

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
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski	Konstruiranje (smer)	1. letnik	2. semester

Univerzitetna koda predmeta/University course code:	0566877
Koda učne enote na članici/UL Member course code:	6027-M

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

Nosilec predmeta/Lecturer:	Domen Šeruga, Jernej Klemenc, Marko Nagode
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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.
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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):
<ol style="list-style-type: none"> Predavanje: <ul style="list-style-type: none"> - Uvod v obratovalno trdnost. Predavanje: Poškodbe kristalne rešetke: <ul style="list-style-type: none"> - Točkovne, linijske in volumnske nepravilnosti. - Poškodbe zaradi monotone in ciklične 	<ol style="list-style-type: none"> Lecture: <ul style="list-style-type: none"> - Introduction into operational strength. Lecture: Defects in crystalline solid: <ul style="list-style-type: none"> - Point, edge, screw and boundary defects. - Defects due to monotonic and cyclic loading.

<p>obremenitve.</p> <p>3. Predavanje: Proces rasti poškodbe: - Vpliv pogojev uporabe in okolja na poškodbe.</p> <p>4. Predavanje: Velikociklično utrujanje: - Opredelitev območja veljavnosti. - Vpliv napetostnih gradientov, mezo tečenja, hrapavosti površine in velikosti prereza.</p> <p>5. Predavanje: Velikociklično utrujanje: - SN krivulja. - Hipoteze o akumulaciji in razvoju utrujenostnih poškodb.</p> <p>6. Predavanje: Velikociklično utrujanje: - Ekvivalentna amplitudna napetost. - Računanje poškodbe za naključno zgodovino obremenitve: konvencionalni pristop.</p> <p>7. Predavanje: Velikociklično utrujanje: - Računanje poškodbe za naključno zgodovino obremenitve: alternativni pristop.</p> <p>8. Predavanje: Malociklično utrujanje: - Opredelitev območja veljavnosti. - Vpliv makro tečenja.</p> <p>9. Predavanje: Malociklično utrujanje: - Napetostno - deformacijski odziv: konvencionalni pristop.</p> <p>10. Predavanje: Malociklično utrujanje: - Napetostno - deformacijski odziv: alternativni pristop.</p> <p>11. Predavanje: Malociklično utrujanje: - EN krivulja. - Poškodbeni parametri.</p> <p>12. Predavanje: Malociklično utrujanje: - Računanje poškodbe za naključno zgodovino obremenitve: konvencionalni in alternativni pristop.</p> <p>13. Predavanje: Ciklično lezenje in relaksacija: - Opredelitev območja veljavnosti. - Časovno - temperaturni parametri. - Računanje poškodbe zaradi lezenja.</p> <p>14. Predavanje: Rast utrujenostnih poškodb: - Opredelitev območja veljavnosti. - Fizikalne osnove mehanike loma. - Faktor intenzivnosti.</p> <p>15. Predavanje: Rast utrujenostnih poškodb: - Parisov zakon. - Računanje poškodbe za naključno zgodovino obremenitve.</p>	<p>3. Lecture: Crack growth propagation: - Influence of usage and environmental conditions on crack growth propagation.</p> <p>4. Lecture: High cycle fatigue: - Region of validity determination. - Influence of stress gradients, mezzo yielding, surface roughness effect and size effect.</p> <p>5. Lecture: High cycle fatigue: - SN curve. - Hypothesis on damage accumulation and damage evolution.</p> <p>6. Lecture: High cycle fatigue: - Equivalent stress amplitude. - Damage calculation for random load history: conventional procedure.</p> <p>7. Lecture: High cycle fatigue: - Damage calculation for random load history: alternative procedure.</p> <p>8. Lecture: Low cycle fatigue: - Region of validity determination. - Influence of macro yielding.</p> <p>9. Lecture: Low cycle fatigue: - Stress - strain response: conventional procedure.</p> <p>10. Lecture: Low cycle fatigue: - Stress - strain response: alternative procedure.</p> <p>11. Lecture: Low cycle fatigue: - EN curve. - Damage parameters.</p> <p>12. Lecture: Low cycle fatigue: - Damage calculation for random load history: conventional and alternative procedure.</p> <p>13. Lecture: Cyclic creep and relaxation: - Region of validity determination. - Time - temperature parameters. - Creep damage calculation.</p> <p>14. Lecture: Crack growth: - Region of validity determination. - Physical backgrounds of fracture mechanics. - Stress intensity factor.</p> <p>15. Lecture: Crack growth: - Paris law. - Damage calculation for random load history.</p>
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Temeljna literatura in viri/Readings:

