UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Metode preizkušanja v proizvodnji
Course title:	TESTING METHODS IN PRODUCTION
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	**Študijska smer**	**Letnik**	**Semestri**
Strojništvo - projektno aplikativni program, prva stopnja, visokošolski strokovni	Proizvodne tehnologije (smer)	2. letnik	2. semester

Univerzitetna koda predmeta/University course code:	0563506
Koda učne enote na članici/UL Member course code:	3057-V

Predavanja	**Seminar**	**Vaje**	**Klinične vaje**	**Druge oblike študija**	**Samostojno delo**	**ECTS**
30		30			40	4

Nosilec predmeta/Lecturer:	Roman Šturm, Tomaž Kek
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. Integriteta površin Opredelitev integritete površin, kriteriji ocenjevanja integritete površin, Integriteta površin materiala orodja in obdelovanca s posebnim ozirom na mehanske in fizikalno kemične vplive, notranje napetosti po različnih izdelovalnih postopkih, fizikalna opredelitev nastanka različnih notranjih napetosti, vpliv različnih obdelovalnih procesov na lastnosti površinskih slojev, vpliv mikrostrukture na notranje napetosti. 2. Optične metode in boreskopija	1. Surface Integrity Definition of surface integrity, criteria for assessment of surface integrity, surface integrity of tool and workpiece material with reference to different influences, residual stresses after different manufacturing processes, formation of different residual stresses, influence of different machining processes on the properties of surface layers, influence of microstructure on residual stresses. 2. Optical Methods and Borescopy

 Uporaba optičnih pripomočkov, ločilna sposobnost optičnih sistemov, vzorci za mikroskopiranje, boreskopija, vrste boreskopov, opis celotnega sistema, sistemi za prenos svetlobe, vrednotenje površine in napak, dokumentiranje, vizualna kontrola, izdelava replik in vrednotenje mikrostrukture, penetranti in penetrantske metode.

3. Ultrazvočno preizkušanje I
 ultrazvočno valovanje, načini širjenja, lastnosti, načini generiranja elastičnih valov, magnetostriktivni in elektromagnetni akustični efekt, bližnje in daljno polje.

4. Ultrazvočno preizkušanje II
 PZT ultrazvočne glave, izbira ustrezne UZ glave, vpliv akustične impedance, način preizkušanja gibljivih objektov, postopki preizkušanja, posebne izvedbe UZ glav, načini preizkušanja zvarov

5. Preiskave materialov in konstrukcij z akustično emisijo:
 fizikalne osnove, metode za vrednotenje signalov in klasifikacija signalov, načini testiranja materialov in konstrukcij z akustično emisijo, primeri uporabe, prednosti in slabosti preiskav z akustično emisijo, opis signalov in analize signalov preiskave tlačnih posod, preiskave nosilnih konstrukcij, preiskave kompozitnih materialov.

6. Preizkušanje z vrtinčnimi tokovi I
 fizikalne osnove generiranja vrtinčnih tokov, opredelitev impedance tuljave za preizkušanje, vplivi na impedanco tuljave, normalizirani impedančni ravninski diagram glede na magnetno permeabilnost, premiki impedance, karakteristični dolžinski parameter,

7. Preizkušanje z vrtinčnimi tokovi II
 osnovni načini preizkušanja, vpliv napake na trajektorijo impedančnega odziva, postopki preizkušanja z induktivnostjo, prednosti in slabosti, primeri preizkušanja v letalski industriji, proizvodnih procesih in pri detekciji primernosti objekta

8. Magnetne metode preizkušanja
 magnetne preizkuševalne metode, fizikalne osnove, opis magnetnega polja, efekt vrste materiala na elektromagnetno polje, pripomočki pri opazovanju površin, načini magnetenja in načini razmagnetenja preizkuševalcev, vrste magnetnih sredstev, merjenje sipanja magnetnega polja s tuljavo in Hallovo sondo, sistemi za kontrolo in prikaz rezultatov, ocenjevanja stanja površin, izdelava procedur.

