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A STUDY ON CREEP, FRACTURE, AND FATIGUE OF HIGH ENTROPY ALLOYS (HEAS)

Ashish Kumar Dixit

PhD Scholar, Mechanical Engineering Department
Sri Satya Sai University of Technology & Medical Sciences, Sehore (MP)
Email: dixitashish47@gmail.com

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ABSTRACT

Because HEAs are being actively investigated for structural materials of the next decade, it is important to gain detailed insight into their creep, fatigue and fracture behaviours. Such three facets of mechanical properties are especially essential as (i) creep resistant determines elevated-temperature application of the alloy; (ii) fatigue breakdown is by far the most commonly observed failsafe mechanism in the tensile life span; (iii) fracturing seems to be the last stage in which the material sacrifices the load-bearing power. In view of their significance in the construction of HEAs for appropriate composite structures. At the end of the day, suggestions for future initiatives are recommended.

Keywords: Creep, Fracture, Fatigue, High Entropy Alloys (HEAs)

INTRODUCTION

Creep losses are one of the lifetime causes for devices with high temperatures. The materials and structural integrity research communities and high-temperature industries have a good scientific understanding of creep deformation and creep fracture, and an exact mathematical description.

Crude cavitation at the grain boundary is generally understood and recognized as causing the creep fractures for the majority of metals and alloys. The mechanic of continuum damage (CDM) of creep deformation and crack fracture has also been developed to model internally dynamic variables, which represent macroscopic behaviour and integrate cavitation in a normal, smeared fashion.

High Cr alloys are one of the metals that have been formed which is used for power generation. They have also been chosen for study and results will be published here. As an illustrative example, the composite macroscopic simulation of surface deformation and fractured fractures is often used for coating-antimony alloy because of the inexistence of the micro-macho-constitutive equation for high Cr alloys. While the improvement examples mentioned are focused on the actual content, the technique is general and does not rely on materials [1].

Strong Entrusted alloys (HEAs), produced by the physical metallurgy of 5 or more metallic components of equivalent or nearly equal sizes, occur as a class of innovative materials as materials with superior properties continuously sought. HEAs tear down the conventional understanding of alloy construction, which is the base of a primary element and introduce limited quantities of more components for fine tuning, opening up endless possibilities for the development of innovative components. A decade of work has shown that many HEAs give incomprehensive properties as opposed to standard alloys, such as good thermal and micro-structural stability, high stiffness, high temperature strength and exceptional battle against damage, rust, corrosion, cracking and temperature change tolerance. Owing to these benefits, HEA technologies are widely studied in various fields, in particular in structural engineering (e.g. used for diesel engine compressors). A detailed under-standing of HEA's actions in creep, fatigue and fracture is important for the sophisticated engineering application among other performance indices [2].

A range of temperatures including the fluid behavior of a number of HEA systems were studied the Al 0.15 CoCrFeNi HEA with a face-centered cubic (fcc) structure at 580–700 °C, the Al 0.6 CoCrFeNi HEA with fcc and body-centered cubic (bcc) phases at 580–700 °C, the Ni 47.9 Al 10.2 Co 16.9 Cr 7.4 Fe 8.9 Ti 5.8 Mo 0.9 Nb 1.2 W 0.4 C 0.4 HEA with fcc 1L1 2 phases at 750–982 °C, 30 the Al 0.3 CoCrFeNi HEA with an fcc structure at room temperature, the AlCoCrFeNi HEA with a bcc structure at room temperature, the CoCrFeMnNi HEA with an fcc structure at room temperature, the as-deposited CoCrFeCuNi HEA film with an fcc structure at room temperature, the annealed CoCrFeCuNi HEA film with an fcc 1bcc structure at room temperature, the as-deposited CoCrFeCuNiAl 2.5 HEA film with a bcc structure at room temperature. The creep responses of such composite materials at ambient level has mostly been categorized with spherical nano-indentation testing or Berkovich nano-indentation evaluations due to the relatively isolated stress field produced in such instances, while uniaxial creep tests and stress-relaxation studies were being used for high-temperature testing. The emphasis had been on the quality of these kind of important substance parameters as the stress exponent (n) and the volume of activation (V *), which can be used to deduce creep mechanisms. The effect on creep reactions, creep specifications and creeping processes of micro-structures, grain lengths, temperature, load levels and load speeds have been studied, too.

