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 CO_2, 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

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

American National Standards Institute (ANSI) standards:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*;

ANSI Z87.1, *Practices for Occupational and Educational Eye and Face Protection*; and

ANSI Z136.1, *Practices for the Safe Use of Lasers*.

American Welding Society (AWS) standards:

AWS A3.0M/A3.0, *Standard Welding Terms and Definition, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*;

AWS B2.1, *Specification for Welding Procedure and Performance Qualification*; and

AWS B4.0, *Standard Methods for Mechanical Testing of Welds*;

Other documents:

SDSs, *Safety Data Sheets*.

3. Terms and Definitions

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions* provides the basis for terms and definitions used herein. The terms and definitions used in this text are generally specific to laser hybrid processing. Terms that are not part of common welding vocabulary are defined, and the definitions of some standard welding terms are changed slightly to more accurately describe those terms as they apply to laser hybrid welding processes. A list of acronyms used within the document can be found in Annex E. However, the following terms and definitions are included to accommodate usage specific to this document.

auxiliary power supply. A secondary energy source used in the laser hybrid welding process, besides the laser beam, which contributes sufficient energy such that the additional absorbed energy augments the resulting molten pool geometry. Examples of an auxiliary power supply are GMAW or hot wire.

cavity. See **resonator**.

CNC. An acronym for computer numerical control, a device that controls a machine tool by reading numerical data and transforming it into machine axis movements.

continuous power. See **continuous wave**.

continuous wave (CW). A laser beam which is produced continuously rather than as a series of pulses.

dilution ratio. The ratio of the substrate area melted to the total area melted and can be measured geometrically by the formula $\frac{a}{(a+b)^2}$, where a is the cross sectional area of the substrate that was melted by the cladding process, and b is the cross sectional area of the cladding bead above the substrate, or determined by other techniques.

diode laser. A type of laser in which the active medium is a semiconductor with polished end facets forming mirror surfaces. Also called semiconductor laser. Diode lasers used for alignment emit in the visible; other diode lasers emitting in the infrared are used for material processing. Typical wavelengths for this type of laser range from 0.63 to 0.99 micrometers depending upon the laser active medium chemical composition.

fiber laser. A solid-state laser design in which the active medium is a doped optical fiber. Typical wavelengths for this type of laser are 1.06, 1.55, or 1.8 micrometers depending upon the active medium dopant.

focal length. In a lens or lens system, the distance from the principal plane, the surface at which the projections of an entering and exiting ray intersect, to the focal point. In a thick lens or system of lenses, the principal plane is often inside the lens itself; for setup purposes, operators often use the back focal length, which is the distance from the front surface of a focusing lens or mirror system to the focal point.

infrared (IR). Electromagnetic radiation possessing wavelengths between those of visible light and microwaves.

keyhole. A laser melting mode characterized by high power densities and vaporization of material that is pushed out, creating a weld that has a high depth to width aspect ratio.

laser. A device that produces a concentrated coherent light beam by stimulated electronic or molecular transitions to lower energy levels. Laser is an acronym for light amplification by stimulated emission of radiation.

laser beam. The output radiation of a laser that can be steered and focused by mirrors, lenses, or both, to do useful work.

laser beam to wire distance. Distance from the center of the laser beam diameter at the workpiece and the projection of the wire tip onto the workpiece surface measured parallel to the weld axis.

laser generator. See **laser**.

laser system. A machine or fabrication tool consisting of a laser, a workpiece holder, and a means of delivering the beam to the workpiece and deflecting it over the workpiece in a controlled manner. The most common type of controller is a computer numerical controller, or CNC, but a robot controller is also used.

lens. A transparent optical element with curved surfaces, used to converge or diverge light rays via refraction.

mirror. An optical element that reflects nearly 100% of the laser beam.

Nd:Glass. Neodymium-doped glass that is utilized as the lasing material in some solid-state lasers. The neodymium atoms form the active medium. A typical wavelength for this type of laser is 1.06 micrometers.