9. Preiskave z X in γ žarki I
 Radiografija in radioskopija, fizikalni načini generiranja X in γ, karakteristično in zvezno sevanje, minimalna valovna dolžina, trdota žarkov, absorpcija X in γ žarkov, struktura rentgenske cevi, vpliv žarišča na kakovost

Use of optical devices, resolution of optical systems, samples for microscopy, borescopy, types of borescopes, system description, light transmission systems, surface and defect evaluation, documentation, visual control, replicas and microstructure evaluation, penetrants and penetrant methods.

3. Ultrasonic Testing I
Ultrasonic wave propagation modes, properties, generation of elastic waves, magnetostrictive and electromagnetic acoustic effects, near and far fields.

4. Ultrasonic Testing II
PZT ultrasonic probes, selection of ultrasonic probe, influence of acoustic impedance, testing of moving objects, testing procedures, special designs of ultrasonic probes, methods of testing welds.

5. Acoustic Emission Testing
Physical fundamentals, signal evaluation and signal classification, AE testing of materials and structures, advantages and disadvantages of acoustic emission testing, signal description and signal analysis of pressure vessel testing, structural health monitoring, composite material testing.

6. Eddy Current Testing I
Fundamentals of eddy current generation, Impedance of the test coil, effects on the coil impedance, normalized impedance plane diagram with respect to magnetic permeability, impedance displacements, characteristic length parameter,

7. Eddy Current Testing II
Basic test methods, impact of flaw on the impedance response trajectory, advantages and disadvantages, test cases in the aviation industry, manufacturing processes and object suitability testing

8. Magnetic Particle Testing
Magnetic testing methods, fundamentals, magnetic field description, effect of material magnetic field, devices, magnetization and demagnetization methods, types of magnetic particles, measurement of magnetic field scattering by coil and Hall probe, control systems, evaluation of the surface condition, procedures.

9. Radiology I
Radiography and radioscopy, generation of X and γ rays, continuous radiation and characteristic radiation, minimum wavelength, absorption of X and γ rays, X-ray tube structure, influence of the focus on image quality, contrast, internal sharpness.

10. Radiology II
X-ray tube types, radioisotope sources, X and γ-ray properties, X-ray film, image quality indicators, G-M tube, image enhancer, various modes of product

