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JOIN TRANS 2022: 6TH EUROPEAN CONFERENCE „JOINING AND CONSTRUCTION OF RAILWAY VEHICLES“

May 11th – 12th 2022, Warsaw Poland

PROCEEDINGS

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JOIN TRANS 2022: 6TH EUROPEAN CONFERENCE „JOINING AND CONSTRUCTION OF RAILWAY VEHICLES“

MAY 11TH – 12TH 2022, WARSAW POLAND

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JOIN TRANS 2022: 6TH EUROPEAN CONFERENCE „JOINING AND CONSTRUCTION OF RAILWAY VEHICLES“

MAY 11TH – 12TH 2022, WARSAW POLAND

Prof. Dr. Steffen Keitel, Chairman of ECWRV

„European Committee for Welding of Railway Vehicles“, Halle, Germany

The activities of ECWRV and online Register EN 15085

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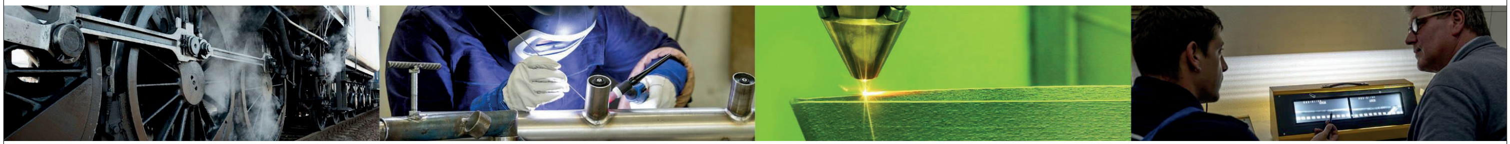

The activities of ECWRV and online Register EN 15085

Prof. Dr. Steffen Keitel, Chairman of ECWRV „European Committee for Welding of Railway Vehicles“, Halle, Germany

Halle (Saale), 04.05.2022

Last Meeting Face to Face in Praha

- 21th ECWRV Meeting, Prague, Czech Mirror Group with SVV, DOM, TÜV Süd 2019-10-22

- **The 22th to the 26th meetings were online because of the pandemic situation**

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Topics of ECWRV during the last two years

- Procedure "Prolongation of certificates and execution of surveillance according EN 15085 under special conditions of SARS-CoV-2 (Covid-19) pandemic" was developed.
- Remote audits to continue the procedure of auditing of welders work shops are runing
  The experiences shows:
  Remote audit could be a tool in addition to common practice especially by surveillance
- Procedure of examination interview had switched to an online version:
  Started with a reduction of only one candidate we found a practicable solution as follows:
  2 candidates and
  2 examiners and
  1 supervisor who controlled the fairness and scoop of the discussion
- First publishing of EN 15085-2 in May 2020 (Germany and Czech Republic)
  Now and today the complete overwork of EN 15085 is under construction
- In Germany a national preface for DIN EN 15085-2 was drafted to address the online register and the guideline DVS 1619 in the standard. DVS 1619 was implemented in Germany and is mentioned on webpage of the national safety authority (EBA) as technical rule.

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Topics of ECWRV during the last two years

- Accreditation processes of MCBs is under construction and partielly already finished by the National Accreditation Body.
- ECWRV reactivated the working group 1 and 2

  working group 1: proposal for the ECWRV-guideline part 1 (chaired by Mr. Arlt)
  Procedure for the application of EN 15085 Online Registers

  working group 2: proposal for the ECWRV-guideline part 2 (chaired by Mr. Hans)
  Technical Interpretation of EN 15085

- DIN 27201-6 will be substitute by EN 15085-6
  The separate education and examination of auditors for maintenance will be no longer needed.
- The Online-Register EN 15085 has been adapted to the new standard. It was integrated in the family of JoinCert (https://joincert.eu)
- It was decided that the MCBs can use the ECWRV logo

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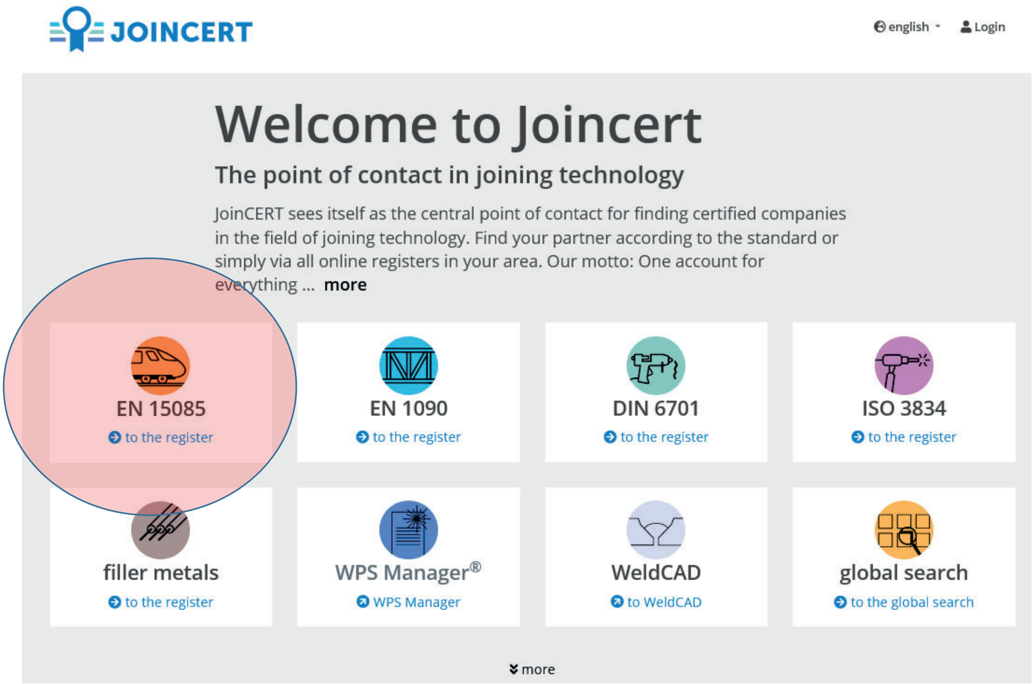
Home Page of JoinCert including Online-Register EN 15085



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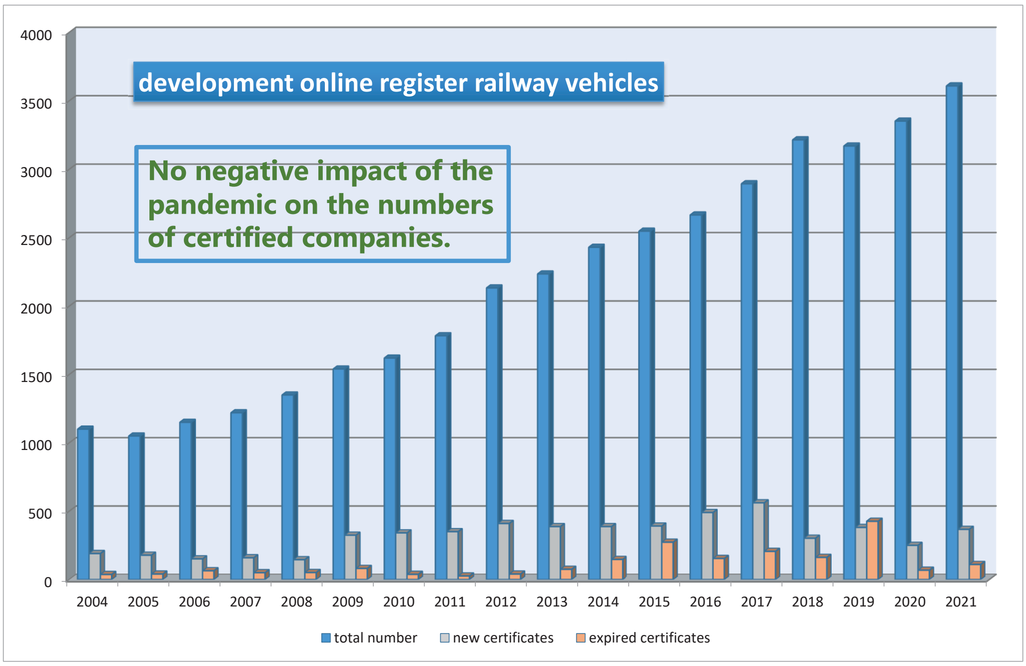
Growth of online register EN 15085



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Statistics of online register EN 15085 (date April 2022)

mcb	country	certs
A3Cert	Sweden	21
Bureau Veritas Italy	Italy	59
DOM	Czech Rep.	33
DVS ZERT GmbH	Germany	1372
First Welding Company	Slovakia	62
GSI SLV-TR	Turkey	39
IIS CERT srl	Italy	155
Kiwa Sweden AB	Sweden	39
IS CERIFICATION	France	124
LRQA Inspection Iberia SA	Spain	217
Q Techna	Slovenia	14
Quality Austria	Austria	7
SGS Italy	Italy	56
SIA Sertificacijas centrs. Ltd.	Latvia	0
SteelCERT GmbH	Austria	60
SVS	Switzerland	164
SVV Praha	Czech Rep.	28
TDT	Poland	16
TÜV Austria Service	Austria	48
TÜV Nord Systems	Germany	269
TÜV Rheinland Industrie Service	Germany	438
TÜV Rheinland Polska	Poland	45
TÜV SÜD Industrie Service	Germany	317
TÜV SÜD LG Österreich	Austria	59
TÜV SÜD Czech	Czech Rep.	57
TÜV SÜD Polska	Poland	96
TÜV Thüringen Polska	Poland	14
TWI Certification	UK	5

amount: **3.814**

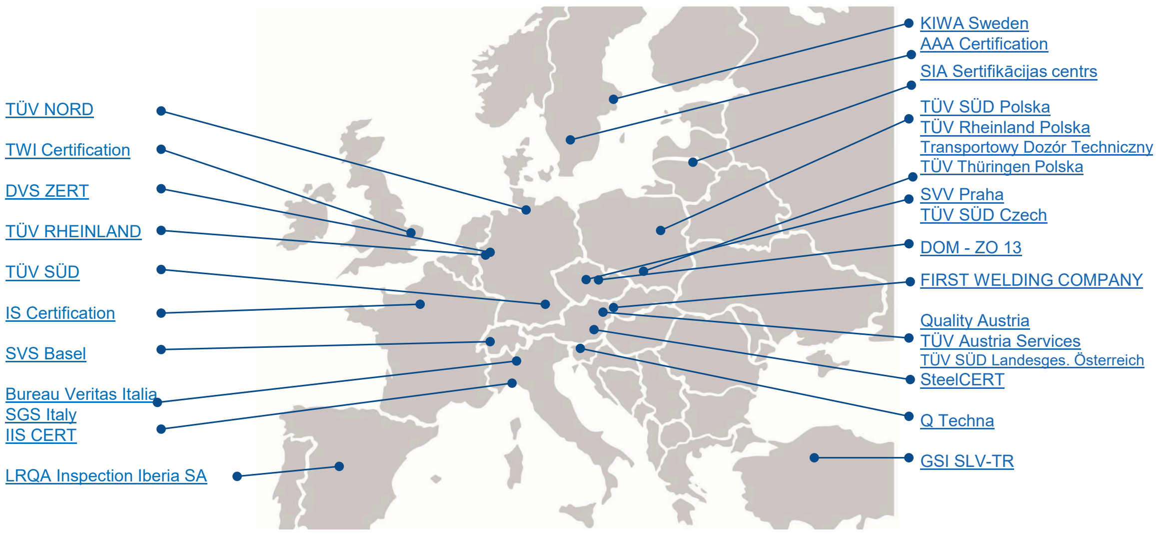
active auditors (maintenance acc. DIN 27201-6): 199 (99)

sum mcb: 28

sum countries: 12

ECWRV – MCBs: Activities all over Europe and worldwide!

Date: May 2022



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JOIN TRANS 2022: 6TH EUROPEAN CONFERENCE „JOINING AND CONSTRUCTION OF RAILWAY VEHICLES“

MAY 11TH – 12TH 2022, WARSAW POLAND

(IWE/EWE) Attila Erdei, István Stósz, László Kovács, MÁV-START ZRT., Budapest, Hungary

Welding aspects of the development of the IC+ vehicle family

Welding aspects of the development of the IC+ vehicle family

Attila ERDEI Mechanical Engineer, IWE/EWE, István STÓSZ Head of Technical Development and László KOVÁCS Structural Engineer, Budapest, Hungary

1 Introduction

The long tradition of railway vehicles production ceased in Hungary at the end of the 1990s. The need for new vehicles to be put into service has become increasingly urgent for the MÁV Group. In 2011 the Company decided to develop a family of passenger cars with a speed of 200 km/h by itself. The first two prototypes of the vehicle series have been running on the tracks of Europe and Hungary since 2014 to the satisfaction of the traveling public.
Using the experiences gained with prototypes, MÁV-START developed and manufactured 10 multi-purpose and 10 second-class coaches at the plant in Szolnok. The multipurpose coaches provide spaces for wheelchairs and bicycles.
Manufacturing of these vehicles started in May 2017 and the 10+10 coaches were completed in summer 2019.
Nowadays the second phase of serial production is going on at Szolnok plant. This batch consists of 35 first-class saloon coaches and 35 second-class multi-purpose coaches similar to the previous 10 coaches. The first class vehicles feature a buffet section and business class compartments.
The design process of a new driving trailer - an unpowered coach fitted with a driving cab- started in 2019 at our department. In this article, I would like to present the current state of the project, the welding aspects of the design and manufacturing of the coaches and the results achieved so far.

2 Task

2.1 An introduction of the IC + rail vehicle family

The development of rail transport is a priority for both the European Union and Hungarian national transport policy. As part of the National Transport Infrastructure Development Strategy, the National Railway Development Concept, adopted by the Hungarian Government in August 2014, set out to increase the share of rail transport and increase its competitiveness (Mezei, 2014). Rail transport plays an important role in connecting cities across Europe. Today, the development of inter-regional rail transport is primarily aimed at competing with air and road transport. MÁV-START's IC+ service aims to enter this challenging and constantly evolving segment by means of creating a competitive service. The aim of the new IC+ series is to build up an internationally competitive fleet.
In 2011, MÁV Group was granted ownership approval for its own production of railway vehicles. The purpose of this initiative was to develop intercity traffic, which is the backbone of the national railway service, and to create domestic jobs and increase the Hungarian share of added work. This multi-year project aims to develop a family of type Z1 vehicles that meet the requirements of the 21st century, including the ever-increasing demands of the passengers, but not ignoring requirements of economical production and maintenance. The coaches of the vehicle family are capable of 200 km/h in both domestic and foreign traffic. For te moment this speed can only be used in foreign traffic due to the lower track speeds in Hungary.

IC+ family members are as follows:
• 2nd class saloon coach (2 prototypes+10+82 pcs) (Figure 1)
• 2nd class Multipurpose Coach (10 + 35 pcs) (Figure 2)
• 1st Class coach with Buffet compartment (35 pcs, under construction)
• Driving trailer with 2nd Class interior (66 pcs, in design phase)

Figure 1. IC+ 2nd class coach (MÁV-VAGON, 2022)

In the first phase of serial production, MÁV-START Zrt. financed the development and production of 20 vehicles suitable for international traffic from its own resources. Half of them are saloon coaches like the prototypes and the other 10 are multipurpose coaches, suitable for transporting bicycles and wheelchairs.
The production of the next 70 coaches (35 multipurpose and 35 1st class) started in 2019 from public sources.

Figure 2. IC+ Multipurpose coach (MÁV-VAGON, 2022)

Further coaches (82+66) will be produced from public sources in the near future. In this series, 66 driving trailers and 82 2nd class coaches will be manufactured.

Significant changes to the prototypes have been made in series version of the second-class coaches:
• Modifications to ease installation
• Changes due to legislative changes
• Standardization of materials
• Improved design of coverings in the vestibule.
• The same color scheme as of the refurbished CAF coaches
• Up-to-date seats, tables
• USB ports for every seat
• Standardization of passenger information systems

The main features of multipurpose coaches are the followings:
• 47 seats + 3 wheelchair spaces
• Bicycle storage room (Figure 3)

Figure 3. Bicycle storage room (MÁV-VAGON, 2022)

• Two family compartments with space for baby carriage (Figure 4)

Figure 4. Family compartments with baby carriage space (MÁV-VAGON, 2022)

• Universal toilet accessible for wheelchair users
• Wide entrance door with lift for wheelchairs
• Charging option for electric wheelchairs
• Pumping option for bikes

The manufacturing of the first-class car is nearly finished, some features of them are as follows :
• 30 seats in class 1 and 8 seats in class 1+
• Buffet section (Figure 5)

Figure 5. Buffet section (MÁV-VAGON, 2022)

• Class 1 compartments
• Class 1+ compartments with premium services primarily for business travellers (Figure 6)

Figure 6. Class 1+ compartments with premium services (MÁV-VAGON, 2022)

The latest piece of the IC+ family, currently in the design phase, is the driving trailer, which is designed to create a modern, state-of-the-art vehicle (Figure 7.).

Figure 7. Desing of IC+driving trailer (MÁV-VAGON, 2022)

The main features of driving trailer are the followings:

- 47 seats
- Playground compartment divided with screen wall
- Two family compartments with baby carriage space
- 2nd class saloon section.

2.2 The design and manufacturing process of carbodies

The key question for the project is how to make a contemporary, distinctive and easily manageable InterCity service and easy to use product that is well identifiable with the new IC+ service. In the life of the project, the breakthrough came with the decision to serialize the vehicle family. This is where the actual design work began, based on the prototype vehicle manufacturing experience.
The Technical Development Directorate of MÁV-START Zrt designed the vehicles in Istvántelek (Budapest, District IV). During the design process, we paid great attention to meet standards and regulations, as the vehicle can only be used in international traffic if it complies with very strict railway standards and the European Interoperability Requirements (TSIs)..

