

# VARJENJE, REZANJE IN NAVARJANJE Z VISOKO GOSTOTO ENERGIJE

## UČNI NAČRT PREDMETA/COURSE SYLLABUS

<b>Predmet:</b>	VARJENJE, REZANJE IN NAVARJANJE Z VISOKO GOSTOTO ENERGIJE
<b>Course title:</b>	WELDING, CUTTING AND SURFACING WITH HIGH ENERGY DENSITY
<b>Članica nosilka/UL Member:</b>	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo, tretja stopnja, doktorski	Proizvodno inženirske znanosti, kibernetika in mehatronika (smer)	1. letnik, 2. letnik	Celoletni	izbirni

<b>Univerzitetna koda predmeta/University course code:</b>	0033474
<b>Koda učne enote na članici/UL Member course code:</b>	7319

Predavanja /Lectures	Seminar /Seminar	Vaje /Tutorial s	Klinične vaje /Clinical tutorials	Druge oblike študija /Other forms of study	Samostojno delo /Individu al student work	ECTS
90					160	10

<b>Nosilec predmeta/Lecturer:</b>	Damjan Klobčar
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<b>Izvajalci predavanj:</b>	Damjan Klobčar
<b>Izvajalci seminarjev:</b>	
<b>Izvajalci vaj:</b>	
<b>Izvajalci kliničnih vaj:</b>	

**Izvajalci drugih oblik:**


**Izvajalci praktičnega usposabljanja:**

**Vrsta predmeta/Course type:**

Izbirni predmet /Elective course

**Jeziki/Languages:**

Predavanja/Lectures:

Angleščina, Slovenščina

Vaje/Tutorial:

Angleščina, Slovenščina

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

**Prerequisites:**

Veljajo splošni pogoji za doktorski študij.

General prerequisites for the third level studies.

**Vsebina:**

**Content (Syllabus outline):**

Fizikalne, kemijske in metalurške osnove varjenja in rezanja z visoko gostoto energije (električni oblok, elektronski in svetlobni snop, plazma). Teorija varjenja in toplotnega rezanja z električnim oblokom, s plazmo, z elektronskim snopom in svetlobnim snopom. Key-hole efekt, marangonijev efekt. Metalurški in tehnični pojavi v zvaru in rezu. Tehnologije, stroji in naprave oz. sistemi za varjenje in rezanje s plazmo, z elektronskim snopom in laserjem. Osnovni in dodajni materiali, vplivni parametri v procesih. Kombinirani postopki varjenja (hibridno varjenje) in rezanja z visoko gostoto energije. Stanje in tendence razvoja varjenja in rezanja z visoko gostoto energije.

Teorija obnavljanja in oplemenitenja površinskih slojev s postopki navarjanja in nabrizgavanja. Primernost dodatnih materialov za določen osnovni material pri obnovi obrabljenih strojnih elementov. Naprave in sistemi. Stanje in tendence razvoja. Fizikalno kemijske in metalurške osnove procesov nanašanja zaščitnih površinskih slojev po različnih postopkih navarjanja in nabrizgavanja. Elektroiskrno navarjanje, navarjanje z laserjem, elektronskim snopom, plazmo, navarjanje v hladnem. Toplotne obdelave

Physical, chemical and metallurgical phenomena of welding and cutting with a high energy density (electric arc, electron and laser beam, plasma arc). The theory of thermal cutting and welding with electric arc, plasma arc, the electron beam and the beam of light. Key-hole effect, Marangony effect. Metallurgical and technical phenomena in weld and cut. Technologies, machines and apparatus or systems for welding and cutting with plasma arc, the electron beam and laser beam. Basic materials and consumables, influential parameters in the welding processes. Combined welding processes (hybrid welding) and cutting with the high energy density. Status and trends of developments in welding and cutting processes with a high energy density.

The theory of regeneration and processing of surface layers with surfacing and metallization. The suitability of consumable materials for a particular base material in the reconstruction of worn-out mechanical elements. The devices and systems. Status and trends of development. Physical, chemical and metallurgical processes basics of processing of protective surface layers using different

<p>nanosov. Možnosti in prednosti kombiniranja raznih postopkov obnavljanja in oplemenitenja površin pri vzdrževanju in izdelavi novih orodij in obrabno obremenjenih strojnih elementov.</p>	<p>surfacing and metallization processes. Electro-spark surfacing, laser beam surfacing, electron beam, plasma arc, and surfacing at room temperatures. Surface layers heat treatment. Opportunities and advantages of combining the various processes for surface renewal at the maintenance and construction of the new tools and wear loaded mechanical elements.</p>
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### Temeljna literatura in viri/Readings:

[1] Tušek, Janez. Varjenje in sorodne tehnike spajanja materialov v neločljivo zvezo, Fakulteta za strojništvo, 2015, str. XII, 467, COBISS.SI-ID - 282414848, ISBN - 978-961-6536-75-2.

