WHAT YOU NEED TO KNOW ABOUT

HANDHELD LASER WELDING

PRACTICAL GUIDE

Safety • Process Development • Production

Practical Guidance
for Shop Owners, Welders, Supervisors, and Students

- PRACTICAL INSIGHTS
- PROVEN TECHNIQUES
- SAFETY FOCUSED
- REAL-WORLD APPLICATIONS

IMPROVE QUALITY | INCREASE PRODUCTIVITY | REDUCE COSTS | BUILD CONFIDENCE

WHAT YOU NEED TO KNOW ABOUT HANDHELD LASER WELDING

A Practical Guide to Safety, Process Development, and Production

Manufacturing With Light
Revised August 2026

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A Practical Guide to Safety, Process Development, and Production

Prepared for Manufacturing With Light (MWL)

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Copyright and Use Notice

This publication is an educational reference. It is not a substitute for the equipment manufacturer's instructions, a site-specific laser-safety evaluation, applicable laws, regulations, codes, or advice from a qualified Laser Safety Officer, industrial hygienist, welding engineer, Certified Welding Inspector, electrician, or other responsible professional.

Specific operating limits, protective equipment, maintenance procedures, and permitted materials vary by machine. Always follow the current manual and safety documentation supplied with the equipment.

AI Use Disclosure

Artificial intelligence was used to assist with the research, organization, drafting, and editing of this book. The final content was reviewed and revised for clarity and accuracy; however, readers should verify safety-critical information with current manufacturer instructions, applicable standards, and qualified professionals before applying it in the workplace.

The fictional shop stories in this revised edition are clearly labeled. Some are original composite teaching examples. Others are labeled “American Welding Society-based fictional safety stories” because they are built from hazards and controls described in AWS publications. Those fictional stories are not AWS accident reports. Separate “American Welding Society shop examples” paraphrase manufacturing examples actually published by AWS and are identified as AWS-reported.

Preface

Handheld laser welding has moved from a specialized industrial process into job shops, repair departments, sheet-metal operations, and training programs. That growth has created a need for information that is practical enough for the shop floor but responsible enough to treat laser welding as the serious industrial process it is.

This book is written for shop owners, working welders, supervisors, and students who are considering handheld laser welding or are in the early stages of using it. It explains the process at approximately a vocational-school level. The goal is not to turn every reader into a laser physicist. The goal is to help readers ask better questions, recognize the important controls, develop sound shop practices, and understand when qualified outside help is needed.

This book deliberately treats certification, procedure qualification, inspection, and documentation as normal parts of professional welding. Handheld laser welding may feel new, but the responsibility to produce repeatable and acceptable welds is not new.

A Personal Note from Bill

I have built Class 1 industrial laser systems with light-tight enclosures and dual-channel monitored safety controls. That experience is one reason I remain cautious about treating a handheld laser welder as if it were simply a faster welding torch.

To me, handheld laser welding has to be introduced as a complete process: laser safety, fume control, training, material and fit-up control, procedure development, inspection, maintenance, and clear ownership. A responsible supplier can provide a great deal of help, but the buyer still needs to understand what remains to be done after delivery, commissioning, and acceptance.

I am especially careful when I hear the phrase “Class 1 solution” without a clear explanation of what complete configuration was evaluated, who is responsible for the final product, and what changes are allowed after installation. This revision addresses those responsibilities directly rather than assuming that a label, brochure, or purchase order settles them.

> **ABOUT THE STORIES**
> This guide uses three clearly identified kinds of examples. An “American Welding Society shop example” paraphrases a manufacturing example published by AWS. An “American Welding Society-based fictional safety story” is a plausible teaching scenario built from AWS safety guidance; its people and events are fictional and it is not an AWS accident report. Other fictional shop stories are also labeled. No dramatic internet mishap is presented as a verified accident unless a reliable primary source documents the event.

> **SAFETY NOTE**
> Most handheld laser welders use a high-power Class 4 laser. Class 4 exposure can cause immediate eye or skin injury from the direct or reflected beam and may present a fire hazard.[1] This book does not authorize anyone to operate a laser.

How to Use This Book

This is organized as a practical guide. It can be read from cover to cover, but each chapter is designed to stand largely on its own.

- Owners and managers may begin with Chapters 1, 2, 7, and 10.
- New operators should begin with Chapters 1 through 7.
- Welding instructors may use the figures, fictional shop stories, checklists, and worksheets.
- Experienced welders moving into laser welding may focus on process parameters, fit-up, inspection, and troubleshooting.
- Readers planning production use should review the process-development, maintenance, purchasing, and production-system chapters.

Table of Contents

Chapter 1 — Understanding Handheld Laser Welding

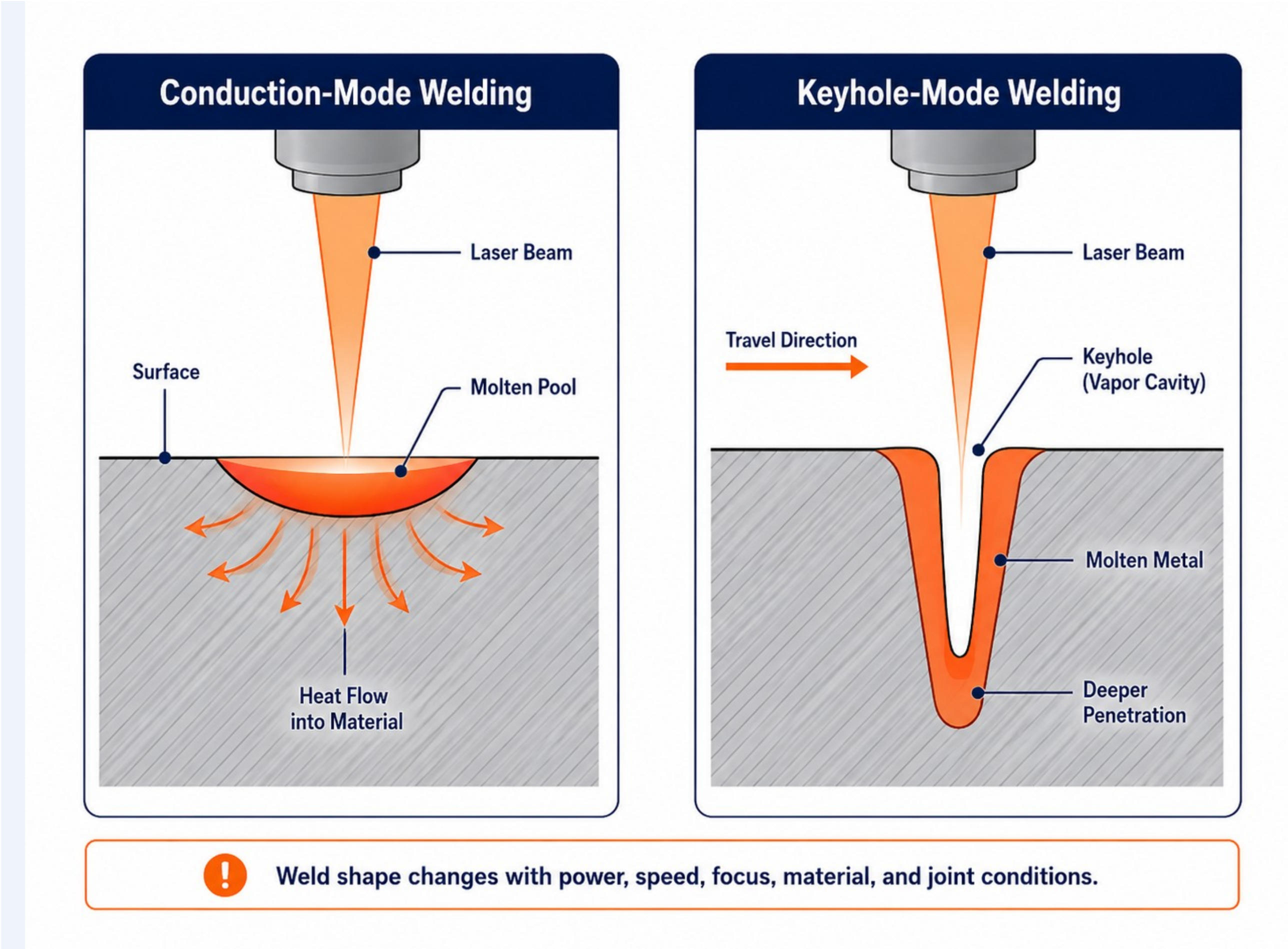

Figure 1-1. Simplified comparison of conduction-mode and keyhole-mode laser welding.

1.1 What the Laser Is Doing

A handheld laser welder directs concentrated optical energy onto the workpiece. The metal absorbs some of that energy and heats rapidly. Depending on the conditions, the process may create a shallow molten pool or a deeper vapor cavity called a keyhole.

In **conduction-mode welding**, heat flows from the surface into the material. The weld tends to be wider and shallower.

In **keyhole-mode welding**, the energy density is high enough to vaporize a small amount of metal. Vapor pressure opens a narrow cavity. The laser energy penetrates more deeply into that cavity, producing a deeper weld.

In real shop work, the operating condition may move between these behaviors. The operator should not assume that a smooth face automatically proves full penetration.

1.2 The Main Process Variables

The most important variables include:

- laser power or programmed energy,

- travel speed,
- focal position and working distance,
- beam-wobble width,
- wobble frequency,
- torch angle,
- shielding-gas type and flow,
- filler-wire type and feed,
- joint gap and fit-up,
- material alloy, thickness, and surface condition.

These variables interact. For example, increasing power without changing travel speed can increase penetration, but it can also increase undercut, spatter, burn-through, instability, or the size of the hazardous reflection.

1.3 Beam Wobble in Plain Language

Imagine drawing a straight line with a pencil. Now imagine moving the pencil rapidly side to side while still moving forward. The second path covers more width.

That is the basic idea behind beam wobble. Internal mirrors move the focused beam through a small pattern. The result can:

- widen the fusion zone,
- help bridge limited fit-up variation,
- spread heat across the joint,
- and make hand travel more manageable.

Wobble does not eliminate the need for fit-up. A large gap still reduces support under the molten pool and may require filler wire or a redesigned joint.

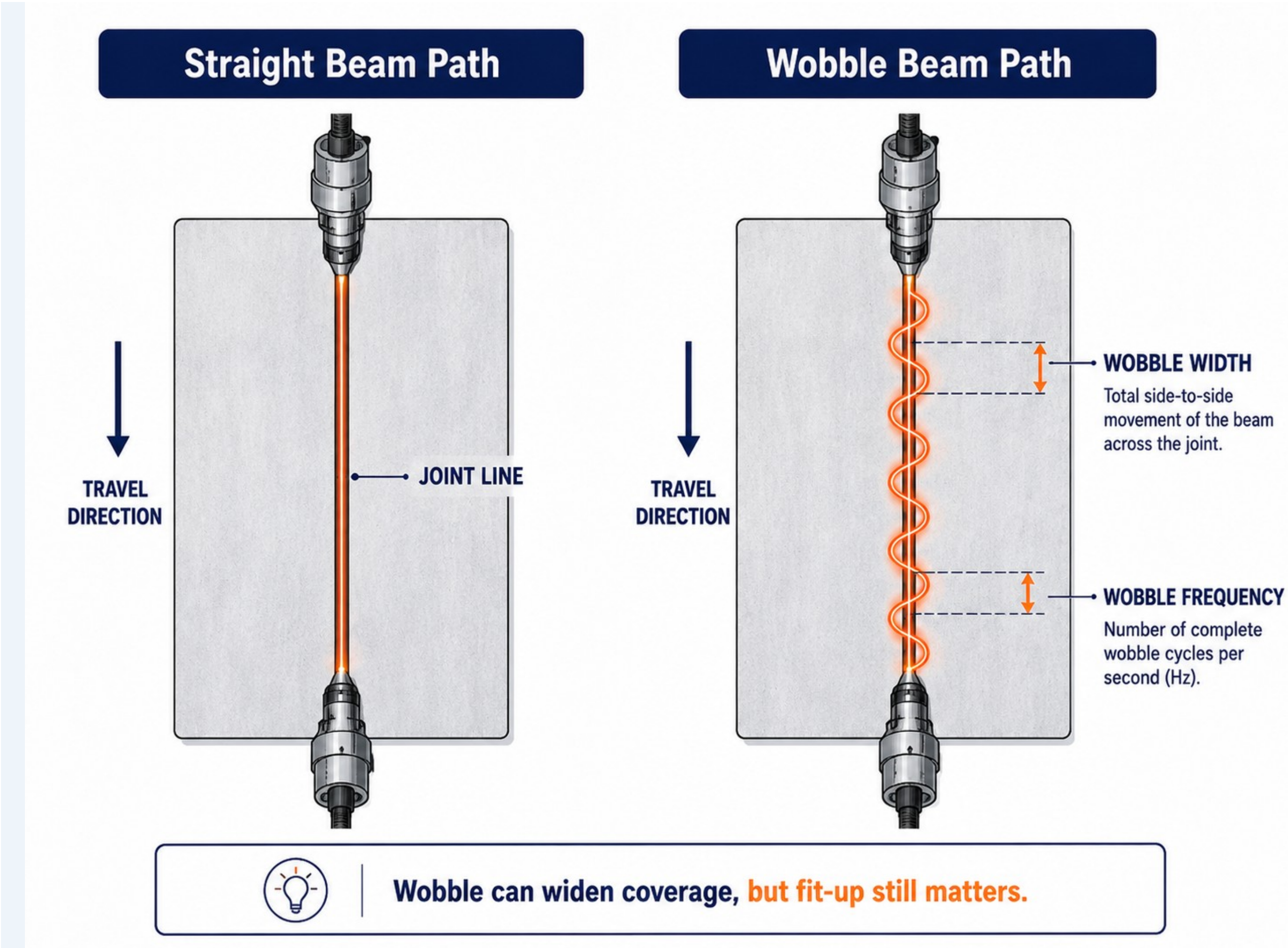

Figure 1-2. Straight and oscillating beam paths. Wobble width and frequency change how the beam covers the joint.

1.4 Comparison with Familiar Welding Processes

Compared with GTAW

Handheld laser welding can be much faster on suitable thin-gauge joints and may produce less overall distortion. GTAW, however, gives the welder direct control of the arc and filler addition and remains highly versatile for many joint conditions.

Compared with GMAW

Laser welding can produce a narrow, clean-looking joint with less spatter and less finishing on suitable parts. GMAW is generally more forgiving of heavy section, open joints, dirty work, and structural fabrication where a larger deposited weld is required.

Compared with Resistance Welding

Laser welding can create continuous seams and reach joints that are not easily clamped between electrodes. Resistance welding may still be simpler and more economical for high-volume sheet-metal spot welds.

1.5 What Handheld Laser Welding Does Well

The process is often attractive when the work has:

- repeatable fit-up,
- clean material,
- accessible seams,
- moderate thickness,
- controlled positioning,
- short finishing requirements,
- and value in reduced distortion.

