UNIVERSITY OF EAST SARAJEVO

FACULTY OF MECHANICAL ENGINEERING

6th INTERNATIONAL SCIENTIFIC CONFERENCE

COMETa 2022

„Conference on Mechanical Engineering Technologies and Applications“

PROCEEDINGS

17th-19th November

East Sarajevo, RS, B&H

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Jahorina, B&H, Republic of Srpska

University of East Sarajevo

Faculty of Mechanical Engineering

Conference on Mechanical Engineering Technologies and Applications

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PREFACE

The economic power of a society can be expressed by different indicators. However, it is certain that the competitiveness of the economy is one of the most important. In this sense, it is necessary for industrial production to follow modern development trends, which are based on current scientific achievements. Only a holistic approach in the application of knowledge in various engineering fields, and especially in the field of mechanical engineering, is a guarantee of economic progress, which enables long-term stability and prosperity of each country. Precisely for these reasons, the Faculty of Mechanical Engineering of the University of East Sarajevo organized the 1st International Scientific Conference COMETa in 2012, and this year is its 6th edition.

The main goal of the conference is to strengthen cooperation with the academic community, scientific-research institutions and, above all, with business entities. Conference COMETa 2022 is an opportunity for all participants to offer guidelines and create a better environment for more intensive industrial development through the exchange of knowledge and experience. That is going to have impact to increasing the competitiveness of national economic entities on the foreign market. The participation of a significant number of domestic and foreign scientists and researchers strengthens our conviction that in the near future we will be able to overcome challenges that are present in the technical-technological development of an advanced society in the 21st century, mainly through the generation of new ideas and the introducing of modern approaches to solving complex tasks in the field of mechanical engineering. In this sense, all your proposals and suggestions are more than welcome and will be carefully considered by the Scientific and Organizing Committee in order to improve the organization of the next conferences. Acknowledging the importance of the wide field of mechanical engineering for the overall industrial development of society, the work of the conference will take place through 7 sections, including the Student section. The program is focused on the following thematic areas:

- Manufacturing technologies and advanced materials,
- Applied mechanics and mechatronics,
- Machine design, simulation and modeling,
- Product development and mechanical systems,
- Energy and thermotechnic,
- Renewable energy and environmental protection,
- Maintenance and technical diagnostics,
- Quality, management and organization.

At this year's conference COMETa 2022, 105 papers including 4 plenary lectures will be published in the Proceedings.

We are specially looking forward that conference registered a record number of participants from abroad. Namely, 300 authors come from 25 countries. This is certainly the result of strenuous activities that were aimed at raising the international reputation and visibility of the conference in the regional, but also in the wider academic and scientific research space, which will be one of the primary goals in the future.

On behalf of the Organizing Committee of the conference COMETa 2022, we express our great gratitude to all the authors of the papers, reviewers, universities, faculties, business entities, national and international institutions and organizations that supported the conference. Without their help the organization and work of the conference would certainly not be at the level that its status deserves.

East Sarajevo, November 14th, 2022.

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PhD Dušan Golubović,
Full Professor

President of the Organizing Committee

PhD Milija Kraišnik,
Associate Professor

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Conference on Mechanical Engineering Technologies and Applications

ISPITIVANJE ZAMORNIH KARAKTERISTIKA LEGURE ALUMINIJUMA 242.0 S CILJEM PROCJENE INTEGRITETA AVIONSKOG CILIDARSKOG SKLOPA SA PRSLINOM

Nikola Vučetić[1], Gordana Jovičić[2], Ranko Antunović[1], Vladimir Milovanović[2], Branimir Krstić[3], Dejan Jeremić[1]

Rezime: U cilju procjene integriteta cilindarskog sklopa avionskog motora Lycoming IO-360-B1F usljed pojave prsline na glavi cilindra potrebno je izvršiti niz eksperimentalnih ispitivanja legure aluminijuma 242.0 kao sastavnog materijala glave cilindra, među kojima je ispitivanje zamornih karakteristika na sobnoj i na povišenoj temperaturi. Dobijeni rezultati korišćeni su kao ulazni podaci u numeričkoj strukturnoj analizi razmatranog cilindarskog sklopa. Cilj ispitivanja materijala na zamor jeste odrediti dinamičku čvrstoću, odnosno najveći dinamički napon koji materijal pri određenom broju promjena opterećenja može da izdrži, a da pri tome ne dođe do loma.

