

Knjiga sažetaka; 18. međunarodno savjetovanje ljevača: Suživot znanosti o materijalima i održive tehnologije u ekonomskom rastu; Studentska sekcija

Edited book / Urednička knjiga

Publication status / Verzija rada: **Published version / Objavljena verzija rada (izdavačev PDF)**

Publication year / Godina izdavanja: **2019**

Permanent link / Trajna poveznica: <https://urn.nsk.hr/urn:nbn:hr:115:155378>

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Download date / Datum preuzimanja: **2025-03-13**



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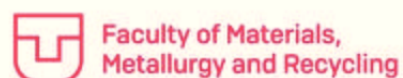
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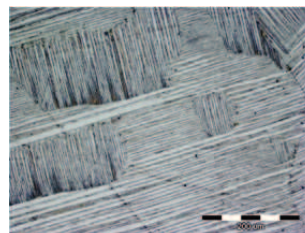


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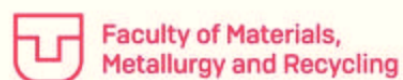
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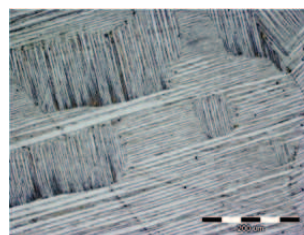


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IZDAVAČ

Sveučilište u Zagrebu Metalurški fakultet, Aleja narodnih heroja 3, 44000 Sisak

TISAK

InfOmArt Zagreb d.o.o., Nikole Tesle 10, 44000 Sisak

BROJ PRIMJERAKA

50 kopija

ISBN

978-953-7082-35-2

ZAHVALA:

Organizacijski odbor najljubaznije zahvaljuje *Studentskom centru Sisak, Gradu Sisku i Sisačko-moslavačkoj županiji* na financijskoj potpori organizaciji 18. Međunarodnog savjetovanja ljevača.



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18th INTERNATIONAL FOUNDRYMEN CONFERENCE: Coexistence of Material Science and Sustainable Technology in Economic Growth; Student's section

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PUBLISHER

University of Zagreb Faculty of Metallurgy, Aleja narodnih heroja 3, 44000 Sisak, Croatia

PRINT

InfOmArt Zagreb d.o.o., Nikole Tesle 10, 44000 Sisak

ISSUE

50 copies

ISBN:

978-953-7082-35-2

ACKNOWLEDGMENT:

Organizing Committee would like to cordially thank to *Student's Centre Sisak, City of Sisak* and *Sisak-moslavina County* for financial support of 18th International Foundrymen Conference organization.



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PREDGOVOR

Metalurgija je specifično polje koje se bavi dizajnom, razvojem i karakterizacijom materijala od onih svakodnevnih koji nas okružuju u našim domovima, radnim mjestima, ali i materijala s posebnim zahtjevima za specifične namjene poput onih za automobilsku ili svemirsku industriju. Pritom treba poznavati i proizvodne procese. Kroz ove prethodne spoznaje provlači se uporaba i zbrinjavanje metalnih materijala i otpada iz proizvodnje kojim se bavi Industrijska ekologija. Industrijske djelatnosti, koje se utvrđuju kao strateške djelatnosti u Republici Hrvatskoj su **Lijevanje metala** i **Proizvodnja gotovih metalnih proizvoda**, prepoznate kao „**pokretači gospodarskog rasta**“ jer se od njih očekuje da ostvaruju veće stope rasta i zapošljavanja.

Sinergijom istraživanja u metalurgiji i drugim poljima tehničkih znanosti poput strojarstva izrazito se doprinosi razvoju i karakterizaciji tehničkih materijala te potiče razvoj tehnologija i njihova optimizacija. Korelacijom inženjerstva tehničkih materijala utemeljenog na znanju i visoko tehnoloških rješenja odvija se transfer znanja interakcijom tvrtki i visokoškolskih institucija. Osim navedenog, a uvažavajući vještine i znanja stečene u praksi Fakulteti prepoznaju i organiziraju radionice, predavanja i prezentacije radi transfera znanja i iskustva stručnjaka iz industrije usmjerenih prema nastavnicima radi podizanja kompetencija, ali i studentima radi stjecanja specifičnih znanja i vještina.