1. Dowling N.E., Kampe S.L., et al. Mechanical Behavior of Materials - Fifth Edition. NE. Pearson Education Limited, 2018.
2. Lemaitre J., Desmorat R. Engineering Damage Mechanics: Ductile, Creep, Fatigue and Brittle Failures.

Springer Vieweg, 2005.

3. Wu X. Deformation and Evolution of Life in Crystalline Materials: An Integrated Creep-Fatigue Theory. CRC Press, 2019.
4. Naumenko K., Altenbach H. Modeling High Temperature Materials Behavior for Structural Analysis: Part II. Solution Procedures and Structural Analysis Examples (Advanced Structured Materials Book 112). Springer, 2019.

Cilji in kompetence:

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 and competences:

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:

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

Intended learning outcomes:

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

<p>napovedovanje rasti utrujenostnih poškodb.</p> <p>Spretnosti:</p> <p>S2.1 Obvladovanje zelo zahtevnih, kompleksnih delovnih procesov in metodoloških orodij na specializiranih področjih:</p> <ul style="list-style-type: none"> • velikociklično in malociklično utrujanje, • lezenje in rast utrujenostnih poškodb. <p>S2.3 Sposobnost izvirnih dognanj/stvaritev in kritične refleksije na področju obratovalne trdnosti.</p>	<p>fatigue crack growth.</p> <p>Skills:</p> <p>S2.1 Mastering of very demanding, complex professional tasks and methodological tools in specialised fields:</p> <ul style="list-style-type: none"> • high cycle and low cycle fatigue, • creep and fatigue crack growth. <p>S2.3 Ability of original breakthroughs/creations and critical reflection in the field of operational strength.</p>
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Metode poučevanja in učenja:

Learning and teaching methods:

<ol style="list-style-type: none"> 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 namenski didaktičnimi pripomočki (uporaba hibridnega vozila, razvitega na FS). 5. P14: Virtualni eksperimenti. 	<ol style="list-style-type: none"> 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.
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Načini ocenjevanja:

Delež/Weight

Assessment:

Teoretične vsebine (predavanja)	50,00 %	Theoretical knowledge (lectures)
Samostojno delo na vajah	20,00 %	Individual work at exercises
Delo na laboratorijskih vajah (vključno s poročili)	20,00 %	Work at laboratory exercises (including reports)
Seminar	10,00 %	Seminar

Reference nosilca/Lecturer's references:

Marko Nagode:

1. NAGODE, Marko, GOSAR, Aleš, SWEENEY, Caoimhe A., JAGUEMONT, Joris, MIERLO, Joeri Van, ŠERUGA, Domen. Mechanistic modelling of cyclic voltage-capacity response for lithium-ion batteries. Energy, ISSN 0360-5442. [Print ed.], Nov. 2019, vol. 186, str. 1-12, ilustr.
<https://www.sciencedirect.com/science/article/pii/S036054421931463X?via%3Dihub#!>, doi: 10.1016/j.energy.2019.07.121. [COBISS.SI-ID 16771099]
2. GOSAR, Aleš, NAGODE, Marko, OMAN, Simon. Continuous fatigue damage prediction of a rubber fibre composite structure using multiaxial energy-based approach. Fatigue & fracture of engineering materials & structures, ISSN 8756-758X, Jan. 2019, vol. 42, iss. 1, str. 307-320, ilustr.
<https://onlinelibrary.wiley.com/doi/epdf/10.1111/ffe.12908>, doi: 10.1111/ffe.12908. [COBISS.SI-ID 16204315]
3. 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, ISSN 0142-1123. [Print ed.], Oct. 2019, vol. 127, str. 291-304, ilustr. <https://www.sciencedirect.com/science/article/pii/S0142112319302397>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=108298&lang=slv>, doi: 10.1016/j.ijfatigue.2019.06.009. [COBISS.SI-ID 16674075]

