Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 07, July-2023

A Review: Engineered Materials for use in Nuclear Fusion

High Entropy Materials

Advait Srinivasan
Jamnabai Narsee School
Road No 7 Narsee Monjee Behind,
Opposite Kalani Ketan, Police Station,
Juhu, Mumbai, Maharashtra 400049

***Abstract*—This literature review discusses engineered materials such as high entropy alloys and in particular high entropy ceramics as alternatives and solutions to be deployed in high temperature applications in the extreme environemtns that prevail in nuclear reactors.**

***Keywords*—ceramics; entropy; alloys; extreme temperature; nuclear; fusion**

I. INTRODUCTION

One of the key challenges that is faced in nuclear fusion is that the materials are rendered radioactive by virtue of fusion neurons that are generated during the process. One way to overcome this problem is to make use of low-activation alloys. These alloys exhibit a very high temperature resistance.

Traditional materials used in the fusion process such as steels have been shown to have low operating temperature range. They are also limited by creep – a process where the metal loses its structural integrity under extreme conditions.

II. HIGH ENTROPY ALLOYS

Barron et al., has shown that high-entropy alloys containing Vanadium (V) such as V-Cr-Mn and V-Cr-Mn-Ti exhibit very high toughness and irradiation resistance. When a metal such as Titanium is embedded in the structural matrix of the alloy, it acts as an interstitial impurity and strengthens the overall matrix. The matrix now offers promising properties such as enhanced high temperature creep resistance, toughness and irradiation resistance.

Research on High Entropy Alloys for studying their irradiation resistance has drawn a lot of interest in recent times. High-entropy alloys (HEAs) provide a distinctive chance to create alloys for advanced nuclear applications by offering enhanced compositional freedom as shown by Pickering et. al(2021). This advantage is especially invaluable when it comes to situations where the thermal and irradiation properties of existing engineering alloys like austenitic steels are insufficient. However, it is important to note that much of the investigations done thus far remain in its infancy and there is ample opportunity to cover ground in this area of research.

Furthermore, Dias et al., have shown that addition of Copper to the lattice of high entropy alloys offers specific advantages of high conductivity and strength thus serving the purpose of a heat sink in nuclear fusion reactors. Not only that, introducing copper in the interstitial lattices causes distortions in the BCC and FCC structures offering unique advantages of high hardness, enhanced oxidation and corrosion resistances and high thermal stability under continuous as well as cyclical operation. Copper containing High Entropy Alloys offer promising advantages for use in extreme environments such as nuclear fusion reactors.

Zhang et al., 2022, have shown a novel technique by the name of laser powder bed fusion technology that can be used to fabricate interstitial high entropy alloys (iHEAs). These iHEA's exhibit superior structural advantages compared to single phase high entropy alloys. This unique manufacturing technique can be controlled so as to influence the grain microstructures of the iHEA's and offer them higher temperature stability, corrosion resistance, electrical resistivity and good mechanical properties over a wide range of temperature.

III. HIGH ENTROPY CERAMICS

Traditionally, ceramics are known for their higher temperature and creep resistance compared to metal alloys and hence an increased interest has been triggered to look at High Entropy Ceramics in recent times.

More recent research conducted by Matheus et.al, 2023 focuses on High Entropy Carbide (HEC) ceramics points towards evidence that these materials exhibit higher thermal resistance, irradiation resistance compared to High Entropy Alloys. The future of nuclear fusion materials shall entail research around the promising area of High Entropy Carbides and a study of their enormous potential in the context of extreme environments.

Toher et al., has reviewed the mechanisms induced within high entropy ceramic materials and their consequent impact on the structural properties such as hardness, yield stress, thermo-chemical stability, thermal-conductivity and increased corrosion resistance.

Nisar et al., 2020, presents the mechanism of high entropy or the state of disorder of the crustal lattice model and its resulting impact on the mechanical properties of High Entropy - Ultra High Temperature Ceramics (HE -UHTC) such as borides, nitrides and carbides. These HE-UHTC's have melting points greater than 3000 oC. The paper discusses the computational models that study the thermodynamic

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 12 Issue 07, July-2023

behaviour of HE-UHTC's and validate these models using experimental data. Among these HE-UTHC's borides and carbides have been studied extensively in literature for extreme temperature aerospace applications while literature on nitrides is fairly limited.