According to the article of Koenig and Friedrich (2011) currently there are different car body concepts in use (Figure 8). These are the following:

- Differential style (metal framework reinforced with plates),
- Integral style (aluminium extruded profiles which are welded together in longitudinal direction and locally reinforced) and
- Hybrid style (mix of different materials)

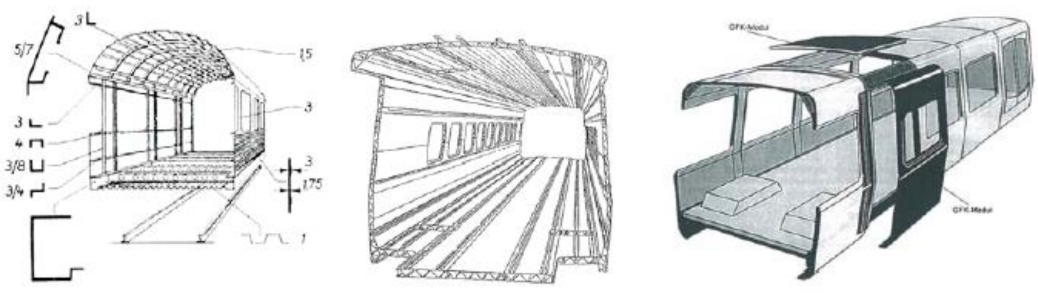

Figure 8. Carbody concepts (from left to right): differential style, integral style, hybrid style
Source: Koenig and Friedrich (2011)

Our vehicle is a kind of the differential car body concept, as it consists of different frameworks of steel profiles and plated with plane and corrugated sheets.

The strength of the vehicle was checked in parallel with the design. In order to verify the compliance with the loads according to MSZ EN 12663-1: 2010 + A1: 2015, calculations were made using the Patran / Nastran software package of MSC.Software. The possibilities of applying this method are also discussed in Borhy and Kovács (2017), Borhy and Belső (2012) and Borhy and Belső (2014) publications. As an example, Figure 11 shows the stresses generated by F_{zmax} (maximum vertical load). Typical heavily-stressed areas are located in the window corners (Figure 9). One carbody of each type was also tested to verify thcalculations and the design.

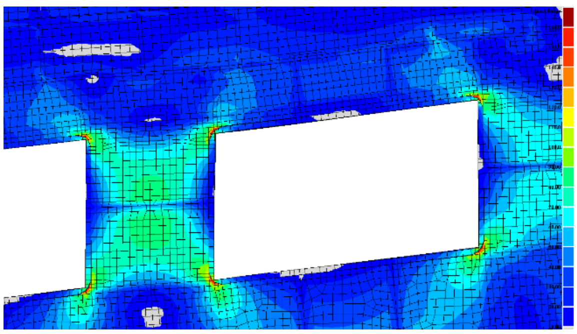

Figure 9. Stress peaks in the sidewall under maximum vertical load.
Source: Own construction

We followed the so called “Concept of pre-built large components” in the design, and the components were divided accordingly. The main components of the car body frame are the underframe with corrugated sheet floor, the end walls, the roof and the sidewalls [6]. (Figure 10).

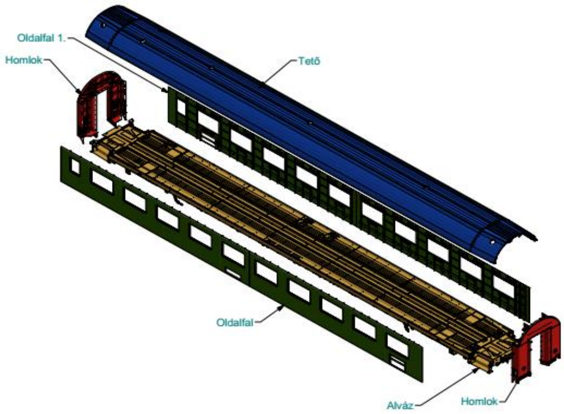

Figure 12. Main Components of IC + Car body
Source: Own construction

All components are manufactured by using production jigs, in order to increase accuracy and productivity. All welded components have been designed in accordance with the requirements and recommendations of MSZ EN 15085-3: 2008.

Figure 13 shows the underframe-end assembly device in which the main components, such as the headstock, the main cross beam and the longitudinal beam have already been installed.

Figure 13. Chassis end assembly device (MÁV-VAGON, 2022)

Figures 14 and 15 show the process of sidewall manufacturing. Figure 14 shows a side frame-welding device in which the welding of window frames and other rolled Z profiles form a strong load-bearing frame. Good access to weld seams is achieved by rotating the device.

Figure 14 . Rotary side frame welding device (MÁV-VAGON, 2022)

Figure 15 illustrates a side frame sheeting workstation, where the finished side frame fixed by hydraulic clamps and welded to the vacuum pre-tensioned and fixed side panels.

Figure 15. Side wall assembly device (MÁV-VAGON, 2022)

Figure 16 illustrates a 3-head MIG/MAG welding device for welding a roof panel running along the entire length of the carriage after completion of the process.

Figure 16. Roof plate welding equipment (MÁV-VAGON, 2022)

This 4-section welded plate is placed on the roof rails in the roof assembly device (Figure 17).

Figure 17. Roof assembly device (MÁV-VAGON, 2022)

Figure 18 illustrates the raw car body of the multipurpose coach, just removed from the assembly device.

Figure 18. Raw Car body of Multipurpose coach (MÁV-VAGON,2022)

In the design of the IC+ driving trailer vehicle, it is an important aspect that the vehicle's carbody structure and driver's cab front structure must comply with the requirements of EN 15227 and EN 12663. The first standard is about the crashworthiness of the vehicle structure, while the second standard is about the structural requirements of railway vehicle bodies.

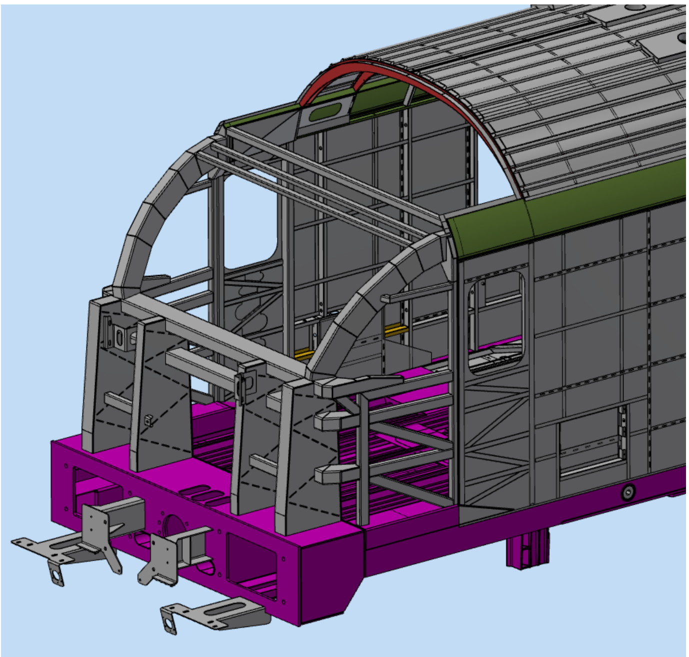

Figure 18. Raw Car body of Multipurpose coach (MÁV-VAGON,2022)

2.3 Summary

In our article, we introduced the current developments of the IC + vehicle family. The importance of the topic is also confirmed by the fact that the second series of cars started to run test routes by the time of the conference. I specifically addressed the current design and manufacturing processes. I introduced the used modern manufacturing and welding methods that can make serial production faster and more cost effective.

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JOIN TRANS 2022: 6TH EUROPEAN CONFERENCE „JOINING AND CONSTRUCTION OF RAILWAY VEHICLES“

MAY 11TH – 12TH 2022, WARSAW POLAND

Dr. Giedymin Orlik, Transportowy Dozór Techniczny (TDT), Warsaw, Poland

Test programs for welders test pieces in the context of the production of rail vehicles and their parts

Test programs for welders test pieces in the context of the production of rail vehicles and their parts

dr inż. Giedymin Orlik Transportowy Dozór Techniczny, Poland

1 Introduction

The systematic and dynamic development of the passenger and freight rail transport market is stimulated by increasingly stringent requirements for ensuring safety and high travel comfort, accompanying the constantly increasing operating speed of trains. This situation imposes on manufacturers of rail vehicles more and more challenges and requirements regarding the quality of production. An additional factor is the desire to reduce the mass of manufactured products by using more and more advanced methods of strength calculations at the design stage, but also by using materials with higher and higher strength properties. This state of affairs concerns the supporting structure of rail vehicles, chassis and bogies of various types, as well as passenger space in rolling stock units [1]. In the latter case, there are also very high requirements regarding the aesthetics of workmanship and travel comfort in technical solutions. These factors have a very significant impact on the production process, also in the field of welding, including the qualifications and skills of welders.

As it is commonly known, the welding process in terms of quality and safety is treated as a special process, which means that the result of a manufacturing operation cannot be fully verified at the production stage, and the final effect on the quality of the product may only be revealed during use. A very imaginative example is the case of a fatigue crack originating in the weld of the side beam of the bogie frame of the Tokaido Shinkansen driving trolley in Japan, which happened in December 2017, during the use of the bogie. One conclusion that is very important for the production process of rail vehicles can be drawn from the presented Report [2]: the highest standards of requirements should be applied at every stage of the welding production of a rail vehicle and constantly strive to improve the quality and certainty of production. It is particularly important considering the fact that fatigue processes occurring in steel materials are of fundamental importance in terms of durability and safety of rail vehicles. This is all the more important as it is known that welded joints can reduce the strength of structures exposed to cyclical loads by up to 30%. Welding processes and all related irregularities significantly affect the parameters determining the fatigue life and safety of the rail vehicle. These include, among others:

- stress concentration, arising during welding on all kinds of material discontinuities and welding imperfections,
- the condition of the surface of elements prepared for welding (e.g. after grinding, removal of auxiliary elements, etc.),
- welding residual stresses,
- lack of fusion and craters associated with starting and stopping welding,
- all kinds of geometric notches, including irregularities in the weld face, undercutting, etc.,
- structural notches, including, in particular, an increase in hardness caused by welding processes.

The welding process in the production of rail vehicles and their components in the production plant is managed by the obligatory provisions contained in the series of standards PN-EN 15085 "Railway-welding of rail vehicles and their components" [3-7] and the currently consulted prEN 15085-6 " Maintenance " [8]. These standards regulate and describe in detail all stages of welding production of rail vehicles, from design to final acceptance of the product. It should be emphasized that all the parameters listed above have a significant impact on the fatigue life of the vehicle. They are created in the welding process and are also dependent on the knowledge, qualifications and experience of the welder. The recommendations contained in the document "Guidelines of the European Committee for the welding of railway vehicles" (ECWRV - 2017-II-28 Part 2) [9], which also includes guidelines for the verification of welders' qualifications, are also very important for the proper conduct of welding works.

2 Requirements of the PN-EN 15085 series of standards

The PN-EN 15085 standard is a series that contain details of the requirements at the subsequent stages of rail vehicle manufacturing:

- for a welding manufacturer [4]
- in the field of design and construction works [5]
- in the field of production, welding [6]
- during inspection, testing and documenting the process [7]
- for maintenance works (standarunder consultation) [8]

At the design stage, the standard [5] introduces the term "Stress Factor", which describes the degree of use of allowable stresses in the design process. In the extreme case, for the stress category "High", the standard allows the level of stress utilization even above 90%. This means that the safety margin and the margin for any undetected execution errors is less than 10%. For the quality of welding production treated as a "special process" it is a very big challenge, taking place at every stage of production. This also translates into the requirements for welders, whose experience, knowledge and skills determine the quality of welded elements produced in rail vehicles. Qualifications of welders of rail vehicles are verified during the examination for qualifications in accordance with PN-EN ISO 9606 standards as well as during production tests in the production plant.

In this context, the standard PN-EN 15085-1 p. 4 [3] includes the requirement to demonstrate by the manufacturer that he has full control over the welding processes carried out and to ensure that the required level of quality during production will be achieved, inter alia, through appropriate qualifications welders and operators. As regards the qualifications of welders, the PN-EN 15085-4 standard [6] in point 4.1.5 „Training and qualifications of welders and operators" states that the manufacturer should have welders with qualifications confirmed in accordance with the requirements of the EN ISO 9606 series of standards. The standard also required from manufacturers of additional training of welders in the scope of tasks that they perform in the workshop. This training should include assessment skills and knowledge of the following:

- proper condition of welding equipment,
- availability and compliance of welding planning documents with the welded element,
- correct preparation of the joint for welding,
- compliance of welding materials,
- cleaning, preheating temperature, interpass temperature, post-weld treatment,
- compliance of the weld with the drawing,
- checking the quality of the weld in accordance with the class of the weld,
- requirements for the welded joint before, during and after welding,
- correct tacking,
- rules on work safety.

It seems that a significant part of the issues presented above should be known to a welder with competences obtained in accordance with the requirements of the PN-EN ISO 9606 series of standards. These topics should be the subject of theoretical training of welders when applying for welding qualifications in accordance with PN-EN ISO 9606 - 1 to PN-EN ISO 9606-5. However, these standards do not require an examination after the theoretical training has been completed. The conduct of such an examination is left to the opinion of the examining body.

Additional training of welders conducted by the manufacturer in the scope of the tasks they perform in the workshop, in accordance with the recommendation of PN-EN ISO 15085-4 point 4.1.5, if it were to cover the above-mentioned issues, it would require many hours of training, which in production conditions as well as natural personnel rotation among welders are practically impossible to achieve. In addition, enabling the welder, in an accessible and simple way, to master such issues as: „the ability to check the quality of the weld according to the class of the weld" requires training in the visual assessment (VT) of the weld. It is also important that to consolidate the acquired skills, also practical exercises are necessary . Such activities are difficult to implement in the conditions of a short workshop training. This problem is also not solved by the production tests required in PN-EN 15085-4 point 4.2, the purpose of which is, inter alia, in accordance with the provisions of the standard: „demonstrating the skills of welders in the field of welded joints, which are not covered by ordinary welding standards regarding the qualifications of the welder". This means that the welder, without specialist training, should demonstrate skills that go beyond the scope of his qualifications. It should be guessed that „normal welding standards" are a series of PN-EN ISO 9606 standards, which would not be applied in this case.

3 Requirements included in the document "Guidelines of the European Committee for the Welding of Railway Vehicles ECWRV 20170-II-28 Part 2". Technical interpretation of EN 15085 standards [9]

The document issued by the European Committee for the welding of rail vehicles details and precisely explains many of the issues described in the series of PN-EN 15085 standards. It also addresses issues related to the requirements for welders and their qualifications. Section 5 presents recommendations for the training of welders:

• Welders and operators should receive training from the welding coordinator. Training must be documented.
• Additional training must be organized by the welding coordinator for new welders, for new production, and for non-conformities caused by welders and operators.
• Production tests of welds are to demonstrate the skill of welders, they are necessary when the welded joints do not comply with EN ISO 9606.

In small contracting companies, it is allowed for the welder to be able to act as a coordinator of welding works and carry out welding works in a self-control mode.

The Guidelines strongly emphasize the role of production tests and care for the high qualifications of welders, which should be closely related to the nature of production. It should be emphasized that it is very difficult to meet such requirements in terms of production and the current natural rotation of employees.

4 Requirements of the series of standards PN-EN ISO 9606 [10 - 13]

Welder's qualifications obtained on the basis of these standards oblige all parties to the welding production process to unequivocally accept the examination, regardless of the product, place and examiner or examining body. These qualifications, in accordance with the provisions of the PN-EN ISO 9606 standards, consist in the welder having the ability to perform the weld of acceptable quality in accordance with oral or written instructions. However, such a standard provision is very general and allows the admission to welding works of people without sufficient knowledge related to the work being performed. At this point, the question arises whether it can be assumed that a welder qualified in accordance with the PN-EN ISO 9606 series of standards is automatically authorized to weld a wide variety of objects, such as: pipelines, pressure vessels, carriages for rail vehicles, building structures or cryogenic installations ?

It is known that each of the above-mentioned structures has different welding requirements and carries very different hazards. Product-specific requirements are not always fully presented in the Welding Instructions (WPS), which are the basic document applicable when making a welded joint. Therefore, it seems legitimate to state that, in addition to the PN-EN ISO 9606 standards, the source of welding requirements, which prove the qualifications that are relevant for welding a specific product, are also product standards, design specifications or requirements of other regulations, such as safety or usage.

As an illustration of this issue, Fig. 1 shows the welded construction of the bogie of the aforementioned Japanese high-speed train, with a visible fatigue crack formed in the weld of the bogie side beam. Due to the high requirements for geometric and dimensional accuracy, work, starting from making tack welds, should be performed by experienced welders. As stated in the Report [2], prepared after the failure was detected, the crack was initiated by the residual stresses and microcracks in the weld, formed during the execution of the joint. It turned out that welders with lower qualifications were involved in the production of tack welds, which are responsible for the correct geometry and dimensional accuracy of the structure being implemented. In such a situation, taking into account the difficult access and the complicated box-section of the side beam, it was not difficult to introduce residual stresses.

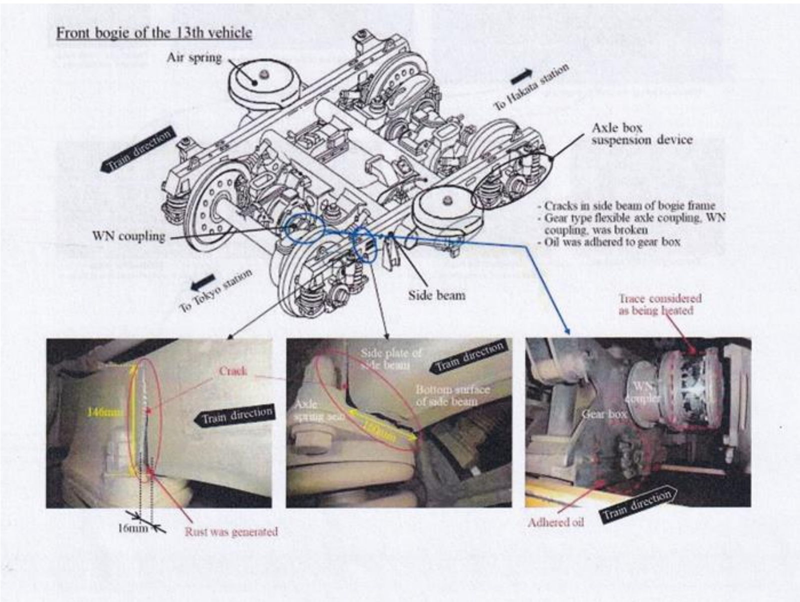

Fig. 1 Bogie structure and the fatigue fracture of the side beam weld. Source [2]

5 Proposal for extended qualifications of welders

Transport Technical Supervision (TDT) is a unit No. AC 163 accredited by the Polish Center for Accreditation certifying persons.
Certification in the field of qualification of welders is based on the following documents:

• PRCo-02 - "Welders Certification Program", the purpose of which is to ensure uniform confirmation of welders' competences.
• OPCo-02 - "Description of the certification process of welders", which presents the requirements for welders and the rules for confirming the competence of welders.

