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Computer Aided Modeling and Analysis on Microgravity Random Access Stowage and Rack Systems Applied in Aerospace Station

Review Article

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Abstract

This research is to design and develop a preliminary Microgravity Random Access Stowage and Rack (MRASR) system for horizontal and vertical deep space habitat configuration through computational 3-D modeling and computational structure analysis. The designed stowage system can be flexible and random access with corridors in limited space station. The built prototype of this MRASR system has been tested to prove its flexible storage access and reliable function. The MRASR system can be applied to horizontal and vertical habitat while making product lighter in weight, safer in use, cost-effective in manufacturing, and reliable in performance. This designed MRASR system can also be applied for some aerospace stations that require fluids, power, gases, and data. The workstations in this stowage system can be folded away when not being used to save space in aerospace station. The expected outcome from this research is to understand the ergonomics, zero-gravity function, and efficiency of stowage racks and moving equipment. The later research will focus on improving MRASR system through computer-aided design and analysis and verifying anti-corrosion processes and mechanisms through the investigation and application of nanomaterial theories, technologies, and techniques.

keywords: 3-D modeling; Computational analysis; Mechanical reliability; Anticorrosion coating; Structural strength

Introduction

MRASR system starts to be studied in recent years to support the aerospace station [1]. It studies neutral buoyance, understand zero-gravity ergonomics, and validate simulated mission duration usage. Computer-aided modeling and engineering design has been brought to the forefront of the scientific and technological renovation for some fields, including NASA and US aerospace frontier exploration [2]. The research of MRASR system seeks to conduct fundamental research with mathematical modeling, computational simulation and technical renovation in order to understand the current issues and determine future scientific and technological endeavor [3]. The engineering design methodology and prototype proposed in this research filed can be served as the fundamental element for developing of renovated science, technology and engineering research that integrates electrical engineering, mechanical engineering, material science, and manufacturing technology [4,5]. The current researches address the novel engineering design and analysis techniques to understand, characterize, and identify the critical factors to facilitate MRASR system for analysis in a microgravity environment [6].

Significance

The goal of this research is to design and develop MRASR system for future aerospace station applications. The interdisciplinary nature of this research will offer research opportunities at the intersection of mechanical engineering, material science, nanotechnology, electrical engineering, chemistry, and manufacturing technology.

Computer Aided 3-D modeling and Analysis of MRASR System

This research proposes the fundamental research with 3-D design modeling, computational simulation and technical renovation to understand current problems and determine future scientific and technological space endeavors. The design modeling and analytic methodology proposed in this project can be served to develop new scientific, technological and engineering research that integrates material science, mechanical engineering, and manufacturing technology. Computational simulations can also verify and determine the strength of structural MRASR system.

Nanoparticles are applied in various applications including material coatings, severe temperature environment, and property enhancement. The nanoparticles are typically 10 to 30 nanometers and specific surface area ranges from 30 to 70 m^2/g[7] (Figure 1 & 2).

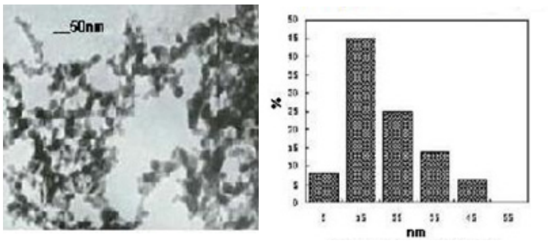
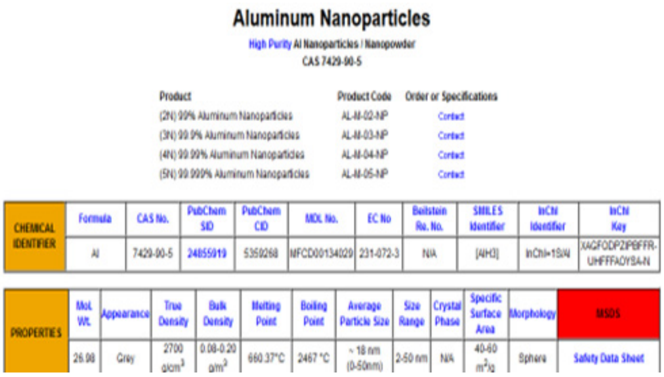


Figure 1: Nanoparticle micrograph and particle size distribution [7].



