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PULSE LASER WELDING

ACADEMY

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DSI PULSE LASER WELDING

DVS ZERT ISO 3834-2:2021

ALPHALASER SOUTHEAST ASIA

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Created and compiled by DSI Thailand Laser-Welding Academy (issue 06.2026)

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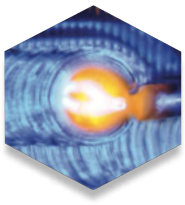
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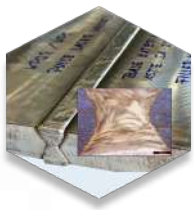
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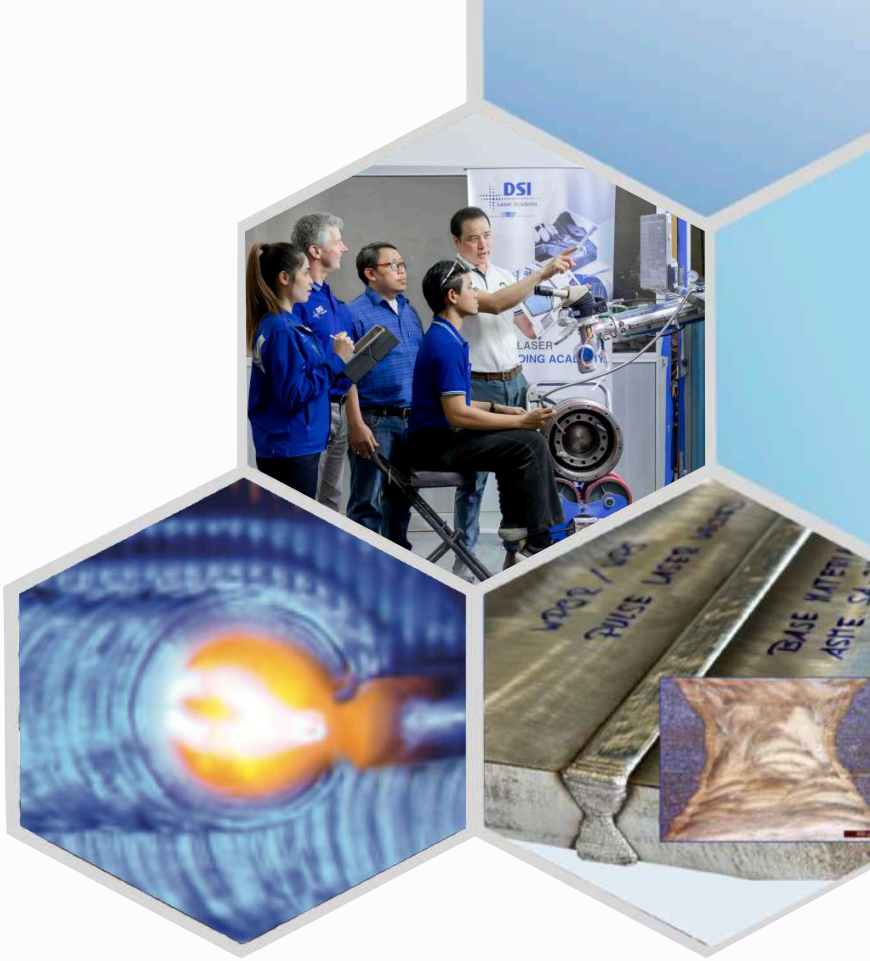






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Chapter I.

Pulse Laser Welding and its Unique Advantages

Pulse Laser Welding

Basic Understanding

HOW classical arc-welding technologies works ?



GTAW



GMAW



SMAW

Classical arc-welding methods use *electricity*.

They *continuous* provide *heat* until the metal melts until the needed melting pool is present.

By applying *continuous heat* to metal causes some negative effects :

- Microstructure Changing
- Coarse Grain Formation
- Graphitisation
- Thermal Distortion
- Residual Stress
- Brittle Structure in the Heat-Affected Zone (HAZ)
- Unacceptable Welding Discontinuities and Defects

And for some materials it requires :

- Pre- or Post Weld Heat Treatment (PWHT)

Conclusion : Classical arc-welding methods provides *negative* influences regarding mechanical- and metallurgical properties.

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Pulse Laser Welding

Basic Understanding

HOW Pulse Laser Welding technology works ?







Pulse Laser Welding creates the melting pool by *pulsed Light* and *its Speed* by *Photons* - travels at 300,000 km/s.

Pulse Laser Welding is happen *within a split of second* means :

- ➜ Release energy supply …
- ➜ Create the molten bath …
- ➜ Add filler material …
- ➜ Stop energy supply …
- ➜ Complete solidification of the molten bath …

… while ***all unique advantages*** are provided.

Pulse Laser Welding Process
1.) Original Speed
2.) Thermo Camera
3.) Super Slow Camera
Video DSI-Dropbox

Based on always full metallurgical bonding :

- ✓ Very low heat input (only about 30 Joules) / very thin HAZ (0.1-0.3 mm)
- ✓ No critical microstructure changing / No coarse grain formation
- ✓ No pre- or post weld heat treatment / welding at room temperature
- ✓ No graphitisation / related to welding (gray) cast iron
- ✓ Almost no thermal distortion / very precisely

Conclusion : Pulse Laser Welding does ***NOT*** provide negative influences regarding mechanical- and metallurgical properties.

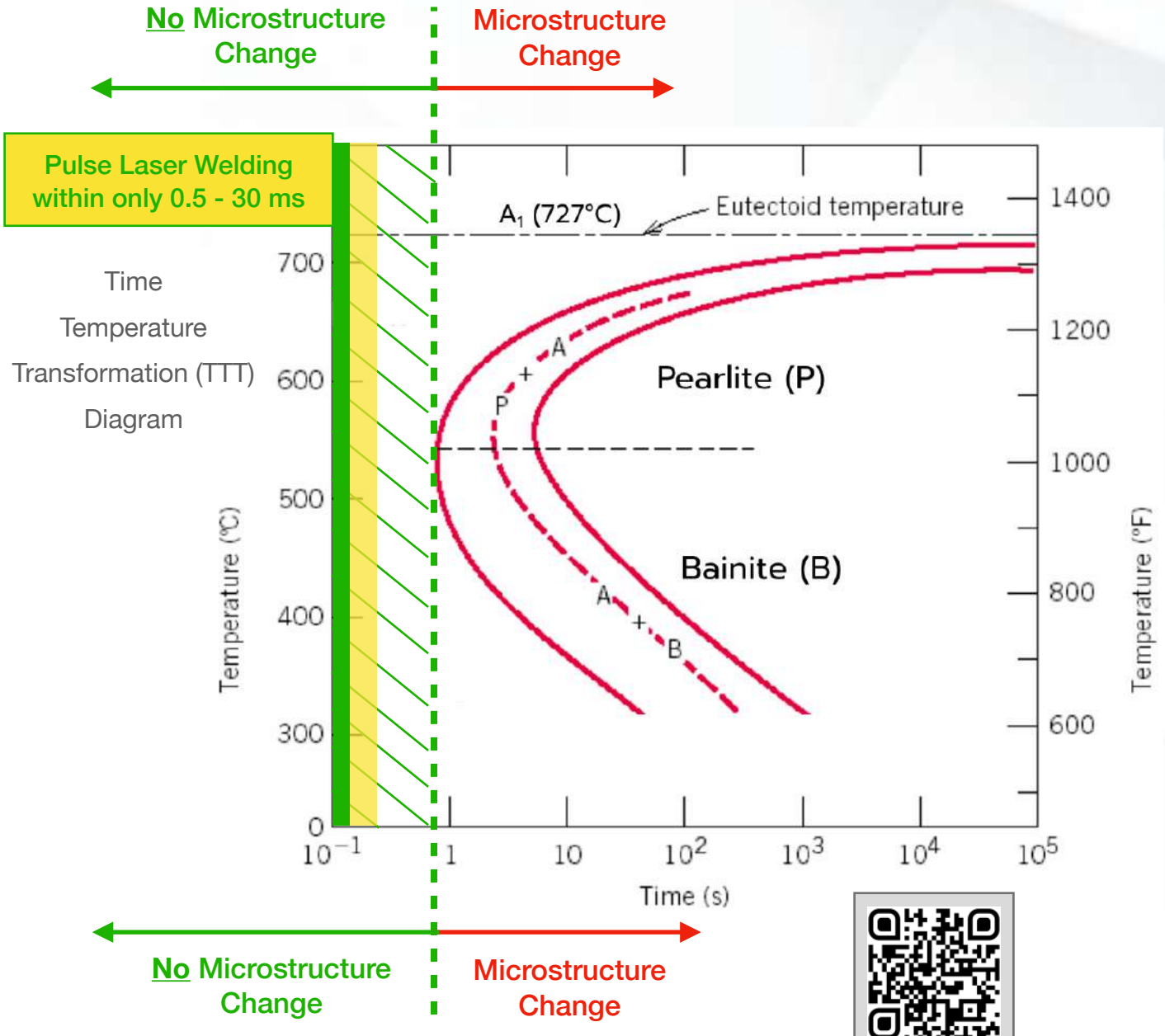
Pulse Laser Welding

Basic Understanding

Pulse Laser Welding is *UNIQUE* !

Pulse Laser Welding has *NONE* competitive Technology !

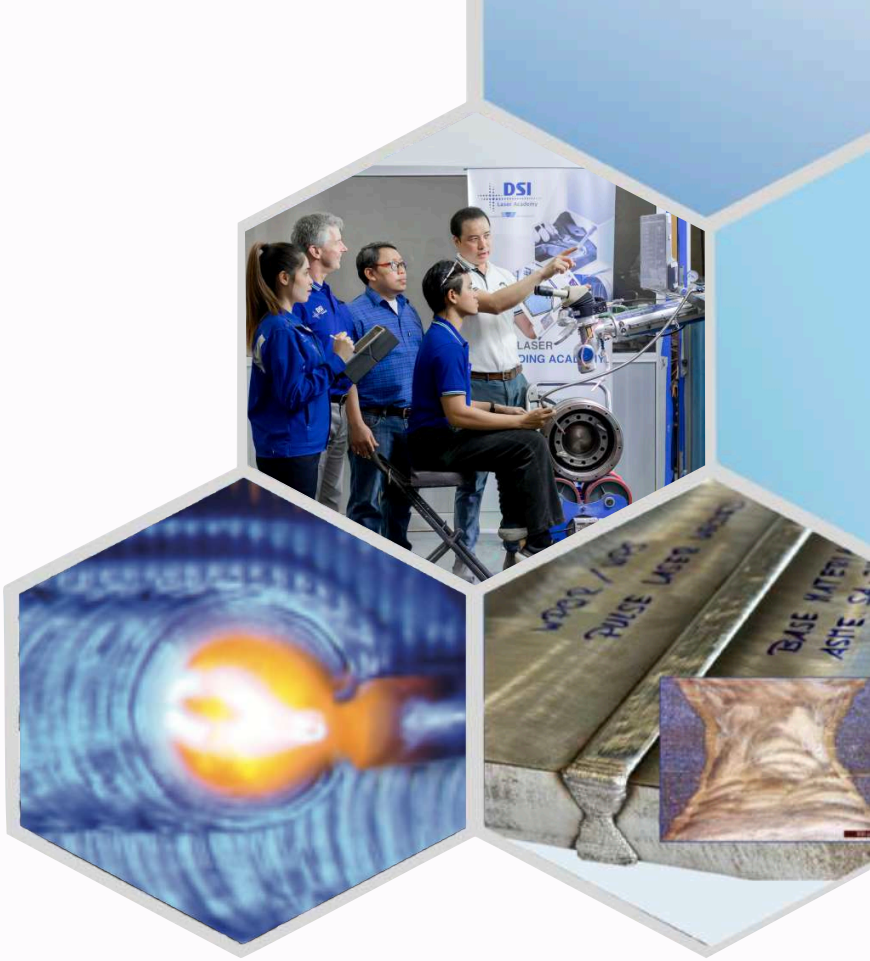
Because only by ***welding with pulsed light and its speed*** all unique advantages can be earned - at the ***Tiny-giant Playground*** which is ***unreachable for any other welding or cladding method***.



Pulse Laser Welding
Melting Pool
Video DSI-Dropbox

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Chapter II.

DSI Thailand Laser-Welding-Academy its Partners and what we provide

DSI Thailand Laser-Welding-Academy

Collaborations

A designated objective of ***DSI Thailand Laser-Welding-Academy*** is a continuous development of Pulse Laser Welding Technology for customers in any industry, which is accompanying with a deeper and wider understanding regarding base- and filler-materials, individual applications and required component performances.

This **Vision & Mission** is based on several strong and solid collaborations with international institutes, third parties and societies who have a deep and wide understanding within the world of welding.

"A strong collaboration of professional parties is the key of success"

Together we offer and carry out :

Investigations - Examinations - Certifications - Publications

King Mongkut's University of Technology Thonburi

DVS SLV HANNOVER

TGI Thai-German Institute สถาบันไทย-เยอรมัน

AWS American Welding Society

DSI Laser Academy

KINGWELD

HOME OF WELDING DAS BRANCHENPORTAL

Fraunhofer ILT Institut Lasertechnik

PULSE LASER WELDING
ACADEMY

EDUCATION

MODULE 1: Laser safety regulation

MODULE 2: Machine operation

MODULE 3: Introduction to welding operation

MODULE 4: Training for welder certification

MODULE 5: Training for welder in Aviation & Aerospace

CERTIFICATION

DIN EN ISO 14732:2013-12

AWS C7.4/C7.4M:2017

AWS D14.6/D14.6M:2012

AWS D17.1/D17.1M:2017

ENGINEERING SUPPORT

Welding procedure development (WPS / WPQR)

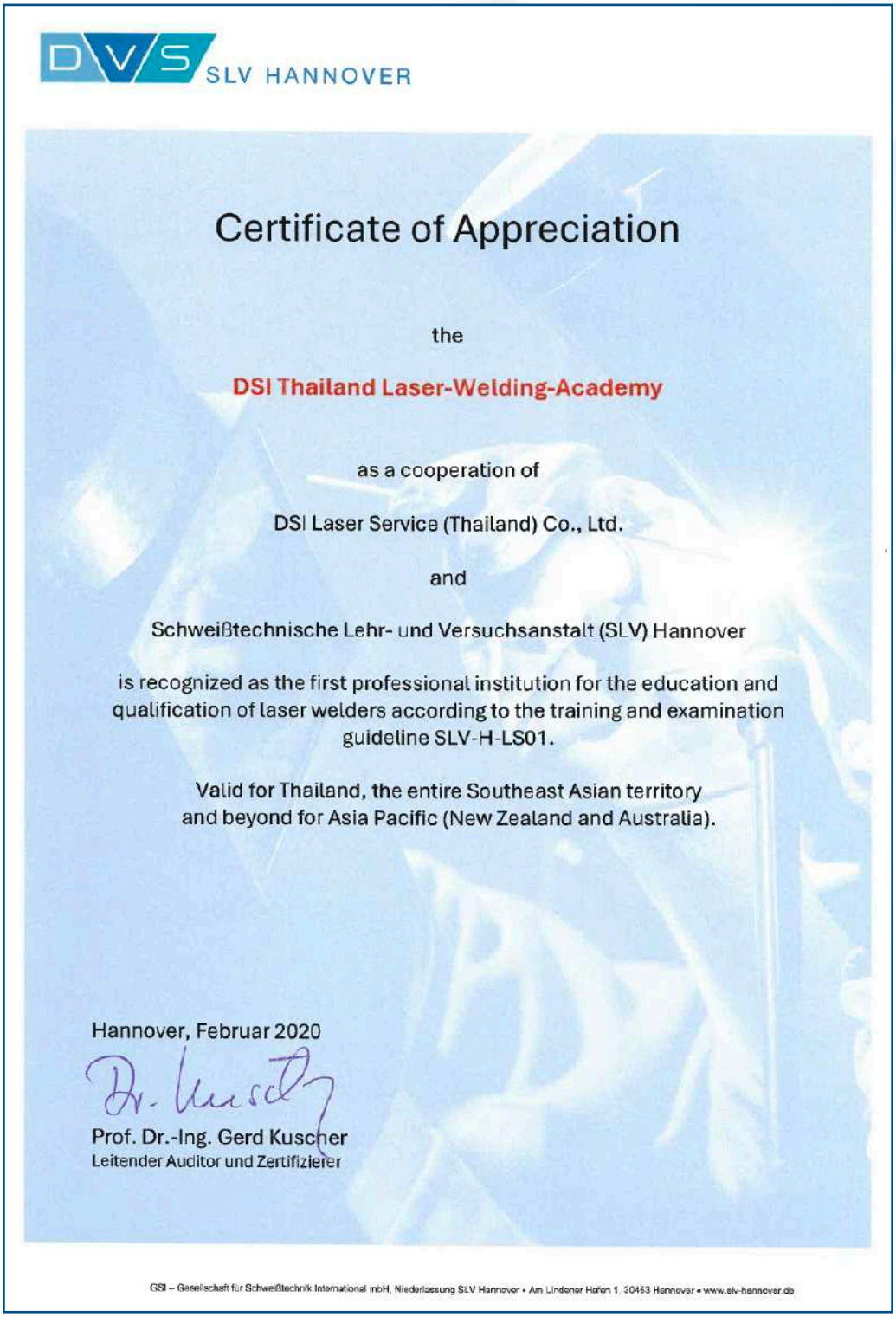
DSI Total Solution for ***Pulse Laser Welding*** with ***DSI Laser Wires***

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SOUTHEAST ASIA

dsilaser.com

In cooperation with German Welding Society *DVS SLV Hannover*, *DSI Thailand Laser-Welding-Academy* is permitted to educate and qualified Pulse Laser Welders and Pulse Laser Welding Machine Operators. Both DSI-Employees and also Customers wo operate with *ALPHA LASER* Systems.



DVS SLV HANNOVER

Certificate of Appreciation

the

DSI Thailand Laser-Welding-Academy

as a cooperation of

DSI Laser Service (Thailand) Co., Ltd.

and

Schweißtechnische Lehr- und Versuchsanstalt (SLV) Hannover

is recognized as the first professional institution for the education and qualification of laser welders according to the training and examination guideline SLV-H-LS01.

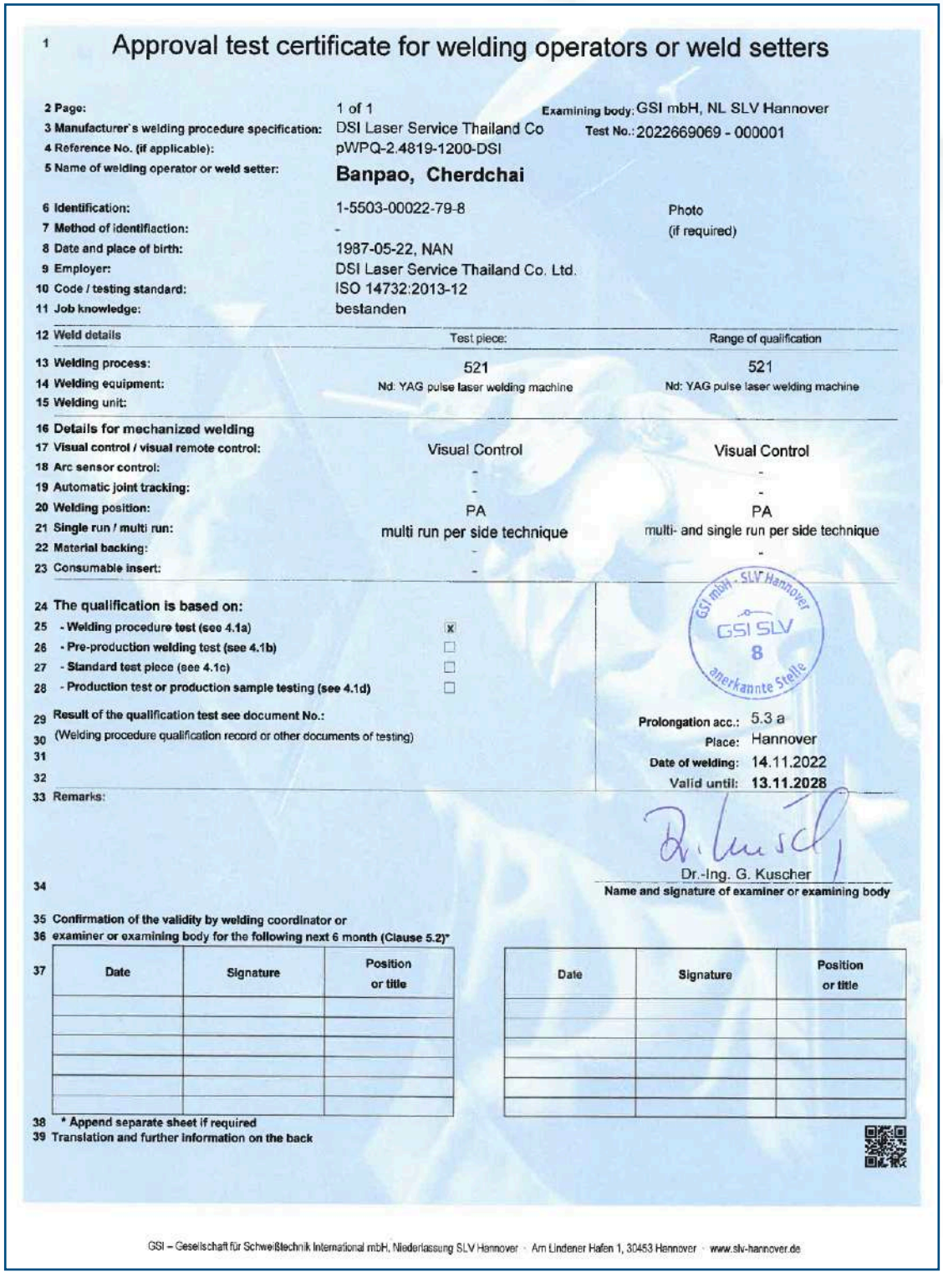
Valid for Thailand, the entire Southeast Asian territory and beyond for Asia Pacific (New Zealand and Australia).

Hannover, Februar 2020

Prof. Dr.-Ing. Gerd Kuscher
Leitender Auditor und Zertifizierer

GSI – Gesellschaft für Schweißtechnik International mbH, Niederlassung SLV Hannover • Am Lindener Hafen 1, 30453 Hannover • www.slv-hannover.de

Approval Test Certificate of „*Pulse Laser Welder*“ and „*Pulse Laser Welding Machine Operator*“, executed by *DSI Thailand Laser-Welding-Academy* based on the approval of German Welding Society *DVS SLV Hannover.*



1 Approval test certificate for welding operators or weld setters

2 Page:	1 of 1	Examining body:	GSI mbH, NL SLV Hannover
3 Manufacturer's welding procedure specification:	DSI Laser Service Thailand Co	Test No.:	2022669069 - 000001
4 Reference No. (if applicable):	pWPQ-2.4819-1200-DSI		
5 Name of welding operator or weld setter:	**Banpao, Cherdchai**		
6 Identification:	1-5503-00022-79-8	Photo (if required)	
7 Method of identifiaction:	-		
8 Date and place of birth:	1987-05-22, NAN		
9 Employer:	DSI Laser Service Thailand Co. Ltd.		
10 Code / testing standard:	ISO 14732:2013-12		
11 Job knowledge:	bestanden		

12 Weld details	Test piece:	Range of qualification
13 Welding process:	521	521
14 Welding equipment:	Nd: YAG pulse laser welding machine	Nd: YAG pulse laser welding machine
15 Welding unit:		
16 Details for mechanized welding		
17 Visual control / visual remote control:	Visual Control	Visual Control
18 Arc sensor control:	-	-
19 Automatic joint tracking:	-	-
20 Welding position:	PA	PA
21 Single run / multi run:	multi run per side technique	multi- and single run per side technique
22 Material backing:	-	-
23 Consumable insert:	-	-

24 The qualification is based on:

25 - Welding procedure test (see 4.1a)	x	
26 - Pre-production welding test (see 4.1b)	☐	
27 - Standard test piece (see 4.1c)	☐	
28 - Production test or production sample testing (see 4.1d)	☐	

GSI mbH - SLV Hannover GSI SLV 8 anerkannte Stelle

29 Result of the qualification test see document No.:
30 (Welding procedure qualification record or other documents of testing)
31
32

Prolongation acc.: 5.3 a
Place: Hannover
Date of welding: 14.11.2022
Valid until: 13.11.2028

33 Remarks:

34 Dr.-Ing. G. Kuscher
Name and signature of examiner or examining body

35 Confirmation of the validity by welding coordinator or
36 examiner or examining body for the following next 6 month (Clause 5.2)*

37

Date	Signature	Position or title	Date	Signature	Position or title

38 * Append separate sheet if required
39 Translation and further information on the back

GSI – Gesellschaft für Schweißtechnik International mbH, Niederlassung SLV Hannover · Am Lindener Hafen 1, 30453 Hannover · www.slv-hannover.de

PLW-Certification for DSI-internal Video DSI-Dropbox

PLW-Certification for Customer Video DSI-Dropbox

Pulse Laser Welding

Qualification & Standards

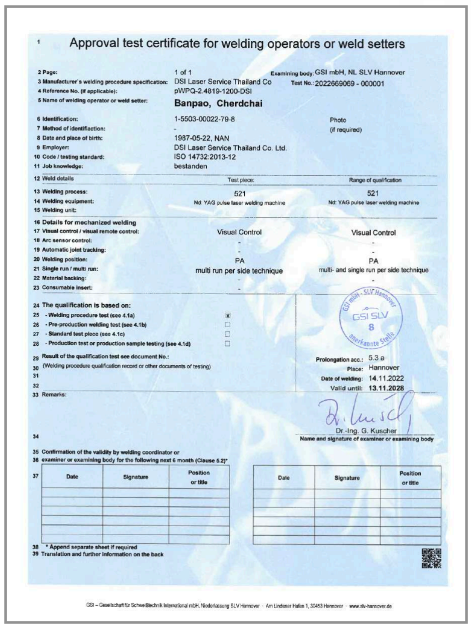
Pulse Laser Welding Technology can follow **any** welding standard and its examinations like ISO, AWS, ASME, JIS, GB/T.

