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Welding and allied processes — Process specification for laser-arc hybrid welding for metallic materials

Soudage et techniques connexes - Descriptif du procédé pour le soudage hybride laser-arc des matériaux métalliques

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 10, *Quality management in the field of welding*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Official interpretations of ISO/TC 44 documents, where they exist, are available from this page: https://committee.iso.org/sites/tc44/home/interpretation.html.

Welding and allied processes — Process specification for laser-arc hybrid welding for metallic materials

1 Scope

This document outlines the equipment and operator qualification needed for laser-arc hybrid welding, and recommends butt, fillet and flange joint preparations and consumables suitable for use with this process.

It also gives an overview of the steps to take during equipment set-up, procedure specification, workpiece set-up immediately prior to welding, and after welding once inspecting and testing the welds.

This document applies to laser-arc hybrid welding of steels, aluminium and its alloys.

This document does not apply to hybrid processes where laser beam welding is hybridized with another welding process not using an electric arc as its heat source.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14175, *Welding consumables — Gases and gas mixtures for fusion welding and allied processes*

ISO 14732:2013, *Welding personnel — Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials*

ISO 15607, *Specification and qualification of welding procedures for metallic materials — General rules*

ISO 15614-14, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 14: Laser-arc hybrid welding of steels, nickel and nickel alloys*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 15607 and ISO 15614-14 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Safety

The environment condition, operation and protective measures for laser-arc hybrid welding should be in accordance with the requirements of related standards (e.g. ISO 11553-1, ISO 13849-1, IEC 62061, IEC 60825-1 and IEC 60825-4).

5 Welding operator qualification

The welding operator should receive necessary training and education and be competent to his/her job. An operator of an automated laser-arc hybrid welding process can be qualified through one of the different routes referred to ISO 14732:2013, Clause 4, relevant to automatic welding, namely:

a) qualification based on a welding procedure test in accordance with ISO 15614-14;

b) qualification based on a pre-production welding test in accordance with ISO 15613, ISO 15609-6 and ISO 15614-14;

c) qualification based on a production test or production sample test.

In addition, any method of qualification shall be supplemented by a test of the functional knowledge of the welding system, referring to ISO 14732:2013, Annex A.

Furthermore, any method of qualification may be supplemented by a discretionary test of knowledge related to welding technology, referring to ISO 14732:2013, Annex B.

6 Laser-arc hybrid welding equipment

The laser-arc hybrid welding equipment mainly includes laser generator, beam delivery system, arc welding power source and laser-arc hybrid welding head, high precise manipulator, high precise clamping device, seam tracking device, wire feeding unit, etc.

The equipment necessary to perform a laser-arc hybrid weld can include:

a) laser beam safety enclosure;

b) laser source;

c) laser source chiller (commonly needed);

d) arc power source;

e) beam delivery means (e.g. optical fibre);

f) welding wire feeder/delivery means (if the arc welding process uses a consumable wire);

g) beam focusing optics, and cover slide (an appropriately anti-reflection coated optical flat) and cross jet for protection of those optics;

h) arc welding torch;

i) torch cooling (commonly needed);

j) current return lead(s);

k) equipment for setting the respective positions of the laser beam focusing optics and the arc welding torch (e.g. torch bracketry);

l) shielding gas delivery system to weld cap (commonly, through wire feeding delivery system to arc welding torch) and, in case of full penetration welding, weld root;

m) some form of automatic beam-to-work manipulation device, e.g. a welding robot;

n) equipment/system controls (optional: seam tracking and/or seam inspection and/or weld process monitoring and/or control devices).

Best practice is that all equipment be the subject of regular scheduled maintenance and calibration checks, irrespective of any other pre-, in- or post-welding monitoring carried out for quality assurance/control purposes.

All equipment shall fulfil the manufacturer's guidelines.

7 Shielding gas

All the shielding gases used for laser-arc hybrid welding shall be in accordance with ISO 14175.

