

NAPREDNI PREOBLIKOVALNI PROCESI

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Napredni preoblikovalni procesi
Course title:	Advanced Forming Processes
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski	Proizvodno strojništvo (smer)	1. letnik	2. semester	obvezni

Univerzitetna koda predmeta/University course code:	0566835
Koda učne enote na članici/UL Member course code:	6047-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:	izr. prof. dr. Tomaž Pepelnjak
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Izvajalci predavanj:	
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	
Izvajalci praktičnega usposabljanja:	

Vrsta predmeta/Course type:	Obvezni strokovni predmet na smeri Proizvodno strojništvo, ki je izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Production 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):
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1. Predavanje: Kriteriji vrednotenja postopkov preoblikovanja kovin - Predstavitev preoblikovalnih lastnosti pomembnih za izvedbo zahtevnih preoblikovalnih operacij - Preoblikovalnost materiala - krivulje mejnih deformacij pločevine in masivnih materialov, vplivi na preoblikovalnost - Procesne omejitve - Omejitve orodja - Omejitve stroja 2. Predavanje: Natezno-tlačno preoblikovanje pločevin - Osnovni pojmi in procesne omejitve - Napredni koncepti natezno-tlačnega preoblikovanja pločevine - Prilagodljiva orodja (polimerna, slojevita orodja ...) - Prilagajanje procesnih parametrov med izvedbo procesa (prilagodljivo pridrževanje) - kombinacije natezno-tlačnega preoblikovanja pločevine in masivnega preoblikovanja (stanjševalni vlek, izdelava ozobj ...) 3. Predavanje: Upogibno preoblikovanje pločevin - Osnovni pojmi, procesne omejitve - Napredni koncepti upogibanja pločevine - Uporaba prilagodljivih orodij - Prilagajanje procesnih parametrov med proizvodnjo glede na vhodne parametre materiala - 3D fleksibilno krivljenje 4. Predavanje: Mikropreoblikovanje - Osnovni pojmi koncepta mikropreoblikovanja - Procesne omejitve pogojene s potekom postopka in uporabljanim materialom - Vpliv velikosti (size effect) na proces preoblikovanja 5. Predavanje: Preoblikovanje visokotrdnostnih jekel in vroče preoblikovanje pločevine - Problematika preoblikovanja visokotrdnostnih jekel - Koncepti za dvig kakovosti pri preoblikovanju - Ukrepi za zmanjševanje elastičnega izravnava - Opredelitev pogojev vročega preoblikovanja - Tehnologija vročega preoblikovanja pločevine (hot stamping) 6. Predavanje: Postopki preoblikovanja z medijem - Opredelitev pogojev preoblikovanja z medijem, delitev postopkov glede na izvedbo procesa - Karakterizacija visokotlačnega in nizkotlačnega preoblikovanja - Procesni parametri in njihovi vplivi na kakovost preoblikovanja 7. Predavanje: Tehnologije maloserijske izdelave pločevinskih izdelkov s preoblikovanjem - Inkrementalno preoblikovanje - karakterizacija procesa, prednosti in slabosti - Omejitve procesa s stališča materialov, procesnih parametrov, izvedbe procesa - Dosegljiva izdelovalna natančnost procesa, vplivi	1. Lecture: Evaluation criteria for metal forming processes - Representation of forming properties that are important for the execution of complex forming operations - Material formability - forming limit curves of sheet and bulk material, effects on formability - Limitations of the process - Restrictions for tools - Limitations of the machine 2. Lecture: Tension-compression forming of sheet metal - Basic concepts and process limits - Advanced concepts of tension-compression forming of sheet metal - Flexible tools (polymeric, layered tools...) - Adaptation of process parameters during process execution with regard to the input parameters of the material used - Combinations of tension-compression sheet metal forming and bulk forming (ironing, production of teeth, etc.) 3. Lecture: Forming the sheet metal by bending - Basic concepts, process limitations - Advanced concepts for sheet metal bending - Use of flexible tools - Adaptation of process parameters during production according to the material input parameters - 3D flexible bending 4. Lecture: Microforming - Fundamentals of the concept of microforming - Process restrictions due to the progress of the process and the material used - Size effect on the forming process 5. Lecture: Forming of high strength steels and hot forming of sheet metal - The problem of forming the high-strength steels - Concepts for increasing the quality of formed parts - Measures to reduce elastic springback - Definition of the conditions required for hot forming - Hot stamping technology 6. Lecture: Media assisted forming processes - Definition of the conditions of forming with the medium, division of the processes according to the execution of the process - Characterization of high and low pressure forming - Process parameters and their influence on the forming quality 7. Lecture: Small batch forming technologies for the manufacture of sheet metal products - Incremental forming - characterization of process, advantages and weaknesses - Process limits from the perspective of materials, process parameters, process execution - Achievable manufacturing precision of the process, influences on the precision of the process