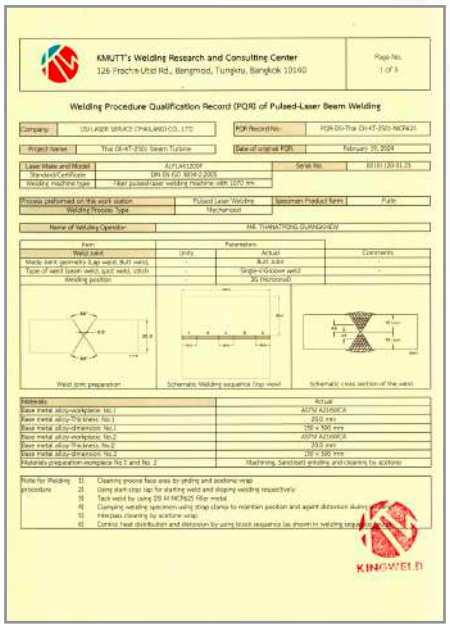
Pulse Laser Welding Processes are specified and qualified by :

- Welding Procedure Qualification Record (WPQR)
- Welding Procedure Specification (WPS)

DSI-Thailand PL-Welders & **PLW-Machine-Operators** are certified according to:

- ISO 14732:2013-12
- AWS D14.6/D14.6M:2012
- AWS D17.1/D17.1M:2017


Approval test certificate for welding operators or weld setters


KMUTT's Welding Research and Consulting Center
Welding Procedure Qualification Record (PQR) of Pulsed-Laser Beam Welding


KING MONGKUT'S WELDING RESEARCH AND CONSULTING CENTER
PERFORMANCE QUALIFICATION TEST RECORD



DSI Laser Academy

CERTIFICATE OF ATTENDANCE

Laser Safety Regulation "DGUV Vorschrift 11" (Former "BGVB2")

CHERDCHAI BANPAO

DSI LASER SERVICE (THAILAND) CO.,LTD.

January 2025 - December 2027

Stephan Thiemonds
Principal

Registed number DSIAC-DGUV-1/25-12/27

DSI Laser Service (Thailand) Co.,Ltd.

Safety Training
BOSCH TH
Video DSI-Dropbox



DSI Laser Academy

CERTIFICATE OF ATTENDANCE

Basic practical Pulse Laser Welding "DSI Welder 5"

CHERDCHAI SUESAT

DSI LASER SERVICE (THAILAND) CO.,LTD.

January 2025 - December 2027

Stephan Thiemonds
Principal

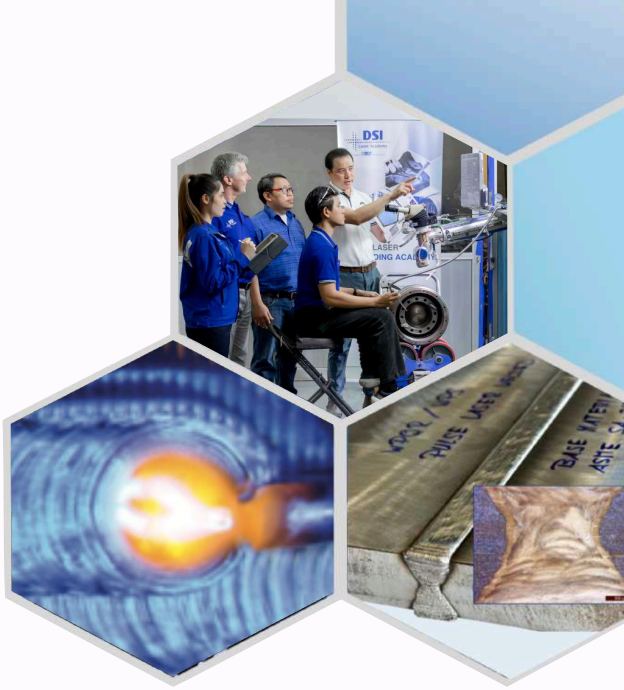
Registed number DSIAC-DGUV-1/25-12/27

DSI Laser Service (Thailand) Co.,Ltd.

PLW-Training
EGAT TH
Video DSI-Dropbox

DSI Laser Academy

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Chapter III.

Pulse Laser Welding Publications Investigations, Examinations, and Developments

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Coarse Grain Formation within Heat Affected Zone (HAZ) : Comparison between Classical Arc-Welding Methods and Pulse Laser Welding Technology	19 - 23
A Novel Approach to Pulsed Laser Welding of Nodular Cast Iron Without Preheating and Post-Weld Heat treatment	24 - 30
Pulsed laser beam welding - start thinking big! Repair welding of a shock absorber housing	31 - 34
Repair of a steam turbine in Thailand using pulsed laser beam welding	35 - 37
Repair welding of spheroidal graphite cast iron: Problem-free without heat pre- and post-treatment	38 - 41
Pulsed laser beam welding: In Seventh Heaven above Thailand	42 - 48
HAZ - The most feared “Danger Zone” in welding technology	49 - 53

The articles are collected in this *DSI Thailand Laser-Welding-Academy* Magazine were published in German and English language, in the Magazines of German Welding Society *DVS-Media* and *American Welding Society*.

Technical Articles

- *Repair of a steam turbine in Thailand using pulsed laser beam welding (in Welding and Cutting, issue 2/2020)*
- *Pulsed Laser Beam Welding – start thinking big! Repair welding of a shock absorber housing (Welding and Cutting, issue 1/2023)*
- *Repair welding of spheroidal graphite cast iron – Problem-free without heat pre-treatment and post-treatment (in Welding and Cutting, issue 2/2023)*
- *Pulsed Laser Welding – High above the clouds of Thailand, (Welding and Cutting, Ausgabe 1/2024)*
- *HAZ – The most feared Danger Zone in welding technology, (Welding and Cutting, issue 2/2024)*
- *Pulse Laser Welding Development: Back then it has started with thinking small – now it's time to start thinking BIG!, (Indias Welding Magazine Weldfab Tech Times, issue 10/11. 2024)*
- *Pulsed Laser Beam Welding Leads the Race - Refurbishment of the Eroded Outlet Nozzle of a Recyled Gas Compressor Housing, (Welding and Cutting, issue 2/2025)*
- *A Novel Approach to Pulsed Laser Welding of Nodular Cast Iron Without Preheating and Post-Weld Heat Treatment, (Welding and Cutting, issue 1/2026)*
- *Pulse Laser Beam Welding of Duplex Steel A balanced metal structure is crucial for quality (Welding & Cutting issue 2/2026)*
- *Coarse Grain Formation within Heat Affected Zone (HAZ) : Comparison between Classical Arc-Welding Methods and Pulse Laser Welding Technology (Welding and Cutting 1/2027)*

Magazine, Handbook, Catalog

- *DSI Thailand Pulse Laser Welding Handbook (issue 10/2025)*
- *DSI Thailand Laser-Welding-Academy Magazine, (issue 05/2026)*
- *DSI Thailand Laser Welding Wires, (issue 03/2026)*
- *DSI Thailand Laser Welding Wires / Molds & Dies (issue 05/2025)*
- *DSI Thailand Pulse Laser Welding Machines, (issue 08/2025)*

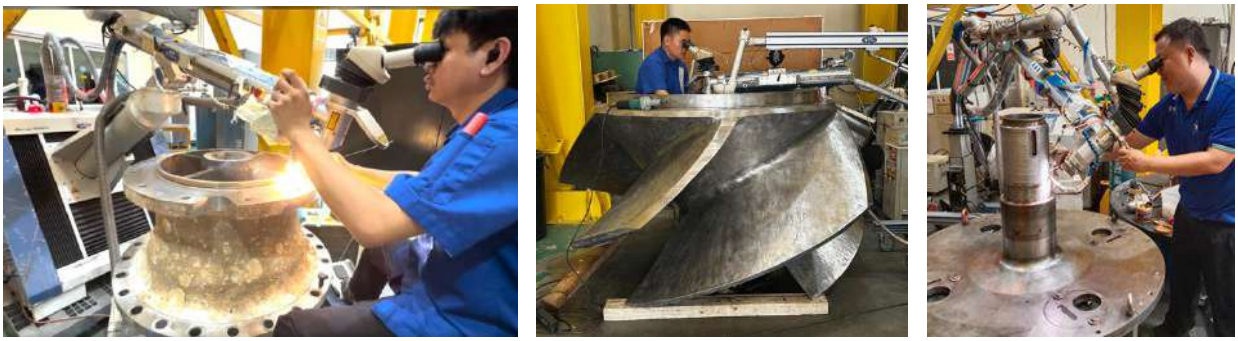
Books

- *Welding Connects - You'll Never Work Alone, DVS-Media, 2023, 408 p., ISBN: 978-3-96144-197-6*
- *Schweißen Verbindet - You'll Never Work Alone, DVS-Media, 2020, 328 p., ISBN: 978-3-96144-078-8*

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 (Rp0.2 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≥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'

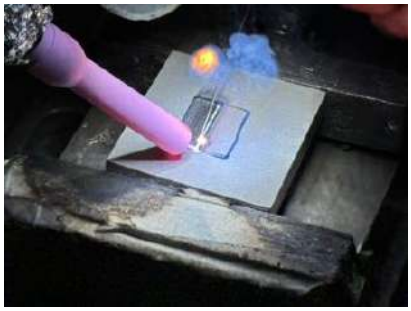
Laser Beam Energy	Pulse Duration	Pulse Frequency	Laser Beam Diameter	Pulse Shape	Shielding Gas Argon 4.6
609 W / 15,30 J	3,0 ms	42,4 Hz	1,5 mm	S3	15 l/min.

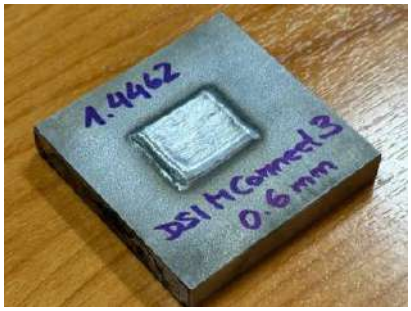
Table 2: Parameter selection 'high energy / D = 1.2 mm'

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.





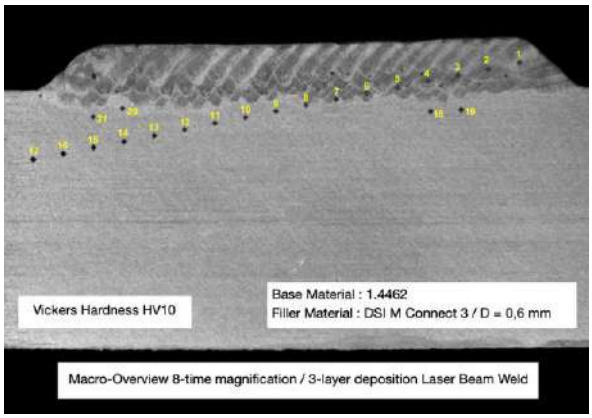


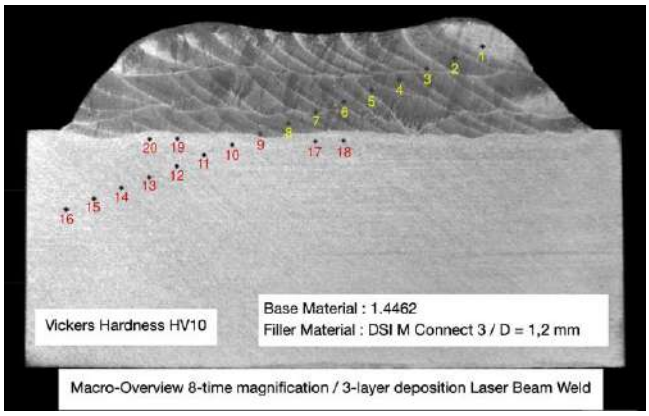
Photos 4–6: During pulse laser beam welding; Completed, three-layer build-up welds

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

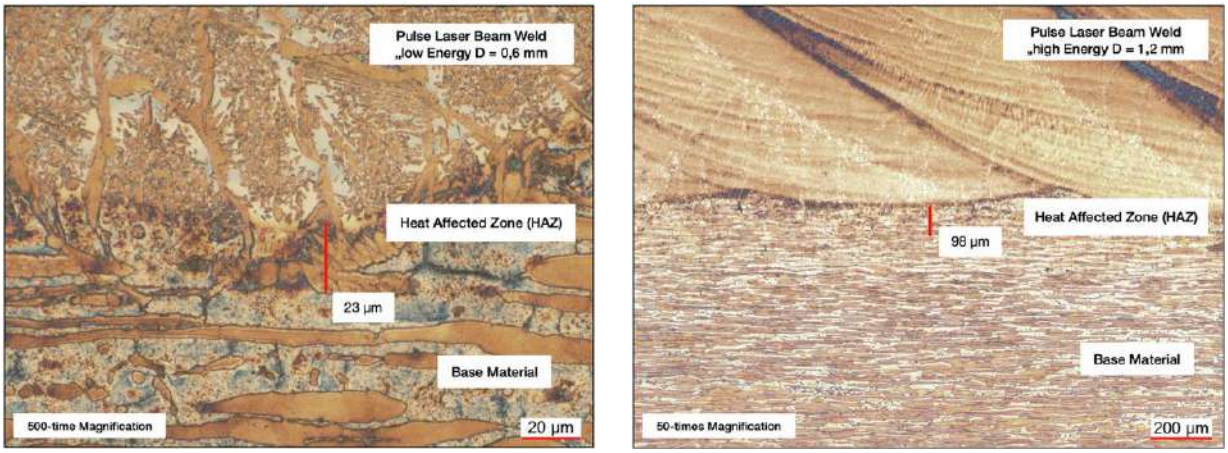
Table 3: Determination of hardness values (HV10) according to Figs. 1 and 2 with measurement point assignment (MP)

	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.

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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

Coarse grain formation within Heat Affected Zone (HAZ) comparison between classical arc-welding methods with pulse laser welding technology

Pulsed Laser Welding (PLW) has emerged as an advanced joining and repair technology, offering precise energy control, low heat input, and minimal thermal distortion compared to conventional arc welding processes. Unlike Gas Tungsten Arc Welding (GTAW), which involves continuous heat input and high peak temperatures, PLW utilizes short, high-energy pulses that significantly reduce the thermal impact on the base material. As reported in this study, the heat input of PLW (1.44 kJ/cm) is substantially lower than that of GTAW (5.88 kJ/cm), resulting in reduced peak temperatures and faster cooling rates during welding . These characteristics enable PLW to produce a narrower Heat Affected Zone (HAZ) and finer microstructures, which are critical factors in maintaining the integrity and performance of engineering components.

In many industrial applications, large and high-value components such as large spur gears, rubber-covered rollers, and integrally bladed rotors (shown in Figure 1-3) are frequently subjected to wear, fatigue, or localized damage during service. The repair of such components is technically challenging due to their size, complex geometry, and stringent performance requirements. Conventional arc welding processes, such as GTAW, often introduce excessive heat input, leading to wide HAZ regions, coarse grain structures, and increased hardness gradients. These metallurgical changes can result in residual stresses, distortion, and a higher susceptibility to cracking, particularly in medium-carbon low-alloy steels such as 42CrMo4 used in this study . Consequently, achieving reliable repair without compromising the mechanical properties of the component remains a significant challenge.

To address these limitations, Pulsed Laser Welding offers a promising alternative for repair applications due to its localized heat input and controlled thermal cycle. The present investigation focuses on comparing PLW and GTAW processes in terms of thermal behavior, macrostructure, microstructure, and mechanical properties. The results demonstrate that PLW significantly reduces HAZ width and promotes finer microstructures with improved mechanical stability. These advantages highlight the potential of PLW as an effective repair technique for critical industrial components, where minimizing thermal damage and ensuring structural reliability are of paramount importance.



Figure 1 : Large spur gears



Figure 2 : Rubber covered rollers



Figure 3 : Integrally bladed rotors

Table 1 The summary of Pulse Laser Welding parameters

Condition	Filler metal	Pulse laser welding parameter									
		Peak power (W)	Pulse duration (ms)	Frequency (Hz)	Beam diameter (mm)	Shape	Average power (W)	Traveling speed (cm/min)	Shield gas	Shielding gas flow (l/min)	Heat input (kJ/cm)
1&2	ø1.2	9800	3.4	40	3.9	2	1200	15.0	Ar 99%	15	1.44

Table 2 The summary of Gas Tungsten Arc welding parameters

Condition	Filler metal	Gas tungsten arc welding parameter					
		Voltage (V)	Current (A)	Traveling speed (cm/min)	Shield gas	Shielding gas flow (l/min)	Heat input (kJ/cm)
3&4	ø1.2	14.0	119	10.2	Ar 99%	20	5.88

Material and Filler materials

The base material used in this study was 42CrMo4 steel (EN 1.7225), equivalent to AISI/SAE 4140, JIS SCM440, and ASTM B7. This medium-carbon low-alloy steel, alloyed with chromium (Cr) and molybdenum (Mo), Which is widely applied in high-strength components such as shafts and gears due to excellent hardenability and mechanical performance.

The filler material employed was DSI M90, a molybdenum-containing low-alloy martensitic laser welding wire. This filler metal is specifically designed for pulsed laser welding, ensuring good metallurgical compatibility and it's supporting formation of control microstructure rapid thermal cycles.

Experimental set up

The experimental program was designed to compare the performance of Pulsed Laser Welding (PLW) and Gas Tungsten Arc Welding (GTAW) processes under controlled conditions. Both processes were selected due to their relevance in industrial repair applications, particularly for high-value components requiring precision and reliability.

A total of four experimental conditions were established to evaluate the influence of welding process and layer configuration on thermal behavior, microstructure, and mechanical properties. These conditions include:

(1) Pulsed Laser Welding with a single layer (PLW1L),
(2) Pulsed Laser Welding with multiple layers (PLW3L),
(3) Gas Tungsten Arc Welding with a single layer (GTAW1L), and
(4) Gas Tungsten Arc Welding with multiple layers (GTAW3L).

This comparative approach allows for a systematic investigation of the effects of heat input and thermal cycling associated with each welding technique, as well as the influence of repeated thermal exposure in multi-layer welding.

Pulsed Laser Welding (PLW) Parameters

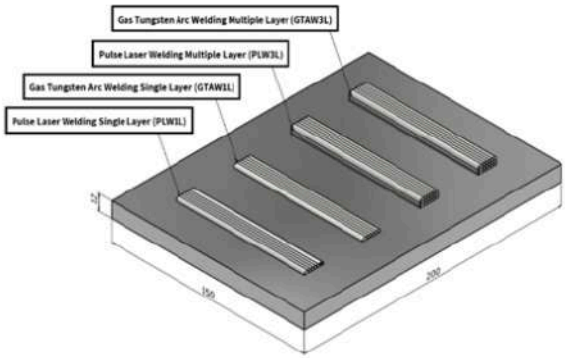
As summarized in Table 1, the Pulsed Laser Welding (PLW) process was carried out using a 1.2 mm diameter filler metal. The welding parameters were selected to achieve controlled heat input and stable weld formation, with an average power of 1200 W, a pulse duration of 3.4 ms, and a pulse frequency of 40 Hz. The laser beam diameter was set to 3.9 mm, and a constant travel speed of 15 cm/min was maintained throughout the process. High-purity argon gas (99.996 %) was employed as shielding gas. These parameters were carefully chosen to promote localized heating and minimize thermal distortion, which are key advantages of the PLW process. The weld bead configuration and the experimental setup for PLW are shown in Figure 4.

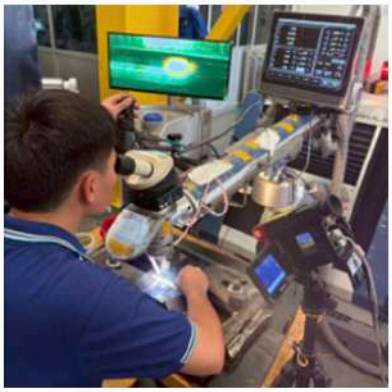
Gas Tungsten Arc Welding (GTAW) Parameters

For comparison, the Gas Tungsten Arc Welding (GTAW) process was conducted using the same filler metal diameter of 1.2 mm, as detailed in Table 2. The welding parameters were set at a voltage of 14 V and a current of 119 A, with a travel speed of 10.2 cm/min. Argon gas (99.996% purity) was also used as shielding gas to protect the weld pool from atmospheric contamination. In contrast to PLW, the GTAW process involves a continuous heat input, leading to higher overall thermal energy during welding. This difference in heat input is expected to significantly influence the thermal cycle, heat-affected zone (HAZ), and resulting microstructure. The weld bead geometry and GTAW experimental setup are also presented Figure 4.

Weld bead appearance and NDT Result

The weld bead appearance results indicate that all welding conditions are free from unacceptable discontinuities (Figure 5-8), and No relevant indications were detected by Penetrant Testing.





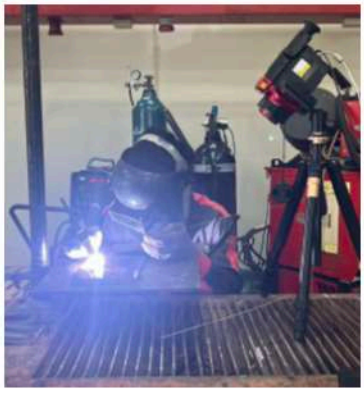


Figure 4 : The layout of weld bead (left) Operator performing Pulse Laser Welding (mid) Gas tungsten arc welding (right)



Figure 5 : PLW Single Layer (PLW1L) Weld Bead



Figure 6 : PLW Multiple layer (PLW3L) Weld Bead



Figure 7 : GTAW Single Layer (GTAW1L) Weld Bead



Figure 8 : GTAW Multiple layer (GTAW3L) Weld Bead

Results and discussions - Macrostructure and Heat Affected Zone (HAZ) characteristics

As shown in Figure [9-12], the macrostructures indicate that the weld metal in all conditions is sound and free from unacceptable discontinuities.

It can be concluded that the HAZ width of the single-layer PLW1L (Figure 9) was approximately 60% narrower than that of the single-layer GTAW1L (Figure 11). Similarly, for the multi -layer conditions, the PLW3L (Figure 10) resulted in a 50% reduct in HAZ size compared to the GTAW3L(Figure 12) .This significant difference is primarily attributed to the heat input; the PLW process show utilized a much lower heat input of 1.44 kJ/cm, Whereas the GTAW process required 5.88 kJ/cm.

