

**Disruption Opportunity
DARPA-PA-24-04-06**

Intrinsically Tough and Affordable Ceramics Today (INTACT)

I. Opportunity Description

The Defense Advanced Research Projects Agency (DARPA) Defense Sciences Office (DSO) is issuing a Disruption Opportunity (DO), inviting submissions of innovative basic or applied research concepts in the technical domain of structural ceramic material development. This DO is issued under the Program Announcement for Disruptioneering, DARPA-PA-24-04. All awards will be made in the form of an Other Transaction (OT) for Prototype project. The total award value for the combined Phase 1 base and Phase 2 option is limited to \$2,000,000. This total award value includes Government funding and performer cost share if required or proposed.

To view the original DARPA Program Announcement (PA) for Disruptioneering, visit SAM.gov under solicitation number DARPA-PA-24-04:

<https://sam.gov/opp/cb7a935d59bb4ceeb62b9515f7d9f9b0/view>

A. Introduction

Structural applications demand materials with a unique combination of properties including high strength, stiffness, environmental resistance, and fracture toughness. As a class of materials, ceramics generally outperform metal alloys in all these properties except fracture toughness. The inherent lack of fracture toughness in ceramics has prevented their use in critical structures such as airframes, turbine disks, ground vehicle chassis, and submarine hulls. This is unfortunate, as structural ceramics have the potential to be 10x stronger than metals, 2x stiffer, half as dense, and capable of operating at 2x higher temperatures and in corrosive environments. Engineering metal-like fracture toughness into bulk ceramics would introduce a new class of damage-tolerant structural materials that could potentially exceed the capabilities of even the most advanced metallic alloys.

The dream of tough ceramics has existed since at least the mid-20th century, but achieving metal-like toughness has not yet been realized. As a compromise, ceramic matrix composites (CMCs) have been developed that exhibit “quasi-ductility” owing to macroscopic interactions between reinforcing fibers and a ceramic matrix. While CMCs have been successfully applied in Department of Defense and commercial applications, their manufacturability remains a significant challenge. Skilled labor and highly specialized equipment are required to produce, coat, and lay up fibers, infiltrate matrix material, and convert the material to a dense finished product. Furthermore, CMCs exhibit anisotropic properties due to the directionality of reinforcing fibers, presenting challenges in design and application. Fabricating complex geometries – including tight radii of curvature, thin-walled sections, or intricate internal features – is also notably difficult in CMCs. These challenges have resulted in high component costs, extended lead times, and restricted applications for CMCs. A breakthrough is needed to overcome the longstanding low-toughness limitation of bulk ceramics to establish a new class of damage-tolerant structural materials with an unprecedented combination of properties and manufacturability.

B. Objective/Technical Scope

The Intrinsically Tough and Affordable Ceramics Today (INTACT) program will explore new approaches to produce tough monolithic ceramic materials. In contrast to fiber reinforcement strategies employed in CMCs, INTACT is focused on atomic-scale toughening mechanisms that

afford ceramics with the ductile characteristics of metallic systems. This *intrinsic* toughening approach is distinct from the *extrinsic* strategies employed in composites, which can only achieve quasi-ductility. Recent reports have shown metal-like behavior in ceramics including, for example, extensive dislocation activity [Porz et al., Mater. Horiz. 8, 1528-1537 (2021)] and transformation-induced plasticity [Zhang et al., Science 378, 371-376 (2022)]. These intrinsic mechanisms operating at the atomic scale driving significant improvements in ductility and fracture toughness. Of particular interest for INTACT, these studies applied emerging nonequilibrium processing techniques to engineer defects (e.g., vacancies, dislocations, phase and grain boundaries) into ceramic materials to accommodate fine-scale plastic deformation. The introduction of mechanical work (akin to forging) and rapid thermal quench rates accessible via laser, electron beam, and other far-from-equilibrium processing techniques opens new possibilities to create radically new ceramic microstructures that may enable breakthroughs in bulk fracture toughness levels while maintaining an impressive balance of other properties.

In addition to structural performance, INTACT is also focused on manufacturability, with the goal of slashing lead times for critical structural hardware. Performers will be required to produce numerous physical test specimens during development and demonstrate production of a challenge part geometry in later stages of the program. Proposed processing methods must be readily scalable and capable of producing components with significantly reduced cycle time relative to existing CMC technology. Production methods resembling traditional composite manufacturing routes (i.e., multistep consolidation of distinct material forms/phases) are not in scope. INTACT is seeking novel manufacturing routes capable of producing complex ceramic shapes at scale, while simultaneously activating intrinsic toughening mechanisms. Approaches producing material with isotropic mechanical behavior are strongly desired. Proposals must specifically address how the proposed manufacturing process will instill intrinsic (*not extrinsic*) toughness in a monolithic ceramic to satisfy all program requirements.

