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Manufacturing Techniques and Process Challenges with CG-47 Class Ship Aluminum Superstructure Modernization and Repairs

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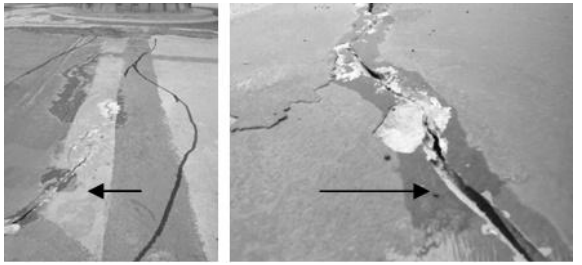
Modernization of CG-47 Class

- Current program to make design changes to reduce fatigue cracking in several areas
- Additional cracking due to Stress Corrosion has been identified
  - Aluminum alloy has become “sensitized” to stress corrosion in some areas
- Repair requirements for sensitized material
  - More stringent welding and inspection procedures
- Methodology for repair and modernization
  - Crack repair
  - Plate replacement
  - Modular replacement
- Manufacturing challenges
  - Dimensional tolerances
  - Non-destructive testing
  - Base metal restoration
- Future efforts



Superstructure Weather Deck Crack

Structural Ship Alteration

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CG-47 Ticonderoga Class Aegis Cruiser

- Hull number 47 through 73
- Produced from 1978-1994
  - Expected service life 40 years
  - Approximately 364 officers and enlisted crew
  - 567 feet long
- Steel hull, superstructure is aluminum to reduce topside weight
- Anti-Air, Anti-Submarine, Anti- Surface, and Strike warfare
- AEGIS system is the SPY-1A radar, which automatically detects and tracks air contacts to beyond 200 miles
  - Theater Ballistic Missile Defense capability demonstrated
- Vertical Launch system
- 5 inch guns

"Most powerful surface combatants in service with any Navy"

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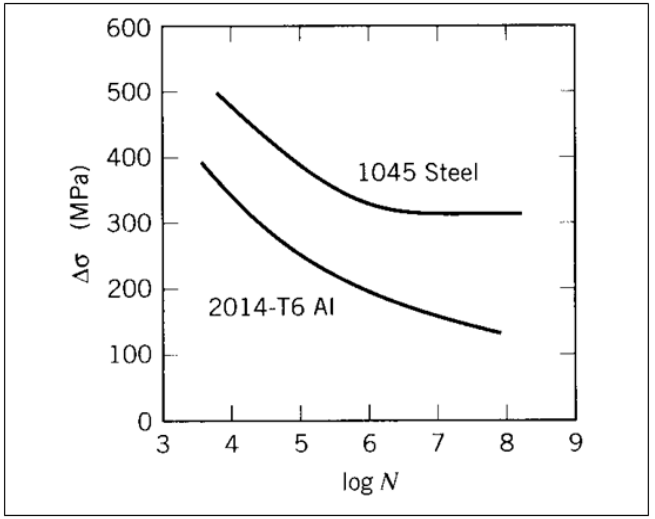
Fatigue Cracking

- Understood phenomenon with metals – cyclic stress application, of sufficient stress magnitude and number of cycles will result in fatigue cracking
- This is particularly prevalent with aluminum which does not have a defined fatigue limit.
- Further complications with fatigue
  - Stress concentrations due to design
  - Stress concentrations due to weld bead geometry
  - Welding process induced residual stresses
- Fatigue occurs in two steps
  - Crack initiation
  - Crack propagation