Temperature Distribution Characteristics during Welding via Thermal Camera

Single layer condition : According to the thermal cycle analysis in Figure [13], the initial temperature of the workpiece before welding was approximately 50°C for PLW1L and 70°C for GTAW1L. At the center of weld pool, where the peak temperature of PLW1L reached only 447°C with a heating rate of 53°C/s but GTAW1L reached higher temperature of 1,717°C at 110°C/s.

Regarding the cooling stage, the temperature of the GTAW1L sample decreased from 1,717°C to -150°C within 23.5 seconds, resulting in a cooling rate of 66.7°C/s. In contrast, the PLW1L sample cooled from 447°C to 150°C in only 4 seconds, yielding a faster cooling rate of 74.3°C/s.

Multiple layer condition : Based on the thermal cycle analysis presented in Figure [14], Before welding the temperature of the workpiece was approximately 80°C for PLW3L process and 140°C for GTAW3L.The maximum temperature at center of weld pool for PLW3L reached only 362°C with a heating rate of 50°C/s, whereas the GTAW3L reached an extreme peak of 1,710°C at 151°C/s .

In terms of the cooling phase, the GTAW3L specimen cooled from 1,710°C down to 175°C in 23.5 seconds, equivalent to a cooling rate of 65.3°C/s. By comparison, the PLW3L specimen dropped from 362°C to 175°C in just 3 seconds, resulting in a cooling rate of 62.3°C/s.

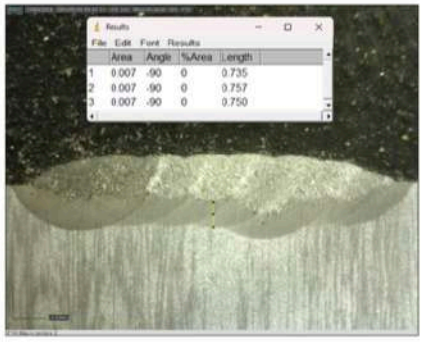


Figure 9 : PLW1L HAZ 0.747 mm

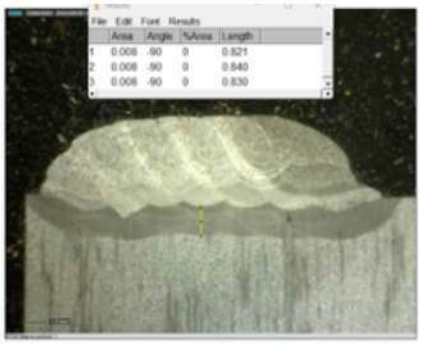


Figure 10 : PLW3L HAZ 0.830 mm

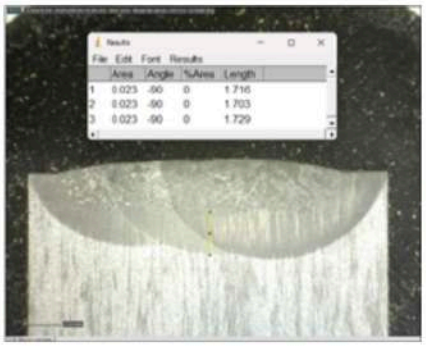


Figure 11 :GTAW1L HAZ 1.716mm

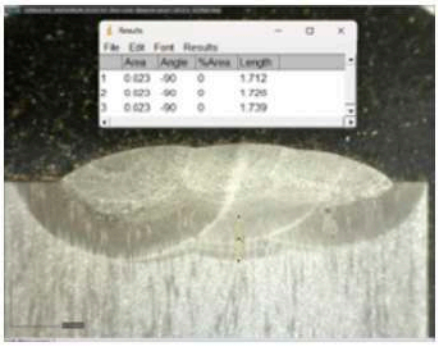


Figure 12:GTAW3L HAZ 1.726mm

Microstructural Examination and Grain Characteristic in the Heat Affected Zone

Single layer condition : The microstructure of the weld metal (WM) in the PLW1L (Figure 15) specimen consists of bainite, martensite, and clearly columnar dendritic from the relatively lower - peak temperature (447°C) at the center of weld pool. In contrast, the WM in the GTAW1L (Figure 17) shows lath martensite from higher peak temperature (1,717°C) during welding.

The Heat Affected Zone PLW1L (Figure 15) produced a fine martensitic structure, whereas the - GTAW1L (Figure 17) resulted in coarse martensite. This structural difference is a direct result of the cooling rates, the PLW1L (Figure 15) process has a significantly higher cooling rate (74.3°C/s) compared to GTAW1L (66.7°C/s). Rapid cooling in PLW1L (Figure 15) limits grain growth, preventing the coarsening seen in the GTAW1L (Figure 17).

Multiple layer condition : Both PLW3L (Figure 16) and GTAW3L (Figure 18) exhibit fine martensite in the weld metal (WM). This similarity is attributed to the temper bead effect, where the heat from subsequent passes refines the microstructure of the previous layers. In the HAZ, PLW3L (Figure 16) retains fine martensite while GTAW3L (Figure 18) shows coarse martensite, proving PLW's effective suppression of grain growth in multi-pass welding.

Mechanical Properties - Vickers Hardness Analysis

Single layer condition : According to the hardness profiles presented in Figure [19], both the PLW1L and GTAW1L conditions exhibit comparable hardness values in the Weld Metal (WM) region, ranging between 300 and 400 HV0.1.

In the HAZ, PLW1L exhibits lower hardness (~420 HV) compared to GTAW1L (~450 HV), indicating superior impact resistance and reduced cracking risk. Additionally, the significantly narrower HAZ width in PLW1L aligns perfectly with macrostructural results.

Multiple layer condition : Based on Figure [20], PLW3L exhibits lower WM hardness (~290 HV) than GTAW3L (~350 HV), suggesting improved ductility and reduced fracture susceptibility.

In the HAZ, both processes - reach similar peak hardness, yet PLW3L displays a much narrower hardened zone. This restricted distribution supports previous macrostructural findings, demonstrating that PLW effectively controls microstructural evolution in multi-layer welds.

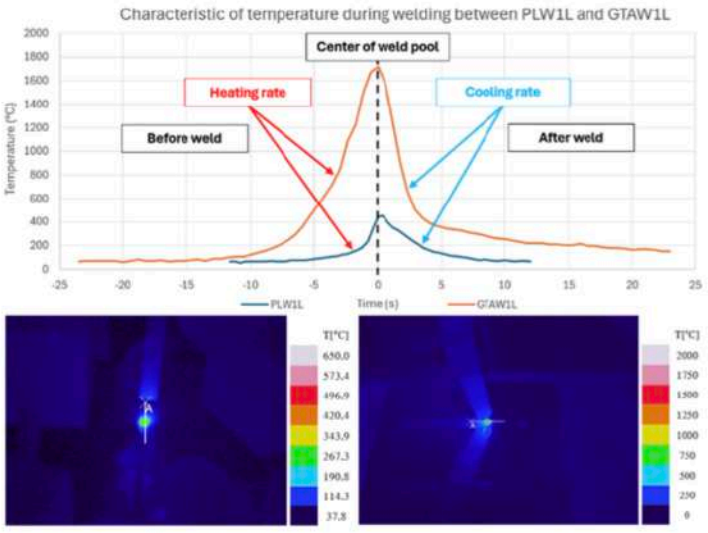


Figure 13 : Temperature Chart in Single layer

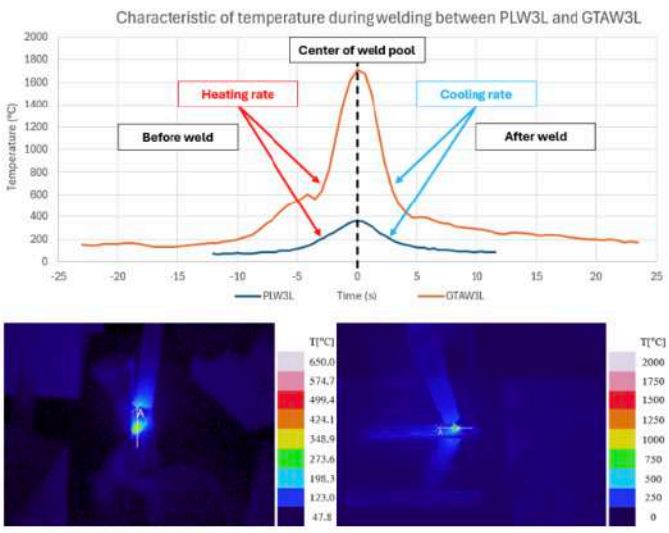


Figure 14 : Temperature Chart in Multiple layer

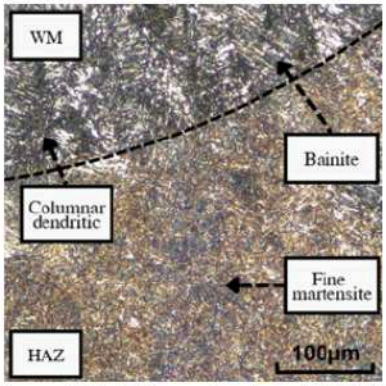


Figure 15 : Microstructure PLW1L

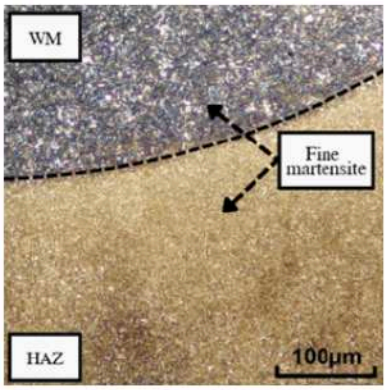


Figure 16 : Microstructure PLW3L

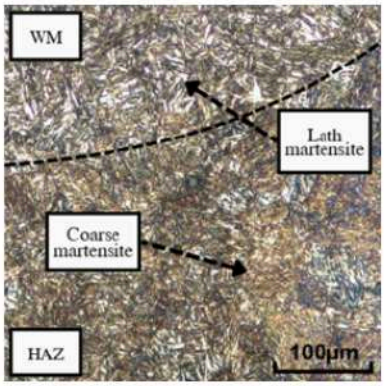


Figure 17:Microstructure GTAW1L

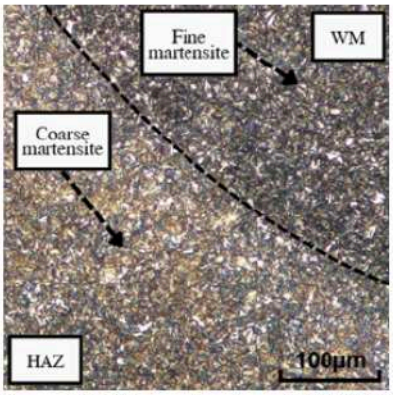


Figure 18:Microstructure GTAW3L

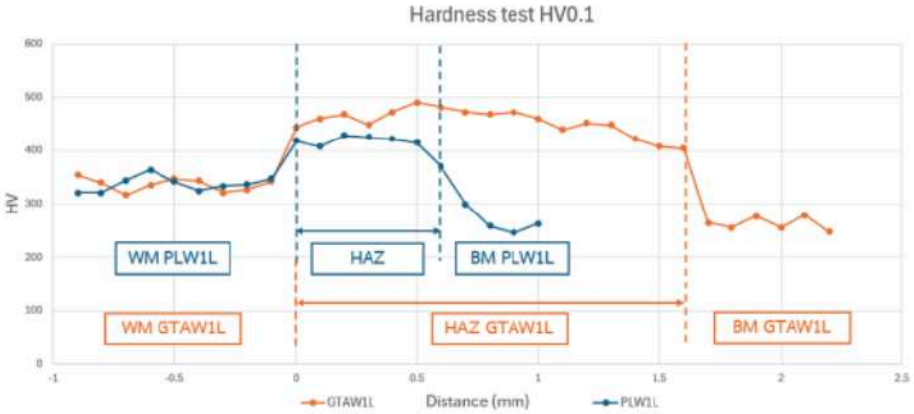


Figure 19 : Hardness testing result chart in single layer

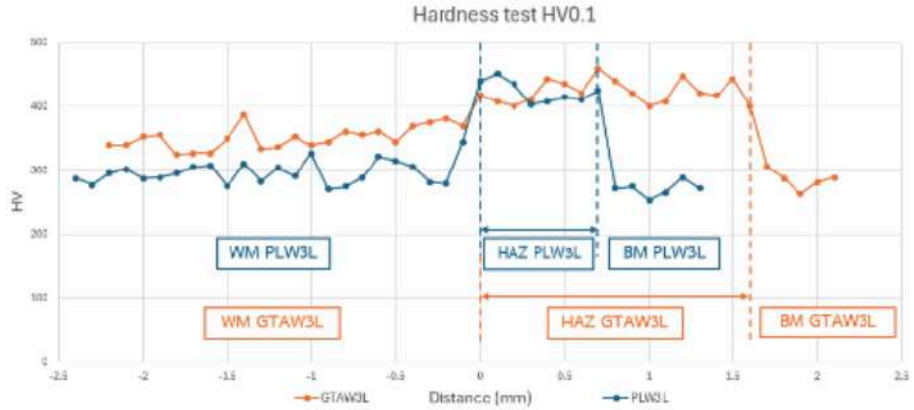


Figure 20 : Hardness testing result chart in multiple layer

Conclusion

All welding conditions produced sound, defect-free joints. However, Pulsed Laser Welding (PLW) demonstrated significant advantages over Gas Tungsten Arc Welding (GTAW), reducing the Heat Affected Zone (HAZ) width by 60% in single-layer and 50% in multi-layer welds. This reduction is attributed to PLW's lower heat input and peak temperatures. Furthermore, the rapid cooling inherent in PLW fostered a refined, fine-grained microstructure. While GTAW exhibited higher hardness over a broader HAZ—increasing cracking susceptibility—PLW provided superior mechanical stability through a restricted hardness distribution and refined grains.

Acknowledgement

The investigation is based on a cooperation between Department of Production Engineering, King Mongkut's University of Technology Thonburi (KMUTT), Thailand and DSI Thailand Laser-Welding-Academy which is in cooperation with German Welding Society GSI DVS SLV Hannover. Investigation leads by Dr. Titinan Methong (KMUTT) and Stephan Thiemonds (DSI Thailand Laser-Welding-Academy) and carried out by the Undergraduate Students, Department of Production Engineering, KMUTT. Test plates welded by DSI Laser Service (Thailand) and examined by KMUTT's Welding research and consulting center, (KINGWELD).

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A Novel Approach to Pulse Laser Welding of Nodular Cast Iron Without Pre- and Post-Weld Heat Treatment

Nodular cast iron is widely used in industry for its excellent mechanical properties, but its poor weldability mainly due to brittle martensite formation. Conventional Shielded Metal Arc Welding (SMAW) typically requires preheating and post-weld heat treatment (PWHT). This study, conducted between August 2024 and May 2025, investigates the use of Pulsed Laser Welding (PLW) as a novel repair method without preheating or post-weld heat treatment (PWHT). Microstructural and hardness analyses showed that multi-layer PLW significantly reduces martensite formation and promotes a pearlitic structure in Heat Affected Zone (HAZ) PLW joints exhibited more uniform and lower hardness than SMAW, reducing brittleness and crack susceptibility

Pulse Laser Welding Technology

Pulse Laser Welding (PLW) is an advanced joining technology that utilizes high-intensity laser pulses, rather than a continuous arc, to create precise and localized welds. Unlike conventional arc welding methods, which rely on electric arcs and plasma as the heat source. PLW employs focused light energy in the form of short, controlled pulses. Each pulse delivers a concentrated energy burst within milliseconds, enabling fusion of the base and filler materials with minimal thermal distortion. This makes PLW particularly well-suited for applications requiring high precision, low heat input, and minimal impact on the surrounding material.

Unique Advantages of Pulsed Laser Welding

The pulsed nature of PLW offers several unique metallurgical and operational advantages that are difficult to achieve with conventional arc welding or cladding technologies.

First, the extremely short welding duration occurring within a fraction of a second, minimizes heat-affected zones and residual stress. This reduces the likelihood of distortion, cracking, or undesirable microstructural transformations. Second, the process provides full metallurgical bonding between the base material and filler metal. Lastly, the low overall energy input enables welding of heat-sensitive or Crack-susceptible material, such as cast iron, without requiring thermal treatments pre and post-welding. These features make PLW a highly efficient and reliable method, especially in applications where precision and structural performance are critical.

Introduction

Nodular cast iron, also known as ductile iron, is extensively used in industrial applications that require high strength, good wear resistance, and excellent fatigue performance. Typical components manufactured from nodular cast iron include worm gear housings, gland seal guides, and impellers, which are widely employed in power transmission systems, rotating machinery, and fluid-handling equipment. These components are frequently subjected to cyclic loading, thermal variation, and severe service conditions, making repair and refurbishment unavoidable during their service life. Representative examples of such industrial cast-iron components are illustrated in Figure 1.



Fig 1: Representative nodular cast iron components commonly used in industrial applications:
(a) housing of a worm gear, (b) guide of a gland seal, and (c) impeller.
These components typically require repair welding during service due to wear, fatigue, or localized damage

Traditional arc welding methods, such as Shielded Metal Arc Welding (SMAW), typically necessitate preheating, post-weld heat treatment (PWHT), and tempering to prevent cracking and to stabilize the weld and HAZ microstructures. These additional thermal steps are labor-intensive, energy-consuming, and often impractical for large workpieces or in-field refurbishments.

Pulsed Laser Welding (PLW) has gained increasing attention due to its ability to deliver high-energy pulses of very short duration, typically in the millisecond range, This process offers high energy density, narrow fusion zones, and low heat input, which help to minimize thermal distortion and preserve the mechanical properties of the surrounding material. Several studies have demonstrated the effectiveness of PLW in joining thin-section steels and high-strength alloys, highlighting its advantages in minimizing metallurgical defects, controlling phase transformations, and improving weld bead geometry. However, relatively few studies have examined the application of PLW to cast irons—materials inherently prone to solidification cracking, porosity, and brittle microstructures due to their high carbon and silicon content.

The use of PLW presents a novel and promising approach to addressing the weldability challenges of cast iron, particularly through the development of a temper bead mechanism. By leveraging the precise thermal control of PLW, it is possible to promote beneficial microstructural evolution in the HAZ without the need for conventional preheating or PWHT. The temper bead effect

Table 1 The summary of welding parameters of PLW

Welding conditions	*Welding process*	*Weld layer*	*Filler metal*	*Pulse frequency*	*Travel speed*	*Beam diameter*	*Pulse duration*	*Welding heat input*
1	PLW	1st	DSI Inconel 625 ø1.2 mm	45 Hz	3 mm/s	5.5 mm	3.2 ms	0.4 kJ/mm
2	PLW	1st	DSI Inconel 625 ø1.2 mm	45 Hz	3 mm/s	5.5 mm	3.2 ms	0.4 kJ/mm (maximum)
	PLW	2nd	DSI M 90 ø1.6 mm	45 Hz	3 mm/s	5.5 mm	3.2 ms	

Table 2 The summary of welding parameters of SMAW

Welding conditions	*Welding process*	*Weld layer*	*Filler metal*	*Electrode diameter*	*Welding current*	*Welding voltage*	*Welding heat input*
1	SMAW	1st	ENi-Cl	3.2 mm	110 A	25 V	0.96 kJ/mm
2	SMAW	1st	ENi-Cl	3.2 mm	110 A	25 V	0.96 kJ/mm (maximum)
	SMAW	2nd	E7016	3.2 mm	90 A	23 V	

Materials used in the study

Base material

The primary material used in this study was nodular cast iron grade EN-GJS-500, also known as FCD500 under JIS standards. This material is a type of ductile iron characterized by its spheroidal graphite microstructure, which imparts a unique combination of high strength, good ductility, and excellent fatigue resistance. FCD500 is widely used in the manufacturing of machine bases, engine blocks, pumps, gearbox casings, and various structural parts in heavy industries. Its ability to absorb impact energy while maintaining dimensional stability under cyclic loading.

Filler metals for PLW and SMAW

Proper filler metal selection is essential for achieving metallurgical compatibility and minimizing cracking in cast iron welding. In this study, different filler metals were applied for PLW and SMAW.

For PLW:

1) EN ISO 18274 (DSI Inconel 625) was used as the buttering layer. Its high nickel content improves compatibility with cast iron and reduces crack risk by accommodating thermal expansion and limiting hard phase formation.
2) EN ISO 21952-A (DSI M 90) was used in the second layer to enhance mechanical performance. This nickel-iron alloy offers good strength and ductility for structural repairs.

For SMAW:

1) EN ISO 1071: E C Ni-CI 3 A specialized nickel electrode for cast iron, applied as the buttering layer. It provides excellent weldability and reduces the risk of cracking by allowing for a softer transition between the weld metal and the base material.
2) EN ISO 2560-A (E7016): A low-hydrogen, iron-based covered electrode. This filler metal provides strong mechanical performance, good resistance to hydrogen-induced cracking.



Fig 2: The experimental set-up (left) Operator performing welding using a PLW (right) Weld bead appearance and weld pool formation (© DSI Laser Service Thailand)

Pulsed Laser Welding (PLW) parameters

PLW was carried out using a pulsed laser welding system operated at 1200 W, with a pulse duration of 3.2 ms, a frequency range of 45 Hz, and a beam diameter of 5.5 mm. A welding speed of 3 mm/s was applied, and argon shielding gas (99.9% purity) was used to prevent oxidation. The experimental set-up and weld bead appearance are shown in Figure 2.

Shielded Metal Arc Welding (SMAW) parameters

SMAW specimens were prepared using E C Ni-CI 3 electrodes (Ø3.2 mm) for the first layer and E7016 electrodes (Ø3.2 mm) for the second layer. Two welding conditions were tested. The first condition involved single-layer welding without preheating or post-weld heat treatment (PWHT). The second condition used two-layer welding, also performed without any thermal treatment.

These welding parameters were selected based on manufacturer recommendations and preliminary trials to achieve complete fusion while minimizing the risk of cracking.

Results and discussions

Macrostructure and Heat Affected Zone (HAZ) formation

The macrostructure results for PLW under all conditions showed complete joint penetration without welding discontinuities. One of the notable advantages of PLW in welding nodular cast iron is its ability to produce a remarkably narrow HAZ. In this study, the HAZ width generated by PLW was consistently measured in the range of approximately 0.4 to 0.5 mm, significantly smaller than that observed in conventional Shielded Metal Arc Welding (SMAW), where the HAZ typically exceeds 2.0 mm. This narrow HAZ is a direct result of the precise heat input control achievable with the pulsed laser beam, which delivers short, high-intensity energy bursts localized within a small region of the material. As a result, the HAZ produced by PLW is approximately 70% to 80% narrower than that formed by SMAW under comparable conditions. The macrostructures of PLW and SMAW are shown in Figure 3.

The ability to tightly confine the thermal cycle is particularly valuable when welding high-carbon materials such as FCD500, which are prone to cracking when exposed to large thermal gradients. Overall, the narrow HAZ produced by PLW offers significant metallurgical and mechanical advantages for cast iron welding applications.

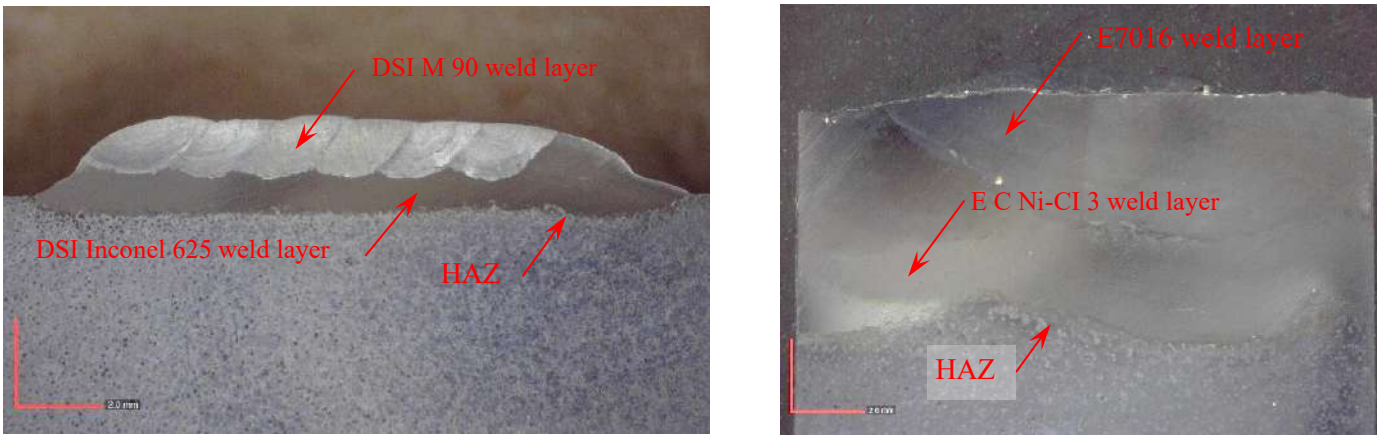


Fig 3: Macrostructure of (Left) PLW with first layer of Inconel 625 and second layer of DSI M90; (Right) SMAW with first layer of E C Ni-CI 3 and second layer of E7016. (© KMUTT)

Microstructural Evolution and Temper Bead Effect in Pulse Laser Welding

The microstructure of the HAZ in PLW under single-layer conditions showed a large amount of martensitic structure near the weld metal interface. This is due to the high cooling rates inherent to the PLW process, which transform the austenitized region of nodular cast iron into hard and brittle martensite. The presence of martensite in the HAZ increases hardness but also raises the risk of cracking. The microstructure of PLW with a single layer is shown in Figure 4.

