

Pulse Laser Beam Welding of Duplex Steel

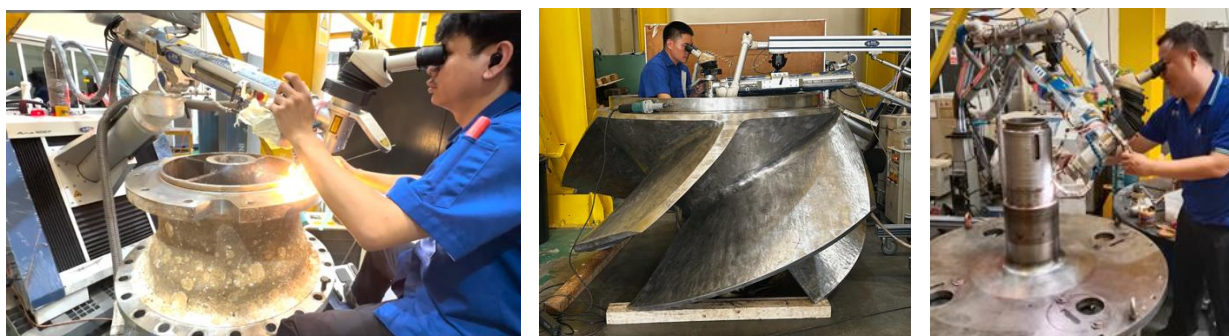
A balanced metal structure is crucial for quality

Initial situation: Facts and previous welding test

Ferritic-austenitic steels (F/A steels) are stainless steels and exhibit high strength with sufficient toughness values. This is due to the ferritic-austenitic steel structure. Ideally, this has a ratio of 50:50%. The ferrite content provides the strength ($R_{p0.2}$ from 400 to 750 MPa) and also the property that makes duplex steels magnetic; the austenite content, in turn, provides sufficient toughness and elongation ($A \geq 18\%$). During the production of

duplex steel, compliance with the ideal F/A ratio is determined on the one hand by the chemical composition and on the other hand by targeted controlled cooling. In contrast, during welding, especially in conventional arc processes, precise heat input and heat transfer are essential in order to maintain or achieve the mechanical and technological properties of the base material and the weld metal. Some duplex steels are classified as highly corrosion-resistant steels. They exhibit high resistance

to stress corrosion cracking, pitting corrosion and chloride-induced corrosion. In addition, most duplex steels are seawater-resistant. The spectrum ranges from lean duplex steels to the previous standard steel 1.4462 (X5CrNiMoN22-5-3) to super and hyper duplex steels. For steel construction alone, nine different duplex steels are currently approved in accordance with general building authority approval Z-30.3-6



Photos 1–3: Pulse laser welds on components made from DUPLEX (1.4462). Spring and groove fit on an offshore pump housing / crack repair on a pump impeller / bearing seats on the drive shaft of a centrifuge. Non-destructive test methods (NDT): Dry penetrant test (PT) and Ultrasonic test (UT).

1.4462 is the most commonly used duplex steel. It is used in chemical and petrochemical plant construction, in seawater desalination plants and in the offshore, oil and gas industries as shown in photos 1–3. This wide range of applications and the high quality requirements prompted an

investigation into the weldability of this standard duplex steel using the pulsed laser beam welding process (process 521 / ISO 4063) – particularly with regard to maintaining the ideal ferrite-austenite ratio. The increasing use of this technology is based on the unique advantages

offered by ‘welding with pulsed light and its speed’: very low heat input (approx. 30 joules); very narrow heat-affected zone (0.1–0.3 mm); no critical change in microstructure; no coarse grain formation; no pre- or post-heat treatment to regain the desired microstructure;

welding at room temperature; no ‘graphitisation’ as occurs when welding cast iron/cast steel; virtually no thermal deformation.

The current study incorporates findings from previous pulse laser beam welding experiments and their evaluations. These showed that conventional welding processes, such as tungsten inert gas, metal active gas and manual arc welding, whose energy source and supply is based on electricity, have a critical heat-affected zone (HAZ) approximately 2.0–3.0 mm wide from a mechanical-technological point of view. In comparison, pulse laser beam welding produces a very narrow HAZ measuring only 0.1–0.3 mm. This also

applies to welded joints in duplex steel structures: these too show no or only very slight changes in their mechanical and technological properties. This positive influence has been proven by the authors in collaboration with independent testing laboratories through numerous practical welding tests. The results have been published in international trade journals, for example in Der Praktiker 7-8/2024 and Welding and Cutting 2/2024.