slike, kontrast, notranja ostrina. 10. Preiskave z X in γ žarki II vrste rentgenskih cevi, Izotopi za γ žarke, lastnosti X in γ žarkov, rentgenski film, indikatorji kakovosti slike, števna cev, ojačevalec slike, različni načini pregledov izdelkov, pregledovanje zvarov, delitve radioskopskih sistemov, optimalna oddaljenost, tipične napake pri preiskavi zvarov in načini ocenjevanja sprejemljivosti zvarov 11. Merjenje zaostalih napetosti teoretične osnove, vpliv notranjih napetosti na obratovalno trdnost, osnovna delitev metod, relaksacijska metoda z elektrokemičnim odtapljanjem, metoda z vrtanjem izvrtine, X-žarkovna difrakcijska metoda, Braggov zakon, prednosti in slabosti posameznih metod, primeri merjenja zaostalih napetosti v industriji, način branja izmerjenih podatkov pri XRD metodi 12. Korozija oblike korozije, elektrokemična korozija, mehanizmi, elektroliti in teorija elektrolitske disociacije, elektrodni potencial, galvanska korozija, napetostna korozija, merjenje korozijske odpornosti, pasivacija, katodna-anodna zaščita. 13. Holografija, tomografija, MRI Holografi, holografska interferometrija, Povezava med fazno razliko in deformacijo/popačenjem površine. Primerjava med medicinskimi in industrijskimi CT sistemi, pregled in delitev industrijskih CT sistemov, primeri uporabe CT sistemov za NDT in metrologijo, prednosti in slabosti. Fizikalni osnove slikanja z magnetno resonanco, aplikacije v industriji, prednosti in slabosti. 14. Porušne preiskovalne metode: metalurški vidiki porušnih preiskav pri konstrukcijskih elementih in zvarih, testiranje in napovedovanje lezenja materiala, utrujanje materialov pri dani ciklični obremenitvi, mikromehanizmi pri utrujanju materialov, vpliv oblike, mikrostrukture in velikosti kristalnih zrn ter toplotne obdelave na dobo trajanja. 15. Lomno mehanski preizkusi merjenje rasti razpoke, lomno mehanske preiskave kovinskih in nekovinskih materialov, napovedovanje rasti razpoke pri znanih obremenitvenih pogojih, primeri uporabe, vrednotenje vplivov okolja na rast razpoke pri kovinskih materialih.	inspection, weld inspection, radioscopic systems, optimal distance, typical weld flaws, and weld acceptability assessing. 11. Residual stress measurement Fundamentals, residual stresses and operational strength, basic measuring methods, relaxation method with electrochemical dissolution, hole drilling method, X-ray diffraction method, Bragg's law, advantages and disadvantages of individual methods, examples of measurements of residual stresses in industry, evaluating measured data in the XRD method 12. Corrosion Forms of corrosion, electrochemical corrosion, mechanisms, electrolytes and electrolyte dissociation, electrode potential, galvanic corrosion, planning and preparation of corrosion tests, passivation, cathode-anode protection. 13. Holography, tomography, MRI Holograms, holographic interferometry, Relationship between phase difference and surface deformation/distortion. Comparison between medical and industrial CT systems, review of industrial CT systems, examples of the use of CT systems for NDT and metrology, advantages and disadvantages. Fundamentals of magnetic resonance imaging, industry applications, strengths and weaknesses. 14. Destructive testing methods Metallurgical aspects in fracture tests for structural components and welds, testing and prediction of material creep, fatigue of materials under a given cyclic loading, micro-mechanisms in fatigue, influence of shape, microstructure and size of crystalline grains, and heat treatment on durability. 15. Fracture Mechanics Tests measurement of crack propagation, fracture mechanical testing of metallic and non-metallic materials, prediction of crack growth under known loading conditions, use cases, evaluation of environmental effects on crack growth in metallic materials.

Temeljna literatura in viri/Readings:

1. Preizkušanje gradiv, Polde Leskovar, Fakulteta za strojništvo, 1975.

2. ASM Handbook, Volume 8, Mechanical Testing and Evaluation, ASM International, 2000.
3. Handbook of nondestructive evaluation, second edition, 2013
4. Fracture mechanics 3rd edition, Fundamentals and applications, T. L. Anderson, Taylor and Francis, 2005
5. Nondestructive Testing Handbook Vol. 1 – Vol. 9, American Society for Nondestructive Testing, 2002.
6. Non-destructive Testing and Diagnosis, Handbook, Eds.: V.V. Klyuev, G. Zusman, Russian Society for Non-destructive Testing and Technical Diagnostics, Moscow, Metrix Inst. Co., Houston, 2004.
7. P. Marcus, F. Mansfeld: Analytical Methods in Corrosion Science and Engineering, CRC Press, Taylor & Francis Group, Boca Raton, USA, 2006.
8. Non-destructive Testing and Diagnosis, Handbook, Eds.: V.V. Klyuev, G. Zusman, Russian Society for Non-destructive Testing and Technical Diagnostics, Moscow, Metrix Inst. Co., Houston, 2004.

