OBRATOVALNA TRDNOST

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Obratovalna trdnost
Course title:	OPERATIONAL STRENGTH
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	**Študijska smer**	**Letnik**	**Semestri**	**Izbirnost**
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski (od študijskega leta 2024/2025 dalje)	Konstruiranje (smer)	1. letnik	2. semester	obvezni

Univerzitetna koda predmeta/University course code:	0566877
Koda učne enote na članici/UL Member course code:	6027-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:	Domen Šeruga, Jernej Klemenc, Marko Nagode

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

Vrsta predmeta/Course type:	Obvezni strokovni predmet na smeri Konstruiranje, ki je izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Design Engineering, 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. Predavanje: - Uvod v obratovalno trdnost. 2. Predavanje: Poškodbe kristalne rešetke: - Točkovne, linijske in volumske nepravilnosti. - Poškodbe zaradi monotone in ciklične obremenitve. 3. Predavanje: Proces rasti poškodbe: - Vpliv pogojev uporabe in okolja na poškodbe. 4. Predavanje: Velikociklično utrujanje: - Opredelitev območja veljavnosti. - Vpliv napetostnih gradientov, mezo tečenja, hrapavosti površine in velikosti prereza. 5. Predavanje: Velikociklično utrujanje: - SN krivulja. - Hipoteze o akumulaciji in razvoju utrujenostnih poškodb. 6. Predavanje: Velikociklično utrujanje: - Ekvivalentna amplitudna napetost.	1. Lecture: - Introduction into operational strength. 2. Lecture: Defects in crystalline solid: - Point, edge, screw and boundary defects. - Defects due to monotonic and cyclic loading. 3. Lecture: Crack growth propagation: - Influence of usage and environmental conditions on crack growth propagation. 4. Lecture: High cycle fatigue: - Region of validity determination. - Influence of stress gradients, mezzo yielding, surface roughness effect and size effect. 5. Lecture: High cycle fatigue: - SN curve. - Hypothesis on damage accumulation and damage evolution. 6. Lecture: High cycle fatigue: - Equivalent stress amplitude.

- Računanje poškodbe za naključno zgodovino obremenitve: konvencionalni pristop.
7. Predavanje: Velikociklično utrujanje:
   - Računanje poškodbe za naključno zgodovino obremenitve: alternativni pristop.
8. Predavanje: Malociklično utrujanje:
   - Opredelitev območja veljavnosti.
   - Vpliv makro tečenja.
9. Predavanje: Malociklično utrujanje:
   - Napetostno - deformacijski odziv: konvencionalni pristop.
10. Predavanje: Malociklično utrujanje:
   - Napetostno - deformacijski odziv: alternativni pristop.
11. Predavanje: Malociklično utrujanje:
   - EN krivulja.
   - Poškodbeni parametri.
12. Predavanje: Malociklično utrujanje:
   - Računanje poškodbe za naključno zgodovino obremenitve: konvencionalni in alternativni pristop.
13. Predavanje: Ciklično lezenje in relaksacija:
   - Opredelitev območja veljavnosti.
   - Časovno - temperaturni parametri.
   - Računanje poškodbe zaradi lezenja.
14. Predavanje: Rast utrujenostnih poškodb:
   - Opredelitev območja veljavnosti.
   - Fizikalne osnove mehanike loma.
   - Faktor intenzivnosti.
15. Predavanje: Rast utrujenostnih poškodb:
   - Parisov zakon.
   - Računanje poškodbe za naključno zgodovino obremenitve.

