L'Space Proposal Research and Methods (2022), , 1–9
doi:TX12.1.1 Lightweight Structural Materials

RESEARCH NOTE

Promising 301 Stainless Steel Alloy Replacement: Using 2DPA-1 Polyaramide for Space Rockets

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Abstract

Spacecraft construction in NASA is a rigorous process that requires several design techniques. The discovery phase is where scientists are consulted on a large quorum to figure out the requirements for a spacecraft. The design phase is where the design team organizes ideas for the spacecraft and the development phase is where a prototype of the spacecraft is built. Afterwards, necessary corrections are made through feedback from supervisors and the final product is built. The teams have to make the final design as robust as possible while still satisfying the constraints: remaining lightweight at large sizes, materials that are strong yet durable, and overall high heat resistance throughout the design. We propose using a new material developed by MIT researchers called 2DPA-1 which is a plastic polymer with unique qualities. These are but not limited to, twice as strong as steel with a density one sixth of steel, and being heat resistant up to 300 °C, contrary to that of steel which is 900 °C. 2DPA-1 has a quite high heat resistance for plastic material, and its heat resistance could even be increased up to 500 °C by layering the material.We propose that this material be used for construction in NASA as it shows potential for several applications. Our focus on its application lies in spacecraft construction, specifically using it as a finishing material for spacecraft in place of 301 Stainless Steel alloy. It is cost-efficient, easy to manufacture, and performs better in terms of physical properties than any metal. From our robust research and analysis, our results show that the potential we found is indeed true and with appropriate testing, 2DPA-1 could become the new material for construction and lessen our dependence on metals.Our focus specifically looks at using 2DPA-1 as structural material replacement for spacecraft instead of 301 Stainless Steel. From our research and analysis, we found that the properties of 2DPA-1 has high tensile strength, less permeability to gasses, low production cost, and the ability to be manufactured easily.

Keywords: 2DPA-1, polymer, lightweight material, replacement, cost-efficient

1. Technology Merit Introduction

The struggle of finding the best materials to use in the construction of spacecraft has existed for decades. Whenever a new spacecraft is developed, scientists come together to design new iterations of the bodily structure and improve upon the currently used materials to increase the spacecraft's durability, decrease its weight, and give it better resistance to different atmospheric conditions. They call this process the Shuttle design debate. In this paper, we continue this debate by introducing a novel material for spacecraft construction. A new polymer material, called 2DPA-1, is a polyaramide that can form 2-dimensional chains which scientists till date considered to be impossible. Upon heating one dimensional polymer, it expands into 3 dimensional layers. A two-dimensional polymer (2DP) is a sheet-like mono-molecular macro-molecule that consists of laterally connected units with end groups along all edges.

This material could be a potential replacement for 301 stainless steel alloy that is currently being used in the construction of spacecraft. Many space companies use aluminum, stainless steel, and titanium to build their structural system. This is due to durability and cost. However, 2DPA-1 is potentially more cost-effective as the cost to manufacture 2DPA-1 would be similar to that of producing plastic. In fact, 2DPA-1 seems similar to stainless steel but it possess twice the strength stainless steel, six times more elastic modulus, high thermal decomposition, and is impermeable to gasses while being more cost-efficient and time efficient as it is easy to produce in bulk. It is not scarce like other materials like stainless steel and aluminum and can be produced in large quantities in a lab with proper facilities and equipment. The application of 2 DPA-1 does not just limit to the outer body of space crafts but it could also be used in constructing other technologies such as coating for satellites, strong building structures, and ballistic missiles for the United States military. 2DPA-1 could also be used for thin coating for the outer body of the spacecraft which will make it impermeable to gasses and the rocket would be able to withstand more damage in space due to its high tensile strength and high thermal decomposition.

Our goal through this research is to explore the strength of this material and compare it to the 301 stainless steel alloy and devise a means to leverage those benefits into designing a better outer material for the body of space crafts in the National Aeronautics and Space Administration. We also aim to provide a cost analysis for using 2DPA-1 in such scenarios. For example, we found the total cost of all the raw chemical materials to just be about $3000 to produce a plate of 2DPA-1 and would be even cheaper on a large scale when we buy those chemical compounds in a bulk purchase. As polyaramide is able to be produced in large quantities, it would be a beneficial source of material in the space industry.