With respect to fatigue, the large-cycle force – lifetime (S – N) relationship and fatigue power of that same as-cast and wrought Al 0.5 CoCrCuFeNi HEAs with a dual fcc processes is defined by four-point stretching fatigue measurements at ambient temperature and pressure ratio, R5r min / r max 50.1, where r min and r max are the lower and higher stress added, simultaneously. Their tiredness and fatigue-endurance levels were determined to be 540–945 and 0.402–0.703 respectively. Such excellent fatigue properties make this alloy superior to other standard alloys (e.g. stones and titanium alloys) and likely have a long life of fatigue, even though stress is below the maximum stress, in functional structural applications. The fatigue-crack-growth rate of the AlCrFeNi 2 Cu and Al 0.2 CrFeNiTi 0.2 HEAs with fcc 1bcc phases was investigated by three-point bending tests at room temperature. By varying the load ratio, R, from 0.1 to 0.7, it was noted that the Paris slope, m, increased from 3.4 to 14.5 for the Al 1 alloy and 4.9 to 25.8 for the Al 0.2 alloy, and the threshold fatigue-stress- intensity-factor range (DK th, representing a stress intensity above which cracks will grow) dropped from 17 to 7 MPa m 1/2 for the former and 16 to 5 MPa m 1/2 for the latter. Furthermore, the effect of temperature on the fatigue-crack growth has been studied for the CrMnFeCoNi HEA with disc-shaped compact-tension [DC(T)] samples at a load ratio of R50.1. Even though the temperatures declined to ambient temperature to 198 K, the alloy showed an upward trend in DK th from; 4.8 to 6.3 MPa m 1/2 while it may barely be modified, i.e. in the range of 3.5–4.5. In order to detect underlying deformation and failure mechanisms, 21 scanning path monitoring's of back-strewn electron (BSE) and backscatter-reduced diffraction (EBSD) 37 were undertaken to track factor research, scan electron microscopy (SEM), observations of microstructural evolution with transmitted electric microscopy (TEM).

The most common type of failure in engineering materials is a fracture that refers to fragmentation of the substance into several parts. Initiation of cracking in previous failures or micro-cracks and spread of cracks to create new discontinuous surfaces within a solid are part of the fracture process. Comprehending why HEA failure is necessary to facilitate structural applications of HEA, and avoiding these possible failures by careful procurement and handling of materials and the prudent nature of modules and devices. Till now, HEAs, based on compositions and microstructural elements, have been found to fail in different modes. The durability of fractures, fractures under quasi-static uniaxial tension, high pressures and processes of fractures and loading at tension rates are currently subject to on-going examinations [3].

ALUMINIUM COMPOSITES' FATIGUE AND CREEP BEHAVIOUR

Composite as a system is defined in terms of "multiscriptual components consisting of multiple phase domains in which at least one phases is continuous." It usually consists of both the matrix and the armour, in which the core metal is the matrix and alloying element is the refurbishment. In composites are insoluble in matrix and reinforcement.

Traditional monolithic materials like metals and its alloys, ceramics or composite materials can not satisfy those unique requirements, such as, for many industrial uses, the perfect balance of strength, hardness, durability and density. To our advantage, a new material revolution class, we called it as composites, started in the 20th century today.

Composite materials demonstrate a rather great range of mechanical as well as microscopic dwellings, like those of lower density, elevated compressive strength, great high-cycle exhaustion reaction, weirdo as well as worn, increased steepness, heavy operating temperature, low thermal expansion coefficient, high strength resistance to corrosion and high specific modulus, etc., due to its high weight to strength ratio, which helps reduce aircraft fuel consumption, and which is desperately needed in the aviation industry.