Based on these facts, the question arises as to whether the pulse laser beam welding process can also achieve a favourable F/A ratio corresponding to that of duplex steel. Both in the weld metal and in the HAZ –

thereby retaining all its application-related advantages.

The main focus of the investigation was on the weld metal. The welding consumable DSI M Connect 3 (EN ISO 14343-A: G 22 9 3 N L), approved for 1.4462, was selected. The aim was to determine the influence of welding with different energy inputs and matching welding wire diameters (high energy / D = 1.2 mm and low energy D = 0.6 mm) in order to draw conclusions about the F/A ratio and its possible variations. The pulse laser welding parameters for low energy and high energy were shown in Table 1 and 2

Table 1: Parameter selection ‘low energy / D = 0.6 mm’					
Laser Beam Energy	Pulse Duration	Pulse Frequency	Laser Beam Diameter	Pulse Shape	Shielding Gas Argon 4.6
609 W / 15,30 J	3,0 ms	42,4 Hz	1,5 mm	S3	15 l/min.

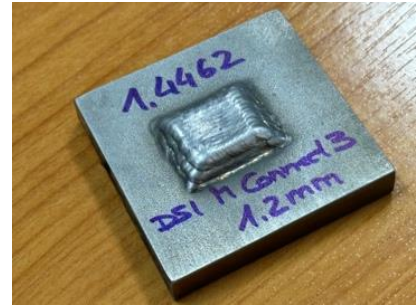
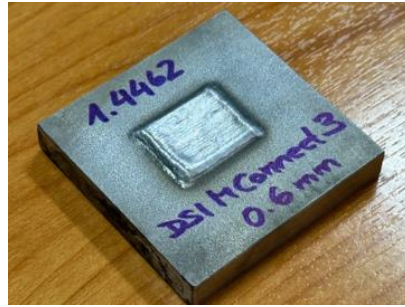
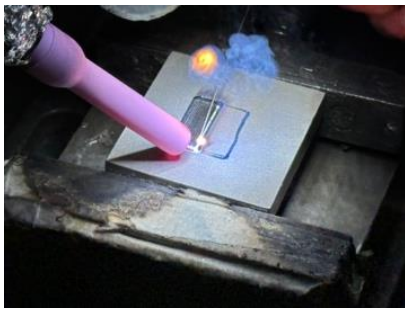
Table 2: Parameter selection ‘high energy / D = 1.2 mm’					
Laser Beam Energy	Pulse Duration	Pulse Frequency	Laser Beam Diameter	Pulse Shape	Shielding Gas Argon 4.6
1112 W / 28,32 J	3,4 ms	42,4 Hz	3,1 mm	S3	15 l/min.

Practical welding tests (technical details)

The test plates with a thickness of 8 mm were provided by a company based in Germany. The test welds were carried out at DSI Laser Service (Thailand) Co., Ltd., based in Chonburi, which has been active in the field of pulsed laser steel welding for

25 years and serves customers in various branches of industry. This includes the chemical/petrochemical and offshore industries, for which high-quality repair welds on components made of duplex steel are absolutely essential – until now, this has been achieved using conventional welding processes, which have the well-known time-

consuming and costly disadvantages. These difficulties, in turn, explain the great interest in the welding technology investigation of duplex steel using pulse laser beam welding. All sample plates were welded in pulse mode using a fibre laser, type ALPHA LASER ALFlak1200F.