Ključne riječi: avionski cilindarski sklop, numerička analiza, prslina, zamor materijala.

TESTING OF THE FATIGUE PROPERTIES OF ALUMINUM ALLOY 242.0 WITH THE PURPOSE OF THE INTEGRITY ASSESSMENT OF AN AIRCRAFT CYLINDER ASSEMBLY WITH A CRACK

Abstract: In order to assess the integrity of the cylinder assembly of the Lycoming IO-360-B1F aircraft engine due to the appearance of the crack on the cylinder head it is necessary to perform a series of experimental tests of aluminum alloy 242.0 as a

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constituent material of the cylinder head, among which is the testing of fatigue properties at room and elevated temperature. The obtained results were used as input data in the numerical structural analysis of the considered cylinder assembly. The main aim of material fatigue testing is to determine the dynamic strength, that is the maximum dynamic stress that the material can withstand with a certain number of load changes without breaking.

Key words: aircraft cylinder assembly, numerical analysis, crack, material fatigue.

1 UVOD

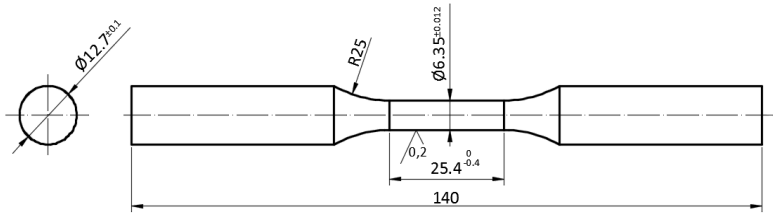
Odlučujući faktor za pojavu loma nije samo amplituda opterećenja, već i učestalost ponavljanja opterećenja. Usljed dugotrajnog djelovanja periodično promjenljivih opterećenja može da se javi postepeno razaranje materijala izazvano pojavom koja se naziva zamor materijala.

Pored visine opterećenja i njegove frekvencije postoji i niz drugih parametara koji utiču na dinamičku čvrstoću materijala, među kojima su kvalitet i stanje površine, koroziona oštećenja, temperatura i slično [1-4].

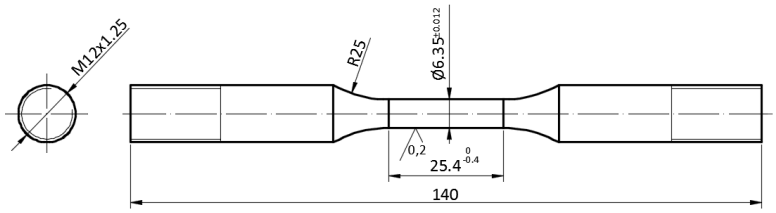
2 UZORCI ZA ISPITIVANJE ZAMORA MATERIJALA

Oblik i dimenzije epruveta propisani su odgovarajućim standardima, u zavisnosti od svrhe i načina ispitivanja na zamor. Broj potrebnih epruveta za određeno ispitivanje može biti različit, što zavisi od vrste i broja podataka koji se traže [5].

Ispitivanje zamornih karakteristika legure aluminijuma 242.0 vršeno je na sobnoj ($23 \pm 5\,°C$) i na povišenoj ($200 \pm 5\,°C$) temperaturi. Zamorne karakteristike legure aluminijuma 242.0, usljed visokocikličnog opterećenja, dobijene su na osnovu rezultata pri ispitivanju epruveta (slika 1 i slika 2) opterećenih na čisto naizmjenično promjenljivo opterećenje. Epruvete su izložene visokocikličnom zamoru u uslovima kontrolisanog napona u skladu sa standardima ASTM E468-90 [6] i ASTM E466-96 [7].



Slika 1. *Oblik i dimenzije epruvete za ispitivanje zamornih karakteristika na sobnoj temperaturi*



Slika 2. *Oblik i dimenzije epruvete za ispitivanje zamornih karakteristika na povišenoj temperaturi*

Prilikom izrade epruveta neophodno je obratiti pažnju na hrapavost, odnosno kvalitet obrađene površine u cilju eliminisanja mogućih zareza, odnosno koncentracije napona, koji mogu biti potencijalna mjesta nastanka prslina. Sve epruvete za ispitivanje zamornih karakteristika materijala izrađene su u Laboratoriji za CNC mašine alatke i CIM sisteme na Mašinskom fakultetu u Istočnom Sarajevu.

