

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 “t_{8/5}” time) is present as a coarse-grained, ferritic-pearlitic, bainitic or martensitic structure. These grain structures, which are

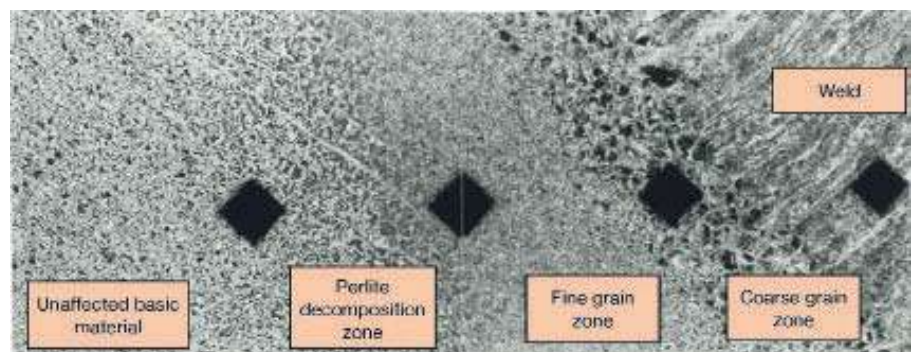


Fig. 1: Overview of the individual areas of the heat-affected zone of the base material S355J2+N (© DSI-Thailand)



Fig. 2: Single-layer manual metal arc welding
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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 regrading: 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



Fig. 4: Three-layer manual metal arc welding
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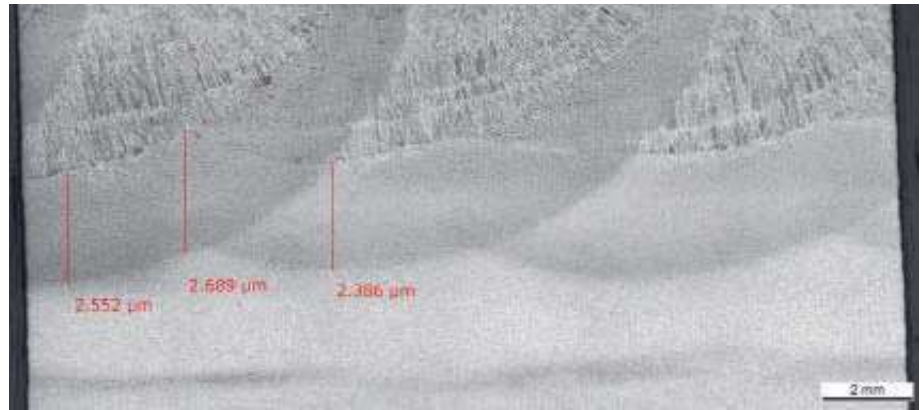


Fig. 3: Single-layer manual metal arc welding (HAZ 2.4 mm-2.7 mm, scale 1:25) (© DSI-Thailand)

two-phase region. The Fe₃C (iron cementite) in the perlite changes here from a striated form to a non-critical globular form.

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 photons 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 Certification). 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 Kuschner.

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

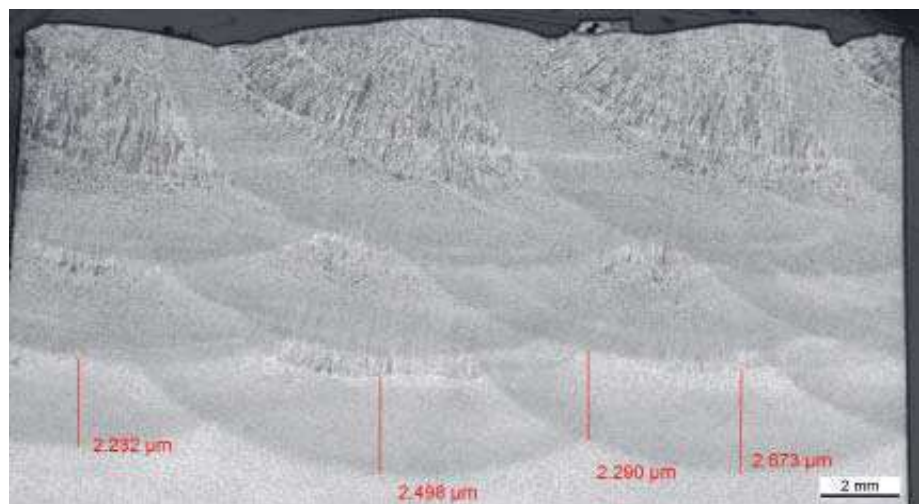


Fig. 5: Three-layer manual metal arc welding (HAZ 2.2 mm-2.7 mm, scale 1:25) (© DSI-Thailand)