These documents enable the qualification of welders in accordance with the requirements of the PN-EN ISO 9606 standard series.

In order to improve and facilitate access to certification of welders at TDT, work has been undertaken to prepare "on-line" access to the certification program, without the need to contact the TDT office in person at the application stage. The interested person or company, based on a remotely submitted application for the welder's qualification, will receive full information on the date, place of the exam, information about the examiner, number and type of examination joints necessary to prepare for the exam, the laboratory in which specific destructive (DT) and non-destructive (NDT) tests will be performe and the cost of the certification process.

The IT program concerns the certification of steel welders, welders of aluminum and its alloys, welders of copper and its alloys, and welders of nickel and its alloys.

As part of the preparatory work, all possible cases and procedures allowed by the standards of the PN-EN ISO 9606 series were completed, taking into account those principal variables that affect the number of test joints as well as the type of tests and the number of samples in destructive (DT) and non-destructive (NDT) tests necessary for evaluation of the exam result. All types of joints stipulated by the above-mentioned standards are considered, including branch pipes with an angle less than 60°.

The online application requires the presentation of the following principal variables: product type, welding process, weld type, joint type, base material thickness, pipe diameter (if applicable), pipe branch angle, welding position.

Other essential variables of the welding process, as they do not affect the number of test joints and the type of laboratory tests, are included in the scope description qualifications in the certificate issued to the welder. Welding technologies that go beyond the standard requirements are admitted to the examination on the basis of individual arrangements between the applicant party and the examining body, during which the number and type of examination joints as well as the types of laboratory tests performed will be determined.

After compiling all the examination requirements resulting from the PN-EN ISO 9606 series of standards, in each case several dozen examination procedures were obtained for each standard. Examples of fragments of the obtained summaries are presented in Table 1. Such a large number of examination procedures resulted from taking into account all, from a formal point of view, the possibilities resulting from the standard provisions. It does not mean that all test procedures presented equivalent in terms of content tests enabling reliable assessment of the test piece. It is hardly equivalent to testing the circumferential tube joint by radiographic (RT) or (UT) and axial tensile (ROZC) methods. For these reasons, these procedures were analyzed in terms of a full evaluation of the tests performed. As a result of the analysis, a significant reduction in the number of laboratory procedures was made, and where it was possible and justified, procedures including volumetric tests were preferred.

Table 1 Example from the specification of the requirements of the PN-EN ISO 9606-1 standard concerning laboratory tests for steel

L.p.	Procedure	Welding process according with OPCo-02	Standard of the product	Test piece description	Welding position	Number of joints pcs.	Type of laboratory tests	Number of tested samples pcs.
Plates, Butt welds								
1	**Procedure 1 P, BW VT, RT** acc. to fig. 3 PN-EN ISO 0606-1	**111, 114, 121, 125, 141, 142, 143, 145, 15.**	Standard of the product	No restrictions on the thickness of the base material	Acc. to PN-EN ISO 6947 or acc. to WPS/ pWPS	1	VT 100 %	1
							RT 100 %	1
Plates, Butt welds								
8	**Procedure 8 P, BW VT, RT, BEND.** acc. to fig. 3 PN-EN ISO 0606-1	**131, 135,136, 138, 311.**	as above	Thickness of the base mat. t < 12 mm	Acc. to PN-EN ISO 6947 or acc. to WPS/ pWPS	1	VT 100 %	1
							RT 100 %	1
							BEND.	2
							BEND.	2
Plates, Fillet welds								
9	**Procedura 9 P, FW VT, BREAK.** acc. to fig. 4 PN-EN ISO 0606-1	**111, 114, 121, 125, 131, 135, 136, 138, 141, 142, 143, 145, 15, 311.**	as above	No restrictions on the thickness of the base material	Acc. to PN-EN ISO 6947 or acc. to WPS/ pWPS	1	VT 100 %	1
							BREAK 100%	1
FW/BW Weld ACC. TO attachment C PN-EN ISO 9606-1								
13	**Procedure 13 P, FW/BW VT, RT MAKRO** Acc. To attachment C fig. C.1 PN-EN ISO 9606-1	**131, 135,136, 138, 311**	as above	thickness of the base material t ≥ 10 mm	Acc. to PN-EN ISO 6947 or acc. to WPS/ pWPS	1	VT 100 % (FW) – inspection	1
							VT 100 % (BW)	1
							RT 100 %	1
							MAKRO	2
							VT before MAKRO	1
Pipes, Butt welds								
15	**Procedure 15 T, BW VT, RT**	**111, 114, 121, 125, 141, 142,**	as above	No restrictions on the thickness	Acc. to PN-EN ISO 6947 or acc. to	1	VT 100 %	1
							RT 100 %	1

	acc. to fig. 5 PN-EN ISO 0606-1	**143, 145, 15.**		of the base material D ≥ 47,78 mm	WPS/ pWPS			
16	**Procedure 16 T, BW VT, RT** acc. to fig. 5 PN-EN ISO 0606-1	**111, 114, 121, 125, 141, 142, 143, 145, 15.**	as above	No restrictions on the thickness of the base material $25 < D < 47{,}78$ mm	Acc. to PN-EN ISO 6947 or acc. to WPS/ pWPS	2	VT 100 % RT 100 %	2 2
20	**Procedura 20 T, BW VT, BREAK** acc. to fig. 5 PN-EN ISO 9606-1	**111, 114, 121, 125, 141, 142, 143, 145, 15.**	as above	No restrictions on the thickness of the base material D ≤ 25 mm	Acc. to PN-EN ISO 6947 or acc. to WPS/ pWPS	3	VT 100 % BREAK.	3 12

In total, for the individual issues of the PN-EN ISO 9606 standard concerning various basic materials, a significant reduction in the number of test procedures was achieved.
The results are presented in Table 2.

Table 2 Summary of examination procedures

No.	Requirements according to the standard	Number of test procedures pcs.	
		primary	after reduction
1	PN-EN ISO 9606-1 Part 1: Steels	64	43
2	PN-EN ISO 9606-2 Part 2: Aluminum and aluminum alloys	46	22
3	PN-EN ISO 9606-3 Part 3: Copper and copper alloys.	46	31
4	PN-EN ISO 9606-4 Part 4: Nickel and nickel alloys.	66	19

6 Conclusions

As mentioned earlier, the certification of welders based on the PN-EN ISO 9606 series of standards does not take into account the welding requirements contained in the product standards, which can often quite significantly extend the requirements of the welder's basic qualifications. As already mentioned, the standard requirements for the production of rail vehicles (PN-EN 15085-4 point 4.1.5) impose the obligation to conduct additional training of welders during production at the manufacturer. Successful conduct of such training may only

apply to a few, large and well-organized production plants. In smaller manufacture, employing fewer welding staff, such training may be practically impossible to do on one's own. Therefore, it seems advisable and necessary to undertake activities enabling obtaining additional, extended welding qualifications in accordance with a specific product standard. Such authorizations for the production of rail vehicles could be granted by units (Manufacturing Certification Bodies MCBs) certifying rail vehicle manufacturers after having completed a specially profiled training course for welders completed with an exam.
Therefore, TDT sees the advisability of carrying out a two-stage certification of welders:

1. Basic qualifications, in accordance with the PN-EN ISO 9606 series of standards, enabling the performance of welding works for production that does not require training in accordance with the requirements of the product standards and allowing the application for qualifications in accordance with a specific product standard.
2. Extended authorizations, in accordance with PN-EN ISO 9606 + PN-EN 15085 or other requirements.
Certification in accordance with the PN-EN ISO 9606 series of standards would be treated as a basic entitlement, the possession of which would allow applying for the extension of entitlements in accordance with the requirements of specific product standards. The specificity of the various welding requirements is confirmed in such products and facilities as: rail vehicles, boilers, tanks and various types of cisterns, pipelines, cryogenic installations, LNG storage tanks, wind towers and floating objects, etc. They are characterized by distinctly different hazards, such as: cyclical variable loads - fatigue strength, use in low or high temperature conditions, use in high pressure conditions, use in a hazardous or corrosive aggressive environment, etc. and therefore require an individual approach in terms of not only inspection and supervision, but also direct performance welding work.

7 Bibliography

[1] Maciej Grzywna, Mateusz Kędziak „Development of electrical structures for units tractive ” National Scientific and Technical Conference – Transport Kolejowy 2017 Past-Present-Future.

[2] Japan Transport Safety Board Report no. RI20219-1-I „Railway serious incident Investigation report” - Wehicle damage of West Japan Railway Company In the premises of Nagoya station, Tokaido Shinkansen.

8 Standards and Recommendations

[3] PN-EN 15085-1: Railway applications - Welding of railway vehicles and components – Part 1: General.

[4] PN-EN 15085-2: Railway applications - Welding of railway vehicles and components – Part2: Requirements for welding manufacturer.

[5] PN-EN 15085-3: Railway applications - Welding of railway vehicles and components – Part 3: Design requirements.

[6] PN-EN 15085-4: Railway applications - Welding of railway vehicles and Components – Part 4: Production Requirements.

[7] PN-EN 15085-5: Railway applications - Welding of railway vehicles and components – Part 5: Inspection, testing and documentation.

[8] prEN 15085-6: Railway applications - Welding of rail vehicles and components - Part 6: Maintenance welding requirements.
[9] ECWRV 20170-II-28 Part 2 „Guidelines of the European Committee for Welding railway vehicles ". Technical interpretation of EN 15085 standard.
[10] PN-EN ISO 9606-1: Qualification examination of welders. Fusion Welding. Part 1: Steels.
[11] PN-EN ISO 9606-2: Qualification examination of welders. Fusion Welding. Part 2: Aluminum and aluminum alloys.
[12] PN-EN ISO 9606-3: Qualification examination of welders. Fusion Welding. Part 3: Copper and copper alloys.
[13] PN-EN ISO 9606-4: Qualification examination of welders. Fusion Welding. Part 4: Nickel and nickel alloys.

SLV HALLE

JOIN TRANS 2022: 6TH EUROPEAN CONFERENCE „JOINING AND CONSTRUCTION OF RAILWAY VEHICLES"

MAY 11TH – 12TH 2022, WARSAW POLAND

Dr. Tobias Loose, Dr. Loose GmbH, Walzbachtal, Germany

Distortion management in railway vehicle construction

Distortion management in railway vehicle construction

Dr.-Ing. Tobias Loose, Walzbachtal, Germany

1 Introduction

The avoidance of shape deviations and material changes due to welding is an interesting and challenging issue, which often leads to difficulties to solve in practice. With welding simulation it is possible to calculate welding distortion, residual stresses and microstructural changes in advance. Welding assembly often takes place in several stages. For multi-stage weld assemblies, the deformations from previous sub-assemblies must also be taken into account in the simulation. This extends the welding simulation to a manufacturing simulation. The FabWeld software was developed by Dr. Loose GmbH to calculate the multi-stage assembly. Figure 1 shows the three-stage assembly using the example of a frame structure made of aluminum profiles.

In welded constructions, several questions arise that can be answered by simulation. Distortion management is about adjusting the welding distortion so that the geometry of the finished structure is within required tolerances. Simulation allows the analysis and design of manufacturing at an early stage of the design planning of components and assemblies. This makes it possible to identify manufacturing challenges at an early stage and to plan and implement necessary improvement measures in good time.

The goal is to save resources, especially raw materials, personnel, time and thus costs. This can be achieved through simulation, as production can start without errors, without loss of time or run-in loops.

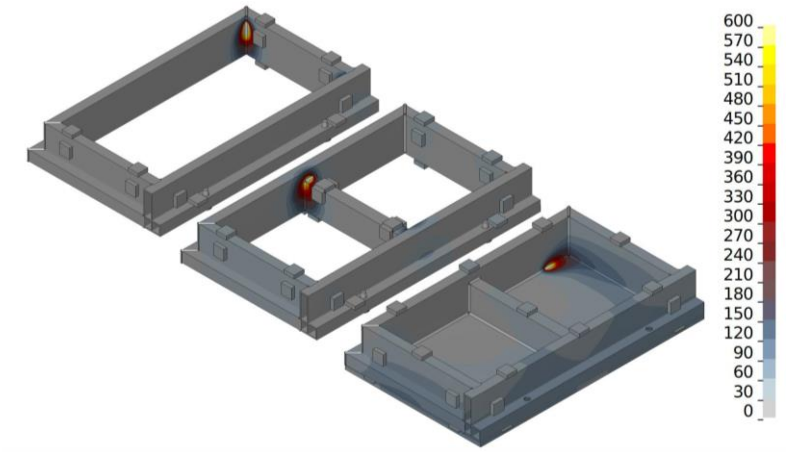

Figure 1: Multi stage assembly of welded frame structure made from Aluminium Alloys

2 Validation of weld structure simulation

The weld structure simulation as a special application of the finite element method considers the effects from welding on the entire component. The input variable is the heat input from the welding heat source. This is applied in the form of a so-called equivalent heat source. This means that any fusion welding process can be modeled, regardless of how the fusion heat is generated. Of course, all boundary conditions must be taken into account in the model. This includes the clamping device, heat dissipation through clamping or cooling jaws and tacking.
Results from the weld structure simulation include the geometry change due to welding, weld distortion, residual stresses and plastic strains, and if the microstructure transformation calculation is included, the microstructure state after welding and the resulting changing yield strength.

Goldak Technologies Inc, Dr. Loose GmbH and TIME - Technology Institute for Metal & Engineering have demonstrated the predictive accuracy of weld structure simulation in a joint research project. For this purpose, an orthotropic plate 1200 mm x 600 mm was chosen, onto which two longitudinal stiffeners and 3 transverse stiffeners were welded. (fig. 2) The stiffeners are fixed with a total of 17 tack welds. The slab is supported in a statically determinate manner and supported at three corners. The fourth corner remains free. This is the corner where the greatest distortion occurs during welding. The corner opposite the free corner on the long side is chamfered so that the corners of the plate can be clearly assigned. While the tack welds are being welded, the plate is supported at the center transverse stiffener on each outer side with a punch. Without support, the plate deflects under its own weight to such an extent that an excessive gap is created between the plate and the stiffener. After tack welding, the support is removed. This leads to a lowering of the plate at the unsupported corner. In the simulation, the removal of the support is mapped realistically.

Figure 2: Validation test TIME plate

Then the longitudinal seams are first welded on the outside as a two-layer seam with 3 weld beads. All other 17 seams are executed as single-layer fillet welds. During welding, the movements normal to the plate are measured at five points with cable tension transducers. At the same locations, the vertical distortion is evaluated from the simulation. Fig. 3 shows an example of the result of the validation test on displacement transducer 4. The graph compares the vertical deformations measured with cable wire transducers with the calculated vertical deformations. It can be seen on the graph that the deformation jump caused by removing the center bearings after tack welding is accurately represented by the simulation. The vertical distortion during the entire welding process is also calculated correctly. This proves that the applied calculation method of the weld structure simulation is able to accurately reproduce the deformation behavior during the entire welding process. This finding is new, since previously only final results, i.e. the condition after welding and cooling, were used for validation. In order to fully use weld structure simulation to analyze welding, the simulation results must also be accurate throughout the process. For example, this comes into play when the gap formations during welding are to be investigated in order to check the clamping or tacking concept.

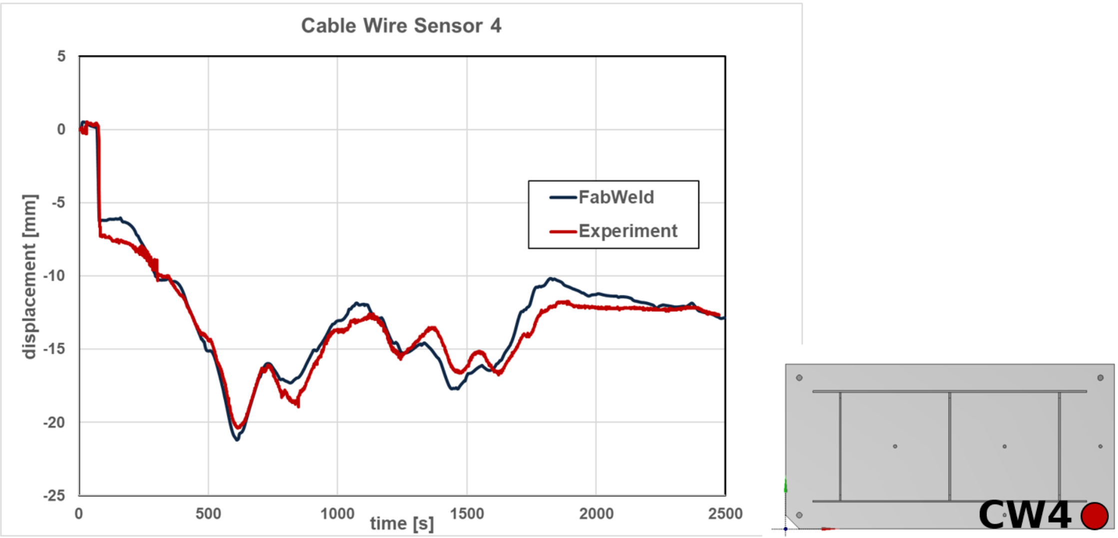

Figure 3: Validation result. Calculated deformation vs. measured deformation

3 Simulation of the weld assembly

In order to obtain accurate results when simulating the welded assembly, the clamping process with the resulting distortions must be mapped correctly. If individual components or subassemblies already deviate from the nominal geometry, clamping distortion occurs when they are clamped in the fixture. Welding generates the thermal distortion. When the clamping forces are released during unclamping, unclamping distortion occurs, which represents springback. All distortion components together result in the final distortion. The clamping process must be mapped realistically in the simulation in order to achieve exact calculation results.