Nd:YAG. Neodymium-doped yttrium aluminum garnet (YAG) crystal that is utilized as the lasing material in a common type of solid-state laser. The neodymium atoms form the active medium. See **YAG.** A typical wavelength for this type of laser is 1.06 micrometers.

nozzle. A device projecting from the focusing head with an outlet to direct gas into the laser beam processing area.

plume. The vapor cloud that forms above the laser/material interaction zone. It can consist of excited and partially ionized assist gases (plasma) and atoms of the material vaporized by the intense laser beam and can have a temperature equivalent to tens of thousands of degrees Kelvin. Under certain conditions, the plume can absorb or scatter the incoming laser beam, reducing transmission of the beam, the energy absorbed by the workpiece, and weld penetration.

polarizer. An optic that transmits light of only a single polarization, or otherwise alters the polarization of radiation.

power. With respect to lasers, power is the rate of energy flow from the radiation source. Power is usually measured in watts, an energy flow of a joule per second, or kilowatts (kW). With respect to the auxiliary power supply, power is the mathematical product of electric current and voltage. In laser hybrid processing, power is referred to as the sum of the laser power and the power of GMAW or hot wire power supplies.

Procedure Qualification Record (PQR). A written record of welding variables used to produce an acceptable test weldment and the results of tests conducted on that weldment to qualify a Welding Procedure Specification (see **Welding Procedure Specification (WPS)**).

process orientation. The relationship between the laser beam, travel direction, and auxiliary process (GMAW or hot wire). The laser hybrid welding process can be divided into two categories: torch leading or laser leading. The auxiliary

power device can be positioned in front of the laser spot in the travel direction, which is referred to as torch leading; otherwise, it is referred to as laser leading.

pulsed laser. A laser that emits light as a pulse or a series of pulses rather than continuously.

pulse duration. The duration measured between the half-peak-power points at the front and trailing edges of a pulse.

pulse length. See **pulse duration**.

Welding Procedure Specification (WPS). A document that delineates or references all required welding variables to provide direction for welding.

YAG (Yttrium Aluminum Garnet). A synthetic crystal used as a laser rod host material in Nd:YAG laser.

Yb Disk Laser. A diode pumped, solid-state laser design in which the active medium is a doped, very thin disk. A typical wavelength for this type of laser is 1.06 micrometers.

Yb:YAG. An active laser medium lasing at 1030 nm.

4. Safety

The following potential hazards are associated with laser hybrid processing: electric shock, invisible light radiation, visible light radiation, fumes, gases, and molten particles.

4.1 Electric Shock. Voltages and currents in the laser and auxiliary power supplies are sufficient to be lethal and should be handled accordingly.

4.2 Fumes and Gases. Ozone, nitrogen oxides, metal vapors, and other noxious/hazardous fumes may be generated by laser beam welding (LBW) or GMAW.

4.2.1 Efficient exhaust venting shall be provided with the laser hybrid processing system to remove noxious fumes to acceptable levels in personnel-occupied areas and to protect the cover lens of the laser head from pollution of GMAW induced fume or spatters. A thermal sensor might be installed to monitor the temperature of the cover lens regarding the safety issues of the laser head and the associated fiber-optic cable. Various types of ventilation systems, including general supply and exhaust and local exhaust, for control of welding fumes and reference to information on air contaminants found in the welding fumes, principles of systems design and selection, and drawings that illustrate ventilation techniques can be found in AWS F3.2M/F3.2.

4.2.2 Safety Data Sheets (SDSs) shall be read to determine hazards in working with all materials associated with the welding/cladding processes. These include the SDS for materials contained in the workpieces, fixturing, and cleaning materials.

4.3 Laser Radiation Hazards. Direct, Diffuse, and Specular Reflection of laser energy is produced by laser hybrid welding/cladding equipment during operation. Proper guarding and/or barriers shall be employed to protect personnel who are in the Nominal Hazard Zone (NHZ) of the laser. See ANSI Z136.1 to calculate the NHZ.

4.4 Radiation Hazards. Direct viewing of the weld area during welding can expose personnel to hazardous visible and invisible Infrared (IR), or Ultraviolet (UV) light radiation with possible long-term eye and skin damage. Appropriate optical filters shall be used as per ANSI Z87.1 to shield personnel from possible exposure to both hazardous visible and invisible (IR and UV) radiation.

4.5 Mechanical Systems. Follow appropriate lock-out and tag-out procedures when servicing laser system equipment to avoid possible pinch points.

5. Requirements

This clause discusses requirements a laser hybrid weldment must meet before it is deemed to meet the welding qualifications in this Standard. The documents generated from following these requirements (WPS's and PQR's) are not intended as public documents but for the users to develop and maintain their procedures to an industrial standard.