Aluminum Nanoparticles
High Purity Al Nanoparticles / Nanopowder
CAS 7429-90-5

Product	Product Code	Order or Specifications
(2N) 99% Aluminum Nanoparticles	AL-M-02-NP	Contact
(3N) 99.9% Aluminum Nanoparticles	AL-M-03-NP	Contact
(4N) 99.99% Aluminum Nanoparticles	AL-M-04-NP	Contact
(5N) 99.999% Aluminum Nanoparticles	AL-M-05-NP	Contact

CHEMICAL IDENTIFIER	Formula	CAS No.	PubChem SID	PubChem CID	MDL No.	EC No	Beilstein Re. No.	SMILES Identifier	InChI Identifier	InChI Key
	Al	7429-90-5	24855919	5359268	MFCD00134029	231-072-3	N/A	[AlH3]	InChI=1S/Al	XAGFODPZIPBFFR-UHFFFAOYSA-N

PROPERTIES	Mol. Wt.	Appearance	True Density	Bulk Density	Melting Point	Boiling Point	Average Particle Size	Size Range	Crystal Phase	Specific Surface Area	Morphology	MSDS
	26.98	Grey	2700 g/cm³	0.08-0.20 g/m³	660.37°C	2467 °C	~ 18 nm (0-50nm)	2-50 nm	N/A	40-60 m²/g	Sphere	Safety Data Sheet

Figure 2: Mechanical properties of Al Nanoparticles [7].

The following Figure 3 & 4 show the preliminary prototype of MRASR system and its moving mechanism. This renovated system design will build an accessible corridor with flexibility to be applied to horizontal or vertical habitats and also be used for workstations requiring power, data, gases, and fluids. This system can be controlled to move towards the left and right by motorized sliders to automatically adjust flexible storage spaces for different operations. In addition, to save room in limited space of aerospace station, the workstations can be folded away by moving to the back of storage/rack system when not being used.

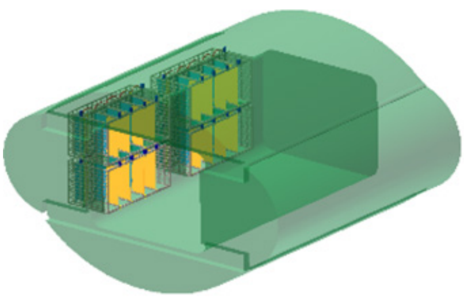


Figure 3: Concept of full MRASR system.

To study the electrodeposition process on MRASR system, the nanoparticle coating functionality can be simulated and identified based on following equations to improve the nanocoating operation on materials in MRASR system:

- Nernst-Planck equation: $\{D_i [\ {}^2 C_i+(Z_i F)/RT\ \ (C_i)]+R_i=(\partial C_i)/\partial t=0\}$
- Electroneutrality $[\Sigma(ZiCi)= 0]$
- Hall Petch Relationship: $\sigma_y=\sigma_o+K_y/\sqrt{d}$

Hall–Petch theory of analyzing Nanocrystalline AL shows a high frictional stress of 168MPa and a high positive slope of 0.125MPa√m as compared to pure Al that has a frictional stress range of 14–31MPa and a slope range of 0.055–0.088MPa √m [8].

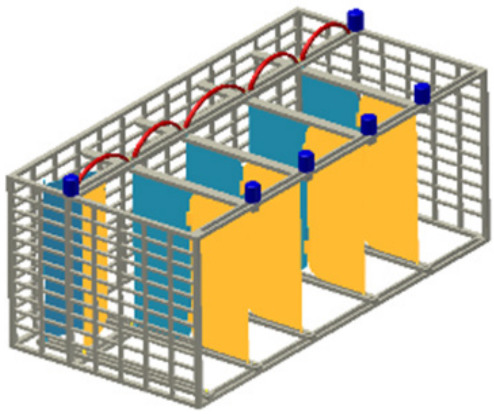


Figure 4: Prototype of MRASR mechanism.