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

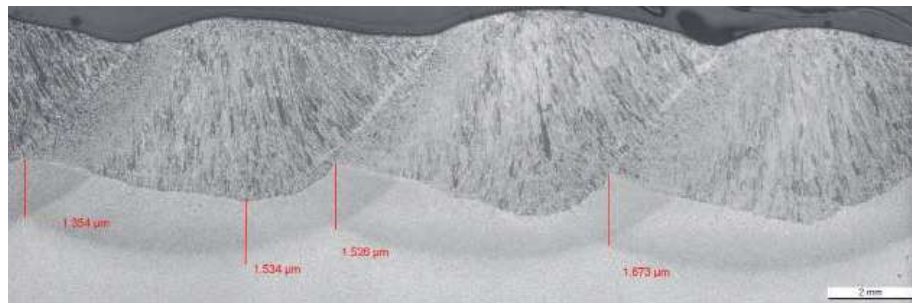


Fig. 7: Single-layer MAG welding (HAZ 1.4 mm-1.7 mm, scale 1:25) (© DSI-Thailand)

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 (T_z) 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 magnification: 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 magnification 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 filler 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 %/CO₂ 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.

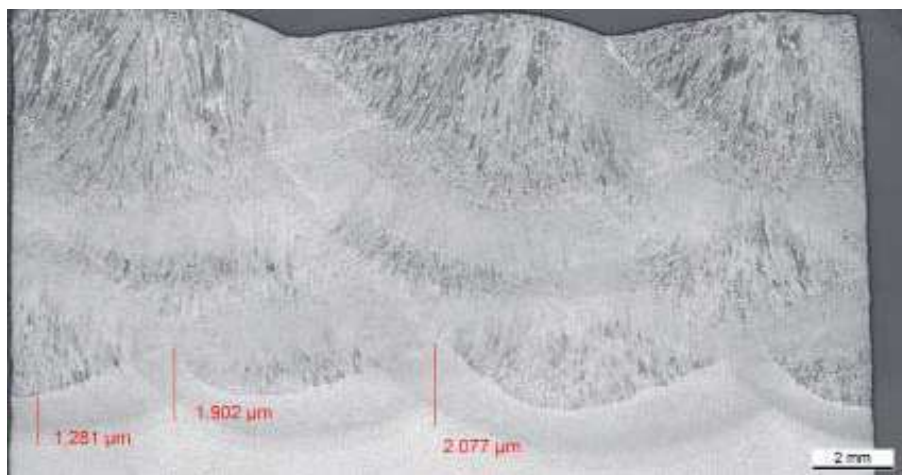


Fig. 9: Three-layer MAG welding (HAZ 1.3 mm-2.1 mm, scale 1:25) (© DSI-Thailand)

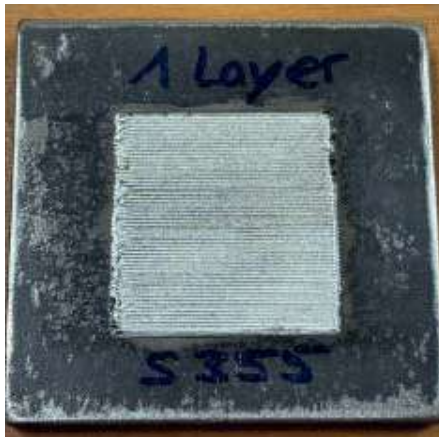


Fig. 10: Single-layer pulsed laser welding
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Summary, findings and conclusions