The recommended gas component and flow rates are given in Table 1.

Table 1 — Recommandation for gas component and flow rates

Base metal	Shielding gas	Gas flow rate L/min
Carbon steel	M20, M21, M22, M26	12 to 30
Stainless steel	M12, M13, M22, R1	
Aluminium alloy	I1, I2, I3	
NOTE When using CO_2 laser source, argon is replaced partly by helium with following condition: $P < 4$ kW than 30 % He; 4 kW ≤ P ≤ 6 kW than 50 % He; $P > 6$ kW than 70 % He.		

8 Joint design and preparation

Generally, the single pass penetration that can be achieved by the laser-arc hybrid welding process is significantly greater than that achieved by electric arc welding, depending on factors such as the laser parameters used, welding speed, welding position, etc. Furthermore, the gap-bridging tolerance of the process is less than that of arc welding. As such, the groove type and size for this process should be designed taking both the penetration capability and gap-bridging tolerance of the laser in to account, e.g. butt joint grooves with significantly broader root faces can be welded, albeit close-fitting, square-edged root preparations are then needed.

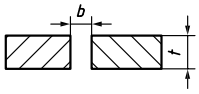
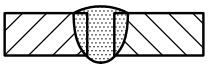
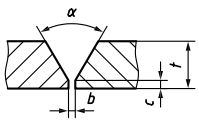
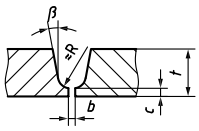
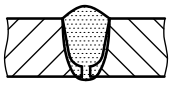
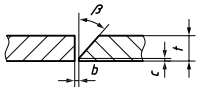
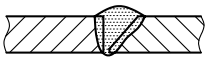
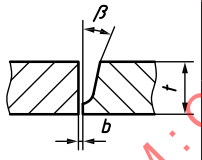
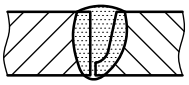
The special groove types have been proved to be useful in application.

The grooved types are based on ISO 9692-1 for steels and ISO 9692-3 for aluminium and aluminium alloys. It is possible, and sometimes with advantage for steel sructures, to use filler materials with lower strength because of the high cooling rates and reduced width of the laser-arc hybrid weld seams.

The butt joint preparations for laser-arc hybrid welding are recommended in Table 2 (for single side welding) and Table 3 (for double side welding). The fillet and flange joint preparations for laser-arc hybrid welding are recommended in Table 4.

The butt joint grooves can be prepared by a mechanical process (machining) or high precision cutting process (e.g. laser cutting or waterjet cutting), provided that a dimensional accuracy suitable for the limited gap bridging tolerance of the hybrid welding process can be insured. As a guide, a maximum butt joint gap tolerance is of the order of 5 % to 10 % of material (or, in thicker materials, root face) thickness, depending on factors such as the material being welded, welding position and resulting weld quality required.