After Pulse Laser Welding under multi-layer conditions, the microstructure of the HAZ showed a clear reduction in martensite and a corresponding increase in pearlite. The application of a second weld layer provided additional heat that altered the microstructure of the first layer's HAZ. The martensitic structure formed during the first pass underwent a tempering-like transformation due to reheating. This microstructural evolution is characteristic of the well-known temper bead effect. In the HAZ, re-austenitization occurred, followed by slow cooling, which promoted pearlite formation. As a result, the final HAZ contained a mixture of martensite and pearlite, with a reduced amount of martensite. This reduction lowers crack susceptibility and enhances mechanical properties compared to conventional arc welding methods such as SMAW. The microstructure of PLW under multi-layer conditions is shown in Figure 5.

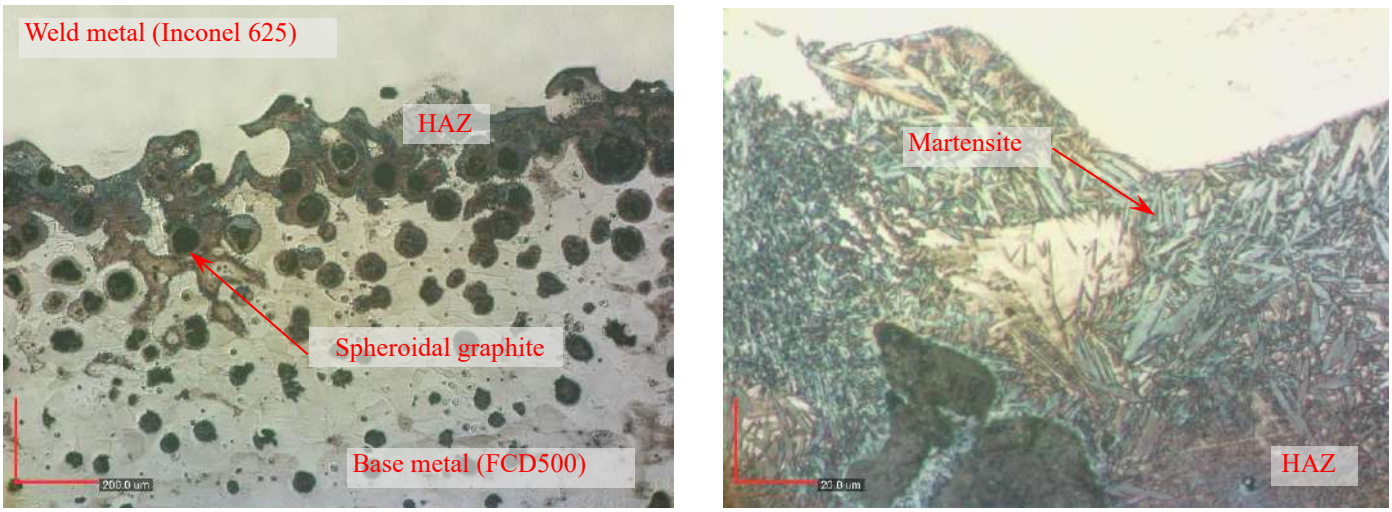


Fig 4: Microstructure of the HAZ in FCD500 base material welded by PLW with a single layer: (Left) 50× magnification; (Right) 500× magnification. (© KMUTT)

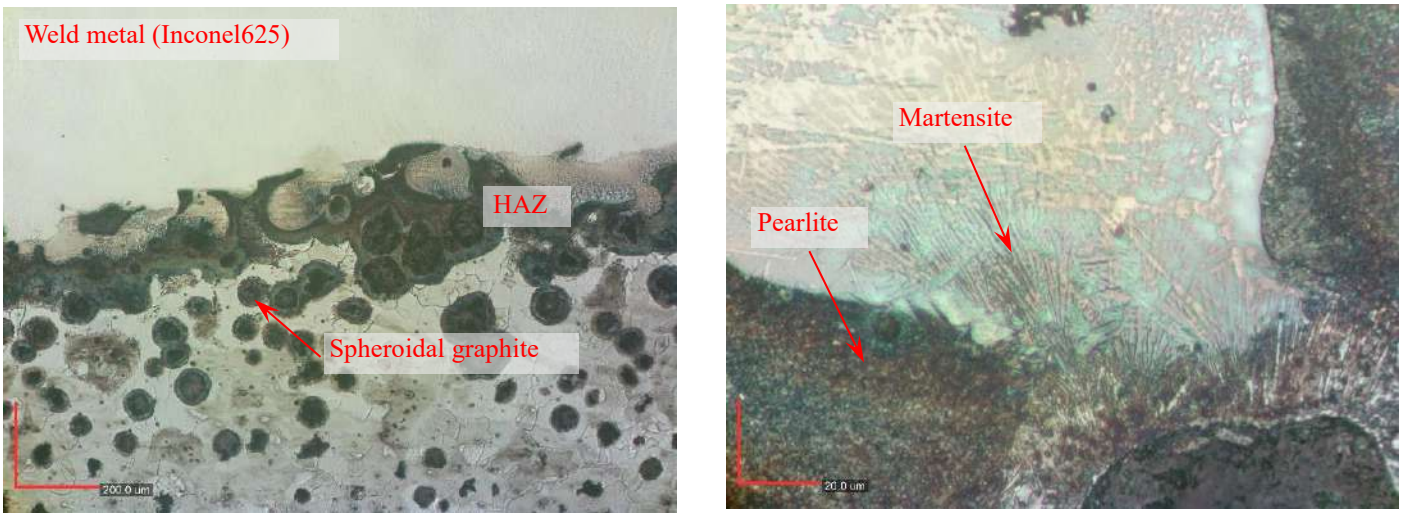


Fig 5: Microstructure of the HAZ in FCD500 base material welded by PLW with multiple layers: (Left) 50× magnification; (Right) 500× magnification. (© KMUTT)

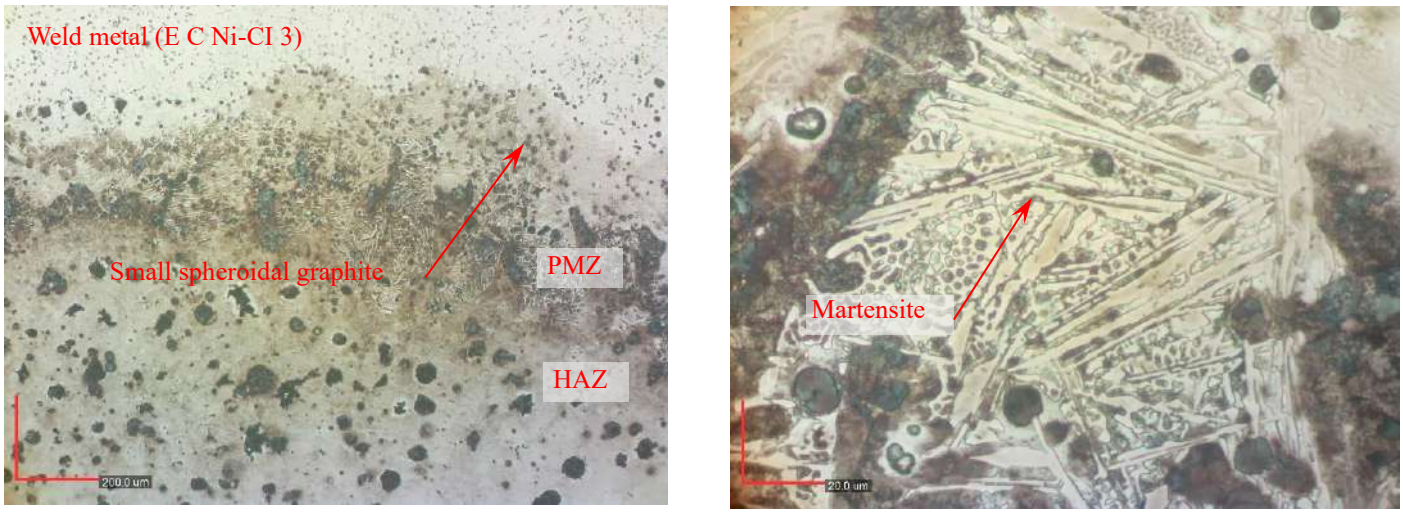


Fig 6: Microstructure of the HAZ in FCD500 base material welded by SMAW with a multiple layer: (Left) 50× magnification; (Right) 500× magnification (© KMUTT)

Compared to the microstructure of the HAZ in SMAW with both single-layer and multi-layer conditions, the results showed a large amount of martensitic structure remaining in the HAZ in both cases. Additionally, the presence of a Partially Melted Zone (PMZ) near the fusion boundary was clearly observed, along with small spheroidal graphite. This indicates that the high heat input of SMAW leads to the formation of a PMZ, where the original spheroidal graphite becomes remelted. After rapid cooling, the graphite re-solidifies in a smaller, rounded shape. The retention of martensite in the HAZ and PMZ contributes to increased hardness and brittleness, which in turn raises the risk of cracking and reduces overall toughness and weldability, especially under service conditions. These characteristics contrast with the modified microstructure observed in the PLW multi-layer condition, where temper bead effects help to mitigate such risks. The microstructure of SMAW under multi-layer conditions is shown in Figure 6.

Due to the retention of martensite in the HAZ and PMZ, the recommended welding procedure for cast iron using SMAW or other arc welding processes should include preheating to a minimum temperature of 400°C and post-weld heat treatment (PWHT) at a minimum of 800°C. However, in many practical cases, applying preheating and PWHT can be very challenging especially when dealing with large components, restricted working environments, or limited access to the weld area.

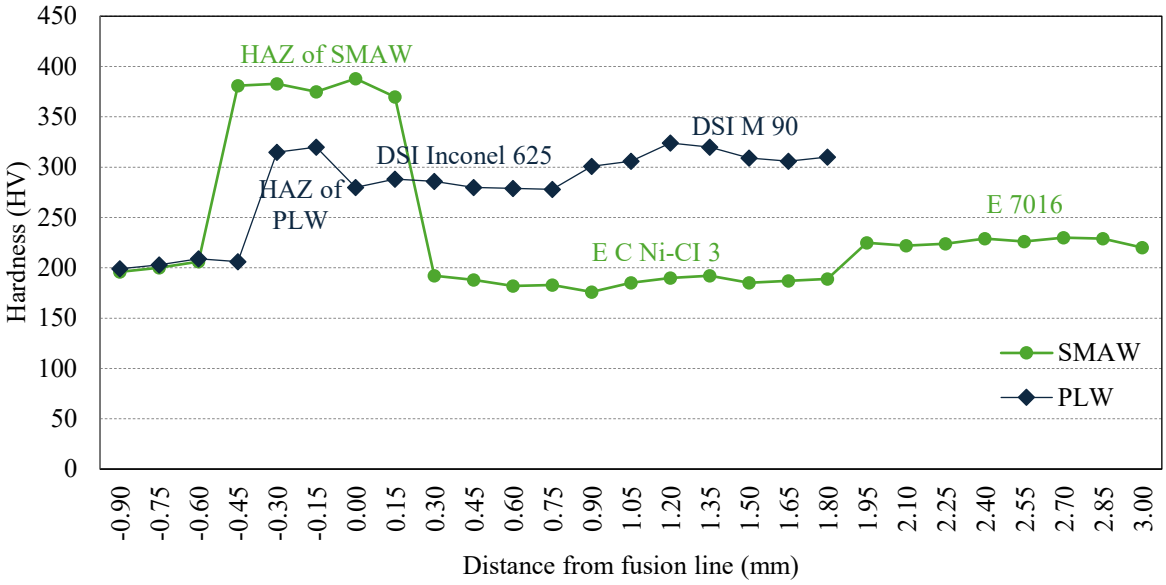


Fig 7: Hardness distribution across the weld zones of FCD500 welded by PLW and SMAW (© KMUTT)

Comparison of Hardness Profiles

The hardness profiles across the weld zones for both PLW and SMAW are shown in Figure 7. In the case of SMAW, the HAZ exhibited a significant hardness increase, reaching values of approximately 400 HV, due to the formation of large amounts of untempered martensite. This high-hardness zone extends over a wider region of the HAZ, increasing susceptibility to cracking. In contrast, the PLW process produced a much narrower HAZ with a moderate hardness peak of approximately 300–320 HV. The reduced hardness in the PLW HAZ reflects the influence of the temper bead effect, where the second layer tempered the initial martensitic structure, promoting partial transformation to pearlite. In the fusion zones, the hardness of the weld metal with Inconel 625 and DSI M90 remained stable and lower than the HAZ peak observed in SMAW. Conversely, the SMAW weld metal (E C Ni-CI 3 and E7016 layers) exhibited lower and more uniform hardness compared to its HAZ. Overall, the PLW process demonstrated superior control over hardness distribution, resulting in a smoother transition from weld metal to base metal and significantly reducing the likelihood of crack initiation in the HAZ.

Conclusion: A Novel Approach to PLW of Nodular Cast Iron FCD500

This study demonstrated the novel application of Pulsed Laser Welding (PLW) for repairing FCD500 nodular cast iron without the need for preheating or post-weld heat treatment. The results confirmed that the temper bead mechanism, achieved through multi-layer PLW, effectively reduced martensite content in the heat-affected zone (HAZ) by promoting pearlite formation, thereby improving mechanical properties and lowering crack susceptibility. Compared to conventional SMAW, which typically produces a HAZ width of approximately 2.0–2.5 mm, the PLW process generated a significantly narrower HAZ of only 0.4 – 0.5 mm. This reduction up to 80%, demonstrates the precision and low thermal impact of PLW, contributing to better weld integrity and reduced cracking risk. Additionally, the "healthy supporting effect" of the narrow hardness peak, stabilized by the surrounding softer weld and base material enhances impact resistance and overall service durability. These findings highlight the potential of this novel PLW technique as an efficient, low-heat-input, and reliable method for the practical refurbishment of nodular cast iron components.

Acknowledgement

The investigation is based on a cooperation between Department of Production Engineering, King Mongkut's University of Technology Thonburi (KMUTT), Thailand and DSI Thailand Laser-Welding-Academy which is in cooperation with German Welding Society GSI DVS SLV Hannover. Investigation leads by Dr. Titinan Methong (KMUTT) and Stephan Thiemonds (DSI Thailand Laser-Welding-Academy) and carried out by the three Undergraduate Students, Department of Production Engineering, KMUTT. Test plates welded by DSI Laser Service (Thailand) and examined by KMUTT's Welding research and consulting center, (KINGWELD), KMUTT.

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Pulse Laser Welding Note [22]

The classic Jedi Knights fight in the STAR WARS universe,

created in 1977 by US producer George Lukas.

The modern Jedi Knights fight in the ALPHA LASER industrial world,

founded in 1994 by the German physicist Josef Höllbauer.

The once use Lightsabers.

The other Pulse Laser Welding Machines.

The one is a Space Opera played on cinema screen.

The other is a Welding Revolution in professional work-life.

Both are united by their positive fight to prevent the Good Force.

More inspiration at DSI Thailand Laser-Welding-Academy

Pulsed laser beam welding – start thinking big! Repair welding of a shock absorber housing

In the perception of welding technology, pulsed laser beam welding as an application for large-scale components in combination with a high deposit welding volume appears to be a contradiction – not to say like an (industrial) fairy tale from the Thousand and One Nights, in this case one from Thailand. However, the latest developments and concrete examples from real professional life prove us wrong – demonstrated by a customer order that Alpha Laser Southeast Asia Co., Ltd. successfully executed at its main location in Chonburi/Thailand in November 2022. The project was managed by Thanapol Pradissun, a technology expert with many years of experience working for Alpha Laser SEA.



Fig. 1 • Shock absorber housing with mechanically machined bearing seat surfaces prepared for welding. (Pictures: Alpha Laser Southeast Asia Co., Ltd.)

The machine component to be welded was a shock absorber housing weighing 3.5 t and made of cast iron with nodular graphite (EN-GJS-500-7/Material No. 5.3200) **(Fig. 1)**. At both ends the housing measures a wall thickness of 80 mm, with an inner diameter of 775 mm and a length of 700 mm. The shock absorber housing is part of a steel sheet rolling mill of a Japanese company based in Thailand, which specialises in the coil production of cold-rolled, galvanised and electroplated steel sheet, with a total annual production volume of about 1.6 million tonnes. In the continuous, rough production process, the shock absorber housing is mainly subjected to mechanical pressure and shocks. Chemical attacks or corrosion play no role in this case.

Welding task – from preparation to execution

The bearing seating surfaces had been affected as a result of bearing damage. Deep grooves, run-in marks and notches had crept into the surface. Since this machine part is indispensable for the ongoing production process, a repair was required as quickly as possible. A new purchase was not an alternative, as the delivery time was twelve months. The job consisted of build-up welding the four bearing seats located on the inner circumference, three of them 130 mm wide, one 190 mm. To prepare the surfaces to be welded, they were turned 0.5 mm below the finished size in an external mechanical workshop. After consultation with the client, the welding was to add 1.2 mm, which provided sufficient material for the mechanical finishing.

The pulsed laser beam welding machine type "AL Flak 1200" from the German manufacturer Alpha Laser was used to carry out the build-up welding. Prior to welding, the optimum welding parameters were determined on the basis of an individually created component WPS (Welding Procedure Specification). The machine was programmed accordingly. The basis for this was a material-specific procedure test according to DIN EN ISO 15614-7. The operators of the pulse laser welding machine were qualified according to DIN EN ISO 14732:2013-12.

For the base material to be welded, cast iron with spheroidal graphite, the filler metal "Inconel 625" (Material No. 2.4831), standard designation: AWS A5.14 (ERNiCrMo-3)/EN ISO 18274 (SNi6625), was selected. The selection of this nickel-based alloy is justified by its properties with regard to tensile, compressive and

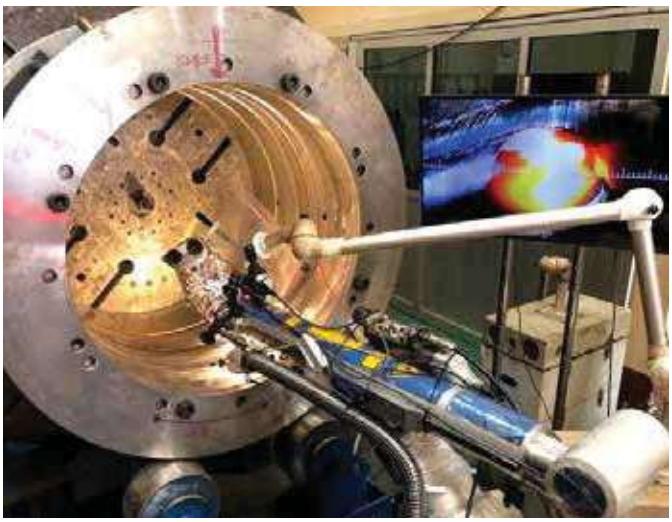


Fig. 2 • Automatic pulsed laser beam welding process.



Fig. 3 • Temporary monitoring of the weld seam quality by Prof. Gerd Kuscher.



Fig. 4 • Partially finished welded bearing seat.



Fig. 5 • Completely welded bearing seats.



Fig. 6 • Shock absorber housing after dye penetrant testing.



Fig. 7 • Mechanically prepared bearing seat shaft.

alternating strength. As was the case with the base material, no primary requirement was placed on the filler metal with regard to corrosion resistance. Due to the high pulse laser power of 1,200 W, a wire diameter of 1.6 mm could be used. This meant that there was no need to use a thinly drawn filler metal – as required for pulsed laser beam welding with lower power – which would have resulted in higher costs. In order to be able to clamp the bulky component onto a tilting turning device, two auxiliary flanges were mounted on both ends of the shock absorber housing (**Fig. 1b**).

How was the welding carried out?

The deposition welding was carried out as a continuous welding process with the workpiece rotating and the laser head static (**Figs. 2 and 3**), resulting in the welding position PA (tub position). The fibre laser operated with a power of 960 W at a pulse frequency of 36 Hz and a pulse duration of 3.4 ms, which was matched to the welding task. This resulted in a melting pool width of 4.2 mm. The 1.6 mm welding wire was automatically fed to the melting pool from a commercially available wire basket spool (BS 300).

The result was a single-layer weld in which the required seam height of 1.2 mm to be applied was achieved. The total welding time for all four bearing seats – in total an area of 1.42 m^2 – amounted to 74 h, whereby about 60 kg of welding filler was applied. Thus, a deposition rate was achieved with pulsed laser beam welding that comes close to that of conventional tungsten inert gas (TIG) welding (**Figs. 4 to 6**).

Reasons for pulsed laser beam welding

The comparison with conventional TIG welding in pulse mode (welding with electric current) explains the advantages of the technology of pulsed laser beam welding (welding with stimulated light). Based on this, the following advantages result:

- no cost- and time-intensive preheating or post-weld heat treatment of the component,
- no critical microstructural changes to the base material in the weld area,
- almost no welding distortion.

Further applications with similarly high build-up welding volumes

Numerous comparable work tasks have already been successfully carried out. For example, the 170 mm wide bearing seat of the shaft of the shock absorber housing discussed in this article, which was damaged by deep grooves, run-in marks and notches, was also repaired by pulsed laser beam welding (**Figs. 7 and 8**). The material of the bearing seat shaft is high-strength carbon steel. The diameter of the shaft is 470 mm, "Inconel 625" (DSI M NICR625) was used as filler metal.

Another example is a surface build-up weld within the application described in this article. The shock absorber housing is a precision component. Its reference surface (**Figs. 9 and 10**) ensures a precise fit in the machine. This 600 mm × 260 mm surface was also build-up welded in a single layer,



Fig. 8 • Temporary monitoring of the weld seam quality through the eyepiece of the pulsed laser beam welding machine.



Fig. 9 • Shock absorber housing with reference surface.



Fig. 10 • Detailed view of the reference surface welded by pulsed laser beam welding.



Fig. 11 • Simultaneous pulsed laser beam deposition welding on both rotor shaft ends.

1 mm thick. This was followed by mechanical processing.

As a third example, the rotor shaft of a 37 MW steam turbine (**Fig. 11**) was successfully repaired by deposition welding in 2019. A report of the turbine repair was published in the German-language technical journal "Der Praktiker" issue 6/2020 and as an English translation in "Welding and Cutting" issue 2/2020. Pulsed laser beam welding was also used for the deposition welding of "worn-in" bearing seats of a 16 t squirrel-cage rotor made of the material AISI 4340 (**Fig. 12**).



Fig. 12 • Squirrel-cage rotor before deposition welding.

What do these real-life examples teach us?

The technology of solid-state lasers and pulsed laser beam welding machines has developed so rapidly in recent years – from the 500 W Nd:YAG laser to the 900 W fibre laser to the current 1,200 W fibre laser – that it is now possible to repair large-format components in combination with a high build-up volume economically and to meet the highest quality requirements. There are almost no limits to the variety of materials that can be welded with the pulsed laser beam – from unalloyed carbon steel to high-temperature steels to high-strength fine-grained steels, ferritic and austenitic steels, duplex steels, "Inconel", "Monel", aluminium, titanium and "Hastelloy".