> **AMERICAN WELDING SOCIETY SHOP EXAMPLE — LESS DISTORTION CHANGED THE NEXT OPERATION**
> The American Welding Society reported that a defense contractor switched from arc welding to handheld laser welding, reducing distortion enough to automate drilling that had been done by hand; AWS noted that a beginner welder completed the welding. AWS also reported a manufacturer that eliminated burn-through and reduced adhesive use. These AWS-reported examples show why the complete production result matters. [33]

1.6 Where It Can Struggle

Challenges include:

- large or changing gaps,
- inconsistent joint position,
- unknown coatings,
- contamination,
- highly reflective geometry,
- difficult out-of-position work,
- thick structural joints,
- code work without a qualified procedure,
- and parts that cannot be placed in a safe controlled area.

Shop Tip

A good demonstration weld is not the same as a production process. Test representative parts, including normal gap variation, edge condition, operator position, and the actual inspection requirement.

Key Takeaways

- Laser welds can be shallow conduction welds or deeper keyhole welds.
- Process variables interact; one setting cannot be judged alone.
- Beam wobble improves practical usability but does not replace fit-up.
- Suitability depends on the part, not only on the machine.

Chapter 2 — Safety, Fume Control, and PPE

Figure 2-1. Example of a controlled handheld laser welding area with access control, extraction, monitoring, and operator PPE.

2.1 Class 4 Means Immediate Hazard

The U.S. Food and Drug Administration describes Class IV lasers as capable of causing immediate skin and eye injury from the direct or reflected beam and as presenting a possible fire hazard.1

Many handheld welding systems operate near 1,070 nm in the near-infrared range. That beam is invisible. The absence of visible brightness does not mean the beam is absent or safe.

A current manufacturer manual for a 2 kW handheld system identifies the processing beam as Class 4 and emphasizes direct, reflected, and scattered radiation, laser-controlled operation, training, PPE, fume extraction, and fire prevention. It also separates operating, advanced-operating, maintenance, electrical, and laser-safety responsibilities. Those divisions are a useful model for any shop introducing the technology.

The American Welding Society's Safety and Health Fact Sheet No. 46 describes handheld laser welding equipment as a high-power Class 4 laser instrument. It calls for a qualified Laser Safety Officer, a documented laser safety program, a Laser Controlled Area for each point of use, and specified laser PPE. [28]

AMERICAN WELDING SOCIETY-BASED FICTIONAL SAFETY STORY — THE HELMET THAT LOOKED RIGHT

At Bay State Fabrication, a skilled GTAW welder prepared for a laser trial wearing a familiar shade helmet and ordinary safety glasses. The Laser Safety Officer stopped the test before the key was turned. The American Welding Society states that the approximately 1070 nm welding beam can be invisible and that standard welding helmets and standard safety eyewear do not provide adequate protection from laser beam hazards. The shop selected wavelength- and optical-density-rated laser eyewear and a laser welding helmet specified for the system. This is a fictional teaching story based on AWS Fact Sheet No. 46 and AWS Welding Digest guidance, not an AWS accident report. [28][30]

2.2 The Laser Controlled Area

A Laser Controlled Area is a space where access and activity are controlled because hazardous exposure may be possible. In practical shop terms, this normally means a properly evaluated room or enclosure with:

- laser-resistant barriers,
- controlled and interlocked access,
- warning signs and status lights,
- key control,
- suitable viewing methods,
- beam stops or safe backstops,
- restricted occupancy,
- documented procedures,
- and supervision by a qualified Laser Safety Officer or equivalent responsible person.

The specific design must be based on the actual laser, wavelength, power, beam divergence, process head, expected reflections, room geometry, and applicable requirements.

> **SAFETY**
> A welding curtain intended for arc welding is not automatically a laser barrier. Use materials and viewing windows rated and evaluated for the laser wavelength and exposure.

The American Welding Society specifically calls for a Laser Controlled Area at each point of use, including demonstrations. Its handheld guidance describes laser-blocking panels, interlocked access, warning signs, trained access, and laser-safe barriers and windows. [28][29]

AMERICAN WELDING SOCIETY-BASED FICTIONAL SAFETY STORY — THE OPEN-HOUSE DEMONSTRATION

A distributor planned to demonstrate a handheld laser in the center aisle of a fabrication shop. Ordinary arc curtains were available, and visitors were told they could stand back and wear welding helmets. The host company's Laser Safety Officer stopped the setup and moved the demonstration into the evaluated laser-controlled room with rated barriers, interlocked access, warning indicators, restricted occupancy, and specified laser PPE. The lesson comes directly from American Welding Society guidance: a demonstration is still a point of use and requires the same controlled approach as production. This is a fictional teaching story based on AWS guidance, not an AWS accident report. [28][29]

2.3 Class 1 Product Versus Class 4 Process

A laser source and a complete laser product are not the same thing. Under U.S. FDA rules, product classification is based on the highest accessible laser emission during operation. A complete product can therefore contain a higher-class laser source while limiting accessible emission to Class I levels through protective housing and safety features. FDA regulations use Roman numerals such as Class I and Class IV; many current manuals and standards use Class 1 and Class 4.[24][25]

The practical point is that a Class 1 statement belongs to a specific complete product and configuration. It does not automatically apply to a laser source, a curtain, a room, or a booth assembled from separate components. FDA guidance describes making, assembling, importing, and modifying laser products as manufacturer activities, so the party that creates or changes the final system may take on regulatory responsibilities. The exact result depends on the facts and should be reviewed by qualified regulatory and laser-safety professionals.[26]

During handheld welding, the high-power process beam must reach the workpiece. Unless the complete installed system controls access to hazardous emission and has been evaluated and certified for that condition, the conservative shop-floor approach is to manage the operation as a Class 4 hazard.[12][24]

Before accepting a “Class 1” description, confirm the following:

- The exact complete product or installed configuration covered by the classification.
- The manufacturer, importer, or integrator responsible for the final product.
- The location of the certification label, classification basis, installation instructions, and operating limitations.
- The part openings, pass-throughs, service modes, interlock-defeat conditions, and viewing arrangements included in the evaluation.
- The field changes that require qualified reevaluation, manufacturer approval, or additional reporting.

> **FICTIONAL SHOP STORY — THE “CLASS 1” BOOTH THAT CHANGED**
> Maple Street Fabrication purchased a handheld welder and a prefabricated enclosure advertised as a Class 1 solution. The original design included an interlocked door, a rated viewing window, and defined cable penetrations. After delivery, the shop cut a larger opening for a fume duct, added a pass-through for long parts, and temporarily bypassed the door switch during setup. No one was injured, but the Laser Safety Officer stopped commissioning because the installed configuration no longer matched the evaluated design. The lesson was not that Class 1 enclosures are unreliable. The lesson was that classification belongs to a specific complete configuration, and openings, barriers, windows, interlocks, and modifications must stay within that approved design.[24][25][26]

2.4 Direct, Specular, and Diffuse Reflections

A mirror-like reflection is called **specular**. It can redirect a concentrated portion of the beam. A rough surface produces more **diffuse** scattering, but a high-power laser can still make scattered energy hazardous.

The reflection direction changes with:

- torch angle,

- part angle,
- material,
- surface finish,
- molten-pool shape,
- and beam motion.

Highly reflective metals require special care, but even steel can create hazardous reflections at the wrong angle.

Back-reflection hazard. A back reflection can return a concentrated portion of the laser energy toward the operator, the welding head, or another surface; on curved work, the likely reflection direction changes as the torch moves. IPG Photonics warns that secondary beams can occur at various angles and may remain intense enough to injure the eye, while the LightWELD 2000 XR manual warns that high-power specular reflections can travel long distances and endanger both eyes and skin.[23][11]

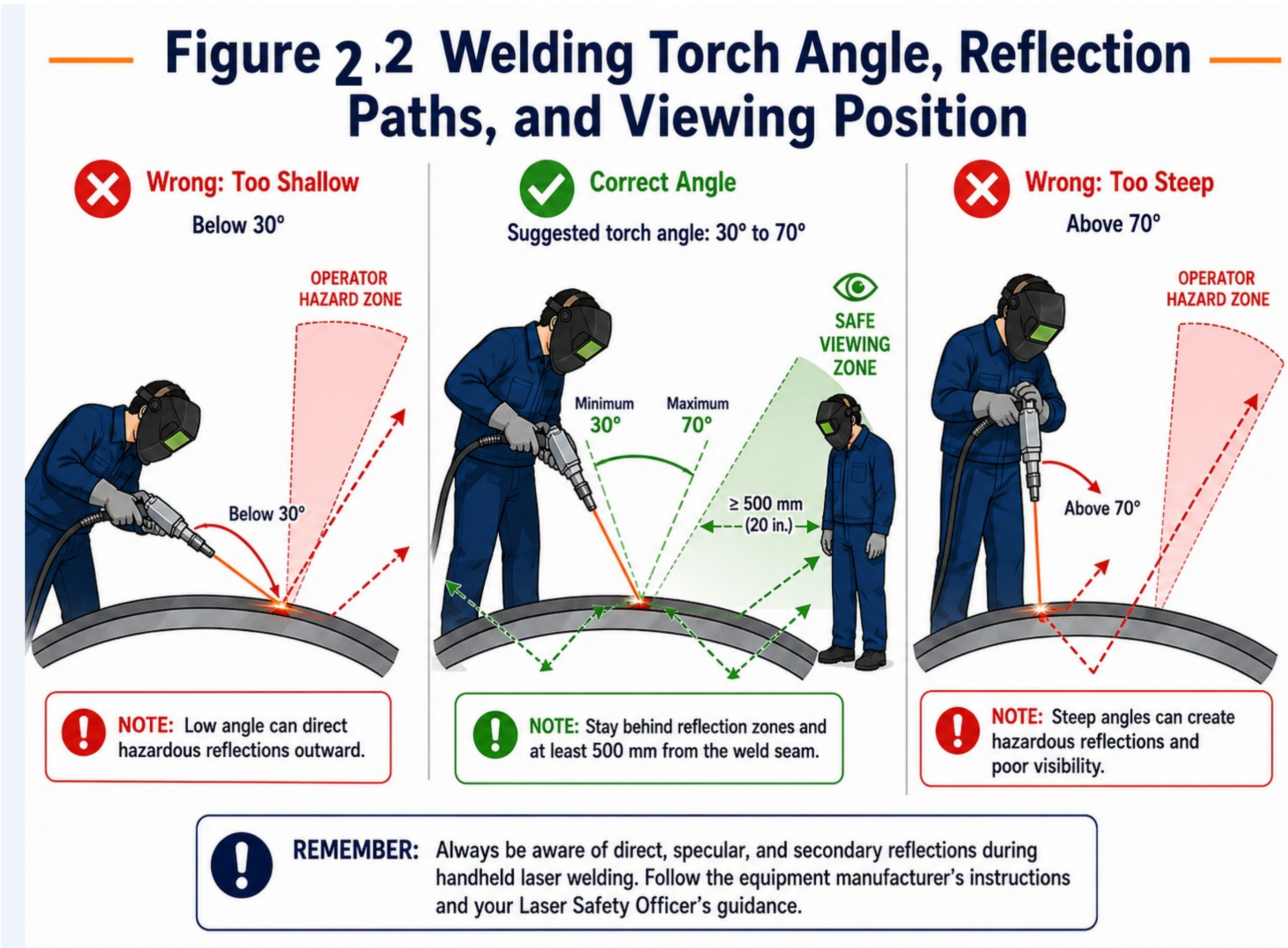

Figure 2.2. A curved surface changes the reflection direction as the torch moves. For the LightWELD 2000 XR, IPG specifies a torch angle from 30° to 70° and a viewing position at least 500 mm (20 in.) from the weld seam and behind the reflection zones. [11]

AMERICAN WELDING SOCIETY-BASED FICTIONAL SAFETY STORY — THE CURVE CHANGED THE HAZARD

At Harbor Sheet Metal, Maria was qualifying a seam around a curved stainless cover. Her torch angle stayed within the equipment guidance, but the likely specular-reflection direction swept across the room as she moved around the radius. During a beam-off review, the Laser Safety Officer noticed that the access door and a shiny tool cart entered the changing reflection zone. The fixture, backstop, and authorized viewing position were changed before emission. The American Welding Society warns that mirror-like reflections can cause instantaneous and permanent severe eye or skin damage and that reflective materials and surface geometry must be evaluated. This is a fictional teaching story based on AWS guidance and manufacturer information, not an AWS accident report. [28][29][32]

2.5 Eye and Face Protection

Laser eyewear must match the wavelength and expected exposure. Optical density is not a universal rating; it is meaningful only for the stated wavelength range and conditions.

The operator may also need a welding helmet or face shield to protect from:

- visible process brightness,
- ultraviolet and infrared process radiation,
- sparks,
- hot particles,
- and direct mechanical impact.

Do not select eyewear by lens color. Use the machine manufacturer's requirements and a qualified laser-safety assessment.

Inspect eyewear before use. Remove it from service if it has:

- cracks,
- deep scratches,
- crazing,
- discoloration,
- damaged coatings,
- loose frames,
- or unreadable markings.

2.6 Clothing and Skin Protection

Class 4 radiation can injure skin. The welding process also creates UV, infrared, hot surfaces, and sparks. Typical protection may include:

- laser- and heat-resistant gloves,
- flame-resistant clothing,
- closed collar and cuffs,
- protective cap,
- leather or approved apron,
- safety footwear,
- and suitable helmet or face protection.

The exact ensemble should come from the hazard assessment and manufacturer instructions.

2.7 Welding Fumes Are Still Welding Fumes

Laser welding may produce less visible smoke in some conditions, but low visibility does not equal low exposure. Welding fumes are complex mixtures that depend on the base metal, filler, coatings, surface contamination, and process.

NIOSH notes that welding fumes contain metals and commonly include manganese. Inhaled manganese is a concern because it can affect the lungs and nervous system.[2]

NIOSH also identifies the eyes, skin, respiratory system, and central nervous system as target organs for welding-fume exposure.[3]

Materials that deserve particular attention include:

- stainless steel,
- galvanized steel,
- nickel alloys,
- chromium-containing alloys,
- painted or plated parts,
- lead- or cadmium-containing surfaces,
- and unknown repair parts.

2.8 Local Exhaust Ventilation

The preferred approach is to capture contaminants close to where they are generated. OSHA guidance for laser operations calls for adequate ventilation to control hazardous fumes and vapors from laser welding and other target interactions.[4]

A practical fume system should be:

- sized for the process,
- positioned close enough to capture the plume,
- arranged so it does not pull shielding gas away from the weld,
- equipped with suitable filtration,
- maintained on schedule,
- and evaluated with representative materials.