[2] O'Brien, Annette. Welding Handbook. Ninth edition. Vol. 1 - Welding Science and Technology, Miami, FL: American Welding Society, 2001. COBISS.SI-ID - 38102021

[3] O'Brien, Annette. Welding Handbook. Ninth edition. Vol. 2 - Welding Processes, Part 1, Miami, FL: American Welding Society, 2004 1991 COBISS.SI-ID - 173761

[4] O'Brien, Annette. Welding Handbook. Ninth edition. Vol. 3 - Welding Processes, Part 2, Miami, FL: American Welding Society, 2007.  
<https://search.ebscohost.com/login.aspx?direct=true&db=e000xww&AN=1839115&lang=sl&site=ehost-live>

[5] O'Brien, Annette. Welding Handbook. Ninth edition. Vol. 4 - Materials and Applications, Part 1, Miami, FL: American Welding Society, 2011.  
<https://search.ebscohost.com/login.aspx?direct=true&db=e000xww&AN=1839116&lang=sl&site=ehost-live>

[6] O'Brien, Annette. Welding Handbook. Ninth edition. Vol. 5 - Materials and Applications, Part 2, Miami, FL: American Welding Society, 2015.  
<https://search.ebscohost.com/login.aspx?direct=true&db=e000xww&AN=1839117&lang=sl&site=ehost-live>

[7] Rak, Inoslav. Tehnologija varjenja. 1. izd., Modrijan, 2008, str. 460, COBISS SI. ID - 239269376

[8] Jeffus, Larry F. Welding: principles and applications. 67th ed., International ed., Delmar Cengage Learning Thomson Delmar Learning, 2008, str. XXVX, 91176, COBISS.SI-ID - 29767429 15628597.

[9] Kou, Sindo. Welding metallurgy. 2nd ed., John Wiley & Sons, 2003, str. XIV, 461, COBISS.SI-ID - 12047387.

### Cilji in kompetence:

### Objectives and competences:

<p><b>Cilji:</b></p> <p>Študentu prikazati vlogo, pomen, lastnosti in uporabnost vseh procesov rezanja, varjenja in navarjanja z visoko gostoto energije v splošni industriji in v znanosti. Pojasniti pomen navarjanja in toplotnega rezanja v industriji in</p>	<p><b>Goals:</b></p> <p>The role, meaning, properties and application of all cutting processes, welding processes and surfacing with high energy density in general industry and science are shown to the student. The meaning of surfacing and thermal</p>
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<p>znanosti. Razjasniti uporabnost posameznih procesov pri učinkovanju visoke gostote energije na material za vse vrste materialov. Pojasniti delo z laserskim žarkom, elektronskim snopom in s plazmo.</p> <p><b>Kompetence:</b></p> <p>Študent osvoji znanja iz procesov toplotnega rezanja in navarjanja z visoko gostoto energije, samostojno odloča o raziskavah in o metodah raziskovalnega dela pri posameznih procesih rezanja in navarjanja z visoko gostoto energije. Študent mora imeti sposobnost uporabe pridobljenega znanja v praksi in pri raziskovalnem delu, pri iskanje novih znanj iz različnih virov, ima sposobnost za samostojno raziskovalno in znanstveno delo ter za svoje delo prevzemati odgovornost, ima sposobnost za delo v skupini in je sposoben odločanja in vodenja.</p>	<p>cutting in the industry and science is explained. The applicability of individual processes on interaction of high energy density on material for all material types is clarified. The manipulation with the laser beam, the electron beam and the plasma arc is explained.</p> <p><b>Competences:</b></p> <p>Student conquers the knowledge of thermal cutting and surfacing with high energy density, independently decides about research and methods of research work at particular thermal cutting and surfacing with high energy density. A student has to be able to use the acquired knowledge in practice, at research work, at searching of new knowledge from different sources, has the ability for independent research and scientific research as well as to contract an obligation, has the ability to work in a team and the ability of making decisions and leadership, is ethical and knows to critically and fairly judge the coworkers, knows to manage the time, is able to communicate orally and in writing, knows the professional terminology in English and German language.</p>
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**Predvideni študijski rezultati:**

Študent osvoji znanja iz procesov toplotnega rezanja in navarjanja z visoko gostoto energije, samostojno odloča o raziskavah in o metodah raziskovalnega dela pri posameznih procesih rezanja in navarjanja z visoko gostoto energije. Študent mora imeti sposobnost uporabe pridobljenega znanja v praksi in pri raziskovalnem delu, pri iskanje novih znanj iz različnih virov, ima sposobnost za samostojno raziskovalno in znanstveno delo ter za svoje delo prevzemati odgovornost, ima sposobnost za delo v skupini in je sposoben odločanja in vodenja.