The simulation of the assembly requires a multi-stage simulation. In the simulation, as in reality, components or subassemblies are added, clamped and welded from manufacturing station to manufacturing station.

Fig. 4 and Fig. 5 show a bottom structure in the 2nd manufacturing stage, where the subassemblies cross member and bottom plate are added. Both pictures show the longitudinal distortion in the X-direction. Fig. 4 represents the situation before insertion and clamping of the cross members. The bottom plate shows deformations in the X-direction. During clamping, the cross members are pressed onto the bottom plate and deformed in the process due to the imperfection of the bottom plate. During welding, this deformation component is frozen (Fig. 5).

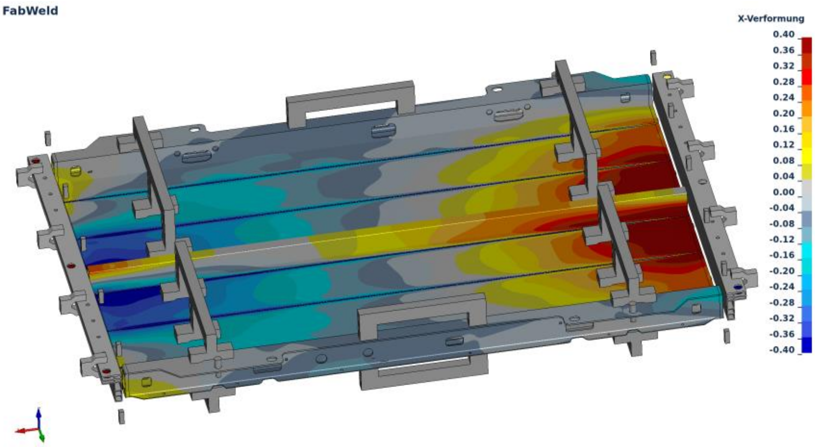

Figure 4: Longitudinal distortion of floor assembly structure before clamping of the cross members

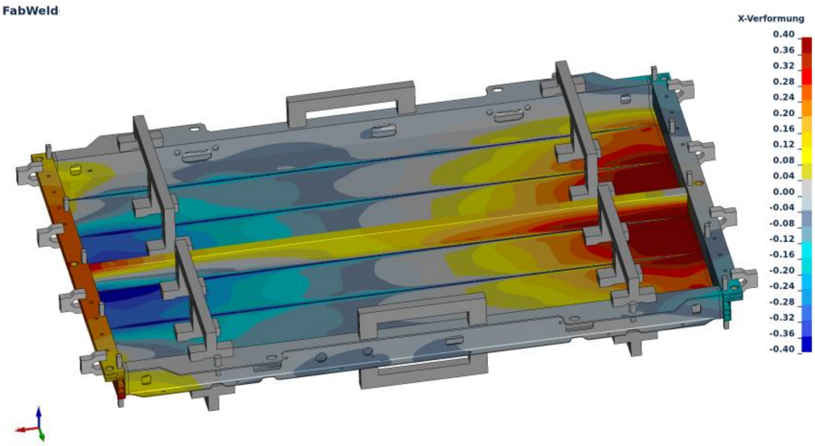

Figure 5: Longitudinal distortion of floor assembly structure after clamping of the cross members

Since distortion-free welding is not possible for many welding tasks, suitable measures must be taken to ensure that the geometry complies with the required tolerances after welding. In addition to the design of the clamping device or the tacking concept, suitable measures include compensation measures:

- Addition to welding shrinkage
- angular allowance
- Pre-oval of circular cross sections
- Pre-stamping of inverse welding distortion
- Geometry adjustment on the component to counteract welding distortion
- Stiffness modification on the single component counteracting the welding distortion

Just as the distortion during weld assembly can be calculated in advance, the compensation measures can also be entered into this calculation. This makes it possible to numerically validate the compensation measures. This is the case if the calculated welding distortion, taking into account the compensation measure, is within the permissible mold deviation tolerance.

4 Simulation-supported distortion optimization using the example of a floor assembly

A floor assembly is manufactured from extruded aluminum profiles. An MSG cold wire process is used. Assembly takes place at three stations with one substation:
Station 1: Assembly of the base plate
Substation 1.1: Subassembly of bushings to outer cross members
Station 2: Assembly of base plate with outer cross members
Station 3: Assembly of inner cross members
For this battery beam, the distortion that occurs during the welding assembly is calculated. As described above, the deformations from the previous welding station are taken into account in this simulation. Figure 6 shows the battery beam during welding station 3.

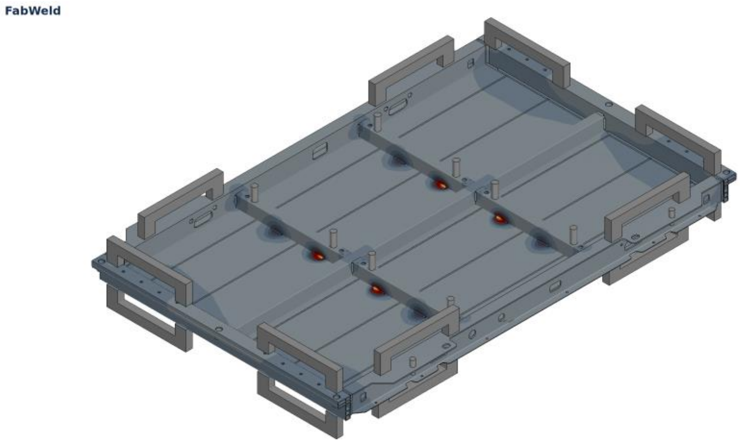

Figure 6: Floor assembly carrier, welding of the third and final station

For the center section, there are the design variants shown in Fig. 7. Variant 1 represents the original design. The center section is designed with the bottom section as an extruded section. This profile is welded to the other profiles in station 1 to form the base plate. Variant 2 represents the optimized construction. The profile is divided into a floor profile and a longitudinal member profile. The bottom profile is installed in station 1, while the longitudinal member profile is not added until the third and final station.

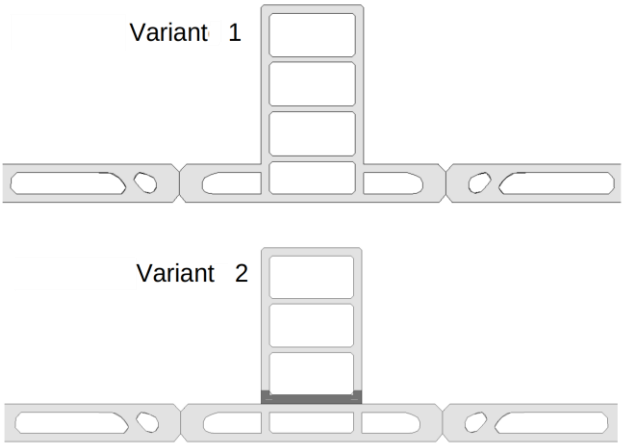

Figure 7: Versions of the center section. Variant 1 as a single profile and variant 2 as a split profile.

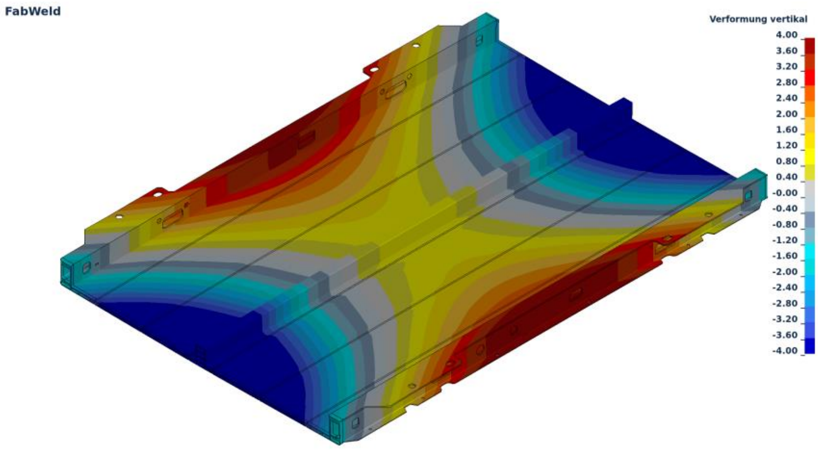

Figure 8: Vertical distortion variant 1 after station 1

From the multi-stage assembly simulation, the station where the greatest distortion occurs can first be determined. In our example, this is station 1 with the welding of the floor profiles. Fig. 8 shows the vertical deformation of variant 1 after unclamping and intermediate cooling shortly before clamping in station 2. The station at which the greatest deformation occurs is also the station at which the compensation measures are most effective. The distortion that occurs with the warping of the plate is explained by the eccentricity between the center section gravity line and the longitudinal welds. The improvement of variant 2 is based on the fact that the longitudinal welds are now arranged symmetrically to the center line of gravity. Fig. 9 shows the vertical distortion of variant 2 after station 1. A clear distortion minimization can be seen. The improvement in station 1 has a direct effect on the total distortion. Fig. 10 shows the vertical deformation after complete cooling for variant 1 with unsplit center section and Fig. 11 for variant 2 with split center section.

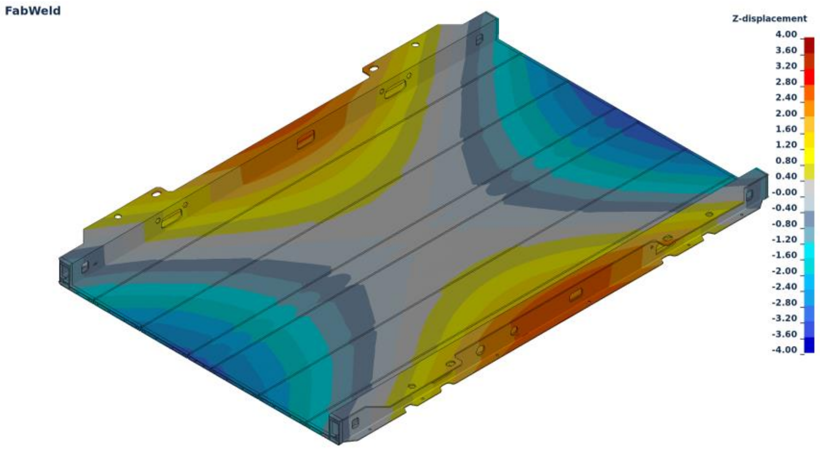

Figure 9: Vertical distortion variant 2 after station 1

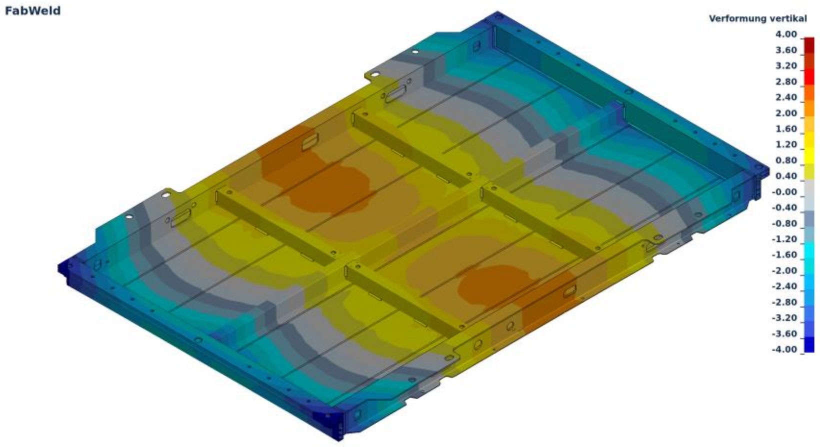

Figure 10: Variant 1, final vertical deformation

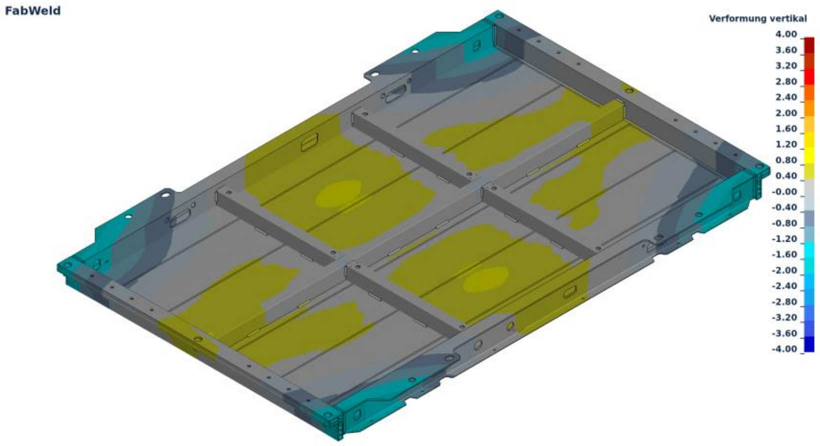

Figure 11: Optimization of variant 2, final vertical deformation

This example clearly shows how profitably assembly simulation can be used in the design phase. If the welding distortion is determined precisely at this early stage, it is possible to minimize the welding distortion efficiently with geometry changes that do not require much effort.

5 Critical assembly points and gap analysis

Critical points can be analyzed from the assembly simulation. By calculating the welding distortions, it can be determined in advance whether the insertion of further components is possible or whether fit conflicts will occur. Fig. 12 shows such a fit conflict. The cross member has the length of the CAD nominal geometry. Due to the welding of the frame from the previous production stage, the side profiles have warped inward to such an extent that it is not possible to insert the cross member. Here, the simulation shows in advance that measures must be taken to enable trouble-free insertion.

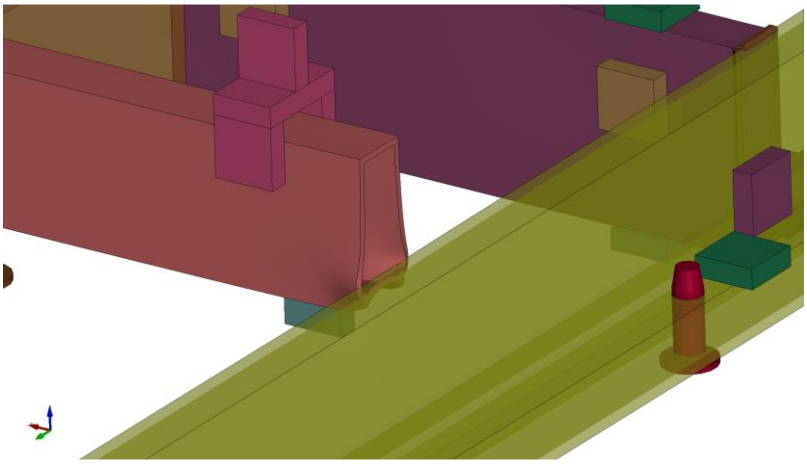

Fig. 12 Fit conflict when inserting a cross member.

The assembly simulation can be used to analyze whether critical gaps occur during production. When the bottom profiles of the battery carrier example are welded together, a gap occurs toward the end between the center profile and the adjacent profile. The gap forms in both the vertical and lateral directions (Fig. 13). The vertical gap can be significantly reduced by optimizing the clamp position.

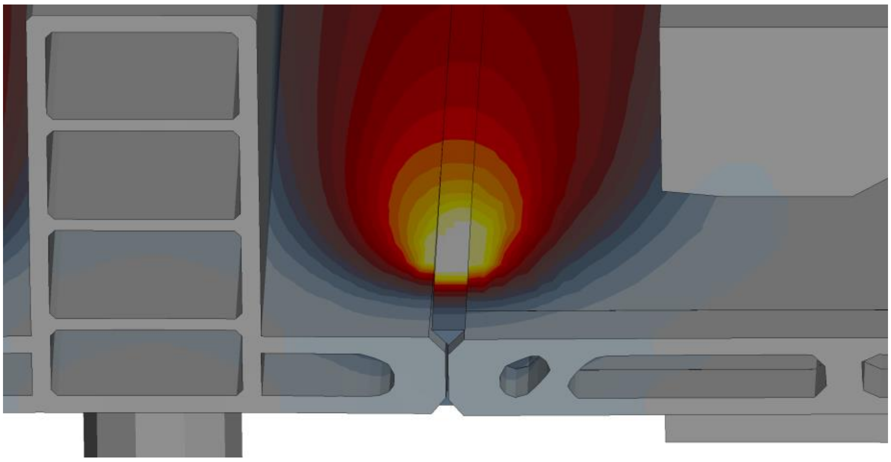

Fig. 13: Gap formation during welding of the assembly

6 Summary

With numerical analysis, it is possible to precisely calculate the deformation during multi-stage assembly of welded structures. The assembly station at which the greatest distortion occurs can thus be determined in advance. This enables the targeted planning design and numerical verification of compensation measures. Furthermore, assembly problems such as gap formation or installation constraints can be identified and eliminated in advance.

Thus, the welding production can be optimally designed in advance, even with multi-stage assembly supported by numerical simulation. This significantly saves costs in terms of time, material, energy and personnel.

JOIN TRANS 2022: 6TH EUROPEAN CONFERENCE „JOINING AND CONSTRUCTION OF RAILWAY VEHICLES“

MAY 11TH – 12TH 2022, WARSAW POLAND

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Experience in the implementation of robotic welding stations in the production of rail vehicle parts

Experiences in the implementation of robotic welding stations in the production of rail vehicle parts.

MSc. Ryszard Ochyra (EWE), Axtone S.A., Kańczuga, Poland

1. Introduction.

The welding process is a special process in which the quality of the product is determined by the use of proven materials, repeatability of process parameters and the involvement of qualified personnel.

The product must also meet the market price criterion. This means that the manufacturer must also strive to reduce manufacturing costs.

The above-mentioned characteristics of the special process also indicate the directions on which we can strive to optimize production costs and product quality.