Not surprising fatigue cracks appear after some time duration



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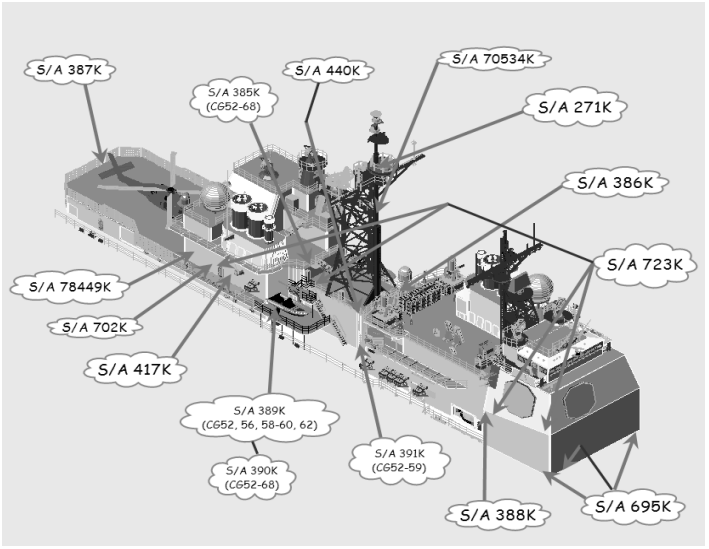
Superstructure Modernization

- Planned or in-progress alterations
  - Designing to meet modern sea service requirements
  - Assessing structural integrity after 17-25 years
  - Assessing building material degradation
  - Increasing ship capabilities and/or performance
  - Implement alterations during maintenance availabilities through the CG-47 class
  - Over 17 structural ship alterations planned or completed

CG 65: USS Chosin



Superstructure Designed Structural Ship Alterations

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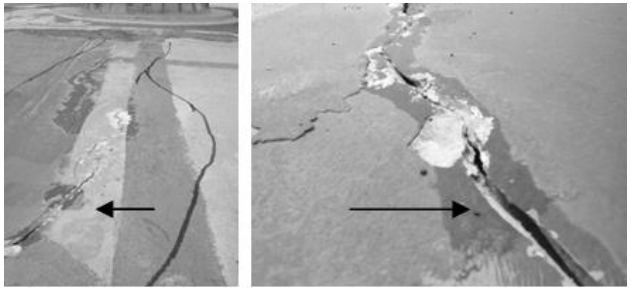
New Cracks in Superstructures Observed

- Unusual cracks, of significant length began to appear 5 years ago
- Did not correlate with the usual stress concentrations
- Navy investigations revealed cracks caused by Stress Corrosion Cracking
  - Superstructure weather deck
  - Internal structure plates in gas turbine intakes
  - Transverse bulkheads
- All cracks located in 5456-H116 material
  - CG-47 class ship superstructure primarily 5456-H116



Superstructure Weather Deck Crack

Internal Structure Gas Turbine Air Intake

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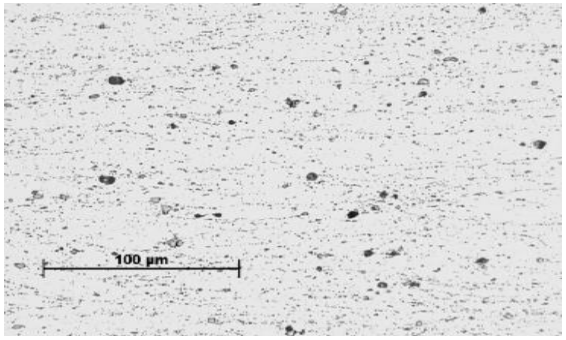
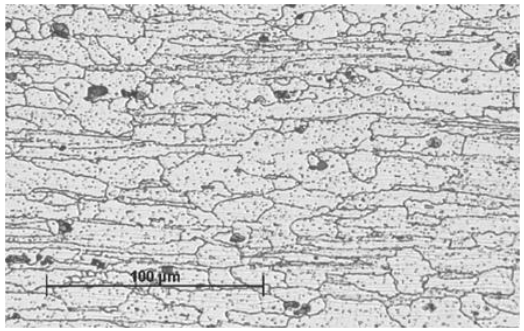
Stress Corrosion Cracking

- SCC requires 3 conditions:
  1. Susceptible Material
     - Although 5XXX alloys are fairly immune to corrosion, microstructural changes can impact corrosion performance
  2. Tensile loading (sustained, not cyclic)
     - Resulting from weld residual stress
  3. Corrosive environment
     - Sea water exposure is sufficient