In Figure 5 & 6, A is the experimental strength of bulk nanocrystalline Al, B is the grain size effects, C is the yield strength of pure Nano-Al, and D is the yield strength of Al. The following computer-aided modeling and simulations show the simulated results to this MRASR system.

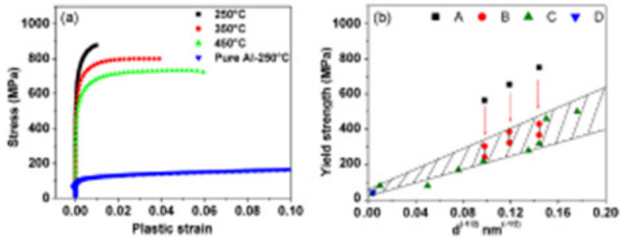


Figure 5: Stress and yield strength of nanocrystalline Al.

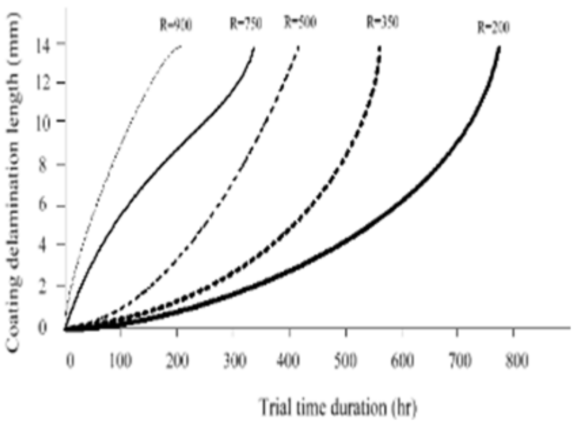


Figure 6: Computer modeling of nanocoating on MRASR system.

Figure 7 displays that dispersive ratio of molecules C0/C is reduced as nanocoated volume ratio is increased since more Nano-elements appeared in the materials can help reducing the material loss due to the strong material bond.

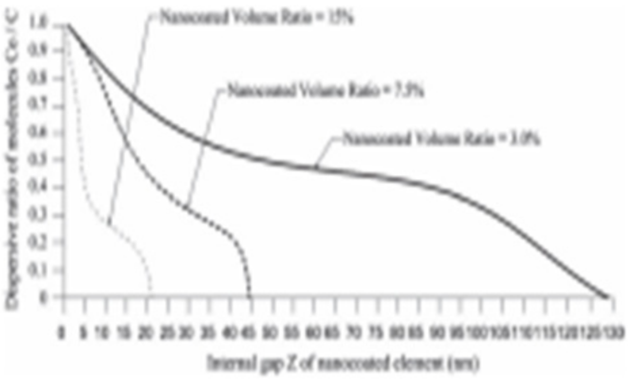


Figure 7: Dispersive ratio of molecules C_0/C.

Figure 8 shows the coated material separation in three different coatings versus cyclic time duration. It indicates that the corrosion-resistant performance in nanocoated material is significantly improved compared with regularly coated materials due to the decreased grain size and increased grain boundary ratio that prevents the external moisture from penetration.

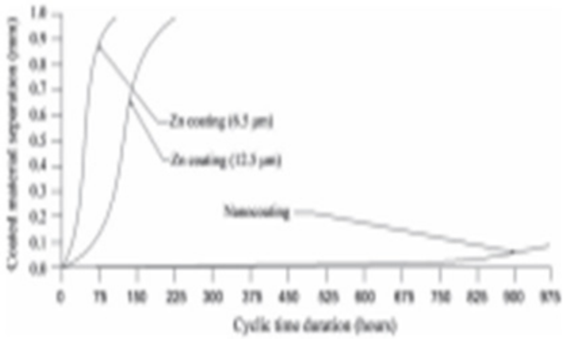


Figure 8: Coated material separation vs time duration.