4. NAGODE, Marko, ŠERUGA, Domen. Fatigue life prediction using multiaxial energy calculations with the mean stress effect to predict failure of linear and nonlinear elastic solids. Results in physics, ISSN 2211-3797, 2016, vol. 6, f. 352-364, ilustr. <http://www.sciencedirect.com/science/article/pii/S2211379716300407>, doi: 10.1016/j.rinp.2016.06.007. [COBISS.SI-ID 14715163]
5. NAGODE, Marko, LÄNGLER, Frank, HACK, Michael. A new approach to thermo mechanical fatigue shown on turbocharger housings. V: 10th international conference on turbochargers and turbocharging, London, 15-16 May 2012. Philadelphia (PA): Woodhead Publishing. 2012, str. 73-82, ilustr. [COBISS.SI-ID 12388123]

Jernej Klemenc:

1. 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]
2. 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]
3. KLEMENC, Jernej, JANEŽIČ, Miha, FAJDIGA, Matija. Modelling the dependency of the Smith-Watson-Topper parameter on the cycles-to-failure using serial hybrid neural networks. Fatigue & fracture of engineering materials & structures, 2012, vol. 35, iss. 9, str. 809-825, ilustr., doi: 10.1111/j.1460-2695.2011.01617.x. [COBISS.SI-ID 12336667]
4. GOSAR, Aleš, KLEMENC, Jernej, FAJDIGA, Matija. Merjenje vpliva kolesnih obremenitev prototipnega vozila Student roadster. V: FAJDIGA, Matija (ur.), KLEMENC, Jernej (ur.), TRENC, Ferdinand (ur.). Zbornik referatov = Proceedings, 9. konferenca in razstava Inovativna avtomobilska tehnologija = 9th conference and exhibition Innovative Automotive Technology IAT'09, Nova Gorica, Slovenija, 23.-24. april 2009. Ljubljana: Fakulteta za strojništvo, LAVEK. cop. 2009, str. 75-82, [COBISS.SI-ID 11815195]
5. ŠKRLEC, Andrej, KLEMENC, Jernej. Numerična in eksperimentalna analiza zdržljivosti varjenega spoja med cevjo in ročico : končno poročilo. Ljubljana: Fakulteta za strojništvo, Laboratorij za vrednotenje konstrukcij, 2015. 35 f., graf. prikazi. [COBISS.SI-ID 13991451]

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], R
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, NAGODE, Marko. A method for long-term creep-rupture strength prediction based on a small sample of experimental results, smoothed bootstrapping and time-temperature parameters. Materials & design, ISSN 0264-1275, Feb. 2015, vol. 67, str. 180-187, ilustr., doi: 10.1016/j.matdes.2014.11.011. [COBISS.SI-ID 13803803]
4. ŠERUGA, Domen, NAGODE, Marko. Unification of the most commonly used time-temperature creep parameters. Materials Science & Engineering. A, Structural materials: Properties, Microstructure and Processing, ISSN 0921-5093. [Print ed.], Mar. 2011, vol. 528, iss. 6, str. 2804-2811, doi: 10.1016/j.msea.2010.12.034. [COBISS.SI-ID 11700251]
5. ŠERUGA, Domen, FAJDIGA, Matija, NAGODE, Marko. Creep damage calculation for thermomechanical fatigue. V: Proceedings = Recueil de conférences, Fatigue design 2009, Senlis, France, November 25-26 2009. Senlis: Centre technique des industries mécaniques. 2009, str. 1-7, ilustr. [COBISS.SI-ID 11239451]