Given that 2DPA-1 is a relatively new material, certain key experiments have not been performed yet to fully evaluate its mechanical properties under stressful conditions, such as those experienced in spaceflight. With that being said, 2DPA-1 shall be able to be easily manufactured on a large scale, shield from Galactic Cosmic Radiation (GCR), possess high heat resistance, and save costs. If 2DPA-1 fails any of these requirements, then our objective “Using 2DPA-1 to reduce our dependence on metals” would be challenged which is a major limitation (Zeng).

2. Potential Benefit Analysis

Much of the comparison of 2DPA-1 to 301 stainless steel is provided in the table below and served as the inspiration for this work. The reason 301 stainless steel was chosen to be compared with 2DPA-1 is because that is the closest aerospace alloy in comparison.

Properties	**301 Stainless Steel**	**2DPA-1**
Density	7.85 g/cm^3	1.308 g/cm^3
Tensile Strength	1276 MPa	12.7 GPa
Yield Strength	965 MPa	488 MPa
Coefficient of Thermal Expansion	276 MPa	50.9 GPa
Thermal Decomposition	840°C	312°C

Table 1: Comparison of Material Properties

1. 2DPA-1 is one-sixth times lighter than 301 stainless steel alloy. Hence, it would be a better material to use in terms of reducing the total density of the final prototype of the spacecraft.
2. 2DPA-1 has a relatively high heat decomposition for a plastic material at 300 °C. However on the downside this value is less than that of 301 stainless steel, which has a thermal decomposition of 900 °C, it does possess the potential of thermal decomposition under heat up to 1800 when coated in multiple layers of itself. Another advantage of 2DPA-1 is that in the aligned form they exhibit isotropic stiffness within the 2D plane, doubling the effective stiffness when compared to 1D polymer counterparts that reinforce in only a single direction (Zeng).
3. After layering an additional 2DPA-1 film onto a polycarbonate (PC) film and scrolling this nanostructure into an Archimedean nanostructured fiber , results found out that fibers exhibit significant larger elastic moduli and tensile strength than PC controls, even at very low volume fraction . For instance, a 6.9% fraction of 2 DPA-1 film enhances the fiber modulus by 72%, while the strength rises from 110 MPa to 185 MPa (Zeng).

301 Stainless Steel Pros	**301 Stainless Steel Cons**
Efficient ductility and strength	Heavier thus increasing the cost for NASA missions
Good corrosion resistance	Resistance is weaker than 304
High heat resistance	Subject to material shortages
Weldable	Non-American Steel is objectively worse

Table 2: Properties of 301 Stainless Steel Comparison

2DPA-1 Pros	**2DPA-1 Cons**
Able to be produced in large amounts (can be synthesized in labs)	Has a lower heat resistance when comparing to 301 SS
Density is one-sixth that of 301 stainless steel	Mechanical properties are not the best when compared to 301 SS
This material serves as an enhancer for other materials by increasing their mechanical properties	Material hasn't been rigorously tested enough for a full scale switch

Table 3: Properties of 2DPA-1 Comparison

Given that 2DPA-1 is a relatively new material, certain key experiments have not been performed to fully evaluate its mechanical properties under stressful conditions. Additionally, NASA does not pursue new technological advancements until they are proven effective, and this material will take some time to prove itself as an effective replacement but it does show potential compared to other materials considered for Aerospace applications. Therefore, we believe it is worth pursuing. While NASA has standards for the use of new technology in Aerospace, our team has also organized requirements that 2DPA-1 has to meet in order for it to be deemed successful: must be able to mass produce, shield from Galactic Cosmic Radiation (GCR), possess high heat resistance, and save costs. If 2DPA-1 falls short in any of these requirements, then our objective of finding a suitable replacement material for 301 stainless steel would have been for nothing.

2DPA-1 has a relatively high heat decomposition for a plastic material at 300 °C. However, the downside of this value is that it is less than 301 stainless steel, which has a thermal decomposition of 900 °C. 2DPA-1 does possess the potential of thermal decomposition under heat up to 1800 when coated in multiple layers of itself. Another advantage of 2DPA-1 is that in the aligned form they exhibit isotropic stiffness within the 2D plane, doubling the effective stiffness when compared to 1D polymer counterparts that reinforce in only a single direction.