3 EKSPERIMENTALNA POSTAVKA

Eksperimentalna ispitivanja zamornih karakteristika legure aluminijuma 242.0 na sobnoj temperaturi vršena su na Fakultetu inženjerskih nauka Univerziteta u Kragujevcu u Centru za inženjerski softver i dinamička ispitivanja. Određivanje zamornih karakteristika pomenutog materijala na povišenoj temperaturi izvršeno je na Institutu „Kemal Kapetanović“ u Zenici.

3.1 Postupak ispitivanja na sobnoj temperaturi

Ispitivanje zamornih karakteristika materijala čisto naizmjenično promjenljivim opterećenjem na sobnoj ($23 \pm 5\,^{\circ}\mathrm{C}$) temperaturi (slika 3) izvedeno je na servohidrauličnom pulzatoru SHIMADZU, tip EHF-EV101K3-070-0A.

Slika 3. *Postupak ispitivanja zamornih karakteristika materijala na sobnoj ($23 \pm 5\,^{\circ}\mathrm{C}$) temperaturi*

U toku ispitivanja zamornih karakteristika materijala frekvencija je iznosila 10-20 Hz, pri čemu je kao kriterijum otkaza, odnosno inicijalizacije prsline, uzet brzi gubitak krutosti, to jeste pad amplitude napona za 10%. Pripremljene epruvete za ispitivanje zamornih karakteristika na sobnoj temperaturi prikazane su na slici 4.

Slika 4. *Epruvete za ispitivanje zamornih karakteristika na sobnoj temperaturi - izgled prije ispitivanja*

3.2 Postupak ispitivanja na povišenoj temperaturi

Ispitivanje zamornih karakteristika materijala jednoosnim, aksijalnim, čisto naizmjeničnim opterećenjem na povišenoj temperaturi (slika 5) izvedeno je na visokofrekventnom pulzatoru za dinamička ispitivanja tip 10 HFP 422 proizvođača Amsler.

Slika 5. *Postupak ispitivanja zamornih karakteristika materijala na povišenoj temperaturi*

Neposredno prije testa epruveta je zajedno sa alatom postavljena u komoru za zagrijavanje, slika 6. Sa slike 6 može se vidjeti da je ostvaren direktan kontakt termoelemenata sa alatom, odnosno sa ispitivanom epruvetom.

Slika 6. *Postavljanje epruvete u komoru za zagrijavanje*

Nakon toga podešena je temperatura zagrijavanja komore pulzatora na 200 °C. Epruvete su podvrgnute jednoosnom, aksijalnom, čisto naizmjenično promjenljivom cikličnom opterećenju sa stepenom promjenljivosti napona R=-1. U toku ispitivanja zamornih karakteristika materijala frekvencija je iznosila 10-20Hz.

Pripremljene epruvete za ispitivanje zamornih karakteristika na povišenoj temperaturi prikazane su na slici 7.

Slika 7. *Epruvete za ispitivanje zamornih karakteristika na povišenoj temperaturi - izgled prije ispitivanja*

Lom jedne od ispitivanih epruveta nakon završenog testa prikazan je na slici 8.

Slika 8. *Lom ispitivane epruvete nakon testa*

4 REZULTATI I DISKUSIJA

U tabeli 1 prikazani su eksperimentalni rezultati ispitivanja navedenih epruveta legure aluminijuma 242.0 izloženih čisto naizmjenično promjenljivom opterećenju u uslovima kontrolisanog napona.

Tabela 1. *Rezultati jednoosnog, aksijalnog ispitivanja epruveta legure aluminijuma 242.0 izloženih čisto naizmjenično promjenljivom opterećenju [8]*

Oznaka uzorka	σ_a **[MPa]**	**Frekvencija [Hz]**	**Broj ciklusa -** N_f
1-S	100	10	1764
2-S	90	10	4237
3-S	80	10	16878
4-S	70	10	64844
5-S	60	20	201590
6-S	55	20	392380
7-S	50	20	797690
8-S	45	20	1430640