Visokoškolsko obrazovanje na Metalurškom fakultetu, ali i drugim suradnim ustanovama koncipirano programima i ishodima učenja zasniva se, između ostalog i na poticanju znanstvenoistraživačkog rada studenata s primijenjenim temama, kako bi ambiciozni i kreativni mladi ljudi postali samostalni rješavatelji problema, razvijajući i podupirući njihovu znatiželju, analitičnost, komunikativnost: ***Kako bi postali diplomci kakve želi tržište rada!***

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PREFACE

Metallurgy, as a specific field of technical sciences, deals with the design, development and characterization of everyday materials in our homes, workplaces, as well as materials with special requirements for specific applications such as those for the automotive or space industry. Knowledge about manufacturing processes should also be acquired. The recovery and disposal of metal materials and waste from the production is underlined as a prerequisite knowledge. Industrial activities, which are defined as strategic activities in the Republic of Croatia are **Metal Casting** and **Production of Final Metal Products**, recognized as **"economic growth drivers"** because they are expected to realize higher rates of growth and employment.

The synergy of research in metallurgy and other fields of technical sciences, such as mechanical engineering, is particularly beneficial for the development and characterization of engineering technical materials and encourages the development of sustainable technologies and their optimization. Correlation of engineering of knowledge-based technical and high technological solutions is the transfer of knowledge through interaction between economy and higher education institutions. In addition to this, recognizing the skills and knowledge acquired in practice, the faculties recognize and recognize workshops, lectures and presentations for the transfer of knowledge and experience from industry-oriented teachers to raise competences, but also to students to acquire specific knowledge and skills.

Higher education at the Faculty of Metallurgy, but also at the other HEIs' conceived through the program and the learning outcomes, is based, inter alia, on promoting students scientific and research work on applied topics, enabling ambitious and creative young people to become independent problem solvers, developing and supporting their curiosity, analytics and communication: ***Graduates like the labour market needs!***

President of Organizing Board

Assoc.Prof. Zdenka Zovko Brodarac, PhD



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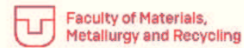
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**UTJECAJ UVJETA SKRUĆIVANJA I DEBLJINE STIJENKE NA RAZVOJ PRIMARNOG
 α -Al u AlSi7Mg LEGURI**

Ivana Gavranović, Zdenka Zovko Brodarac, Franjo Kozina, Tomislav Rupčić

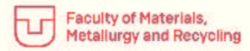
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Legura AlSi7Mg je jedna od najčešće primjenjivanih podeutektskih Al-Si legura, namijenjena lijevanju odljevaka kompleksne geometrije u automobilske, kemijske i prehrambene industrije zbog dobrih mehaničkih svojstava i mogućnosti njihova povećanja naknadnom toplinskom obradom. Lijevanje u trajne kalupe osigurava brže odvođenje toplote, dok se primjenom hlađenja optimiziraju parametri lijevanja i usmjerava skrućivanje u debljim stijenkama radi postizanja kompaktne i homogene mikrostrukture u svim presjecima. Tehnologija gravitacijskog lijevanja u trajne kalupe sa zakretanjem omogućava kontrolirano punjenje alata i usmjereno skrućivanje. Metalografskim ispitivanjem AlSi7Mg legure, osim primarnih α -Al dendrita i eutektika (α -Al+ β -Si) uočene su i intermetalne faze na osnovi Fe i Mg. U radu je istraživana utjecaj 2 postavljena parametara lijevanja: I optimalni parametri s hlađenjem alata i II bez hlađenja alata, na razvoj mikrostrukture i to prvenstveno na razvoj α -Al u korelaciji s debljinom stijenke. Utvrđeno je pozitivan utjecaj primijenjenog hlađenja na smanjenje udjela α -Al i SDAS-a do 25 mm debljine stijenke.