Program metrics are outlined in the table below and include targets for flexural strength (measured at 1200°C), fracture toughness, and cycle time. This solicitation references standard ASTM tests for strength (ASTM C1211) and fracture toughness (ASTM C1421), but equivalent proposed test methods are also acceptable. Note that strength and fracture toughness testing must be performed on bulk test specimens (>1 mm dimensions) to satisfy program metrics. Nano- or micro-scale testing (including indentation, pillar compression, etc.) may be used for development purposes but are not sufficient to substantiate metrics. Cycle time is defined here to include only the primary production step(s) to achieve a near net shape part from raw feedstock material. The near net shape part must have properties meeting or exceeding strength and fracture toughness metrics. Any post-process machining that may be required to achieve final part dimensions and/or subsequent inspection steps are not included in the cycle time target. Cycle time estimates must be provided for producing both mechanical test specimens (for strength and toughness testing) and a performer-proposed challenge part as described in the next section.

Metric	Units	Phase 1	Phase 2
Flexural strength at 1200°C ^a	MPa	300	500
Fracture toughness ^b	MPa·m ^{1/2}	15	30
Cycle time ^c	hours	48	24

^a As measured by ASTM C1211 (or equivalent)

^b As measured by ASTM C1421 (or equivalent) at room temperature

^c Total time from start of production to near net shape, excluding post-process machining and inspection

In addition to the program metrics, the following requirements must also be met:

- Bulk material density $\leq 6 \text{ g/cm}^3$ with $< 1\%$ residual porosity
- Flexural modulus $> 100 \text{ GPa}$ at room temperature
- Strength and fracture toughness targets must be met both at initial production and after a $1200^\circ\text{C}/24\text{-hr}$ anneal

The bulk material density requirement ($\leq 6 \text{ g/cm}^3$) excludes some notable ultrahigh temperature ceramic (UHTC) compositions, such as HfB_2 and TaC . These and other high-density ceramic compositions are out of scope. Manufacturing approaches proposed on INTACT must also yield material that is near full density, defined here as containing $< 1\%$ residual porosity. The second requirement sets a 100 GPa lower limit on room-temperature flexural modulus. This is to ensure that materials developed on INTACT have sufficient stiffness for structural applications. Finally, the last program requirement listed above is intended to assess the stability of performer-developed materials after thermal exposure. An intrinsically ductile microstructure derived via nonequilibrium processing techniques must persist at elevated temperature and not transform to a brittle state. Performers must therefore directly test the effect of (at least) a $1200^\circ\text{C}/24\text{-hr}$ thermal exposure on properties. This exposure may be conducted in an air (preferable) vacuum, or inert gas environment.

INTACT is not constrained to any particular ceramic material composition or processing approach. However, proposed approaches relying on any of the following toughening mechanisms will be deemed out of scope:

- Architected material solutions where toughness is derived through mechanical design and/or structural geometry
- Engineered residual stress distribution (surface and/or bulk) to delay the onset of cracking
- Any other processes relying on traditional CMC toughening mechanisms that operate at characteristic length scales exceeding $1 \mu\text{m}$

Proposals must detail the ceramic material(s) and processing method(s) the team proposes to investigate to satisfy program metrics and requirements. Proposed program strategies focusing heavily on the *method* of discovery (e.g., artificial intelligence-driven autonomous research) and lacking sound theoretical materials science underpinnings will be reviewed unfavorably. Preliminary experimental results, modeling and/or simulation, or theoretical justification to support any assertions in the proposal are *strongly* encouraged. Proposals that fail to justify their claims will not be deemed selectable.

C. Structure

In Phase 1 (12-month base), performers must experimentally develop the proposed material(s) and processing approach at a coupon level and test for flexural strength and fracture toughness per program metrics. Preliminary manufacturing process plans (MPPs) and a material datasheet must also be drafted. MPPs must cover all production steps in sufficient detail to enable replication at an external facility. This includes the full sequence of operations, required machinery and tooling, input materials, process conditions, and quality control measures. The MPP must also detail any significant risks and abatement strategies in the manufacturing process.