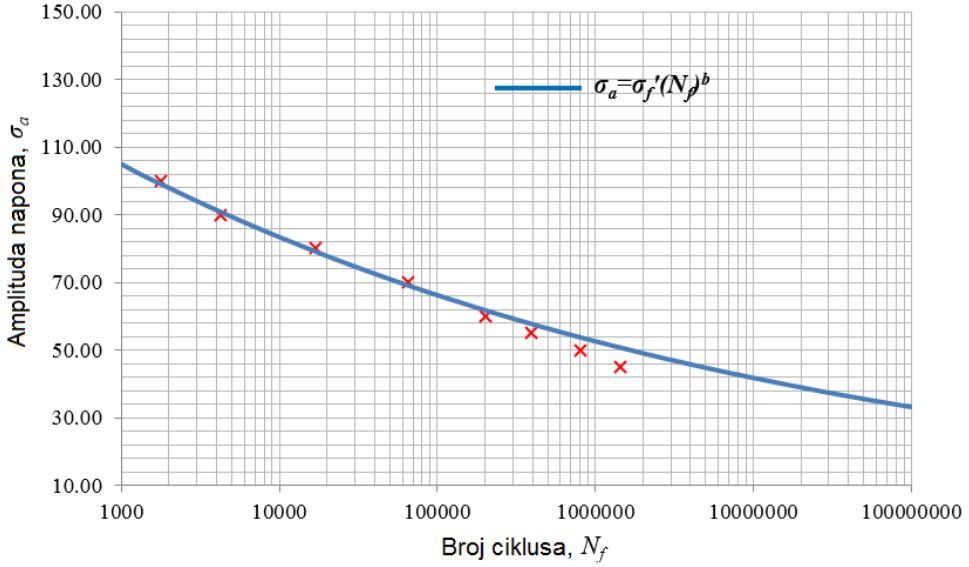
Na osnovu eksperimentalnih rezultata iz tabele 1 i na osnovu statističkih analiza, u skladu sa standardom ASTM E739-91 [9] određene su zamorne karakteristike legure aluminijuma 242.0.

U tabeli 2 prikazani su parametri zamora jednoosnog ispitivanja epruveta legure aluminijuma 242.0 izloženih čisto naizmjenično promjenljivom opterećenju u uslovima kontrolisanog napona.

Tabela 2. *Zamorne karakteristike legure aluminijuma 242.0 pri jednoosnom ispitivanju epruveta izloženih čisto naizmjenično promjenljivom opterećenju [8]*

Veličina	**Vrijednost**
Faktor zamorne čvrstoće $\sigma_f^{'}$	224.5
Eksponent zamorne čvrstoće b	-0.100

S-N kriva u polu-logaritamskoj skali, prikazana na slici 9, određena je na osnovu eksperimentalno dobijenih zamornih karakteristika pri jednoosnom ispitivanju epruveta legure aluminijuma 242.0 izloženih čisto naizmjenično promjenljivom opterećenju u uslovima kontrolisanog napona.



Slika 9. *S-N kriva legure aluminijuma 242.0 dobijena ispitivanjem pri čisto naizmjenično promjenljivom opterećenju na sobnoj temperaturi [8]*

Može se uočiti da nema velikog rasipanja dobijenih rezultata na S-N krivoj sa slike 9. Ispitivanom materijalu, odnosno leguri aluminijuma 242.0 odgovara zamorna čvrstoća od 35 MPa. Može se smatrati da je to vrijednost napona pri kome bi materijal imao „beskonačan“ životni vijek.

U tabeli 3 prikazani su eksperimentalni rezultati jednoosnog, aksijalnog ispitivanja navedenih epruveta legure aluminijuma 242.0 na povišenoj temperaturi izloženih čisto naizmjenično promjenljivom opterećenju u uslovima kontrolisanog napona.

Tabela 3. *Rezultati jednoosnog, aksijalnog ispitivanja epruveta legure aluminijuma 242.0 na povišenoj temperaturi izloženih čisto naizmjenično promjenljivom opterećenju*

Oznaka uzorka	σ_a **[MPa]**	**Frekvencija [Hz]**	**Broj ciklusa - N_f**
1-P	100	10	1352
2-P	90	10	3870
3-P	80	10	15219
4-P	70	10	57350
5-P	65	10	87660
6-P	60	20	178970
7-P	55	20	330800
8-P	50	20	724310
9-P	45	20	1270920

