SSC Project Recommendation for FY 2022

Innovative and Adaptable Metrology, NDT, and Process Monitoring for Metal Additive Manufacturing Parts in Ship Structures

1.0 OBJECTIVE.

1.1 Experimental and technical study to evaluate the metrology needs for metal additive manufacturing (AM) parts in ship structures for mechanical properties, nondestructive testing techniques (NDT) and corrosion measurements.

1.2 Identify and evaluate the innovative and adaptable in-situ monitoring and NDT techniques for AM parts in ship structures for mechanical properties and corrosion measurements.

1.3 Experimental study of in-situ monitoring and NDT techniques identified in 1.2 to provide an applicable guidelines and procedures.

1.4 Assessment of innovative and adaptable process in-situ monitoring and NDT procedures for metal AM for manufacturing quality assessment.

2.0 BACKGROUND.

2.1 Background: Additive manufacturing (AM) is making a big leap in the manufacturing technology world primarily due to its unique capability to produce parts in a layer-by-layer fashion from the digital 3D models with immense versatility in terms of design complexity. The shipbuilding supply chain stands to benefit tremendously from integrating AM solutions into their operations. The benefits of AM such as part optimization, weight reduction, and ease of prototyping are the factors accelerating the popularity of AM in shipbuilding industry [1]. Complex structures and metal components can be 'printed' faster and in an efficient manner. Instead of cutting and welding various alloys, spare parts and elements are produced layer-by-layer with the precise requirements. While not all of the sea-worthy components of naval vessels can be produced using AM methods at this moment, their maintenance and repair works are being disrupted by this technology, making the whole process more automated and cost-effective. Though on-site AM solutions are prominent in shipbuilding, numerous initiatives and projects are propelling the industry towards the implementation of on-board 3D printers that make sailing safer, more reliable and self-sufficient, especially in emergency cases where repairs are needed while at sea. Metrology and Nondestructive Testing (NDT) of AM components have been identified to be one of the major bottlenecks of AM technology expansion in many fields [2] specifically for on-board applications as mentioned. This is important for ensuring the acceptable structural integrity and materials properties based on the standards and criteria in different industries. In ship building, ensuring the adequate quality and structural integrity is even more crucial. Many organizations are currently investing in metrology and NDT needs for AM. As an example, navy and marine applications, NSWC Corona, the leading agency for the U.S. Navy's Metrology and Calibration (METCAL) program, is playing an important role towards addressing these AM metrology challenges [3].

2.2 Justification of project: Despite these technological advantages, AM is not making inroads to its potential, mainly due to a lack of fundamental understanding of all the AM processes and cohesive efforts in standardization, metrology (the science of measurement), qualification and certification. As a result, AM produces parts with higher complexity and features yet lacking dimensional accuracy, precision, the required level of tolerances and intended material properties. Particularly, the process-specific standardized metrology and inspection methods for the parts made by AM play a major role in imparting the desired quality and subsequently facilitate the process of certification of the AM part [4], [5]. This is particularly important in ship structures and ship building materials considering the complexity of the structures, environmental conditions and level of safety and reliability needs in ship building industries. There are several challenges that must be overcome while considering the use of NDE-type systems for these kinds of applications in AM. The extremely localized, very rapid melting and cooling of the powders, using high-power energy sources such as lasers and electron-beams, make high-fidelity detection difficult. Materials characterization of AM parts is challenged by machine variability, both machine-to-machine as well as day-to-day on any given machine. This variability can lead to inconsistent mechanical properties. In addition, the large number of process variables can make materials pedigree difficult to ascertain, making the inter-comparisons necessary for material qualification difficult. Traditional nondestructive inspections are performed much the same for additive parts, but there are some new limitations introduced by the AM methods which implies the crucial need for new, innovative, accurate and adaptable NDT and metrology for AM parts [6]–[8]. The maritime industry has a long-standing tradition and is based on old, reliable techniques; therefore, it implements new solutions very carefully. Besides, shipbuilding has to face very high classification requirements that force the use of technologies that guarantee repeatability and high quality. This project aims to study the innovative, reliable and adaptable quality measurement and inspection in the field of implementing AM in shipbuilding, possible benefits, opportunities and threats of implementation. Multi-disciplinary approaches that include expertise from both the AM and NDE communities which exist in proposal team could lead to solutions for the challenges identified above, which in turn would lead to a wider adoption of AM technologies [9].

3.0 **REQUIREMENTS.**

3.1 Scope:

3.1.1 The Contractor shall identify and design of AM samples for high throughput mechanical testing

3.1.2 The Contractor shall manufacture of samples using Powder Bed Fusion (PBF) and Wire-Arc Additive Manufacturing (WAAM) methods

3.1.3 The Contractor shall perform in-situ condition monitoring of the manufacturing processes

3.1.4 The Contractor shall perform NDT adaptable to the sample's properties

3.1.5 The Contractor shall perform high throughput mechanical testing and metrology

3.1.6 The Contractor shall provide guidelines and recommendations for adaptable practice of metrology, NDT and in-situ monitoring for ship building applications

3.1.7 The Contractor shall prepare reports and publications of the results and outcomes of the project

3.2 Tasks. (Identify the tasks to carry out the scope of the project).

3.2.1 The Contractor shall design AM samples appropriate for ship building applications for testing

3.2.2 The Contractor shall manufacture AM samples from stainless-steel powders using PBF-AM method, and stainless-steel wires for WAAM methods. Two types of wires will be used in WAAM manufacturing: a fully dense wire, and a wire containing powders.