The material datasheet must present a comprehensive overview of the material microstructure and a full suite of properties. Property measurements beyond those required per the metrics and requirements, such as thermal conductivity, electrical resistivity, chemical resistance, etc., are encouraged for completeness and potential parallel applications.

Performers that continue to Phase 2 (12-month option) must further develop and improve (as needed) their material and process to achieve Phase 2 property metrics. Proposers should note that meeting the Phase 1 metrics does not guarantee a Phase 2 award. Likewise, if a performer fails to meet the Phase 1 metrics but has a highly innovative, and potentially disruptive approach, DARPA may decide to continue those efforts into Phase 2, subject to the availability of funds. In addition to material property testing, a challenge part must also be manufactured to demonstrate process capability in Phase 2. Performers must include a challenge part geometry in their proposal. The proposed challenge part geometry must be larger than a 1x1x10 cm envelope and contain at least one feature that is difficult or impossible to realize in conventional CMC manufacturing (e.g., tight radii of curvature, thin-walled sections, and/or internal geometric features). Updated MPPs and a revised material datasheet must also be delivered in Phase 2 to facilitate potential follow-on opportunities.

Submissions in response to this DO must be unclassified and must address two independent and sequential project phases: Phase 1 (base) and Phase 2 (option). The periods of performance are 12 months for Phase 1 and 12 months for Phase 2. Combined Phase 1 and Phase 2 efforts for this DO must not exceed 24 months. Phase 1 award values must not exceed \$1,250,000, and Phase 2 awards must not exceed \$1,250,000. Both Phase 1 and Phase 2 award value limits include performer cost share, if proposed. The total award value for the combined Phase 1 and Phase 2 effort is limited to \$2,000,000. This total award value includes Government funding and performer cost share, if proposed.

D. Schedule/Milestones

Proposers must address the following fixed payable milestones in their proposals. Proposers must complete the “Schedule of Milestones and Payments” Excel Attachment provided with this DO to submit a complete proposal and fulfill the requirements under Volume 2, Price Volume. If selected for award negotiation, the fixed payable milestones provided will be directly incorporated into Attachment 3 of the OT agreement (“Schedule of Milestones and Payments”). Proposers must use the Task Description Document template provided with the Program Announcement DARPA-PA-24-04, which will be Attachment 1 of the OT agreement.

Phase 1 fixed milestones for this program must include, at a minimum, the following:

- Month 1:
 - Project kick-off meeting
 - All supporting positions and level of effort identified in the proposal are assigned to personnel
- Month 4:
 - First bulk (>1 mm) test coupon produced, and microstructure characterized
 - All personnel working on project at proposed levels of effort
- Month 6:
 - Preliminary strength and fracture toughness testing results
 - Plan to improve properties (as needed) presented
- Month 9:

- Material microstructure stability assessed through elevated temperature exposure
- Preliminary MPPs drafted for test coupons and challenge part geometry
- Month 12:
 - Strength and fracture toughness test results with repeatability assessed through ≥ 10 tests per property
 - Comprehensive material datasheet drafted
 - Phase 1 final report including MPP for Phase 2 challenge part

Phase 2 fixed milestones for this program must include, at a minimum, the following:

- Month 13:
 - Phase 2 kickoff meeting reviewing challenge part MPP and approach to improve material properties (as needed)
- Month 17:
 - Material property stability assessed through elevated temperature exposure including strength and fracture toughness testing results after 1200°C/24-hr exposure
- Month 20:
 - Sensitivity study conducted to establish manufacturing process window
 - Expanded mechanical property testing (including additional properties of interest)
- Month 23:
 - Challenge part manufacturing demonstration
- Month 24:
 - Final project report (covering Phase 1 and 2) complete, including comprehensive documentation of manufacturing process, material properties, and potential directions for follow-on research and development
 - Path for industry adoption presented, including cost analysis and environmental considerations

For planning and budgetary purposes, proposers should assume a program start date of May 12, 2025. Schedules will be synchronized across performers, as required, and monitored/revised as necessary throughout the program's period of performance.

All proposals must include the following meetings and travel in the proposed schedule and costs:

- A one-day project kickoff meeting to be held in Arlington, VA, during month 1.
- A one-day Phase 2 kickoff meeting to be held in Arlington, VA, during month 13.
- To foster collaboration between teams and disseminate program developments, a one-day virtual Principal Investigator (PI) meeting will be held approximately midway through Phase 1 and Phase 2.
- Monthly teleconference meetings will be scheduled with the Government team for progress reporting and problem identification and mitigation. Proposers should also anticipate at least one site visit per phase by the DARPA Program Manager and Government team to demonstrate progress towards agreed-upon milestones.