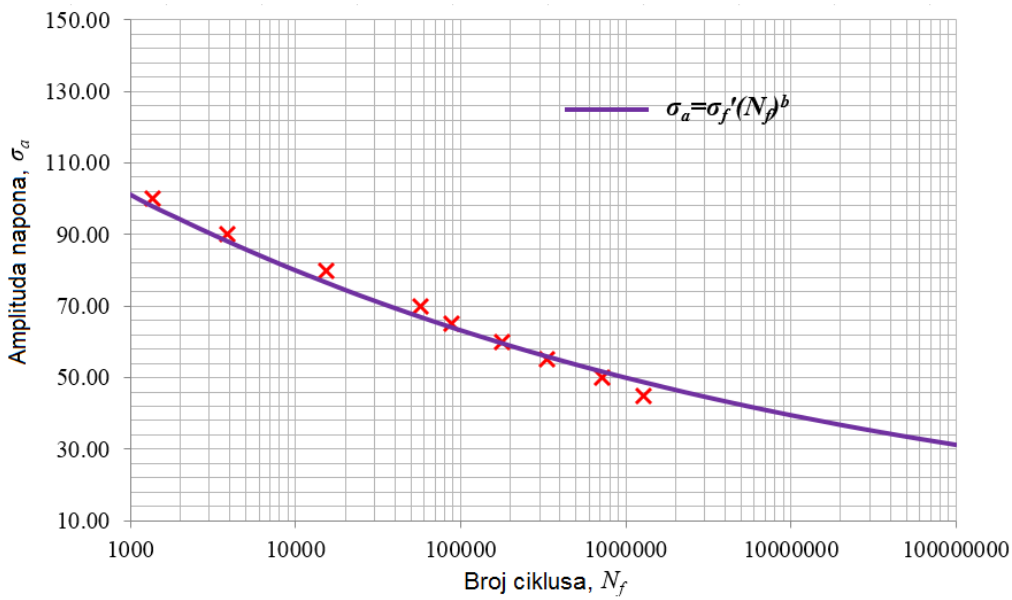
Na osnovu eksperimentalnih rezultata iz tabele 3 i na osnovu statističkih analiza, u skladu sa standardom ASTM E739-91 [9] određene su zamorne karakteristike legure aluminijuma 242.0 na povišenoj temperaturi.

U tabeli 4 prikazani su parametri zamora jednoosnog ispitivanja epruveta legure aluminijuma 242.0 na povišenoj temperaturi izloženih čisto naizmjenično promjenljivom opterećenju u uslovima kontrolisanog napona.

Tabela 4. *Zamorne karakteristike legure aluminijuma 242.0 na povišenoj temperaturi pri jednoosnom ispitivanju epruveta izloženih čisto naizmjenično promjenljivom opterećenju*

Veličina	Vrijednost
Faktor zamorne čvrstoće $\sigma_f^{'}$	219.7
Eksponent zamorne čvrstoće b	-0.102

S-N kriva u polu-logaritamskoj skali, prikazana dijagramom na slici 10, određena je na osnovu eksperimentalno dobijenih zamornih karakteristika pri jednoosnom ispitivanju epruveta legure aluminijuma 242.0 na povišenoj temperaturi izloženih čisto naizmjenično promjenljivom opterećenju u uslovima kontrolisanog napona.



Slika 10. *S-N kriva legure aluminijuma 242.0 dobijena ispitivanjem pri čisto naizmjenično promjenljivom opterećenju na povišenoj temperaturi*

Povećavanjem temperature dolazi do opadanja zamorne čvrstoće legure aluminijuma 242.0. Na osnovu dobijenih rezultata uočava se da na temperaturi od broj ciklusa za isti nivo opterećenja opada poredeći sa rezultatima dobijenim ispitivanjem materijala na sobnoj temperaturi.