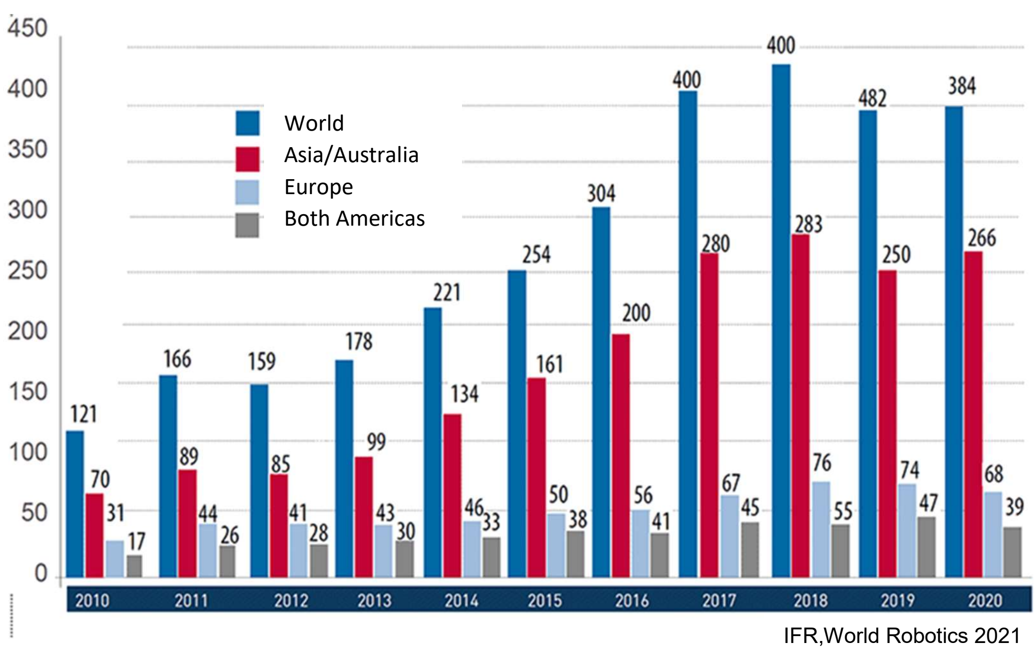
The manufacturer has a limited influence on material costs. The availability of qualified personnel is limited with increasing wage pressure. The repeatability of parameters can be ensured by automatic process control.

Robotization seems to be the ideal solution.

Technical and organizational factors that should be taken into account when implementing a robotic welding station - are the subject of this study.

2. Elaboration

2.1. The state of the industrial robots market in the world.



IFR,World Robotics 2021

Fig. 1. Number of new industrial robots installed in the world (thousand) (IV) IFR,

Asia remains the world's largest market for industrial robots. 71% of all newly deployed robots in 2020 have been installed on this continent (2019: 67%).

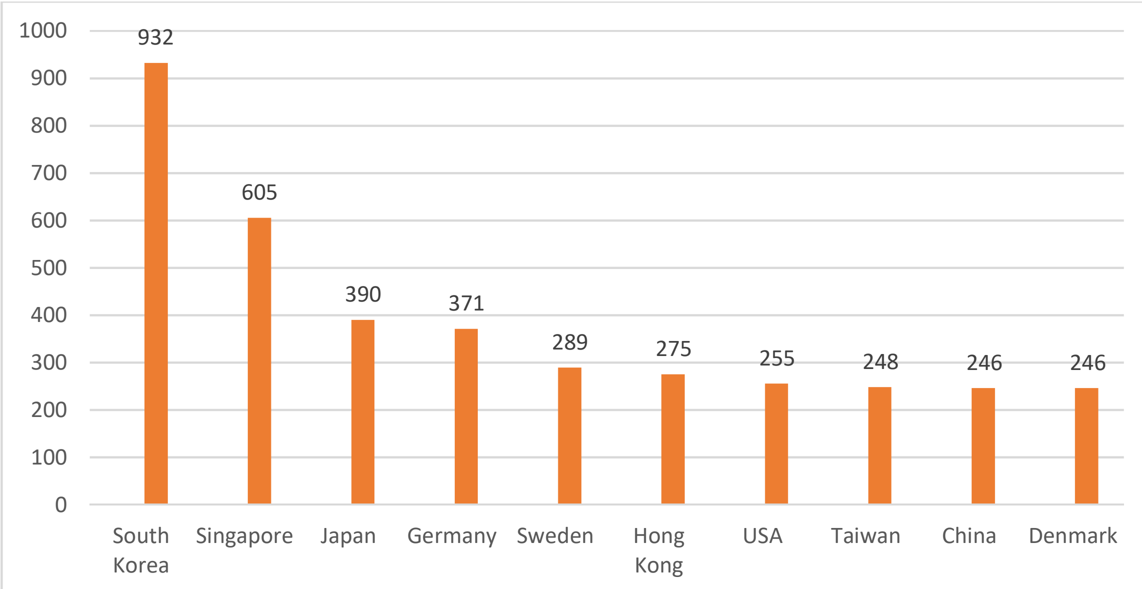


Fig. 2. Robotization density - the number of robots per 10.000 workers employed in the processing industry (IV), IFR World Robotics 2021

2.2. Robotization in Poland compared to Central and Eastern Europe

In 2019, the Polish industry was promoted to the top 15 countries with the largest number of new industrial robots for the first time in history. Unfortunately, this result could not be repeated in 2020. (IV)

In Poland, the automotive industry is the most robotized, with 165 industrial robots per 10,000 employees. (I)

Table 1. Robotization density in CEE countries, 2017. (II)

Country	Increase in the number of robots installed (%)	Robotization density the number of robots per 10.000 workers employed in the processing industry
Poland	16	36
The Czech Republic	47	119
Hungary	24	151
Slovakia	-31	78
Russia	99	-

When comparing Poland to other countries in terms of the level of industrial robotization, it is worth starting by comparing the average hourly wages for work. (IV).

2.3. The impact of robotization on welding operations.

Each welding operation consists of two steps.

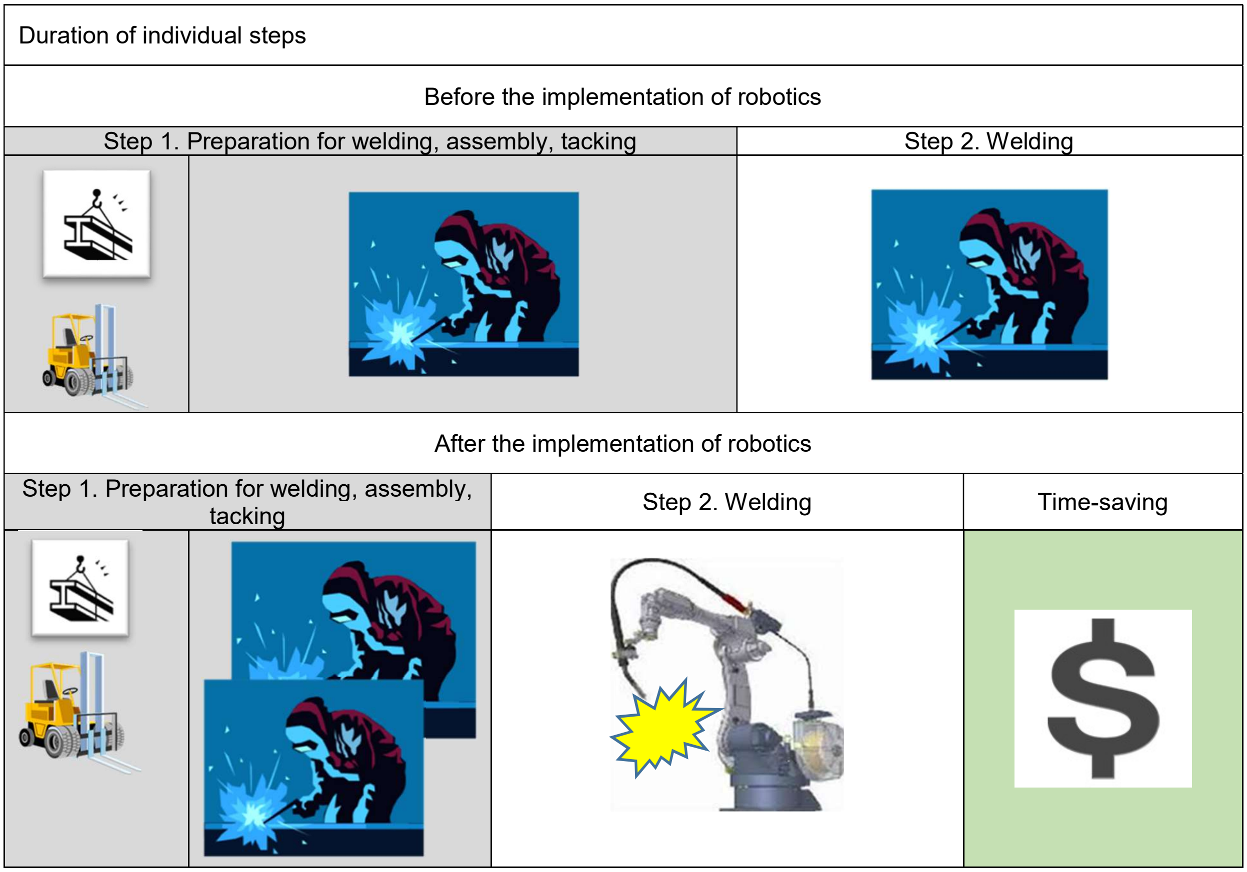


Fig. 3. The impact of robotization on welding operations.

2.4. The effects of robotization in the welding process

- Increase in productivity - reduction of cycle times,
- Declining demand for manual work,
- Increased occupational health and safety, improved ergonomics,
- Increase in repeatability,
- Increase in quality.

2.5. What technical and organizational factors should be taken into account when implementing robotic welding stations? (I)

2.5.1. Adaptation to the product range.

When selecting the stand, the following should be taken into account: "product mix" and number of products in the batch, the range of dimensions and masses of products, the type and thickness of welded joints, single and multi-pass welds, the need to clean the welds, the need for preheating, the need to control the interpass temperature, the structure's susceptibility to deformation, another.

The range of products and the number of products in the series have a significant influence on the construction of the stand.

2.5.2. Robotic welding station - integrated or "from one source"?

The robotic stations generally consist of: "welding robot", "welding machine", "welding manipulator". All of these components can be sourced from a variety of specialized manufacturers and be put together by integrators.

There is also a producer of complete robotic stations with its own "welding machines", manipulators and "welding robots".

- " Welding machine " - a power source with many functionalities such as synergic programs, pulse welding, crater filling, saving, controlling and recording welding parameters and others.
- "Robot" - a robot controller that controls the movement of the robot arm, welding manipulators and welding parameters.

The basic task of the integrator is to ensure full and efficient communication between the robot controller and the power source controller so that the controller has access to all power source functions. Full communication enables the arm movement trajectory and welding parameters to be continuously adapted to the actual welding conditions. The full use of the power source has a significant impact on the efficiency of robotic welding.

Devices "from one source", from a single manufacturer, are immediately ready for use.

2.5.3. Fast robot or efficient welding machine?

The possible speeds of the robot arm movements are in the order of 10 - 12 m / sec. The speed of movement is limited by the welding speed. In spatial structures or structures requiring segment welding, the arm travel speeds are important.

So the most efficient combination is a high-speed robot and a high-performance welding machine.

2.5.4. "Robot teaching" or off-line programming?

Moving the program from the virtual environment is possible, but requires meticulous step-by-step verification.

With a large number of changes to the product assortment, off-line programming gives a measurable effect - only checking the program remains on the production machine.

2.5.5. The complexity of the position.

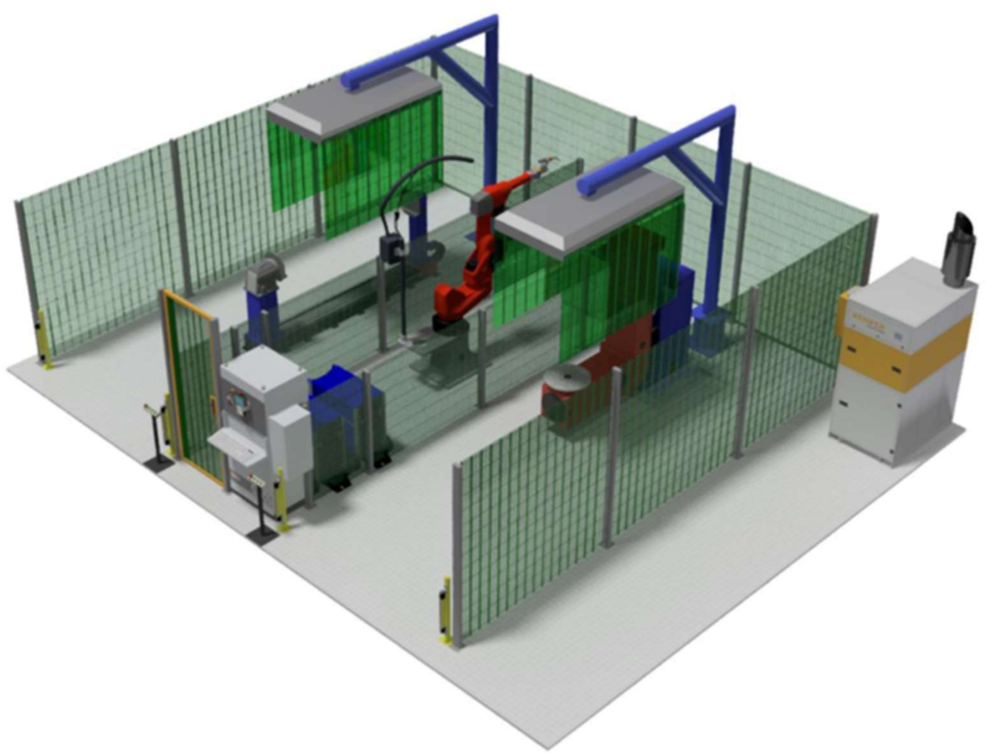


Fig. 4. Complicated robotic welding station (III)

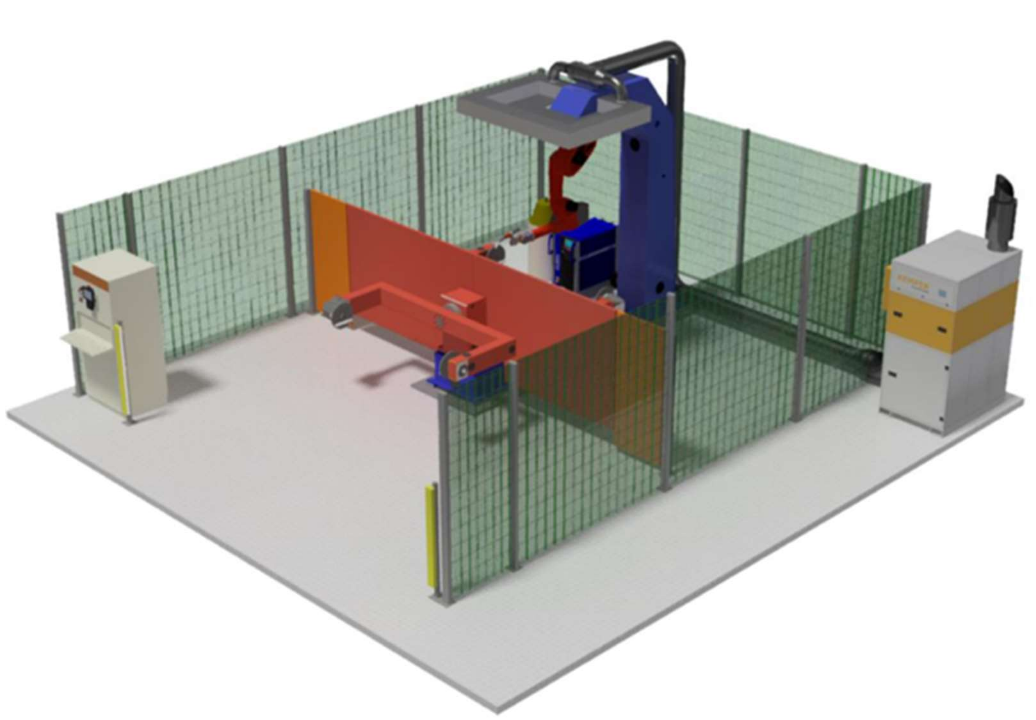


Fig. 5. Simple robotic welding station (III)

2.5.6. What else is important when choosing an offer?

When selecting an offer, the following factors should be taken into account.

- Number of implementations of the position provider in the rail vehicle industry. Reference list. Reference visits. Users' opinions.
- Training of programmers, operators, maintenance staff. Training program tailored to the robotic station. Training base. Skills required for staff defined in advance of the training.
- Support of the tenderer in the implementation of the machine - delivery of technology, instrumentation and software with the machine.
- Support by the tenderer's professional staff in using the machine after implementation.
- Failure response time.
- Spare parts access time.

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JOIN TRANS 2022: 6TH EUROPEAN CONFERENCE
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Gaining Benefits of Laser Beam Welding in Small and Medium Volume Rail Car Projects (Rocky Mountaineer/Skoda FCX)

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1. Introduction

Today – in times of a fully justified common attention to our environmental conscience – our approach and behaviour in our personal mobility and its related CO_2-footprint are becoming more and more important for people of all genders, ages and professions. Our current "private car philosophy" that beneficially supported a common worldwide industrial and wealth raise over the last 100 years since its invention by Carl Benz will very probably not provide a sustainable solution for the upcoming global challenges of mobility – neither with fuel nor with electrical based engines. The worldwide developments towards global travelling and mass transport into, out of and in between mega-cities meanwhile demand new mobility solutions for mass transport. Accompanying with these demands new manufacturing solutions for train-, ship- and aviation-production are necessary to reduce manufacturing costs, increase product features, gain efficiencies and further optimize the ecological balance sheet of new ships, trains and planes.

Though "laser-based-lightweight-design" has been one of the major arguments for laser material processing in sheet metal industry since its availability in the late nineties the biggest amount of laser installations has been motivated by the opportunities of higher welding speed and shorter cycle times for mass production of rather small parts, e.g. pacemakers or razors in medical industry, chip production in semiconductor industry and – certainly widely well known – all kind of parts in automotive industry [1] [2].

Despite all this solutions provided great steps forward in the laser sheet metal manufacturing processes a laser-based approach as alternative solution has been rather fast crossed out while talking about weld assemblies of several metres dimensions and several millimetres of sheet thickness, so called XXL-production. The main arguments for this dismissive decision over the years have been amongst others insufficient part precision, too small process windows and too small volume of parts to refinance the non-recurring costs for machines, fixtures, programming, etc.