In electrical moulding industries, improving overlaid materials, first class cookware, sealants and gaskets, warm confirmation structures, portions for high-temperature gas turbines, for instance, start chambers, stator vanes and turbine vanes, brake circles, brake plates and stop frameworks of pieces used amazingly hot stunning conditions, sliding bearing sections subject to exceptional weights requiring high utilization and hindering wear are undauntedly delivered Alloy drills using preposterous cobalt gratings with solid tungsten carbide particles inside, burner fragments, fire holders and hot gas lines. Other utilization of composites fuses Aircrafts skins, bearing, electronic packaging, engine chamber lines, chambers, space structure tubing in nuclear plants, etc [4].

A number of different matrix available, such as aluminium alloy, titanium, and magnesium, etc., the most widely available composite type is aluminium due to its exceptional characteristics. A verity of reinforcement is available such as Gr, TiB, TiC, TiO2, Al2O3, Fly ash, SiC, Hematite, and ZrO2 etc.

There are various methods used in the manufacture of composites, like those of

- Solid state method
- Liquid state method
- Semi solid-state method
- Vapour deposition
- In-situ fabrication technique

The major drawback of composites is fatigue and creep life is very poor, but the major failure load in the aircraft industry is thermal fatigue that can sometimes result in serious damage. Furthermore, a ton of progress has been made throughout this field. Composite materials are influenced by the thickness of the particle reinforcement and the type of production process followed.

Composite thermal fatigue failure is most severe. Thermal fatigue is caused by regular or cyclical temperature fluctuations and internal or external pressures resulting in stress accumulation resulting in the distribution of cracks in materials. The intrinsic restriction is the stress differential created by the difference in temperature in the matrix and the interphase reinforcement, which contributes to cracking creation at intervention. Their existences of reinforcing well into the composite materials are demonstrated by its own analysis of the Composite Microstructure by XRD, EDS Techniques.

A composite material is a material framework made out of a reasonably organized blend or mix of at least two Nano, small scale, or large scale constituents with an interface isolating them that vary in synthetic synthesis, shape, which are basically insoluble in one another. Diverse kinds of composite materials are accessible and these are expanding a direct result of their great improved properties, among these Metal Matrix Composites discovers its applications in different viewpoints like aviation, car, barrier, and marine and so on. In these MMCs, aluminium-based metal grid composites are by and by broadly being used in vehicle area, aviation and brandishing types of gear because of their high quality and firmness with diminished weight. There are a few creation procedures are accessible to process these composites. The readied composites are generally assessed for improved properties. To assess these composites, one can lead the investigations like hardness, pliable, pressure, fatigue, creep and tribological tests according to ASTM guidelines.

It was found in the study that particulate reinforced metal matrix composites are widely used in military and aerospace applications. Several matrix materials are available as a matrix. Among all the metal matrix composites aluminium based metal composites are finding more applications. Micro particulates like Al2O3, graphite; B4C, TiC, TiO2and WC can be used as the reinforcements. In processing of aluminium metal matrix composites, several techniques like solid and liquid state methods are used. Among all the fabrication techniques liquid stir casting process is the more simpler and economical one. Addition of reinforcements usually enhances the properties of aluminium alloys. Fatigue and creep properties are important for certain aerospace applications.

CURRENT CREEP CAVITY DAMAGE MODELING

In an attempt to model the long-term creep behavior, Yin et al. [8] have pro- posed a phenomenological relationship between the creep cavity damage and creep strain, which departed from the firm and well-known mechanism-based relation- ship of Dyson [9]. The relevant equations are listed below for completeness:

Dyson [9]:

$$\dot{D}_n = \frac{k_N}{\varepsilon_{f_u}}\dot{\varepsilon} \qquad (1)$$

Yin et al. [8]:

$$\dot{D}_n = A\varepsilon^{B'}\dot{\varepsilon} \qquad (2)$$

Where A is the creep cavity damage coefficient, and it is assumed that it does not change with stress, it changes with temperature.