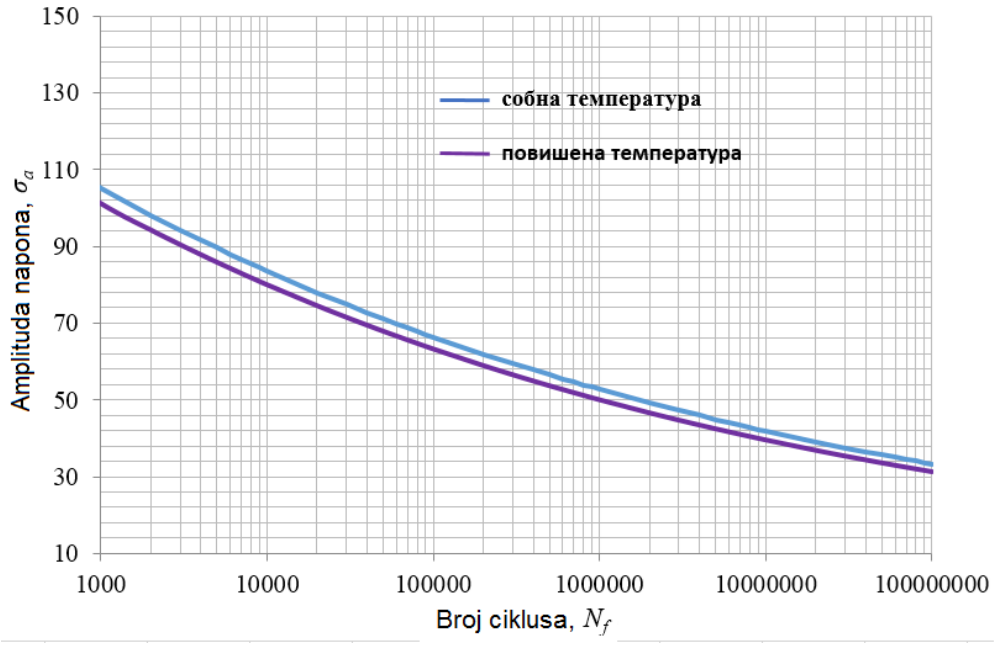
U tabeli 5 dato je poređenje rezultata ispitivanja zamora legure aluminijuma 242.0 dobijenih pri istoj amplitudi napona na sobnoj i na povišenoj temperaturi.

Tabela 5. *Poređenje rezultata ispitivanja zamora legure aluminijuma 242.0 dobijenih na sobnoj i na povišenoj temperaturi*

Oznaka epruvete	Amplituda napona	Broj ciklusa do otkaza - N_f	Oznaka epruvete	Amplituda napona	Broj ciklusa do otkaza - N_f	Smanjenje broja ciklusa do otkaza [%]
1-S	100	1764	**1-P**	100	1352	**23.4**
2-S	90	4237	**2-P**	90	3870	**8.7**
3-S	80	16878	**3-P**	80	15219	**9.8**
4-S	70	64844	**4-P**	70	57350	**11.6**
5-S	60	201590	**6-P**	60	178970	**11.2**
6-S	55	392380	**7-P**	55	330800	**15.7**
7-S	50	797690	**8-P**	50	724310	**9.2**
8-S	45	1430640	**9-P**	45	1270920	**11.2**

Rezultati iz prethodne tabele pokazuju da pri temperaturi od $200°C$, pri istoj amplitudi napona, dolazi do smanjenja broja ciklusa do otkaza legure aluminijuma 242.0 od 8.7% do 23.4%. Povećanjem temperature dolazi do opadanja otpornosti materijala na plastične deformacije [10].

Na slici 11 predstavljen je uporedni prikaz S-N krivih legure aluminijuma 242.0 dobijenih ispitivanjem epruveta na sobnoj i na povišenoj temperaturi od $200°C$.



Slika 11. *Uporedni prikaz S-N krivih legure aluminijuma 242.0 dobijenih ispitivanjem epruveta na sobnoj i na povišenoj temperaturi*

5 ZAKLJUČAK

Legura aluminijuma 242.0 se koristi za izradu glava cilindara avionskih motora, što predstavlja izuzetno odgovornu funkciju za ovaj materijal. Stoga, veoma je važno poznavati osobine ovoga materijala, kako hemijske, tako i mehaničke i to na sobnim i na povišenim temperaturama. Činjenica je da se u dostupnoj literaturi nalazi veoma mali broj podataka vezanih za mehaničke karakteristike navedenog materijala. Iz tog razloga potrebno je naglasiti i istaći značaj prikazanih eksperimentalnih istraživanja legure aluminijuma 242.0 prikazanih u okviru ovog poglavlja disertacije. Svaki novi podatak i određena mehanička karakteristika materijala predstavlja veliki doprinos u oblasti ispitivanja konstruktivnih elemenata izrađenih od ovoga materijala. Posebno je važno istaći značaj ispitivanja zamornih karakteristika legure aluminijuma 242.0 na povišenoj temperaturi. Dobijeni rezultati biće direktno korišćeni za procjenu integriteta razmatranog cilindarskog sklopa kao ulazni materijalni podaci neophodni za numeričke proračune.

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