Photos 4–6: During pulse laser beam welding; Completed, three-layer build-up welds

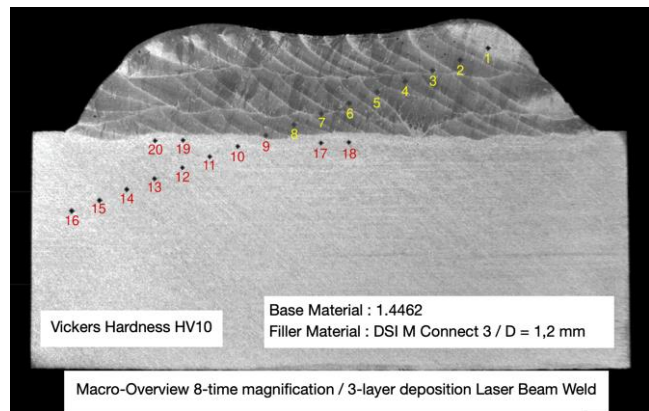
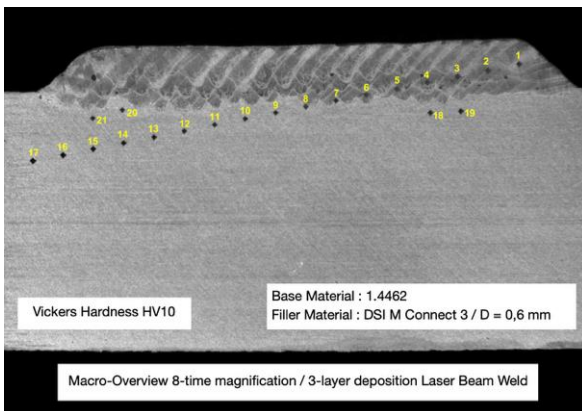
In both cases ('low energy/high energy'), two samples were welded: one single-layer and one three-layer build-up weld.

Evaluation of test welds:

The metallographic sections, hardness series and delta ferrite content determinations

were carried out by the authorised third party KMUTT's Welding Research and Consulting Center (KINGWELD), which is affiliated with King Mongkut's University Thonburi (KMUTT), Bangkok, Thailand. In order to have their test results verified by a second

independent body, the sections obtained from the test welds were sent to GSI SLV Hannover and the magnifications, in the range between 50 and 500 times, were re-evaluated. In this technical article, two micrographs relevant to the evaluation were selected (photos 7–8).



Photos 7–8: Macro overview 8x magnification with Vickers hardness scale HV-10 3-layer pulse laser steel welding

Table 3: Determination of hardness values (HV10) according to Figs. 1 and 2 with measurement point assignment (MP)		
	Low Energy / D = 0,6mm	High Energy / D = 1,2mm
Weld metal	MP 1-7 = 269-287	MP 1-9 = 249-272
Heat Affected zone (HAZ)	MP 8-10 / 18-21 = 266-279	MP 10,11 / 17-20 = 266-272
Base Material	MP 11-17 = 234-266	MP 12-16 = 241-272

Table 4: Determination of the delta ferrite content in %		
	Low Energy / D = 0,6mm	High Energy / D = 1,2mm
Weld metal / upper covering layer	59,57	48,81
Weld metal / lower covering layer	42,27	48,71
Heat Affected zone (HAZ)	54,78	53,16
Base Material	50,88	50,37

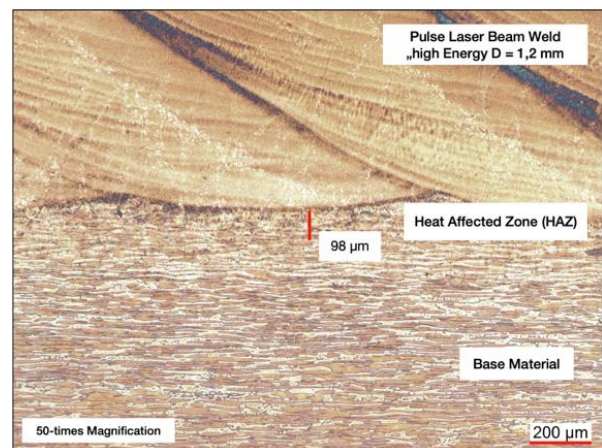
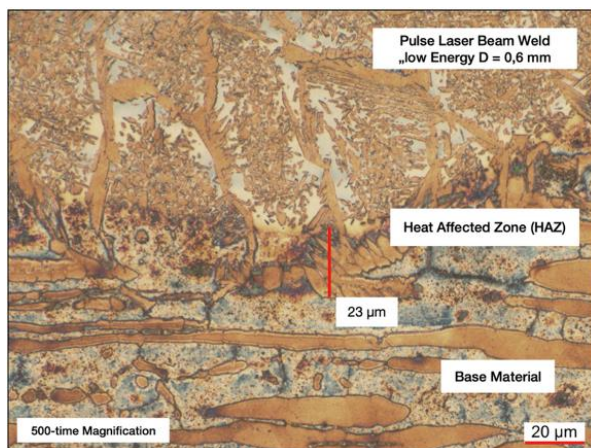
Evaluation of hardness values (Table 3):