After layering an additional 2DPA-1 film onto a polycarbonate (PC) film and scrolling this nano-structure into an Archimedean nano-structured fiber, results revealed that fibers exhibited a significantly larger elastic moduli and tensile strength than PC controls, even at very low volume fraction. For instance, a 6.9% fraction of 2DPA-1 film enhances the fiber modulus by 72%, while the strength rises from 110 MPa to 185 MPa (Fig. 4j).

3. Technology Development Work Plan

Our model rocket would need to complete a launch test, an anti-gravity test, wet dress rehearsal test, static fire test, thrust stand test, rocket and exhaust duct rocket test, observations in thermal vacuums, and space simulations to ensure the rocket has passed the necessary qualifications. The duration mentioned above is the best case scenario if everything goes well. We have estimated that the worse case scenario is dependent on experimentation and development phase which could take upwards to a year.

PHASES	DATE	DURATION	TASKS
I	May 1, 2022	6 months	Create a blueprint and framework in order for a smooth process flow (i.e. preparing project roles, vendors, mentors, partners)
II	December, 2022	1-1.5 months	Contacting vendors and preparing shipments of materials
III	Janurary 1, 2023	1 month	Preparing lab and machinery
IV	Feburary 1, 2023	4 months	Full scale experimentation on creating a sample of 2DPA-1
V	June 1, 2023	2 months	Building a sample model rocket to test material durability
VI	September 1, 2023	3 months	Full scale experimentation with the model rocket (i.e. test flights)
VII	Janurary 1, 2024	6 months	Fine tuning development variables, material properties, and additional research
VIII	July, 1 2024	2 months	Large scale production for 2DPA-1

Table 4: Development Timeline

2DPA-1 in many aspects is similar to 301 stainless steel. We aim to complement the existing materials and technology used at NASA. This technology involves the design and finishing of the outer body of space crafts with the best of materials and our proposal is only to provide an even better material over the existing ones. Having discussed 2DPA-1's properties above, we conclude that this material, if synthesized, manufactured and implemented properly, would be a game changer as it would reduce dependency on metals for building spacecraft.

4. Cost-Based Analysis

We researched the prices of each material used in the production and manufacturing of 2DPA-1 to find a sum total of the amount spent to develop the final product (laboratory equipment excluded). We then multiplied that amount by the scale of expansion we would use. The final product is a thin sheet of 2DPA-1 for developing the outer layer of rockets. We scale our testing to use 2DPA-1 on a model rocket one meter in height and 25 centimeters in diameter. Our calculations estimate that it would cost approximately $6,609 to acquire all the materials sufficient for producing enough 2DPA-1 to completely cover the body of our model rocket.

For equipment and materials we will depend on the resources available at a laboratory from a university. This method would lower the cost and it will cost approximately $50 to rent lab materials for a day. We also included the cost for purchasing online courses to get familiar with the process from experienced engineers who charge by the hour. We also included transportation costs to commute between the university lab and wherever we decide is the best place for testing our model rocket.

The surplus cost would be additional costs or emergency funds that may be needed throughout development. Hence, the total cost for testing our project concept and technology on a small scale sample rocket amounts to $\$9,900 \sim \$10,000$.

Material	Vendor	Mass	Needed	Cost From Vendor	Sales Tax	Total
Polycarbonate (PC, granule)	Sigma-Aldrich	100g		$216.00	$12.96	$228.96
Melamine	Sigma-Aldrich	5g	126 mg	$20.10	$1.21	$21.31
Trimesoyl-chloride	Sigma-Aldrich	10g	265 mg	$50.10	$3.01	$53.11
Isothaloyl Chloride	Sigma-Aldrich	100g		$35.00	$2.10	$37.10
CaCl2	Sigma-Aldrich	100g		$41.80	$2.51	$44.31
Pyridine	Sigma-Aldrich	100mL	1 mL	$110.00	$6.60	$116.60
N-methyl-2-pyrrolidone	Sigma-Aldrich	100mL	1 mL	$90.80	$5.45	$96.25
Acetone	Sigma-Aldrich	1L	80 mL	$72.70	$4.36	$77.06
Trifluoroacetic Acid	Sigma-Aldrich	100mL	2-5 mL	$51.10	$3.07	$54.17
Thermal oxide wafers	Waferpro			$680.00	$40.80	$720.80
Arrow UHF	Oxford Instruments			$660.00	$39.60	$699.60
NPG-10	Bruker			$285.00	$17.10	$302.10
AC-160	Oxford Instruments			$410.00	$24.60	$434.60
FASTSCAN-D-SS	Bruker			$1,100.00	$66.00	$1,166.00
TEM Grids	Ted Pella			$225.00	$13.50	$238.50
Highest Grade V1 Mica Discs	Ted Pella			$49.90	$2.99	$52.89
Ultra-Flat Si	Ted Pella			$198.75	$11.93	$210.68
SiO2	Ted Pella			$51.70	$3.10	$54.80
Spin Coater	Laurell					$2,000.00
Borrowing equipment from University cost				$600		$600.00
Buying online courses to learn more				$300		$300.00
Transportation Cost				$300		$300.00
Surplus/ Emergency Funds						$2,191.17
					TOTAL	$10,000.00

