KONSTRUIRANJE NA UTRUJANJE

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Konstruiranje na utrujanje
Course title:	Fatigue Design
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo - projektno aplikativni program, prva stopnja, visokošolski strokovni (od študijskega leta 2026/2027 dalje)	Konstruiranje strojev in naprav (smer)	3. letnik	1. semester	obvezni

Univerzitetna koda predmeta/University course code:	0563429
Koda učne enote na članici/UL Member course code:	3046-V

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			40	4

Nosilec predmeta/Lecturer:	prof. dr. Jernej Klemenc, prof. dr. Marko Nagode, izr. prof. dr. Simon Oman, izr. prof. dr. Domen Šeruga

Izvajalci predavanj:	
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	
Izvajalci praktičnega usposabljanja:	

Vrsta predmeta/Course type:	Izbirni strokovni predmet/Elective specialised course

Jeziki/Languages:	Predavanja/Lectures:	Slovenščina
	Vaje/Tutorial:	Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:	Prerequisites:
Izpolnjevanje pogojev za vpis v Visokošolski strokovni študijski program I. stopnje Strojništvo - Projektno aplikativni program.	Meeting the enrollment conditions for the MECHANICAL ENGINEERING - Project Oriented Applied Programme.

Vsebina:	Content (Syllabus outline):
1. Predavanje: Uvod v konstruiranje na utrujanje. 2. Predavanje: Obdelava naključnih zgodovin obremenitev:	1. Lecture: Introduction into fatigue design. 2. Lecture: Treatment of random load histories: - Compression and filtering.

- Komprimiranje in filtriranje. 3. Predavanje: Števne metode: - Enoparametrične in dvoparametrične. 4. Predavanje: Naprave za teste utrujanja in lezenja: - Možnosti in omejitve. 5. Predavanje: Preskušanci za teste utrujanja in lezenja. 6. Predavanje: Posebne zahteve za preskušanje ploščatih preskušancev in preskušanje pri visokih oziroma nizkih temperaturah. 7. Predavanje: Velikociklično utrujanje: - SN krivulje za različne materiale in koncentratorje napetosti. - Standardni postopki določitve SN krivulj z raztrosi. 8. Predavanje: Vpliv oblike izdelka na koncentracije napetosti: - Zarezni in podporni učinek. - Povezava z velikostjo obremenitve. 9. Predavanje: Vpliv oblike izdelka na koncentracije napetosti: - Principi dobrega in slabega oblikovanja glede na koncentracije napetosti. 10. Predavanje: Malociklično utrujanje. Stabilizirane ciklične napetostno - deformacijske krivulje: - Standardni postopki določitve napetostno - deformacijskih krivulj. 11. Predavanje: Malociklično utrujanje. EN krivulje za različne materiale in koncentratorje napetosti: - Standardni postopki določitve EN krivulj z raztrosi. 12. Predavanje: Trajna dinamična trdnost: - Postopki določitve trajne dinamične trdnosti. 13. Predavanje: Ciklično lezenje in relaksacija: - Krivulje lezenja. - Postopki določitve krivulj lezenja. 14. Predavanje: Rast utrujenostnih poškodb: - Krivulje rasti utrujenostnih poškodb. - Postopki določitve krivulj rasti utrujenostnih poškodb. 15. Predavanje: Programska oprema za vrednotenje na utrujanje in lezenje.	3. Lecture: Counting methods: - Univariate and bivariate. 4. Lecture: Hardware for fatigue and creep tests: - Possibilities and limitations. 5. Lecture: Test specimens for fatigue and creep tests. 6. Lecture: Special requests regarding flat specimen testing and testing at high or low temperatures. 7. Lecture: High cycle fatigue: - SN curves for different materials and stress concentrations. - Standardized procedures for SN curve and its scatter determination. 8. Lecture: Product shape influence on stress concentrations: - Notch effect and support effect. - Load magnitude and notch and support effect. 9. Lecture: Product shape influence on stress concentrations: - Principles of good and bad design regarding stress concentrations. 10. Lecture: Low cycle fatigue. Stabilized cyclic stress - strain curves: - Standardized procedures for stress - strain curve determination. 11. Lecture: Low cycle fatigue. EN curves for different materials and stress concentrations: - Standardized procedures for EN curve and its scatter determination. 12. Lecture: Endurance limit: - Procedures for endurance limit determination. 13. Lecture: Cyclic creep and relaxation: - Creep curves. - Procedures for creep curve determination. 14. Lecture: Crack growth: - Crack growth curves. - Procedures for crack growth curve determination. 15. Lecture: Software equipment for fatigue and creep evaluations.