Table 2 — Butt joint preparations for single side welding

No.	Material thickness t mm	Symbol in accordance with ISO 2553	Cross-section	Dimensions Angle α or β	Root gap b mm	Thickness of root face c mm	Weld illustration
1	$1< t \leq 5$	‖		—	$0 \leq b \leq 0{,}3$	—	
2	$5 < t \leq 10$			—	$0 \leq b \leq 0{,}3$	—	
3	$10 < t \leq 16$			—	$0 \leq b \leq 0{,}3$	—	
4	$16 < t \leq 20$			—	$2 \leq b \leq 3$	—	
5	$5 < t \leq 15$	V		$3° \leq \alpha \leq 20°$	$0 \leq b \leq 0{,}3$	$2 \leq c \leq 8$	
6	$t > 16$			$30° \leq \alpha \leq 45°$	$0 \leq b \leq 1$	$2 \leq c \leq 8$	
7	$16< t \leq 25$			$30° \leq \alpha \leq 45°$	$0 \leq b \leq 0{,}1$	$10 \leq c \leq 16$	
8	$t > 25$			$45° \leq \alpha \leq 60°$	$0 \leq b \leq 0{,}1$	$14 \leq c \leq 16$	
9	$t > 15$	Y		$8° \leq \beta \leq 12°$ $2 \text{ mm} \leq R \leq 4 \text{ mm}$	$0 \leq b \leq 0{,}1$	$2 \leq c \leq 8$	
10	$t > 25$				$0 \leq b \leq 0{,}1$	$14 \leq c \leq 16$	
11	$5< t \leq 12$	V		$15° \leq \beta \leq 30°$	$0 \leq b \leq 1$	$2 \leq c \leq 8$	
12	$t > 12$			$15° \leq \beta \leq 30°$	$0 \leq b \leq 1$	$2 \leq c \leq 8$	
13	$16< t \leq 25$			$15° \leq \beta \leq 30°$	$0 \leq b \leq 0{,}1$	$14 \leq c \leq 16$	
14	$t > 25$			$15° \leq \beta \leq 30°$	$0 \leq b \leq 0{,}1$	$14 \leq c \leq 16$	
15	$5< t \leq 12$	Y		$15° \leq \beta \leq 30°$ $2 \text{ mm} \leq R \leq 4 \text{ mm}$	$0 \leq b \leq 1$	$2 \leq c \leq 8$	
16	$t > 12$			$15° \leq \beta \leq 30°$ $2 \text{ mm} \leq R \leq 6 \text{ mm}$	$0 \leq b \leq 1$	$2 \leq c \leq 8$	
17	$16< t \leq 25$			$15° \leq \beta \leq 30°$ $2 \text{ mm} \leq R \leq 4 \text{ mm}$	$0 \leq b \leq 0{,}1$	$14 \leq c \leq 16$	
18	$t > 25$			$15° \leq \beta \leq 30°$ $2 \text{ mm} \leq R \leq 6 \text{ mm}$	$0 \leq b \leq 0{,}1$	$14 \leq c \leq 16$	

NOTE 1 All of the grooves are suitable to single pass and mult-pass welding.

NOTE 2 The grooves in No. 2, 3, 4, 7, 8, 9, 10, 13, 14, 17 and 18 are subject to high-power laser beam;

NOTE 3 The groove in No. 4 is filled with pre-positioned cut wire (pieces of wire with the length of several mm) and backing plate is required.

