MAG, P5-MAG) 	<p>Objectives:</p> <ol style="list-style-type: none"> 1. Aim 1: to understand the importance of rheology for polymer materials 2. Aim 2: to understand the determination of rheological properties and interpretation of the obtained results 3. Aim 3: to learn about the importance of rheological properties in mechanical engineering 4. Aim 4: to learn about the rheological properties of polymer materials in R&D 5. Aim 5: to understand the scientific literature in the field of rheological properties of polymers in mechanical engineering <p>Competences:</p> <ol style="list-style-type: none"> 1. Competence 1: application of rheological properties for polymer products (S2-MAG + P1-MAG) 2. Competence 2: the ability to analyze the experimental results of rheological tests (S2-MAG + P3-MAG) 3. Competence 3: the ability to apply rheological properties in special process applications (S7-MAG, S10-MAG + P2-MAG) 4. Competence 4: the ability to use rheological properties in R&D (S1-MAG, S2-MAG + P7-MAG) 5. Competence 5: the ability to analyse the published scientific results (S5-MAG, S8-MAG + P5-MAG)
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Predvideni študijski rezultati:

<p>Znanja:</p> <p>Poglobljeno strokovno teoretično in praktično znanje na področju reoloških lastnosti polimernih materialov s poudarkom na strojniških aplikacijah.</p> <p>Spretnosti:</p> <ol style="list-style-type: none"> 1. S2.1 priprava osnovnih metod za 	<p>Knowledge:</p> <p>In-depth theoretical and practical knowledge of rheological properties of polymers with the emphasis on mechanical engineering applications</p> <p>Skills:</p> <ol style="list-style-type: none"> 1. S2.1 preparation of basic methods
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določevanje reoloških lastnosti polimerov	for determination of rheological properties of polymers
2. S2.2 uporaba različnih metod za načrtovanje in interpretacijo reološkega obnašanja polimerov v realnih procesnih aplikacijah	2. S2.2 application of various rheological methods for prediction and interpretation of rheological behaviour of polymers in real process applications.

Metode poučevanja in učenja:

1. Metoda 1: Klasične oblike poučevanja:
<ul style="list-style-type: none"> • P1 Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov. • P2 Obravnava snovi po urejeni in vnaprej razloženi sistematiki. • P5 Uporaba študijskega gradiva v obliki skripta, e-verzija predstavitve predavanj
2. Metoda 2: Moderne in prožne oblike poučevanja:
<ul style="list-style-type: none"> • P7 Študij literature in razprava • P8 Izdelava in predstavitev aplikativnih seminarskih nalog • P10 Uporaba anket v realnem času • P14 Virtualni eksperimenti • P15 Uporaba video vsebin kot priprava na predavanja

Learning and teaching methods:

1. Method 1: Conventional teaching methods:
<ul style="list-style-type: none"> • P1 Auditorial lectures with solving selected field - specific theoretical and applied use cases. • P2 Presenting the content according to the explained system. • P5 Application of study material (textbook, e-book of the lectures).
2. Method 2: Contemporary and flexible teaching methods:
<ul style="list-style-type: none"> • P7 Literature study and discussion. • P8 Making and presenting applied seminar exercises. • P10 Application of questionnaires in real time. • P14 Virtual experiments. • P15 Application of videos for preparations to the lectures and exercises

Načini ocenjevanja:

Delež/ Weight

Assessment:

- Teoretične vsebine (predavanja)	40,00 %	- Theoretical part (lectures)
- Samostojno delo na vajah	30,00 %	- Individual work during laboratory practice
- Delo na laboratorijskih vajah (vključno s poročili)	30,00 %	- Laboratory work (report included)

Ocenjevalna lestvica:

Grading system:

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Reference nosilca/Lecturer's references:

Lidija Slemenik Perše:

1. **SLEMENIK PERŠE, Lidija**, HUSKIĆ, Miroslav. Rheological characterization of multiarm star copolymers. European Polymer Journal, ISSN 0014-3057. [Print ed.], Mar. 2016, vol. 76, str. 188-195. [COBISS.SI-ID [5862682](#)]
2. OSELI, Alen, TOMKOVIĆ, Tanja, HATZIKIRIAKOS, Savvas G., VESEL, Alenka, ARZENŠEK, Matija, ROJAC, Tadej, MIHELČIČ, Mohor, **SLEMENIK PERŠE, Lidija**. Carbon nanotube network formation and configuration/morphology on reinforcing and conductive performance of polymer-based nanocomposites. Composites science and technology. 26 May 2023, vol. 237, [article no.] 110010, str. 1-9, ilustr. ISSN 1879-1050.
<https://www.sciencedirect.com/science/article/pii/S0266353823001033>,
<https://repozitorij.uni-lj.si/IzpisGradiva.php?id=145001>, DOI:
10.1016/j.compscitech.2023.110010. [COBISS.SI-ID [147041027](#)]
3. **SLEMENIK PERŠE, Lidija**, MIHELČIČ, Mohor, OREL, Boris. Rheological and optical properties of solar absorbing paints with POSS-treated pigments. Materials chemistry and physics, ISSN 0254-0584. [Print ed.], Jan. 2015, vol. 149/150, str. 368-377. [COBISS.SI-ID [5607706](#)]
4. OBLAK, Pavel, AULOVA, Alexandra, BEK, Marko, **SLEMENIK PERŠE, Lidija**. The Influence of HDPE recycling on rheological properties and processing conditions. V: KÁDÁR, R. (ur.). Papers presented at the Nordic Rheology Conference, Trondheim, Norway, June 14-15, 2018, Nordic Rheology Conference, Trondheim, Norway, June 14-15, 2018, (Annual transactions of the Nordic Rheology Society, ISSN 1601-4057, Vol. 26). [Trondheim]: Nordic Rheology Society. 2018, vol. 26, str. 103-107. [COBISS.SI-ID [16139291](#)]
5. BEK, Marko, GONZALEZ-GUTIERREZ, Joamin, KUKLA, Christian, **SLEMENIK PERŠE, Lidija**. Flow characteristics of highly filled polymers for powder injection molding. V: Polytrib 2018, 3rd International Conference on Polymer Tribology, 24th-25th September 2018, Portorož, Slovenia. [Ljubljana]: Slovenian Society for Tribology. 2018. [COBISS.SI-ID [16264731](#)]