Temeljna literatura in viri/Readings:

1. Dowling, Norman E. ; Kampe, Stephen L. ; Kral, Milo V. Mechanical behavior of materials : engineering methods for deformation, fracture, and fatigue [COBISS.SI-ID 52374787]
2. Farahmand, Bahram ; Bockrath, George ; Glassco, James. Fatigue and fracture mechanics of high risk parts : application of LEFM & FMDM theory [COBISS.SI-ID 18108677]
3. Dowling, Norman E. Mechanical behavior of materials : engineering methods for deformation, fracture, and fatigue [COBISS.SI-ID 12600859]

Cilji in kompetence:	**Objectives and competences:**
Cilji: 1. Spoznati načine obdelave naključnih zgodovin obremenitev ter števne metode. 2. Spoznati naprave za teste utrujanja in lezenja.	Objectives: 1. Gain knowledge of processing random loading histories and counting methods. 2. Gain knowledge of test rigs for fatigue and creep tests.

3. Spoznati preskušance za teste utrujanja in lezenja ter posebnosti preskušanja ploščatih preskušancev in preskušanja pri nizkih oziroma visokih temperaturah. 4. Spoznati vzroke za koncentracije napetosti ter dobre in slabe prakse oblikovanja izdelkov. 5. Spoznati standardne postopke določitve materialnih parametrov utrujanja in lezenja. 6. Spoznati programsko opremo za vrednotenje na utrujanje in lezenje. Kompetence: 1. S1-PAP: Sposobnost uporabe postopkov za eksperimentalno določanje materialnih parametrov utrujanja in lezenja v praksi. 2. S9-PAP: Upoštevanje varnostnih in funkcionalnih načel pri izvajanju preskusov utrujanja in lezenja. 3. S12-PAP: Sposobnost uporabe programske opreme za izvajanje preskusov utrujanja in lezenja ter za vrednotenja na utrujanje in lezenje. 4. P4-PAP: Poznavanje osnovne merilne instrumente in merilne verige za preskuse utrujanja in lezenja. 5. P7-PAP: Pozna nekatera potrebna programska orodja za računalniško obdelavo podatkov.	3. Gain knowledge of fatigue and creep specimens as well as peculiarities of flat specimens and testing at high and low temperatures, respectively. 4. Gain knowledge of causes for peak stresses as well as good and bad design of products. 5. Gain knowledge of standard procedures to determine fatigue and creep material parameters. 6. Gain knowledge of computer software to evaluate fatigue and creep. Competences: 1. S1-PAP: The ability to use procedures for experimental determination of fatigue and creep material parameters in the practice. 2. S9-PAP: Considering the safety, functional, economic and environmental principles in fatigue and creep experiments. 3. S12-PAP: The ability to use information and communications technology in performing fatigue and creep tests as well as in evaluating fatigue and creep. 4. P4-PAP: Knowing the basic measuring instruments and measuring chains used to test fatigue and creep. 5. P7-PAP: Knowing some software tools necessary for computer data processing.

