Process Specification and Operator Qualification for Laser Hybrid Welding
Statement on the Use of American Welding Society Standards

All standards (codes, specifications, recommended practices, methods, classifications, and guides) of the American Welding Society (AWS) are voluntary consensus standards that have been developed in accordance with the rules of the American National Standards Institute (ANSI). When AWS American National Standards are either incorporated in, or made part of, documents that are included in federal or state laws and regulations, or the regulations of other governmental bodies, their provisions carry the full legal authority of the statute. In such cases, any changes in those AWS standards must be approved by the governmental body having statutory jurisdiction before they can become a part of those laws and regulations. In all cases, these standards carry the full legal authority of the contract or other document that invokes the AWS standards. Where this contractual relationship exists, changes in or deviations from requirements of an AWS standard must be by agreement between the contracting parties.

AWS American National Standards are developed through a consensus standards development process that brings together volunteers representing varied viewpoints and interests to achieve consensus. While AWS administers the process and establishes rules to promote fairness in the development of consensus, it does not independently test, evaluate, or verify the accuracy of any information or the soundness of any judgments contained in its standards.

AWS disclaims liability for any injury to persons or to property, or other damages of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this standard. AWS also makes no guarantee or warranty as to the accuracy or completeness of any information published herein.

In issuing and making this standard available, AWS is neither undertaking to render professional or other services for or on behalf of any person or entity, nor is AWS undertaking to perform any duty owed by any person or entity to someone else. Anyone using these documents should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances. It is assumed that the use of this standard and its provisions is entrusted to appropriately qualified and competent personnel.

This standard may be superseded by new editions. This standard may also be corrected through publication of amendments or errata, or supplemented by publication of addenda. Information on the latest editions of AWS standards including amendments, errata, and addenda is posted on the AWS web page (www.aws.org). Users should ensure that they have the latest edition, amendments, errata, and addenda.

Publication of this standard does not authorize infringement of any patent or trade name. Users of this standard accept any and all liabilities for infringement of any patent or trade name items. AWS disclaims liability for the infringement of any patent or product trade name resulting from the use of this standard.

AWS does not monitor, police, or enforce compliance with this standard, nor does it have the power to do so.

Official interpretations of any of the technical requirements of this standard may only be obtained by sending a request, in writing, to the appropriate technical committee. Such requests should be addressed to the American Welding Society, Attention: Managing Director, Standards Development, 8669 NW 36 St, # 130, Miami, FL 33166 (see Annex G). With regard to technical inquiries made concerning AWS standards, oral opinions on AWS standards may be rendered. These opinions are offered solely as a convenience to users of this standard, and they do not constitute professional advice. Such opinions represent only the personal opinions of the particular individuals giving them. These individuals do not speak on behalf of AWS, nor do these oral opinions constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.

This standard is subject to revision at any time by the AWS C7 Committee on High Energy Beam Welding and Cutting. It must be reviewed every five years, and if not revised, it must be either reaffirmed or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data that may be of use in improving this standard are requested and should be addressed to AWS Headquarters. Such comments will receive careful consideration by the AWS C7 Committee on High Energy Beam Welding and Cutting and the author of the comments will be informed of the Committee’s response to the comments. Guests are invited to attend all meetings of the AWS C7 Committee on High Energy Beam Welding and Cutting to express their comments verbally. Procedures for appeal of an adverse decision concerning all such comments are provided in the Rules of Operation of the Technical Activities Committee. A copy of these Rules can be obtained from the American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.
Personnel

AWS C7 Committee on High Energy Beam Welding and Cutting

T. A. Palmer, Chair
K. W. Lachenberg, Vice Chair
D. D. Kautz, 2nd Vice Chair
P. Portela, Secretary
P. Denney
J. W. Elmer
P. W. Hochandel
F. Kong
G. R. LaFlamme
E. D. Levert
E. M. Lord
R. P. Martukanitz
B. D. Ribic

Penn State University
Sciaky Corporation
Los Alamos National Laboratory
American Welding Society
The Lincoln Electric Company
Lawrence Livermore National Laboratory
Los Alamos National Laboratory
ESAB Welding & Cutting Products
PTR-Precision Technologies, Incorporated
Lockheed Martin Missiles & Fire Control
Bechtel Marine Propulsion Corporation