Yin's approach cannot be extrapolated into a lower stress level than it has been calibrated according to Lee et al [5] as a constant value of A is not able to depict the stress breakdown phenomenon.

[4] followed Yin's approach but allowed the cavity damage coefficient to be stress level dependent, in the following form [4]:

$$\dot{D}_n = A\dot{\varepsilon}\varepsilon^{0.9} \qquad (3)$$

However, an unexpected abnormal variation of the value of A with stress level occurred which is shown in Table 1 and graphically in Figure 1 [6]. Due to the lack of a trend with stress level, it is hard to use them in prediction with confidence. The concept of creep cavity damage coefficient to be stress level dependent had been introduced by the first author in 2003 [5] for low Cr alloy creep damage modeling where no such abnormality occurred. Hence, the phenomenological modeling of creep cavity damage for high Cr alloy is not satisfactory.

Furthermore, the methodology, based on the isochronous surface concept only, for the generalization of a set of uniaxial creep damage constitutive equations into a set of multiracial version is conceptually flawed [7]. Though the creep deformation consistence has to be included, this has not been very well appreciated by the majority of research community, even in the published review type of articles. Progress can be found only in very limited publications, for example, the original one [2] and the more recent one [8].

The study concluded that Modeling of creep deformation and creep facture is very challenging. However, research work report here has made some progress. These progress and suggestions for future work are presented as:

1. A modified hyperbolic sine function was proposed, and suitability for a wider range of stresses is demonstrated. Its successful applications to both low Cr alloy and high Cr alloy merit it to be tried to other alloys. It is worth to research to find any material scientific reasons for the similar magnitude of the q among different alloys.
2. A new creep cavity fracture model was proposed and developed based on the cavity nucleation, growth, and coalesce at grain boundary using the cavitation data from X-ray synchrotron investigation.
3. The creep cavity fracture lifetime coefficient U0can be experimentally produced, and it can be used for lifetime prediction and extrapolation.
4. Creep cavity fracture lifetime prediction works very well over a stress range, and there is no stress breakdown in this model.
5. Research work on the stress state's effect on the cavitation should be pursued in the future.
6. Furthermore, the creep cavitation modeling approach reported here should be generic and can be used for any other cavitation controlled damage and fracture problems such as ductile fracture, fatigue fracture, creep, and fatigue combined fracture.

7. A mesoscopic creep deformation and creep damage model concept was proposed and preliminarily realized in a plane stress version; its potential for providing the right size has been demonstrated.
8. Parallel to the development of 3D computational platform, there is a great need for the development of creep damage constitutive equations for grain and grain boundary separately.

SYSTEMATIC LITERATURE REVIEW

Researchers have extensively tested the docking tests of high entropy alloys (HEAs) for creping, fracture and fatigue with various experiments. This rigorous assessment was based on widely published peer-reviewed publications. It was not then forwarded for approval to an ethics commission.

Sr. No.	Topic	Results	Author Name
1.	Heavy Entropy Alloy microstructure, tensile and creep featuresTa20Nb20Hf20Zr20Ti20	Contrarily to the contraction characteristics, both materials were found to be extremely brittle under pressure, during either room temperature pressure testing or during creep experiments performed at 282 C. Fractographic fractures resulted in a brittle fracture without plastic deformation pre-fracture proof.	Larianovsky et al[9].
2.	High Entropy Alloys' Fatigue Comportment	Such microstructural defects have been found to have a major effect on the fatigue behavior of HEAs. A review of the HEA hardness limits and fatigue ratios with traditional structural alloys indicates that HEAs can outperform other traditional alloys under fatigue conditions. This is assumed that a reduction in the number of defects added during manufacturing and processing can result in a superior fatigue performance that exceeds that of traditional alloys.	Hemphill, [10].
3.	Microstructural interpretation as well as mechanical behaviours of room and high temperature and high entropy alloys	The subsequent deformation framework being created by the involvement of misalignments with specific Burgers vectors that could serve as a hindrance to dislocation motion to reinforce fatigue activity and release stress energy and compressive stresses to increase resistance to cyclic loading.	Chen, [11].
4.	Crack growth behavior As-Cast high entropy alloys Fatigue Crack and Fracture Toughness	Fatigue crack growth experimentation discovered higher fatigue threshold which significantly reduced significantly by an improvement in load ratio, whereas Paris law slope demonstrated metal-like behavior at low R with significant increases at high R. Fracture surface analyses showed variations of brittle and ductile / dimpled regions overflowing, with plenty of scientific proof of fatigue indentations in the Paris law system.	Seifi et al [12]
5.	Fatigue Conduct and Crack Initiation in CoCrFeNiMn Elevated-Entropy Compound Manufactured through Powdered Structure	Also relatively minor improvements in the microstructure have a major effect on the life of the fatigue. The tiredness stamina mark for HEA 5 and HEA 10 respectively was 1100 MPa and 1000 MPa. Detailed research showed that abnormally large grains located on the tensile loaded surface	Zdeněk et al [13].

