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Doctoral project in Metz (France)

Mechanical behavior and microstructure characterizations of irradiated ceramics

for the new generation of nuclear reactors

The doctoral researcher will be part of the team for the HEIRMAX project (*Development of High Entropy, Irradiation Resistant MAX Phases*), which is funded up to 712 k€ by the ANR (French National Agency for Research) over 48 months.

Nuclear energy is a crucial component of the European energy mix, ensuring independence and reducing greenhouse gas emissions. Fueled by the powerful nuclear interaction and the fission of heavy atoms, it offers unparalleled energy density, with one gram of uranium generating two million times more energy than burning a gram of gasoline. This high energy density results in a significantly smaller material footprint compared to other energy sources. Moreover, nuclear fission produces no greenhouse gases, and the chain reaction can be controlled to adjust power generation. To enhance reactor safety and support the development of new generations, innovative materials are essential. In this context, molten salt reactors, operating at close-to-atmospheric pressure with salt as a cooling agent, represent a promising avenue. Academic and industrial research in Europe is actively pursuing breakthrough materials within this framework.

Our project centers on two specific ceramics: MAX phases and silicon carbide (SiC), both boasting significant potential owing to their distinct attributes.

The MAX phases are compounds characterized by the stoichiometry $M_{n+1}AX_n$ (n = 1, 2, or 3), where M represents an early transition metal, A is an element from groups 12 to 16, and X is either carbon or nitrogen [1,2]. These compounds have garnered significant attention due to their distinctive combination of metallic traits and ceramic properties. Furthermore, select MAX phases exhibit notable resistance to irradiation damage [3]. High-entropy MAX phases, which incorporate 3 to 5 elements in M or A constituents, have gained attention. By tuning the composition of MAX phases towards higher complexity, it is possible to develop high-entropy MAX phases with improved stability under irradiation, combining desired nuclear application properties with enhanced mechanical strength and radiation resistance.

The integration of SiC offers notable enhancements to safety, efficiency, and sustainability within nuclear reactors. SiC displays exceptional radiation resistance, making it an optimal choice for demanding environments. Its capacity to endure high temperatures and pressure is pivotal in reducing susceptibility to failure under extreme conditions.

The objective of the doctoral project will be to assess the initial mechanical properties of conventional and high-entropy MAX phases, as well as SiC. Their evolution under irradiation will be investigated by means of micro-mechanical tests, required considering the size of sample and the irradiation depth of few µm. Hardness and plasticity behavior will be determined by nano-indentation and micro-compression, respectively. The toughness will be evaluated using Scanning Electron Microscope (SEM) *in-situ* microcantilever bending tests. The results will allow determining the potential of improvement in mechanical properties after irradiation of high-entropy MAX phase in comparison to conventional MAX phases and SiC.

[1] M.W. Barsoum, T. El-Raghy; AMERICAN SCIENTIST, 2001 (89)
[2] A. Guitton; PhD thesis, Université de Poitiers, France, 2013
[3] D.J. Tallman; PhD thesis, Drexel University, USA, 2015

Your skills

The following qualifications are required:

- Master in materials sciences or related fields
- Good knowledge in materials science and mechanical behavior
- Knowledge in characterization of microstructures using electron microscopy.

The following qualifications are beneficial:

- Experience with computation languages such as Python or MatLab

We offer

A 36-month full-time PhD position. The doctoral contract is ideally starting on October 1, 2024, but with flexibility to begin earlier. The contract includes health coverage and paid holidays. The position offers a dynamic international environment and close supervision by senior scientists. The opportunity to develop experimental skills such as micromechanical testing, etc. is available to foster a career in academia or industry. The gross salary for the PhD position is approximately 2530 €/month[1].

[1] The median gross salary in France is 2500 €/month (source: French Ministry of Employment, https://code.travail.gouv.fr/outils/simulateur-embauche).

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The doctoral school:

As PhD student, you will be registered at the Université de Lorraine and will be part of the C2MP (***C**himie, **M**écanique, **M**atériaux, **P**hysique*: Chemistry, Mechanics, Materials, Physics) doctoral school. You will have the opportunity to benefit from a wide range of training programs during your PhD.

The local team of HEIRMAX:

- **Prof. Olivier BOUAZIZ**, full professor at Université de Lorraine, expert in metallurgy.
- **Dr. Julien GUÉNOLÉ**, CNRS research scientist, expert in materials plasticity and atomistic simulations. [www.julien-guenole.fr]
- **Dr. Antoine GUITTON**, tenured associate professor HdR at Université de Lorraine & Adjunct Associate Professor at Georgia Institute of Technology school of Materials Science and Engineering (USA), expert in microscopy and materials plasticity. [www.antoine-guitton.fr]

Host laboratory of the doctoral researcher:

The LEM3 laboratory (***L**aboratoire d'**É**tude des **M**icrostructures et de **M**écanique des **M**atériaux:* Laboratory of Study of Microstructures and Mechanics of Materials) is a joint research center of the Université de Lorraine, the French National Center for Scientific Research (CNRS), and the engineer school Arts et Métiers. LEM3 is one of the largest research institutes for the physics of materials and engineering in France. It is located in Metz, near the tripoint along the junction of France, Germany, and Luxembourg, and forms a central hub for science in Europe. Over 250 scientists from France and around the world work at LEM3 to perform world-class research in materials science, mechanics, and processes. By conducting both fundamental and applied research, researchers at LEM3 work on long-term solutions for the major challenges facing society, industry, and science.

Advantages of working at the LEM3:

As a valued member of our team, you will have access to the comprehensive social protection system in France, including:

- **Universal healthcare coverage:** Universal healthcare coverage: Our comprehensive healthcare system ensures that all necessary medical treatments, including doctor visits, prescription drugs, and hospital stays, are covered with a reference reimbursement rate of around 90% on average (thanks to the *Alsace/Moselle* local regime).
- **Generous annual paid leave:** Take advantage of the LEM3's generous annual leave policy, which allows you to take up to 45 days of annual leave to recharge and rejuvenate.
- **Retirement pensions:** Contribute to the French retirement system and enjoy a pension when you reach retirement age.
- **Unemployment benefits:** when your contract ends, you may be eligible for unemployment benefits to help you cover your expenses while you search for new employment.
- **Sickness benefits:** If you are ill or injured, you may be eligible for daily sickness benefits to cover your lost income.
- **Maternity, paternity, and family leave:** Take time off to care for your family and bond with your new child.
- **Professional training and development opportunities:** Take advantage of the many professional training and development opportunities available in France, to improve your skills and advance your career.
- **Free education:** Education is free in France for children up to 18 years old.
- **Personalized housing allowance:** Assistance for housing costs for low-income individuals.
- **Participation in your public transportation subscription:** 50% of your subscription fees to public transportation for your commute will be supported by the Université de Lorraine.

It is important to note that the level of financial assistance provided by the state may vary depending on your income and the composition of your household.

- **Opportunity for teaching:** There may be the opportunity for you to teach at the Université de Lorraine, which includes an additional salary for this responsibility.

Application:

Please send a detailed CV, a cover letter, and transcripts of your bachelor's and master's degree to the three email addresses provided in the header. Recommendation letters are not required, but please include the contact information of your references.

Applications without the requested attachments may not be considered.