3.2.3 The contractor shall perform in-situ monitoring of WAAM processes using acoustic technique (acoustic emission) for process quality monitoring.

3.2.4 The contractor shall conduct metrology measurement on as-built samples including surface roughness, dimensions, metallography, microstructure (SEM, AFM)

3.2.5 The contractor shall plan and conduct corrosion simulation experiments using accelerated corrosion simulator chamber

3.2.6 The contractor shall perform corrosion assessment and measurement using NDT and microscopy techniques

3.2.7 The contractor shall establish procedure and conduct Eddy Current Array (ECA) defect and corrosion mapping and measurement NDT tests on the samples

3.2.8 The contractor shall establish and conduct Phased Array Ultrasonic Testing (PAUT) with advanced features of Full Matrix Capturing (FMC) and Total Focusing Method (TFM) for defect and corrosion mapping and measurement NDT on the samples

3.2.9 The contractor shall analyze the in-situ, NDT and metrology measurement results and prepare guidelines, recommendations and reports for the client

3.3 Project Timeline. See Enclosure (*A*).

4.0 <u>GOVERNMENT FURNISHED INFORMATION</u>.

4.1 The contractor shall follow Standards for the Preparation and Publication of SSC Technical Reports.

5.0 <u>DELIVERY REQUIREMENTS</u>.

5.1 The Contractor shall provide quarterly progress reports to the Project Technical Committee, the Ship Structure Committee Executive Director, and the Contract Specialist.

5.2 The Contractor shall provide guidelines, recommendations and presentations to the Project Technical Committee, the Ship Structure Committee Executive Director, and the Contract Specialist based on the project results.

5.3 The Contractor shall provide a print ready master final report and an electronic copy, including the above deliverables, formatted as per the SSC Report Style Manual.

6.0 <u>PERIOD OF PERFORMANCE</u>.

6.1 Project Initiation Date: 08/01/2022.

6.2 Project Completion Date: *18* months from the date of award.

7.0 <u>GOVERNMENT ESTIMATE</u>. These contractor direct costs are based on previous project participation expenses.

7.1 Project Duration: *18* months.

7.2 Total Estimate: $96,669

7.3 The Independent Government Cost Estimate is attached as enclosure (*B*).

8.0 <u>REFERENCES</u>.

8.1 References:

[1] M. Ziółkowski and T. Dyl, "Possible applications of additive manufacturing technologies in shipbuilding: A review," *Machines*, vol. 8, no. 4, pp. 1–34, 2020, doi: 10.3390/machines8040084.

[2] M. S. Hossain, H. Taheri, N. Pudasaini, A. Reichenbach, and B. Silwal, "Ultrasonic Nondestructive Testing for In-Line Monitoring of Wire-Arc Additive Manufacturing (WAAM)," in *ASME 2020 International Mechanical Engineering Congress and Exposition*, Nov. 2020, p. V02BT02A037; 6 pages, doi:

10.1115/IMECE2020-23317.
[3] H. D. Vora and S. Sanyal, "A comprehensive review: metrology in additive manufacturing and 3D printing technology," *Prog. Addit. Manuf.*, vol. 5, no. 4, pp. 319–353, 2020, doi: 10.1007/s40964-020-00142-6.
[4] M. S. Hossain and H. Taheri, "In Situ Process Monitoring for Additive Manufacturing Through Acoustic Techniques," *J. Mater. Eng. Perform.*, pp. 6249–6262, 2020, doi: 10.1007/s11665-020-05125-w.
[5] H. Taheri, L. W. Koester, T. A. Bigelow, E. J. Faierson, and L. J. Bond, "In-situ Process Monitoring of Additive Manufacturing using Clustering of Spectral Features for Acoustic Signals," *J. Manuf. Sci. Eng.*, vol. 141, no. 4, p. 041011 (10 pages), 2019, doi: 10.1115/1.4042786.
[6] L. Koester, H. Taheri, L. J. Bond, D. Barnard, and J. Gray, "Additive manufacturing metrology: State of the art and needs assessment," in *AIP Conf. Proc. 1706*, 2016, p. 130001, doi: 10.1063/1.4940604.
[7] L. W. Koester, H. Taheri, T. A. Bigelow, P. C. Collins, and L. J. Bond, "Nondestructive testing for metal parts fabricated using powder-based additive manufacturing," *Mater. Eval.*, vol. 76, no. 4, pp. 514–524, 2018.
[8] L. J. Bond, L. W. Koester, and H. Taheri, "NDE in-process for metal parts fabricated using powder based additive manufacturing," in *Proc.SPIE*, Mar. 2019, vol. 10973, p. 1097302, doi: 10.1117/12.2520611.
[9] J. A. Slotwinski, "Additive manufacturing: Overview and NDE challenges," *AIP Conf. Proc.*, vol. 1581 33, no. 2014, pp. 1173–1177, 2014, doi: 10.1063/1.4864953.