		in the microstructure constitute the standard initiation site for fatigue. Owing to cyclic loading, the development of (nano) twins and dislocation glits contributed to the crack nucleation	
6.	High entropy alloys with transformational plasticity nano-indentation behavior	The study therefore highlighted that while a class of HEAs with similar composition has been designed to produce higher strength, each alloy can be tuned to achieve improved characteristics.	Sinha et al [14].
7.	Higher-temperature new and exciting class of alloys: high entropy eutectic alloys.	Good mechanical properties can be preserved up to 700 ° C. This modern alloy construction approach can be easily applied to large-scale industrial development of HEAs with high fracture strength and ductility at the same time.	Yiping et al [15].
8.	Computing analysis of AlxCoCrFeNiTi1−x high entropy alloys for structural and mechanical properties	The AlxCoCrFeNiTi1−x alloys studied are expected to have good overall mechanical strength, particularly for x=0.8 and 0.6 for bcc structures and x=0.5 for fcc structures. The adding / reducing of Al atoms either from structures changes the internationalization / deallocation of electrons, which has a direct effect on the interatomic communication power of the alloy structures.	Nanyunet al [16].
9.	Hight-Entropy Alloys Spark Plasma Sintered: An innovative aerospace material	In order to contribute, the temperature-stress-tidiness reaction of formed HEA can also be studied by means of finite element analysis (FEA) such that the nature of interatomic interactions that are important to the inherent material properties are well understood.	Ayodeji. Abimbola Patricia and Olawale[17].
10.	Aerospace Powder Bed Manufacturing: processes, fabric and fabric / ceramic composite materials and patterns	Discussions on the additive manufacturing (AM) of vital aerospace components made from titanium alloys, superalloys made from nickel, metal composites (MMCs), potassium matrix composites (CMC) and high entropy alloys are being given special focus. More focus is on the quality management of PB-AM products and opportunities for future material production methods for PB-AM targeted at aerospace applications.	Katz-Demyanetz, et al [18].
11.	High-performance refractory high-entropy alloy manufacture and analysis through selective laser melting (SLM)	In contrast to standard high aluminium alloys, the HEA exhibits excellent microstructure, hardness and corrosion resistance efficiency, making it a modern alternative for aerospace and energy applications.	Zhanget al [19].
12.	High-entropy alloys' behavior of creep, fatigue and fracture	This article provides a detailed look at what has been done in these three areas, taking into account their significance in constructing HEAs for relevant structural materials. The following subjects are a comparison between various methods for creep testing, creep parameter extraction,	Li et al [20].