NIOSH documents source-capture methods as an effective engineering-control approach for welding fumes.[5]

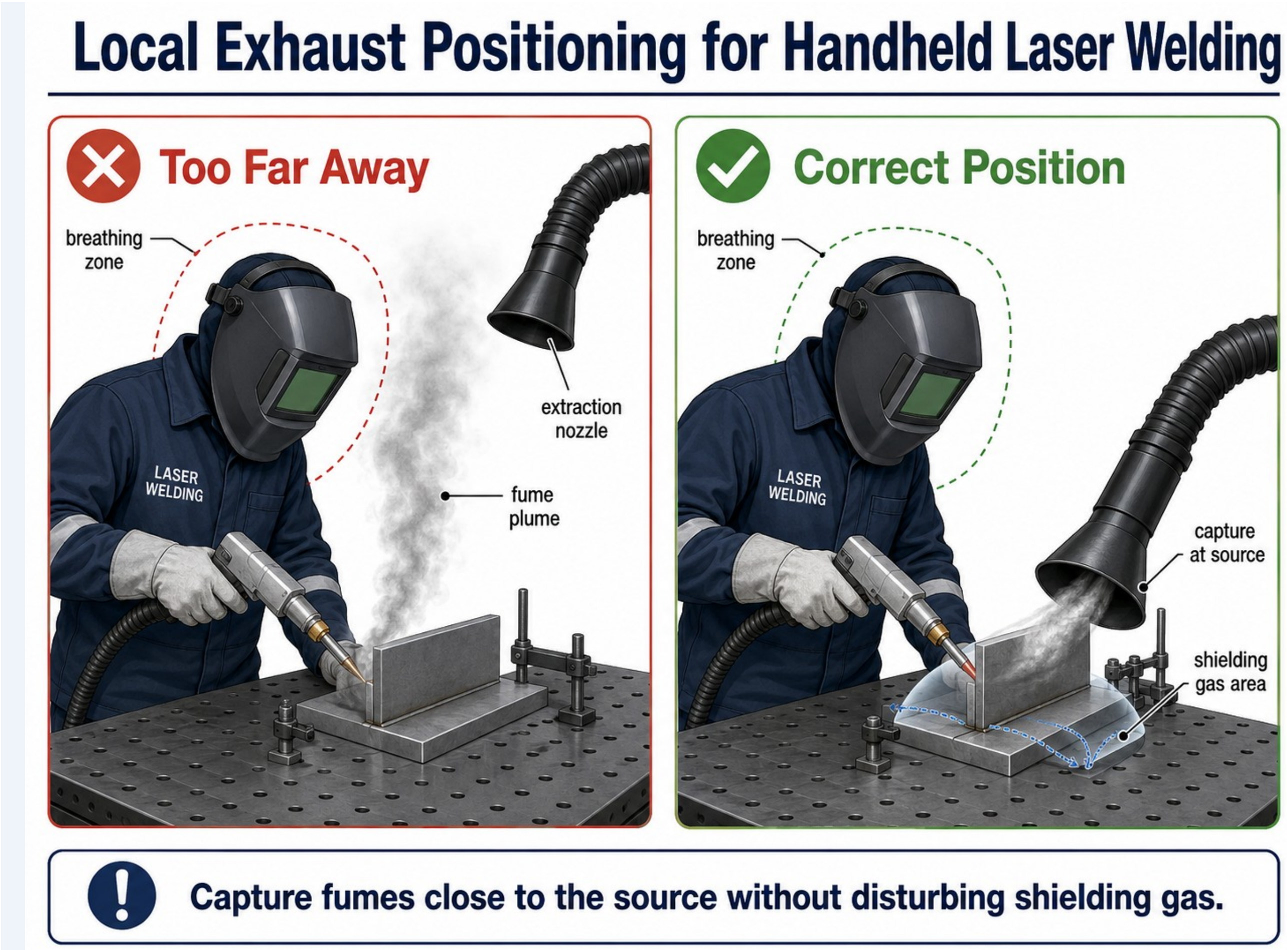

Figure 2-3. Local exhaust should capture the fume near its source without pulling shielding gas away from the weld.

FICTIONAL SHOP STORY — THE HOOD SOUNDED STRONG

A small shop began welding galvanized brackets with an extraction hood positioned well above the table. The fan was loud and the visible smoke looked minor, so the setup seemed adequate. During a capture-visualization review, an industrial hygienist showed that the plume passed through the operator's breathing zone before reaching the hood. The shop moved the hood closer, adjusted the angle, verified that shielding gas was not being pulled away, and added filter and airflow checks to the startup routine. The lesson was simple: fan noise and low visible smoke are not proof of effective exposure control.[2][4][5][22]

2.9 Respirators

Respirators may be needed when engineering controls cannot adequately control exposure, during certain maintenance tasks, or while controls are being improved. A respirator is not just another piece of PPE to hand out. In the United States, required respiratory protection normally involves a formal program, medical evaluation, fit testing, selection, training, and maintenance.

An industrial hygienist can help determine whether air sampling is needed and what contaminants must be measured.

2.10 Fire and Explosion Hazards

Laser welding can ignite combustible material and can penetrate thin work. Before welding:

- remove flammable materials,
- check the far side of the joint,
- inspect cavities and hidden spaces,
- do not weld unknown containers,
- control sparks and hot metal,
- maintain appropriate extinguishing equipment,
- and use a hot-work permit where required.

A beam that passes through a seam can strike material behind the part. Provide a suitable laser-rated and fire-resistant backstop.

> **AMERICAN WELDING SOCIETY-BASED FICTIONAL SAFETY STORY — THE BEAM DID NOT END AT THE SEAM**
> During a beam-off setup review of a thin-gauge box, the team noticed a maintenance aisle directly behind the joint. Controlled testing with a properly positioned laser-rated witness backstop showed that full penetration could leave hazardous energy beyond the seam. The Laser Safety Officer relocated the job, installed a laser-rated fire-resistant backstop, and restricted the line of sight. The American Welding Society tells operators not to place any body part behind the weld joint, and AWS guidance warns that laser hazards can persist over long distances along an unprotected path. This is a fictional teaching story based on AWS guidance, not an AWS accident report. [31][32]

2.11 Gas Cylinder and Asphyxiation Hazards

Shielding gas cylinders must be secured, protected from damage, and used with compatible regulators and hoses.

Argon can displace oxygen. This is especially important in small rooms, pits, tanks, and other confined spaces. A room can look normal while oxygen concentration is becoming unsafe.

2.12 Electrical and Stored-Energy Hazards

High-power laser welders may require significant electrical service and include internal high-voltage components. Electrical installation should be performed by qualified personnel and follow the current manual and local electrical code.

Do not open the equipment unless the manufacturer specifically identifies the task as user-serviceable and the person is qualified to perform it.

2.13 Training and Roles

A responsible program distinguishes between:

- operator,
- advanced operator or process technician,
- maintenance technician,
- electrician,
- welding supervisor or engineer,
- inspector,
- and Laser Safety Officer.

The operator should know what can be adjusted and what must be escalated.

2.14 Responsibility by Role

Safety responsibilities overlap. A purchase contract can assign tasks, but it does not necessarily eliminate duties imposed by law, and no single party should assume that someone else owns an unnamed responsibility.

Manufacturer or importer. Designs, classifies, certifies, labels, documents, tests, and reports the laser product as applicable to its role and the governing requirements.[24][25][26]

System integrator. Evaluates and documents the complete installed machine within the contracted scope, including interfaces, barriers, interlocks, safety functions, limitations, installation conditions, and validation. Depending on what is assembled or modified, the integrator may also have manufacturer responsibilities.[26]

Employer or owner. Provides a safe workplace and owns the site-specific program: hazard evaluation, controlled area, Laser Safety Officer authority, ventilation, PPE, training, operating procedures, maintenance, emergency response, and supervision.[27]

Laser Safety Officer. Administers the laser-safety program, evaluates hazards and controls, approves procedures and changes within the person's authority, supports training, and performs or coordinates audits.[12]

Process owner or welding engineer. Defines the welding procedure, process window, qualification plan, inspection method, acceptance criteria, and change-control rules.[15]

Operator. Uses only authorized equipment and procedures, performs required pre-use checks, remains in the approved position, protects the fiber and optics, and stops work when the part, setup, controls, or process no longer match the approved condition.

> **PRACTICAL RULE**
> Not every supplier must provide every service, but every responsibility must have a named owner before commissioning. "The vendor is taking care of safety" and "the customer owns everything after delivery" are both too vague for a Class 4 process.

Safety Planning Checklist

- [ ] Current manufacturer manual available at the machine
- [ ] Qualified laser-safety review completed
- [ ] Controlled area designed and documented
- [ ] Barriers and windows rated for the laser
- [ ] Door interlocks and warning indicators tested
- [ ] Key-control procedure in place
- [ ] Reflection paths evaluated
- [ ] Fume extraction installed and verified
- [ ] PPE selected and inspected
- [ ] Fire hazards and back side of weld controlled
- [ ] Gas cylinders secured
- [ ] Operator training documented
- [ ] Emergency procedures posted
- [ ] Maintenance responsibilities assigned

Key Takeaways

- Class 4 hazards include direct, reflected, and scattered energy.
- Engineering controls come before PPE.
- Invisible fumes and invisible laser radiation must both be taken seriously.
- Safety is a system: enclosure, access control, extraction, procedures, training, and PPE.
- Class 1 describes the accessible emission of a specific complete product; it is not a casual synonym for “we put curtains around it.”
- Manufacturer, integrator, employer, LSO, process-owner, and operator responsibilities should be documented before operation.

Chapter 3 — The Equipment and Its Supporting Systems

Figure 3-1. Major components of a modern integrated handheld laser welding system, illustrated with an IPG Photonics LightWELD 2000 XR. The light-gray curtain represents a laser-rated barrier selected for the specific installation.

ILLUSTRATION LIMITATION
Figure 3-1 is a component-identification illustration, not a complete safety design. The visible curtains and open arrangement should not be interpreted as sufficient by themselves. A real installation requires a site-specific evaluation of barrier ratings, seams and openings, access control, interlocks, reflections, viewing, ventilation, fire hazards, and the exact operating configuration.[11][12][14]

3.1 Laser Source

The source creates the processing beam. Handheld systems commonly use continuous-wave fiber lasers, sometimes with pulsed or high-peak-power operating modes.

Important source characteristics include:

- wavelength,
- rated average power,

- available peak power,
- modulation capability,
- beam quality,
- cooling demand,
- and control interface.

Do not compare machines only by the largest wattage number printed on the cabinet.

3.2 Cooling System

Cooling design varies. Some systems use liquid chillers; the LightWELD 2000 XR is air-cooled, with the laser source, controls, and cooling packaged in one main unit. Keep airflow openings clear and follow IPG Photonics' installation-clearance requirements [11].

The shop must follow manufacturer requirements for:

- ambient temperature and airflow clearance,
- vents, filters, and fan condition,
- coolant type and water quality when liquid cooling is used,
- freeze protection when applicable,
- and scheduled cleaning and service.

3.3 Delivery Fiber

The delivery fiber carries high optical power from the source to the torch. It is not an ordinary cable.

Protect it from:

- sharp bends,
- crushing,
- hot slag,
- vehicle traffic,
- twisting,
- contamination at connectors,
- and pulling loads.

A damaged high-power fiber can be expensive and unsafe.

3.4 The Processing Head

A typical handheld head contains:

- beam collimation optics,
- motorized wobble mirrors,
- a focusing lens,
- a protective window,
- a nozzle,
- trigger controls,
- status indicators,
- gas passages,
- and safety sensors.

The protective window is a sacrificial optical component that helps shield more expensive internal optics from smoke and spatter.

3.5 Nozzles and Stand-Off

Nozzles may be shaped for butt joints, corners, fillets, outside corners, wire feeding, or cleaning. The correct nozzle helps the operator maintain:

- working distance,
- angle,
- joint tracking,
- and gas coverage.

The nozzle is not just a convenience. On some systems, it also participates in a workpiece-contact safety circuit.

3.6 Workpiece Clamp and Interlocks

Some handheld systems require electrical contact between the nozzle, workpiece, and work clamp before enabling emission. Other interlocks may monitor:

- fiber connection,
- door status,
- gas pressure,
- temperature,
- plasma or back reflection,
- trigger sequence,
- and emergency stop.

Never bypass an interlock to "keep production running."

> **AMERICAN WELDING SOCIETY-BASED FICTIONAL SAFETY STORY — THE JUMPER-WIRE REQUEST**
> A production lead asked a technician to jumper the workpiece-contact circuit because an oxidized clamp was causing nuisance faults. The technician stopped, locked out the machine, repaired the connection, and tested the safety functions under the approved procedure instead. The American Welding Society identifies key switches, emergency stops, external interlocks, two-stage triggers, plasma detection, workpiece-contact circuits, and fiber interlocks as important safeguards, and it states that only qualified persons should install, operate, maintain, or repair the equipment. This is a fictional teaching story based on AWS guidance, not an AWS accident report. [28][29]

3.7 Shielding Gas System

The system may use argon, nitrogen, or another manufacturer-approved gas depending on the material and application. Gas delivery includes:

- cylinder or bulk supply,
- regulator,
- flow control,
- hose,
- machine valves,

- and nozzle passages.

Gas purity, leaks, pressure, flow, and nozzle position all affect results.

3.8 Wire Feeder

Filler wire can help with:

- gaps,
- joint reinforcement,
- alloy control,
- edge protection,
- and fillet size.

The wire feeder must deliver the correct wire at a stable speed and angle without interfering with the torch or reflection plan.

3.9 Fume Extraction

The extractor is supporting process equipment, not an optional cleaning appliance. It should be included in the cell layout from the start.

3.10 Electrical Service and Shop Utilities

Before delivery, confirm:

- voltage and phase,
- breaker and disconnect,
- receptacle or hardwiring requirements,
- grounding,
- gas supply,
- extraction power,
- floor loading,
- access clearances,
- and room cooling.

3.11 The Machine Is Not the Whole Process

A handheld laser welder becomes useful only when the supporting process is complete. A responsible deployment addresses:

- the laser source, torch, fiber, controls, and approved accessories;
- the enclosure or Laser Controlled Area, barriers, interlocks, and reflection control;
- local exhaust ventilation, filtration, and material-specific fume concerns;
- shielding gas, cylinders, regulators, and safe routing;
- laser eyewear, helmet or face protection, clothing, gloves, and inspection of PPE;
- operator, LSO, maintenance, process, inspection, and emergency training;
- representative application testing, documented process limits, and acceptance criteria;
- inspection, maintenance, output verification, records, and change control;
- and clear supplier, integrator, employer, and operator responsibilities.

A supplier may provide some or all of these elements. The buyer's job is not to do everything alone; it is to verify that nothing important has been left without an owner.[11][12][27]

Installation Acceptance Checklist

- Current manual for the exact model reviewed and available.
- Electrical load and installation requirements confirmed from the nameplate and manual.
- Laser Controlled Area complete before commissioning.
- Extraction and shielding-gas systems operational and verified.
- Interlocks tested and results documented.
- Operators trained on startup, shutdown, normal operation, and emergencies.
- Clean, controlled storage provided for optics and consumables.
- Safety, process development, training, acceptance, maintenance, and post-installation responsibilities assigned in writing.

Key Takeaways

- A handheld laser welder is a complete system, not only a torch.
- Optical fiber and protective optics require careful handling.
- Interlocks are part of the safety design.
- Utilities, extraction, and the controlled area should be planned before delivery.
- The machine, safety system, process procedure, inspection plan, training, and maintenance program should be purchased and managed as one complete process.