9.0 <u>SUGGESTED CONTRACTING STRATEGY</u>.

9.1 Contracting strategy.

Enclosure (A): Project Timeline

Task		Month																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Design AM samples appropriate for ship building applications for testing																		
2	Manufacture AM samples from stainless-steel powders using PBF-AM method, and stainless-steel wires for WAAM methods. Two types of wires will be used in WAAM manufacturing: a fully dense wire, and a wire containing powders																		
3	Perform in-situ monitoring of WAAM processes using acoustic technique (acoustic emission) for process quality monitoring																		
4	Conduct metrology measurement on as-built samples including surface roughness, dimensions, metallography, microstructure (SEM, AFM)																		
5	Plan and conduct corrosion simulation experiments using accelerated corrosion simulator chamber																		
6	Perform corrosion assessment and measurement using NDT and microscopy techniques																		
7	Establish procedure and conduct Eddy Current Array (ECA) defect and corrosion mapping and measurement NDT tests on the samples																		
8	Establish and conduct Phased Array Ultrasonic Testing (PAUT) with advanced features of Full Matrix Capturing (FMC) and Total Focusing Method (TFM) for defect and corrosion mapping and measurement NDT on the samples																		
9	Analyze the in-situ, NDT and metrology measurement results and prepare guidelines, recommendations and reports for the client			Q1			Q2			Q3			Q4			Q5			Q6-F
	Months	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

Enclosure (B): Cost Estimate

Budget Summary	Rate	# of Months/Wks	# of Semesters or Hours and # of Students		P1 (08/01/2022–07/31/2023)	P2 (08/01/2023–01/31/2024)	Totals
Personnel							
A: Senior Personnel							
PI: Faculty Hossein Taheri (Summer) —3.00% in year 2	$9,501	0.25			$2,375.33	$2,447	$4,822
Co-PI: Faculty Bishal Silwal (Summer) —3.00% in year 2	$9,758	0.25			$2,439.51	$2,513	$4,952
B: Other Personnel			**#Semest**	**#Students**			
Graduate Student **—# of students and # of semesters shown for each period.-Fall & Spring Semesters**	$5,000		2	1	$10,000	$5,000	$15,000
Graduate Student **—# of students and # of semesters shown for each period.-Summer Semester**	$3,875		1	1	$3,875	$0	$3,875
Master level hourly Student (summer)	$12	8	25	0	$0	$0	$0
Undergraduate Student (Calendar)	$10	15	15	0	$0	$0	$0
C: Fringe							
Faculty Hossein Taheri (Summer)—29.54%		0.2954			$701.67	$722.72	$1,424
Faculty Bishal Silwal (Summer)—29.54%		0.2954			$720.63	$742.25	$1,463
Graduate Student(s) **—7.65%**		0.0765			$1,061.44	$382.50	$1,444
Master level hourly Student (summer) —7.65%		0.0765			$0	$0	$0
Undergraduate Student(s) —**7.65%**		0.0765			$0	$0	$0
Personnel Subtotal					$21,174	$11,807	$32,980
Non-personnel							
D: Equipment							
#1 ITEM —**above $5,000**					$0	$0	$0
#2 ITEM —**above $5,000**					$0	$0	$0
Line D: Equipment Subtotal—above $5,000—NO F&A					$0	$0	$0
E: Travel							
1. Travel (Domestic)—**3.00% escalation in year 2**		1.03			$2,500	$0	$2,500
2. Travel (International): **3.00% escalation in year 2**		1.03			$0	$0	$0
Line E: Travel Subtotal					$2,500	$0	$2,500
F: Participant Support					$0	$0	$0
1. Stipends					$0	$0	$0
2. Travel					$0	$0	$0
3. Subsistence							
4. Other (Seminar Award)					$0	$0	$0
Line F: Participant Support Subtotal—NO F&A					$0	$0	$0
G: Other Direct Costs	**Rate**	**Rate: Escalator**	**Semesters**	**# Student(s)**			
1. Materials and Supplies					$20,000	$0	$20,000
2. Publication (Professional Editor,Publication Fee)					$0	$2,500	$2,500
3. Other: Service fees					$0	$0	$0
4. Other: Graduate Student(s)' Tuition**—5.00% escalation fee in year 2**	$2,493	1.05	3	1	$7,479	$2,617.65	$10,096.65
Line G: Other Direct Costs Subtotal					$27,479	$5,118	$32,597
Non-Personnel Direct Subtotal					$29,979	$5,118	$35,097
Totals							
Line H: Total Direct Cost					**$51,153**	**$16,924**	**$68,077**
Line I: Total F&A Costs—42%					**$21,484**	**$7,108**	**$28,592**
Line J: Total Direct and Indirect Costs					**$72,637**	**$24,032**	**$96,669**