Advisors to the AWS C7 Committee on High Energy Beam Welding and Cutting

P. Blomquist
P. W. Fuerschbach
J. O. Milewski
T. M. Mustaleski
D. E. Powers
D. A. Zoller

Edison Welding Institute
SmartWeld Solutions
Los Alamos National Laboratory
Welding Engineer
PTR-Precision Technologies, Incorporated
ESAB Welding & Cutting Products

AWS C7D Subcommittee on Laser Hybrid Welding

B. D. Ribic, Chair
F. Kong, Vice Chair
P. E. Denney, 2nd Vice Chair
P. Portela, Secretary
K. Egland
P. W. Hochandel
W. M. Penn

Rolls-Royce Corporation
ESAB Welding & Cutting Products
The Lincoln Electric Company
American Welding Society
Caterpillar, Incorporated
Los Alamos National Laboratory
Alabama Laser

Advisors to the AWS C7D Subcommittee on Laser Hybrid Welding

L. Blais
E. D. Levert
J. Milewski

Novika Solutions
Lockheed Martin Missiles & Fire Control
Los Alamos National Laboratory
Combining lasers with other welding techniques to achieve a *hybrid process* has been around almost as long as laser welding. While there are many advantages associated with the high power density properties of lasers, it was determined that gap, base material metallurgy, and weldment performance may be difficult to address with the laser beam alone. One approach was to utilize the advantages of the laser while addressing its shortcomings with the addition of a process that added material to the weld joint. While material could be added in a number of methods (blown powder, preplaced inserts, sacrificial features, etc.), one simple method was to combine the laser with techniques already used for conventional arc welding. This included combining the laser with a Gas Metal Arc Welding (GMAW) process or with a resistant heated wire as is used in Gas Tungsten Arc Welding (GTAW) to form a *Hybrid Process*.

The hybrid laser process has already been accepted for many applications. It has been utilized in the welding of ship structures, structural components, and automotive parts. While the materials processing applications of hybrid laser processing are diverse and may be required to meet other performance criteria, this document focuses on the process specification and operator qualification.

The data contained in this *Process Specification and Operator Qualification for Laser Hybrid Welding* has been compiled and reviewed by the C7D Laser Hybrid Welding Subcommittee of the American Welding Society, which includes representatives from manufacturers and users of laser beam welding and those involved in hybrid laser processes and equipment.
# Table of Contents

1. General Requirements ................................................................. 1  
   1.1 Scope ..................................................................................... 1  
   1.2 Units of Measurement ......................................................... 1  
   1.3 Safety ................................................................................... 1  

2. Normative References .................................................................. 2  

3. Terms and Definitions .................................................................. 2  

4. Safety .......................................................................................... 4  
   4.1 Electric Shock ......................................................................... 4  
   4.2 Fumes and Gases ..................................................................... 4  
   4.3 Laser Radiation Hazards ......................................................... 4  
   4.4 Radiation Hazards .................................................................... 4  
   4.5 Mechanical Systems .............................................................. 4  

5. Requirements .............................................................................. 4  
   5.1 Equipment .............................................................................. 5  
   5.2 Materials ................................................................................ 6  
   5.3 Joint/Surface Design ............................................................. 6  
   5.4 Procedures .............................................................................. 6  
   5.5 Essential Variables and Limits .............................................. 9  
   5.6 Operator Qualification Test Record ...................................... 12  
   5.7 Production Welding/Cladding Records ................................. 13  
   5.8 Inspection Procedures ......................................................... 13  

6. Fabrication .................................................................................. 13  

7. Quality Examination .................................................................... 13  
   7.1 Nondestructive Examination (NDE) .................................... 13  
   7.2 Discontinuity Limits .............................................................. 13  
   7.3 Destructive Evaluation ......................................................... 13  
   7.4 Traceability ............................................................................ 14  
   7.5 Archive of Records .............................................................. 14  

8. System Calibration ....................................................................... 14  

9. Quality Assurance ....................................................................... 15  
   9.1 Sampling Plans ....................................................................... 15  
   9.2 Lot Definition ........................................................................ 15  
   9.3 Preproduction Sampling ....................................................... 15  
   9.4 Part Acceptance ..................................................................... 15  
   9.5 Part Repair or Rework ......................................................... 15  
   9.6 Traceability ........................................................................... 15  
   9.7 Archive of Records .............................................................. 15  

Personnel ....................................................................................... v  
Foreword .......................................................................................... vii  
List of Tables ................................................................................... ix  