Ključne riječi: AlSi7Mg legura, hlađenje, mikrostruktura, debljina stijenke



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**INFLUENCE OF SOLIDIFICATION CONDITIONS AND WALL THICKNESS ON THE
DEVELOPMENT OF PRIMARY α -Al in AlSi7Mg Alloy**

Ivana Gavranović, Zdenka Zovko Brodarac, Franjo Kozina, Tomislav Rupčić

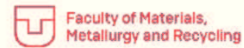
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AlSi7Mg alloy is one of the most used hypoeutectic Al-Si alloys, intended for casting with complex geometries in the automotive, chemical and food industry due to good mechanical properties and its increase with subsequent heat treatment. Casting in permanent molds ensures faster heat removal while application of cooling optimizes casting parameters and solidification direction in thicker walls for ensuring compact and homogeneous microstructure in all cross sections. Gravity tilt casting allows controlled die filling and directional solidification. Metallographic examination of AlSi7Mg alloy reveals primary α -Al dendrites and eutectics (α -Al+ β -Si) and other intermetallic phases on the basis on Fe and Mg. This investigation revealed an influence of two sets of casting parameters: I optimal casting parameters with applied cooling and II casting parameters without cooling on microstructure development in particularly α -Al in correlation to wall thickness. A positive impact of applied cooling has been established on α -Al surface ratio and SDAS decreasing till the wall thickness of 25 mm.

Keywords: AlSi7Mg alloy, cooling, microstructure, wall thickness



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PROIZVODNJA I ISPITIVANJE NODULARNOG LIJEVA KVALITETE EN GJS 400-15

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Nodularni lijev karakterizira grafit koji se izlučuje u obliku kuglica ili nodula. U mnogim područjima primjene nodularni lijev danas zamjenjuje čelične ljevove ili čelične otkivke srednje i veće masivnosti radi povoljnih mehaničkih svojstava i manje gustoće u odnosu na čelik. U ovom radu prezentirat će se prednosti i nedostaci nodularnog lijeva u odnosu na ostale željezne ljevove, utjecaj legirnih i pratećih elemenata na mehanička svojstva nodularnog lijeva te kratak osvrt na talioničke peći i postupak dobivanja nodularne taline. Prikazat će se postupak proizvodnje nodularnog lijeva HRN EN GJS 400-15, koji se sastoji od dobivanja primarne taline i naknadne modifikacije te taline u nodularnu te ispitivanje kemijskog sastava, metalografska ispitivanja i ispitivanje mehaničkih svojstava nodularnog lijeva kvalitete HRN EN GJS 400-15.

Ključne riječi: nodularni lijev, mehanička svojstva, mikrostruktura, kemijski sastav

**PRODUCTION AND CHARACTERIZATION OF NODULAR CAST IRON GRADE
EN GJS 400-15**

Juraj Godinić, Sanja Šolić

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Ductile or nodular cast iron is characterized by graphite that is excreted in the form of balls or nodules. In many areas of application, the nodular cast iron today replaces steel castings or steel forgings of medium and greater massive strength due to the favourable mechanical properties and less density in relation to steel. In this paper, the advantages and disadvantages of nodular cast iron in relation to other iron casts, the influence of alloying and accompanying elements on the mechanical properties of nodular cast iron, and a brief review of the casting furnace and the process of obtaining nodular melt will be presented. The process of producing a nodular cast iron grade HRN EN GJS 400-15, which consists of the preparation of primary melt and subsequent modification, with the chemical composition testing, metallographic analysis and testing of the mechanical properties of HRN EN GJS 400-15 will be presented as well.

Keywords: ductile cast iron, mechanical properties, microstructure, chemical composition