- Damage calculation for random load history: conventional procedure.
7. Lecture: High cycle fatigue:
   - Damage calculation for random load history: alternative procedure.
8. Lecture: Low cycle fatigue:
   - Region of validity determination.
   - Influence of macro yielding.
9. Lecture: Low cycle fatigue:
   - Stress - strain response: conventional procedure.
10. Lecture: Low cycle fatigue:
   - Stress - strain response: alternative procedure.
11. Lecture: Low cycle fatigue:
   - EN curve.
   - Damage parameters.
12. Lecture: Low cycle fatigue:
   - Damage calculation for random load history: conventional and alternative procedure.
13. Lecture: Cyclic creep and relaxation:
   - Region of validity determination.
   - Time - temperature parameters.
   - Creep damage calculation.
14. Lecture: Crack growth:
   - Region of validity determination.
   - Physical backgrounds of fracture mechanics.
   - Stress intensity factor.
15. Lecture: Crack growth:
   - Paris law.
   - Damage calculation for random load history.

Temeljna literatura in viri/Readings:

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

[COBISS.SI-ID 18108677]
3. Mechanical behavior of materials : engineering methods for deformation, fracture, and fatigue - Dowling, Norman E. [COBISS.SI-ID 12600859]
4. Mechanics of solid materials - Lemaître, Jean, 1934- ; Chaboche, Jean-Louis [COBISS.SI-ID 6898715]

Cilji in kompetence:	**Objectives and competences:**
Cilji: 1. Spoznati poškodbe kristalne rešetke zaradi ciklične in monotone obremenitve. 2. Spoznati proces rasti poškodbe in vplive nanje. 3. Spoznati in razumeti velikociklično in malociklično utrujanje, rast utrujenostnih poškodb ter se naučiti uporabe pripadajočih metod in programske opreme na praktičnih primerih. 4. Nadgraditi temeljna strojniška znanja in jih uporabiti na praktičnih primerih. Kompetence: 1. S1-MAG: Sposobnost za opredelitev, razumevanje temeljnih znanstvenih problemov in ustvarjalno reševanje strokovnih izzivov na področju obratovalne trdnosti. 2. S7-MAG: Usposobljenost za uporabo pridobljenih znanj pri samostojnem reševanju tehničnih problemov na področju obratovalne trdnosti. 3. P1-MAG: Sposobnost za nadgradnje in uporabo temeljnih strojniških znanj ter njihovo razvojno-tehniško implementacijo. 4. P4-MAG: Sposobnost fizikalnega, matematičnega in numeričnega modeliranja problemov z razvito sposobnostjo kritične analize rezultatov.	Objectives: 1. Gain knowledge of damage of crystal lattice due to cyclic and monotonous loading. 2. Gain knowledge of the damage growth process and the influences to this process. 3. Gain knowledge and understand high cycle and low cycle fatigue, fatigue crack growth and learn to use associated methods and computer software on practical examples. 4. Upgrade fundamental knowledge of mechanical engineering and use it on practical examples. Competences: 1. S1-MAG: The ability to define and understand fundamental scientific problems and to creatively deal with professional challenges in the field of operational strength. 2. S7-MAG: The qualification to use the attained knowledge to autonomously solve technical problems in the field of operational strength. 3. P1-MAG: The ability to upgrade and use the fundamental mechanical engineering knowledge, including the developmental-technical implementation thereof. 4. P4-MAG: The ability for physical, mathematical and numerical modelling of problems, including a developed ability to critically analyse the results.

Predvideni študijski rezultati:	**Intended learning outcomes:**

Znanja: Z2: Poglobljeno teoretično, metodološko in analitično znanje z elementi raziskovanja, ki je osnova za zelo zahtevno strokovno delo: • Razumevanje in obvladovanje mehanizmov, ki lahko privedejo do poškodb zaradi ciklične in monotone obremenitve. • Obvladovanje metod za napovedovanje dobe trajanja zaradi velikocikličnega in malocikličnega utrujanja ter lezenja. • Razumevanje in obvladovanje metod za napovedovanje rasti utrujenostnih poškodb. Spretnosti: S2.1 Obvladovanje zelo zahtevnih, kompleksnih delovnih procesov in metodoloških orodij na specializiranih področjih: • velikociklično in malociklično utrujanje, • lezenje in rast utrujenostnih poškodb. S2.3 Sposobnost izvirnih dognanj/stvaritev in kritične refleksije na področju obratovalne trdnosti.	Knowledge: Z2: In-depth theoretical, methodological and analytical knowledge with elements of research, which is fundamental for very demanding professional tasks: • Understanding and mastering mechanisms that lead to damage due to cyclic and monotonous loading. • Mastering methods to predict durability due to high cycle and load-cycle fatigue and creep. • Understanding and mastering methods to predict fatigue crack growth. Skills: S2.1 Mastering of very demanding, complex professional tasks and methodological tools in specialised fields: • high cycle and low cycle fatigue, • creep and fatigue crack growth. S2.3 Ability of original breakthroughs/creations and critical reflection in the field of operational strength.

