Abstract

This specification on laser beam welding discusses applicable specifications, safety, requirements, fabrication, quality examination, equipment calibration and maintenance, approval of work, and delivery of work.
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: Director, Standards Development, 8669 NW 36 St, # 130, Miami, FL 33166 (see Annex F). 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 required 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  
Applied Research Laboratory, Penn State University
K. W. Lachenberg, Vice Chair  
Sciaky, Incorporated
D. Kautz, 2nd Vice Chair  
Los Alamos National Laboratory
P. Portela, Secretary  
American Welding Society
A. N. Black  
PTR—Precision Technologies, Incorporated
P. E. Denney  
The Lincoln Electric Company
J. W. Elmer  
Lawrence Livermore National Laboratory
P. W. Hochanadel  
Los Alamos National Laboratory
F. Kong  
ESAB Welding and Cutting Products
G. R. LaFlamme  
PTR—Precision Technologies, Incorporated
E. D. Levert  
Lockheed Martin Missiles & Fire Control
E. M. Lord  
Bechtel Marine Propulsion Corporation
M. C. Maguire  
Sandia National Laboratory
R. P. Martukanitz  
Penn State University
B. D. Ribic  
Rolls-Royce Corporation
D. Zoller  
ESAB Welding and Cutting

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

P. Blomquist  
Edison Welding Institute
P. W. Fuerschbach  
SmartWeld Solutions
J. O. Milewski  
Los Alamos National Laboratory
T. M. Mustaleski  
Alabama Specialty Products, Incorporated
D. E. Powers  
PTR—Precision Technologies, Incorporated (Retired)
D. A. Zoller  
ESAB Welding & Cutting Products

AWS C7C Subcommittee on Laser Beam Welding and Cutting

R. P. Martukanitz, Chair  
Penn State University
S. L. Engel, Vice Chair  
HDE Technologies, Incorporated
P. Portela, Secretary  
American Welding Society
T. J. Baber  
Santa Carita Community College
A. N. Black  
PTR—Precision Technologies, Incorporated
J. C. Bryant  
Heraeus Electro-Nite Company
D. A. Capostagno  
SPI Lasers, LLC
P. E. Denney  
The Lincoln Electric Company
J. W. Elmer  
Lawrence Livermore National Laboratory
K. J. Erickson  
St. Jude Medical
J. J. C. Gerdin  
Anoka Technical College
A. P. Hoult  
IPG Photonics
J. P. Hurley  
Trumpf, Incorporated
D. D. Kautz  
Los Alamos National Laboratory
J. P. Lavoie  
Coherent Incorporated
E. M. Lord  
Bechtel Marine Propulsion Corporation
M. C. Maguire  
Sandia National Laboratory
S. A. Miner  
Las Positas College
AWS C7C Subcommittee on Laser Beam Welding and Cutting (Continued)

T. A. Palmer  Penn State University
E. A. Pfeif  National Institute of Standards and Technology
B. M. Weinkamer  Praxair Distribution
B. Zimmerman  Heraeus Electro-Nite Company

Advisors to the AWS C7C Subcommittee on Laser Beam Welding and Cutting

P. Blomquist  Edison Welding Institute
R. D. Bucurel  WEC Welding & Machining
P. W. Hochanadel  Los Alamos National Laboratory
J. O. Milewski  Los Alamos National Laboratory
D. E. Powers  PTR—Precision Technologies, Incorporated
Foreword

This foreword is not part of this standard but is included for informational purposes only.

In the year 2010 the laser industry celebrated the 50th Anniversary of the invention of the laser. Since its introduction, the output power of lasers has increased to the level where the use of lasers for material processing has become widespread worldwide. Lasers are accepted as industrial tools for various materials processing applications. The main subjects of this document are process specifications for laser welding and welding operator qualifications.

This is the second edition of the C7.4/C7.4M. This update was prepared recognizing the technological changes in lasers, beam delivery optics, laser beam diagnostic technology, and real time process monitoring. Furthermore, the Committee also recognized the need for formal training and qualification of the technical staff that is necessary to qualify the welding equipment and the laser welding process. With this document, the C7 Committee and the C7C Subcommittee hope to provide a working document for manufacturing professionals and educators involved in industrial laser welding.

The information contained in this Process Specification and Operator Qualification for Laser Beam Welding has been compiled and reviewed by the C7C Laser Beam Welding and Cutting Subcommittee of the American Welding Society, which includes representatives from manufacturers and users of laser beam welding equipment.

Flow Diagrams below are provided as guidelines* to the reader.

Laser Weld Procedure Qualification

The ‘Employer’ or the ‘Manufacturer’ using Engineering and Production Resources should follow this suggested procedure for a laser welding program:

- Define:
  - Production requirements
  - Process requirements
  - Test requirements

- Define test weldment for process qualification

- Produce test weldments to ‘optimize’ the welding parameters and record the process parameters

- Test and evaluate the weldments
Laser Welding Operator Qualification

To qualify a person (Applicant) as a laser ‘Welder’ or the ‘Welding Operator,’ the Test Site Administrator (TSA) of the AWS Accredited Testing Facility (ATF), or a Certified Welding Inspector (CWI), should follow this suggested procedure:

1. Document the variables used to establish the test performance and test results in a Procedure Qualification Record (PQR)
2. Approve the Procedure Qualification Record
3. If all results are acceptable, prepare Welding Procedure Specification (WPS)

