

UČNI NAČRT PREDMETA/COURSE SYLLABUS

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

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

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

| Predavanja | Seminar | Vaje | Klinične vaje | Druge oblike študija | Samostojno delo | ECTS |
|------------|---------|------|---------------|----------------------|-----------------|------|
| 30 | | 30 | | | 65 | 5 |

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| Nosilec predmeta/Lecturer: | Lidija Slemenik Perše |
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| Vrsta predmeta/Course type: | Obvezni strokovni predmet na smeri Mehanika, ki je 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. |
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| Jeziki/Languages: | Predavanja/Lectures: | Slovenščina |
| | Vaje/Tutorial: | Slovenščina |

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

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

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| 1. Vsebina 1. Predavanja: UVOD Osnovni reološki pojmi in količine, Materialne funkcije v časovnem in frekvenčnem prostoru, Osnovni tokovni režimi, Vpliv molekulske mase | 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 |
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| <p>na mehanske in reološke lastnosti</p> <p>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</p> <p>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</p> <p>4. Vsebina 4. Predavanja: VISKOELASTIČNOST Lezenje in relaksacija – zveze med 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</p> <p>5. Vsebina 5. Predavanja: LINEARNA TEORIJA VISKOELASTIČNOSTI Linearno in nelinearno vedenje materialov, Praktični pomen teorije linearne viskoelastičnosti, Določanje napetostne limite</p> <p>6. Vsebina 6. Predavanja: ČASOVNA ODVISNOST MEHANSKIH LASTNOSTI Relaksacijski čas, Tiksotropija, Fizikalno staranje, Mehanski spekter</p> <p>7. Vsebina 7. Predavanja: VPLIV TEMPERATURE NA REOLOŠKE in MEHANSKE LASTNOSTI POLIMEROV Temperaturni testi, Določanje faznih prehodov na podlagi dinamičnih modulov, Degradacija</p> <p>8. Vsebina 8. Predavanja: REOLOŠKE MERITVE POLIMERNIH MATERIALOV Izbira ustrezne reološke metode, Interpretacija rezultatov reoloških meritev, Povezava reoloških lastnosti s strukturo polimera</p> <p>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, ...)</p> <p>10. – 15. Vsebina 10.-15. Predavanja: POSEBNE APLIKACIJE POMENA REOLOŠKIH LASTNOSTI POLIMEROV V STROJNIŠTVU – primeri:</p> | <p>Instruments for determination of rheological properties, Geometries of sensor systems, Methods for determination of rheological properties of melts and solids, Calculation of rheological parameters</p> <p>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</p> <p>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 stress-strain state of viscoelastic materials using material functions</p> <p>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</p> <p>6. Content of Lecture 6: TIME DEPEDENCY of MECHANICAL PROPERTIES Relaxation time, Thixotropy, Physical aging, Mechanical spectra</p> <p>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</p> <p>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</p> <p>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, ...)</p> <p>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 shear dependent response of the material b) Tribology – the importance of rheological properties for lubricants (viscoelasticity)</p> |
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| <p>a) Tikсотropija – 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>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. Vir 1: Shaw M.T.: Introduction to Polymer Rheology, John Wiley & Sons, 2012
2. Vir 2: Ferry J.D.: Viscoelastic Properties of Polymers, John Wiley & Sons, 1980
3. Vir 3: Osswald T.A., Rudolph N.: Polymer Rheology Fundamentals and Applications, Hanser Publishers, 2014
4. Vir 4: Lakes R.S.: Viscoelastic materials, Cambridge University Press, 2009
5. Vir 5: Ward I.M., Sweeney J.: Mechanical properties of solid polymers. John Wiley & Sons, 2012

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 | <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 |
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| (S2-MAG, P3-MAG) | experimental results of rheological tests (S2-MAG + P3- MAG) |
| 3. Kompetenca 3: sposobnost uporabe reoloških lastnosti v posebnih strojniških aplikacijah (S7-MAG, S10-MAG, P2-MAG) | 3. Competence 3: the ability to apply rheological properties in special process applications (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) | 4. Competence 4: the ability to use rheological properties in R&D (S1-MAG, S2-MAG + P7-MAG) |
| 5. Kompetenca 5: sposobnost analize objavljenih znanstvenih rezultatov (S5-MAG, S8-MAG, P5-MAG) | 5. Competence 5: the ability to analyse the published scientific results (S5-MAG, S8-MAG + P5-MAG) |

Predvideni študijski rezultati:

Intended learning outcomes:

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| <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 določevanje reoloških lastnosti polimerov 2. S2.2 uporaba različnih metod za načrtovanje in interpretacijo reološkega obnašanja polimerov v realnih procesnih aplikacijah | <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 for determination of rheological properties of polymers 2. S2.2 application of various rheological methods for prediction and interpretation of rheological behaviour of polymers in real process applications. |
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Metode poučevanja in učenja:

Learning and teaching methods:

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| <ol style="list-style-type: none"> 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 | <ol style="list-style-type: none"> 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 |
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Načini ocenjevanja:

Delež/Weight Assessment:

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

Reference nosilca/Lecturer's references:

Lidija Slemenik Perše

1. Ref 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.
2. Ref 2: SLEMENIK PERŠE, Lidija, BIZJAK, Aleš, OREL, Boris. The role of rheological properties and spraying parameters on the spectral selectivity of Thickness Insensitive Spectrally Selective (TISS) paint coatings. Solar energy materials and solar cells, ISSN 0927-0248. [Print ed.], Mar. 2013, vol. 110, str. 115-125
3. Ref 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.
4. Ref 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.
5. Ref 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.