Table 5: Cost Analysis

5. Project Management Approach

NFT is divided into three sub-teams: Engineering, Science, and Business. The team leads communicated with the PI, Project Manager, and rest of their respective team members throughout the proposal writing and developmental phases. This involves answering questions and hosting meetings at specific times each week for a general discussion on the project and how we could move forward.

We started our final push for proposal completion on March 3, 2022 where the Project Manager started to host Zoom meetings from 7-8 pm Pacific Standard Time. This was an effective way to ensure everyone provided an adequate amount of work on the proposal. The team decided on a soft deadline where we would have a final rough draft ready for submission by March 12, 2022. This ensured the team had more than enough time to proof read the proposal prior to the final deadline. On average, the team spent 6-8 hours working on the proposal. Individual team members decide the amount of time they are willing to spend individually on the proposal.

5.1 Roles and Responsibilities

1. **Austin Pereira** is the **Principal Investigator** and the main driver of the project idea. He kept the team in check and suggested what improvements could be done to the proposal. He spent an average of 8 hours a week on the project. He coordinated with the SME and shared information and suggestions provided by the SME. **(De Anza College, Cupertino, California)**.
2. **Praise Ogwuche** is the **Project Manager** and keeps check on the progress and completion of the proposal. He worked together with each team lead, team members, and the Principal Investigator to monitor the status of each members progress. He spent an average of 6 hours a week on the proposal. **(Minerva University, San Francisco, California)**.
3. **Fernando Gonzalez** is the lead of the **Business Team**. He monitored the team members with Praise and oversaw more than just the business team. He worked together with other teams to research and develop working mechanisms for the completion of the project. Additionally, he has experience working with CAD software, primarily Solidworks, Matlab and NX CAD software. He He spent on average 9 hours a week on the proposal. **(California State University, LA, California)**.
4. Amber Ramirez is the lead of the Engineering subteam. She oversaw the status of the proposal and worked outside her subteam to generate ideas that moved the project forward. **(University of California, Irvine, California)**.
5. **Kiran Datwani** is the head of the **Science Team** and spent approximately 6-8 hours per week on the proposal. **(University of Hawaii at Manoa, Honolulu, Hawaii)**.
6. **Edith Ngundi** is a Science Team Member who participated in required team activities although time zone difference was a restriction. She helped out with the analysis of the properties of our concept in comparison with the other elements. **(Minerva University, San Francisco, California)**.
7. **In Woo Park** is a **Science Team Member** and he supported the team with research and applications. He was in charge of the proposal design document and visualization. **(University of Hawaii at Manoa, Honolulu, Hawaii)**.
8. **Parham Khodadi** is an **Engineering and Business Team Member** and worked together with Fernando on the business aspect to estimate costs of production and also developed concept comparison ideas. He additionally researched information for the Engineering team. He dedicated an average of 2 hours per week to the project. **(Santa Monica College, California)**.
9. **Nathan McMurray** is a **Science Team Member** and researched for the science team supporting general research with articles relevant to the concept. **(California State Cal Polytechnic University, Pomona)**.
10. **Yujin Jeong** is on the **Engineering Team** and she worked together with the engineering team lead to create the concept's applications. **(University of California, San Diego, California)**.