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ALTERNATIVNI NAČINI PROIZVODNJE ALUMINIJA

Ana-Marija Hirš, Natalija Dolić

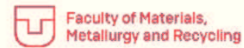
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U ovom radu dan je pregled alternativnih načina i procesa proizvodnje aluminija. Hall Héroultov proces elektrolitičke redukcije glinice razvijen je krajem 19. stoljeća te je još uvijek jedini industrijski proces za proizvodnju aluminija. Svrstan je među energetske najintenzivnije procese i najveće proizvođače CO₂. Čak 1 % od ukupne svjetske električne energije troši se na ovaj proces koji ukupnoj svjetskoj emisiji stakleničkih plinova pridonosi s 2.5 %. Kao alternativni procesi predloženi su procesi: direktna karbotermijska redukcija glinice, karbotermijska redukcija pod vakuumom i inertnim plinom, indirektna karbotermijska redukcija te redukcija kaolinata. Svaki od ovih procesa pokazuje izrazit potencijal smanjenja potrošnje energije i emisije štetnih plinova. Međutim, javljaju se određeni problemi koji sprječavaju njihovo uvođenje u industriju (mali izvadak aluminija i previsok udio karbida u aluminiju). Zamjenom Hall Héroultovih ugljičnih anoda inertnim anodama, uvođenjem moćivih katoda te multipolarnih ćelija troškovi Hall Héroultovog procesa znatno bi se smanjili, a proces bi postao prihvatljiviji za okoliš.

Ključne riječi: aluminij, Hall Héroultov proces, prednosti i nedostaci



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ALTERNATIVE METHODS OF ALUMINIUM PRODUCTION

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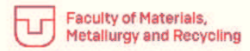
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This paper gives an overview of alternative methods and processes for aluminium production. The Hall-Héroult process for the electrolytic reduction of alumina was developed at the end of the 19th century and is still currently the only industrial process for the production of aluminium. Today this process is ranked among the most energy and CO₂ intensive industrial processes. About 1 % of the globally produced electric energy is consumed by this process which produces 2.5 % of the World's anthropogenic greenhouse gases. Proposed alternative processes include: direct carbothermic reduction of alumina, carbothermic reduction under vacuum or inert gas conditions, indirect carbothermic reduction and kaolinite reduction. Every one of those processes shows distinct potential to reduce energy consumption and greenhouse gas emissions. However, there are certain problems that hinder their implementation in industry (low yield and very high carbon content in the product). By replacing Hall Heroult carbon anodes with inert anodes, wetted cathodes and multipolar cells costs of Hall Heroult process would decrease considerably and process would become more environmentally friendly.

Keywords: aluminium, Hall Heroult process, advantages and disadvantages



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**COMPARISON OF CASTED AND RAPIDLY SOLIDIFIED MICROSTRUCTURE OF
Ag-2La Alloy**

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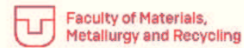
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Silver is very attractive as electric contact material due to its great electrical and thermal conductivity. However, silver requires a considerable improvement in strengths to be applicable in the electronic industry. To overcome this problem, the inclusion of fine dispersoids in the Ag-matrix can be used. As the most promising candidates belong the oxides of rare earths. Unfortunately, because of very low solubility, these elements occur in the cast structure of the silver alloys as coarse intermetallic particles that prevent a fine dispersion of oxide particles by internal oxidation. The rapid solidification can be used as a means to refine the intermetallic phases to a scale that would enable a fine dispersion of oxide particles during subsequent internal oxidation. Hence the microstructure of rapidly solidified ribbons of Ag-2wt%La alloy prepared by Melt spinning technique will be discussed in our presentation and compared with the as cast microstructure of the alloy.

Keywords: silver, lanthanum, microstructure, casting, rapidly solidifying



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**NAPETOSNA KOROZIJA METALA I METALNIH LEGURA KAO FENOMEN
PRISUTAN U LJEVARSTVU**

Blanka Krčelić, Anita Begić Hadžipašić

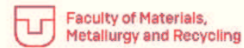
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Problem pojave napetosne korozije najčešće se javlja na metalima i metalnim legurama izloženim utjecaju okolišnih uvjeta koji napadaju metale te neočekivanoj pojavi naprezanja materijala. Djelovanje prevelikog opterećenja na materijal, odnosno metalnu konstrukciju uzrokuju pojave naprezanja kao što su smicanje, vlačno naprezanje, tlačno naprezanje, savijanje i uvijanje koje uz medij koji nagriza metal može dovesti do pukotina, a kasnije i do loma materijala. Načini širenja pukotina kod napetosne korozije mogu biti transkristalno napredovanje po površini kristalnih zrna ili interkristalno napredovanje duž granica zrna. Napetosna korozija nastupit će najčešće na hladno deformiranim lokalitetima, gdje mogu zaostati naprezanja ili u okolini zavarenih spojeva, gdje ima i strukturnih promjena. Složeni odljevci koji se koriste kao kućišta vodenih pumpi i dijelovi strojeva u elektronskoj i prehrambenoj industriji mogu biti izloženi različitim medijima koji otapaju ili nagrizzaju materijal, povišenim temperaturama, a dodatno su opterećeni naprezanjem koje dovodi do trajnih deformacija metala. Stoga, trebaju se poduzeti određene mjere zaštite od korozije, koje će dovesti do usporavanja korozijskog procesa i produženja vijeka trajanja opreme.