AWS C7.6/C7.6M:2017
10. Approval for Work ........................................................................................................................................... 15
   10.1 Preproduction Development Approval ......................................................................................................15
   10.2 Deviations to WPS ....................................................................................................................................15
   10.3 Reports ...................................................................................................................................................... 15
   10.4 Traceability ............................................................................................................................................... 15
   10.5 Archive of Reports ....................................................................................................................................15

Annex A (Informative)—Sample Equipment Qualification Record .............................................................................. 17
Annex B (Informative)—Sample Welding Procedure Qualification Record (PQR) .............................................................. 21
Annex C (Informative)—Sample Welding Procedure Specification (WPS) ........................................................................ 29
Annex D (Informative)—Laser Weld Discontinuity Limits ........................................................................................... 33
Annex E (Informative)—Acronyms .................................................................................................................................... 35
Annex F (Informative)—Sample Operator Process Qualification Test Record (OPQTR) ....................................................... 37
Annex G (Informative)—Requesting an Official Interpretation on an AWS Standard .................................................... 39

List of AWS Documents on High Energy Beam Welding & Cutting ............................................................................ 41

List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5.1</td>
<td>Laser Beam Generator</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Laser Beam Delivery Hardware</td>
</tr>
<tr>
<td>5.5.3.1</td>
<td>Auxiliary Power Supply</td>
</tr>
<tr>
<td>5.5.3.2</td>
<td>Wire Feed</td>
</tr>
<tr>
<td>5.5.3.3</td>
<td>Wire</td>
</tr>
<tr>
<td>5.5.4</td>
<td>Motion Control, Weld Direction, and Filler Metal Delivery</td>
</tr>
<tr>
<td>5.5.5</td>
<td>Shielding Gas</td>
</tr>
<tr>
<td>5.5.6</td>
<td>Materials</td>
</tr>
<tr>
<td>5.5.7</td>
<td>Weld or Cladding Surface Design and Tooling</td>
</tr>
<tr>
<td>7.1</td>
<td>Nondestructive Examination</td>
</tr>
</tbody>
</table>
Process Specification and Operator Qualification for Laser Hybrid Welding

1. General Requirements

1.1 Scope. This specification covers processing and quality control requirements for Laser Hybrid Processing. Equipment includes any laser source (examples include, but are not exclusive to CO₂, Nd: YAG, Diode, Ruby, Yb Fiber (Fibre), Yb Disk (Disc), Nd: Glass) in combination with an arc welding system (power supply, wire feeder, torch, etc.) as defined by AWS A3.0M/A3.0, Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying.

Specifically, this specification covers both (1) Laser Hybrid Arc Welding that uses both a laser to create a keyhole and GMAW (Gas Metal Arc Welding) to add filler material (resulting in a weld bead that is deeper compared to a traditional arc weld and wider than an autogenous laser weld) and (2) Laser Hot Wire Processing that uses a laser to create a conduction mode or keyhole mode molten puddle and an auxiliary power supply that adds heat to the filler wire that enters the puddle (resulting in a lower heat input weldment that could be used to weld joints or to add a hardfacing overlay).

Tutorial information regarding techniques of welding or details of machine setup or operation of laser hybrid processing and laser hybrid processing systems is beyond the scope of this specification. For more information on this subject, refer to AWS C7.2. Recommended Practices for Laser Welding, Cutting, and Related Processes.

1.1.1 Materials. This specification covers all major engineering alloys including the following:

(1) Ferrous Alloys (e.g., steels and stainless steels)
(2) Non-Ferrous Alloys (e.g., Al alloys, Ni alloys, Ti alloys, Superalloys)
(3) Heat-Resisting Alloys (e.g., Mo alloys, Ta alloys, W alloys)
(4) Other Metals (e.g., Be and Cu alloys, precious metals)

1.2 Units of Measurement. This standard makes use of both U.S. Customary Units and the International System of Units (SI). The latter are shown within brackets [ ] or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system must be used independently.

1.3 Safety. Safety and health issues and concerns are beyond the scope of this standard; some safety and health information is provided, but such issues are not fully addressed herein.

Safety and health information is available in the following sources:

American Welding Society:

(1) ANSI Z49.1, Safety in Welding, Cutting, and Allied Processes
(2) AWS Safety and Health Fact Sheets
(3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

(1) Safety Data Sheets supplied by materials manufacturers
(2) Operating Manuals supplied by equipment manufacturers