Throughout the entire research proposal, Amber and Fernando learned NX cad in order to apply its application to the proposal. Austin took regular guidance from the Subject Matter Expert to improve the framework for the proposal. The rest of the NFT Team provided an equal amount of time and effort to complete the proposal through research. Since completing the proposal project for L'Space, NFT Team Members have elevated their technical and non-technical skills (i.e. communication, leadership, organization, task delegation) where if we were assigned a similar project, we will be more than ready to prove ourselves again.

5.2 Milestones

1. **March 3, 2022**: The team starts working on the rough draft. The meeting is held every day on a regular basis at 7 pm Pacific Standard Time to ensure the punctuality and contribution of each team member.
2. **March 9, 2022**: PI attends the meeting with the SME and gets feedback on the proposal.
3. **March 13, 2022**: NTR is submitted by the Project Manager.
4. **March 13, 2022**: Rough draft for the proposal is completed by 11 pm.
5. **March 14, 2022**: PI and Project Manager hold a final meeting with the SME to cross-check on final edits for the proposal.
6. **March 15**: The proposal is completed with final edits and is ready for submission.
7. **March 16 3 pm PST**: Proposal is submitted for review.

5.3 Deliverable(s)

1. A complete research proposal
2. A New Technology Report

5.4 Resources

The resources that were utilized include: Zoom for our daily meetings, Google Drive File Share (written proposal) where we stored all our team project documents, LinkedIn to connect with the SME, and Discord which was our main channel for team communication.

References

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[10] Zeng, Yuwen. (PDF) An Irreversible Synthetic Route to an Ultra-Strong Two-Dimensional Polymer. https://tinyurl.com/ycx537kj

[11] Zeng, Yuwen, et al. An Irreversible Synthetic Route to an Ultra-Strong Two-Dimensional Polymer. Feb. 2022, arxiv.org/pdf/2103.13925.pdf.

6. Appendix

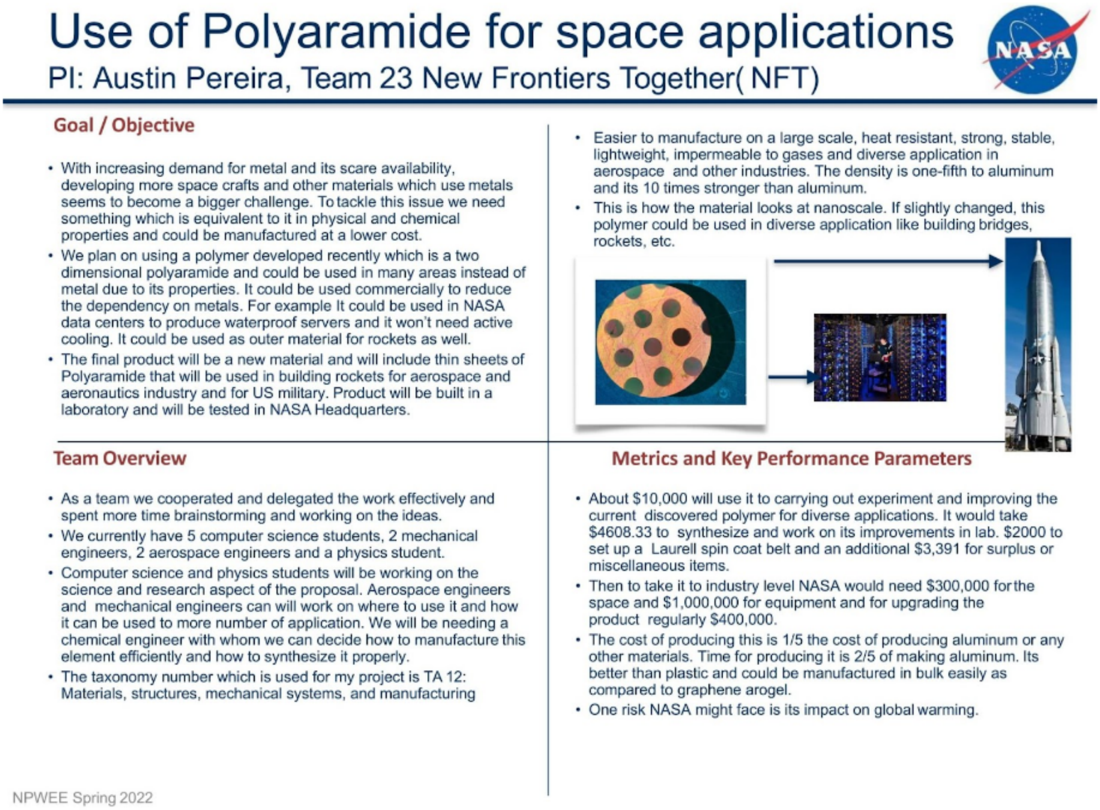

Figure 1: NFT Quad-Chart

National Aeronautics and Space Administration

Disclosure of Invention and New Technology (Including Software)