Another advantage in terms of welding technology is that conventional wire diameters (for example 1.2 mm, 1.6 mm, 2.0 mm) available on wire basket spools (BS300) can be used at this high laser pow-

er. This eliminates the use of thinly drawn, cost-intensive welding wires.

More and more companies from the oil and gas, petrochemical, steel and heavy industry sectors are learning to appreciate the manifold possibilities of pulsed laser beam welding and its advantages. Communicating the fact that this rapidly developing technology can now also serve these industries at the highest quality level is one of the main tasks of Alpha Laser Southeast Asia Co., Ltd. which will transfer this positive development from its headquarters in Thailand to the entire Southeast Asian region.

It is no exaggeration to say that a new era of pulsed laser beam welding technology has begun for the size of the components in connection with the volume of the build-up, and that its technology will become the standard in the areas of "Maintenance, Repair and Operations" (MRO), or has already become so for many customers. The beginning of this era was heralded by the motto: "Pulsed laser beam welding – start thinking big!"

Prof. Dr.-Ing. Gerd Kuscher, Auditor and Certifier, GSI – Gesellschaft für Schweißtechnik International mbH, Branch SLV Hannover, Hanover/Germany and Stephan Thiemonds (IWS), Manager Welding Department, Alpha Laser Southeast Asia Co., Ltd., Chonburi/Thailand

Pulse Laser Welding
(almost) unlimited Applications

Videos
DSI-Dropbox

Pulse Laser Welding Note [27]

DSI Laser Academy

About refurbishing, bonding and deposition :

If you want a cheap method but only mechanical bonding,
choose Thermal Spraying.

If you want a high deposition rate,
choose Laser Cladding.

If you want to earn unique advantages and full metallurgic bonding,
you have no choice :
Only Pulse Laser Welding Technology can provide.

More inspiration at DSI Thailand Laser-Welding-Academy

Repair of a steam turbine in Thailand using pulsed laser beam welding



Fig. 1 • Placing the turbine rotor on the head lathe for mechanical pre-machining of the damaged surfaces.

Welding with the pulsed laser beam provides a new approach to the weldability of metallic materials. In particular, the solid-state laser (Nd:YAG) with the possibility of guiding the laser beam independently of the laser to any location in a structure via fibre optic cables offers new possibilities for pulsed laser beam welding. In addition, steel materials that undergo a structural transformation during cooling and thus form a heat-affected zone (HAZ) behave differently when welded with the pulsed laser beam than in conventional welding processes. The extremely short welding time due to a pulse frequency of a few milliseconds and the resulting very fast cooling time ($t_{8/5}$) results in a HAZ that is only a few tenths of a mm narrow and avoids the formation of the critical coarse grain zone due to the parameters. These facts result in a different laser-specific classification of the weldability of metallic materials.

For almost 20 years now, DSI Laser Service (Thailand) Co., Ltd. from Chonburi, near Bangkok, has been using this knowledge to successfully perform pulsed laser beam welding on large components using mobile laser welding systems from Alpha Laser GmbH, Puchheim in Bavaria/Germany. In addition to its main business area as a laser welding service provider in various industries (automotive industry, oil and gas industry, petrochemical industry and recently also in aviation), DSI (Thailand) is also active as an authorised dealer for Alpha Laser welding systems in Thailand. For 15 years, DSI (Thailand) has been certified according to DIN EN ISO 3834-2 by DVS Zert, audited by DVS SLV Hannover, which also provides technical support to DSI (Thailand).

The rotor repaired by DSI (Thailand) **(Fig. 1)** is the rotor of a steam turbine built by Siemens in 2005. The 37 MW turbine is used in the company's own power plant at a Thai cement factory, with excess capacity being sold to EGAT (Electricity Generating Authority of Thailand). EGAT is the largest Thai electricity supplier, operating 45 power plants with a total capacity of 15,548 MW. EGAT maintains its own workshops, which are specialised in turbine repairs, among other things. In an EGAT workshop located in the north of the state capital Bangkok, pulsed laser repair welding began in November 2018 and lasted four weeks without mechanical pre- and post-processing.



Fig. 2 • The Nd:YAG pulsed laser welding machine "900W ALFlak fibre" from the German manufacturer Alpha Laser in the welding application at the turbine rotor in Thailand.

What was the wear on the rotor to be repaired?

The rotor of the turbine is oil-bearing. Due to a faulty operation during the operation of the turbine, a "deficient lubrication" occurred, i.e. an insufficient, "tearing off" lubricating film between the rotor shaft, which rotates at 3,000 revolutions per minute, and its mountings. The metallic friction and the resulting heat development caused cracks at both rotor shaft ends. After an initial damage assessment, cracks up to a depth of 2 mm were expected. Cracks up to a depth of 7 mm were found during the subsequent magnetic particle inspection (MT inspection) and during mechanical machining of the flaws on a head lathe.

Technical data

The rotor material is ASTM A335 P22. The EN ISO 21952-A CrMo1 (formerly 1.7339) with D = 0,8 mm, specified by

EGAT, was used as welding filler. The laser used was a Nd:YAG pulsed laser welding machine **(Fig. 2)** with an average laser output power of 900 W. The wavelength was 1,059 nm. The welding was performed with a pulse frequency of 33.6 Hz, a pulse duration of 3.5 ms, a beam diameter of 2.5 mm and the shielding gas Ar 99.9%. A pWPS (pWPS-DSI-EGAT-Turbine-18.11.12) was available with all further necessary data. The DSI (Thailand) laser beam welders used had a valid operator's test according to ISO 14732:2013 for deposition welding.

Training, testing and certification of pulsed laser beam welders

In addition to metallurgical knowledge, compliance with the high quality requirements of repair welding on a turbine operating at several thousand revolutions per minute requires very well-trained welders. The project management of the turbine rotor repair was carried out by the DSI colleague with the most experience in metallurgical and laser welding technology: the General Manager Miss Thongplew Banpao. The training of the DSI (Thailand) laser beam welders qualified in both build-up welding and joint welding was carried out at the company's own DSI (Thailand) Laser Welding Academy. The training was tested and certified according to the internal training guideline "SLV-H-LS01"



Fig. 3 • The turbine shaft mechanically prepared for welding.

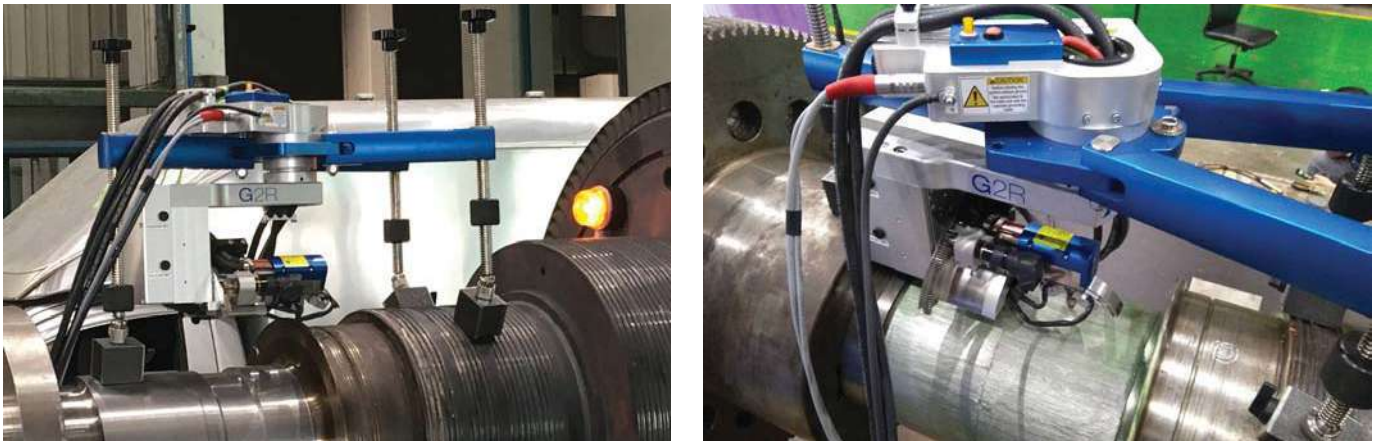


Fig. 4 • The measuring device installed before and during welding for stress testing of the turbine shaft.



Fig. 5 • On-site welding on the turbine rotor.



Fig. 6 • Layer structure of the pulsed laser beam repair welding.

developed by DVS SLV Hannover. In addition to the DSI (Thailand) internal welders, laser beam welders are also trained by customers at the academy and qualified and certified by the DVS SLV Hannover.

Preparation of the surfaces to be welded (rotor shaft ends)

After cleaning, the machining surfaces were machined to a depth of 2 mm in the crack area over a width of 332 or 340 mm and an additional 5 mm deep in the direct crack area over a width of 100 mm **(Fig. 3)**.



Fig. 7 • The finished pulsed laser beam weld during the final stress check.

Welding technology

In order to determine possible component stresses, a stress test was carried out using the "Residual Stress Measurement" method based on the "X-Ray-Diffraction" technique, in each case before, in intermediate steps during and after welding **(Fig. 4)**. The welding on the turbine rotor on site in Thailand is shown in **Fig. 5**.

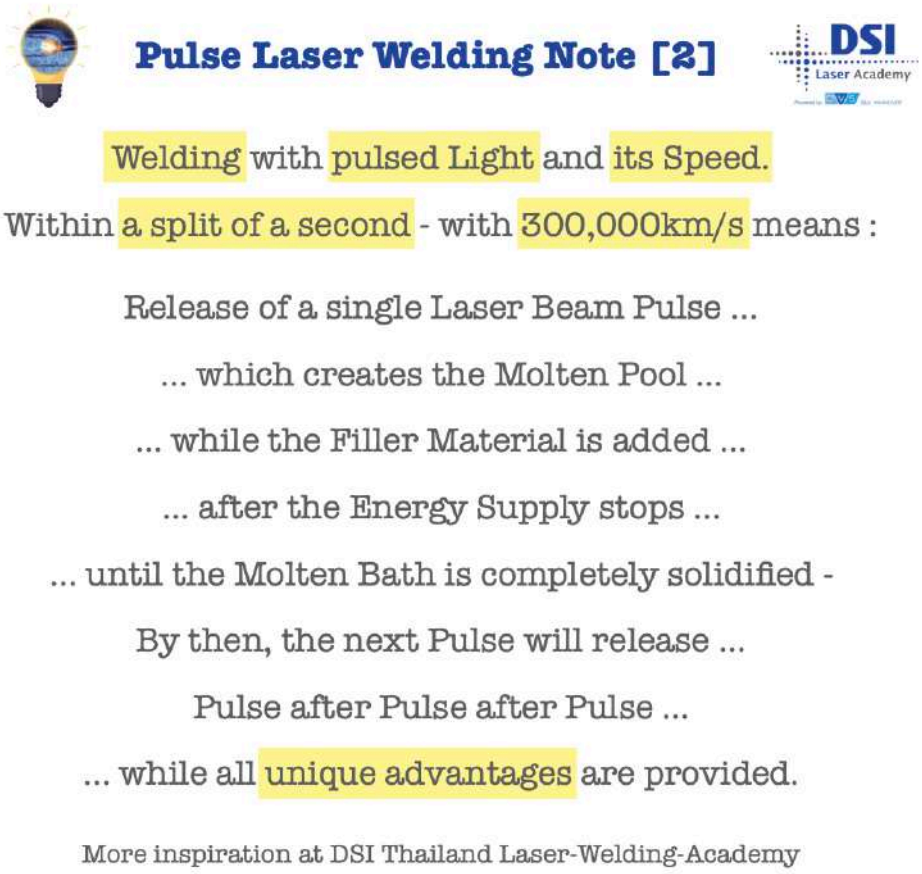
The thickness of the seam applied in each layer was about 1 mm. In the direct crack area of the shaft (100 mm wide) there were approx. five to six circumferential layers, on the surface (332 or 340 mm) there were three layers.

From an economic/temporal point of view, this wide-area and large-volume repair welding was only possible by using two 900 W fibre lasers, which were used to weld simultaneously at both shaft ends. An interlayer result is shown in **Fig. 6**. In addition to the final stress tests and visual inspections (VT), the finished welds **(Fig. 7)** were also tested by means of dye penetrant testing (PT), magnetic particle testing (MT) and ultrasonic testing (UT). After the successful tests, the welded surfaces at the rotor shaft ends were machined on a head lathe to the original dimensions and tolerances determined for their use.

Result

Since recommissioning in spring 2019, the steam turbine has been operating without any problems.

Prof. Dr. Gerd Kuscher,
GSI – Gesellschaft für Schweißtechnik International, Subsidiary SLV Hannover, Hannover/Germany
and Stephan Thiemonds,
DSI Laser Service (Thailand) Co., Ltd., Chonburi/Thailand



Pulse Laser Welding Note [24]

DSI Laser Academy

Imagine - welding WITHOUT

pre- and post-weld heat treatment

microstructure changing

coarse grain formation

graphitisation

distortion and WITHOUT

... negative influence of mechanical-technological properties.

In fact, it's NOT just an imagination. It's possible by

Welding WITH pulsed Light and its Speed.

More inspiration at DSI Thailand Laser-Welding-Academy

Repair welding of spheroidal graphite cast iron: Problem-free without heat pre- and post-treatment

From the classical viewpoint of welding technology, the repair welding of ductile cast iron requires special expertise as well as a high expenditure of time and money. The reasons can be explained metallographically and cannot be avoided if the mechanical-technological properties of the base material are to be maintained. Recent tests have shown that this effort no longer needs to be expended through the use of pulsed laser beam welding, and that heat pre-treat-



Fig. 1 • Machine components made of cast iron, type GJS-400-15 (EN 1563), which should be repaired by local deposition welding. (Picture: Alpha Laser Southeast Asia Co., Ltd.)

ment and post-treatment can be dispensed with entirely – without any negative impact on the welding result. This was demonstrated and proved in a practical application.

Behind the headline, which sounds like an industrial fairy tale from "One Thousand and One Nights", stands a success story in welding technology. As is so often the case, the challenge was requested by the customer, a manufacturer of electric furnace melting plants, continuous casting plants and rolling mills, producing in Thailand. He required repair welding of ductile iron (spheroidal graphite iron) without heat pre-treatment and post-treatment, which is possible thanks to pulsed laser beam technology. DSI Laser-Welding Academy Thailand, in cooperation with Alpha Laser Southeast Asia Co., Ltd. welcomed this challenge. In the specific case, machine components made of cast iron, type GJS-400-15 (EN 1563), (Figs. 1 and 2) were to be repaired by local deposition welding. Fig. 3 shows an example of the defects to be repaired caused during casting of these parts – by non-metallic inclusions, gas bubbles, hot cracks or blowholes.

The material to be welded is spheroidal graphite cast iron, also known by the abbreviation FCD (Ferro Casting Ductile). The advantage of this material, also known as nodular cast iron, is that it has mechanical properties like those of carbon steel (AHSS, Advanced High Strength Steel).

From theory to practice: technology in the burden of proof

The cast iron components are parts of a machine for the production of continuous cast round steel, which are subjected to high and multiple mechanical stresses in their function as linear plain bearing supports and for radial alignment in 24/7 continuous operation. Since a component failure would lead to the failure of the machine and consequently of the entire continuous casting production, accompanied by economically high losses, the experienced welding engineer and head of the quality department responsible on the customer side not only relied on the results of the visual inspection (VT) and the dye penetrant test (PT) for the repair welding, but also demanded a work sample in advance (Fig. 4). This was to prove the main theoretical advantage of pulsed laser beam welding – no relevant negative influence in the heat-affected zone and thus no microstructural changes in the base material – by means of the practical test.



Fig. 2 • Machine components made of cast iron, type GJS-400-15 (EN 1563), which should be repaired by local deposition welding. (Picture: Alpha Laser Southeast Asia Co., Ltd.)

The problems that arise in classical repair welding, for example manual arc welding, of such a cast iron material are primarily the high time and cost involved, caused by the metallurgy of the base material: high carbon content (over 3 %), brittleness and low elongation at fracture, risk of cracking due to residual stresses, low melting temperature, thin-bodied melt as well as high phosphorus and sulfur contents. In short, the weldability of all unalloyed graphitic cast iron materials depends primarily on the amount of embrittling microstructure constituents, on the pearlite, on the graphite form and on the amount of graphite particles in the area of the weld.

A look into the microstructure: What happens during traditional welding of cast iron?

From a temperature of over 420°C introduced into the workpiece and an exposure time of longer than 1 s (which is always the case with classical welding), the carbon (graphite) present in the ferrous metal matrix of the cast iron dissolves. This migrates to the grain boundaries and forms graphite nodules. Individually depending on the carbon saturation of the respective material and the cooling rate during welding, the very hard and brittle microstructural constituents martensite and – in molten areas – ledeburite are formed. These processes negatively affect the strength and toughness of the welded component.

In order to prevent this deterioration of the mechanical-technological properties – caused by classical welding – suitable countermeasures must be taken. Specifically, the material science relationships must be translated into production parameters that allow the desired weld seam properties to be set in a targeted and process-reliable manner. The main control variables that can be influenced are preheating temperature and, if necessary, postweld heat treatment, and during the welding process also the heat input, which in turn depends on the welding speed and the cooling process. Extensive sets of rules describe the variants of welding processing.

Pulsed welding – with light and its speed

Expertly aware of these welding challenges and the time and expense they entail, imagine a technology that does not need to take any of this into account: pulsed welding with light and the speed of light using pulsed laser beam technology. In just a few milliseconds (one pulse duration), photons (light particles) shoot onto the workpiece surface at almost 300,000 km/s (the speed of light), creating a molten pool (speed = energy) into which the filler metal is immersed, after which it solidifies. Only after complete solidification does the next pulse start – pulse after pulse after pulse, while the structure of the base material does not change due to the speed and the low energy input. The solution to the problem sounds and is sim-



Fig. 3 • Example of defects to be repaired during casting caused by non-metallic inclusions, gas bubbles, hot cracks or blowholes. (Picture: Alpha Laser Southeast Asia Co., Ltd.)



Fig. 4 • Work sample with three-layer pulsed laser deposition welding. (Picture: Alpha Laser Southeast Asia Co., Ltd.)

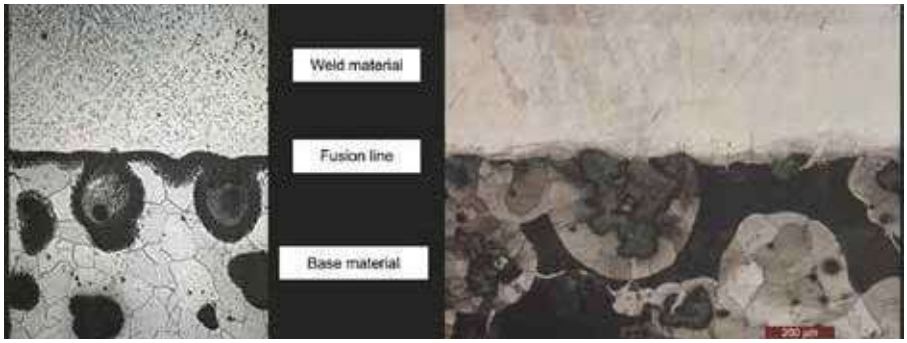


Fig. 5 • left: Micrograph of GJS-400-15 cast material (carbon content 3.25 to 3.70%) with an "alien" deposition welding performed by conventional manual arc welding with a Ni-Fe filler metal; right: Micrograph of EN-GJS-500-7 ductile iron material (carbon content 3.40 to 3.60%) with an "alien" deposition welding performed by the "energy of light", by pulsed laser beam welding. (Picture: Alpha Laser Southeast Asia Co., Ltd.)

ple: be faster than the undesired reaction. The pulsed laser makes it possible.

Thanapol Pradissun, technological manager of Alpha Laser Southeast Asia Co., Ltd., was in charge of welding supervision during the work test required by the customer. Welding was performed with a fibre laser machine of the type "AL Flak 1200F" manufactured by Alpha Laser GmbH, programmed with the following welding parameters: 440 W laser power, 1.6 ms pulse duration, 42 Hz pulse frequency, fusion pool diameter 1.8 mm.

Comparison of the melting lines

For the deposition welding of the test specimen, a high nickel content (20 to 23 %) "foreign" filler metal (diameter of 0.6 mm) was selected: "Inconel 625" (material no.: 2.4856, trade name "DSI M NICR 625"). This produces a "pure weld metal". Its microstructure is not in the form of an iron matrix, as is the case with the base metal, but is austenitic. This is clearly visible in micrographs as a colour difference between the base metal and the weld metal (Fig. 5). Fig. 5 on the left shows the micrograph of the cast material GJS-400-15 (carbon content 3.25 to 3.70 %) with an "alien" deposition welding performed by conventional manual arc welding with a Ni-Fe filler metal. Fig. 5 on the right shows the micrograph of the nodular cast iron material EN-GJS-500-7 (carbon content 3.40 to 3.60 %) with an "alien" deposition welding carried out by the "energy of light", by pulsed laser beam welding.

The microsection of the conventional weld (Fig. 5 left) clearly shows how the carbon present in the metallic matrix of the cast iron dissolved, migrated to the grain boundaries and formed graphite nodules due to the high heat input not initiated by electricity. In addition, it can be seen how the nickel-containing weld metal in the segregation zone absorbed iron particles from the base metal, which expressed itself as nickel martensite (speckled black). In comparison, the microsection of the pulsed laser beam weld (Fig. 5 right) shows no changes whatsoever – neither graphitization in the base metal nor a change in the carbon in the segregation zone.

Despite the theoretical knowledge – great astonishment

At the customer's request, the evaluation of the work sample was carried out by an independent third party, the Thai German Institute (TGI) in Chonburi, which was expertly accompanied by Prof. Dr. Gerd Kuscher of GSI – Gesellschaft für Schweißtechnik International mbH, branch SLV Hannover, Germany. Although all those involved in the project were well aware of the theory associated with the technology used – the main advantages of pulsed laser beam welding – everyone, without exception, was equally amazed and delighted by the undoubtedly positive results.

The practical test provided proof of the theory: spheroidal graphite cast iron (GJS/FCD) can be welded without defects at room temperature without any heat treatment. Thus, pulsed laser beam welding technology has removed the almost insurmountable barrier to trouble-free and economical repair welding of ductile cast iron – thanks to its two main advantages of no "graphitization" and no microstructural changes to the base material:

- Very low heat input (welding with light and the speed of light),
- Welding with pulse with ultra-high frequency (maximum 100 Hz).



Fig. 6 • Unchanged base material of the welded work-plate. (Picture: Alpha Laser Southeast Asia Co., Ltd.)

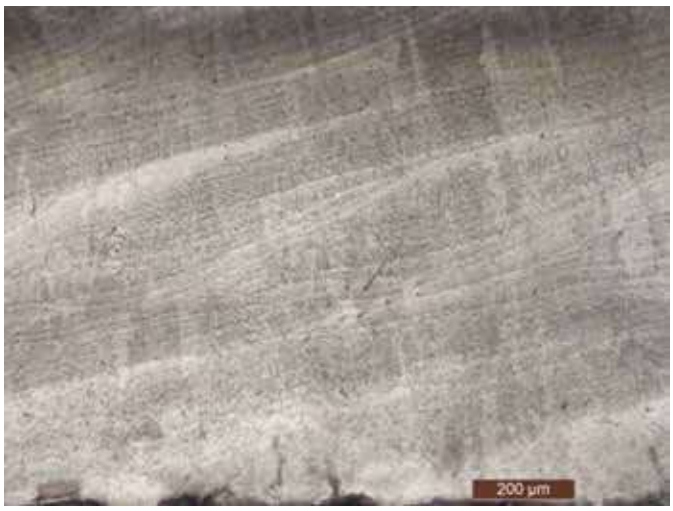


Fig. 7 • Pure weld metal of the welded work-plate (Picture: Alpha Laser Southeast Asia Co., Ltd.)

Ready for further challenges

Saving time and costs, but without compromising on quality: The technology of pulsed laser beam welding has mastered this challenge, both in the work trial and in the machine components that were subsequently repair-welded and are now successfully in continuous use (Figs. 1 and 2).

This practical example shows a previously undreamed-of possibility with regard to the repair and construction welding of materials that are conventionally complex to weld. At the same time, it gives an idea of the wide range of possible applications for customers from a wide variety of industrial sectors.