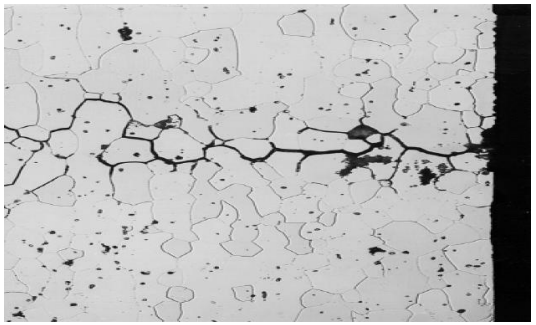
- 5456-H116 materials were found to be “sensitized”
  - 5456-H116 contains 4.5 to 5.7% magnesium (strengthening alloy element)
  - Magnesium is very soluble in aluminum at high temperatures
  - At temperatures above 150ºF Mg2Al3 migrates and to grain boundaries creating a sensitized aluminum microstructure susceptible to SCC
- Exposure to elevated temperatures – e.g., solar loading suspected
- Rolling into plate process must be controlled to avoid sensitizing material
  - H116 temper for this purpose, stabilization
  - New requirement for H116 temper to test for intergranular corrosion (since 2004)



5456-H116 Normal Microstructure with Uniform Distribution of the Magnesium Compounds, Mg_2Al_3



Sensitized 5456-H116 Microstructure with Mg_2Al_3 precipitation preferentially at the grain boundaries.



Intergranular Stress Corrosion Cracking in 5456-H116

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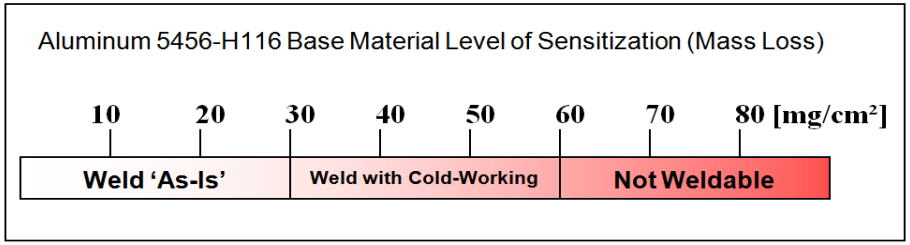
How to repair SCC cracks

- Identification of sensitized material
  - Take samples for ASTM G67 Intergranular corrosion test (destructive)
    - Leaves holes in ship structure if test is negative
  - Weldability test – run bead, examine for cracks
  - Degree of Sensitization Probe (non-destructive)
    - Still under development (Navy funded project)
  - *In situ* metallography (non destructive)
    - Need comparison standards

Portable Metallography Kit

- Range of Sensitization measured by Mass Loss Intergranular corrosion test
  - 0 to 30 [mg/cm^2] mass-loss, weld base material 'as-is'
  - 31 to 59 [mg/cm^2] mass-loss, weld with base material cold-working stress-relief (impact/peening)
  - 60 and greater [mg/cm^2] mass-loss, not weldable



- Use low stress weld repair methods
  - Low heat input pulse gas metal arc welding
  - Develop residual compressive stress by ultrasonic impact treatment – before and after welding
  - Manual weld contour grinding
- Use ASTM B928 certified repair materials (intergranular and exfoliation corrosion tested)

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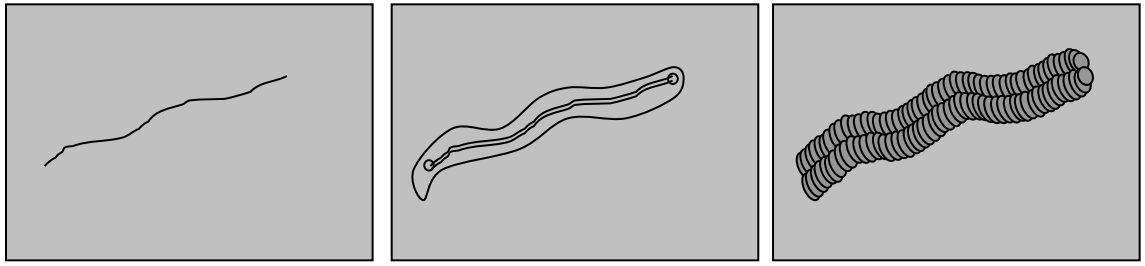
Repair And Modernization Methodology