Cilji in kompetence:	**Objectives and competences:**
Cilji: 1. Seznanitev z različnimi metodami porušnega in neporušnega testiranja materialov in pripadajočimi fizikalnimi zakonitostmi 2. Pridobitev sposobnosti izbire ustrezne metode testiranja glede na vrsto izdelka oziroma strojnega dela. 3. Spoznati proceduro za dano metodo testiranja, 4. Spoznati kriterije sprejemljivosti preizkušanih izdelkov in materialov in analizirati rezultate testiranja. Kompetence: 1. Sposobnost uporabe pridobljenega znanja pri izvajanju neporušnih preiskav v proizvodnji in pridobi sposobnost samostojnega opravljanja aplikativnih inženirskih del ter reševanja posameznih nalog na področju preizkušanja materialov (S1-PAP + S2-PAP+ P9-PAP). 2. Razume fizikalne zakone in pojave, na katerih temelji preizkušanje materialov (P1-PAP). 3. Obvlada temeljna strokovna znanja s področja preizkušanja materialov in zagotavljanja kakovosti izdelkov in polizdelkov in bistvenih komplementarnih ved (kovinska in nekovinska gradiva) ter obvlada osnovna in potrebna specifična znanja v izbrani študijski smeri (P3-PAP + P8-PAP). 4. Pozna osnovne merilne instrumente in merilne verige za preizkušanje materialov (P4-PAP).	Objectives: 1. Familiarity with the various methods of destructive and non-destructive testing of materials and the associated physical laws 2. Gaining the ability to choose the appropriate test method according to the type of product or machine part. 3. Gaining the knowledge of procedures for a given test method, 4. Gaining the knowledge of acceptance criteria for materials and products and analysis of the test results. Competences: 1. Ability to use the acquired knowledge in conducting non-destructive testing in the production, and the ability to independently perform applied engineering works and to solve individual tasks in the field of material testing (S1-PAP + S2-PAP + P9-PAP). 2. Understands the physical laws and phenomena in the field of material testing (P1-PAP). 3. Knows basic expertise in materials testing and quality assurance of products and semi-finished products and essential complementary sciences (metallic and non-metallic materials) and masters basic and required specific knowledge in the chosen study area (P3-PAP + P8-PAP). 4. Knows basic measuring instruments and material testing chains (P4-PAP).

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanja: Poglobljeno strokovno, teoretično in praktično znanje na področju neporušnega in porušnega preizkušanja različnih polizdelkov in končnih izdelkov. Spretnosti:	Knovledge: In-depth professional, theoretical and practical knowledge in the field of non-destructive and destructive testing of various semi-finished and finished products.

1. S1 Izvajanje kompleksnih operativno-strokovnih porušnih in neporušnih preizkusov materialov. 2. S1.2 Obvladovanje zahtevnih, kompleksnih preizkusov ob samostojni uporabi znanja v novih delovnih situacijah. 3. S1.3 Diagnosticiranje in reševanje problemov pri preverjanju kakovosti izdelkov v proizvodnih procesih	Skills: 1. S1 Executing complex operational-professional tasks that incorporate usage of methodological tools on the area of destructive and non-destructive testing. 2. S1.2 Mastering demanding and complex testing techniques by independent usage of knowledge in new working situations. 3. S1.3 Problem diagnostics and solving in quality control in production

Metode poučevanja in učenja:	**Learning and teaching methods:**
Klasične oblike poučevanja: P1 Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov. P3 Avditorne in laboratorijske vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. P5 Uporaba študijskega gradiva v obliki: knjige, tiskana verzija predstavitve predavanj. Moderne in prožne oblike poučevanja: P6 Interaktivna predavanja P7 Študij literature in razprava P8 Izdelava in predstavitev aplikativnih seminarskih nalog P15 Uporaba video vsebin kot priprava na predavanja in vaje	**Conventional teaching methods:** P1 Auditorial lectures with solving selected field-specific theoretical and applied use cases. P3 Auditorial exercises, in which theoretical content from the lectures is supplemented with practical examples. P5 Application of study material (textbook, e-book, printed lecture presentations). **Contemporary and flexible teaching methods:** P6 Interactive lectures. P7 Literature study and discussion. P8 Making and presenting applied seminar exercises. P15 Application of videos for preparations to the lectures and exercises.