Prof. Dr.-Ing. Gerd Kuscher,
Auditor and certifier, GSI – Gesellschaft für Schweißtechnik International mbH, Branch SLV Hannover, Hannover/Gernany
and Stephan Thiemonds (IWS),
Manager Welding Department, Alpha Laser Southeast Asia Co., Ltd., Chonburi/Thailand

Pulse Laser Welding Note [14]

DSI Laser Academy

Only welding with PULSED Light and its Speed

provides UNIQUE advantages :

Very LOW welding energy, very LOW heat input on the component

NO pre- or post-weld heat treatment (PWHT) required

NO critical microstructure changing

Very THIN Heat Affected Zone (0,1 - 0,3mm)

NO coarse grain formation within HAZ

NO graphitisation

Almost NO distortion

NO significant decrease in ductility

More inspiration at DSI Thailand Laser-Welding-Academy

Pulse Laser Beam Welding : In Seventh Heaven above Thailand

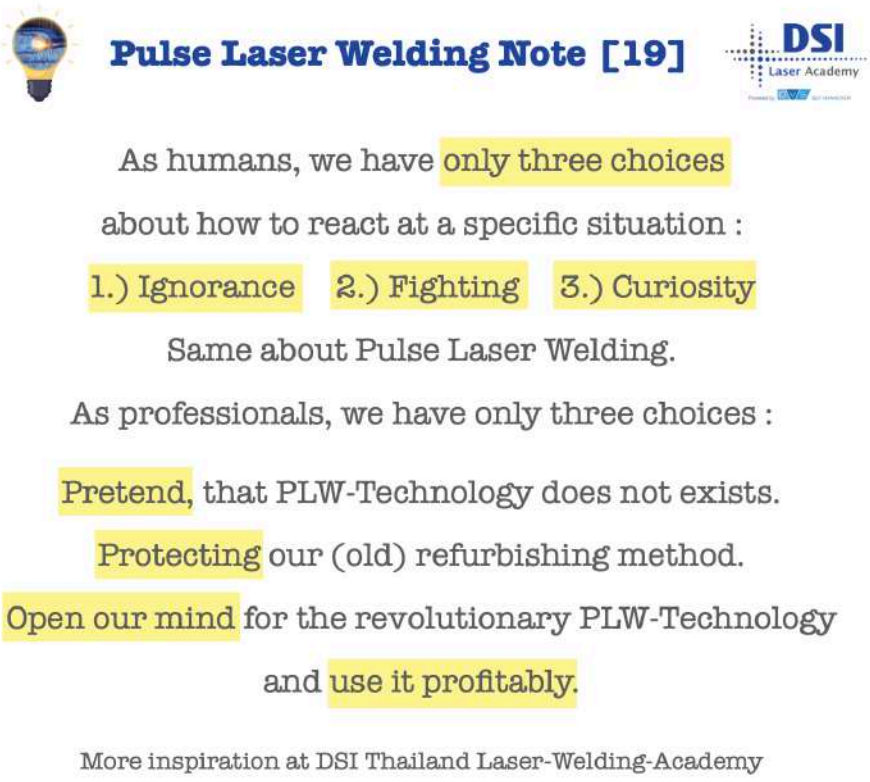
The work task was unmistakably defined: "To eliminate the difficulties encountered in the repair welding of aircraft turbine parts by using pulsed laser welding." It was triggered by the vision of an excellently trained aerospace engineer with inter-national professional experience, who recognized the decisive difference between this material-bonding joint technology and classic welding processes: Do not weld with electricity, but instead with pulsed light and its speed – resulting in unique advantages. The visionary's name was Barry Borji. In cooperation with DSI Laser Service (Thailand) Co., Ltd. he brought pulsed laser welded seams to above the clouds of Thailand, and far beyond. For the first time in 2018.

Thailand: Not only a paradise for holiday-makers, but also an MRO paradise

From a general tourist perspective, it is hard to imagine that Thailand is an important service hub for the aircraft industry. Internationally renowned companies are based there, inspecting, modifying and repairing components that are vital for take-off, flight and landing, such as landing gear, wings and turbines. In their technical language, this is called MRO for short: Maintenance. Repair. Overhaul. The customer Barry was working for at that time, plays the main role in this story and is active in this industry: A Thailand-based U.S. MRO company, a service provider for customers flying high above the clouds. A global leader in the manufacture of aerospace structures, aircraft systems and components. An Original Equipment Manufacturer (OEM) for giants of the skies such as Boeing, Airbus, Lockheed Martin, Land Power Turbines and GE Aviation.

Before Barry's vision came to reality, damaged turbine parts were welded in the traditional way, using either tungsten inert gas (TIG) or metal inert gas (MIG) welding, but, for lack of a better technology, with quality compromises – keyword: pores and cracks – high above the clouds.

The cause of these and the generally poor weldability of the parts to be repaired lies in the current condition of the base material. In most cases, these are titani-



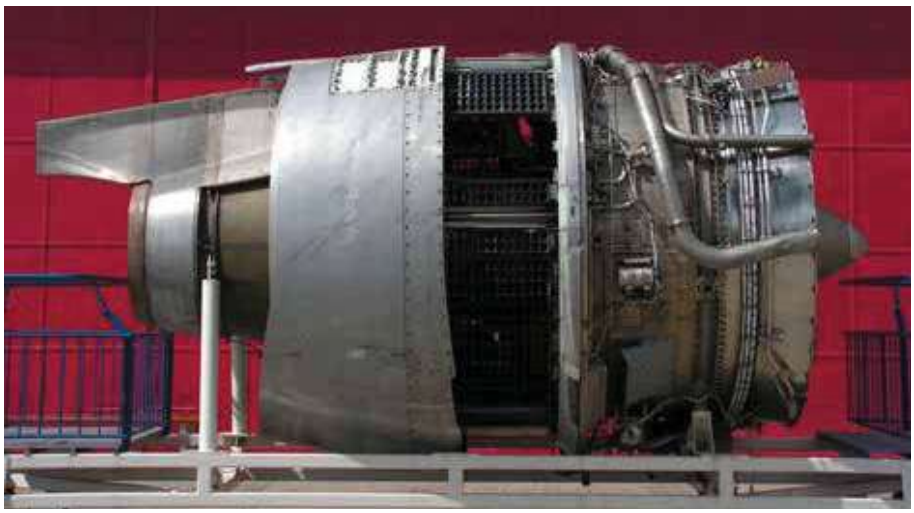


Fig. 1: A turbofan engine of the 1970s, type Rolls-Royce RB211 with the main components inlet, compression, combustion, exhaust gas (seen from right to left). (© Wikipedia)

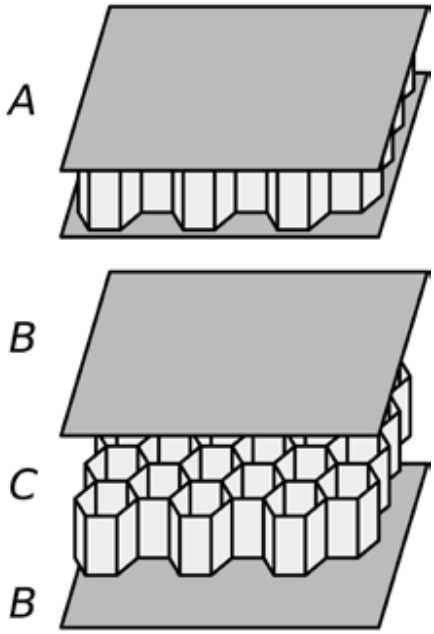


Fig. 2: Sandwich panel (A) with load-bearing face skins (B) and support core in honeycomb form (C). (© Wikipedia)

um alloys or "Inconel" that, at the time of their repair welding, are already many hundreds or even thousands of flight hours old, during which they have been exposed to high thermal-dynamic stresses. Mechanical deformations caused by a constantly changing operating temperature range of several hundred degrees Celsius: takeoff, landing, takeoff, landing ... hot, cold, hot, cold ... stretch, shrink, stretch, shrink ...

Compounding the general weldability, fast weld repairs, and desired seam quality are the ubiquitous topics of the aerospace industry: Weight Savings, Repair Down Time and Turn Around time (TAT), Aircraft on Ground (AOG). The equation is simple: less weight = more lightness = less fuel = greater efficiency. Every tenth of a millimeter and every gram saved counts. Accordingly, the sheets to be welded are extremely thin, which accelerates their thermal aging and the reduction of their service life, thus making them more difficult to weld. As already mentioned: pores and cracks.

This is how Barry, an engineer for stress and structural design, explained it during the first conversation with DSI Laser Service Thailand with a worry furrowed brow, which, however, smoothed out reflexively when he – rather unusual for an aircraft engineer aware of his great responsibility – almost euphorically talked about pulsed laser welding. This was closely followed by the concrete proposal of an extremely critical expert who, when it comes down to it, wanted to see the theoretically advertised advantages of a technology in question proven by extensive practical tests: in a case study called "Aircraft engine exhaust-nozzle skin repair" – a simulated repair weld on the conically shaped exhaust of an aircraft turbine, which operates with a gas temperature of more than 600 °C **(Fig. 1)**.

As can be easily imagined, this is designed differently from the exhaust-gas-diverting pipes under an automobile: thin, but not single-walled. Instead, it is a three-layer composite structure in honeycomb technology, known in aviation jargon as a "honeycomb structure" **(Figs. 2 and 3)**: consisting of a honeycomb support core with cover skins covering the honeycombs on both sides, thus supporting the composite – light as a feather and dimensionally stable. It is a classic example of structural bionics, in which a structure provided by biology (in this case the honeycomb) was successfully adopted in technology, colloquially known by the English portmanteau word "bionic". This was created by the US military service neurologist Jack E. Steele (1924-2009) from the Greek word "bios" (life) and the suffix "-onics" meaning "study of" and was publicly in-



Fig. 3: Conical honeycomb exhaust jacket made of "Inconel 625". (© DSI Laser Service (Thailand))

troduced in 1960 during a symposium with the theme "Living Prototypes – The Key to New Technology". The Chinese National Stadium in Beijing, the world's most famous "bird's nest", is also an example of successful bionics.

Back to the aircraft exhaust: The hexagonal shape of the honeycomb ensures perfect use of space, because there are no gaps. It is joined by ultra-thin cover plates of typically 0.54 to 1.5 mm on both sides, which guarantee a considerable reduction in weight – while at the same time providing enormously high stability thanks to the honeycomb structure.

The long journey: training, qualifications, sample welds and evaluations

The effort involved is justified when it is considered that, in the final analysis, human life depends on the implementation of a new technology. For this reason, an aircraft turbine is considered an "A-class component" in MRO jargon, the classification for major components of the aircraft fuselage and static engine components. On these, Barry's vision envisaged, welding would soon be carried out using pulsed lasers. In addition, there would also be welding on load-bearing structural elements or PSE parts (Principal Structural Elements). These contribute, quite literally, to absorbing the flight, ground and pressure loads, which in turn reveals the fatal definition of an A-class component: Their failure will, in all likelihood, lead to a catastrophic failure of the aircraft – with a crash out of the seventh heaven.

Because the 100 % reliability of these components to be repaired using pulsed laser welding is directly related to human life, Barry explained, extensive upfront trial welding and testing, qualification and certification are essential – all according to guidelines from the American Welding Society (AWS). The laser welding process was carried out with respect to the two standards AWS C7.4 "Process Specification and Operator Qualification for Laser Beam Welding" and AWS D17.1 "Specification for Fusion Welding for Aerospace Applications".

Extensive training course with a final knowledge test

As no one, neither at the customer nor at DSI, was familiar with the application of these standards, an extensive training course with a final knowledge test had to be held at the customer's facility. It was conducted by a lecturer, Mr. Ali Khan, who had traveled by invitation of Barry from England to Thailand especially for this purpose. He had been sent by The Welding Institute (TWI), which was founded more than 100 years ago in London's Holborn Restaurant by 20 men with the aim of bringing together acetylene and manual arc welders. Their mission: "Welding connects."

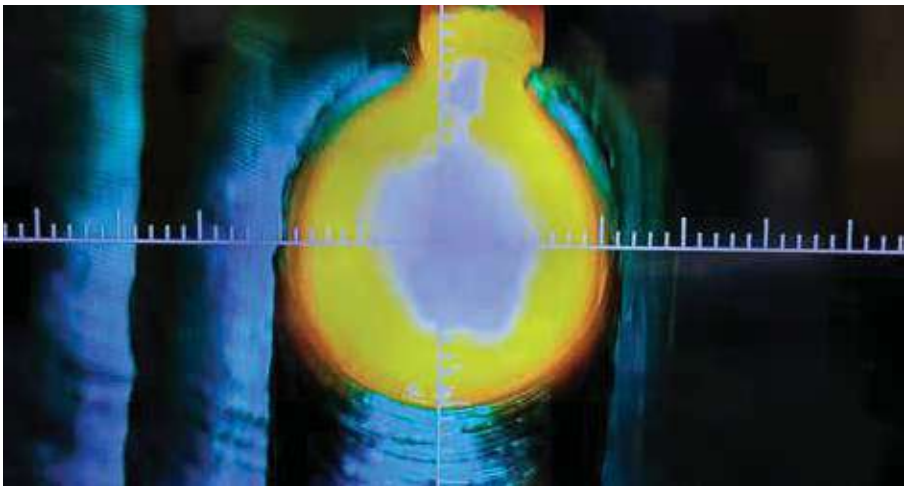


Fig. 4: Real-time monitoring of the pulsed laser deposition welding process, transmitted from the camera to the screen. Left: finished overlapping weld beads, centre: the "football-sized" melt pool into which the welder dips the "thick, goalpost-like" welding wire. (© DSI Laser Service (Thailand))

Since 1946, The Welding Institute has been located in Great Abington, near Cambridge. Nowadays, TWI is a large research and technology institute that is professionally focused on welding and joining technology, comparable to the numerous DVS SLVs in Germany. In addition to its headquarters and other branches in the UK, TWI has a presence in the USA and China, in Southeast Asia, South America and the Middle East.

After plenty of theory and final Certificate of Attendant awards for all attendees, they approached the practice: familiarizing themselves with the base material Barry selected for the case study, corresponding to the original turbine exhaust, called "Inconel" – the brand name of a minimum 58% nickel-based superalloy developed in the 1960s by Special Metals Corporation, a company based out of West Virgina. Specifically, Barry chose the non-magnetic alloy type "Inconel 625", material number 2.4856 (AMS 5599). This has the high tensile strength properties required for gas turbine applications (up to 910 MPa) and a wide operating temperature range, from cryogenic to 982 °C. In addition, "Inconel 625" provides protection against corrosion and oxidation and has a hardness of 26-30 Rockwell (HRC) in the untreated state.

Two different material thicknesses were selected: 0.54 and 1.53 mm, so that the test welds could cover the widest possible range of applications, considering the strict standard specifications. What was still missing for welding was the filler metal, which was matched to the base material, was of the same type and met the strictly quality-monitored aerospace guidelines. In the industry it is known under the racy-sounding brand name "Turballoy 625", selected diameter: 0.51 mm. Both sheet and wire were supplied by the customer.

To ensure neutral monitoring and evaluation of the test welds, the standard prescribes the involvement of an external, independent inspection authority. On the one hand, the Faculty of Engineering and Welding Technology of the King Mongkut's University of Technology Thonburi (KMUTT) in Bangkok was commissioned, represented by the Japan-trained welding engineer, Dr. Titinan Methong,

who works for the university as a teacher and examiner. On the other hand, some of the test welds were analyzed at the Material Testing Center of the Chonburi-based Thai German Institute (TGI), managed and supervised by Arun Jeangsrijaroen, a materials engineer trained in Germany at RWTH Aachen University.

All samples were welded in the presence of Barry as representative of the customer and Dr. Titinan as independent welding supervisor at the DSI Thailand Laser-Welding-Academy. Since 2020, the Academy has a technological cooperation with the DVS SLV-Hannover, which is why Prof. Dr.-Ing. Gerd Kuscher was also involved in the case study as material and technology expert. The study started with single- and multi-layer buildup welding, carried out with a 500 W powerful fibre laser machine manufactured by Alpha Laser Germany.

While the welder observed the molten pool through the microscope of the pulsed laser machine at 10 × magnification and manually fed the wire, real-time monitoring of the welding process took place by all present. A camera installed between the microscope and the optics transmitted the ongoing process to a flat screen. The molten pool, with the size of a soccer ball, and the welding wire immersed in it, which appeared to be as thick and long as a goal post, could be observed **(Fig. 4)**: A fascinating reality show from several points of view, which seemed to show a continuous welding process, but in fact consisted of individual pulses, each lasting 18 ms, whereby and during which the unique advantages of this welding process, which takes place with pulsed light and its speed, occurred.



Fig. 5: Macrosection of a successful position-counterposition joint weld with no significant heat-affected area of the base metal "Inconel 625", test piece thickness: 0.54 mm. (© DSI Laser Service (Thailand))

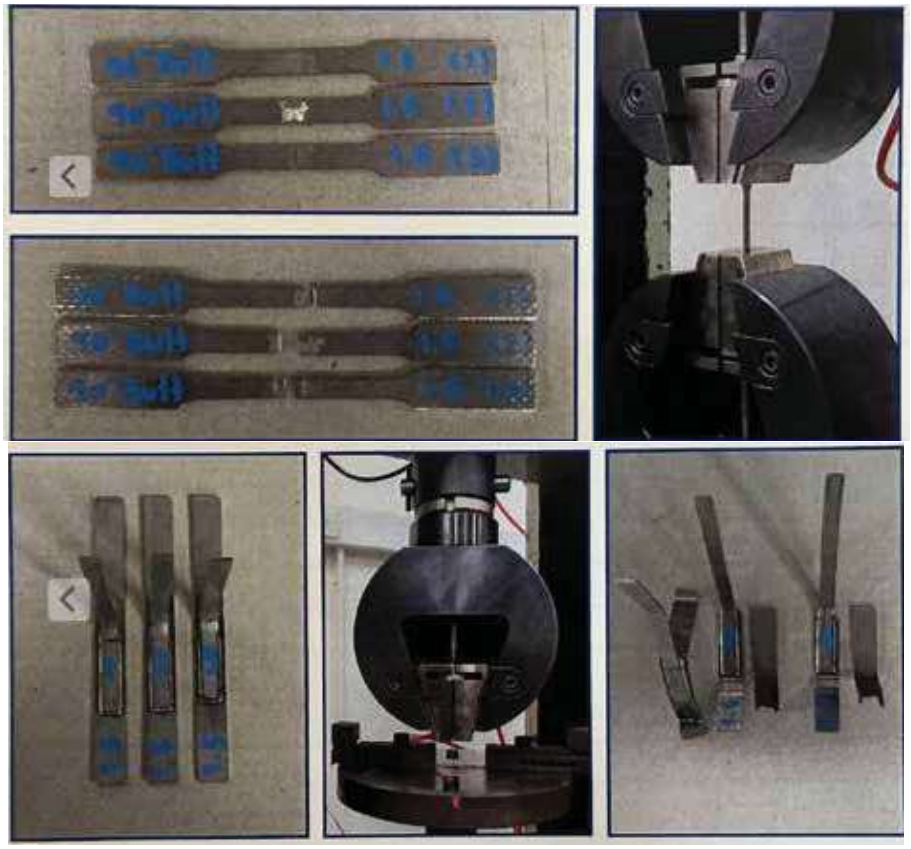


Fig. 6: Tensile test of 90-degree butt joints (top) and L-shaped doublers (bottom), made from "Inconel 625", test piece thickness 1.53 mm each, cracked in the base material, outside the heat-affected zone, at 932.26 MPa. (© DSI Laser Service (Thailand))

It is extremely fascinating to hear the typical cracking pulse noise as background music while watching and to consider how the molten bath is not created. Not classically by electricity, but by shooting out of the optics of the resonator and – attention! – with 300,000 km/s onto the sheet metal. In lyrical terms: metal liquefied by tiny clouds of light. This process is extremely fascinating from several points of view, also due to the fact, that the melting bath diameter is not really the size of a soccer ball, but only 1.2 mm in diameter, into the centre of which the welder does not push a goal post, but rather dips his fingertip a 0.5 mm thin wire.

Dozens of test welds and just as many analyses

The aim of the first single- and multi-layer buildup welds was to check both the metallic bonding between the base material and the filler metal and the bonding in the layer structure on the basis of the macro-sections made by them. This led to a gradual approximation, more and more completed from section to section, of the welding parameters adapted to the material and meeting the quality criteria laid down in the standard – an individual combination of pulse power (W), pulse duration (ms), pulse frequency (Hz) and pulse shaping (shape).



Fig. 7: Examples of areas in need of repair by pulsed laser: dented outer shell (left); inner shell previously repaired by TIG or MIG weld-ing (rest). (© DSI Laser Service (Thailand))

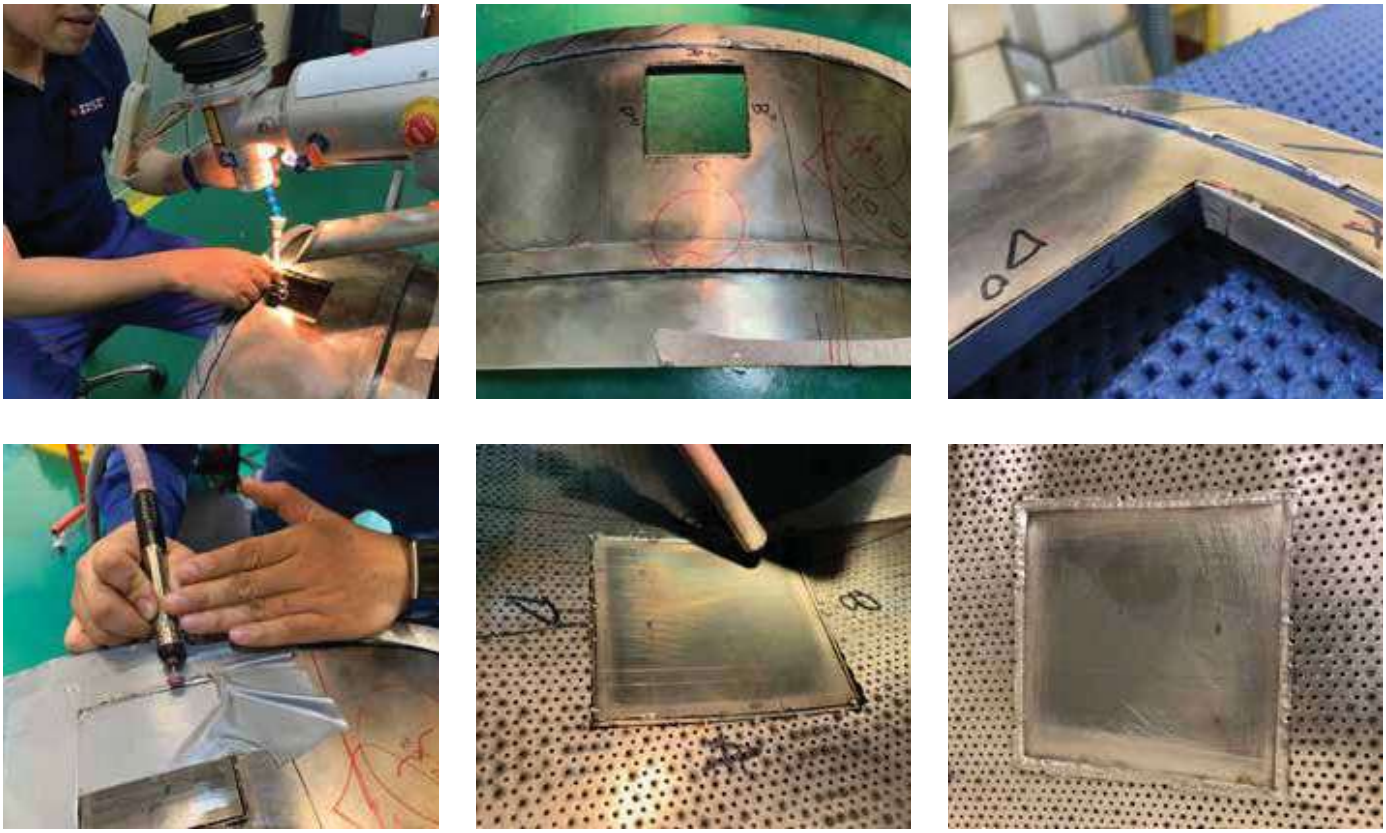


Fig. 8: Repair sequence (Standard Repair Procedure) honeycomb structure. (© DSI Laser Service (Thailand))

These were recorded, along with a dimensioned sketch of the test sheet, details of the welder, the welding sequence and other process-relevant data, in a preliminary Welding Procedure Specification, or pWPS. Later, after the required quality had been confirmed by tests on the test plate, the "p" was dropped: the preliminary instruction became the welding procedure specification. Its specifications must be strictly followed in the subsequent practical application to ensure the reproducibility of the tested and required quality. In parallel, a pWPQR (preliminary Welding Procedure Qualification Record) was created, which, in addition to the WPS, contains the area of approval for the procedure.