In the areas of weld metal, heat-affected zone (HAZ) and base material, the hardness values for 'low energy D = 0.6 mm' welds are below 287 HV10. For 'high energy D = 1.2 mm' welds, they are below 272 HV10.

Evaluation of delta ferrite content (Table 4):

The welds with 'low energy D = 0.6 mm' and those with 'high energy D = 1.2 mm' show very similar results. In total, the delta ferrite content relative to austenite was determined in each area of the weld, in the base material, in the HAZ and

in the weld metal, using five individual value determinations in each case. In all cases, these were within the technically acceptable F/A structure range of 60:40% and, conversely, 40:60%. The ferrite content was determined to be max. = 59.57% and min. = 42.27%.



Photos 9–10: Pulse laser welds with complete bonding to the base material and barely detectable heat-affected zones (HAZ).

Evaluation of heat-affected zones (photo 9): The microstructure in the section with 'low energy D = 0.6 mm' shows a barely detectable, and therefore barely existent, HAZ of approx. 23 μm (0.023 mm) at 500x magnification.

The microstructure in the 'high energy D = 1.2 mm' cut (photo 10) shows a 98 μm

(0.098 mm) wide WEZ at 50x magnification. When viewing and evaluating, it should be noted that the 'widths' of the heat-affected zones are given in micrometres (μm).

Summary of the investigation results:

The evaluations of the available weld samples

demonstrates, as already proven by similar tests on other materials, that pulse laser beam welding also makes it possible to achieve non-critical, high-quality welds in duplex steel with regard to the entire welded joint without the need for preheating or post-weld heat treatment (PWHT) – from the base material to the very

narrow heat-affected zone to the weld metal. The positive test results confirm and justify the safe use of pulsed laser beam welding technology in the aforementioned industrial sectors.

Practical applications prove the high quality:

Over the past few years, the results of numerous repair welds have confirmed the

high quality of pulse laser beam welding on components made of duplex steel: 1.) During the welding process: generally crack-free welding (no cracks in the weld metal due to the selection and individual setting of 5 different welding parameters). Welding without preheating and/or post-heating. 2.) In operational use: long service life. High corrosion resistance to seawater. This applies to

welding repairs on static components (pump housings, diffusers, valve seats and spindles, heat exchangers) as well as rotating components (rotors, shafts, impellers); both for build-up welding and joint welding. The repair welds on the components listed below were successfully carried out by DSI Laser Service (Thailand) Co., Ltd.

AUTHORS



Prof. Dr.-Ing. Gerd Kuser,
Auditor and Certifier, GSI –
Gesellschaft für Schweißtechnik
International mbH, Niederlassung
SLV Hannover,
kuser@slv-hannover.de



Dr. Titinan Methong,
Lecturer, Department of
Production Engineering,
King Mongkut's University of
Technology Thonburi
(KMUTT), Thailand,
titinan.met@mail.kmutt.ac.th



Stephan Thiemoonds (IWS)
Principal, DSI Thailand
Laser Welding Academy,
Deputy General Manager, DSI
Laser Service (Thailand) Co., Ltd.,
Chonburi/Thailand,
thiemoonds@dslaser.com



Pulse Laser Welding Note [26]



Pulse Laser Welding is **NOT** the same than Laser Welding.

One is operating in **Pulse Wave** mode. The other in **Continuous Wave** mode.

Only by welding with **PULSED** light and its speed,
all unique advantages can be earned.

Only by welding within a **split of a second**

PULSE after PULSE after PULSE ...

at the **„Tiny-GIANT Playground“**

unreachable for any other welding or cladding method.

More inspiration at DSI Thailand Laser-Welding-Academy