The ship- and railcar-building industry made some first steps towards laser applications with laser-hybrid-welding processes to gain also some benefits in welding speed, but the general approach of manufacturing concepts and joint design did not change, which limited the implementation of applications [3] [4]. The aviation industry only – forced and supported by its enormous effects for weight saving on return on investment calculations – has developed and integrated some successful XXL-laser applications, e.g. stringer-skin welds for plane skin elements [5] [6].

Photon AG (Photon) with its daughter companies, employees and partners is successfully developing and supplying laser based produced assemblies since the mid-nineties for nearly all kind of customers – starting from automotive industry via medical and general industry up to railways and aviation industry, but specializes over the last 10 years in XXL-production. This challenge of "Jack's Journey to the Giants" has been motivated and supported by Photon's long lasting experience and unique expertise in industrial laser applications.

Photon's approach with use of up to date technologies narrows or even closes the big gap between on one side the (unfortunately necessary) non-recurring costs at project start (e.g. robot programming, tool design, die production, machine setup, clamping fixtures, ramping up, etc.) and on the other side the normally rather small numbers of parts to be produced in ship- and railcar-manufacturing.

For its customers Photon solves and supplies the complete production chain of chosen parts. Starting with design support, forming simulation of pressed parts, manufacturing of press dies, production of primary parts, subcomponents and stampings and finally the laser beam welding of the complete XXL-assembly. Therefore the final products are now also gaining the commonly known benefits of laser beam welding as e.g. less distortion, higher stiffness, reduced production costs and finally – but maybe most important – a high profitable "photonic-lightweight-design".

Within several projects Photon has successfully proven that due to a sophisticated combination of modern design and manufacturing methods, e.g. as laser suitable design, offline computing, 3D-scanning sensors, process monitoring and semi-automated processing for low volume production the laser beam welding technology has become a very profitable approach also for XXL-assemblies.

Two current examples will be shown and discussed:

1. The laser weld assembly of 25 m long railcar sidewalls for a special train with only ten cars manufactured in total
2. Implementation of laser welding technology for a new tram, enabling light weight design with laser welding technology

2. Rocky Mountaineer
In 2017 Photon won the contract to build sidewalls, front- and back-end segments and roof segments for 10 “Rocky Mountaineer” double deck panorama coaches for Stadler. An innovative concept for manufacturing has been developed and realized.

The task was solved with an intelligent combination of welding technologies (Laser, TIG, MAG). The most difficult challenge was to join 6mm U-profiles onto the 2mm outer surface. This combination restricts the accessibility to the outside of the U-profile. In this case, the laser technology with the specific high energy density was the right tool for the job. A full penetration connection has been achieved and welding distortion has been minimized compared to conventional welding. Photon’s unique XXL-Lasercell enabled the manufacturing of these 25m long sidewalls.

The application in short:
- Part size: 25m x 4m
- Volume: 20 (10 Coaches)
- Joint types: Fillet weld, butt weld
- Material thickness: 2 up to 6mm
- Weld seams: 1250
- Certification level: 15085-2 CL1

Fig. 1: Inner view of the parts manufactured by Photon for the Stadler Rocky Mountaineer (Copyright Photon)

Fig. 2: Rocky Mountaineer, new coach with extra wide windows in the middle (Copyright Rocky Mountaineer)

3. Skoda FCX

In 2019 Photon started a project with Skoda to build side walls for a new tramcar. The project is a remarkable success for Photon, as Skoda created a new lightweight design based on Photon’s manufacturing processes.

For weight saving, a 2mm tailored blank is used in the sidewall. The tailored blank is a combination of S355 steel grade with S500 reinforcements, joined by laser welding. The inner structure is built of various profiles between 2 and 3mm, which are laser welded onto the tailored blank. In many cases, accessibility for welding is only given from one side and most of the connections are designed and calculated with a full connection of the cross section. It is possible to create these joints with laser technology although the skin material is thin. Additionally despite the thin lightweight sheet material, the evenness and thus visual appearance is improved.

Another big challenge was to meet the cost criteria. Over the past years, Photon improved the manufacturing workflow with simplified programming and automated processing to an extent that allows competing with cheaper processes. So the customer is able to use the latest improvements in laser welding technology for weight saving without compromising on the side of costs.

The application in short:

- Part size: up to 9,5m x 2,6m
- Material: Mild steel grades, stainless steel and combinations
- Material thickness: 2 up to 5mm
- Joint types: Butt weld, fillet weld
- Certification level: 15085-2 CL1, ČD V 95/5

Fig. 3: Skoda Tramcar Forcity Smart Pilsen (Copyright Skoda)

4. XXL-Lasercell

For most flexible use of the laser welding technology, Photon developed an automated Laser cell with the outer dimensions 30x9x7m. The laser working space in this cell is 25x4x1m. Application specific welding tables of different sizes are exchangeable through four gates. This allows laser-on time of up to 90% for the welding process in this cell. All non-laser tasks for preparation, quality assurance and handling are undertaken parallel outside on the welding tables. The laser optic is handled by a standard industrial robot, which is installed on a 7th axis to allow access to the complete length of the cell. The robot is equipped with an automatic tool change system, so that different laser optics can be used. The laser light is transmitted from the source to the optics through a flexible glass fiber. This allows (nearly) free positioning of the focal spot over the complete working space. Sensors are used to guide the process along the planned trajectory. Industrially available optics and laser sources have been significantly improved over the last 20 years. Today, 8 or more kW are available at reasonable cost and with current systemtechnologies focus positioning tolerances can be held within the limits even for sensitive industrial applications.

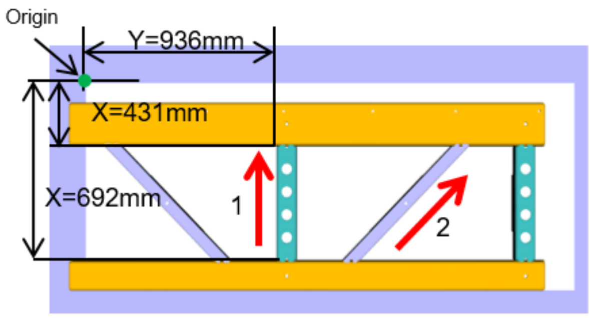
5. Fixtures

The fixture design for the Rocky Mountaineer project requested the Photon designers to do a nearly impossible task: due to the small volume of the project, the budget for the fixture was extremely limited. Still the fixture had to handle parts, which have not been welded before in size and type. In standard approaches the fixture is the key component for successful laser welding projects, as the fixture enables the reproduction of tight tolerances of a few 1/10mm over years in serial production. These non-recurring costs are normally split over large volumes. For the Rocky Mountaineer project, Photon had to develop an alternative solution: a combination of a 2D-XXL-table with clamping elements has been designed and manufactured in-house. The manufacturing concept completes this fixture concept with sensors to compensate the limited accuracy of the part positioning.

6. Programming interface

Robot programs for welding are prepared offline by the programing team and are distributed via a server-based data communication. Machine operators download determined programs from a central data storage and control server unit and start the automated welding process. For the Rocky Mountaineer project 1100 different robot programs have been used. With the standard state-of-the-art offline programming system, the preparation would have consumed more time than available because of the need for manual interaction with the 3D simulation to create the coordinates. To solve this conflict between work amount delivery date and costs, Photon developed an own programming interface. With this new interface, manual offline programming has been eliminated from the task list and timeline. This reduced the time for preparing robot programs significantly.

	Start 1	Stop 1	Start 2	Stop 2
X	692	431	692	431
Y	936	936	1300	1650



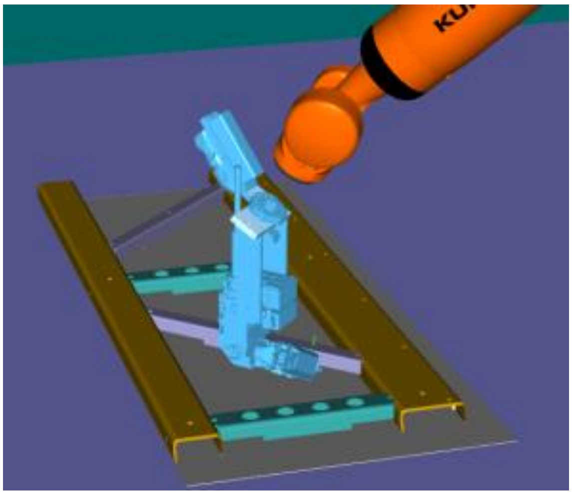


Fig. 4: Schematic illustration of the structure with weld seams 1 and 2, table with the corresponding coordinates for weld start and –stop (left). Visualisation of robot, optic and part from the simulation software. Welding seam 2 (Copyright Photon)

The innovative workflow is as follows:

- Identification of the positions from the CAD model and input of the data into the interface
- Supplying programs for all weld seam via server
- Preparation of the parts for the current weld step (placement on the fixture, tack welding)
- Selection of the robot program for the weld step based on the part number
- Transfer of data from server to robot controller, filter based transformation of the point data into proprietary robot language
- Input of part position and orientation on the fixture
- Transfer of the welding parameters for individual weld seams through the robot controller
- Welding with the robot handled, sensor guided optics
- Monitoring and documentation of the process parameters

7. Sensors

The Photon programming interface allows to create individual weld seams within reasonable time. Deviations between 3D model / drawing and the real parts are under control by sensors. For laser welding, tolerances of a few 1/10mm are necessary. In reality, deviations can be as big as some mm for parts of several meters dimension. Photon uses feedback control systems to bridge the gap automatically. This includes sensors to adjust the weld path before process start and online sensors that adjust the positioning during welding. Additionally, the use of sensors allows using simpler and cheaper fixture designs than usually needed for laser welding. This is the key enabler for small volume serial production.

8. Certification

For weight saving, low distortion and good flatness, the high energy density and resulting small weld seams of the laser welding process are useful. Photon's laser welding specialists have established weld geometries for cross sections, which are impossible for arc welding processes. In case of the Rocky Mountaineer, the 2mm thin outside is joined to 6mm U-profiles (see Fig. 4) with a full penetration weld. The weld is done single sided from the outsides of the U-channel. The Skoda FCX project offered similar challenges, a typical connection is a T-joint with a 3mm profile on 2mm sheet, with a full connection welded with single side access. With standard laser welding technology the power that is necessary to create full connection would burn through the thin sheet material, which would be not acceptable. Photon's welding department developed a combination of beam forming and guiding sensor to allow welding these extreme sheet thickness proportions as required by the customer. Over 90 samples where welded to qualify the new integrated optic and software system for manufacturing. This large number of tests covered all weld parameters and possible deviations. The welding coordinators can adjust welding parameters within determined ranges at the working desk. The shrinkage of the first real parts confirmed the results from prototypes. The programming interface allows making dimensional changes for final adjustments quick and without interruptions for manufacturing. The given flexibility helps creating dimensional correct parts faster and reduces the time of the project ramp-up phase.

Fig. 6: Photon team in front of a Rocky Mountaineer sidewall (Copyright Photon)

9. Summary

Photons unique technology integration attracts more and more customers to start projects. New designs for weight saving and therefore more economical and ecological operations are enabled by Photons developments of cutting-edge laser welding processes. The time from design to prototype and serial production is significantly shortened by Photon's programming interface. Often most important, costs are competitive with arc- and spot welding. This is possible through the new high level of automation at Photon.

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JOIN TRANS 2022: 6TH EUROPEAN CONFERENCE
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Industrial application of modified GMA tandem pulsed-arc welding - Investigation of specific control parameters to increase productivity and joint quality

Industrial application of modified GMA tandem pulsed-arc welding - Investigation of specific control parameters to increase productivity and joint quality

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Abstract:

With the GMA tandem welding process, the user is increasingly demanding that the leading arc be operated at a considerably higher power than the trailing arc to achieve a higher deposition rate or welding depth and a good seam appearance at the same time. In addition, the joining quality must meet the set requirements and a high productivity must be achieved. To meet these requirements, a new GMA tandem welding process was investigated, in which the leading and trailing wire electrodes operate in a modified pulsed arc mode. Recently, the technological advances made in the further development of GMA single wire welding have been transferred to tandem welding, resulting in a completely new tandem welding system. In this system a new process variant for tandem welding has been investigated and new process functions have been developed. These include a new process controller which allows the user to select widely differing wire feed speeds for both arcs independently of each other, with the system automatically making the necessary corrections. To make this possible, a process has been developed in which the leading arc operates with a double or triple drop release frequency compared to the trailing arc. The results show the influence of these process characteristics, on the welding speed and penetration in fillet and butt welds on a thick-walled mild steel of grade S 355 J2. Furthermore, the metal deposition was visualized by means of high-resolution image camera. The advantages of the new process-specific details are demonstrated by means of practical examples from industry.

1. Introduction and state of the art:

Crucial to tandem welding is that high deposition rates are present at a significantly lower energy density and with a significantly larger melt pool compared to single-wire welding [1]. This affects the maximum reachable welding speed, since the process is less prone to formation of undercut. Also, it is possible to replace multi-layer seams by a single pass therefore to save welding time. Another benefit of the larger weld pool is the higher gap bridging ability allowing for savings in part preparation.

Multi-wire welding was first applied with the introduction of the double – wire submerged arc welding (SAW) process [2, 3, 4]. An improvement concerning welding speeds, deposition rates and hence overall productivity has been detected.
The first system available on the market using shielding gas arc welding was the double-wire process with common electrical potential. The contact tube was connected to the same power source [5].

Some researchers [6, 7] state, that stable multi-wire metal transfer should be staggered to minimize undesirable arc interference effects. Therefore, a welding process with two insulated electrodes (GMA-Tandem) was developed. GMA-Tandem is characterised by using two wire feeding units and two power sources. The wire electrodes have two different potentials and therefore the welding parameters for the two wires can be operated individually. The distance between the electrodes is relatively small, so that the two wires work in a common weld pool. Both arcs have to heat and penetrate into the base metal so as to form a molten pool.

It is mentioned in the literature [8, 9] that undercut and humping are the common defects which limit the maximum welding speed of GMA-Tandem pulsed welding. The undercut and humping are attributed to the irregular flow of molten metal towards the rear of the weld pool. The irregular flow in GMA-Tandem is also related to the distance between the leading and the trailing wire, and the flow becomes regular as the distance appears to be in an appropriate range.

In [10] a comparison and a study of different high power welding processes is carried out. The process window appears to be smaller for GMA-Tandem than for conventional GMA welding. So, the welding equipment carrier and the entire installation must be more accurate than that for single wire welding.

However, with the development of modern microprocessor-controlled inverter power sources and an improved physical understanding of metal transfer characteristics, GMA-Tandem welding is now successfully applied. A synchronisation between the two power sources makes it possible to time-wise control the instants of metal transfer from each of the wire electrodes during pulsed arc welding in such a way that there is less impairment by magnetic arc-blow. Figure 1 shows the schematic representation of GMA-Tandem welding in the pulsed mode with phase shift.

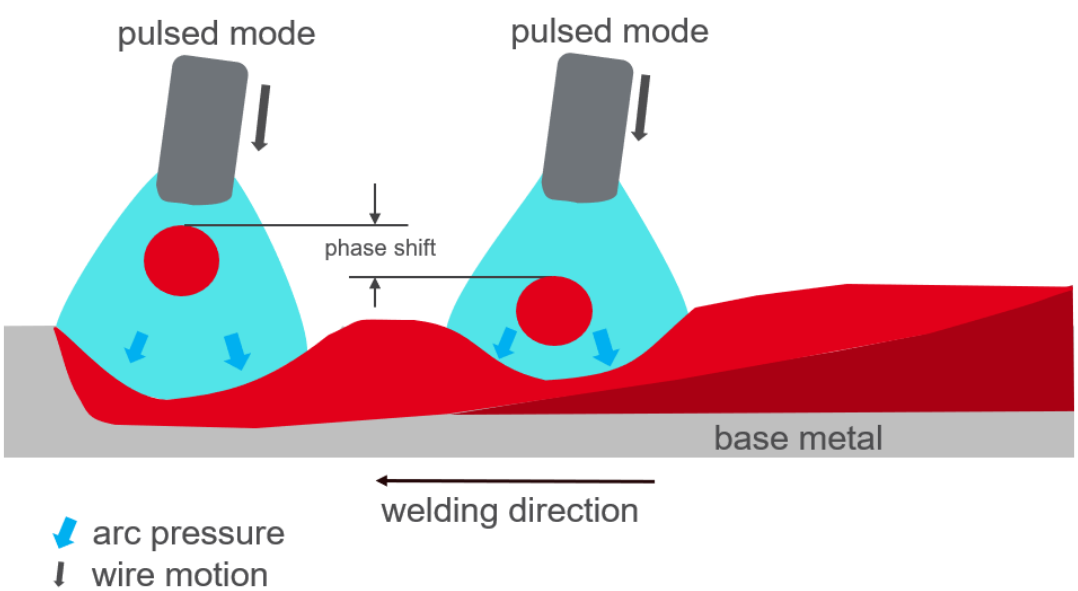


***Figure 1**: Schematic representation GMA-Tandem welding with phase shift*

Given optimal parameter adjustment, the pulsed arc delivers short-circuit-free, low-spatter metal transfer in which one droplet of filler wire per pulse is pinched off into the weld pool. In GMA welding, there is only limited scope for high arc power to transmute into higher welding speeds. The reason is that when the power is increased, the arc pressure rises very rapidly, which makes the weld pool difficult to control [7].

It shows the advantage resulting from separately controlling metal transfers when two wire electrodes are being melted off into one shared weld pool. The length of each arc should be kept short. When the arcs are short, the weld pool remains narrow. It is also reported that a slightly higher power is set for the leading arc. The cold base metal is thus thoroughly melted and exact fusion takes place into the molten pool. The weld-metal deposit from the second electrode fills the weld pool. In addition, the trailing arc prolongs the weld-pool degasification time, reducing the pore-formation sensitivity [7].

The increased productivity and benefits associated with GMA-Tandem are repeatedly mentioned in the literature [10]. There are also some drawbacks in GMA-Tandem. One of which is the complexity of the welding process, due to many parameters to adjust.