Other works by Xin et al., 2023 have shown reduced Helium ion induced irradiation damage in Zirconium carbide ZrC and other high entropy carbide structures with alloying elements including Titanium, Niobium, Tantalum and Tungsten (Zr0.2Ti0.2Nb0.2Ta0.2W0.2)C. The lattice energies are measured to compare the irradiation induced damage in both types of ZrC alloys. The high entropy of these structures allows for equitable distribution of Helium ions, thus resulting in high irradiation resistance and mechanical toughness, both of which are cardinal in surviving extreme nuclear environments.

Tan et al., 2023 have studied the behaviour of high entropy alloys inside a nuclear fusion reactor environment using computational modelling and simulation techniques. The objective of studying these mechanisms of irradiation damage is to use these models for the designing the microstructure of high entropy materials that can withstand such extreme environments.

IV. UNRESOLVED CHALLENGES

Among high entropy materials which garnered interest in the last decade, high entropy alloys are reasonably well covered in literature and their mechanisms well understood. The area that is garnering a lot of attention in recent times is high entropy ceramics for ultra-high temperature applications and other extreme environments. Within the scope of high entropy ceramics, carbides appears to have been explored relatively more than the other ceramics such as nitrides, borides, diborides and oxides.

The design of high entropy ceramic materials for extreme environments offers a very promising area for further study and investigation.

ACKNOWLEDGMENT

The work covered in this research is a literature review in the area of high entropy materials and their applications for high temperature nuclear fusion environments.

REFERENCES

[1] Barron P.J., Carruthers, A.W., Fellowes, J.W., Jones, N.G., Dawson, H., Pickering, E.J., "Towards V-based high-entropy alloys for nuclear fusion applications", Scripta Materialia, 176, (2020), 12-16

[2] Ed J. Pickering 1,2,* , Alexander W. Carruthers 1 , Paul J. Barron 1 , Simon C. Middleburgh 3 , David E. J. Armstrong 4 and Amy S. Gandy 5, "High-Entropy Alloys for Advanced Nuclear Applications", Entropy, 2021, 23, 98

[3] M. Dias,⁎ , F. Antãoa , N. Catarinoa , A. Galatanub , M. Galatanub , P. Ferreirac , J.B. Correiad , R.C da Silvaa , A.P. Gonçalvese , E. Alvesa, "Sintering and irradiation of copper-based high entropy alloys for nuclear fusion.", Fusion Engineering and Design, 2019

[4] Wei Zhang a , Jiajia Shen c , J.P. Oliveira c,d , Bart J. Kooi b , Yutao Pei a,*" Crystallographic orientation-dependent deformation characteristics of additive manufactured interstitial-strengthened high entropy alloys.", Scripta Materialia, 222, 2023, (115049)

[5] Matheus A. Tunes , Stefan Fritze b,* , Barbara Osinger b , Patrick Willenshofer g , Andrew M. Alvarado d,e,f , Enrique Martinez d,e,f , Ashok S. Menon b , Petter Strom¨ c , Graeme Greaves h , Erik Lewin b , Ulf Jansson b , Stefan Pogatscher g , Tarik A. Saleh a , Vladimir M. Vishnyakov h , Osman El-Atwani, "From high-entropy alloys to high-entropy ceramics: The radiation-resistant highly concentrated refractory carbide (CrNbTaTiW)C", Acta Materialia, 250 (2023), 118856

[6] Cormac Toher,1 Corey Oses,1 Marco Esters,1 David Hicks,1 George N. Kotsonis,2, Christina M. Rost,3 Donald W. Brenner,4 Jon-Paul Maria,2 and Stefano Curtarolo1, "High-entropy ceramics: propelling applications through disorder", MRS Bulletin, 2022, Springer

[7] Xiao-Ting Xina,c,†, Weichao Baoa,†,*, Xin-Gang Wanga,*, Xiao-Jie Guoa,c , Ying Lud , Chenxi Zhua , Ji-Xuan Liub , Qiang Lia , Fangfang Xua,*, Guo-Jun Zhangb, "Reduced He ion irradiation damage in ZrC-based high-entropy ceramics", Journal of Advanced Ceramics, 12(5), 916-929, 2023

[8] Fusheng Tan a , Li Li a , Jia Li a,* , Bin Liu b , Peter K. Liaw c , Qihong Fang, "Multiscale modelling of irradiation damage behavior in high entropy alloys", Advanced Powder Materials, 2, 2023