Chapter 4 — Materials, Joint Design, and Part Preparation

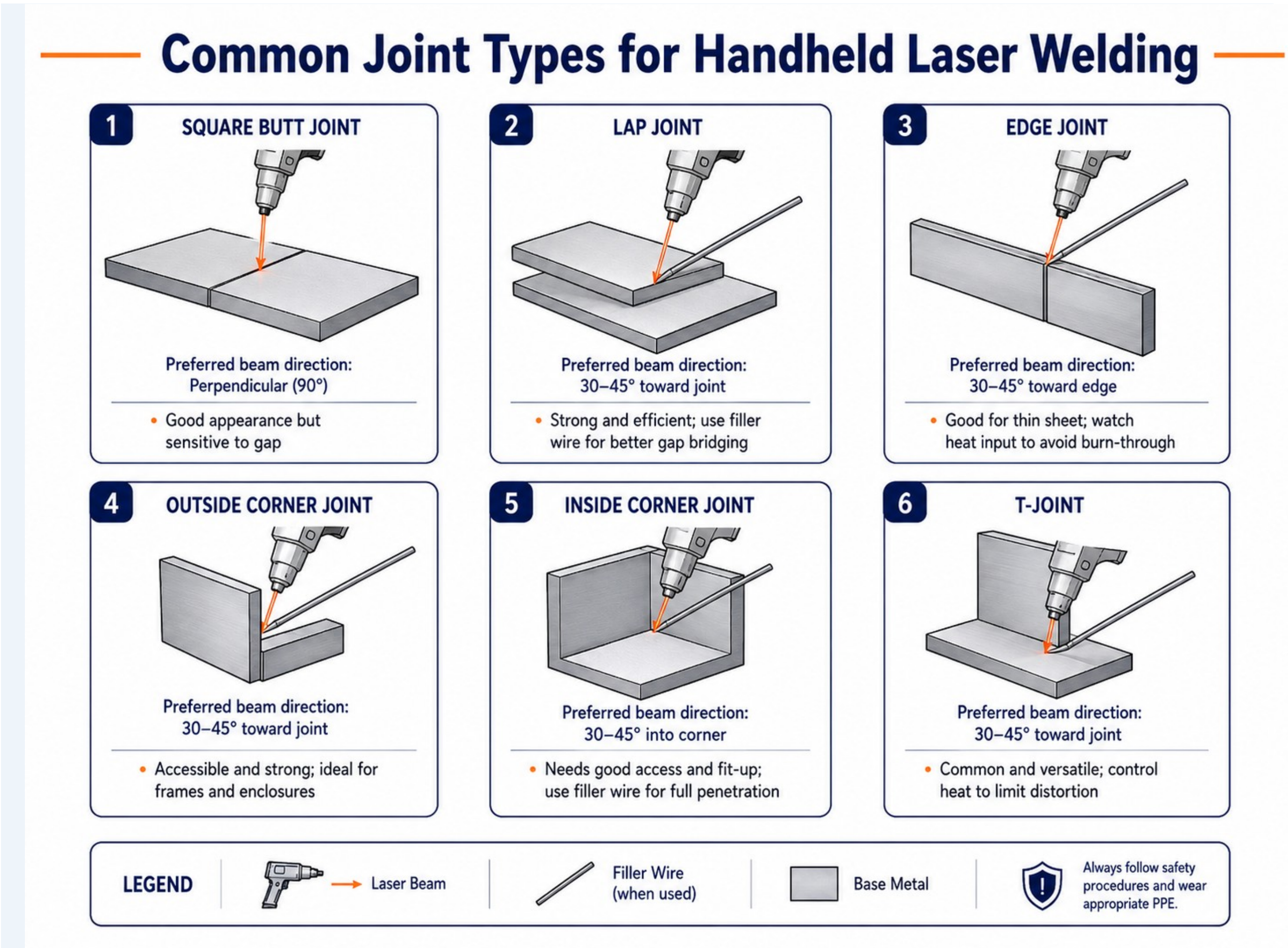

Figure 4-1. Common joint types used in handheld laser welding. Final torch position and parameters must follow the qualified procedure and machine guidance.

4.1 Material Identification Comes First

Do not build a process around "some stainless" or "probably aluminum." Record:

- base-metal specification or alloy,
- thickness,
- temper or condition,
- coating,
- surface finish,
- filler metal,
- and intended service.

Material identification affects absorption, melting behavior, cracking risk, fumes, corrosion, and inspection.

4.2 Mild and Carbon Steel

Clean carbon steel is often a practical starting material. Watch for:

- mill scale,
- oil,
- rust,
- paint,
- plating,
- and sulfur or phosphorus effects.

Low visible spatter does not eliminate the need for fume control.

4.3 Stainless Steel

Stainless steel is a common handheld application because low distortion and appearance can be valuable. Important concerns include:

- chromium- and nickel-containing fumes,
- heat tint,
- corrosion performance,
- backside oxidation,
- alloy mix,
- and final cleaning or passivation requirements.

The correct acceptance criteria depend on service. A decorative enclosure and a sanitary product-contact surface are not the same job.

4.4 Galvanized Steel

Zinc vaporizes at a much lower temperature than steel melts. Trapped zinc vapor can cause porosity, spatter, instability, and hazardous fumes.

Joint design may need a controlled vent path. Coating removal may be appropriate in some work, but any change must consider corrosion protection and customer requirements.

4.5 Aluminum

Aluminum reflects much near-infrared energy when cold and conducts heat quickly. Its oxide melts at a much higher temperature than the base metal. Some alloys are crack-sensitive.

Control:

- alloy identification,
- oxide and contamination,
- joint gap,
- filler selection,
- heat input,
- and torch/reflection angle.

4.6 Copper, Brass, and Other Reflective Alloys

Copper and brass can be difficult for near-infrared sources because of reflectivity and thermal conductivity. Some modern systems offer operating modes intended to improve coupling, but the application must still be proven by testing.

Brass also introduces zinc-fume concerns.

4.7 Coatings and Unknown Surfaces

Paint, oils, plating, sealants, adhesives, and cleaning chemicals can:

- contaminate the weld,
- create porosity,
- produce hazardous decomposition products,
- damage optics,
- and start fires.

Unknown repair parts should be treated as unknown hazards until identified.

4.8 Fit-Up

Laser welding rewards accurate fit-up.

Track:

- gap,
- mismatch or hi-low,
- edge straightness,
- joint location,
- tack size,
- fixture pressure,
- and distortion during welding.

A common error is to qualify a process on perfectly machined coupons, then release it to production parts with variable gaps.

4.9 Joint Types

Square Butt Joint

Efficient and low in filler volume, but sensitive to gap and beam position.

Lap Joint

Offers molten-metal support and can be easier to fixture. It may create crevice-corrosion or inspection concerns.

Outside Corner

Often produces attractive visible seams, but edge fit-up and melt loss must be controlled.

Inside Corner and Fillet

May require filler wire to obtain the required throat or leg size. A fused line at the root is not automatically an acceptable fillet weld.

Edge Joint

Useful on thin enclosures but sensitive to edge condition and alignment.

4.10 Cleaning and Preparation

A basic preparation sequence may include:

1. Verify material.
2. Remove oil and shop dirt.
3. Remove inappropriate coatings.
4. Prepare edges.
5. Clean oxide as required.
6. Avoid recontamination.
7. Fixture the part.
8. Record joint gap.
9. Make and inspect trial welds.

Use cleaning products compatible with the material and downstream service. Do not use chlorinated solvents near welding.

Shop Worksheet — Joint Readiness

Item	Requirement	Actual	Accept/Reject
Material/alloy			
Thickness			
Coating			
Joint type			
Maximum gap			
Maximum mismatch			
Surface preparation			
Fixture method			
Backside condition			

Key Takeaways

- Material identity and condition must be documented.
- Fit-up is one of the most important process inputs.
- Joint type affects reflection, support, strength, corrosion, and inspection.
- Preparation is part of welding, not a separate cosmetic step.

Chapter 5 — Operating Technique and Process Parameters

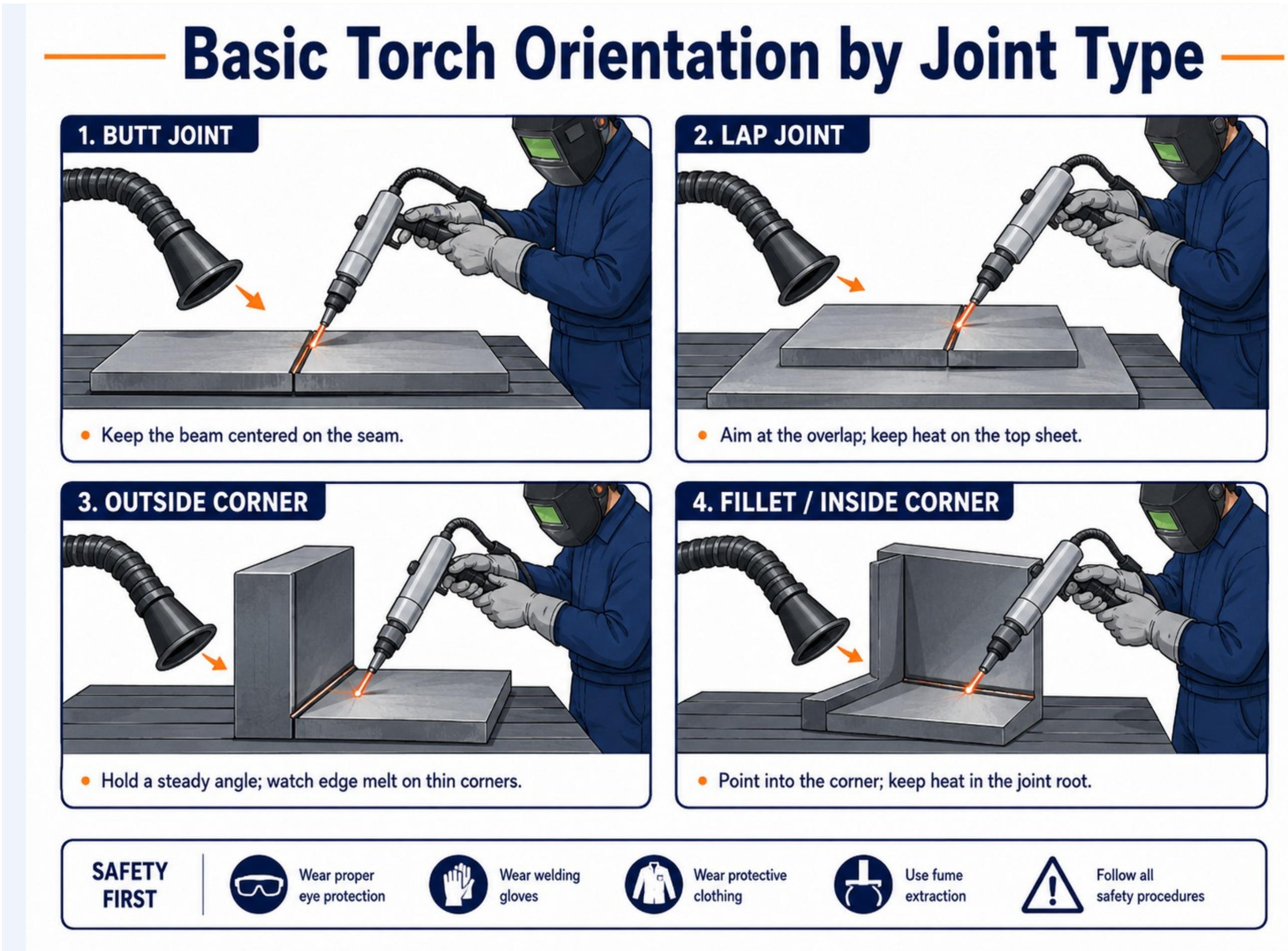

Figure 5-1. Basic torch-orientation concepts for several joint types. Exact angles and travel technique depend on the equipment, joint, material, and qualified procedure.

5.1 Start with the Manufacturer Recipe

Preset recipes are useful starting points, not proof that a production weld is acceptable. Begin with the recommended setting for:

- material,
- thickness,
- joint,
- gas,
- wire,
- and operating mode.

Then test the actual part.

5.2 Power

More power generally increases the available melting capacity. Too little can cause:

- lack of fusion,
- shallow penetration,
- irregular tie-in,
- and intermittent bonding.

Too much can cause:

- burn-through,
- undercut,
- excessive keyhole activity,
- spatter,
- porosity,
- distortion,
- or optical contamination.

5.3 Travel Speed

Travel speed controls how long energy acts on each part of the joint.

Too fast may produce incomplete fusion or a narrow unstable seam. Too slow may create excessive penetration, overheating, undercut, or burn-through.

Hand travel should be smooth. Starting, stopping, and changing wrist angle can create defects even when the machine display remains unchanged.

5.4 Focus and Working Distance

The optical system is designed to place the focused beam at a controlled location. Incorrect stand-off changes spot size and energy density.

Nozzle guides can help, but the operator must keep them properly seated and oriented.

5.5 Wobble Width

Increasing wobble width spreads energy across a wider area. This can increase joint coverage but may reduce penetration if power and speed are unchanged.

5.6 Wobble Frequency

Frequency is how many times the beam completes its pattern per second. It interacts with travel speed and width. A pattern that works at one speed may leave a different overlap at another speed.

5.7 Torch Angle

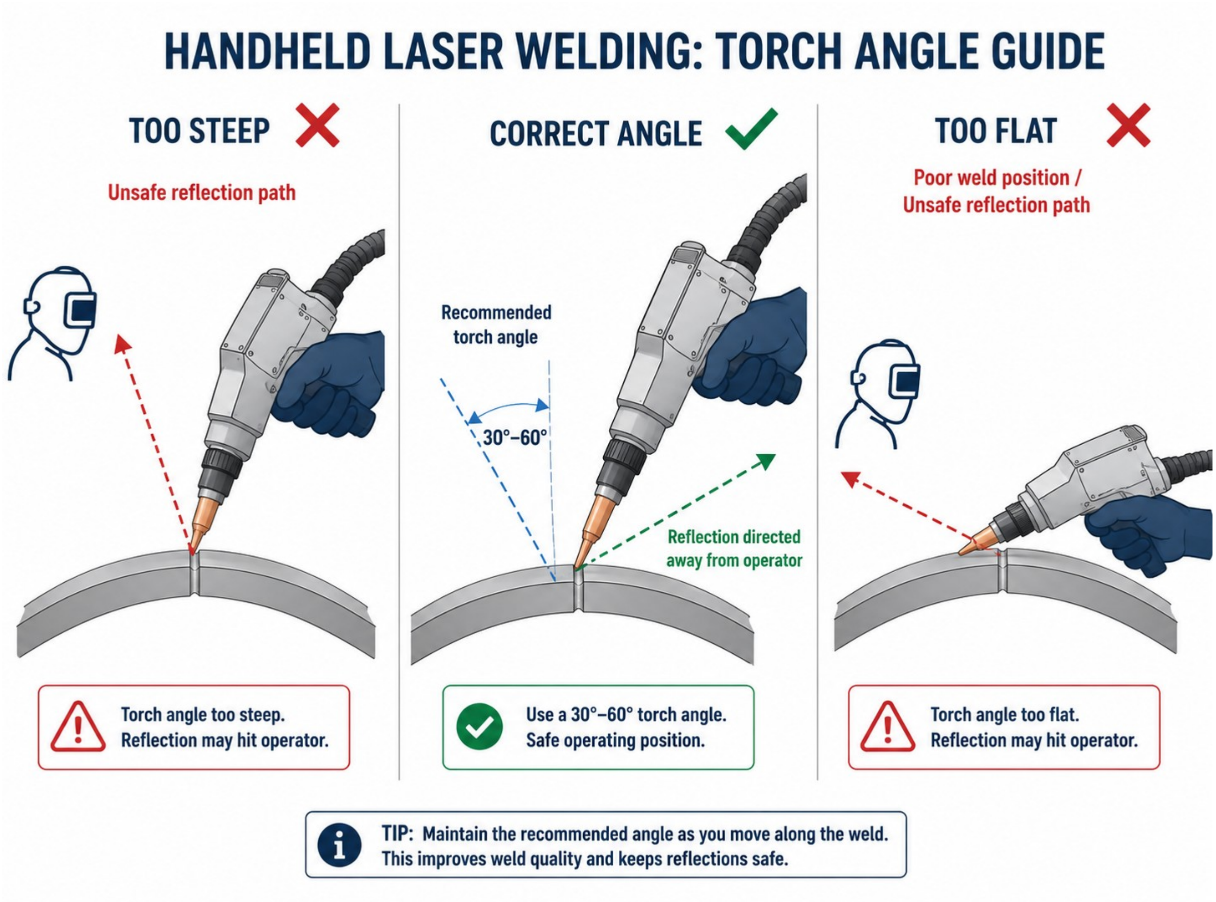

Figure 5-2. Torch-angle training illustration. Verify machine-specific guidance with the manufacturer and Laser Safety Officer.