In [8] the GMA-Tandem process was studied, amongst others, investigating the electrode spacing. The results show that this has such a strong influence on the welding result that two different process conditions can be discussed:

- The first has a larger weld pool created by larger electrode spacing, approximately 15-20 mm, and is suitable for deep penetration or high productivity welding.
- The second type has a smaller weld pool, created by a smaller electrode spacing (approximately 6-8 mm) and is more suitable for welding with a reduced heat input or for positional welding and will typically provide a more normal GMA penetration.

The proprietary systems referred to as “TIME TWIN”, “CMT (Cold Metal Transfer) TWIN” as well as the new TPS/I TWIN Push all provide tandem processes with two different potentials on each wire. CMT TWIN is an unsynchronized, however, yet stable and highly recommended process combining two different arc characteristics e.g., pulsed/CMT. With the Cold Metal Transfer process, any High-Speed Bus synchronisation is unneeded. This is due to the high droplet transfer frequency of equal or less than 120 Hertz, i.e., droplets per second, leading to the most stable welding conditions. [11, 12] report about a stationary CMT-Twin welding process, in which both arcs are operated in the CMT mode. A closer look was taken at a development referred to as CMT-Twin. Two single CMT systems are combined to achieve a sophisticated joining tandem system. Using the regular CMT-mode for the first layer, both consecutive fill- and cap-passes were carried out under applying pulsed GMA-Tandem welding [12]. Excellent weld quality and process stability can be achieved using this process combination. This equipment can be applied again in manifold ways, e.g., for fusion welding as also for weld overlay [11]. TIME TWIN and its replacement TPS/i TWIN Push are both synchronized push systems that operate mostly in pulse/pulse mode.

2. Industrial setup

The TPS/i TWIN Push welding system, employing the newly available modified pulse GMA-Tandem process variant explained in more detail in the following sections, was used for welding Harvester rims. Figure 2 gives a brief overview of the industrial setup: The TWIN Controller connects both power sources and is responsible for the synchronization of both arcs. It also manages the flow of information and error handling between both process lines and acts as a single point of access for the integration into a robot system via common fieldbus protocols. As the power sources two TPS 600i where used each suppling a welding current of up to 500 A at a duty-cycle of 100 %.

All periphery parts (hose packs, torch, wire feeder) are designed to handle this total amount of 1 kA at 100 % duty-cycle. The compact two-in-one wire feeder can feed achieving a speed of up to 30 m/min on each process line.

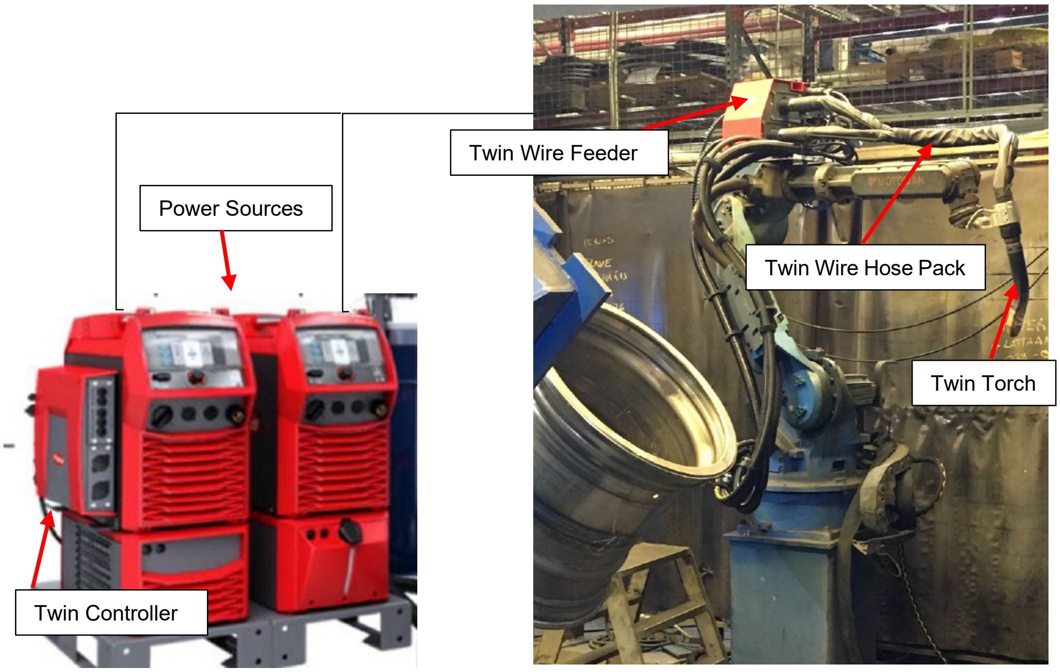


***Figure 2**: Industrial setup of TPS/I TWIN Push for welding Harvester rims [13]*

The inter wire distance is an important factor in successful high-speed or deep penetration welding by maintaining the bulge of the weld pool produced by the leading and trailing wires in a stable condition. In this industrial setup, each wire electrode can be operated by using independent current wave forms.

3. Process development and arc phenomena

Figure 3a shows the process principle in case of $f_L/f_T = 2$ (f_L: droplet detachment frequency leading electrode; f_T: droplet detachment frequency trailing electrode), while Figure 3b is showing the process principle of $f_L/f_T = 3$. The temperature difference between the two areas becomes bigger the higher the ratio of the leading to the trailing current (I_L/I_T) is. The temperature difference causes the variation in the surface tension of the front and the rear part of the weld pool. And this surface tension difference causes the molten metal to flow from the front part to the rear [8]. At high welding currents, the strong arc force gouges the weld pool in the base metal underneath the arc.

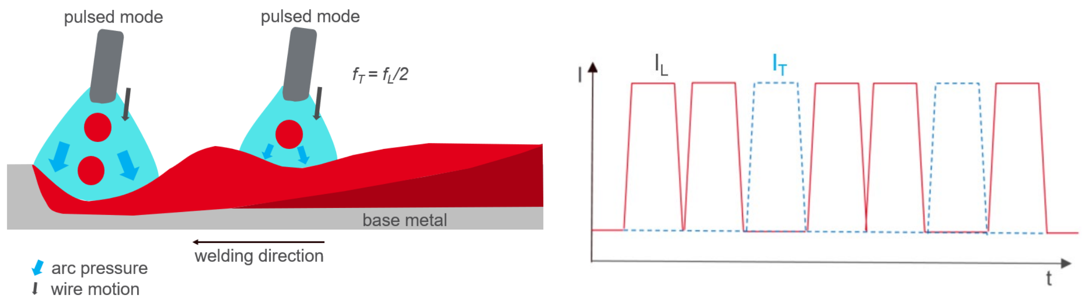


***Figure 3a**: Process principle in case of $f_L/f_T = 2$; left picture: schematic representation, right picture: transient welding current distribution*

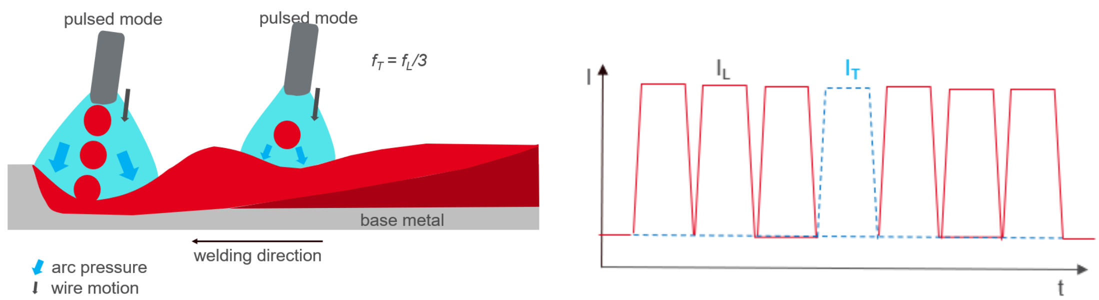


***Figure 3b**: Process principle in case of $f_L/f_T = 3$; left picture: schematic representation, right picture: transient welding current distribution*

Figure 3c illustrates the principle of the "PulseSync" function. In this example the wire feed speed of the leading process line wfs_L is kept constant while gradually reducing the wire feed speed of the trailing arc wfs_T. For small deviations in wire feed speed, corrections on the welding parameters are applied to compensate for the smaller amount of wire to melt. At a certain point the corrections reach their maximum and the pulse frequency of the trail is reduced to $f_T = f_L/2$. In this way the synchronization of both arcs is always maintained. The straightforward strategy to gradually reduce pulse frequency and welding current cannot be applied without losing synchronization. Hence, for small deviations in wire feed speed a stable droplet formation is maintained by applying corrections to some welding parameters while keeping the frequency of the trailing arc constant at $f_T = f_L$. This can only be done up to a specific point where a further reduction of power would lead to imperfect droplet formation. Again, additional corrections are employed and are gradually reduced as the wire feed speed of the trailing arc decreases. Using this strategy, the synchronization of both arcs is entirely maintained by the power sources in all cases by sparing out every second pulse on the trailing arc.

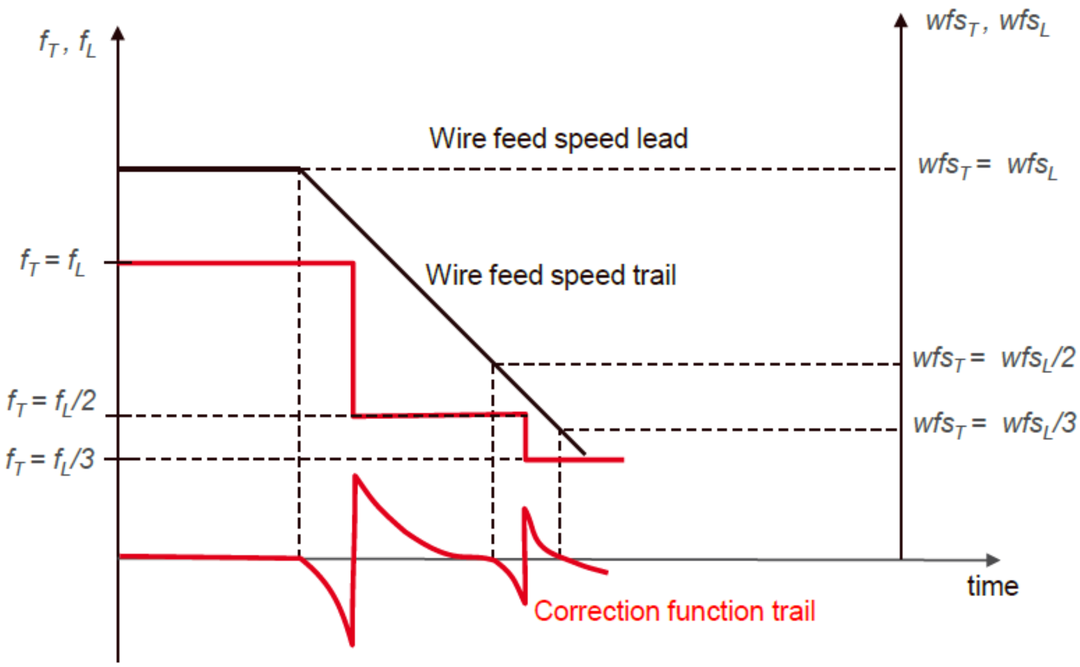


***Figure 3c**: Principle of the PulseSync function*

Influence of interwire distance:
Ueyama [8] showed the effect of interwire distance on the number of arc interruptions. There was no arc interruption in both the leading and trailing arcs when the interwire distance was 5 mm. When the interwire distance was 10 mm, the number of arc interruptions increased, however decreased as the distance was increased to 20 mm.

Influence of arc mode:
Depending on the boundary conditions, the electromagnetic forces produced may dramatically degrade process stability [14, 15].

To study the behaviour of the weld pool, the process respectively the droplet detachment was recorded in our study by a digital high speed video camera. During this investigation, it was observed, that there is less critical influence concerning humping and irregular weld bead flow. The video sequence showed that the leading arc had a frequency of 250 Hz, while the trailing arc operates with 125 Hz. The images in Figure 4 show the metal transfer of leading and trailing wires.

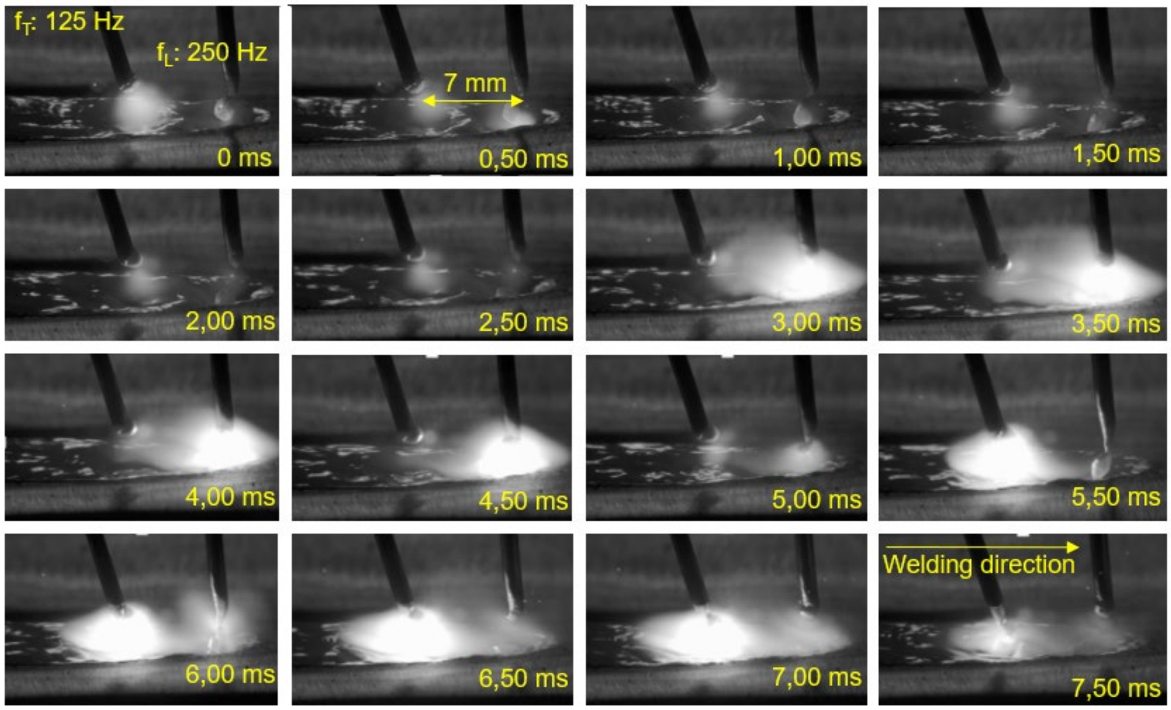


Figure 4*: Metal transfer f_L/f_T = 2 (leading electrode: pulsed arc (PMC); trailing electrode: pulsed arc (PMC); one troplet detachment on the trailing wire electrode und two on the leading one*

4. Welding test and results in the laboratory

For the welding of thick-walled mild steel plate joints using the “Twin Push” process, a series of tests have been conducted varying certain operating conditions, such as for example the material thickness, wire feed spread and the weld speed, to identify the optimal conditions in terms of process stability, penetration, productivity, and reduced distortion.
All welding tests were carried out on mild steel (EN 10025 S355JR) using a 1.2 mm diameter wire of G3Si 1 according to EN 14341-A as filler material. Processes were either pulse/pulse or PMC/PMC (PMC is a variation of the pulsed controlled arc mode) with activated arc length stabilizer (to ensure a constant arc length). T-joint filled welds in welding position PB according to EN ISO 6947 with zero gap and without seam preparation in all cases were welded. Table 1 shows the used setting and Table 2 the welding parameters.

Table 1: Experimental parameter setup

Base material	S355JR
Material thickness	8 mm / 10 mm / 12 mm / 15 mm
Welding position	PB
Joint geometry	T-joint, zero gap
Shielding gas	90%Ar + 10%Co_2
Filler wire	G3Si1
Wire diameter	1.2 mm
Contact tip angle	11,5°
Interwire distance	7 mm
Electrode travel angle	3 ° forehand
Wire feed spread	0,96 - 0,42

Table 2: *Welding parameters*

Throat thickness [mm]	Wfs [m/min]	Current [A]	Voltage [V]	Travel speed [cm/min]	Heat input per unit length [kJ/cm]
3,5	21,0+11,2	378+230	24,1+27,8	250	3,7
4,0	22,5+15,0	394+326	27,3+29,7	200	6,1
4,5	22,0+13,0	414+302	28,6+27,9	160	7,5
5,0	24,0+15,0	430+325	27,8+27,5	125	10,0
6,0	23,0+12,5	430+301	26,8+27,5	90	13,2
7,0	26,2+12,0	409+273	27,6+30,0	78	15,0
8,0	24,6+10,1	451+259	27,6+27,9	60	19,6
8,5	20,0+10,0	369+238	24,9+27,4	45	20,9
9,0	22,5+9,5	429+258	27,0+26,9	40	26,5

Figure 5 represents the results of the direct comparison between pulse/pulse and PMC/PMC. A significant increase of 23 % in welding speed as well as an increase in web plate penetration depth of 36 % was achieved.