E. Deliverables

Performers will be expected to provide, at a minimum, the following deliverables:

- Monthly presentation slides highlighting progress, challenges, and future direction

- Comprehensive, stand-alone written reports for Months 4, 6, 9, and 17 project milestones
- Draft (Month 9) and final (Month 23) MPPs
- A draft (Month 12) and final (Month 20) material datasheet
- Comprehensive manufacturing demonstration report at Month 23
- Phase 1 completion (Month 12) and project completion (Month 24) reports

II. Award Information

Selected proposals that are successfully negotiated will result in the award of an OT for Prototype project. See Section 4 of DARPA-PA-24-04 for information on awards that may result from proposals submitted in response to this announcement.

Proposers must review the model OT for Prototype agreement provided as an attachment to DARPA-PA-24-04 prior to submitting a proposal. DARPA has provided the model OT to expedite the negotiation and award process and ensure DARPA achieves the goal of Disruptioneering, which is to enable DARPA to initiate a new investment in less than 120 calendar days from idea inception. The model OT is representative of the terms and conditions that DARPA intends to include in all DO awards. The task description document, schedule of milestones and payments, and data rights assertions requested under Volumes 1, 2, and 3 will be included as attachments to the OT agreement upon negotiation and award.

Proposers may suggest edits to the model OT for consideration by DARPA and provide a copy of the model OT with track changes as part of their proposal package. DARPA may not accept suggested edits. The Government reserves the right to remove a proposal from award consideration should the parties fail to reach an agreement on OT award terms and conditions. If edits to the model OT are not provided as part of the proposal package, DARPA assumes that the proposer has reviewed and accepted the award terms and conditions to which they may have to adhere and the model OT agreement provided as an attachment, indicating agreement (in principle) with the listed terms and conditions applicable to the specific award instrument.

To ensure that DARPA achieves the goal of an award within 118 calendar days from the posting date (January 15, 2025) of this announcement, DARPA reserves the right to cease negotiations when an award is not executed by both parties (DARPA and the selected organization) on or before May 12, 2025.

III. Eligibility

See Section 7 of DARPA-PA-24-04 for information on who may be eligible to respond to this announcement.

IV. Disruption Opportunity Responses

A. Proposal Content and Format

All proposals submitted in response to this announcement must comply with the content and format instructions in Section 5 of DARPA-PA-24-04. All proposals must use the templates provided as Attachments to DARPA-PA-24-04, except for Volume 1: Technical & Management template. Proposers must use the version of Volume 1 provided with this DO in place of the version included in DARPA-PA-24-04. Additionally, proposers must use the “Schedule of Milestones and Payments” Excel Attachment provided with this DO. Proposers must follow the instructions included in each template.

Information not explicitly requested in DARPA-PA-24-04, its Attachments, or this announcement may not be evaluated.

DARPA is currently interested in whether, and to what extent, proposers are using artificial intelligence (AI) tools during proposal generation. Proposers must answer the following questions on the cover sheet of “Volume 1: Technical & Management template (INTACT)”¹:

- 1) Did you use AI tools to assist in preparing this proposal?
- 2) If yes, what tools did you employ?

Any content in Volume 1 – Technical and Management that utilized an AI tool to generate information, assist in technical understanding, or guide the technical work should have a citation and a corresponding reference in the Bibliography section of Volume 1. The citation should specify the tool, content, and purpose. For example, “[AI tool] was used to understand existing state-of-the-art in manufacturing.” NOTE – THIS INFORMATION WILL NOT BE USED FOR EVALUATION PURPOSES. Proposals will be evaluated in accordance with the Evaluation Criteria outlined in the Disruptioneering Program Announcement (DARPA-PA-24-04) regardless of whether AI tools were employed. The Government is collecting data only to understand the implementation of AI tools in proposal production.

B. Submission Instructions

Responses to DARPA-PA-24-04-06 shall be submitted electronically to DARPA’s Broad Agency Announcement (BAA) Portal (<https://baa.darpa.mil>).

DARPA will acknowledge receipt of complete submissions via email and assign identifying numbers that should be used in all further correspondence regarding those submissions. If no confirmation is received within two (2) business days, please contact INTACT@darpa.mil to verify receipt.