Torch angle affects:

- beam entry,
- reflection direction,
- gas coverage,
- access,
- wire position,
- and effective geometry.

Do not lean over the expected reflection path. Establish an approved angle range during process development.

5.8 Starts and Stops

Starts and stops are common defect locations. Look for:

- crater or depression,
- excess buildup,
- missed tie-in,
- pinhole,
- oxidation,
- and local burn-through.

Use programmed ramping or overlap where the system and procedure allow it.

5.9 Tack Welding

Tacks must:

- hold alignment,
- fit under the final pass,
- avoid excessive contamination,
- and not create large local gaps.

A tack that is too large can disturb the final beam path.

5.10 A One-Variable-at-a-Time Method

When possible:

1. Establish a baseline.
2. Record all settings.
3. Change one variable.
4. Make a labeled coupon.
5. Inspect visually.
6. Section or test when penetration matters.
7. Record the result.
8. Keep the best condition and continue.

Changing power, speed, wobble, gas, and angle at the same time makes learning difficult.

Parameter Development Sheet

Coupon ID	Power	Speed	Wobble Width	Frequency	Gas/Flow	Wire/ Speed	Angle	Result

Operator Technique Checklist

- [ ] Correct program selected
- [ ] Correct nozzle installed
- [ ] Lens window inspected
- [ ] Gas flowing
- [ ] Extraction positioned
- [ ] Joint gap acceptable
- [ ] Work clamp connected
- [ ] Reflection path clear
- [ ] Stable stance and cable routing
- [ ] Approved travel direction
- [ ] Start/stop location planned
- [ ] Trial coupon accepted

Key Takeaways

- Parameters work as a system.
- Operator angle and travel are process variables.
- Change one variable at a time during development.
- Starts, stops, tacks, and corners deserve separate inspection.

Chapter 6 — Shielding Gas, Wire, and Consumables

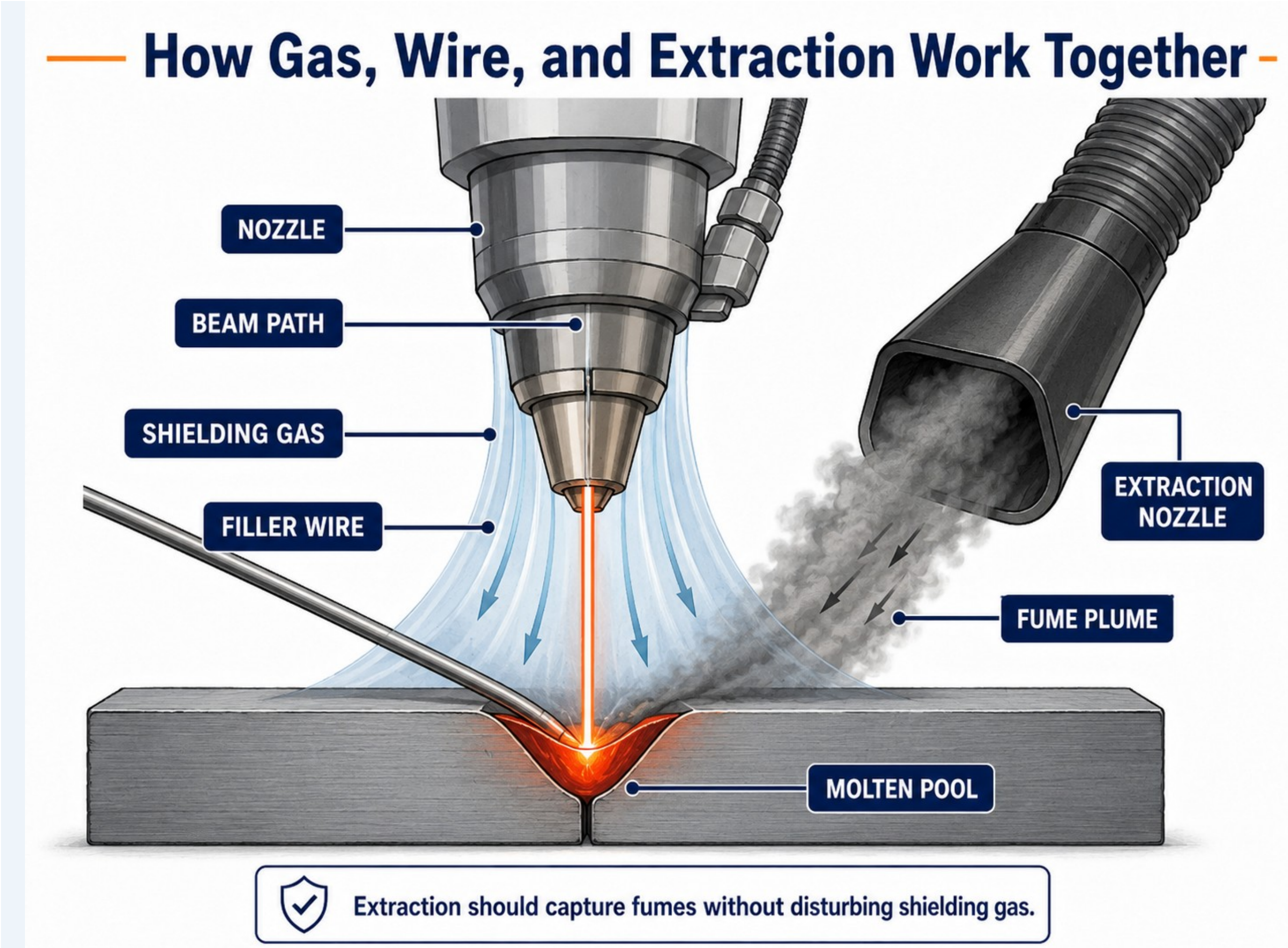

Figure 6-1. The beam, shielding gas, filler wire, and extraction must work together without interfering with one another.

6.1 Why Shielding Gas Is Used

Shielding gas limits contact between the molten metal and the surrounding atmosphere. It can affect:

- oxidation,
- weld color,
- surface finish,
- porosity,
- plasma behavior,
- and lens contamination.

The correct gas depends on the machine, material, and procedure.

6.2 Argon and Nitrogen

Argon is widely used because it is inert and suitable for many metals. Nitrogen may be acceptable for selected stainless applications but can affect metallurgy in some alloys.

Use only gases approved for the application and equipment.

6.3 Flow Problems

Too little gas can cause oxidation and inconsistent protection. Too much flow can create turbulence and pull room air into the shielding zone.

Common problems include:

- leaking fittings,
- damaged hoses,
- wrong regulator,
- low cylinder pressure,
- blocked nozzle,
- extraction placed too close,
- or torch angle that exposes the pool.

6.4 Filler Wire

Filler wire may be needed when:

- joint gap cannot be eliminated,
- required reinforcement exceeds simple fusion,
- crack-sensitive material needs a suitable filler,
- fillet size must be built,
- or chemistry must be controlled.

Wire classification should match the base material, service, and applicable procedure.

6.5 Wire Position

The wire should feed into the leading or approved portion of the molten pool without blocking the beam. Poor wire angle can cause:

- stubbing,
- balling,
- intermittent transfer,
- lack of fusion,
- or contamination of the nozzle and window.

6.6 Protective Windows

The protective window is a consumable optical barrier. Its condition affects transmitted power and beam quality.

Signs of trouble include:

- visible spatter,
- haze,
- discoloration,
- cracking,
- repeated overtemperature alarms,
- or a process that gradually requires more displayed power.

Never touch optical surfaces with bare fingers. Follow the exact manufacturer procedure for inspection and replacement.

6.7 Nozzles and Guides

Inspect for:

- spatter buildup,
- bending,
- worn contact surfaces,
- damaged insulation,
- blocked gas passages,
- and incorrect assembly.

Consumables Control Log

Date	Machine	Item	Part Number	Lot	Installed By	Reason	Next Check

Key Takeaways

- Shielding gas affects weld quality and surface condition.
- More gas is not always better.
- Filler wire is a process variable, not a patch for uncontrolled fit-up.
- Optical consumables must be kept clean and documented.

Chapter 7 — Building and Documenting a Welding Process

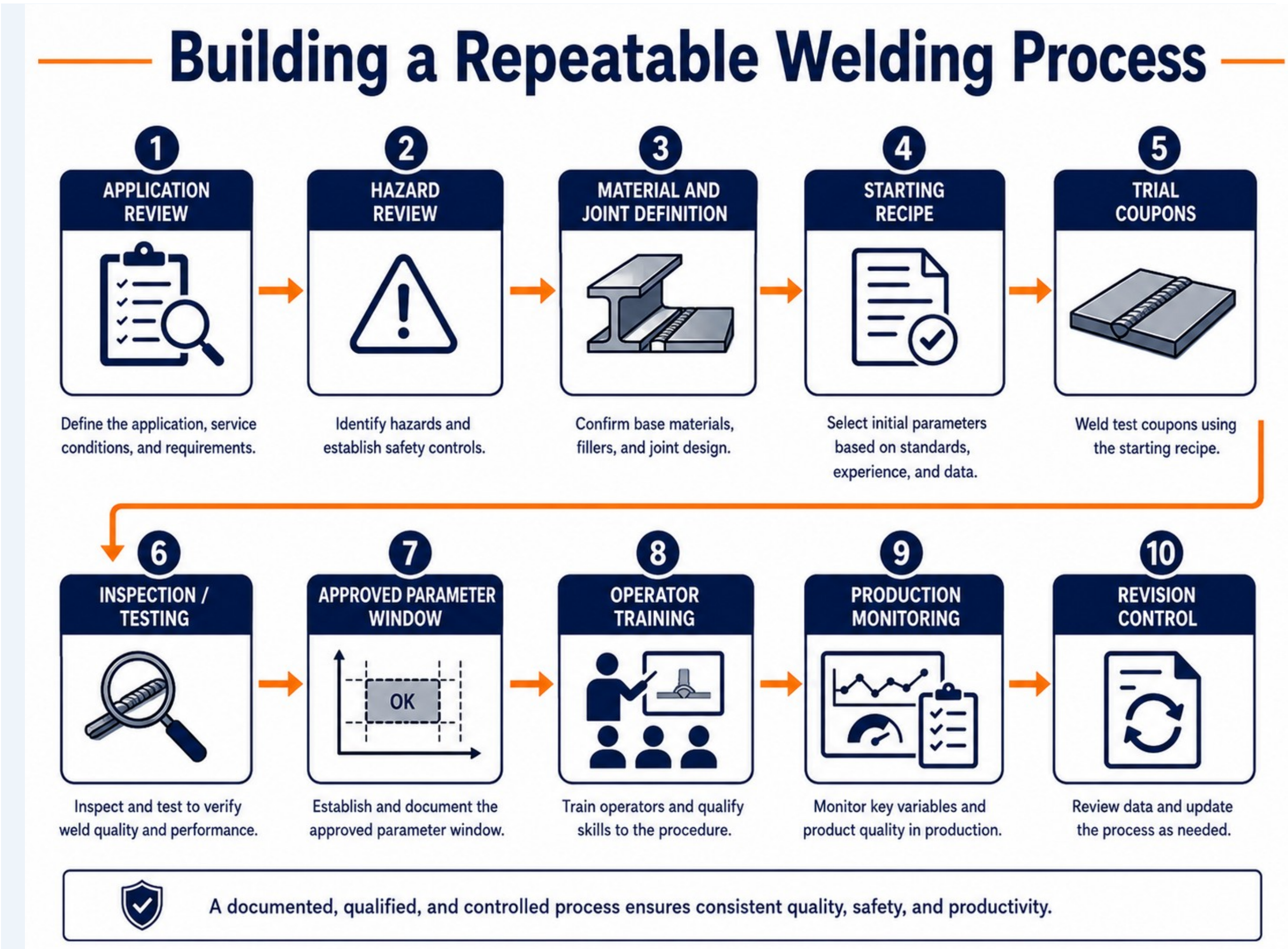

Figure 7-1. A repeatable process is developed through application review, hazard control, testing, documented limits, training, monitoring, and revision control.

7.1 The Difference Between a Setting and a Procedure

A machine setting might be “1,400 watts, 4 mm wobble.” A welding procedure includes much more:

- machine and mode,
- material and thickness,
- joint design,
- gap and mismatch limits,
- cleaning,
- fixture,
- nozzle,
- power and parameter range,
- travel-speed range,
- gas and flow,
- wire,

- position,
- technique,
- start/stop method,
- inspection,
- and acceptance criteria.

7.2 Acceptance, Handover, and Process Ownership

Acceptance should prove the delivered system and the agreed welding process against written criteria. The following is a practical allocation of responsibility, not a universal legal rule; the purchase contract, governing code, and applicable regulations control.

Supplier or integrator. Demonstrates the contracted equipment functions, safety interfaces, documented settings or process-development work, training, manuals, and acceptance tests. The supplier remains responsible for warranty and service obligations and for correcting delivered items that do not meet the agreement.

Customer or end user. Provides representative parts and materials, agreed incoming-part quality, utilities, site conditions, qualified personnel, and clear functional and inspection requirements. After acceptance, the end user normally controls daily production variables such as material identity, fit-up, operator authorization, maintenance, inspection, records, and change control.[27]

Shared responsibility. Defines the test parts, normal and worst-case variation, safety conditions, process window, inspection method, acceptance criteria, data to be delivered, open issues, and the point at which the process is handed over.[15]

A balanced handoff recognizes two truths: the customer should not inherit a machine or safety system that fails the contract, and the supplier cannot control every production part, operator decision, maintenance condition, or unapproved change forever. The process window has to be maintained after acceptance.

> **FICTIONAL SHOP STORY — THE PERFECT COUPON TRAP**
> Northline Enclosures qualified a beautiful weld on laser-cut coupons with nearly zero gap. The company's new production panels were still being developed, so only ideal samples were available during the supplier visit. When stamped production parts arrived, flange springback created changing gaps and mismatch. The same recipe produced inconsistent fusion. Neither side had written incoming-part limits or required worst-case samples for acceptance. They paused production, agreed on maximum gap and mismatch, improved the fixture, tested representative parts, and revised the process window. The lesson was not that the laser had failed. The acceptance test had not represented the actual process inputs.