Form Approved O.M.B. NO. 2700-0009	DATE 03/14/2022
CONTRACTOR CASE NO. **NA**	

This is an important legal document. Carefully complete and forward to the Patent Representative (NASA in-house innovation) or New Technology Representative (contractor/grantee innovation) at NASA. Use of this report form by contractor/grantee is optional; however, an alternative format must at a minimum contain the information required herein. NASA in-house disclosures should be read, understood and signed by a technically competent witness in the witness signature block at the end of this form. In completing each section, use whatever detail deemed appropriate for a "full and complete disclosure." Contractors/Grantees please refer to the New Technology or Patent Rights – Retention by the Contractor clauses. When necessary, attach additional documentation to provide a full, detailed description.

NASA CASE NO. (OFFICIAL USE ONLY)

1. DESCRIPTIVE TITLE

AN IRREVERSIBLE SYNTHESIS OF AN ULTRA-STRONG TWO DIMENSIONAL POLYMER - 2DPA-1 POLYARAMIDE

2. INNOVATOR(S) *(For each innovator provide: Name, Title, Work Address, Work Phone Number, and Work E-mail Address. If multiple innovators, number each to match Box 5.)*

Yuwen Zeng, Pavlo Gordiichuk, Takeo Ichihara, Ge Zhang, Xun Gong, Sandoz-Rosado Emil, Eric D. Wetzel, Jason Tresback, Jing Yang, Zhongyue Yang, Daichi Kozawa, Matthias Kuehne, Pingwei Liu, Albert Tianxiang Liu, Jingfan Yang, Heather J. Kulik, Michael S. Strano

3. INNOVATOR'S EMPLOYER WHEN INNOVATION WAS MADE *(For each innovator provide: Name, Division and Address of Employer, Organizational Code/Mail Code, and Contract/Grant Number if applicable. If multiple innovators, number each to match Box 5.)*

Department of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA.

4. PLACE OF PERFORMANCE *(Address(es) where innovation made)*

Department of Chemical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
U.S. Army Research Laboratory, Aberdeen Proving Ground, MD 21005-5069, USA
Center for Nanoscale Systems, Harvard University, Cambridge, MA 02139, USA

5. EMPLOYER STATUS *(choose one for each innovator)*

Innovator #1	Innovator #2
Yuwen Zeng	**Michael S. Strano**
CU	**CU**
Innovator #3	Innovator #4
Ge Zhang	**Takeo Ichihara**
CU	**CU**

GE = Government
CU = College or University
NP = Non-Profit Organization
SB = Small Business Firm
LE = Large Entity

6. ORIGIN *(Check all that apply and provide all applicable numbers. If multiple Contracts/Grants, etc., list Contract/Grant Numbers in Box 3 with applicable employer information.)*

- ☐ NASA In-house Org. Mail Code _____ — WBS _____ WBS _____
- ■ Grant/Cooperative Agreement No. **80NSSC19M0186** — WBS _____
- ☐ Prime Contract No. _____ Task No. _____ Report No. _____ — WBS _____
- ☐ Subcontractor; Subcontract Tier _____
- ☐ Joint Effort *(contractor, subcontractor and/or grantee contribution(s), and NASA in-house contribution)*
- ☐ Multiple Effort *(multiple contractor, subcontractor and/or grantee contributions, no NASA in-house contribution)* — WBS _____
- ☐ Other (e.g., Space Act Agreement, MOA) No. _____

7. NASA CONTRACTING OFFICER'S TECHNICAL REPRESENTATIVE *(COTR)*

John Dankanich

8. CONTRACTOR/GRANTEE NEW TECHNOLOGY REPRESENTATIVE *(POC)*

NA

9. BRIEF ABSTRACT *(A general description of the innovation which describes its capabilities, but does not reveal details that would enable duplication or imitation of the innovation.)*