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

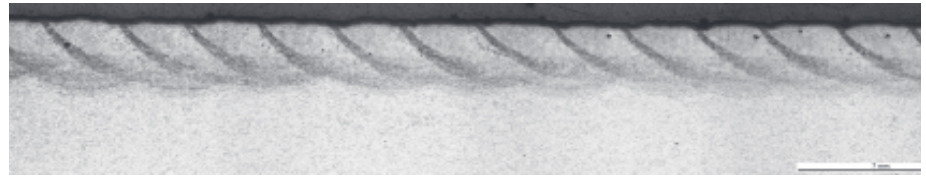


Fig. 11: Single-layer pulsed laser beam welding (scale 1:25) (© DSI-Thailand)

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.; Thimonds, 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.; Thimonds, 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.; Thimonds, S.: Repair welding of cast iron with spheroidal graphite – without pre- or post-heating. *Welding and Cutting* 22 (2023), No. 2, pp. 20–23.

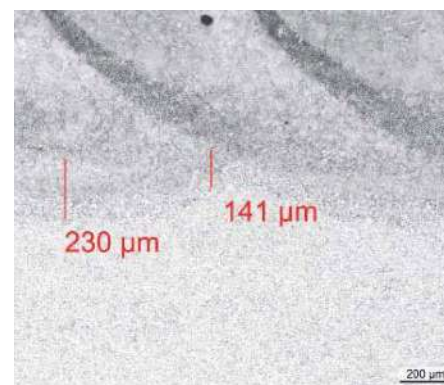


Fig. 12: Single-layer pulsed laser beam welding (HAZ 0.14 mm-0.23 mm, scale 1:50) (© DSI-Thailand)

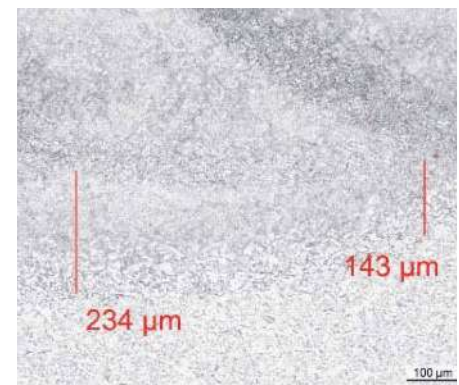


Fig. 13: Single-layer pulsed laser beam welding (HAZ 0.14 mm-0.23 mm, scale 1:100) (© DSI-Thailand)



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

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

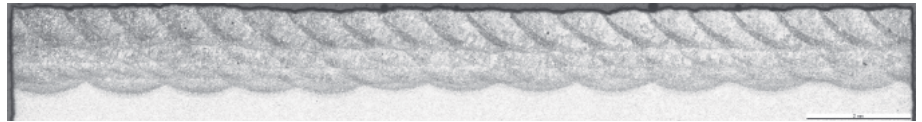


Fig. 15: Three-layer pulsed laser beam welding (scale 1:25) (© DSI-Thailand)

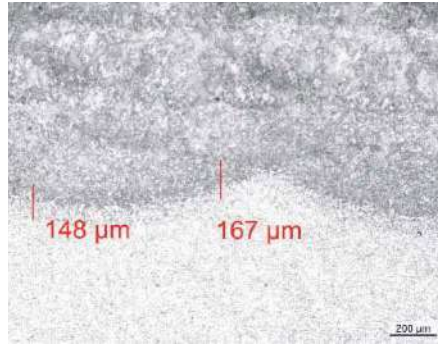


Fig. 16: Three-layer pulsed laser beam welding
(HAZ 0.15 mm-0.17 mm, scale 1:50) (© DSI-Thailand)

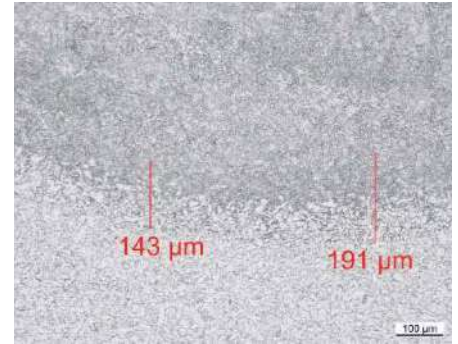


Fig. 17: Three-layer pulsed laser beam welding (HAZ
0.14 mm-0.19 mm, scale 1:100) (© DSI-Thailand)

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Pulse Laser Welding Note [28]



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