When planning a response to this DO, proposers should consider the submission time zone and that some parts of the submission process may take from one (1) business day to one month to complete (e.g., registering for a SAM Unique Entity ID (UEI) number or Tax Identification Number (TIN)).

Electronic Upload

First-time users of the DARPA BAA Portal must complete a two-step account creation process. The first step consists of registering for an extranet account by going to the URL above and selecting the “Account Request” link. Upon completion of the online form, proposers will receive two separate emails; one will contain a username, and the second will provide a temporary password. Once both emails have been received, the second step requires proposers to go back to the submission website and log in using that username and password. After accessing the extranet, proposers may then create a user account for the DARPA Submission website by selecting the “Register your Organization” link at the top of the page. Once the user account is created, proposers will be able to see a list of solicitations open for submissions, view submission instructions, and upload/finalize their submission.

¹ INTACT proposers should use the PROPOSAL TEMPLATE – VOLUME 1: TECHNICAL & MANAGEMENT (INTACT) attached to this DO instead of the PROPOSAL TEMPLATE – VOLUME 1: TECHNICAL & MANAGEMENT provided in the Disruptioneering PA.

Proposers who already have an account on the DARPA BAA Portal may log in at <https://baa.darpa.mil>, select this solicitation from the list of open DARPA solicitations and proceed with their submission. Note: proposers who have created a DARPA Submission website account to submit to another DARPA Technical Office's solicitations do not need to create a new account to submit to this solicitation.

All submissions provided electronically through the DARPA Submission website must meet the following requirements: (1) uploaded as a zip file (.zip or .zipx extension); (2) only contain the document(s) requested herein; (3) only contain unclassified information; and (4) must not exceed 100 MB in size. Only one zip file will be accepted per full submission. The DARPA Submission website will reject submissions not uploaded as zip files. Technical support for the DARPA Submission website is available during regular business hours, Monday – Friday, 9:00 a.m. – 5:00 p.m. Requests for technical support must be emailed to BAAT_Support@darpa.mil with a copy to INTACT@darpa.mil. Questions regarding submission contents, format, deadlines, etc., should be emailed to INTACT@darpa.mil. Questions/requests for support sent to any other email address may result in delayed/no response.

Since proposers may encounter heavy traffic on the web server, DARPA discourages waiting until the day submissions are due to request an account and/or upload the submission. Note: Proposers submitting via the DARPA Submission site MUST (1) click the “Finalize” button for the submission to upload AND (2) do so with sufficient time for the upload to complete prior to the deadline. Failure to do so will result in a late submission.

C. Proposal Due Date and Time

Proposals in response to this announcement are due no later than 4:00 p.m. on March 14, 2025. As described in Section 5 of DARPA-PA-24-04, full proposal packages must be submitted per the instructions outlined in this DO *and received by DARPA* no later than the above time and date. Proposals received after this time and date may not be reviewed.

Proposers are warned that the proposal deadline outlined herein is in Eastern Time and will be strictly enforced. When planning a response to this announcement, proposers should consider that some parts of the submission process may take from one (1) business day to one (1) month to complete.

V. Proposal Evaluation and Selection

Proposals will be evaluated and selected in accordance with Section 6 of DARPA-PA-24-04. Proposers will be notified of the results of this process as described in Section 8.1 of DARPA-PA-24-04.

VI. Administrative and National Policy Requirements

Section 8.2 of DARPA-PA-24-04 provides information on Administrative and National Policy Requirements that may be applicable for proposal submission and performance under an award.

VII. Point of Contact Information

Andrew Detor, Program Manager, DARPA/DSO, INTACT@darpa.mil

VIII. Frequently Asked Questions (FAQs)

All technical, contractual, and administrative questions regarding this announcement must be emailed to INTACT@darpa.mil. Emails sent directly to the Program Manager, or any other

address will not be returned.

All questions must be in English and must include the name, email address, and telephone number of a point of contact. DARPA will attempt to answer questions publicly in a timely manner; however, questions submitted within seven (7) calendar days of the proposal due date listed herein may not be answered.

DARPA will post an FAQ on the INTACT program page on the DARPA website. The list will be updated on an ongoing basis until one (1) week before the proposal due date.

For those new to DARPA or national security, DARPA makes available a free, comprehensive resource via DARPACONnect on how to do business with the agency. In addition to DARPA 101 materials, relevant preparatory modules include “Understanding DARPA Broad Agency Announcements.” Registration and access are free at www.darpaconnect.us.