Laser Welding Equipment Qualification

To qualify the laser welding equipment for engineering, production welds, or Welding Operator Qualification, the ‘Employer,’ the ‘Manufacturer,’ or the ‘Test Site Administrator’ should follow this suggested procedures and maintain the corresponding records:

1. Maintain the equipment qualification by:
   - Calibration of the laser welding system to original equipment specifications and recording the results of the calibration in the Equipment Qualification Record (EQR)
   - Performing and recording all maintenance performed on the system

# Table of Contents

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

1. **General Requirements** .................................................................................................................. 1
   1.1 Scope .............................................................................................................................................. 1
   1.2 Units of Measure ............................................................................................................................ 1
   1.3 Safety .............................................................................................................................................. 1

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

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

4. **Safety** .............................................................................................................................................. 4

5. **Requirements** ................................................................................................................................ 5
   5.1 Equipment ....................................................................................................................................... 5
   5.2 Materials ......................................................................................................................................... 6
   5.3 Weld Joint Design ............................................................................................................................ 6
   5.4 Welding Procedures .......................................................................................................................... 6
   5.5 Essential Variables and Limits ......................................................................................................... 7
   5.6 Testing of Laser Welds ...................................................................................................................... 9
   5.7 Welding (Operator) Performance Qualification .............................................................................. 10
   5.8 Production Welding Records .......................................................................................................... 10
   5.9 Inspection Procedures ...................................................................................................................... 10

6. **Welding Operator Performance Qualification** .............................................................................. 10
   6.1 Formal Training ............................................................................................................................... 10
   6.2 Safety in the Facility ......................................................................................................................... 11
   6.3 Assessment Methods ....................................................................................................................... 11
   6.4 Recommended Performance Tests ................................................................................................... 11
   6.5 Equipment ....................................................................................................................................... 12
   6.6 Materials ......................................................................................................................................... 13
   6.7 Welding Operator Performance Qualification (WOPQ) Test ......................................................... 14
   6.8 Evaluation of the Welds .................................................................................................................... 15
   6.9 Retesting of the Applicant ................................................................................................................ 15
   6.10 Qualification of the Applicant ....................................................................................................... 15

7. **Fabrication** ..................................................................................................................................... 15

8. **Quality Examination** ..................................................................................................................... 16
   8.1 Nondestructive Examination (NDE) ............................................................................................... 16
   8.2 Discontinuity Limits .......................................................................................................................... 16
   8.3 Traceability ....................................................................................................................................... 16
   8.4 Archive of Inspection Records ....................................................................................................... 16

9. **Weld Equipment Qualification** .................................................................................................... 16
   9.1 Suggested Equipment Qualification Schedules ............................................................................. 16
   9.2 Devices for Equipment Qualification ............................................................................................ 17
   9.3 Measurements to be Included ......................................................................................................... 17
## List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Laser Beam Characteristics</td>
<td>8</td>
</tr>
<tr>
<td>2 Laser Beam Delivery Hardware</td>
<td>8</td>
</tr>
<tr>
<td>3 Motion Control, Weld Direction, Filler Metals, and Shielding Gases</td>
<td>8</td>
</tr>
<tr>
<td>4 Materials</td>
<td>9</td>
</tr>
<tr>
<td>5 Weld Joint Design and Tooling</td>
<td>9</td>
</tr>
<tr>
<td>6 Nondestructive Examination</td>
<td>16</td>
</tr>
</tbody>
</table>
This page is intentionally blank.
Process Specification and Operator Qualification for Laser Beam Welding

1. General Requirements

1.1 Scope. This specification covers the preparation, the process control, and quality control requirements for laser beam welding. Welding equipment includes Gas Lasers (CO₂) and Solid-State Lasers (Nd:YAG, Yb:YAG, Nd:Glass, Diode, Ruby, Disk and Fiber) in pulsed, continuous wave (CW), and quasi-continuous wave (QCW) output as defined in AWS A3.0M/A3.0, Standard Welding Terms and Definitions.

Tutorial information regarding techniques of welding or details of equipment setup or operation is beyond the scope of this specification. For more information on this subject and recommended practices, refer to the latest published version of AWS C7.2, Recommended Practices for Laser Welding, Cutting, and Allied Processes.

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

   (1) Ferrous Alloys (e.g., Carbon steels, stainless steels, etc.);
   (2) Nonferrous Alloys (e.g., Alloys of Al, Ni, Ti, etc. and Super-alloys);
   (3) Heat-Resisting and Refractory Metal Alloys (e.g., Alloys of Mo, Ta, W, etc.);
   (4) Other Alloys (e.g., Be and Cu alloys, precious metals);
   (5) Nonmetals (Plastics, polymers, etc.).

1.1.2 Qualification Categories. There are three categories to which welds may be qualified: Class A, B, or C. Classification levels are intended to delineate inspection level and process control. Examples of acceptance criteria, which may be applied to the classification levels, are presented in Annex D.

   1.1.2.1 Class A—Critical Applications. Critical weldments include those where a failure of any portion of a weldment would cause loss of system, loss of major component, loss of control, unintentional release of critical stores, such as fuel or cargo, or endangerment of personnel.

   1.1.2.2 Class B—Semicritical Applications. Semicritical weldments include those where a failure of any portion of a weldment would reduce the overall efficiency of the system, but loss of the system or endangerment of personnel would not be experienced.

   1.1.2.3 Class C—Noncritical Applications. Noncritical weldments include those where a failure of any portion of a weldment would not affect the efficiency of the system or endanger personnel.

1.2 Units of Measure. 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 from 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