		creep process, S – N fatigue-high-cycle relationship, fatigue- cracks-widening behaviour, ruggedness of the fracture, fracture under various load conditions and fractography. In the end, recommendations are recommended for future activities.	
13.	Creep Deformation and Fracture Simulation	Moreover, the cavitation fracture simulation techniques mentioned in this paper are intended to be used to analyse and model other modes of failure such as ductile failure and fatigue failure.	Xu& Lu[21].
14.	Creep of moderately high quality alloys in warm atmospheres at natural temperature	That being said, a development toward one of the improved ductility and an improvement in stress failure periods greater than σo.2 makes the time for the start of the rapid creep stage to be calculated extrapolated and low test stress from assessed values at higher stresses in the macroplastic area to be calculated. Fractogenic and strain indices showed the adverse influence of humid atmospheres on alloys with extended load distortion and failure resistance.	Polyanskii et al [22].
15.	Aluminium alloys resistant to creep and their applications	Alloys which have been used for commercial use at high temperatures are listed. Latest innovations and future growth prospects are explored.	Robinson, Cudd and Evans [23].
16.	Aluminium Cyclic Elastoplasty Efficiency 7075-T6 Below loading regulated by strain and stress	The observational findings have been further analyzed through published work on microstructure over the last 2 decades to better explain the relation of the micro-mechanism to cyclical transient behaviour.	Agius, Wallbrink and Kourousis[24].
17.	The research on X-70 carbon steel and 7075-T5 aluminical alloys graded and probabilistic models for creep loss in structures	Pragmatic use of the mathematical model for calculating creep activation capacity, the remainder of the life of the superheated tube and the probability of exceed ration of the failures of the X-70 carbon steel strain by 0.04%.	Mohammad Nuhi[25]
18.	Creep and creep-break comportment of alloy 718	Technical systems for creep-rupture even included one based on the Lot-Center Regression analysis and two focused along the Minimum Commitment Process. The master's curve method was used to establish an equation for calculating creep protrusion up to the initiation of tertiary creep.	Charles et al [26].
19.	Fatigue and Creep Behavior Analysis of Aluminium Composites	Assess such composites, investigations such as hardness, bending, friction, fatigue, creeping and tribological testing can be performed in compliance with the ASTM guidelines. An attempt has been made in the present survey paper to analyze different MMC preparation strategies and evaluation of property.	Asif et al [27].
20.	Strong Entropic Alloys for Aerospace Application	However, Laser Engineering Net Forming (LENSTM) and Selective Laser Melting (SLM); the powder-based ray additive	Dada et al [28].

		manufacturing process provides flexibility, precision in configuration as well as the manufacture of three-dimensional rigid surface frameworks by layer minimizing development errors.	
21.	Cooperative deformation at ultralow temperatures in high-entropy alloys	A key factor in bridging the slip and clamping was low stacking energy and the stable, facial-centered cubical structure at extreme low temperatures that enabled the high-entropy alloy. Viewing the role of entropy in the creation of structural materials with superior properties leads to in-situ experiments.	Muhammad Naeem et al [29]
22.	Phase sampling trends in High Entropy Alloys identified by combination techniques: Wide atomic size gap supports BCC over FCC	This choice, not indicated by the Hume-Rothery law, originates from the ability of the BCC system to tolerate a large atomic size difference with a lower energy cost, which can be theoretically started to realise except in High Entropy Alloys.	Sebastian Alexanderet al [30].
23.	Significant grain influence on the degeneration of the Al0.1CoCrFeNi high-entropy alloy.	As grain size decreases, twin spacing increases and the twin thickness decreases, this results in low twinning operation. The twinning behavior of the re-crystallized HEA is highly hindered by grain grinding, something that deteriorates its development of coupling by strain-hardening and compressive machinability.	Wu et al [31].
24.	Strong Entropic Alloys: Revolutionary Materials for Aero Engine Applications?	On the basis of these two reviews, several problems were detected that required further studies to fill the gap with possible solutions and possible HEA systems for specific engine parts produced by GKN Aero Engine Systems were ultimately proposed.	Daniel [32].
25.	Tests of coherent cubic nanoprecipitate formation in Al2(Ni, Co, Fe, Cr)14compositions-centric, cubical high-entropy alloys	In view of the lattice weakness in these HEAs, optimum reinforcement was debated as a function of the form and size of the clear precipitates.	Ma et al [33].