Metode poučevanja in učenja:	**Learning and teaching methods:**
1. P1: Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov. 2. P7: Študij literature in razprava. 3. P3: Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. 4. P4: Laboratorijske vaje z namenskimi didaktičnimi pripomočki (uporaba hibridnega vozila, razvitega na FS). 5. P14: Virtualni eksperimenti.	1. P1: Auditory lectures including solution procedures for selected – for the field typical - theoretical and practical examples. 2. P7: Literature study and discussion. 3. P3: Auditory exercises where theoretical knowledge gained at auditory lectures is substantiated by numerical examples. 4. P4: Laboratory exercises using purposeful educational accessories (use of the hybrid vehicle designed at the Faculty of Mechanical Engineering). 5. P14: Virtual experiments.

Načini ocenjevanja:	Delež/ Weight	Assessment:
Teoretična znanja (pisni kolokviji in izpit z opcijskim ustnim zagovorom).	50,00 %	Theoretical knowledge (written colloquia and exam with an optional oral examination).
Praktična znanja (pisni kolokviji in izpit z opcijskim ustnim zagovorom).	50,00 %	Practical knowledge (written colloquia and exam with an optional oral examination).

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. GOSAR, Aleš, EMRI, Igor, KLEMENC, Jernej, **NAGODE, Marko**, OMAN, Simon. On the vibration-damping properties of the prestressed polyurethane granular material. Polymers. 2023, vol. 15, iss. 5, str. 1-22, ilustr. ISSN 2073-4360. https://www.mdpi.com/2073-4360/15/5/1299, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=144812, DOI: 10.3390/polym15051299. [COBISS.SI-ID 145104131]
2. PANIĆ, Branislav, KLEMENC, Jernej, **NAGODE, Marko**. Optimizing the estimation of a histogram-bin width - application to the multivariate mixture-model estimation. Mathematics. Jul. 2020, vol. 8, iss. 7, f. 1-30, ilustr. ISSN 2227-7390. https://www.mdpi.com/2227-7390/8/7/1090, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=117438, DOI: 10.3390/math8071090. [COBISS.SI-ID 22207235]
3. YE, X. W., XI, P. S., **NAGODE, Marko**. Extension of REBMIX algorithm to von Mises parametric family for modeling joint distribution of wind speed and direction. Engineering structures. [Print ed.]. Mar. 2019, vol. 183, str. 1134-1145, ilustr. ISSN 0141-0296. https://www.sciencedirect.com/science/article/pii/S0141029618303584?via%3Dihub#!, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=106626, DOI: 10.1016/j.engstruct.2018.08.035. [COBISS.SI-ID 16469019]
4. ŠERUGA, Domen, **NAGODE, Marko**, KLEMENC, Jernej. Stress-strain response determination during incremental step tests and variable loadings on flat specimens. Technologies. 2019, vol. 7, iss. 3, f. 1-9, ilustr. ISSN 2227-7080. https://www.mdpi.com/2227-7080/7/3/53/htm, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=108939, DOI: 10.3390/technologies7030053. [COBISS.SI-ID 16744731]
5. ŠERUGA, Domen, KLEMENC, Jernej, **NAGODE, Marko**, OMAN, Simon. Consideration of wall surface roughness in simulations during the pumping operation : project Downhole pump phase 2. Ljubljana: Faculty of Mechanical Engineering, 2022. 9 f., graf. prikazi. [COBISS.SI-ID 121229827]