Table 3 — Joint preparations for butt welds, welded from both sides

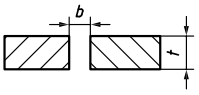
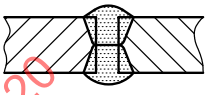
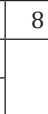
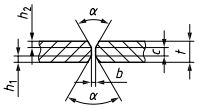
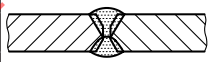
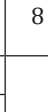
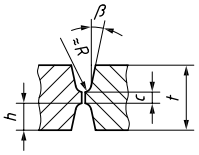
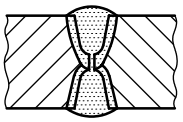
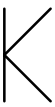
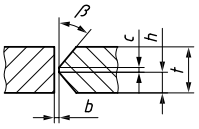
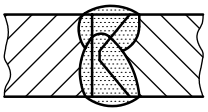
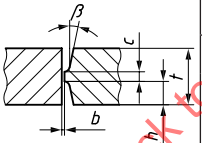
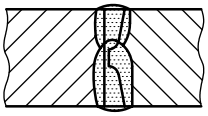
No.	Material thickness t mm	Symbol in accordance with ISO 2553	Cross-section	Dimensions: Angle α or β	Dimensions: Root gap b mm	Dimensions: Thick-ness of root face c mm	Weld illustration
1	$t \leq 25$			—	$0 < b \leq 0{,}5$	—	
2	$8 < t \leq 25$			$30° \leq \alpha \leq 45°$	$0 \leq b \leq 1$	$4 \leq c \leq 8$	
3	$t > 25$			$45° \leq \alpha \leq 60°$	$0 \leq b \leq 1$	$4 \leq c \leq 8$	
4					$0 \leq b \leq 0{,}5$	$15 \leq c \leq 20$	
5	$8 < t \leq 25$			$8° \leq \beta \leq 12°$ $2 \text{ mm} \leq R \leq 6 \text{ mm}$	$0 \leq b \leq 1$	$4 \leq c \leq 8$	
6	$t > 25$			$15° \leq \beta \leq 30°$ $2 \text{ mm} \leq R \leq 6 \text{ mm}$	$0 \leq b \leq 1$	$4 \leq c \leq 8$	
7					$0 \leq b \leq 0{,}5$	$15 \leq c \leq 20$	
8	$8 < t \leq 25$			$30° \leq \beta \leq 45°$	$0 \leq b \leq 1$	$4 \leq c \leq 8$	
9	$t > 25$			$15° \leq \beta \leq 30°$	$0 \leq b \leq 1$	$4 \leq c \leq 8$	
10					$0 \leq b \leq 0{,}5$	$15 \leq c \leq 20$	
11	$8 < t \leq 25$			$30° \leq \beta \leq 45°$	$0 \leq b \leq 1$	$4 \leq c \leq 8$	
12	$t > 25$			$15° \leq \beta \leq 30°$	$0 \leq b \leq 1$	$4 \leq c \leq 8$	
13					$0 \leq b \leq 0{,}5$	$15 \leq c \leq 20$	
NOTE The grooves in No. 4, 7, 10 and 13 are subject to high- power laser beam.							

Table 4 — Joint preparations for fillet welds and flange joints

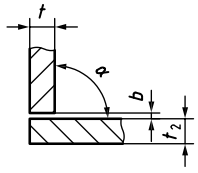
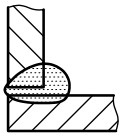
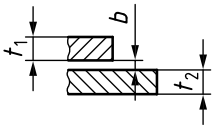
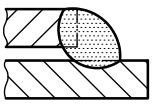
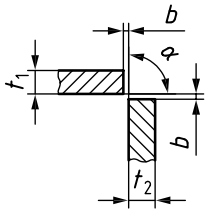
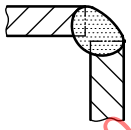
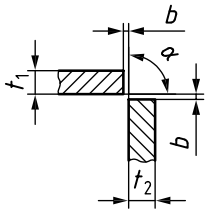
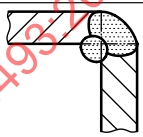
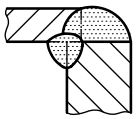
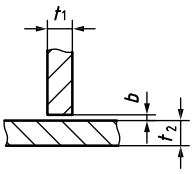
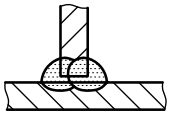
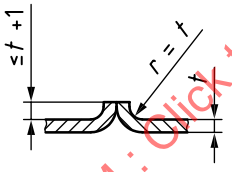
No.	Material thickness t mm	Symbol in accordance with ISO 2553	Cross-section	Dimensions: Angle α or β	Dimensions: Root gap b mm	Weld illustration
1	$t_1 > 2$ $t_2 > 2$			$70° \leq \alpha \leq 100°$	$b \leq 1$	
2	$t_1 > 10$ $t_2 > 10$					
3	$t_1 > 2$ $t_2 > 2$			—	$b \leq 1$	
NOTE The grooves in No. 2 and 8 are subject to high- power laser beam.						