Figure 9 &10 show the computational simulations on structure and deflection of MRASR system. The above computational simulation and analysis validate the normal material coating process, reliable mechanical structure and good function in this preliminary MRASR system.

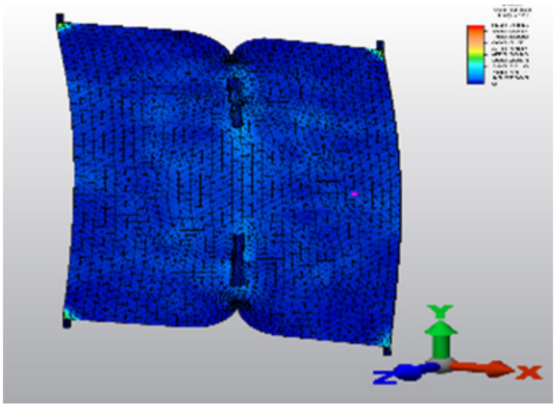


Figure 9: Computational structure analysis on MRASR system.

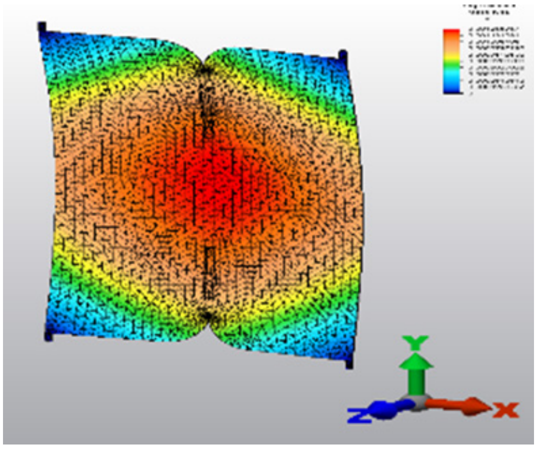


Figure 10: Computational simulation of deflection on MRASR system.

Mechanisms for Integration

The above study and analysis will lead important theoretical findings based on current research, in which the evidence has been collected and verified to determine the dimensional geometry of MRASR system and conditions that stabilize and enhance the structure of this system. It helps to establish the future theoretical foundation of comprehensive and fundamental restructuring of MRASR system and aims to identify nanoscale material structure stabilization, atomic growth, improved strength and intensified strain effect, which are not well explored from a scientific and engineering perspective. There is still little understanding of all the above fundamental theories that directly influence the mechanical, electrical and thermal properties of this random-access stowage/rack system. The continuous research will use an interdisciplinary approach, integrating product design, nanotechnology, material science, mechanical engineering, manufacturing technology, and chemistry, to apply computational modeling and simulation software of COMSOL, failure mode error analysis (FMEA) and Finite Element Analysis (FEA) techniques to the NASA and aerospace products. The computer aided engineering (CAE) model is applied to design and model the MRASR system, the COMSOL model is used to analyze the nanomaterial and anti-corrosion coating performance, the FMEA model is utilized to identify the impact of process variables on nanomaterial and coating processes, and the FEA model is applied to verify the structural and functional properties of MRASR system. These approaches can help to design this stowage/rack system, predict future performance of nanocoating operations, and verify the operation's risk or vulnerability in nanomaterial and coating processes through the FMEA analysis model.

Conclusion

The preliminary MRASR system has been studied and simulated in this research. The objective of this research is to design, develop and build the 3-D model and prototype of MRASR system for future NASA and aerospace explorer applications. The prototype of MRASR system has been tested and the experiments show its flexible storage access and reliable function. It will help astronauts, researchers and engineers working in no-gravity space environment to perform scientific research and engineering projects. This newly proposed MRASR system can also be applied for international space workstations that require power, gases, fluid and information data. The workstations in this system is flexible to be folded away when not being used in order to give more free space in space station. This simple system design can also ease the manufacturing and maintenance processes. The expected outcome from this research is to understand the ergonomics, zero-gravity function, and efficiency of MRASR system. The computational simulation and analysis of this system shows its reliable mechanical/structural design and normal function.

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