Jernej Klemenc:

1. **KLEMENC, Jernej,** NAGODE, Marko. Sensitivity of step-stress accelerated fatigue-life tests on type I censored data : an engineering perspective. Fatigue & fracture of engineering materials & structures. 2024, vol. 7, iss. 2, str. 397-412, ilustr. ISSN 1460-2695. https://onlinelibrary.wiley.com/doi/10.1111/ffe.14186, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=153579, DOI: 10.1111/ffe.14186. [COBISS.SI-ID 173920515].
2. BARTOŠÁK, Michal, NAGODE, Marko, **KLEMENC, Jernej**, DOUBRAVA, Karel, ŠERUGA, Domen. Use of Prandtl operators in simulating the cyclic softening of Inconel 718 under isothermal low-cycle fatigue loading. International journal of mechanical sciences. May 2022, vol. 222, str. 1-11, ilustr. ISSN 0020-7403. https://www.sciencedirect.com/science/article/pii/S0020740322001072, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=135896, DOI: 10.1016/j.ijmecsci.202107182. [COBISS.SI-ID 102892035].
3. 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, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=137291, DOI: 10.1016/j.engfailanal.2022.106495. [COBISS.SI-ID 111079427]
4. ŠOLINC, Urša, **KLEMENC, Jernej**, NAGODE, Marko, ŠERUGA, Domen. A direct approach to modelling the complex response of magnesium AZ31 alloy sheets to variable strain amplitude loading using Prandtl-Ishlinskii operators. International journal of fatigue, Oct. 2019, vol. 127, str. 291-304, doi: 10.1016/j.ijfatigue.2019.06.009. [COBISS.SI-ID 16674075]
5. ŠERUGA, Domen, NAGODE, Marko, **KLEMENC, Jernej**. Stress-strain response determination during incremental step tests and variable loadings on flat specimens. Technologies, 2019, vol. 7, iss. 3, f. 1-9, doi: 10.3390/technologies7030053. [COBISS.SI-ID 16744731]

Domen Šeruga:

1. **ŠERUGA, Domen**, NAGODE, Marko. A new approach to finite element modelling of cyclic thermomechanical stress-strain responses. International journal of mechanical sciences, ISSN 0020-7403. [Print ed.], Dec. 2019, vol. 164, str. 1-14, ilustr. https://www.sciencedirect.com/science/article/pii/S0020740319306964?via%3Dihub, doi: 10.1016/j.ijmecsci.2019.105139. [COBISS.SI-ID 16795675],
2. **ŠERUGA, Domen**, NAGODE, Marko, KLEMENC, Jernej. Eliminating friction between flat specimens and an antibuckling support during cyclic tests using a simple sensor. Measurement science & technology, ISSN 0957-0233. [Print ed.], 2019, vol. 30, no. 9, str. 1-15, ilustr. https://iopscience.iop.org/article/10.1088/1361-6501/ab1e35, doi: 10.1088/1361-6501/ab1e35. [COBISS.SI-ID 16600091]
3. **ŠERUGA, Domen**, KOSMAS, Odysseas, JIVKOV, Andrey P. Geometric modelling of elastic and elastic-plastic solids by separation of deformation energy and Prandtl operators. International journal of solids and structures.

[Print ed.]. Aug. 2020, vol. 198, str. 136-148, ilustr. ISSN 0020-7683. [COBISS.SI-ID 17592323]
4. BARTOŠÁK, Michal, NAGODE, Marko, KLEMENC, Jernej, DOUBRAVA, Karel, **ŠERUGA, Domen**. Use of Prandtl operators in simulating the cyclic softening of Inconel 718 under isothermal low-cycle fatigue loading. International journal of mechanical sciences. Maj 2022, vol. 222, str. 1-11, ilustr. ISSN 0020-7403. DOI: 10.1016/j.ijmecsci.202107182. [COBISS.SI-ID 102892035]
5. 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. DOI: 10.1016/j.mtcomm.2023.106342. [COBISS.SI-ID 161846019]