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanja: Z1: Poglobljeno strokovno teoretično in praktično znanje na določenem področju, podprto s širšo teoretično in metodološko osnovo: • Razumevanje naključnih obremenitvenih signalov in pridobivanje ključnih informacij. • Razumevanje delovanja preskuševališč za teste utrujanja in lezenja ter priprave testov. • Razumevanje parametričnega opisa rezultatov meritev in obdelave podatkov. Spretnosti: S1.1 Izvajanje kompleksnih operativno-strokovnih opravil, ki vključujejo tudi uporabo metodoloških orodij: • Določitev zdržljivostnih krivulj. • Oblikovanje izdelkov s ciljem nizkih koncentracij napetosti. S1.2 Obvladovanje zahtevnih, kompleksnih delovnih procesov ob samostojni uporabi znanja v novih delovnih situacijah: • Izvedba preskusov za določitev zdržljivostnih krivulj.	Knowledge: Z1: In-depth professional theoretical and practical knowledge of a certain field, supported by a broader theoretical and methodological fundament: • Understanding of random load signals and extraction of the key information • Understanding of working principles of test rigs for fatigue and creep tests as well as understanding of a test setup. • Understanding of parametric description of the test results and data processing. Skills: S1.1 Performance of complex operational-professional tasks which include the use of methodological tools: • Determination of durability curves. • Design of products targeting forms with low peak stresses. S1.2 Mastering of demanding, complex operational processes and autonomous use of knowledge in new professional circumstances: • Performance of tests for determination of durability curves.

Metode poučevanja in učenja:	**Learning and teaching methods:**
P1: Avditorna predavanja z reševanjem izbranih teoretičnih in praktično uporabnih primerov. P7: Študij literature in razprava - študentje na predavanjih razložijo del snovi, ki so jo naštudirali sami.	P1: Auditory lectures including solution procedures for selected theoretical and practical examples. P7: Literature study and discussion – students explain a part of the syllabus at the auditory lectures which they have acquainted themselves with by self-study.

P3: Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. P4: Laboratorijske vaje, kjer se teoretično znanje s predavanj podkrepi z laboratorijskimi preskusi.	P3: Auditory exercises where theoretical knowledge gained at auditory lectures is substantiated by numerical examples. P4: Laboratory exercises where theoretical knowledge gained at auditory lectures is substantiated by laboratory experiments.

Načini ocenjevanja:	**Delež/Weight**	**Assessment:**
Teoretične vsebine (predavanja).	50,00 %	Theoretical knowledge (lectures).
Samostojno delo na vajah.	35,00 %	Individual work at exercises.
Delo na laboratorijskih vajah (vključno s poročili).	15,00 %	Work at laboratory exercises (including reports).

Ocenjevalna lestvica:	**Grading system:**
5 - 10, pri čemer velja, da je pozitivna ocena od 6 - 10	5 - 10, a student passes the exam if he is graded from 6 to 10

Reference nosilca/Lecturer's references:

Marko Nagode:

1. DURJAVA, Aleš, **NAGODE, Marko**, ŠERUGA, Domen. Applicability of memory rules during cyclic stress–strain response of polymers PA6 and PA66 GF30. Materials today communications. Jun. 2023, vol. 35, str. 1-10, ilustr. ISSN 2352-4928. https://www.sciencedirect.com/science/article/pii/S2352492823010334, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=148421, DOI: 10.1016/j.mtcomm.2023.106342. [COBISS.SI-ID 161846019]
2. ŠERUGA, Domen, GOSAR, Aleš, SWEENEY, Caoimhe A., JAGUEMONT, Joris, MIERLO, Joeri Van, **NAGODE, Marko**. Continuous modelling of cyclic ageing for lithium-ion batteries. Energy. Jan. 2021, vol. 215, part b, str. 1-14, ilustr. ISSN 0360-544 https://www.sciencedirect.com/science/article/abs/pii/S0360544220321861?via%3Dihub, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=121873, DOI: 10.1016/j.energy.2020.119079. [COBISS.SI-ID 35666179]
3. **NAGODE, Marko**, KLEMENC, Jernej. Modelling of load spectra containing clusters of less probable load cycles. International journal of fatigue. Feb. 2021, vol. 143, str. 1-10, ilustr. ISSN 0142-112 https://www.sciencedirect.com/science/article/abs/pii/S0142112320305387, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=121869, DOI: 10.1016/j.ijfatigue.2020.106006. [COBISS.SI-ID 35679235]
4. KLEMENC, Jernej, ŠERUGA, Domen, **NAGODE, Marko**. A durability prediction for the magnesium alloy AZ31 based on plastic and total energy. Metals. Sep. 2019, vol. 9, iss. 9, f. 1-16, ilustr. ISSN 2075-4701. https://www.mdpi.com/2075-4701/9/9/973, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=109459, DOI: 10.3390/met9090973. [COBISS.SI-ID 16772379]
5. ŠERUGA, Domen, **NAGODE, Marko**, MALNARIČ, Vili, KLEMENC, Jernej. Priprava za vpetje ploščatega preizkušanca med izvajanjem cikličnega preizkusa mehanske trdnosti materiala : patent SI 25679 A, 2020-01-31. Ljubljana: Urad Republike Slovenije za intelektualno lastnino, 2020. 6 f., ilustr. [COBISS.SI-ID 16335899]