CONCLUSION

From the open literature above, the authors agreed that the current market material used in high-temperature applications such as gas turbine and turbine engine in the aerospace industry experience several failures such as high-temperature oxidation and corrosion, limited hardness, and wear resistance. It is confirmed that spark plasma sintering is a potential way to fabricate HEAs which possess properties such as improved micro hardness, compressive/tensile strength, tribology, thermal properties, and corrosion resistance properties for low and high-temperature applications as generally agreed by all the authors.

REFERENCES

1. Vijaya Ramnath, B. Elanchezhian, C. Jaivignesh, M.Rajesh, S.and Parswajinan,C. (2014). “Evaluation of mechanical properties of aluminium alloy –alumina-boron carbide metal matrix composites”, Materials and Design, 58, 332-338.
2. Baradeswaran, A. and Elaya Perumal, A. (2014). “Study on mechanical and wear properties of Al 7075- Al2O3-graphite hybrid composites”, Composites Part B, 56,464-471.
3. Madeva Nagaral, V. Auradi, S. A. Kori, Reddappa H. N. J. and Shivaprasad,V. (2017). “Studies on 3 and 9 wt.% B4C particulates reinforced Al7025 alloy composites”, American Institute of Physics Proceedings. 1859.
4. Jadhav, P. R. Sridhar, B. R. Nagaral,M.and Harti,J. (2017). “Evaluation of mechanical properties of B4C and graphite particulates reinforced A356 alloy hybrid composites,” Materials Today Proceedings, 4, 9972-9976.