Ključne riječi: napetosna korozija, naprezanje, metali, odljevci, pukotine



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**STRESS CORROSION CRACKING OF METALS AND METAL ALLOYS AS
PHENOMENON OCCURS IN FOUNDRY**

Blanka Krčelić, Anita Begić Hadžipašić

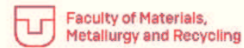
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Stress corrosion cracking phenomenon is most frequently found on metals and metal alloys which are exposed to the environmental influences that attack metals and the unexpected stress of the material. The effect of excessive load on the material or metal construction causes stress such as shear stress, tensile stress, compressive stress, bending and torsion that can with a corrosion medium lead to cracking and later material fracture. Ways of metal cracks expanding at stress corrosion cracking can be transgranular progression along the surface of the crystal grains or intergranular progression along the grain boundaries. Stress corrosion cracking is most likely to manifest at cold-deformed locations where stresses may remain or in the region of the welded joints, where there are structural changes. Complex castings used as water pump housings and machine parts in the electronics and food industry may be exposed to a variety of media that dissolve or corrode material, at elevated temperatures and are additionally loaded with stress that results in permanent metal deformations. Therefore, certain corrosion protection measures should be taken, which will lead to slowing down the corrosion process and extending the life of equipment.

Keywords: stress corrosion cracking, strain, metals, castings, cracks



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ELEKTROKEMIJSKA SVOJSTVA AA5083 I AA6060 LEGURA U MORSKOJ VODI

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Aluminijske legure AA5083 i AA6060 često nalaze svoju upotrebu u pomorskoj industriji te je ispitivanje njihovih elektrokemijskih parametara u morskoj vodi s ciljem utvrđivanja korozivskih svojstava od značajnog interesa. U ovom radu su provedena elektrokemijska mjerenja pri dvije različite temperature ($18 \pm 0,5$)°C i ($30 \pm 0,5$)°C. Mjerenja su obuhvaćala sljedeće metode: linearnu polarizaciju, elektrokemijsku impedancijsku spektroskopiju (EIS) i potenciodinamičku polarizaciju. Kako bi se postigli uvjeti što bliži realnima kao elektrolit se koristila svježa morska voda uzorkovana na šibenskom području. Dobiveni rezultati daju uvid u ponašanje AA5083 i AA6060 legura u prirodnoj morskoj vodi kao i na utjecaj promjene temperature na elektrokemijske parametre.

Ključne riječi: morska voda, aluminijske legure, elektrokemijska mjerenja, korozija

**ELECTROCHEMICAL PROPERTIES OF AA5083 AND AA6060 ALLOYS IN
SEAWATER**

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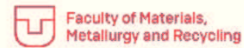
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AA5083 and AA6060 are alloys commonly used in marine application. Therefore, investigation of their electrochemical parameters in seawater with the aim to determine corrosion properties is of quite some interest. In this paper, following electrochemical tests were carried out at ($18 \pm 0,5$)°C and at ($30 \pm 0,5$)°C: linear polarization, electrochemical impedance spectroscopy (EIS) as well as potentiodynamic polarization. In order to obtain conditions more close to real one, fresh seawater was sampled as an electrolyte in Šibenik region. Obtained result give more insight in AA5083 and AA6060 alloys behaviour in natural seawater as well as on the effect of temperature change on electrochemical parameters.