7.3 Begin with the Application Requirement

Define the application requirement in writing, including:

- The required function of the weld.
- Whether the joint is structural, pressure-retaining, sanitary, leak-tight, cosmetic, or only a locating seam.
- The applicable code, customer specification, and drawing requirements.
- The inspection method and sampling plan.

7.4 Define the Essential Inputs

Control the inputs that can change the weld result:

- alloy,
- thickness,
- joint type,
- gap,
- surface condition,
- program,
- power,
- speed,
- wobble,
- gas,
- wire,
- position,
- and operator technique.

7.5 Coupon Testing

Use coupons representative of production. Include:

- minimum and maximum thickness,
- realistic gap,
- typical tack welds,
- actual surface finish,
- actual joint position,
- expected start/stop,
- and worst practical access.

Test methods may include:

- visual examination,
- macro section,
- bend test,
- tensile or shear test,
- leak test,
- dye penetrant,
- radiography,
- ultrasonic methods,
- and service-specific testing.

7.6 Establish a Parameter Window

A single “perfect” point is fragile. A process window identifies acceptable ranges.

For example:

- power range,
- travel-speed range,

- gap limit,
- wobble range,
- and gas-flow range.

The edges of the window should be tested.

7.7 Work Instructions

A clear work instruction should show:

- part and joint,
- fixture,
- torch orientation,
- travel direction,
- extraction position,
- program,
- parameter limits,
- gas,
- wire,
- inspection points,
- and examples of acceptable and unacceptable welds.

7.8 Operator Qualification

Operator qualification may include:

- laser safety training,
- equipment-specific training,
- written review,
- demonstration of setup,
- supervised test coupons,
- inspection of test welds,
- and documented authorization by the employer.

Do not confuse machine training with qualification for code work. AWS C7.4/C7.4M, *Process Specification and Operator Qualification for Laser Beam Welding*, is the most directly relevant AWS publication for laser beam welding process control and operator qualification.[15]

AWS D17.1/D17.1M, *Specification for Fusion Welding for Aerospace Applications*, also includes high-energy-beam processes, but it is written for aircraft and space hardware rather than ordinary job-shop fabrication.[16]

AWS D1.6/D1.6M applies to stainless-steel structural assemblies, but the listed processes are conventional arc and stud-welding processes; it should not be treated as a laser-specific qualification document.[17] ASME BPVC Section IX covers welding, brazing, and fusing qualifications for work governed by the ASME Boiler and Pressure Vessel Code.[18]

The governing drawing, contract, code, customer specification, and local authority determine which qualification rules apply. For code work, have a qualified welding engineer, Certified Welding Inspector, Authorized Inspector, or other responsible code professional confirm the qualification path before production begins.

7.9 Change Control

Reevaluate the procedure when changing:

- machine or optical head,
- material alloy,
- thickness range,
- joint design,
- filler,
- gas,
- parameter range,
- fixture,
- or acceptance standard.

Welding Process Record

Part/Assembly:

Drawing/Revision:

Material/Thickness:

Joint:

Gap Limit:

Machine/Serial:

Program:

Power Range:

Travel-Speed Range:

Wobble Width/Frequency:

Gas/Flow:

Wire:

Nozzle:

Position:

Preparation:

Inspection:

Approved By/Date:

Key Takeaways

- A recipe is not a complete procedure.
- Representative testing must include real production variation.
- Approved ranges are stronger than one ideal setting.

Chapter 8 — Weld Quality, Inspection, and Certification

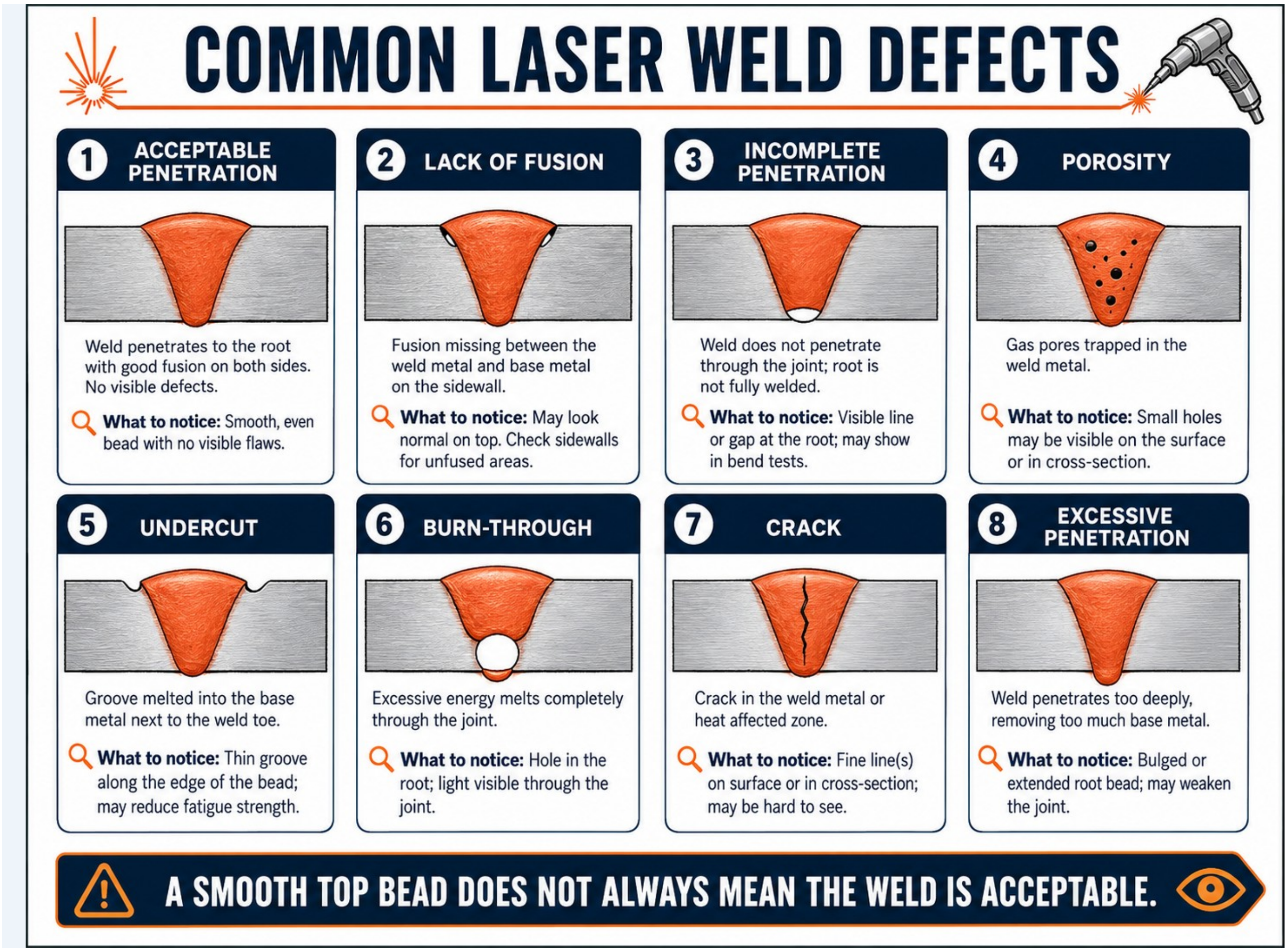

Figure 8-1. Simplified cross-sections of common laser-weld conditions and discontinuities.

8.1 A Good-Looking Weld Can Still Fail

Handheld laser welding can produce a narrow, smooth bead. That appearance may be encouraging, but it does not prove:

- penetration,
- root fusion,
- internal soundness,
- required throat,
- leak tightness,
- fatigue performance,
- or corrosion resistance.

Inspection begins with the requirement.

8.2 Common Discontinuities

Lack of Fusion

Possible causes:

- insufficient energy,
- excessive speed,
- beam off the joint,
- gap or mismatch,
- poor angle,
- oxide or contamination,
- unstable hand motion.

Incomplete Penetration

Possible causes:

- insufficient energy density,
- excessive speed,
- wrong focus,
- joint geometry,
- or thickness outside the proven range.

Porosity

Possible causes:

- oil or moisture,
- coating,
- unstable keyhole,
- trapped zinc vapor,
- poor shielding,
- incorrect wire,
- or contaminated surface.

Undercut

A groove at the weld toe can reduce section thickness. Causes include high energy, excessive speed, wide oscillation, edge melt loss, or poor alignment.

Cracking

Cracking may be related to:

- alloy sensitivity,
- filler selection,
- restraint,
- solidification behavior,
- contamination,
- or excessive heat input.

Burn-Through and Excessive Penetration

These can damage the far side, create sharp protrusion, or strike material behind the joint.

8.3 Visual Inspection

Visual inspection should be performed under suitable lighting and may include:

- bead continuity,
- width,
- undercut,
- overlap,
- surface porosity,
- cracks,
- start/stop condition,
- discoloration,
- distortion,
- and dimensional requirements.

Use gauges where appropriate. Record the acceptance standard.

8.4 Macro Sectioning

A polished and etched cross-section is one of the clearest ways to understand a developing process. It shows:

- penetration depth,
- fusion line,
- throat,
- internal porosity,
- root shape,
- and heat-affected zone.

A macro does not represent every inch of a production weld, but it is extremely useful during qualification and troubleshooting.

8.5 Bend, Tensile, Shear, and Peel Tests

The correct mechanical test depends on joint type and service. A lap joint may use tensile-shear or peel testing. Butt joints may use bend or tensile specimens.

8.6 Leak and Pressure Testing

A visually acceptable seam may still leak through a pore, missed start, or incomplete overlap. Use the specified leak method and pressure.

8.7 Penetrant Testing

Liquid penetrant can reveal surface-breaking discontinuities in suitable nonporous materials. It does not reveal defects that do not reach the surface.

8.8 Radiographic and Ultrasonic Examination

Radiography can reveal volumetric internal discontinuities, but thin geometry and small laser-weld dimensions can make technique important.

Conventional ultrasonic inspection may be challenging on thin or narrow joints. Specialized techniques may be available, but capability should be verified with qualified NDT personnel.

8.9 Inspection Personnel

Inspection should be assigned to people with appropriate training. AWS Certified Welding Inspector programs are widely recognized in the United States, but the required credential depends on the code and contract.

8.10 Welder Certification

Certification is common in the welding trade. The AWS Certified Welder program uses performance qualification tests at Accredited Testing Facilities and can support transfer of qualifications between employers under the program rules.[6]

Handheld laser welding does not automatically fit every existing qualification path. The employer, engineer, customer, and governing code must determine:

- what procedure qualification applies,
- what operator performance qualification applies,
- what variables are essential,
- and how continuity is maintained.

8.11 Codes, Standards, and Customer Requirements

Possible sources of requirements include:

- AWS structural codes,
- ASME boiler and pressure-vessel rules,
- API requirements,
- military or aerospace specifications,
- automotive standards,
- sanitary standards,
- customer drawings,
- and company procedures.

Never assume that “laser welded” exempts a joint from normal requirements.

Inspection Record

Part/Lot	Procedure	Inspector	Visual	Dimension	NDT/Test	Result	Disposition

Key Takeaways

- Appearance does not prove internal fusion.
- Acceptance criteria must be defined before production.
- Macro sections are valuable during development.
- Certification and inspection are normal parts of professional welding.

Chapter 9 — Troubleshooting and Corrective Action

Figure 9-1. A systematic troubleshooting sequence protects safety, preserves evidence, and avoids changing several variables at once.

9.1 Stop Safely

When the process changes unexpectedly:

1. Stop emission.
2. Place the system in a safe state.
3. Preserve the alarm message.
4. Record what changed.
5. Do not repeatedly reset a safety alarm without understanding it.

9.2 Distinguishing Equipment and Process Causes

Equipment-related clues:

- machine alarm,
- cooling fault,
- gas-pressure fault,
- interlock not satisfied,

- unstable or missing guide beam,
- repeated protective-window damage,
- network or recipe error.

Process-related clues:

- result changes with joint gap,
- defect follows material lot,
- defect occurs only at corners,
- variation follows operator travel,
- weld changes after cleaning,
- oxidation follows gas position.

9.3 No Laser Enable

Check only approved operator items:

- emergency stop,
- key and operating state,
- door interlock,
- workpiece contact,
- clamp connection,
- gas pressure,
- fiber status,
- nozzle condition,
- and displayed alarm.

Escalate internal faults.

9.4 Low or Inconsistent Penetration

Possible causes:

- wrong program,
- speed too high,
- power too low,
- focus or stand-off error,
- dirty protective window,
- beam off joint,
- excessive wobble width,
- material variation,
- unstable contact or trigger sequence.

9.5 Excessive Spatter

Possible causes:

- contamination,
- unstable keyhole,
- too much energy,
- incorrect angle,

- gap,
- zinc coating,
- poor wire delivery,
- or incorrect stand-off.

9.6 Porosity

Check:

- oil and moisture,
- coating,
- gas leaks,
- shielding position,
- extraction interference,
- joint venting,
- wire cleanliness,
- and start/stop technique.

9.7 Oxidation or Dark Color

Check:

- gas type and purity,
- flow,
- leaks,
- nozzle blockage,
- torch angle,
- hot trailing surface,
- extraction position,
- and backside shielding where required.

9.8 Repeated Window Contamination

Check:

- nozzle damage,
- spatter direction,
- stand-off,
- gas flow,
- smoke capture,
- torch angle,
- process instability,
- and replacement technique.

Troubleshooting Table

Symptom	First Checks	Controlled Test	Escalate When
No enable	E-stop, key, door, clamp, gas, alarm	Approved reset after cause corrected	Safety circuit remains faulted
Low penetration	recipe, speed, gap, focus,	labeled coupon	output appears unstable

	window		
Porosity	cleaning, gas, coating	clean uncoated coupon	persists with verified inputs
Oxidation	gas, leaks, nozzle, extraction	flow and position test	gas system fault suspected
Window damage	nozzle, angle, spatter	inspect process condition	internal optics suspected

Corrective Action Record

Problem:

Date/Time:

Machine:

Part/Lot:

Operator:

Alarm:

Observed Condition:

Immediate Containment:

Root Cause:

Corrective Action:

Verification Test:

Approved By:

Key Takeaways

- Put the machine in a safe state before troubleshooting.
- Record alarms and conditions before resetting.
- Separate equipment, material, fit-up, and operator causes.
- Corrective action is not complete until the fix is verified.