Localized Welding of Cracks

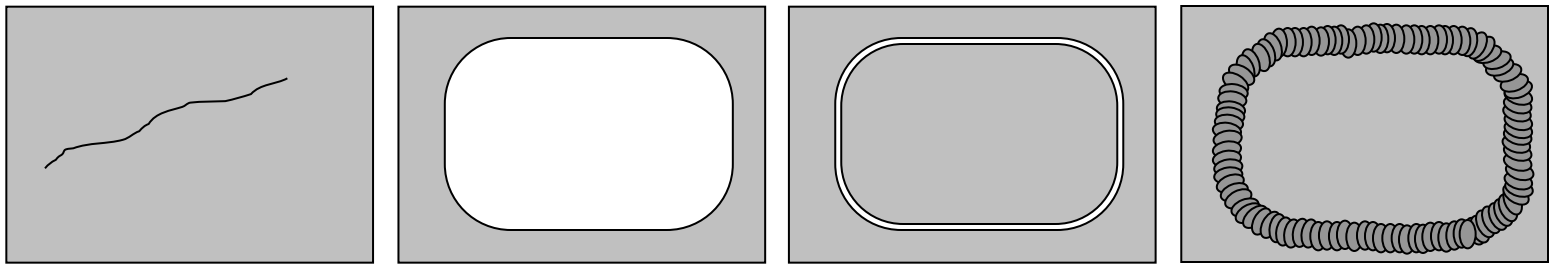
- The extent of a crack region is identified by finding the crack-tip boundaries and mechanically excavating the region, then weld repair with a full-penetration weld joint design.



Identified Crack | Mechanically Excavate V-Groove Joint | Full Penetration Weld

Small to Large Insert Plate Removal of Cracked Base Material

- If crack repairs are within regions of sensitized aluminum alloy base material then larger insert plate removal to replace and renew the base material is required.



Identified Crack | Remove Crack with a Plate Cut-Out | Ship-Fit an Insert Renewal Plate | Weld Insert Plate, Full Penetration

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Modular Modernization Structural Replacement

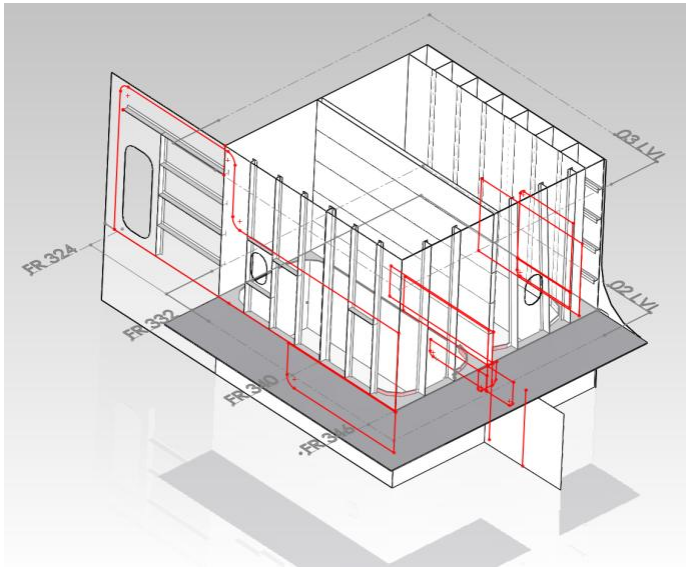
Practical to replace large areas where multiple repairs or alterations are planned
Maximize shore side work to assure sections are fabricated under ‘shop’ vs field conditions

Designed Structural Ship Alterations

- Over 17 structural ship alterations planned or completed
- Aluminum alloy sensitization expands the work scope on some alterations due to ship specific conditions

Structural Repairs Lead to Aluminum Alloy Plate Renewal

- Sensitized aluminum alloy would be removed if time and cost permits, opportunity to replace aluminum with new material



Structural Ship Alteration Designed to Strengthen a Deck to Bulkhead Transition for a Gas Turbine Air Intake

Structural Ship Alteration Expanded for the Gas Turbine Air Intake on Specific CG-47 Ships to Renew Adjacent Aluminum Alloy Plate