Table 4 *(continued)*

No.	Material thickness t mm	Symbol in accordance with ISO 2553	Cross-section	Dimensions		Weld illustration
				Angle α or β	Root gap b mm	
4	$t_1 > 2$ $t_2 > 2$			$60° \le \alpha \le 120°$	$b \le 0,3$	
5	$t_1 > 3$ $t_2 > 3$			$70° \le \alpha \le 100°$	$b \le 0,3$	
6	$t_1 > 2$ $t_2 > 5$			$60° \le \alpha \le 120°$	—	
7	$2 \le t_1 \le 4$ $2 \le t_2 \le 4$			—	$b \le 1$	
8	$10 \le t_1 \le 20$ $10 \le t_2 \le 20$					
9	$t \le 2$			—	—	
NOTE The grooves in No. 2 and 8 are subject to high-power laser beam.						

9 Wire selection

Wire should be selected according to the base metal and meet the requirements of related standards, such as ISO 14341, ISO 14343, ISO 16834 and ISO 18273.

10 Preparation prior to welding

10.1 Handling of work piece

10.1.1 Work piece condition inspection

Necessary inspection of the work pieces should be carried out before assembling, including whether there are apparent problems with material and joint groove dimensions, or material preparation, such as burrs or unacceptable surface roughness or scratches on the abutting surfaces of the work pieces.

Should preheating of the work pieces be required prior to welding, it should also be checked that this has been carried out in accordance with the requirements of the welding procedure specification (WPS).

10.1.2 Cleaning before welding

In order to avoid defects like porosity and slag inclusions, the groove and its immediate surroundings should be cleaned (as specified in the WPS) before welding, ensuring removal of any rust, oxide film or mill scale, contamination by oils, machining fluids and any other organic materials, and burrs brought about during joint preparation.

Especially for aluminium and its alloys, cleaning before welding is very important, if unacceptable levels of weld metal porosity are to be avoided. The oxide film in on and near the groove shall be removed in dry conditions. The work pieces, after cleaning, should then be kept dry and clean and welded as soon as possible within 24 h.

The surface condition of any other materials using in the making of the weld metal (filler wires, consumable backing, etc.) should also be checked and cleaned as necessary.

10.2 Assembling and fixturing

Place the work pieces of the assembly to be welded in to the welding fixture and apply sufficient clamping to hold the work pieces together in the configuration required and prevent any movement during welding. Then, check the joint fit-up (gap and hi/lo mismatch) to ensure this is within the requirements of the WPS. Adjust the fixture until the fit-up between the work pieces is acceptable. Finally, apply any additional material cleaning required to those parts of the joint still accessible

10.3 Equipment status checking

The status of the equipment outlined in Clause 6 is to be checked prior to welding, to ensure it is ready to work and set in accordance with whatever relevant requirements for a given individual piece of equipment are specified in the WPS. Particular attention is recommended for the following:

— laser source settings: in particular, separate, independent measurements of laser beam output power are recommended prior to, periodically during, and after welding;

— arc power source settings: wire feeder settings (if used), and the wire position and inclination with respect to the laser beam position, joint position, work pieces and welding direction;

— manipulation device settings: the status of the laser beam optics cover slide.

The checking items include:

— focus position of the beam with respect to the joint position, and any inclination of the beam with respect to the work pieces and welding direction;

— the condition of the arc welding torch, its cooling (if used) and correct connection of the current return lead(s);

— the condition and settings of the shielding gas delivery system to weld cap and (if used) root (optional: seam tracking and/or weld process monitoring and/or control device settings, if used).

Prepare to weld after the correct status of the equipment as outlined above has been confirmed.

11 Torch design

For laser-arc hybrid welding, the arc welding torch is generally of a paraxial type.

The design factors that should be taken into consideration include the optical parameters of the beam from the laser source (e.g. focus position used during welding, focal length of beam focusing lens, etc.), the structural parameters of the arc welding torch (size, electrode stick-out used, etc.), the relative positions and inclinations of both the laser beam and arc torch, the requirement to shield the arc and the weld cap, and any additional assist gas requirements to suppress plasma or plume from the laser keyhole.