Keywords: seawater, aluminium alloys, electrochemical measurements, corrosion



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**UTJECAJ BRZINE RAZVLAČENJA NA POČETAK
HLADNE DEFORMACIJE ČELIKA MIKROLEGIRANOG NIOBIJEM**

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Čelik je danas najrasprostranjeniji materijal u svijetu. Istraživanja su pokazala kako mikrolegirani čelici s titanom ili niobijem imaju bolja mehanička svojstva od ostalih čelika. Dobra mehanička svojstva podrazumijevaju visoku žilavost, deformabilnost, otpornost i čvrstoću. Takva svojstva postižu se odgovarajućom kombinacijom kemijskog sastava i parametara termomehaničke obrade. U ovom radu ispitano je ponašanje niskougličnog čelika mikrolegiranog s 0.035% niobija na početku plastičnog toka materijala. Ispitivanja su provedena statičkim vlačnim pokusom i digitalnom korelacijom slike. Dobiveni rezultati su pokazali da brzina razvlačenja ima utjecaj na početak plastičnog toka niobijem mikrolegiranog čelika.

Ključne riječi: digitalna korelacija slike, statičko vlačno ispitivanje, početak plastične deformacije čelika, mikrolegirani čelik

**INFLUENCE OF STRETCHING RATE ON THE BEGINNING OF COLD
DEFORMATION IN NIOBIUM MICROALLOYED STEEL**

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Today, steel is the most widespread material in the world. Studies have shown that microalloyed steel with titanium or niobium has better mechanical properties than other steels. Good mechanical properties include high toughness, deformability, resistance and strength. Such properties are achieved by an appropriate combination of chemical composition and thermomechanical processing parameters. In this paper has been examined the behaviour of low-carbon steel microalloyed with 0.035% niobium on the start of plastic flow of material. Researches were conducted by static tensile test and digital image correlation. Obtained results have shown that the stretching rate has an influence on the start of the plastic flow of niobium microalloyed steel.

Keywords: digital image correlation, static tensile test, start of plastic flow of steel, microalloyed steel



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HLADNO IZVLAČENJE ČELIČNIH CIJEVI

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Precizno hladno deformirane cijevi proizvode se hladnim izvlačenjem i hladnim pilgerovanjem. Hladno izvlačenje cijevi provodi se na tzv. vučnoj klupi, gdje se kroz matricu određenih dimenzija izvlači cijev s većeg promjera na manji. Kako bi se dobila tražena debljina stijenke cijevi i promjera potrebno je prije sljedećeg izvlačenja provesti žarenje. U ovom radu prikazani su rezultati hladnog izvlačenja cijevi. Istraživanja su provedena na čeliku E355. Cijev promjera 30 mm i debljine stijenke 3 mm vučena je na konačnu dimenziju promjera 20 mm i debljine stijenke cijevi 2 mm. Nakon izvlačenja cijevi su ispitivane metalografski na optičkom mikroskopu te statičkim vlačnim pokusom i mjerenjem tvrdoće po Vickersu. Detaljno je ispitana promjena tvrdoće u zoni deformacije i određen stupanj očvršćavanja tijekom hladne deformacije u jednoj provlaci.

Ključne riječi: hladno deformiranje, izvlačenje cijevi, stupanj deformacije, očvršćenje

COLD DRAWING OF STEEL TUBES

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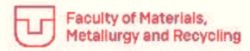
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Precision cold-drawn tubes are produced by cold drawing and cold pilgering. The cold drawing of the tubes is carried out at the so called draw bench, where the diameter of the tube from a larger diameter to the smaller is drawn through the die of certain dimensions. In order to obtain the required thickness of the tube wall and diameter, it is necessary to carry out the annealing before the next draw. This paper presents the results of cold drawn tubes. Research was carried out on steel E355. The tube diameter of 30 mm and wall thickness of 3 mm is drawn to the final dimension of 20 mm diameter and wall thickness of 2 mm. Metallographic tests on optical microscope, static tensile tests and Vickers hardness tests were used for testing tubes after cold drawing. The hardness change in the deformation zone and the degree of hardening during cold deformation in one draw were examined in detail.

Keywords: cold deformation, tubes drawing, deformation degree, hardening



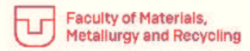
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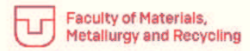
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