Jernej Klemenc:

1. TOMAŽINČIČ, Dejan, VESENJAK, Matej, **KLEMENC, Jernej**. Prediction of static and low-cycle durability of porous cellular structures with positive and negative Poisson's ratios. Theoretical and Applied Fracture Mechanics. [Print ed.]. Apr. 2020, vol. 106 (102479), str. 1-13, ilustr. ISSN 0167-8442. https://www.sciencedirect.com/science/article/pii/S0167844219307323, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=113842, DOI: 10.1016/j.tafmec.2020.102479. [COBISS.SI-ID 22988310]
2. TOMAŽINČIČ, Dejan, BOROVINŠEK, Matej, REN, Zoran, **KLEMENC, Jernej**. Improved prediction of low-cycle fatigue life for high-pressure die-cast aluminium alloy AlSi9Cu3 with significant porosity. International journal of fatigue. Mar. 2021, vol. 144, str. 1-12, ilustr. ISSN 0142-1123. https://www.sciencedirect.com/science/article/pii/S0142112320305934?via%3Dihub, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=124298, DOI: 10.1016/j.ijfatigue.2020.106061. [COBISS.SI-ID 46594307]

3. **KLEMENC, Jernej**, ŠERUGA, Domen, NAGODE, Marko. A durability prediction for the magnesium alloy AZ31 based on plastic and total energy. Metals, Sep. 2019, vol. 9, iss. 9, f. 1-16, doi: 10.3390/met909097 [COBISS.SI-ID 16772379]
4. **KLEMENC, Jernej**, PODGORNIK, Bojan. An improved model for predicting the scattered S-N curves. Strojniški vestnik, May 2019, vol. 65, no. 5, str. 265-275, doi: 10.5545/sv-jme.2018.5918. [COBISS.SI-ID 16644891]
5. ŠERUGA, Domen, **KLEMENC, Jernej**, OMAN, Simon, NAGODE, Marko. Stress-strain simulation of a porous metallic material using femimplemented prandtl operator approach. V: IBRAHIMBEGOVIĆ, Adnan (ur.), DOLAREVIĆ, Samir (ur.), ČOHODAR HUSIĆ, Maida (ur.). ECCOMAS MSF 2023 : 6th International Conference on Multi-scale Computational Methods for Solids and Fluids, June 25-27, 2023, Sarajevo : proceedings. Sarajevo: Faculty of Civil Engineering, 2023. Str. 73-76, ilustr. ISBN 978-9958-638-73- https://eccomas.gf.unsa.ba/Eccomas_2023_proceedings.pdf. [COBISS.SI-ID 155649027]

Domen Šeruga:

1. LITROP, Aljaž, KLEMENC, Jernej, NAGODE, Marko, **ŠERUGA, Domen**. Enhanced cyclically stable plasticity model for multiaxial behaviour of magnesium alloy AZ31 under low-cycle fatigue conditions. *Materials*. Sep 2024, vol. 17, iss. 18, [article no.] 4659, str. 1-22, ilustr. ISSN 1996-1944. https://www.mdpi.com/1996-1944/17/18/4659, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.3390/ma17184659. [COBISS.SI-ID 208986627].
2. KLEMENC, Jernej, **ŠERUGA, Domen**, NAGODE, Marko. A durability prediction for the magnesium alloy AZ31 based on plastic and total energy. Metals, ISSN 2075-4701, Sep. 2019, vol. 9, iss. 9, f. 1-16, ilustr. https://www.mdpi.com/2075-4701/9/9/973, doi: 10.3390/met9090973. [COBISS.SI-ID 16772379].
3. **ŠERUGA, Domen**, NAGODE, Marko, KLEMENC, Jernej. Stress-strain response determination during incremental step tests and variable loadings on flat specimens. Technologies, ISSN 2227-7080, 2019, vol. 7, iss. 3, f. 1-9, ilustr. https://www.mdpi.com/2227-7080/7/3/53/htm, doi: 10.3390/technologies703005 [COBISS.SI-ID 16744731].
4. **ŠERUGA, Domen**, KLEMENC, Jernej, OMAN, Simon, NAGODE, Marko. A coupled simulation of parametric porous microstructure and stress-strain behavior in mechanical components under variable cyclic loads. Coupled systems mechanics : an international journal. Oct. 2023, vol. 12, no. 5, str. 409-418, ilustr. http://www.techno-press.org/content/?page=article&journal=csm&volume=12&num=5&ordernum=2. [COBISS.SI-ID 170212355].
5. LITROP, Aljaž, ZOBEC, Peter, **ŠERUGA, Domen**, NAGODE, Marko, KLEMENC, Jernej. Experimental analysis of crack initiation and propagation in dynamically shear-loaded aluminium specimens using the digital image correlation method. Engineering failure analysis. Sep. 2022, vol. 139, str. 1-11, ilustr. ISSN 1350-6307. https://www.sciencedirect.com/science/article/pii/S1350630722004691. [COBISS.SI-ID 111079427].

Simon Oman:

1. KOCJAN, Tadej, NAGODE, Marko, KLEMENC, Jernej, **OMAN, Simon**. Coupling of fatigue crack growth and crack nucleation fatigue approach for non-crystallising rubber under fully relaxing uniaxial loading with multiaxial stress–strain state of 3D dumbbell test specimen. *Polymer testing*. 2025, vol. 145, [article no.] 108752, 13 str., ilustr. ISSN 1873-2348. https://www.sciencedirect.com/science/article/pii/S0142941825000662?via%3Dihub, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1016/j.polymertesting.2025.108752. [COBISS.SI-ID 229220099]
2. **OMAN, Simon**, KLEMENC, Jernej, GOSAR, Aleš, NAGODE, Marko. Critical factors affecting the strength of climbing ropes : a study of wear, fatigue loading and temperature. *Results in engineering*. 2025, vol. 27, [article no.] 106471, str. 1-16, ilustr. ISSN 2590-1230. https://www.sciencedirect.com/science/article/pii/S259012302502540X, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1016/j.rineng.2025.106471. [COBISS.SI-ID 246191107]
3. NAGODE, Marko, **OMAN, Simon**, KLEMENC, Jernej, ŠERUGA, Domen. Cyclic thermomechanical elasto-viscoplasticity implementation using user material interface. *Materials*. 2025, vol. 18, iss. 11, [art. no.] 2512, str. 1-26, ilustr. ISSN 1996-1944. https://www.mdpi.com/1996-1944/18/11/2512, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.3390/ma18112512. [COBISS.SI-ID 238506499]
4. OKORN, Ivan, NAGODE, Marko, KLEMENC, Jernej, **OMAN, Simon**. Influence of geometric imperfections of flange joints on the fatigue load of preloaded bolts. *International journal of pressure vessels and piping*. Aug. 2024, vol. 210, [art.] 105237, str. 1-16, ilustr. ISSN 1879-3541.

https://www.sciencedirect.com/science/article/pii/S0308016124001145, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1016/j.ijpvp.2024.105237. [COBISS.SI-ID 200732163]

5. NAGODE, Marko, KLEMENC, Jernej, **OMAN, Simon**, ŠERUGA, Domen. Elasto-viscoplastic material modelling using the multiaxial Prandtl operator approach. *International journal of mechanical sciences*. 2024, vol. 267, [article no.] 108953, str. 1-16, ilustr. ISSN 1879-2162. https://www.sciencedirect.com/science/article/pii/S002074032300855X, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1016/j.ijmecsci.2023.108953. [COBISS.SI-ID 183728643]