The buildup welds were followed by different joint welds **(Fig. 5)**: first in the classic butt joint and 90° fillet weld design, then with flat-face and L-shaped doubles, each welded all around. Finally, corner welds in 45°- and 90°-degree designs. In total, there were dozens of test welds and just as many evaluations.

The American Welding Society also prescribes the quality tests that the test welds have to undergo: Both non-destructive material tests (NDT) and destructive material tests (NDT), starting with visual testing (VT), followed by penetrant testing (PT).

To detect defects inside the weld, the standard prescribes radiographic testing (RT). In addition, because the welds are on a critical "A-class component", ultrasonic testing is required, supplemented by a C-scan, a sophisticated method of displaying ultrasonic test data: Three-dimensional cross-sectional representations of the test object, and that although the specimen sheets were only 0.54 mm and 1.53 mm thick, respectively.

If an irregularity was detected in a weld sample, its length and width, its geometry and exact location were determined, then the result was compared with the allowances prescribed by the standard. This was followed by the verdict of the non-destructive tests: "Quality test passed" or "failed". Barry defined a failure as the worst-case scenario: the bursting of his vision, that is, with a full reversal thrust back to traditional welding methods. At this point, after so many test welds, the point of no return had long since passed from Barry's ever-optimistic point of view. A return to the starting point was no longer possible.

Destructive materials testing is about the eternal test of strength in welding technology: Who is the strongest? The base material or the filler metal, measured in megapascals (MPa)? The test of strength was performed and answered by the incorruptibly working tensile machine, which slowly but steadily first stretched and finally tore apart the weld specimens clamped between its claws one by one **(Fig. 6)**. These tests, which also put Barry's nerves to the test, were used to characterize the strength and deformation behaviour under tensile stress. Taken with the high-speed camera, it was clearly observable how the plate gradually tapered off-centre and eventually cracked: In all weld cases exclusively in the base metal, far outside the heat-affected zone. The clear winner was: the welding technology of the pulsed laser.

At the end of all samples and their evaluation: A superior winner

When all test results were available, it came to the showdown: the direct quality comparison with those work samples that were carried out using classic repair welding processes, TIG and MIG. The comparison clearly showed the advantages of welding with pulsed light:

1) High weld strength
2) No significant HAZ, no heat-affected area of the base metal
3) No coarse grain formation weakening the microstructure
4) Clean welding process, no pores or cracks
5) No heat pre-treatment or post-treatment
6) Welding at room temperature.

The conclusion of the welding supervisors and test commission: Problem-free pulsed laser repair welding of the dynamically heavily preloaded superalloy "Inconel 625".

Immediately after the successful qualification at the end of 2018, DSI Laser Service Thailand performed the first repair welds on original turbine parts at the customer's plant. Each time, the pulsed laser welding system had to be used on the move because the turbine parts are not allowed to leave the factory during the entire repair process for reasons of quality assurance and flight safety. This was preceded, carried out by Barry, by elaborate structural calculations and simulations. A union of the high arts of engineering and those of welding technology. In this specific case, with regard to the areas to be repaired. Regarding their size, shape and location. Critically checking whether the overall component still meets the quality requirements of the original dynamic stress after repair.

In the future, primarily those areas are to be replaced that are either dented or in need of quality improvement: those areas that have been repair-welded by TIG or MIG in the past **(Fig. 7)**.

In parallel with Barry's calculations, a working sample in the original format and material ("Inconel 625") was started as training of the honeycomb-structure repair sequence (Standard Repair Procedure) **(Fig. 8)**:

1) Cutting out the damaged honeycomb structure
2) Grinding of interfaces without burrs and covering by frame sheets consisting of "Inconel 625", tacked by pulsed laser
3) Grind edges protruding from the frame flat
4) Staple prefabricated cover plates ("Inconel 625") corresponding to the original contour into the frame on both sides
5) Weld frame and plates on both sides to the original structure using pulsed laser
6) Quality control: In addition to the usual non-destructive tests mentioned earlier, geometry testing was added due to the curved, slightly conical shape of the component. That is, checking compliance with permissible distortions and form and positional tolerances.

Training on the work sample was followed by the first honeycomb repair on an original turbine part **(Fig. 9)**, with which the first pulsed-laser-welded seams flew into the Seventh Heaven over Thailand a little later, and far beyond.

The technology of pulsed laser welding takes off

The success story that began with Barry's vision and materialized in an aircraft exhaust quickly continued, both with this and other customers within the MRO industry, where one knows another and word of the unique benefits of pulse laser welding spread like wildfire. Test welds on other "Inconel" alloys and materials followed: for example, on "Inconel 718" (AMS 5832) and "Inconel 713 LC" (AMS 5391), where LC stands for low carbon and guarantees a maximum carbon content of 0.03 -0.07%. In addition, test welds were made on the high-strength titanium alloy TI 6-2-4-2 (Ti6Al2Sn4Zr2Mo).

All these materials, which are also capable of withstanding high thermodynamic temperatures and stresses, are used to make components for Auxiliary Power Units (APU), combustion chambers, exhaust nozzles, also jet engine exhaust tail cones. Soon, these were also being repair-welded using pulsed lasers. But that is another exciting story, told separately, about welding with pulsed light and its speed.

On the way to even higher spheres

Time leap to the year 2023: Once again, the view leads to the sky – and this time, too, driven by the vision of a customer also based in Thailand, originally from Singapore. This customer wants to send pulsed laser-welded seams into space.





Fig. 9: Repair welding by pulsed laser on a conical exhaust gas jacket made of "Inconel 625" and constructed using honeycomb technology. (© DSI Laser Service (Thailand))

Only this much can be revealed: These are to hold together the high-strength aluminium fuel tanks, operating under 60-bar overpressure, of a launch vehicle traveling at 4 km/s from Earth ... all the way to an orbit 400 km above.

It remains to be seen whether the technology of pulsed laser welding will be able to continue its success story, which once began on the safety of the workshop floor, far beyond the earth's atmosphere. One thing is certain: it remains exciting.

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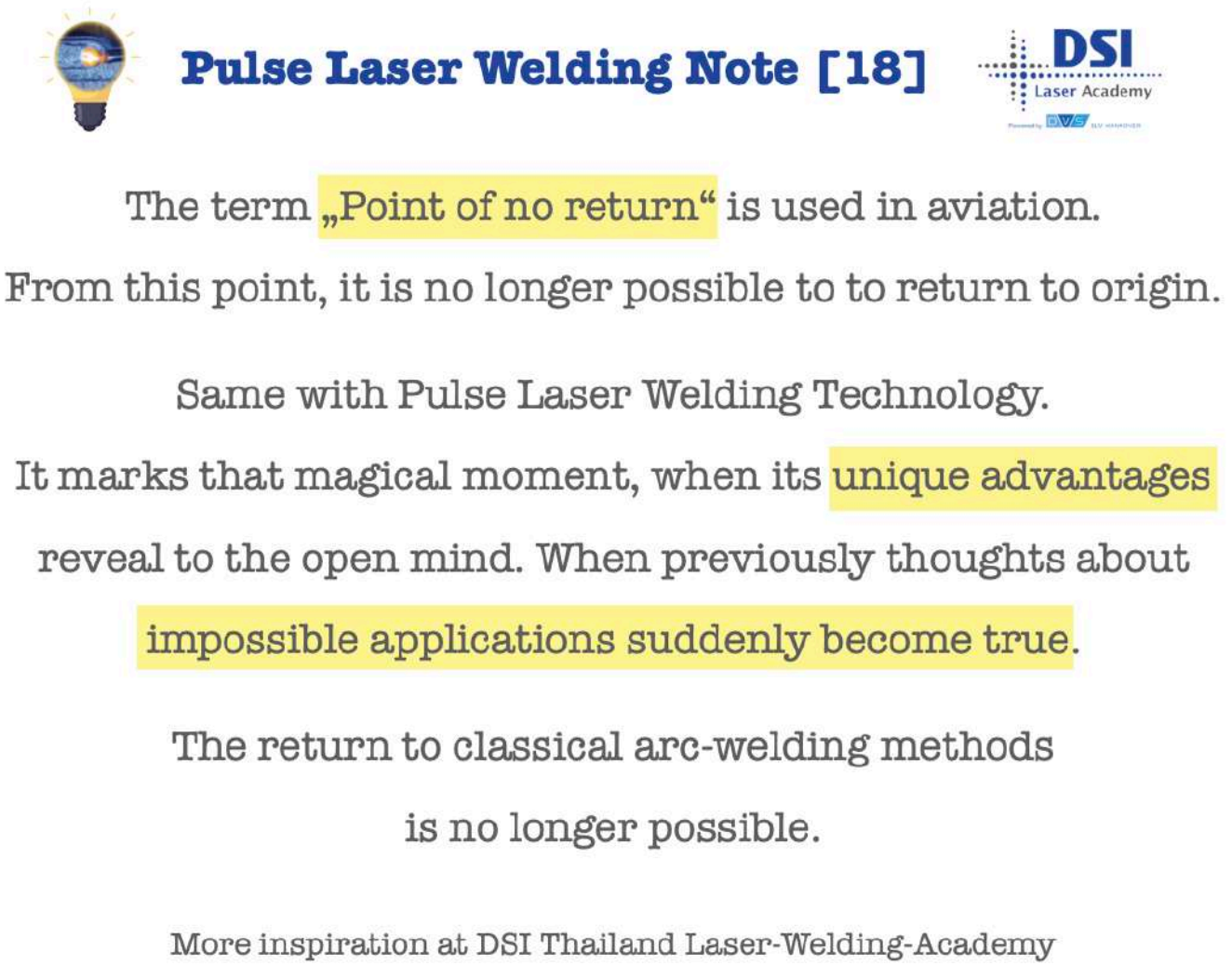
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HAZ – The most feared "Danger Zone" in welding technology

The knowledge gained from classic arc welding processes regarding the factors influencing the mechanical-technological properties in the heat-affected zone (HAZ) – particularly with regard to coarse grain formation – cannot be transferred to pulsed laser beam welding technology. This article explains that on the basis of test welds, their investigations, comparisons and practical applications. The central factors that significantly influence the result are the energy sources used to weld the samples: on the one hand, continuously applied electricity and, on the other hand, pulsed light.

In order to understand the different material behaviour, it is essential to dive deep into the areas of the base material that are changed by the heat applied during welding – into the heat-affected zone (HAZ), which is feared even by experienced welding experts and is located far beyond the professional comfort zone. Avoiding this "Danger Zone" or even denying it is only done by the foolhardy.

Instead of fearing the danger lurking in it and its effects, real experts turn to it: looking through the eyepiece of the microscope in the laboratory to experience it "up close" in multiple magnification, to study its size, shapes and structures, to analyze its structural transformations and final solidifications, with the aim of using the knowledge gained to find specialist solutions that allow them to deal professionally and carefree with the completely unavoidable HAZ in their everyday working life.

What exactly is the HAZ?

The solid, unmelted area between a weld seam and the unaltered base material is referred to as the HAZ. Its dimensions depend on the material properties, the amount of heat applied during welding and the duration of the heat exposure. The longer and higher the thermal load, the more pronounced the HAZ. The effect of heat above 1,000°C changes the metallic structure. This leads to undesirable weak points in components: grain enlargement and the associated deterioration in toughness values, hot and cold cracks, residual stresses, reduced corrosion resistance and increased brittleness.

In short, the mechanical and technological properties of the HAZ differ significantly from those of the base material. This in turn is the reason why component failures do not occur in the weld seam itself, but mostly in the adjacent heat-affected zone. "Welding HAZ diagrams" show the formation conditions and are used for the planning and assessment of welding processes – as indispensable technical reading, compiled and published under the title 'Großer Atlas Schweiß-ZTU-Schaubilder' by DVS Media GmbH.

Significance of the HAZ when welding unalloyed and low-alloy steels

Due to the rapid cooling rates associated with welding processes, the hardening of the HAZ is a particular problem with unalloyed and low-alloy steels; exacerbated by the fact that the cooling behaviour of the weld seam and that of the HAZ are not identical to that of the original base material microstructure. Different microstructure formation zones result within the HAZ, particularly due to the level of the temperatures during welding in the seam area. The coarse-grain zone adjacent to the weld metal and the adjoining fine-grain zone are particularly responsible for the mechanical-technological properties of welded joints, whereby the coarse-grain zone is to be regarded as critical, while the fine-grain zone has a positive influence on the welded joint.

Individual areas of the heat affected zone

Fig. 1 shows an overview of the individual areas of the heat-affected zone of the base material S355J2+N.

Coarse grain zone (GKZ)

At temperatures far above the A3 temperature specified in the Fe-C diagram (GOS line), a coarse grain can form due to overheating at over 1,000 °C up to the melting temperature, which after the respective cooling time (based on the "t8/5" time) is present as a coarse-grained, ferritic-pearlitic, bainitic or martensitic structure. These grain structures, which are

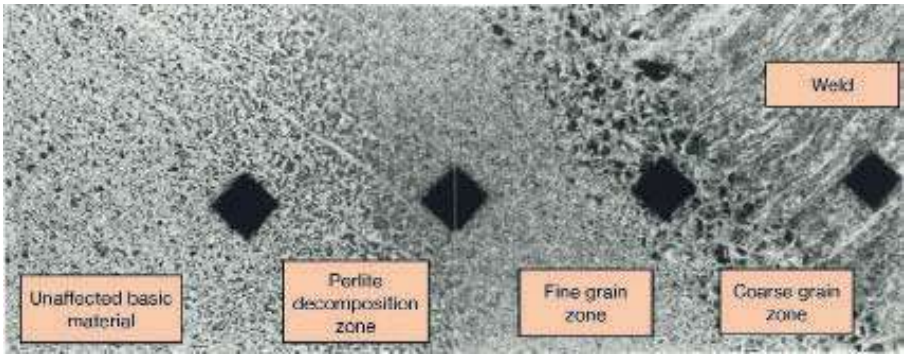


Fig. 1: Overview of the individual areas of the heat-affected zone of the base material S355J2+N (© DSI-Thailand)



Fig. 2: Single-layer manual metal arc welding (© DSI-Thailand)

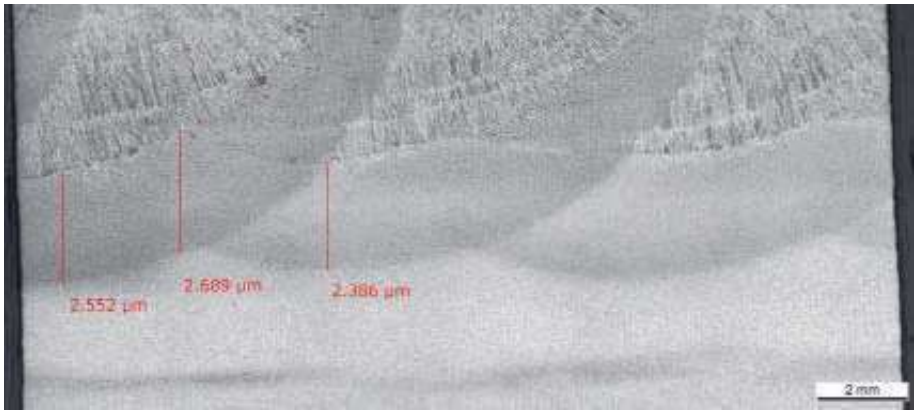


Fig. 3: Single-layer manual metal arc welding (HAZ 2.4 mm-2.7 mm, scale 1:25) (© DSI-Thailand)

larger than those of the base material, lead to a reduction in the grain boundaries per unit volume. As grain boundaries within a crystal lattice serve to block dislocation movements caused by crystal growth, residual stresses or plastic deformation, their reduction leads to a decrease in the yield point and plastic hardening. This decrease in toughness is often accompanied by a considerable increase in hardness, which results in poor toughness values in particular.

Fine grain zone (FGZ)

When the HAZ is cooled from temperatures slightly above the GOS line shown in the iron-carbon diagram – depending on the carbon content, this is between 911 °C and 723 °C for structural steels suitable for welding – a fine-grained microstructure is formed. The reason for this is a double regraining: when heated from a body-centered cubic lattice (krz) to a face-centered cubic lattice (kfz) and when cooled back to a krz lattice. This has uncritical strength and toughness values.

Perlite decomposition zone (PDZ)

This forms the area adjacent to the fine-grain zone at temperatures in the α-γ two-phase region. The Fe3C (iron cementite) in the perlite changes here from a striated form to a non-critical globular form.



Fig. 4: Three-layer manual metal arc welding (© DSI-Thailand)

A transnational project: six comparative welds, one goal

The declared aim was to investigate the characteristics of the heat-affected zones in different welding processes: the comparison between two classic processes, manual metal arc welding (111) and metal active gas welding (135), in which heat is introduced into the base material and the molten pool is generated by electric current. These were compared with pulsed laser beam welding (521), which uses phontons as the energy source, i.e. bundled, rectified, pulsating light particles and their speed – melting metal and welding at 300,000 km/s!

The manual arc and MAG welds were performed by the Thai German Institute (TGI) located in Chonburi, Thailand, represented by Arun Jeangsrijaroen (Head of Testing Laboratory and Certi□cation). The impulse laser beam welded samples were carried out by DSI Laser Service (Thailand), under the supervision of DSI Thailand Laser Welding Academy, represented by Stephan Thiemonds (IWS). The evaluation of all test welds, including the preparation of the microsections, was carried out in Germany at the DVS SLV Hannover, under the supervision of Prof. Dr. Gerd Kuscher.

Base material, welding samples and macrosections

A classic unalloyed structural steel in accordance with DIN EN 10025-2 was selected as the base material for the test

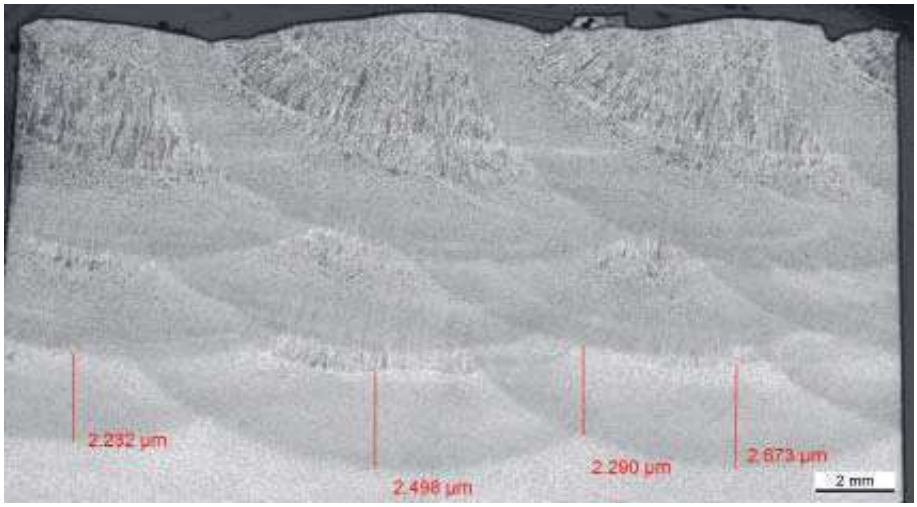


Fig. 5: Three-layer manual metal arc welding (HAZ 2.2 mm-2.7 mm, scale 1:25) (© DSI-Thailand)



Fig. 6: Single-layer MAG welding (© DSI-Thailand)

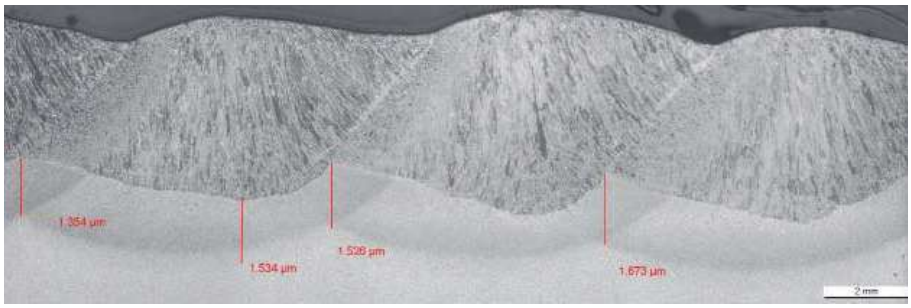


Fig. 7: Single-layer MAG welding (HAZ 1.4 mm-1.7 mm, scale 1:25) (© DSI-Thailand)

plates to be welded: S355J2+N (maximum C content 0.22 %), material number 1.0577. A total of six samples measuring 12 mm × 100 mm × 100 mm were welded. The dimensions of the deposition welding were 70 mm × 50 mm. Two samples each were produced by manual arc welding, metal active gas welding and pulsed laser beam welding.

In each case, one test weld was made in one layer and the second weld in three layers, whereby an interpass temperature (Tz) of less than 80 °C was maintained.



Fig. 8: Three-layer MAG welding (© DSI-Thailand)

Note regarding the evaluation of the macrosections and the choice of magni□cation: Due to the very narrow HAZ measuring only a few tenths of a millimeter in pulsed laser beam welding, the size of the HAZ was marked at a higher magni□cation of up to 100 x compared to 25 x for conventional welding processes.

Case study 1: Manual metal arc welding (process number 111)

- Base material: unalloyed structural steel S355J2+N (maximum C content: 0.22 %), material number 1.0577 in accordance with DIN EN 10025-2,
- Welding □ller material: EN ISO 2560-A E 38 2 RB 12/AWS A5.1: E6013,
- Electrode diameter: 4 mm/rutile-basic coated,
- Type of welding machine: Fronius "TransPocket 180"/amperage: 160A.

Fig. 2 and **Fig. 3** show the evaluation of the single-layer manual metal arc welding, **Fig. 4** and **Fig. 5** the evaluation of the three-layer manual metal arc welding.

Case study 2: Metal active gas welding (process number 135)

- Base material: unalloyed structural steel S355J2+N (maximum C content: 0.22%), material number 1.0577 in accordance with DIN EN 10025-2,
- Welding filler material: AWS A5.18: ER70S-6,
- Solid wire diameter: 1.2 mm,
- Shielding gas mixture: M21 (argon 82 %/CO_2 18 %),
- Type of welding machine: Fronius "TPS 4000"/current: 170 A.

Fig. 6 and **Fig. 7** show the evaluation of the single-layer MAG weld, **Fig. 8** and **Fig. 9** the evaluation of the three-layer MAG weld.

Case study 3: Pulsed laser beam welding (process number 52)

- Base material: unalloyed structural steel S355J2+N (maximum C content: 0.22 %), material number 1.0577 in accordance with DIN EN 10025-2,
- Welding filler material: DSI M90/1.5424/10MnMo4-5,
- Type of pulsed laser beam welding machine: "Alpha Laser AL Flak 1200 F" (laser beam source: fiber laser 1070 nm),
- Welding parameters: Pulse laser power 1200 W, beam diameter 2.4 mm, pulse duration 2.8 ms, pulse frequency 34.0 Hz, shielding gas argon 5.9.

Fig. 10 to **Fig. 13** show the evaluation of the single-layer, **Fig. 14** to **Fig. 17** the evaluation of the three-layer pulsed laser beam weld.