5. Nagaral,M. Auradi, V. Parashivamurthy, K. I. Kori, S. A. and Shivananda, B. K. (2018). “Synthesis and characterization of Al6061-SiC-Graphite composites fabricated by liquid metallurgy,” Materials Toady Proceedings. 5, 2836-2843.
6. Lee, J. S. Armakia, H. G. Maruyamab K, Murakic, T. and Asahic, H. (2016). Causes of breakdown of creep strength in 9Cr–1.8W–0.5Mo–VNb steel. Materials Science and Engineering. 428, 270-275.
7. Parker, J. (2013). In-service behavior of creep strength enhanced ferritic steels grade 91 and grade 92 – Part 1 parent metal. International Journal of Pressure Vessels and Piping. 101, 30-36.
8. Wen, J. F. and Tu, S. D. (2014). A multiaxial creepdamage model for creep crack growth considering cavity growth and microcrack interaction. Engineering Fracture Mechanics. 123, 197-210.
9. Larianovsky, N. Katz-Demyanetz, A. Eshed, E. & Regev, M. (2017). Microstructure, Tensile and Creep Properties of Ta20Nb20Hf20Zr20Ti20 High Entropy Alloy. Materials. 10.
10. Hemphill, M. A. (2012). Fatigue Behavior of High-Entropy Alloys , University of Tennessee, Knoxville Trace: Tennessee Research and Creative Exchange. 2.
11. Chen, S. (2019). Microstructural Characterization and Mechanical Behaviors of High Entropy Alloys at Room and Elevated-Temperatures, 2.
12. Seifi, M. Li, D. Zhang, Y. Liaw, P. & Lewandowski, J. (2015). Fracture Toughness and Fatigue Crack Growth Behavior of As-Cast High Entropy Alloys. JOM: the journal of the Minerals, Metals & Materials Society. 67, 2288-2295.
13. Zdeněk, C. Fintová, S. Hadraba, H. Kuběna, I. Vilémová, M. & Matějíček, J. (2019). Fatigue Behaviour and Crack Initiation in CoCrFeNiMn High-Entropy Alloy Processed by Powder Metallurgy. Metals. 9.
14. Sinha,S. Wang, T. Nene, S. S.Frank, M. Liu, K. & Mishra, R. S. (2019). Nanoindentation behavior of high entropy alloys with transformation-induced plasticity, Scientific Reports. 2.
15. Yiping, L. Yong, D. Li, J. Huijun, K. Jinchuan, J. Zhiqiang, C. & Tingju, L. (2019). A Promising New Class of High-Temperature Alloys: Eutectic High-Entropy Alloys, Scientific Reports. 2-60.
16. Nanyun, B. et al (2019). Computational characterization of the structural and mechanical properties of Al xCoCrFeNiTi1−x high entropy alloys, Materials Research Express. 1-60.
17. Ayodeji, E, A, Abimbola Patricia, I. P. and Olawale, M. P. (2019). Spark Plasma Sintered High-Entropy Alloys: An Advanced Material for Aerospace Applications, ecent Advancements in the Metallurgical Engineering and Electrodeposition. 2.
18. Katz-Demyanetz, A.Vladimir, V. Popov, J. Aleksey, K. Safranchik, D. and Koptyug,A. (2019). Powder-bed additive manufacturing for aerospace application: Techniques, metallic and metal/ceramic composite materials and trends, Manufacturing Rev. 6, 5.
19. Zhang, H. et al (2019). Manufacturing and Analysis of High-Performance Refractory High-Entropy Alloy via Selective Laser Melting (SLM), Materials (Basel). 12(5), 720.
20. Li, W.Wang, G. Wu, S. & Liaw, P. (2018). Creep, fatigue, and fracture behavior of high-entropy alloys. Journal of Materials Research. 1-24.
21. Xu, Q. & Lu, Z. (2019). Modeling of Creep Deformation and Creep Fracture. 10.
22. Polyanskii,V. M.Volkov,N. I. Gorodkova, O. M. Yu. N. Kopanov, T. A. Frol'tsova & Khailov, A. N. (1990). Creep of medium and high strength aluminum alloys at normal temperature in moist atmospheres, Scientific and Technical Section. 22, 59–70.
23. Robinson, J. Cudd, R. & Evans, J. (2003). Creep resistant aluminium alloys and their applications. Materials Science and Technology. 19, 143-155
24. Agius, D.Wallbrink, C. & Kourousis, K. (2017). Cyclic Elastoplastic Performance of Aluminum 7075-T6 Under Strain- and Stress-Controlled Loading. Journal of Materials Engineering and Performance. 26, 10.
25. Mohammad Nuhi, F. (2011). Classification and probabilistic model development for creep failures of structures: study of x-70 carbon steel and 7075-t6 aluminum alloys , 2.
26. Charles, R. Brinkman, M. Keith, B. and Ji Lie, D. (1990). Creep and creep-rupture behavior of alloy 718, Superalloys 718,625 and Various Derivatives. 2.
27. Asif, S. Kodanda, C. Madeva, N. and Auradi,V (2018). A Review On Fatigue And Creep Behaviour Of Aluminium Composites, Shaik Asif Journal of Engineering Research and Application . 8, 26-33.
28. Dada, M. Popoola, P. Adeosun, S. and Ntombi, M. (2019). High Entropy Alloys for Aerospace Applications, Environmental Impact of Aviation and Sustainable Solutions. 1-30.
29. Muhammad Naeem et al (2020). Cooperative deformation in high-entropy alloys at ultralow temperatures, research articlematerials science. 6(13)
30. Sebastian Alexander, K. and Other (2019). Phase selection motifs in High Entropy Alloys revealed through combinatorial methods: Large atomic size difference favors BCC over FCC, Acta Materialia. 166, 677-686.
31. Wu, S. W. Wang, G. Yi, J. Jia, Y. D. Hussain, I. Zhai, Q. J. & Liaw, P. K. (2017). Strong grain-size effect on deformation twinning of an Al0.1CoCrFeNi high-entropy alloy, Materials Research Letters, 5(4), 276-283.
32. Daniel O. S. (2015). High Entropy Alloys: Breakthrough Materials for Aero Engine Applications, Materials and Design, 58, 332-338.

33. Ma, Y. et al (2018). Controlled formation of coherent cuboidal Nano precipitates in body-centered cubic high-entropy alloys based on Al2(Ni,Co,Fe,Cr)14 compositions, journal homepage: www.elsevier.com/locate/actamat. 147, 213-225