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na natančnost procesa 8. Predavanje: Večosno tlačno preoblikovanje kovin - Opredelitev napetostno-deformacijskih pogojev pri iztiskavanju - Omejitve posameznih postopkov, tehnološke meje - Dopustne obremenitve orodij in določitev preoblikovalnih sil 9. Predavanje: Orodja in orodni sistemi za preoblikovanje kovin - Opredelitev problematike obremenjevanja aktivnih delov preoblikovalnega orodja - Koncepti zgradbe preoblikovalnih orodij, glavni sklopi orodja in njihove karakteristike - Uravnavanje razmerij napetosti preoblikovalnih orodij skladno z njihovimi obremenitvami 10. Predavanje: Brizganje in napredni postopki brizganja podprti s plinom/vodo (GIT in WIT) - Karakteristike in parametri procesa brizganja - Karakteristike procesa brizganja podprtega s plinom - Karakteristike procesa brizganja podprtega z vodo - Procesne izboljšave brizganja podprtega s plinom/vodo in specifične obeh procesov napram procesu klasičnega brizganja - Napake pri brizganju podprtem s plinom/vodo - Potrebna oprema za brizganje podprto s plinom/vodo 11. Predavanje: Brizganje večkomponentnih izdelkov (2K in več-K) - Osnove in koncepti 2K tehnologije brizganja - Izvedbe postopkov 2K brizganja in specifične posamezne različice - Orodni koncepti 2K brizganja, prednosti in slabosti 2K tehnologije 12. Predavanje: Tehnologije predelave polimerov za izdelave malih serij funkcionalnih izdelkov - Karakterizacija maloserijske proizvodnje - Polimerni orodni koncepti za brizganje malih serij, njihove prednosti in slabosti - Inkrementalno preoblikovanje polimernih plošč v hladnem ali lokalno ogretem stanju, prednosti in slabosti postopka 13. Predavanje: Sodobna oprema za brizganje - Predstavitev sestavnih delov orodja - Delitev orodij glede na način dovajanja taline - Senzorika v brizgalnih orodjih, načini krmiljenja procesa in sodobni avtomatizirani brizgalni stroji 14. Predavanje: Preoblikovanje polimernih kompozitnih materialov - Opredelitev pojma kompozitnega materiala in njegovih prednosti pred neojačanim polimernim materialom - Preoblikovanje kratko-vlakenskih kompozitov - Preoblikovanje dolgo-vlakenskih termoplastičnih kompozitov - Preoblikovanje dolgo-vlakenskih duroplastičnih kompozitov	8. Lecture: Multiaxial compression forming of metals - Definition of stress-strain conditions for extrusion - Process limitations, technological limits - Permissible tool loads and determination of the forming forces 9. Lecture: Tools and tooling systems for metal forming - Identification of the load problem of the active parts of the forming tool - Concepts for the design of forming tools, main tool sets and their properties - Stress ratio adjustment of the forming tools according to their load 10. Lecture: Injection molding and advanced gas/water assisted injection molding processes (GIT and WIT) - Features and parameters of the injection molding process - Features of the gas-assisted injection molding process - Features of the water-assisted injection molding process - Process improvements for gas/water-assisted injection molding and the special features of both processes with respect to the conventional injection molding process - Errors that occur during gas/water-assisted injection molding - Machines for gas/water assisted injection molding 11. Lecture: Injection molding of multi-component products (2K and more - K) - Basics and concepts of 2K injection molding technology - Implementation of 2K injection molding processes and the special features of each version - 2K injection molding tools, advantages and disadvantages of 2K technology 12. Lecture: Polymer processing technologies for the production of small batches of functional products - Characterization of small series production - Polymer mold concepts for small series injection molding, their advantages and disadvantages - Incremental forming of polymer plates in cold or locally heated state, advantages and disadvantages of the process 13. Lecture: Modern injection molding equipment - Presentation of tool components - Division of the tools according to the type of melt supply - Sensors in injection molds, process control methods and modern automated injection molding machines 14. Lecture: Forming of polymer composite materials - Definition of the term "composite material" and its advantages over non-reinforced polymer material - Forming of short fiber composites - Forming of long-fiber thermoplastic composites - Forming of thermoset long fiber composites
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15. Predavanje: Kriteriji izbire tehnologije preoblikovanja - Opredelitev kriterijev za izbiro tehnologije preoblikovanja kovinskih izdelkov - Opredelitev kriterijev za izbiro tehnologije preoblikovanja nekovinskih izdelkov - Vrednotenje izvedljivosti postopka - Vrednotenje obremenitev orodij, izbira vrste stroja (kinematika gibanja, hitrosti procesa ...)	15. Lecture: Selection criteria for forming technology - Definition of criteria for the selection of technology for the forming of metal products - Definition of criteria for the selection of technology for forming non-metallic products - Evaluation of the feasibility of the process - Evaluation of the tool load, selection of the machine type (motion kinematics, process speeds ...)
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Temeljna literatura in viri/Readings:

1. Hosford, W. F., & Caddell, R. M. (2007). Metal forming: mechanics and metallurgy (3rd ed., str. XIII, 312). Cambridge University Press. http://www.loc.gov/catdir/toc/ecip0712/2007008558.html , [COBISS.SI-ID 10256923] 2. Montgomery, D. C. (2005). Design and analysis of experiments (6th ed., str. XV, 643). J. Wiley & Sons., [COBISS.SI-ID 1495462] 3. Injection molding handbook (str. XVII, 748). (2002). C. Hanser Verlag; Hanser Gardner Publications., [COBISS.SI-ID 4936475] 4. Golobranc, F. (1991). Preoblikovanje (str. Zv. <1-2>). Fakulteta za strojništvo., [COBISS.SI-ID 24041728] 5. Kampuš, Z., & Kuzman, K. (2016). Priporočila preoblikovanja (2. izd., str. IV, 78). Fakulteta za strojništvo., [COBISS.SI-ID 283051776]	
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Cilji in kompetence:

Cilji: 1. Spoznati sposobnosti izdelave proizvodov z naprednimi procesi preoblikovanja in izbirati ustrezen tehnološki proces. 2. Poglobljeno spoznati standardne in inovativne procese preoblikovanja kovinskih in nekovinskih gradiv in optimirati njihove vplivne parametre. 3. Na osnovi poznavanja obstoječih preoblikovalnih procesov snovati preoblikovalne procese in njihove ključne tehnološke parametre. 4. Poglobljeno razumevanje inovativnih preoblikovalnih konceptov, sintetično razumevanje pridobljenih znanj iz dostopnih virov in snovanje novih inovativnih rešitev preoblikovalnih postopkov. Kompetence: 1. S2-MAG+S8-MAG+P5-MAG Sposobnost identifikacije ustreznosti naprednega preoblikovalnega procesa za izdelavo produkta. 2. P7-MAG +S10-MAG Sposobnosti izbire preoblikovalne tehnologije, in optimalnih parametrov procesa.	Objectives and competences: Objectives: 1. Acquire the ability to manufacture products using advanced forming processes and to select the appropriate technological process. 2. In-depth knowledge of standard and innovative processes for forming metallic and non-metallic materials and the optimisation of their influencing parameters 3. Based on the knowledge of existing forming processes, design of the forming processes and their key technological parameters. 4. In-depth knowledge of innovative forming concepts, synthetic understanding of the acquired knowledge from accessible sources, and design of new innovative solutions of forming processes. Competences: 1. S2-MAG+S8-MAG+P5-MAG: The ability to identify the appropriateness of an advanced forming process for the manufacture of the product. 2. P7-MAG +S10-MAG: The ability to select the forming technology and optimum process parameters. 3. S10-MAG+P3-MAG+P4-MAG: The ability to develop advanced and innovative forming
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3. S10-MAG+P3-MAG+P4-MAG: Sposobnost snovanja naprednih in inovativnih preoblikovalni procesov za izdelavo tehnološko najzahtevnejših izdelkov.	processes to produce the most technologically advanced products.
4. S1-MAG+S2-MAG+S7-MAG+P6-MAG: Sposobnost razvoja inovativnih preoblikovalnih konceptov in njihove aplikacijev proizvodnjo obstoječih in/ali novih izdelkov.	4. S1-MAG+S2-MAG+S7-MAG+P6-MAG: The ability to develop innovative forming concepts and their applications to produce existing and/or new products.

Predvideni študijski rezultati:

Znanja: Z2: Poglobljeno teoretično, metodološko in analitično znanje o naprednih preoblikovalnih postopkih predelave kovinskih in polimernih materialov z elementi raziskovanja, ki je osnova za zelo zahtevno strokovno delo. Spretnosti: S2.1 Obvladovanje naprednih procesov zahtevnih tehnologij preoblikovanja kovinskih gradiv in polimernih materialov. S2.2 Načrtovanje inovativnih preoblikovalnih postopkov na podlagi ustvarjalnega reševanja problemov in sinteze pridobljenih znanj. S2.3 Sposobnost kritičnega presojanja ustreznosti izbire tehnologije preoblikovanja in prenos izvirnih dognanj/stvaritev in kritične refleksije v tehnološke aplikacije.
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Intended learning outcomes:

Knowledge: Z2: Thorough theoretical, methodological and analytical knowledge of advanced forming processes of processing metal and polymer materials with elements of a research work that form a basis for very demanding professional work. Skills: S2.1 Mastering advanced processes of very demanding technologies of forming metal and polymer materials. S2.2 Planning innovative forming processes on the basis of creative solving of problems that are linked to the teaching and training content. S2.3 Ability to critically evaluate the appropriateness of the selection of forming technology and to transfer the original findings/creations and critical reflections into technology applications.
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Metode poučevanja in učenja:

P1 Avditorna predavanja z reševanjem izbranih -za področje značilnih - teoretičnih in praktično uporabnih primerov P3 Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. P4 Laboratorijske vaje z namenskimi didaktičnimi pripomočki: • Hidravlična stiskalnica • Stroj za brizganje polimerov • Hidravlični preizkuševalni stroj P7 Študij literature in razprava P8 Izdelava in predstavitev aplikativnih seminarskih nalog
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Learning and 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. P4 Laboratory exercises with special-purpose didactic devices: • Hydraulic press • Injection moulding machine • Hydraulic testing machine P7 Literature study and discussion. P8 Making and presenting applied seminar exercises.
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P12 Individualizirane domače naloge v spletni učilnici	P12 Individualised homeworks in a web classroom.
P15 Uporaba video vsebin kot priprava na predavanja in vaje	P15 Application of videos for preparations to the lectures and exercises.

Načini ocenjevanja:	Delež/Weight	Assessment:
- Teoretične vsebine (predavanja)	50,00 %	- Theoretical content (lectures)
- Delo na laboratorijskih vajah (vključno s poročili)	30,00 %	- Laboratory work (including reports)
- Seminar	20,00 %	- Seminar

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:

Tomaž Pepelnjak:

- SEVŠEK, Luka, ŠEGOTA, Sandi Baressi, CAR, Zlatan, **PEPELNJAK, Tomaž**. Determining the influence and correlation for parameters of flexible forming using the random forest method. *Applied soft computing*. [Print ed.]. Jun. 2023, str. 1-36, ilustr. ISSN 1568-4946. <https://www.sciencedirect.com/science/article/pii/S156849462300515X>, DOI: [10.1016/j.asoc.2023.110497](https://doi.org/10.1016/j.asoc.2023.110497). [COBISS.SI-ID [156012547](#)]
- SATOŠEK, Roman, **PEPELNJAK, Tomaž**, STARMAN, Bojan. Characterisation of out-of-plane shear behaviour of anisotropic sheet materials based on indentation plastometry. *International journal of mechanical sciences*. Sep. 2023, vol. 253, str. 1-15, ilustr. ISSN 0020-7403. <https://www.sciencedirect.com/science/article/pii/S0020740323003053>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=145687>, DOI: [10.1016/j.ijmecsci.2023.108403](https://doi.org/10.1016/j.ijmecsci.2023.108403). [COBISS.SI-ID [149875203](#)]
- PEPELNJAK, Tomaž**, STOJŠIĆ, Josip, SEVŠEK, Luka, MOVRIN, Dejan, MILUTINOVIĆ, Mladomir. Influence of process parameters on the characteristics of additively manufactured parts made from advanced biopolymers. *Polymers*. Jan. 2023, vol. 15, iss. 3, str. 1-45, ilustr. ISSN 2073-4360. <https://www.mdpi.com/2073-4360/15/3/716>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=144093>, DOI: [10.3390/polym15030716](https://doi.org/10.3390/polym15030716). [COBISS.SI-ID [140131075](#)]
- STEFANOVSKA, E., **PEPELNJAK, Tomaž**. Development of a flexible tooling system for sheet metal bending. *Advances in production engineering & management*. Sep. 2022, vol. 17, nr. 3, str. 311–325, ilustr. ISSN 1854-6250. https://apem-journal.org/Archives/2022/Abstract-APEM17-3_311-325.html, <http://www.dlib.si/details/URN:NBN:SI:doc-AT8JK5H8>, DOI: [10.14743/apem2022.3.438](https://doi.org/10.14743/apem2022.3.438). [COBISS.SI-ID [132538371](#)]
- KARIMI, Ako, MOLE, Nikolaj, **PEPELNJAK, Tomaž**. Numerical investigation of the cycling loading behavior of 3D-Printed poly-lactic acid (PLA) cylindrical lightweight samples during compression testing. *Applied sciences*. Aug. 2022, vol. 12, iss. 16, str. 1-18, ilustr. ISSN 2076-3417. <https://www.mdpi.com/2076-3417/12/16/8018>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=138754>, DOI: [10.3390/app12168018](https://doi.org/10.3390/app12168018). [COBISS.SI-ID [118174211](#)]