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Manufacturing Process Challenges

Degraded aluminum alloy base material

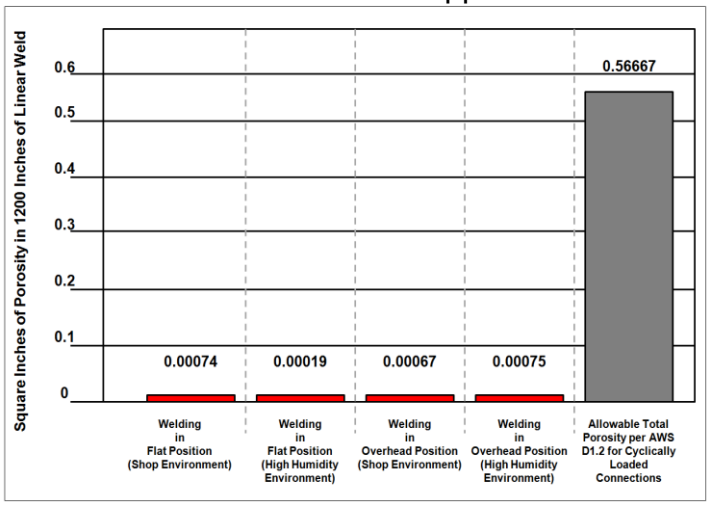
- Pits and surface corrosion traps contaminates which creates weld porosity
- Also cause “false positive” indications during dye penetrant testing
- Increased porosity as found by radiographic inspection

Pulse Transfer, Gas-Metal-Arc-Welding [GMAW-P]

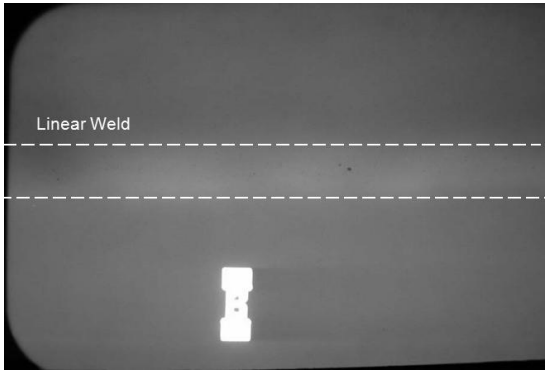
- Welding Process Specification (WPS) and Procedure Qualification Report (PQR)
- Fabrication process step qualification based on environment influence

Assessing Base Material Influence on Qualified Welding Practices

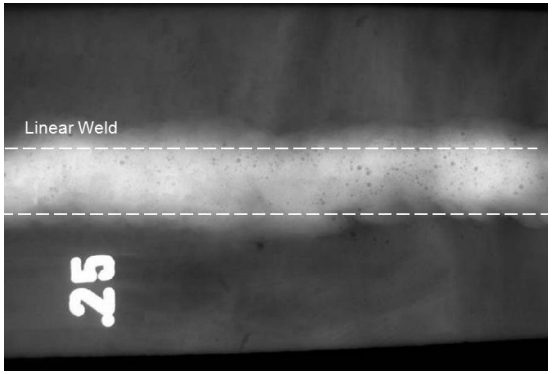
- GMAW-P applications on new procured 5456-H116 aluminum alloy plate
- GMAW-P applications on old marine service 5456-H116 aluminum alloy plate



WPS/PQR Fabrication Process Assessment for Porosity Development with Overhead/Flat Welding Positions in Shop and High Humidity Environments for Semi-Automated GMAW-P



Radiograph of New Aluminum Alloy Base Material [5456-H116] Utilizing WPS/PQR for Semi-Automated GMAW-P



Radiograph of Sensitized Aluminum Alloy Base Material [5456-H116] Utilizing WPS/PQR for Semi-Automated GMAW-P

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Enhanced Non-destructive Testing for Welds on Sensitized Material