Chapter 10 — Maintenance, Shop Management, and Application Planning

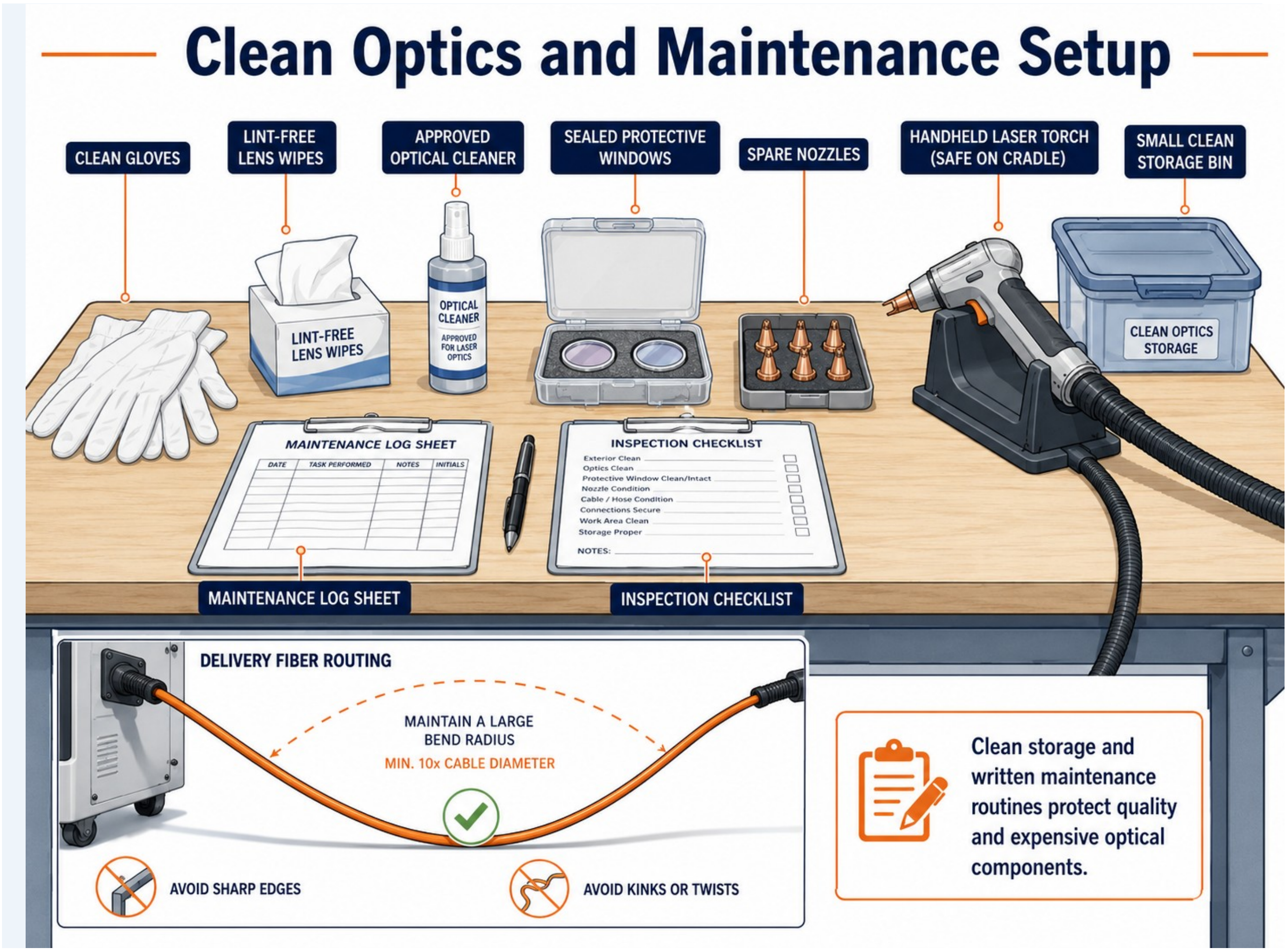

Figure 10-1. A clean maintenance area and controlled storage help protect optical components and process consistency.

10.1 Preventive Maintenance

Follow the current manufacturer schedule. Typical categories include:

- daily visual inspection,
- protective-window inspection,
- nozzle cleaning,
- gas-leak check,
- extraction check,
- filter service,
- chiller inspection,
- coolant service,
- cable and fiber inspection,
- interlock test,
- software or recipe backup,
- and periodic qualified service.

10.2 Clean Optics Practice

Optical contamination can become burned into a window or lens. Create a clean process:

- safe shutdown,
- clean work surface,
- clean gloves,
- approved tools,
- sealed replacement optics,
- approved cleaning material,
- no compressed shop air,
- immediate capping of open connections,
- and documented replacement.

10.3 Fiber Management

Use a routing plan that avoids:

- tight bends,
- forklift lanes,
- sharp table edges,
- hot work,
- pinch points,
- and operator trip hazards.

10.4 Extraction Maintenance

A clogged filter can reduce capture. Track:

- filter differential pressure or indicator,
- airflow,
- spark control,
- hose condition,
- dust disposal,
- and scheduled service.

10.5 Calibration and Output Verification

A displayed power value is not the same as a measured output. Depending on quality requirements, a shop may need periodic verification by the manufacturer or qualified service provider.

Indirect process checks can include:

- reference coupons,
- macro sections,
- penetration monitoring,
- and documented baseline tests.

10.6 Spare Parts

Keep appropriate spares such as:

- protective windows,
- approved nozzles,
- seals,
- filters,
- gas components,
- and manufacturer-recommended service items.

Do not substitute unverified optical components.

10.7 What to Confirm Before Buying

This is not a buyer's guide. It is a practical requirements checklist that helps a supplier and buyer define the job before equipment is selected.

Part and Application Requirements

- Exact materials and alloys to be welded.
- Required thickness range.
- Joint types and access conditions.
- Normal and worst-case joint gap and mismatch.
- Need for filler wire and required filler alloy.
- Coatings, plating, oils, sealants, or other surface conditions.
- Required function: structural, leak-tight, sanitary, cosmetic, pressure-retaining, or another defined service.
- Inspection method and acceptance criteria.
- Representative parts available for process development and acceptance testing.

Safety Requirements

- Laser class, wavelength, operating modes, and rated power.
- Required enclosure or Laser Controlled Area design.
- Available interlock, ready, alarm, and status interfaces.
- Specified wavelength- and exposure-rated eyewear and helmet requirements.
- Manufacturer-recommended reflection-control method and operating limits.
- Recommended source-capture and room-ventilation arrangement.
- Scope and responsibility for the formal site assessment.
- Training supplied for operators, supervisors, maintenance personnel, and the Laser Safety Officer.
- Exact complete configuration, limits, and documentation covered by any Class 1 claim.
- Manufacturer, importer, and system integrator of record for the final installation.
- Responsibility for FDA certification, reporting, labeling, and documentation when applicable.
- Openings, pass-throughs, windows, duct changes, interlock changes, and service conditions that require reevaluation.

Service Support

- Service location and coverage area.
- Normal service response time.
- Availability and location of replacement optics and critical spares.

- User-permitted maintenance tasks and required qualifications.
- Tasks reserved for factory or authorized service.
- Method and schedule for output verification.
- Available data, alarm history, backups, and export formats.
- Warranty coverage and exclusions for optics, fiber, and contamination damage.

Process Support

- Supplier support for developing and documenting procedures with actual parts.
- Whether the supplier provides validated parameter limits or only starting recipes.
- Support for macro sections, mechanical tests, leak tests, or other required validation.
- Materials, thicknesses, gases, wires, and operating modes specifically approved for the system.
- Software, recipe, configuration, and recovery-backup method.
- Wire-feed options, control interface, and supported wire range.
- Documented interfaces for future positioners, linear motion, sensing, or automation.
- Responsibility for supplying representative process-development and acceptance parts.
- Incoming material, gap, mismatch, coating, and cleanliness limits for acceptance parts.
- Documentation of the delivered process window, trial results, and inspection evidence.
- Process-support responsibilities that end at acceptance and those that continue under warranty or service agreements.
- Authority for approving future changes to materials, fixtures, parameters, software, gas, wire, and inspection criteria.

10.8 What the Buyer Still Owns

Buying a compliant laser product and good supplier support does not remove the employer's responsibility to provide a safe workplace. The buyer or end user still needs an internal program that fits the actual building, people, parts, production schedule, and maintenance practices.[27]

The buyer normally needs to own or explicitly assign:

- the site-specific hazard assessment and Laser Safety Officer authority;
- the final installed configuration and control of unauthorized modifications;
- operator authorization, refresher training, supervision, and emergency response;
- material identity, coatings, part cleanliness, fit-up, and fixture condition;
- the approved welding procedure, inspection plan, and production records;
- PPE inspection, ventilation performance, interlock tests, maintenance, and spare-part control;
- and revalidation when the product, process, equipment, or safety configuration changes.

A USEFUL BUYING PRINCIPLE

A good supplier should help the customer succeed, but help is not the same as invisible ownership. Before the purchase order is signed, write down who will do the site assessment, who will approve the enclosure, who will train each role, who will qualify the process, what parts will be used for acceptance, and who will maintain the process afterward.

10.9 Example Applications and Planning Considerations

Stainless Cabinet

Evaluate:

- outside-corner fit-up,
- heat tint,
- distortion,
- cosmetic acceptance,
- seam cleaning,
- and extraction for stainless fumes.

Galvanized HVAC Assembly

Evaluate:

- zinc venting,
- coating damage,
- porosity,
- fume control,
- and corrosion repair.

Aluminum Tank

Evaluate:

- alloy,
- crack sensitivity,
- leak testing,
- backside access,
- gap control,
- and procedure qualification.

Decorative Tube Furniture

Evaluate:

- fixture repeatability,
- corner access,
- finishing,
- distortion,
- and whether the joint needs filler.

Repair Work

Evaluate:

- material identification,
- unknown coatings,
- part cleanliness,
- safe enclosure,

- service loading,
- and inspection.

10.10 Shop Management

A successful program needs ownership of:

- safety,
- process approval,
- training,
- maintenance,
- consumables,
- inspection,
- documentation,
- and change control.

Assign names, not just departments.

Maintenance Log

Date	Hours	Inspection/ Service	Finding	Action	Parts	Technician	Next Due

Key Takeaways

- Maintenance protects quality, uptime, and safety.
- Optical cleanliness deserves a controlled procedure.
- Ask suppliers about the application, not just wattage.
- The shop needs clear ownership for safety, process, inspection, and maintenance.
- A buyer should understand the exact scope of any Class 1 claim and the responsibilities that remain after installation and acceptance.

Chapter 11 — From Handheld Welder to Production-Ready System

A PERSONAL DESIGN PERSPECTIVE

The system in this chapter shows how handheld laser welding could be designed for repeatable production from the beginning, rather than treated as a portable machine parked beside a welding table. As an automation and controls engineer, I would expect the laser, controls, safety interfaces, extraction, gas, wire feed, recipes, documentation, and future expansion to be designed as one platform. The concept shown here does not yet exist as a validated commercial product. It is a design direction, not a claim of compliance or performance.

Figure 11-1. MWL concept for a production-ready handheld laser welding system using a configurable rack-mounted laser platform, integrated controls, a dedicated laser-safe work cell, source-capture fume extraction, shielding gas, cable support, wire feed, and a fixture-ready table.

CONCEPT AND CLASSIFICATION LIMITATION

The illustration uses the phrase "Class 1 laser work cell." Class 1 status would apply only to the accessible emission of a specific, complete, evaluated product in its approved configuration. An enclosure, warning light, or set of curtains does not create that classification by itself. The final manufacturer or integrator would have to evaluate and document the complete installation, including barriers, seams, openings, windows, access, interlocks, viewing, extraction penetrations, fault conditions, service modes, and foreseeable changes.[12][14][24][25][26]

11.1 Moving Beyond a Portable Unit

Portable integrated welders can be useful for demonstrations, process development, repair, and carefully controlled production. Production work, however, usually needs more than a machine and a torch. It needs controlled recipes, repeatable fixtures, managed access, documented setup, reliable utilities, maintenance planning, and a clear way to prove that the approved process is still being followed.

In this guide, “production-ready” does not mean that the torch must be automated. The operator can still hold and guide the torch. Production-ready means that the surrounding system is designed to make safe, repeatable, documented work practical day after day.

11.2 The Rack-Mounted Laser Platform

The center of the concept is a stand-up industrial system rack. The rack creates a common platform for the laser and the controls while allowing the laser source to be selected for the actual application. Depending on the manufacturer and process, that could include continuous-wave or quasi-continuous-wave operating options. Cooling, electrical service, ventilation, fiber delivery, process head, and safety interfaces must be designed around the selected source and approved component combination.[11][14]

- a laser source selected for the material, thickness, joint, duty cycle, and required operating mode;
- industrial PC and touchscreen HMI;
- machine controller or PLC for process sequencing and utilities;
- safety controller and safety-rated input/output for the evaluated safety functions;
- process input/output and documented interfaces for the laser, extraction, gas, wire feed, and future equipment;
- power distribution, disconnects, protective devices, cooling support, and forced rack ventilation based on the installed components;
- service access, labeled wiring, drawings, backups, and spare-part documentation.

> **PRACTICAL LIMIT**
> A configurable rack does not mean that any laser, fiber, head, optic, or safety circuit can be mixed and matched. The source, delivery fiber, processing head, optics, controls, cooling, software, and interlocks must be an approved and validated combination.

11.3 Process Control, Recipes, and Permissions

A production HMI should do more than display laser power. It should help the shop control the complete process. Part-specific recipes can reduce setup mistakes and make it easier to move from one approved job to another.

- part number, material, alloy, thickness, and joint type;
- laser mode, power or energy settings, wobble settings, and approved operating limits;
- shielding-gas type, pressure or flow, and wire-feed settings when used;
- required nozzle, protective window, fixture, and setup instructions;
- operator notes, inspection requirements, and links to the current work instruction;
- recipe version, approval status, and change history.

User permissions matter. An operator may be allowed to select an approved recipe and record production information, while a process engineer or authorized technician controls parameter edits. Safety functions should remain in the evaluated safety system; they should not depend only on an ordinary HMI password or standard PLC bit. Machinery standards treat controllers, software, sensors, actuators, fixtures, and associated equipment as parts of the overall machine system.[34][35][36]

11.4 Dedicated Work Cell and Safety Integration

The concept places the rack and welding station in a dedicated laser-safe work cell. The final design should come from a documented risk assessment and laser-safety evaluation, not from the appearance of the illustration.

- laser-rated barriers, seams, doors, windows, and penetrations evaluated for the wavelength and possible exposure;
- controlled and interlocked access;
- key control, warning indicators, signage, and restricted occupancy;
- beam stops or fire-resistant backstops for direct, reflected, and pass-through energy;
- emergency stop, safe restart, and documented recovery from interlock faults;
- safe maintenance and service modes with clear authorization;
- tested safety interfaces between the laser, door system, extraction, utilities, and any future motion equipment.

American Welding Society guidance treats demonstrations and production points of use as Laser Controlled Areas requiring evaluated barriers, access control, training, and laser-specific PPE. The same principle applies here: the cell must be designed around the actual system and work, not around a generic picture of what a laser booth should look like.[12][14][28][29][30][31]

11.5 Fume Extraction, Shielding Gas, and Fire Control

The source-capture hood should be positioned close enough to capture the plume without pulling shielding gas away from the weld. The production concept also monitors extraction status so a loss of airflow can be detected before welding continues. The exact response to low airflow must come from the hazard assessment and control design.

- extraction sized and filtered for the actual materials, coatings, wire, and production rate;
- airflow indication, filter maintenance, and documented inspection;
- secured gas cylinders or an approved bulk supply with compatible regulators and hoses;
- gas-pressure or flow monitoring when required by the process or safety design;
- control of combustible materials, hidden cavities, and the far side of the weld;
- appropriate extinguishing equipment and hot-work procedures where required.