2DPA-1 is a plastic material - a polymer. Developed originally in MIT, this material has been tested to be twice as strong as steel and one sixth lighter which is not only phonomenal for a plastic but also revolutionary. It has also been tested to be irreversible. Hence, more applicable for construction purposes. 2DPA-1 is by any means on of the best versions of any plastic material present in the world today. It possesses high tensile strength, high heat resistance, ability to form plates and flexible enough to be adapted to different kind of shapes and figures. It produces a chance for NASA to exploit in using it in the finishing of various NASA equipments like Rockets, Satellites, and rovers.

SECTION I – DESCRIPTION OF THE PROBLEM OR OBJECTIVE THAT MOTIVATED THE INNOVATION'S DEVELOPMENT ***(Enter as appropriate: A. – General description of problem/objective; B. – Key or unique problem characteristics; C. – Prior art, i.e., prior techniques, methods, materials, or devices performing function of the innovation, or previous means for performing function of software; and D. – Disadvantages or limitation of prior art.)***

The Department of Chemical Engineering at MIT wanted to create a Polymer that extends covalently in two dimensions as a means of combining mechanical strength and in-plane energy conduction of a conventional 2D materials, with the low densities, synthetic processability, and organic composition of their one-dimensional counterparts. This resulted in an irreversible, solution-phase polymerization that promises new families of mechanically and chemically stable 2D polymers, analogous in properties to their 1D organic counterparts.

SECTION II – TECHNICALLY COMPLETE AND EASILY UNDERSTANDABLE DESCRIPTION OF INNOVATION DEVELOPED TO SOLVE THE PROBLEM OR MEET THE OBJECTIVE ***(Enter as appropriate; existing reports, if available, may form a part of the disclosure, and reference thereto can be made to complete this description: A. – Purpose and description of innovation/software; B. – Identification of component parts or steps, and explanation of mode of operation of innovation/software preferably referring to drawings, sketches, photographs, graphs, flow charts, and/or parts or ingredient lists illustrating the components; C. – Functional operation; D. – Alternate embodiments of the innovation/software; E. – Supportive theory; F. – Engineering specifications; G. – Peripheral equipment; and H. – Maintenance, reliability, safety factors.)***

According to the MIT Research Paper, the team envisions that the 2D polyaramid system could be further structurally tuned, paving the way for a new generation of polymer materials as barrier coatings, lightweight structure reinforcement, nanofiltration, and gas separation.

SECTION III – UNIQUE OR NOVEL FEATURES OF THE INNOVATION AND THE RESULTS OR BENEFITS OF ITS APPLICATION *(Enter as appropriate: A. – Novel or unique features; B. – Advantages of innovation/software; C. – Development or new conceptual problems; D. – Test data and source of error; E. – Analysis of capabilities; and F. – For software, any re-use or re-engineering of existing code, use of shareware, or use of code owned by a non-federal entity.)*

1. **It is twice as strong as steel: This would be beneficial to NASA in that materials stronger than steel for construction purposes are hard to come by and with appropriate application, we would be able to exploit this property on constructing parts of space rockets and satellites**
2. **It is one sixth lighter than steel: Being that much lighter than steel, it would account for reducing the average weight of a spacecraft which is one of the main goals of NASA when designing them. If this material is effectively utilized, a lighter rocket might increase the speed and accuracy in trajectory of these rockets.**
3. **It can be shaped and structured as we wish in the lab: The material itself can be structured and bonded in different ways in the lab. So, if we wanna produce more plates, we would synthesize the chemical process to bond together as plates. If we need more straws, we can also do that. This wide range of flexibility in shape and structure gives us a chance to apply it for diverse construction purposes.**

SECTION IV – SPECULATION REGARDING POTENTIAL COMMERCIAL APPLICATIONS AND POINTS OF CONTACT (*Including names of companies producing or using similar products.)*

Given that 2DPA-1 was synthesized in a lab, the potential for manufacturing at large scale is definitely there. Additionally, the potential commercial applications are listed within the Research Paper and those include barrier coatings, lightweight structure reinforcement, nanofiltration, and gas separation. While the potential commercial application is there, the material itself can not be synthesized without the chemicals needed, furthermore, the point of contact can be reached here with Dr. Yuwen Zeng being the lead scientist for further explanation on how to synthesize 2DPA-1.