Sensitized or partially sensitized 5456-H116 base material

Weld contour grinding, manual labor intensive process

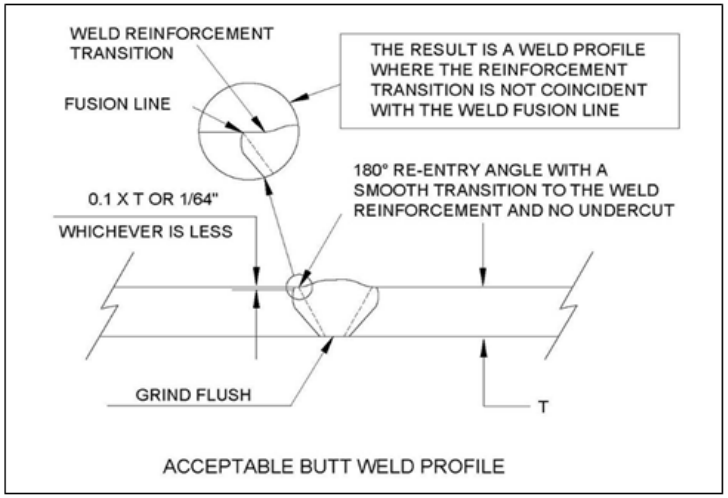
Dye Penetrant Testing Technique on Sensitized Aluminum Alloy

Required NDT process for 5456-H116 welded structures:

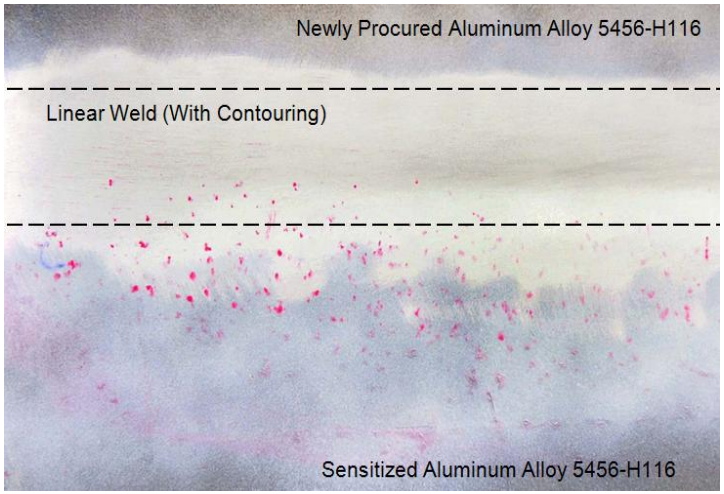
- Difficulty with interpretation and evaluation of relevant and non-relevant indications at stated acceptance limits
- Grinding surface of interest, weld reinforcement contouring, adds to instability with repeated PT inspections

Numerous non-relevant indications evaluation has been displayed on sensitized aluminum alloy base material during dye penetrant testing.

Weld Solidification Ripples Providing a Known Process Variable for PT Interpretation with Indication Relevancy



Required Weld Reinforcement Grinding on a PT Inspection Surface for all CG-47 Class 5XXX Series Aluminum Weldments



Liquid Dye Penetrant Testing on Aluminum Alloy Weldment with Sensitized Base Material and New Base Material.

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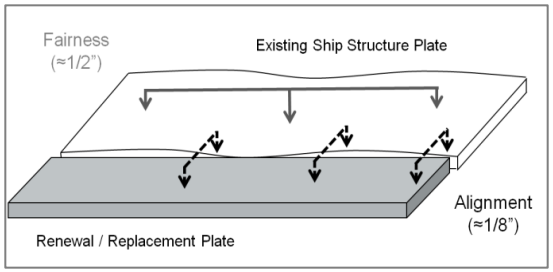
Maintaining Ship Structural Dimensional Tolerances for Modular Alterations

- Accommodation of Structural Tolerances for Structural Ship Alterations
  - **As designed**
  - **As built**
  - **After modifications during service**
  - **Actual dimensions after sea service deformation**