Source capture is an engineering control, not a cosmetic accessory. Welding-fume hazards remain dependent on the metal, coating, contamination, filler, and process even when the visible plume looks small.[5][13][22][28]

11.6 Fixture-Ready Table, Torch Support, and Fiber Protection

A heavy fixture-ready table gives the shop a stable place for part-specific tooling, clamps, datums, backstops, and inspection references. The support arm keeps the torch, fiber, gas hose, and wire-feed components controlled above the work area. That can reduce operator fatigue, improve cable management, and protect the delivery fiber from sharp bends, hot metal, crushing, and floor traffic.

- repeatable part location and controlled joint gap;

- fixtures designed for thermal movement and safe torch access;
- reflection paths considered as part of the fixture design;
- a defined torch holster and safe state between welds;
- fiber bend radius, support, routing, and service access;
- source-capture positioning that can follow the actual seam.

11.7 External Wire Feed and Consumable Control

An external wire-feed module keeps the main rack serviceable and gives the operator clear access to the spool. The wire feeder should be controlled as part of the recipe, with documented wire alloy, diameter, feed speed, torch relationship, and replacement method. Nozzles, protective windows, guides, and wire are production inputs; they should be identified, stored, inspected, and changed under a controlled process.

11.8 Documentation and Data Logging

Data logging is optional in the illustration, but it becomes increasingly valuable as the shop moves from demonstration work to customer production. A useful record may include:

- operator, job, part number, and timestamp;
- recipe and software version;
- laser-ready, gas, extraction, and interlock status;
- alarms, resets, aborted welds, and maintenance events;
- protective-window or nozzle changes;
- inspection results and disposition of nonconforming parts.

A log does not prove that a weld is acceptable, and a green HMI screen does not replace inspection. Logging provides traceability and helps the shop understand what changed when quality changes.

> **FICTIONAL SHOP STORY — THE RECIPE WAS RIGHT, BUT THE PARTS CHANGED**
> North River Fabrication developed a locked recipe for a stainless enclosure and recorded the approved gas, nozzle, fixture, and laser settings. Several weeks later, a new batch of formed panels arrived with a larger corner gap. The operator selected the correct recipe and the machine recorded a normal cycle, but several seams failed the leak test. The investigation found that the controlled recipe had repeated the approved settings on parts that no longer met the approved fit-up window. The shop added an incoming gap check and a fixture-verification step. The story is fictional, but the lesson is real: process control only works when the material, part, fixture, operator technique, and inspection remain controlled too.

11.9 Process Development, Acceptance, and Ownership

Before a production platform is released, the shop should prove the process with representative parts —not perfect coupons that hide the normal variation. Acceptance should cover the safety system and the welding process as separate but connected responsibilities.

- representative materials, coatings, thicknesses, joint types, gaps, and fixtures;
- approved recipes and documented parameter windows;
- operator position, torch angle, travel technique, and wire placement;
- inspection method, acceptance criteria, and evidence from trial parts;

- interlock, emergency-stop, warning, access, extraction, gas, and fault-recovery tests;
- training for operators, supervisors, maintenance personnel, process owners, and the Laser Safety Officer;
- drawings, manuals, backups, spare parts, maintenance schedules, and change-control rules;
- written ownership of post-acceptance safety, process support, maintenance, and future modifications.

AWS process specifications treat documented procedures, operator qualification, and controlled changes as normal parts of laser welding. OSHA also makes clear that the employer retains responsibility for the workplace. A supplier or integrator can provide substantial help, but the final responsibilities must be assigned rather than assumed.[15][27][33]

11.10 Future-Ready Without Pretending It Is Automated

The platform can include documented interfaces for a positioner, linear axis, seam-tracking sensor, camera, process monitor, or future automated handling. That does not make the base system automated, and it does not mean a future device can be connected without engineering work.

Adding motion, automated triggers, remote commands, new openings, or new service modes changes the complete machine and may change both the risk assessment and the laser-product evaluation. Future-ready should mean that the controls, electrical design, space, interfaces, and documentation make responsible expansion possible—not that expansion is automatically safe or qualified.[34][35][36]

11.11 What “Production-Ready” Really Means

A rack, HMI, enclosure, and fixture table can make the system easier to operate and manage. They cannot compensate for unknown materials, uncontrolled gaps, poor part location, unsuitable joint design, weak procedures, inadequate inspection, damaged optics, bad maintenance, or untrained people.

For me, the value of this concept is that it treats handheld laser welding as a manufacturing system. The torch remains flexible, but the process around it becomes controlled, documented, serviceable, and ready to grow.

Production System Planning Checklist

- [ ] Representative parts and production requirements defined
- [ ] Laser source, head, fiber, optics, cooling, and operating modes selected as an approved combination
- [ ] Rack electrical design, ventilation, service access, and drawings completed
- [ ] Process HMI, recipe permissions, backups, and change control defined
- [ ] Dedicated work cell evaluated; Class 1 claims limited to the documented complete configuration
- [ ] Interlocks, emergency stop, warning indicators, access control, and safe restart tested
- [ ] Extraction, gas, fire control, and backstop arrangements verified
- [ ] Fixtures, torch support, fiber routing, and wire feed proven on actual work
- [ ] Procedures, parameter windows, operator qualification, and inspection evidence documented
- [ ] Maintenance, spares, output verification, and consumable control assigned

- [ ] Data logging and production-record requirements defined
- [ ] Future motion or automation interfaces documented and subject to revalidation
- [ ] Supplier, integrator, employer, LSO, process owner, maintenance, and operator responsibilities assigned in writing

Key Takeaways

- Production-ready handheld laser welding is a complete system, not simply a portable laser placed beside a table.
- A configurable rack can support different laser options, but every source, head, fiber, optic, cooling, and control combination must be approved and validated.
- Recipes, permissions, documentation, and data logging improve control but do not replace representative parts, qualification, and inspection.
- A dedicated work cell does not become Class 1 by appearance or terminology; the complete configuration must be evaluated and documented.
- Future-ready interfaces can support responsible expansion, but every meaningful change requires engineering review and revalidation.

Appendix A — Shop Forms and Worksheets

A1. Daily Startup Checklist

Date:

Machine:

Operator:

- [ ] Controlled area clear
- [ ] Door and interlock functional
- [ ] Warning light functional
- [ ] E-stop checked per procedure
- [ ] PPE inspected
- [ ] Extraction on and positioned
- [ ] Gas supply available
- [ ] Cylinder secured
- [ ] Fiber/cable visually acceptable
- [ ] Correct nozzle installed
- [ ] Protective window checked
- [ ] Work clamp connected
- [ ] Correct program selected
- [ ] Trial coupon completed
- [ ] Trial coupon accepted

Comments:

Operator Signature:

A2. Daily Shutdown Checklist

- [ ] Laser emission disabled
- [ ] Machine shut down by approved sequence
- [ ] Key removed and secured
- [ ] Gas closed as required
- [ ] Extraction run-on completed
- [ ] Torch returned to cradle
- [ ] Nozzle inspected
- [ ] Fiber protected
- [ ] Hot parts identified
- [ ] Work area checked for fire
- [ ] Defects or alarms logged

A3. Laser Controlled Area Inspection

Item	Acceptable	Correction Needed	Date Corrected
Barriers			

Viewing window			
Door interlock			
Warning signs			
Warning lights			
Key control			
Camera			
Beam stop			
Fire control			
Extraction			
Housekeeping			

A4. Operator Training Record

Employee:

Trainer:

Machine:

Training Date:

- [ ] Laser fundamentals
- [ ] Class 4 hazards
- [ ] Controlled-area rules
- [ ] PPE
- [ ] Reflection planning
- [ ] Fume hazards
- [ ] Fire and gas hazards
- [ ] Startup/shutdown
- [ ] Program selection
- [ ] Nozzle and window inspection
- [ ] Work clamp/interlock
- [ ] Trial coupon
- [ ] Emergency stop
- [ ] Alarm response
- [ ] Maintenance limits
- [ ] Practical weld test

Authorization Level: Operator / Advanced Operator / Maintenance

Expiration or Review Date:

A5. Weld Procedure Worksheet

Procedure ID:

Revision:

Part:

Material:

Thickness:

Joint:

Position:

Gap:

Mismatch:

Preparation:

Fixture:

Machine:

Mode/Program:

Power Range:

Speed Range:

Wobble Width:

Wobble Frequency:

Gas and Flow:

Wire:

Nozzle:

Torch Angle:

Start/Stop Method:

Inspection:

Acceptance Criteria:

Qualified By:

Date:

A6. Visual Inspection Form

Feature	Requirement	Result	Accept/Reject
Continuity			
Width			
Undercut			
Overlap			
Surface pores			
Cracks	None		

Start/stop			
Discoloration			
Distortion			
Dimensions			

A7. Parameter Development Log

Coupon	Power	Speed	Wobble	Frequency	Focus/ Stand-Off	Gas	Wire	Gap	Test	Result

A8. Maintenance Log

Date	Machine Hours	Task	Condition	Action	Part Number	Technician

A9. Incident and Near-Miss Form

Date/Time:

Location:

People Involved:

Machine State:

Description:

Injury or Exposure:

Immediate Action:

Area Secured:

Equipment Quarantined:

LSO/Supervisor Notified:

Root Cause Review:

Corrective Action:

Approval to Return to Service:

A10. Application Review Form

Customer/Product:

Material/Alloy:

Thickness Range:

Joint Types:

Gap Range:

Coatings:

Required Function: Structural / Leak / Cosmetic / Sanitary / Other

Code or Specification:

Inspection:

Production Volume:

Part Handling:

Controlled Area Available:

Extraction Available:

Trial Parts Supplied:

Supplier Test Results:

Open Items:

A11. Purchase, Acceptance, and Responsibility Checklist

Project / Product:

Laser Model and Serial Number:

Supplier:

Manufacturer / Importer / Integrator of Record:

Final Product Classification and Configuration:

Classification / Certification Documentation Received:

Laser Safety Officer:

Site-Specific Hazard Review Completed By / Date:

Barrier, Window, Interlock, Access, and Reflection Scope:

Ventilation and Industrial-Hygiene Scope:

Operator / LSO / Maintenance / Process Training Scope:

Representative Acceptance Parts and Allowed Variation:

Incoming Material, Gap, Mismatch, Coating, and Cleanliness Limits:

Process Window and Inspection Method to Be Delivered:

Acceptance Criteria and Sign-Off:

Warranty and Ongoing Process-Support Scope:

Maintenance, Output Verification, and Spare-Parts Plan:

Allowed Field Modifications and Reevaluation Requirements:

Post-Acceptance Process Owner:

Appendix B — Glossary

Accessible emission: Laser radiation to which human access is possible under the conditions used to classify the product.

Class 1 laser product: Complete laser product whose accessible emission during operation is within Class 1 limits. It may contain a higher-class embedded laser source.

Laser product manufacturer: In FDA usage, a person or organization that makes, assembles, imports, or modifies a laser product; the exact regulatory role depends on the activity and facts.

Process owner: Person assigned to maintain the approved welding procedure, process window, qualification status, inspection plan, records, and change control.

System integrator: Party that combines components into a functioning installed system. Its technical and regulatory responsibilities depend on the scope of integration and applicable requirements.

Absorption: Portion of incident laser energy converted into heat in the material.

Beam quality: Description of how tightly and predictably a laser beam can be focused.

Class 4 laser: Highest major hazard class; direct or reflected exposure can cause immediate eye or skin injury and may present a fire hazard.

Conduction-mode welding: Welding in which surface heat conducts into the material without a sustained vapor keyhole.

Controlled area: Area where access and activity are managed because hazardous laser exposure may be possible.

Essential variable: A variable that can affect the validity or performance of a qualified welding procedure or operator qualification.

Focal position: Location of the smallest or intended beam waist relative to the workpiece.

Fume extraction: Ventilation system that captures airborne contaminants generated by the process.

Heat-affected zone: Base metal altered by heat but not melted.

Interlock: Device or circuit that prevents or stops hazardous operation when a required condition is not satisfied.

Keyhole: Vapor cavity formed in the molten metal during high-energy-density welding.

Lack of fusion: Failure of weld metal to fuse to the base metal or previous weld metal.

Laser Safety Officer: Person with authority and responsibility for laser-safety program administration.

Macro section: Cut, polished, and usually etched cross-section used to examine weld geometry and fusion.

Nominal Hazard Zone: Space where direct, reflected, or scattered radiation may exceed the applicable exposure limit.

Optical density: Logarithmic measure of attenuation provided by an optical filter at specified wavelengths.

Porosity: Gas cavities trapped in solidified weld metal.

Protective window: Sacrificial optical element that protects internal focusing optics.

Specular reflection: Mirror-like reflection.

Stand-off: Distance from nozzle or reference surface to the workpiece.

Travel speed: Rate at which the torch moves along the joint.

Wobble: Rapid programmed movement of the focused beam through a repeated pattern.

Welding procedure: Documented combination of variables and instructions used to produce a weld.

Autogenous weld: Weld made without adding filler metal.

Back purge: Shielding gas supplied to the root side of a joint to limit oxidation.

Beam oscillation: Controlled movement of the focused beam; often called wobble in handheld systems.

Burn-through: Unwanted opening or collapse caused by excessive penetration or heat input.

Certified Welding Inspector (CWI): AWS credential for qualified personnel who perform and oversee welding inspection within the scope of their qualifications.

Discontinuity: Interruption in the normal structure of a weld or base metal. A discontinuity becomes a defect when it exceeds the acceptance criteria.

Filler wire: Added metal fed into the weld pool to fill a gap, change weld chemistry, or build weld size.

Fit-up: Alignment, contact, gap, and positioning of parts before welding.

Incomplete penetration: Weld penetration that does not reach the required joint depth or root.

Laser beam welding (LBW): Fusion-welding process that uses concentrated laser energy as the heat source.

Local exhaust ventilation (LEV): Source-capture system that removes fume close to where it is generated.

Macroetch: Prepared weld cross-section treated to reveal fusion boundaries and weld geometry.

Parameter window: Tested range of settings and conditions that produces acceptable results.

Procedure Qualification Record (PQR): Record of the actual variables and test results used to establish that a welding procedure can meet specified requirements.

Root fusion: Fusion at the root or far side of the joint.

Shielding gas: Gas directed around the molten pool to reduce contact with the atmosphere.

Specular reflection: Mirror-like reflection that can retain hazardous beam intensity.

Undercut: Groove melted into the base metal next to the weld and left unfilled.

Welder or operator qualification: Documented demonstration that a person can produce acceptable welds under defined conditions.

Welding Procedure Specification (WPS): Written instructions defining how a weld is to be made and controlled.

> Illustration note: The diagrams in this guide are simplified teaching illustrations. They do not replace machine-specific instructions, an approved welding procedure, or a site-specific laser-safety assessment.

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End Matter

About Manufacturing With Light

Manufacturing With Light focuses on industrial laser processing, photonics, automation, motion control, welding, inspection, and advanced manufacturing. The goal is to translate technical subjects into practical information for shops, educators, and working professionals.

About the Author

Bill Kane is an automation and controls engineer whose work has included industrial laser processing systems, motion control, machine integration, safety-related controls, and shop-floor troubleshooting. His goal with Manufacturing With Light is to translate complex technology into practical guidance that manufacturers can use.

This revised edition was completed in August 2026. Because regulations, standards, equipment manuals, and product configurations change, readers should verify all safety-critical information against the current sources that apply to their exact installation.