**Intended learning outcomes:**

Student conquers the knowledge of thermal cutting and surfacing with high energy density, independently decides about research and methods of research work at particular thermal cutting and surfacing with high energy density. A student has to be able to use the acquired knowledge in practice, at research work, at searching of new knowledge from different sources, has the ability for independent research and scientific research as well as to contract an obligation, has the ability to work in a team and the ability of making decisions and leadership, is ethical and knows to critically and fairly judge the coworkers, knows to manage the time, is able to communicate orally and in writing, knows the professional terminology in

	English and German language.
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**Metode poučevanja in učenja:**

**Learning and teaching methods:**

Predavanja, laboratorijske vaje, seminarsko delo, e-izobraževanje, konzultacije. Seminarsko delo v čim večji meri navezuje se na področje doktorskega raziskovanja. Študij z uporabo priporočene literature.	Lectures, laboratory practice & seminar work, e-education, consulting. The seminar work is related, as much as possible, to the student's doctoral research field. Study on a recommended literature basis.
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**Načini ocenjevanja:**

**Delež/Weight**

**Assessment:**

Ustni izpit, poročilo o seminarskem delu. Pogoji za opravljanje ustnega izpita je uspešno izdelano in pozitivno ocenjeno seminarsko delo. Način (pisni izpit, ustno izpraševanje, naloge, projekt): • naloge 25% • projektno delo 25% • ustno zagovor 50%.		Oral exam, report on seminar work. The condition for admission to oral exam is successful completion of seminar work, rewarded with a passing grade. Method (written exam, oral examination, assignments, project): • assignments (25%) • project seminar (25%) • oral examination (50%)
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**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
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**Reference nosilca/Lecturer's references:**

**izr. prof. dr. dr. Damjan KLOBČAR**

KENDA, Miha, KLOBČAR, Damjan, BRAČUN, Drago. Condition based maintenance of the two-beam laser welding in high volume manufacturing of piezoelectric pressure sensor. *Journal of manufacturing systems*. Apr. 2021, vol. 59, str. 117-126, ilustr. ISSN 0278-6125.

<https://www.sciencedirect.com/science/article/pii/S0278612521000352>, DOI: [10.1016/j.jmsy.2021.02.007](https://doi.org/10.1016/j.jmsy.2021.02.007).

ŠČETINEC, Aljaž, KLOBČAR, Damjan, BRAČUN, Drago. In-process path replanning and online layer height control through deposition arc current for gas metal arc based additive manufacturing. *Journal of manufacturing processes*. [Print ed.]. Apr. 2021, vol. 64, str. 1169-1179, ilustr. ISSN 1526-6125.

<https://www.sciencedirect.com/science/article/pii/S1526612521001249>, DOI: [10.1016/j.jmapro.2021.02.038](https://doi.org/10.1016/j.jmapro.2021.02.038).

GODEC, Matjaž, MALEJ, Simon, FEIZPOUR, Darja, DONIK, Črtomir, BALAŽIČ, Matej, KLOBČAR, Damjan, PAMBAGUIAN, L., CONRADI, Marjetka, KOCIJAN,

Aleksandra. Hybrid additive manufacturing of Inconel 718 for future space applications. *Materials characterization*. [Print ed.]. 2021, vol. 172, str. 1-16, ilustr. ISSN 1044-5803.

<https://www.sciencedirect.com/science/article/pii/S1044580320323135?via%3Dihub>, DOI: [10.1016/j.matchar.2020.110842](https://doi.org/10.1016/j.matchar.2020.110842).

BALOŠ, Sebastian, DRAMIĆANIN, Miroslav D., JANJATOVIC, Petar, KULUNDZIC, Nenad, ZABUNOV, Ivan, PILIĆ, Branka, KLOBČAR, Damjan. Influence of metallic oxide nanoparticles on the mechanical properties of an A-TIG welded 304L austenitic stainless steel. *Materials*. Oct. 2020, vol. 13, iss. 20, f. 1-11, ilustr. ISSN 1996-1944. <https://www.mdpi.com/1996-1944/13/20/4513>, DOI: [10.3390/ma13204513](https://doi.org/10.3390/ma13204513).