10. ADDITIONAL DOCUMENTATION *(Include copies or list below any pertinent documentation which aids in the understanding or application of the innovation (e.g., articles, contractor reports, engineering specs, assembly/manufacturing drawings, parts or ingredients list, operating manuals, test data, assembly/manufacturing procedures, etc.).)*

TITLE	PAGE	DATE
Zeng, Yuwen, et al. *An Irreversible Synthetic Route to an Ultra-Strong Two-Dimensional Polymer*., arxiv.org/pdf/2103.13925.pdf.		Feb. 2022

11. DEGREE OF TECHNOLOGY SIGNIFICANCE (*Which best expresses the degree of technological significance of this innovation?)*

■Modification to Existing Technology ☐ Substantial Advancement in the Art ☐ Major Breakthrough

12. STATE OF DEVELOPMENT

■Concept Only ☐Design ☐Prototype ☐Modification ☐Production Model ☐Used in Current Work

13. PATENT STATUS (Prior patent on/or related to this innovation.)

■Application Filed Application No. **NA** Application Date **NA**

☐Patent Issued Patent No. _____ Issue Date _____

14. INDICATE THE DATE OR THE APPROXIMATE TIME PERIOD WHICH THIS INNOVATION WAS DEVELOPED (*i.e., conceived, constructed, tested, etc.)*

February 2022

15. PREVIOUS OR CONTEMPLATED PUBLICATION OR PUBLIC DISCLOSURE INCLUDING DATES *(Provide as applicable: A. – Type of publication or disclosure, e.g., report, conference or seminar, oral presentation; B. – Disclosure by NASA or Contractor/Grantee; and C. – Title, volume no., page no., and date of publication.)*

NA

16. QUESTIONS FOR SOFTWARE ONLY

(a) Using non-NASA employees to beta-test the program? ■YES ☐NO If Yes, done under a beta-test agreement? ■YES ☐NO

(b) Modification of this program continued by civil servant and/or contractual agreement? ■YES ☐NO

(c) Copyright registered? ☐YES ☐NO ■UNKNOWN If Yes, then by whom? _____

(d) Has the latest version been distributed outside of NASA or contractor? ☐YES ☐NO ■ UNKNOWN

If Yes, date of first disclosure: _____

(e) Were prior versions distributed outside of NASA or Contractor? ☐YES NO If Yes, supply NASA or contractor contract: _____

(f) Contains or based on code not owned by U.S. Government or its contractors? ☐YES ☐NO ■ UNKNOWN

If Yes, name of code and code's owner: _____

Has a license for use been obtained? ☐YES ■NO ☐ UNKNOWN

17. DEVELOPMENT HISTORY

STAGE OF DEVELOPMENT	DATE (MM/YYYY)	LOCATION	IDENTIFY SUPPORTING WITNESSES (NASA in-house only)
a. First disclosure to others	**NA**	**NA**	**NA**
b. First sketch, drawing, logic chart or code	**NA**	**NA**	**NA**
c. First written description	**NA**	**NA**	**NA**
d. Completion of first model of full size device *(invention)* or beta version *(software)*	**February 2022**	**Department of Engineering, MIT**	**NA**

e. First successful operational test *(invention)* or alpha version *(software)*	**NA**	**NA**	**NA**

f. Contribution of innovators *(if jointly developed, provide the contribution of each innovator)*

NA

g. Indicate any past, present, or contemplated government use of the innovation

NA

18. SIGNATURES OF INNOVATOR(S), WITNESS(ES), AND NASA APPROVAL

TYPED NAME AND SIGNATURE *(Innovator #1)* **NA**	DATE	TYPED NAME AND SIGNATURE *(Innovator #2)* **NA**	DATE
TYPED NAME AND SIGNATURE *(Innovator #3)* **NA**	DATE	TYPED NAME AND SIGNATURE *(Innovator #4)* **NA**	DATE
TYPED NAME AND SIGNATURE *(Witness #1)* **Austin Pereira**	DATE	TYPED NAME AND SIGNATURE *(Witness #2)* **Praise Ogwuche**	DATE
NASA APPROVED / TYPED NAME		SIGNATURE	DATE