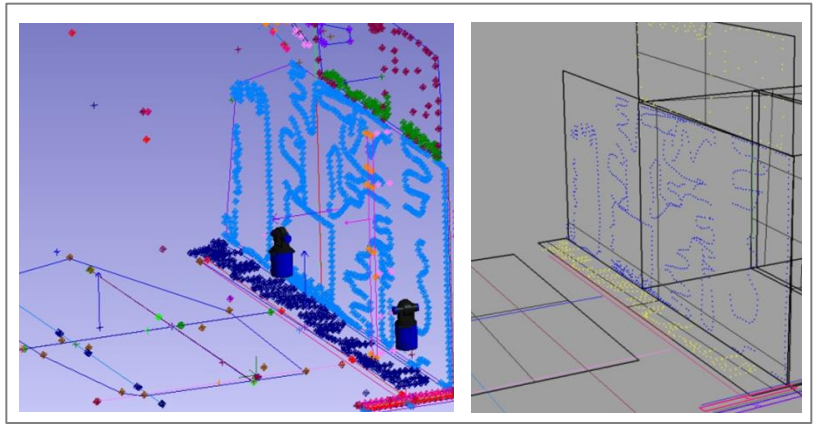
  - Simply fabricating modules to meet the original design drawings, will not work. The boundaries of the modules must meet design dimensions, BUT within weld joint fit-up tolerances to the remaining structure for alignment, fairness, and bulkhead opposition as defined in new shipbuilding practices.

- Measuring Existing Ship Superstructure
  - Portable three dimensional laser tracker to capture 'actual' dimensions
  - Capture surface features and develop a computer model for 'best-fit' repair alteration structural ship-fitting



Structural Ship Building Tolerances with Two Different Orientations of Measurement

Ship Superstructure Plate Deflection Between Structural Members



Field Measurement with Portable Laser Tracker (Left) and Create 'Best-Fit' Models for Structural Ship-Fitting with Alterations (Right)

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Conclusions

Challenges that have been encountered recently during the maintenance, repair and modernization of CG-47 class cruiser superstructures.

- The most recent challenge is the discovery of sensitized aluminum alloy in areas of the superstructure, and how that complicates modernization of these vessels.

- Continual improvement in techniques and methods to overcome these challenges in a cost effective manner include:

  - Detecting and testing sensitized aluminum (destructive and nondestructive techniques).

  - Implementing specific weld profiles and surface finishes to aid NDT and reduce stress concentrations.

  - Applying cold work to develop surface compressive stresses to prevent stress corrosion cracking (SCC).

  - Performing enhanced non-destructive testing to better identify relevant indications.

  - Using three dimensional coordinate measuring techniques to develop a model of the existing ship structure so that accurate replacement modules can be fabricated prior to a docked ship maintenance availability.

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Future Work

Continuing Manufacturing Techniques and Improvements to Meet Emergent Challenges

- Application of non-destructive sensitization assessment techniques
  - Portable electrochemical degree of sensitization probe.
  - Comparative micrograph chart for degree of sensitization utilizing field metallography on aluminum alloy 5456-H116
- Review the influences of automated welding on sensitized base material aluminum alloy
  - Gas-metal-arc-welding, pulse transfer for single and multiple-pass fillet weldments
- Evaluate single pass automated welding procedures on new and sensitized aluminum alloy per ASTM B928 for radiographic quantification of gas porosity
- Quantify residual stress utilizing current welding and structural fabrication processes
  - Focusing on practical implementations of laboratory trials utilizing experimental low-distortion-techniques are applicable for deck-plate production.
- Possibly Reduce grinding with the application of ultrasonic impact treatment / ultrasonic peening (UIT/UP)
  - Mechanical property enhancement and fatigue improvement
  - Achieve the final weld (toe) reinforcement contour and ultimately replace contour grinding.

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ACKNOWLEDGMENTS

The authors would like to thank and acknowledge the following organizations and teams for their technical leadership with CG-47 class ship superstructure challenges, innovative contributions and content support of this paper:

- Naval Sea Systems Command: SEA 05, SEA 21
- CG-47 Superstructure Integrated Product Team
- Past Aluminum Task Force Findings
- Regional Maintenance Centers: NSSA, SERMC, SWRMC, and PHNSY&IMF
- BAE Systems – Land and Armaments: Combat Systems Division
- Naval Surface Warfare Center, Philadelphia
- Naval Surface Warfare Center, Carderock
- Alcoa Aluminum Corporation
- BAE Systems – Ship Repair
- BAE Systems – Norfolk Ship Repair

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