Načini ocenjevanja:	**Delež/Weight**	**Assessment:**
Teoretične vsebine (predavanja)	60,00 %	Theoretical content (lectures)
Delo na laboratorijskih vajah (vključno s poročili)	40,00 %	Laboratory work (including reports)

Reference nosilca/Lecturer's references:

Roman Šturm:

1. TRDAN, Uroš, TOMOKAZU, Sano, KLOBČAR, Damjan, SANO, Yuji, GRUM, Janez, **ŠTURM, Roman**. Improvement of corrosion resistance of AA2024-T3 using femtosecond laser peening without protective and confining medium. Corrosion science, ISSN 0010-938X. [Print ed.], Oct. 2018, vol. 143, str. 46-55,
2. PEČNIK, Boštjan, **ŠTURM, Roman**, HOČEVAR, Marko, DULAR, Matevž, ŠIROK, Brane. Cavitation erosion of the calcium carbonate deposits. International journal of microstructure and materials properties. 2015, vol. 10, nr. 5/6, str. 445-462
3. LI, Yingzhi, **ŠTURM, Roman**. Small punch test for weld heat affected zones. Materials at high temperatures, 2006, letn. 23, št. 3/4, str. 225-232.
4. GRUM, Janez, ŽEROVNIK, Pavle, **ŠTURM, Roman**. Material characterization with new methods of processing of Barkhausen noise. V: *Technological forum 2015 : [book of proceedings]*. 6th International Technical Conference,

Kouty, Czech Republic, 23. - 25. 6. 2015. Jaroměř: J. Kudláček, 2015. Str. 192-201.

5. PEČNIK, Boštjan, **ŠTURM, Roman**, GRUM, Janez. Influence of lift off effects on magnetic Barkhausen noise measurements performed with a compact sensor unit. V: GRUM, Janez (ur.), KEK, Tomaž (ur.). *Conference proceedings*. The 14th International Conference of the Slovenian Society for Non-Destructive Testing titled Application of contemporary non-destructive testing in engineering, [Portorož, 4-6 September 2017, Slovenia]. Ljubljana: Slovenian Society for Non-Destructive Testing, 2017. Str. 163-170.

Tomaž Kek:

1. **KEK, Tomaž**, KUSIĆ, Dragan, SVEČKO, Rajko, HANČIČ, Aleš, GRUM, Janez. Use of acoustic emission testing in injection moulding process. *International journal of microstructure and materials properties*, ISSN 1741-8410, 2014, vol. 9, no. 3/4/5, str. 327-337, ilustr.
2. **KEK, Tomaž**, GRUM, Janez. AE signal measurements during laser cutting of structural steel sheet and deep-drawn parts. *International journal of microstructure and materials properties*, ISSN 1741-8410, 2011, vol. 6, no. 3/4, str. 249-258, doi: 10.1504/IJMMP.2011.043220.
3. SVEČKO, Rajko, KUSIĆ, Dragan, **KEK, Tomaž**, SARJAŠ, Andrej, HANČIČ, Aleš, GRUM, Janez. Acoustic emission detection of macro-cracks on engraving tool steel inserts during the injection molding cycle using PZT sensors. *Sensors*, ISSN 1424-8220, 2013, vol. 13, no. 5, str. 6365-6379, ilustr., doi: 10.3390/s130506365.
4. KUSIĆ, Dragan, SVEČKO, Rajko, **KEK, Tomaž**, HANČIČ, Aleš, GRUM, Janez. Influence of increased injection pressure load on the captured acoustic emission signals and dimensional accuracies of polypropylene test specimens. *Insight*, ISSN 1354-2575, Dec. 2013, vol. 55, no. 12, str. 659-664, doi: 10.1784/insi.2012.55.12.659.
5. SUBADRA, Sharath Peethambaran, **KEK, Tomaž**, BERGANT, Zoran, GRIŠKEVIČIUS, Paulius. Study of acoustic emission signals during crack propagation in multiscale nano-composites. Mechanika, ISSN 1392-1207, 2018, vol. 24, nr. 4, str. 391-398, ilustr. http://mechanika.ktu.lt/index.php/Mech/article/view/20535, doi: 10.5755/j01.mech.24.4.20535. [COBISS.SI-ID 16239899].