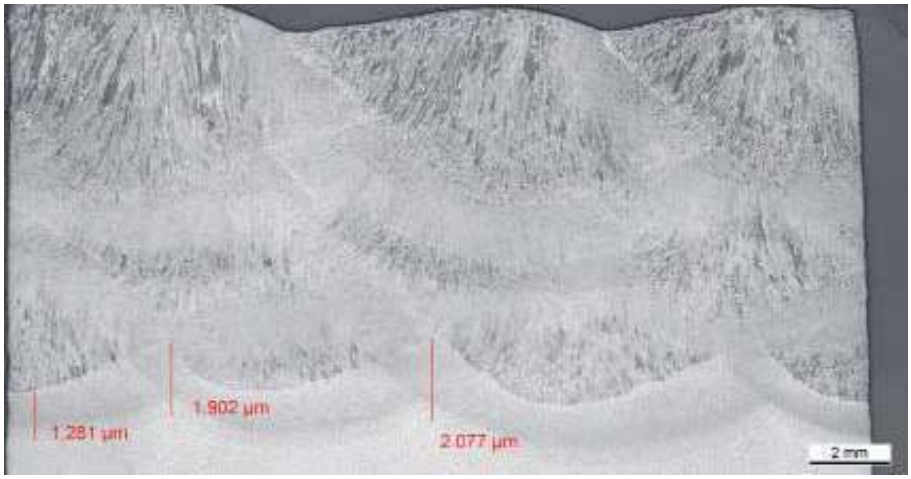


Fig. 9: Three-layer MAG welding (HAZ 1.3 mm-2.1 mm, scale 1:25) (© DSI-Thailand)

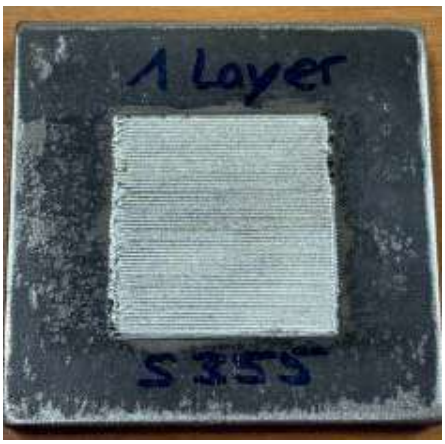


Fig. 10: Single-layer pulsed laser welding (© DSI-Thailand)

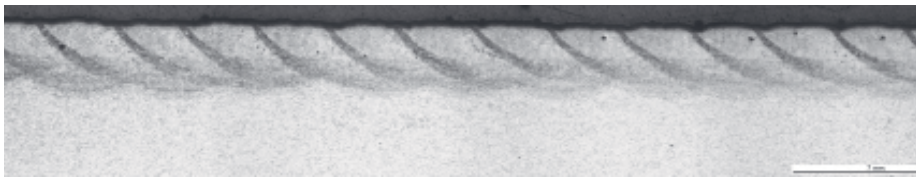


Fig. 11: Single-layer pulsed laser beam welding (scale 1:25) (© DSI-Thailand)

Summary, findings and conclusions

A comparison of the welding samples shows that the heat-affected zone is approx. 2 mm wide in the classic manual metal arc and metal active gas welding processes (**Figs. 3, 5, 7, 9**). With pulsed laser beam welding, on the other hand, it is only approx. 0.2 mm wide (**Figs. 12, 13, 16, 17**). This narrowness creates the positive aspect of a "support effect". This means that the very narrow HAZ is "supported" on both sides and thus "protected", on one side by the base material and on the other by the weld metal. This reduces the – in the classical sense – negative influence of the HAZ with regard to the load-bearing capacity of the welded joint to a minimum. Numerous studies of pulsed laser beam welding, which have been carried out at GSI – Gesellschaft für Schweißtechnik International mbH, SLV Hannover branch, since 1990, have already come to the same conclusions.

There is also a second positive effect, based on the fact that the cooling times for pulsed laser beam welding are significantly less than one second. The speed of a few milliseconds – in which the entire pulsed welding process takes place – prevents the formation of coarse grain and the development of a critical coarse grain zone, as shown in the overview of the individual HAZ zones (**Fig. 1**). In short: Cooling takes place much faster than the coarse grain formation controlled by diffusion. There is no evidence of critical grain coarsening that weakens the microstructure. This positive cooling effect makes it possible to weld difficult steels with limited weldability without heat pre-treatment or post-treatment using the pulsed laser beam process technology – while retaining all the advantages already explained.

Conclusion: The technology "welding with pulsed light and its speed" is able to reduce the originally high risk potential of the "danger zone" in classic welding processes using electric current as an energy source to a minimum and to harmonize between the base material and the weld metal.

Practical applications: "Start thinking big!"

Pulsed laser beam welding is currently on everyone's lips and the subject of many specialist presentations. From the point of view of potential users, it would be pleasing if the presentations were to focus more on the positive effects described in this article. The advantages resulting from them on the component were successfully demonstrated – beyond the theory – by means of practical applications.

The metallurgical and economic advantages of this technology, combined with the rapid development of pulsed laser beam welding machines, open up new dimensions in terms of component dimensions and deposition rates – applied in the day-to-day work of DSI Laser Service (Thailand), where approx. 90 % of the work involves repair deposition welding and approx. 10 % production welding.

Different applications have already been described by the authors in other technical articles. This was also preceded by test welds and their evaluations, carried out as cooperation projects by the DSI Thailand Laser-Welding-Academy with the SLV Hannover and published in German and English-language specialist magazines:

- Kuscher, G.; Thiemonds, S.: Repair of a steam turbine rotor using pulsed laser beam welding in Thailand. Welding and Cutting 19 (2020), No. 2, pp. 104–106.
- Kuscher, G.; Thiemonds, S.: Repair deposition welding of a shock absorber housing using pulsed laser beam welding. Welding and Cutting 22 (2023), No. 1, pp. 10–13.
- Kuscher, G.; Thiemonds, S.: Repair welding of cast iron with spheroidal graphite – without pre- or post-heating. Welding and Cutting 22 (2023), No. 2, pp. 20–23.

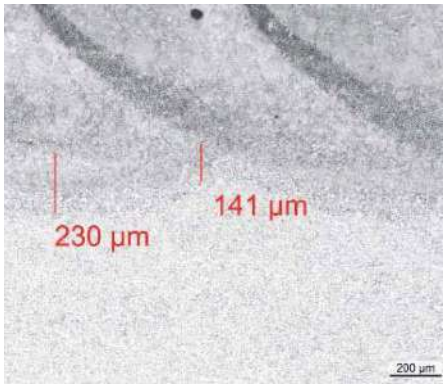


Fig. 12: Single-layer pulsed laser beam welding (HAZ 0.14 mm-0.23 mm, scale 1:50) (© DSI-Thailand)

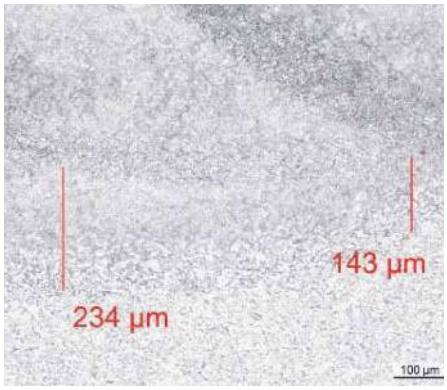


Fig. 13: Single-layer pulsed laser beam welding (HAZ 0.14 mm-0.23 mm, scale 1:100) (© DSI-Thailand)



Fig. 14: Three-layer pulsed laser beam welding (© DSI-Thailand)

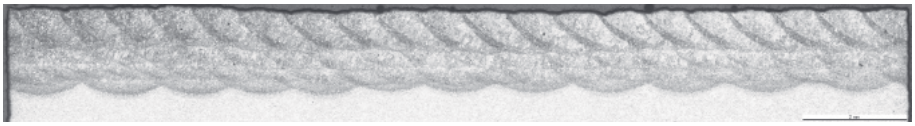


Fig. 15: Three-layer pulsed laser beam welding (scale 1:25) (© DSI-Thailand)

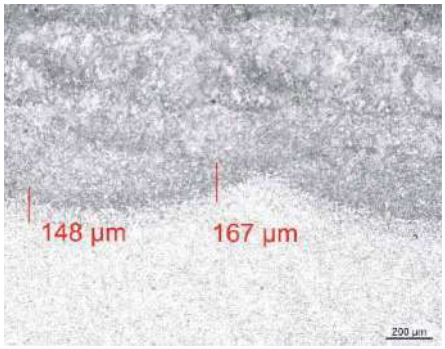


Fig. 16: Three-layer pulsed laser beam welding (HAZ 0.15 mm-0.17 mm, scale 1:50) (© DSI-Thailand)

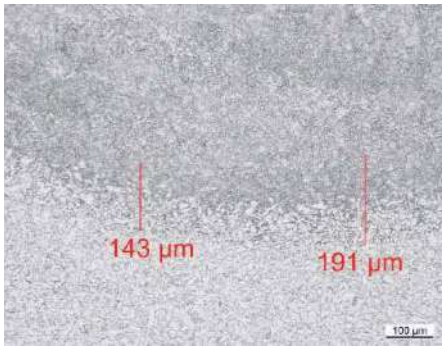


Fig. 17: Three-layer pulsed laser beam welding (HAZ 0.14 mm-0.19 mm, scale 1:100) (© DSI-Thailand)

- Kuscher, G.; Thiemonds, S.: Repair welding of aircraft turbine parts using pulsed laser beam welding. Welding and Cutting 23 (2024), No. 1, pp. 82–88.

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Pulse Laser Welding Note [28]

DSI Laser Academy

Welding Connects

Metals & Humans.

Locally & Globally.

Always Phenomenally.

Welding Connects - Pulse Laser Welding as well.

By both :

Professional Facts & Fantastic Fictions.

More inspiration at DSI Thailand Laser-Welding-Academy

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KMUTT King Mongkut's University of Technology Thonburi



Chapter IV.

Pulse Laser Welding meets University.

Lectures

Internship

Apprenticeship

Pulse Laser Welding meets University

On 17. November 2025, *DSI Thailand Laser-Welding-Academy* signed MOU with the *Faculty of Engineering King Mongkut's University of Technology Thonburi*, Bangkok.



King Mongkut's University of Technology Thonburi

DSI Laser Academy

Memorandum of Understanding

BETWEEN
THE DEPARTMENT OF PRODUCTION ENGINEERING, FACULTY OF ENGINEERING
KING MONGKUT'S UNIVERSITY OF TECHNOLOGY THONBURI, BANGKOK, THAILAND
AND
DSI LASER SERVICE (THAILAND) CO., LTD., CHONBURI, THAILAND

This is to certify that The Department of Production Engineering, Faculty of Engineering, King Mongkut's University of Technology Thonburi (KMUTT), and DSI Laser Service (Thailand) Co., Ltd., have entered into a partnership to promote collaboration, technical information exchange, and promotion of joint research.
This collaboration includes:

- Exchange of researchers, and students for internships and training.
- Joint research activities in Pulse laser welding and manufacturing.
- Joint Pulse laser welding lecture series, workshops, and hands-on training.
- Development of practical skills and strengthened academic-industry cooperation.

17 November 2025

Dr. Somporn Peansukmanee
Head of The Department of Production Engineering, King Mongkut's University of Technology Thonburi

Mr. Stephan Thiemonds
Director & Principal of the DSI Academy, DSI Laser Service (Thailand) Co., Ltd.



Our designated Focus are on :

- Lecture & Technology Transformation
- Workshop & Practical Oriented
- Research & Development
- Publication

DSI Thailand Laser-Welding-Academy

Internship & Apprenticeship

As an opportunity to discover the amazing world of Pulse Laser Welding Technology, *DSI Thailand Laser-Welding-Academy* provide Internship & Apprenticeship programs to students from different universities e.g. King Mongut's University of Thonburi, Bangkok (KMUTT) and Prince of Songkla University.









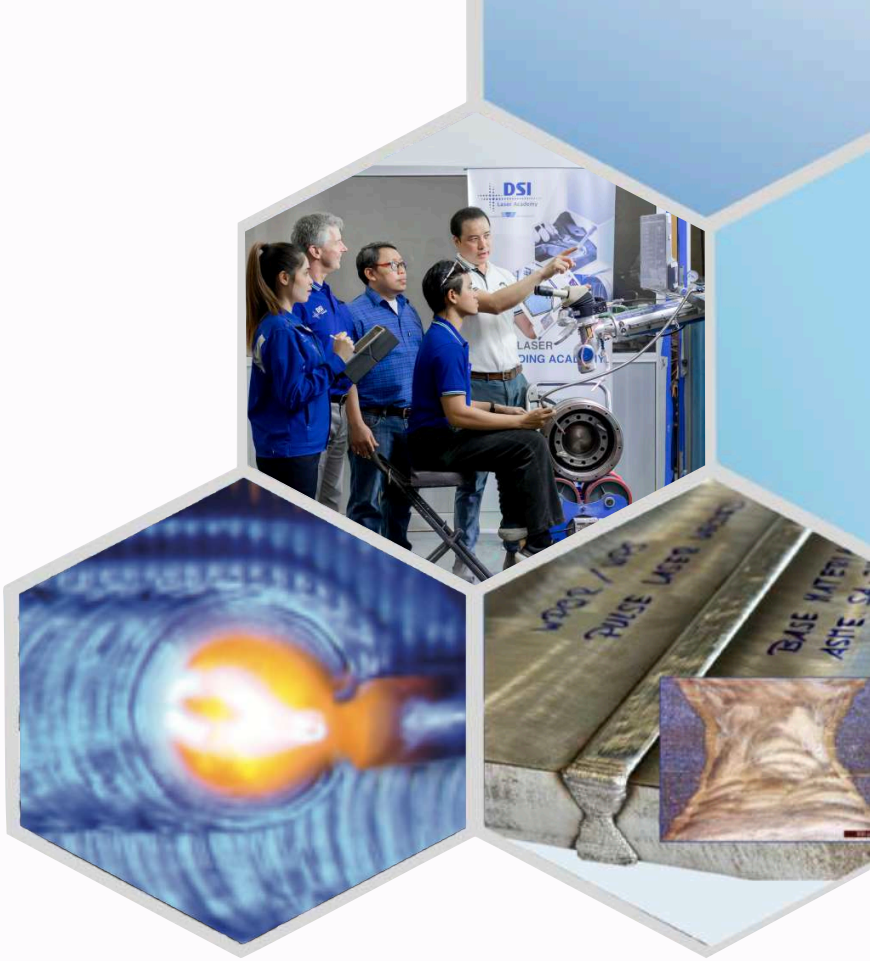






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Chapter V.

Pulse Laser Welding

Professional Facts

&

Fantastic Fictions

When Technology meets Art

DSI Thailand Laser-Welding-Academy presents :

The return of the modern Jedi-Knights who fights (in a positive sense) with their *ALPHA LASER* Machines for the prevention of the Good Force within all industrial sectors in Thailand and whole Southeast Asia.



Oil on Canvas, 50x40cm / paint by Christian Banpao, 2024





The painting process
Video DSI-Dropbox

Master Yoda of PLW-Technology & DSI-Academy









Prof. Dr.-Ing. G. Kuscher
German Welding Society - DVS SLV Hannover
Master Yoda of PLW-Technology - DSI Academy Thailand

Good to know - Professional Fact :

In the early 1990, Prof. Kuscher was one of the visionaries who understood the unique advantages of the pulsed Laser and saw the benefit of its (almost) unlimited applications, adaptable for any industrial sector. At about the same time ALPHA LASER has the Vision of engineering and manufacturing Pulse Laser Welding Systems which leads to the company foundation in 1994. Soon later ALPHA LASER presented the first Nd:YAG Machine with a pulsed laser power of 25 Watt - from which on the successful story began and continued … until nowadays.

Jedi-Knight Wisdom I. : Master Yoda says …



Jedi-Knight Wisdom 1
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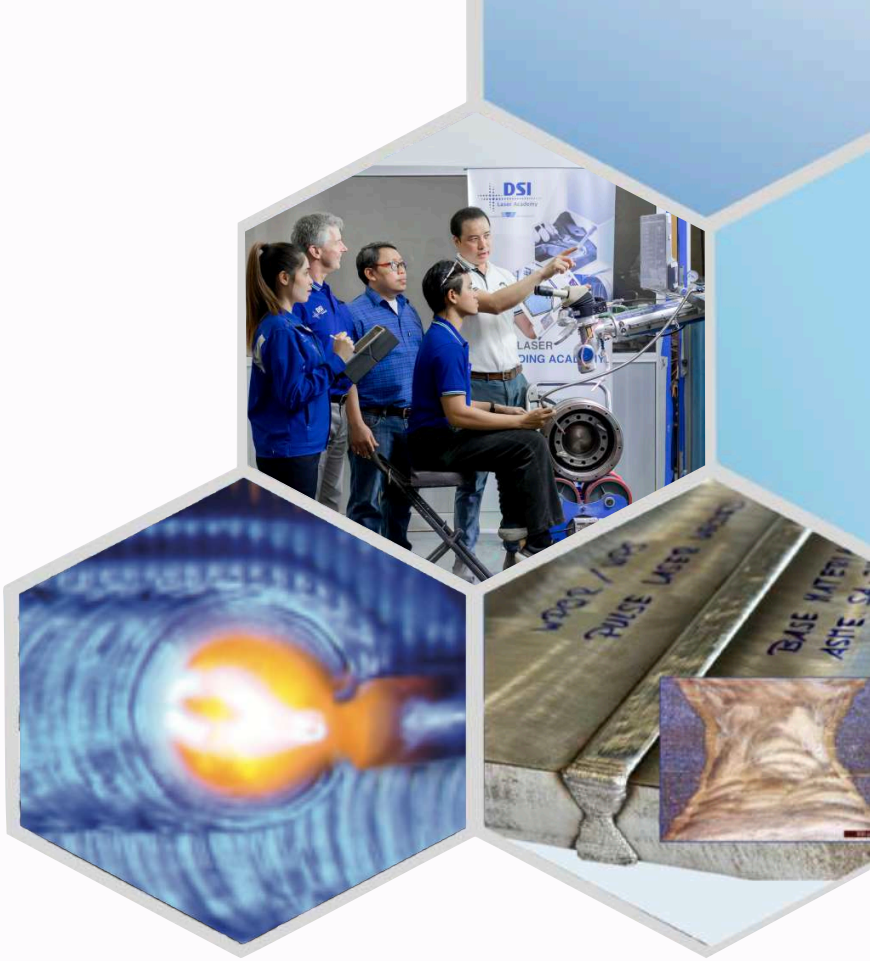
Jedi-Knight Wisdom II. : Master Yoda says …



Jedi-Knight Wisdom 2
Video DSI-Dropbox

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Chapter VI.

DSI Total Solution

for

Pulse Laser Welding

with

DSI Laser Wires

ALPHALASER
SOUTHEAST ASIA

Pulse Laser Welding

ALPHA LASER SOUTHEAST ASIA



"DSI Total Solution
for
Pulse Laser Welding
in whole
Southeast Asia & Japan"

Since 2000 located in Southeast Asia, *DSI Laser Service (Thailand) follows* **25 years** of continuous development which leads to the concept of :

DSI Total Solution for ***Pulse Laser Welding*** with ***DSI Laser Wires***

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- ✓ DSI Laser Welding Wires
- ✓ Machine processing / pre- and finishing of surfaces
- ✓ Authorised Dealer of ALPHA LASER Machines
- ✓ Service & Maintenance for ALPHA LASER Machines
- ✓ DSI Thailand Laser-Welding-Academy

Good to know :

DSI Laser Service (Thailand)
is
ALPHA LASER Southeast Asia

Thailand

ALPHA LASER Southeast Asia
DSI-Thailand Chonburi (Head office)

ALPHALASER
SOUTHEAST ASIA

Pulse Laser Welding

ALPHA LASER SOUTHEAST ASIA

ALPHA LASER Southeast Asia provides **DSI TOTAL SOLUTION** - each single segment, which is necessary for the professional execution of a Pulse Laser Weld whose superior quality is compliant with international welding standards and the requirements of a reliable operation condition of the component.

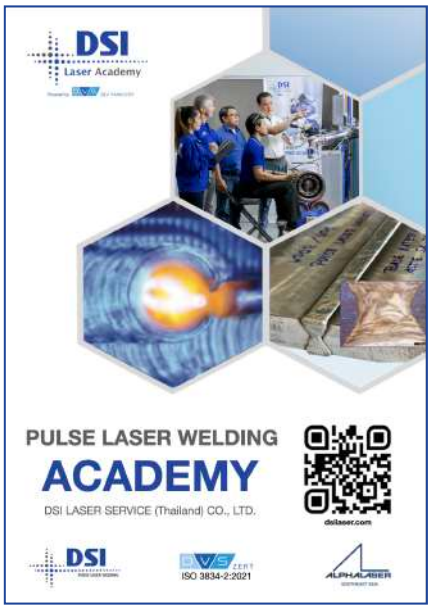


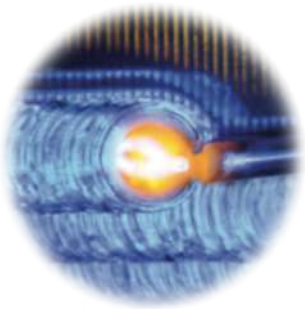
DSI Laser Welding | DSI Laser Wires | ALPHALASER SOUTHEAST ASIA | DSI Service & Maintenance | DSI Laser Academy

DSI Total Solution for *Pulse Laser Welding* with *DSI Laser Wires*













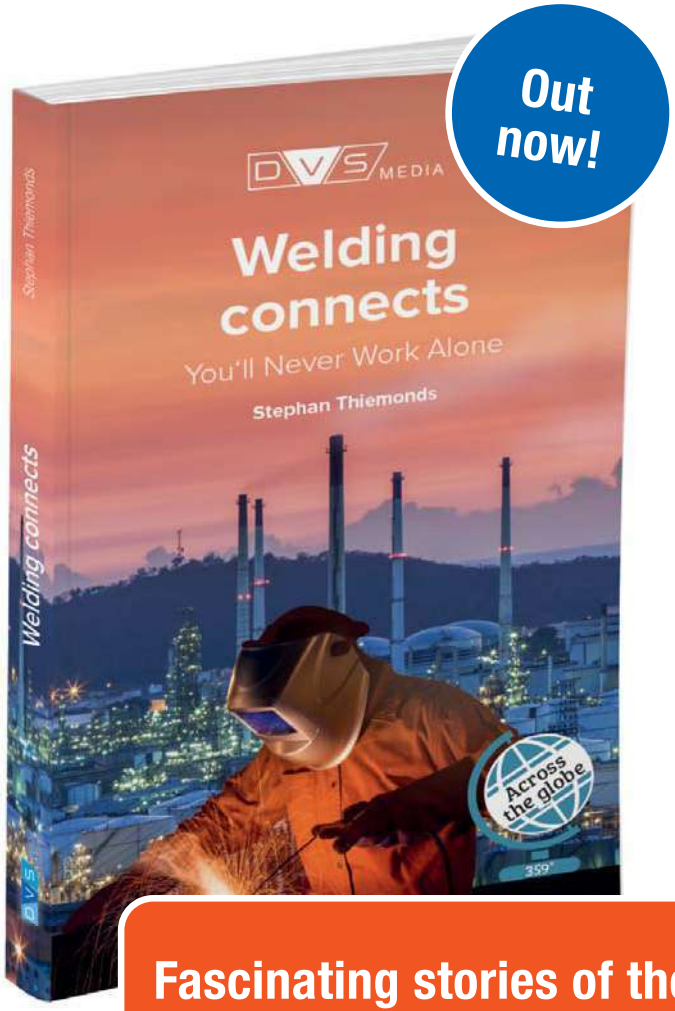




Welding Connects

Pulse Laser Welding as well

Metals and people.
Professionally and privately.
Locally and globally.



The author, an educated coppersmith and welder, discovers and experiences this welding phenomenon again and again during his professional world travels. Written in the style of Magical Realism and based on technical and factual knowledge, he tells the story of welding technology in an entertaining conversational tone.

How and why welding connects; why the healing power of singing while welding in the middle of a narrow copper pipe brought him as far as Singapore; from an Antarctic storm night aboard a krill fishing vessel that was separated, lengthened and welded back together; why ten little sewage sludge dryers and the archangel Raphael have a welding connection; and why the return of the Jedi Knights is critical to the future of welding technology. Surprised by the phenomenon associated with his profession, that welding not only connects, but can even fulfill children's dreams: through the magic of the welding industry!

Exceptional reading for industry insiders. Fascinating insights into the world of welding technology for all industry outsiders.

Fascinating stories of the welding industry.

Welding Connects – You'll never work alone
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The proceeds from the book sales will turn children's dreams into reality: their desire for education.

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