Examples of important parameters are given below.

EXAMPLE 1 Laser-arc separation: this is the distance from the centre of the laser spot on the work piece surface to the centre of the point where the wire would touch down on to that surface, were it not being melted: it can be designed as both adjustable and fixed, according to requirements.

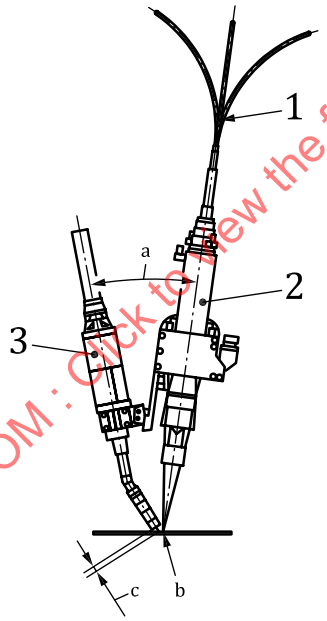
EXAMPLE 2 Laser beam focusing lens focal length: this is the distance along the beam's axis from the centre of the laser beam focusing lens to the point at which the beam passes through its minimum beam waist. For laser-arc hybrid welding, focusing lenses with longer focal lengths (e.g. >300 mm) are preferred, to avoid weld fume and spatter from quickly contaminating the cover slide.

EXAMPLE 3 As another important design factor, the angle between the laser beam and the axis of welding torch is commonly set between 30° to 45°, depending on welding and access requirements.

EXAMPLE 4 The wire stick-out is defined as the distance along the wire's axis from where the wire exits the contact tip to where it would touch down on to the work piece surface, were it not being melted by the arc. For laser-arc hybrid welding, stick-out distances are generally set to a value between 12 mm to 22 mm.

EXAMPLE 5 Plasma or plume can be suppressed using a suitably placed side jet of assist gas (not shown in Figure 1).

EXAMPLE 6 The weld pool and bead are shielded against oxidation using a flow of gas through the arc welding torch and/or additional paraxial protection.



Key

1	transmission optical fiber for laser	a	Angle between laser beam and axis of welding torch.
2	laser welding torch	b	Laser arc distance.
3	arc welding torch	c	Wire extensions.

Figure 1 — Welding gun (sketch)

12 Welding procedure specification and qualification

Welding parameters of laser-arc hybrid welding should be recorded/specified according to ISO 15609-6 and qualified in accordance with ISO 15614-14.

13 Welding parameters

In the laser-arc hybrid welding process, important parameters include laser beam focus position with respect to the work piece surface, welding speed, laser beam power, welding current, welding voltage, metal transfer mode across the arc, shielding gas flow, etc.

The laser beam is not necessarily focused on the workpiece surface, as this can increase spatter. Small negative (in to the workpiece) or positive (above the work piece) offsets in the beam focus position are commonly used, depending on the specifics of the welding being undertaken. These offsets are often in the range of a half of the plate thickness, being related to the depth of focus of the laser beam, the focal length of the beam focusing lens being used and the quality of the beam.

When the materials with high reflectivity is welded, the laser beam should be inclined by 5° to 10° off the normal to the reflective surface, as this can be helpful to avoid back-reflection of the laser beam and inadvertent damage to equipment.

Recommended laser-arc hybrid welding parameters for steels and aluminium alloys with different thickness are shown in Tables 5 to 8. Normally, laser power should be determined according to the rated power, work piece thickness, groove sizes, the defocus amount and welding speed. The welding current and the voltage should be adjusted according to reinforcement and groove sizes of the product.

In addition, a welding procedure specification example for laser-arc hybrid welding is listed in ISO 15609-6:2013, Annex A.

Heat input requirements are not the same for different materials. Accordingly, parameters such as laser beam power, welding speed, arc current and voltage need to be adjusted.

Table 5 — Recommended butt-welding parameters for laser- arc hybrid welding process (steel, single pass)

Base material thickness mm	Groove type	Groove angles °	Thickness of root face mm	Laser power kW	Welding current A	Arc voltage V	Welding speed m/min
2[a]	I	—	—	3 to 3,5	60 to 80	17 to 18	2 to 3
3 to 4[a]				4 to 4,5	80 to 100	19 to 20	2 to 2,5
5[a]				4,5 to 5	80 to 120	19 to 20	1,5 to 2
10[b]				8 to 12	280 to 350	26 to 32	1,5 to 2,5
12[b]				10 to 12	300 to 350	28 to 32	2 to 2,5
16[b]				16 to 18	320 to 360	30 to 34	2 to 2,5
20[b,c]				12 to 16	350 to 380	33 to 36	0,5 to 1,5
25[b,c]				19 to 20	350 to 380	33 to 36	0,8 to 1

[a] The focal length of laser gun is 300 mm, the operating fiber core diameter is 400 µm, and the focus position is 3 mm on the work piece surface.

[b] The focal length of laser gun is 350 mm, the operating fiber core diameter is 200 µm, the focus position is 4 mm below root face upper point and the laser-arc separation is 3 mm.

[c] If welded in PA(1G) position, backing is required either in form of ceramic backing plate or in form of contactless electromagnetic support system.

[d] Welding of 25 mm with combined tandem process. The distance laser beam to the combined tandem arc is approximately 60 mm.

Table 5 *(continued)*

Base material thickness mm	Groove type	Groove angles °	Thickness of root face mm	Laser power kW	Welding current A	Arc voltage V	Welding speed m/min
3[a]	V	30	2	2,5 to 3	160 to 180	21 to 22	1,5 to 2
4[a]			2	2,5 to 3	260 to 280	26 to 27	1,5 to 2
5[a]			2 to 3	3 to 3,5	260 to 280	26 to 27	1 to 1,5
6[a]			3 to 4	4,5 to 5	260 to 280	26 to 27	0,8 to 1,2
12[b]		60	8	8 to 10	350 to 380	32 to 36	2 to 2,5
16[b]			12	12 to 16	350 to 380	32 to 36	2 to 2,5
20[b]			16	19 to 20	360 to 400	34 to 38	1,8 to 2,3
25[b,d]		30	12	14 to 16	110 to 140 2 × 400 to 440	21 to 23 2 × 28 to 30	1 to 3

[a] The focal length of laser gun is 300 mm, the operating fiber core diameter is 400 µm, and the focus position is 3 mm on the work piece surface.

[b] The focal length of laser gun is 350 mm, the operating fiber core diameter is 200 µm, the focus position is 4 mm below root face upper point and the laser-arc separation is 3 mm.

[c] If welded in PA(1G) position, backing is required either in form of ceramic backing plate or in form of contactless electromagnetic support system.

[d] Welding of 25 mm with combined tandem process. The distance laser beam to the combined tandem arc is approximately 60 mm.

Table 6 — Recommended butt-welding parameters for laser-arc hybrid welding processes (steel, multi-pass[a])

Groove type	Groove angles °	Thickness of root face mm	Welding position	Laser power kW	Welding current A	Welding voltage V	Welding speed m/min
Type single V and U	30 to 45	2 to 4	Backing	3,0 to 4,0	200 to 220	18 to 20	0,5 to 0,8
			Filling	0,8 to 1,5	260 to 280	26 to 27	
Type double V and U	30 to 45	5 to 8	Backing	5,5 to 6,0	200 to 220	18 to 20	0,5 to 0,8
			Backing welds of the other side	1,0 to 2,0	200 to 220	18 to 20	
			Filling	0,8 to 1,5	260 to 280	26 to 27	

[a] For the multi-pass welding, it is recommended to use lower current and voltage for the backing pass.