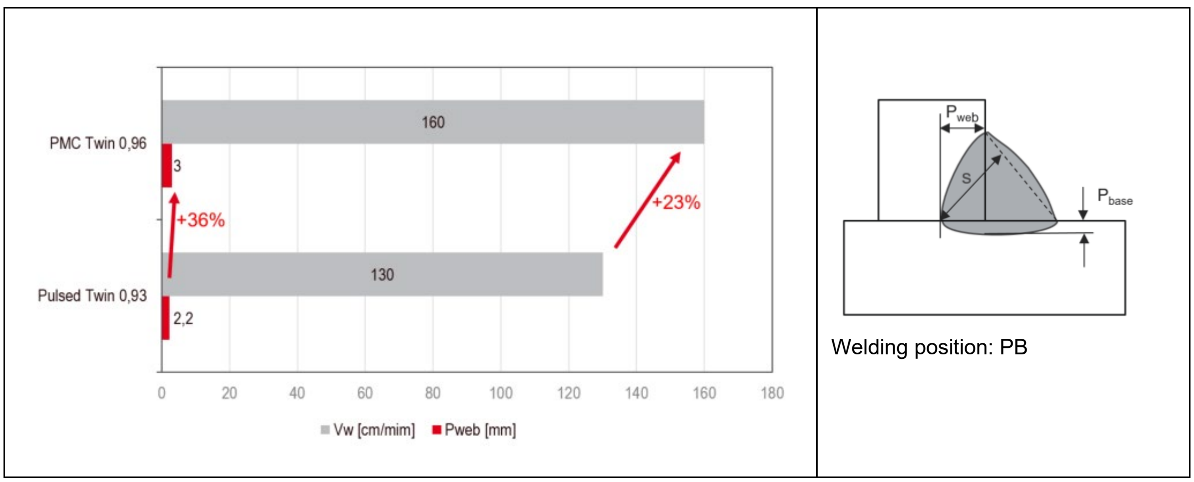


Figure 5: *Comparing the pulsed Twin with the new PMC/PMC Process: Welding speed and penetration depth are raised; s: weld seam thickness, P_{web}: web plate penetration depth, P_{base}: base plate penetration depth; throat thickness: 4 mm*

Further improvements lead to a maximum welding speed at a wire feed speed spreading of $wfs_T/wfs_L = 0.6$ and an electrode travel angle of 8°. As shown in Fig. 6 the welding speed of 180 cm/min could be reached by using the PMC/PMC mode with a wire feed spread of 0.6 and a weld seam thickness of 3 mm. The further increase in welding speed could only be reached by increasing wire feed spread and enlarging the distance between the wires.

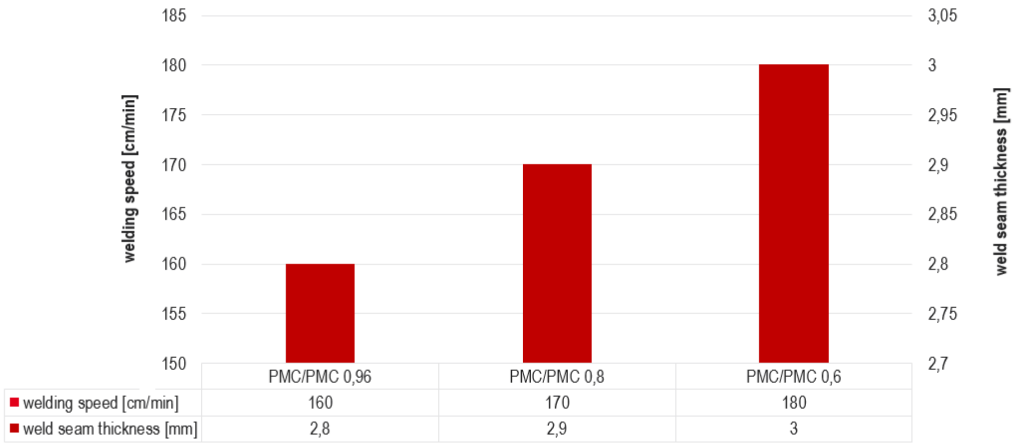


Figure 6: *Further improvements in welding speed were reached by increasing wire feed spreading: Welding position: PB*

Welding tests were carried out to show the maximum reachable welding speed for different throat thicknesses. For a throat thickness between 4 and 9 mm the maximum achievable welding speed ranged between 28 and 42 cm/min. The according energy input increased from 6.1 to 26.5 kJ/cm and deposition rate ranged from 16 to 22 kg/h. To maintain a deep penetration the wire feed speed of the trail was decreased relative to the lead from 65 to 41 %. In this way the weld seam thickness was kept roughly by a factor 1.4 larger than nominal throat thickness (Figure 7). Figure 8 represents the heat input per unit length depending on throat thickness.

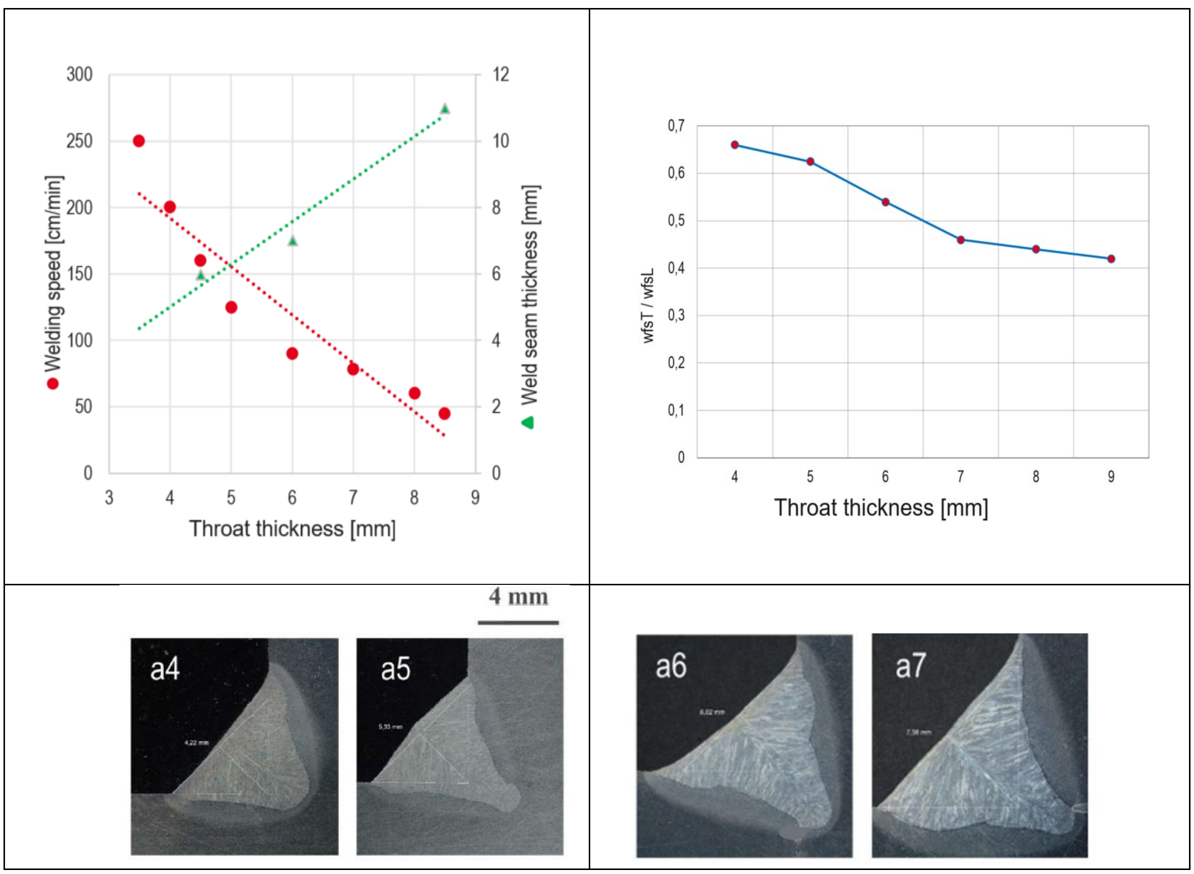


Figure 7: *Maximum achievable welding speed for fillet welds welded in PA position with PMC/PMC. The wire feed speed spread is continuously decreased to maintain a deep penetration; material thickness: 8 – 15mm*

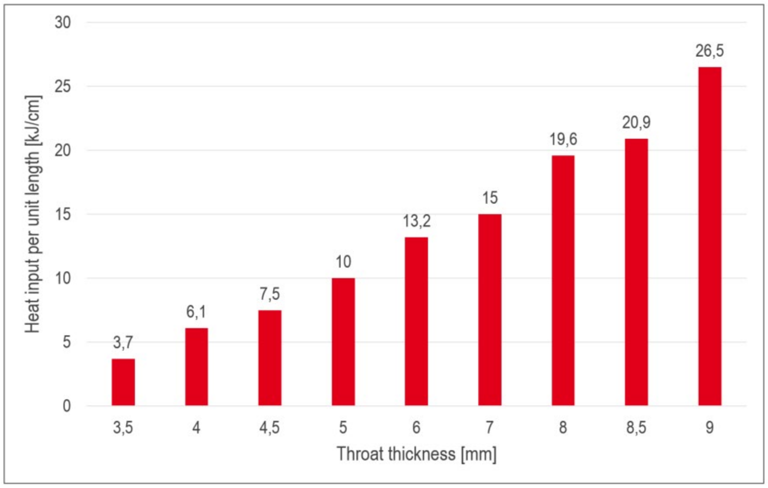


Figure 8*: Heat input per unit length vs. throat thickness*

In general, the results obtained have confirmed that the greatest benefit to be derived from use of the Twin Push technique in comparison to single wire GMA welding is increased productivity (between 50 and 100%) associated with reduced deformations, without producing any deterioration in the mechanical behaviour of the joint when compared to traditional processes. In any case, the welding operation conditions, optimized for greater productivity, have maintained a level of joint quality and structural integrity, comparable with that of GMA welded and SAW welded joints.

5. Industrial applications with TPS/I Twin Push

Welding of Harvester rims

The first industrial application with the TPS/I Twin Push was done at the customer Levypypyörä in Finland on Harvesters (Figure 9 left) using 2 x TPS 600i Pulse with the cooling unit CU 2000i Pro/MC and a torch cleaning station Robacta TSS/I including a TC2000. For these weldments the Robot YASKAWA YR HP20 B10 (extended fourth axis) with the Interface NX100 controller converted to DeviceNet was applied. It needs mention, that the seam tracking type Scansonic TH6D was used (figure 9 right). The welding parameters are listed in Table 3.

Figure 9*: Industrial application at company Levypypyörä, Finland [13]*

Table 3: Parameters for welding Harvester rims

	Lead:	**Trail:**
Travel speed:	66 cm/min	66 cm/min
Wire feed speed:	9.2 m/min	5.0 m/min
Droplet frequency	200 Hz	100 Hz
Current:	465 A	269 A
Voltage:	27,7 V	23,8 V
Arc length correction:	-0.5	-0.6
Pulse/dynamic correction:	-1.5	0.0
R/L measurement:	6.7 mΩ / 18.2 µH	6.8 mΩ / 18.4 µH
Contact tip to work distance (CTWD):	23 mm	22 mm
Filler wire:	ER70S-6 Ø1,6 mm	ER70S-6 Ø1,6 mm
Shielding gas:	85% Argon + 15% CO_2	85% Argon + 15% CO_2
Welding process:	PMC TWIN	PMC TWIN

***Figure 10**: Welding of rims; material thickness: 8 mm, base metal: S235JR acc. to EN 10025*

After some welding experiments in the laboratory, following parameters were used for the serial production: The symmetric welding torch was set with an electrode travel angle in forehand technique of 11.5° und the inter wire distance of 7 mm at a contact tip to work distance of 15 mm.

The goal for this rim type was to reach a throat thickness of 5.5 mm in PA position in one layer without weaving motion. To fulfil the requirement, it was necessary to use the Scansonic laser tracking system to stay on track. By having gaps of approx. 2-3 mm, it was possible to control the weld pool and generate good shaped, concave weld seams. After optimizing the welding parameters, a welding speed of 66 cm/min was reached which equals 158 seconds welding time for each rim. Compared to the results of the former used single wire process it can be said that a doubling in welding speed was reached for this application.

Application of bogie frames for the railway industry:

The international railway industry is forced to use highly competitive production means and joining processes. Conventional single wire arc welding is broadly employed for such applications.
The most important sections of the locomotive and wagon include the bogie frame, which receives high loads at high travel speeds of the train. Therefore, is it very important to weld such components in a high quality, that means, that undercut or incomplete penetration have to be

avoided. On the other hand, the productivity should also be given. To overcome both quality and economic considerations a GMA-Tandem welding process was chosen for this application.

Figure 11 left shows an axle unit which consists of following components: bogie frame (1), wheel set (2), coil spring (3), brake shoe (4) and hed beam (5). The right portion of Figure 11 represents a weld completed bogie frame.

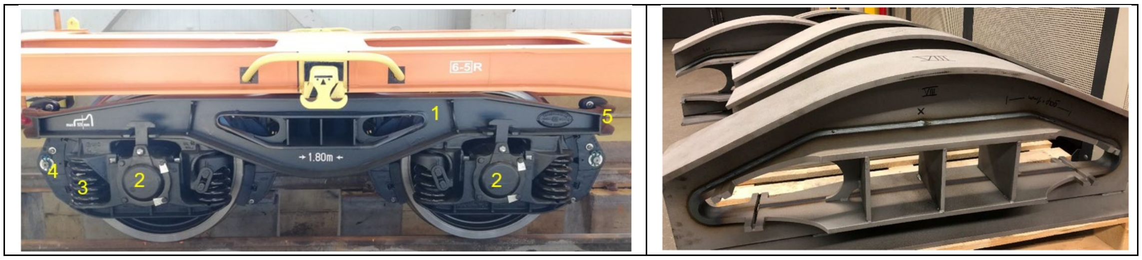
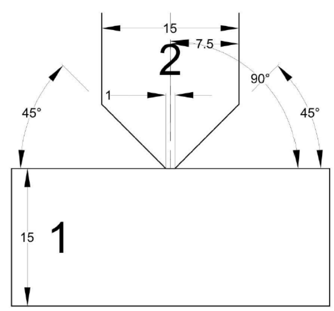


Figure 11: *Industrial application on bogie frames*

The general parameters and the weld seam details are shown in Table 4. Both the ground plate and the vertical plate have material thickness of 15 mm and it was decided to prepare the joint as K-bevel design. Furthermore, in this application both straight seams and non-linear seams were welded.

Table 4: *General parameters and weld seam details*

Shielding gas	90% Argon + 10% CO_2	
Welding wire	ER70S-6 Ø1,2mm	
Base material	S355JR	
CTWD	25mm	
Fronius power source	2x TPS600i	
Torch neck	MTB 2x500i PB 30°	

A comparison of PMC and spray arc to Twin Push (PMC/PMC) is shown in Figure 12. The welding speed could be doubled by using the TPS/I Twin Push variant, so that the component could be welded with a travel speed of 84 cm/min, while the deposition rate in this case was 17.39 kg/h, more than twice that of TPS/i PMC.

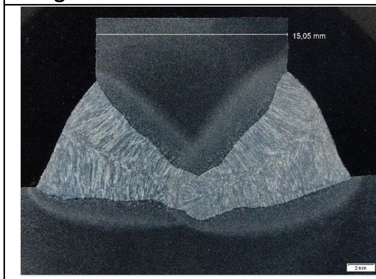
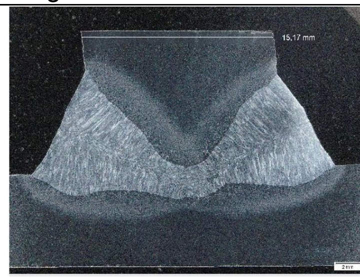
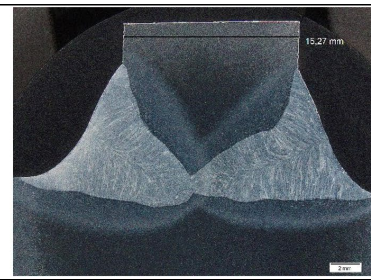
TPS/i PMC single wire	TPS/i spray arc single wire	TPS/i PMC/PMC double wire
		
v_T: 42 cm/min wfs: 15,5 m/min I: 356 A U: 26,6 V Q: 13,52 KJ/cm D: 7,93 kg/h	v_T: 42 cm/min wfs: 13,4 m/min I: 360 A U: 26,9 V Q: 13,83 KJ/cm D: 6,85 kg/h	v_T: 84 cm/min wfs: 23,5+10,5 m/min f_L+f_T: 350Hz+175Hz I: 437+279 A U: 28,4+27,2 V Q: 14,29 KJ/cm D: 17,39 kg/h

***Figure 12**: Comparison of PMC single wire and spray arc single wire to Twin Push (PMC/PMC; I: welding current, U: welding voltage, Q: heat input per unit length, D: deposition rate*

Welding of axle carriers for commercial vehicles:

The growing need for a welding process that guarantees optimal joint quality, while at the same time allowing for increased production and reduced cost, has made the synchronized tandem wire welding process particularly competitive in various industrial fields of application, e.g., welding of axle carriers for commercial vehicles. Indeed, based on the arc welding technology with the simultaneous fusion of two electrode wires, the GMA-Tandem process is an effective way to increase weld speed, maintaining similar levels of penetration, with the quantity of metal deposited, similarly to that in GMA welding and with the advantage of relatively modest heat input.

For this industrial application more then 10 000 axle housings need being produced per year. Figure 13 shows the workshop applying the TPS/I Twin Push welding systems. By switching to the new technology, the welding speed could be increased by the factor of 1.8.

***Figure 13**: Welding of axle carriers for commercial vehicles, factory photo from “Axles India”*

Table 4 shows, the requirement was to obtain a penetration depth rate of 70% meaning 9.8 mm for this application.

***Table 4**: Welding parameters; I: welding current, U: welding voltage, Q: heat input per unit length, D: deposition rate*

Joint geometry	Square butt joint	v_T: 50 cm/min
Thickness	14 mm	wfs: 10,4+10,1 m/min
Penetration depth required	70 % of material thickness	f_L+f_T: 220 Hz+220 Hz
Weld seam length total	1920 mm	I: 482+473 A
Cycle time	7.5 min	U: 31,0+30,6 V
Components per day	168 axles	Q: 35,52 KJ/cm
Material	S 235JR	D: 10,9 kg/h
Filler wire	G3 Si1, 1,2 mm	

6. Conclusions

1. In this paper a new process variant of the GMA-Tandem welding process is introduced in which both wires operate in the PMC transfer mode. With this modification an advanced GMA-Tandem process is expected to provide a significant improvement for the welding performance. Present research shows the effects of the different droplet detachment frequencies and adjustable phase shifts.

2. The arc force balance between the leading and the trailing arc can be controlled, and thereby sound weld beads can be obtained without undercut and humping.

3. To study the behaviour of the weld pool, the metal transfer was recorded by a digital high-speed video camera. It was observed that the penetration is determined mainly by the leading arc. Twin PMC/PMC can also conquer new applications in the field of welding thick sections.

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Dipl.-Wirtsch.-Ing. (SFI/IWE) Boyan Ivanov, EWM AG, Muendersbach, Germany

Implementation of a Welding 4.0 welding quality management system explained on real applications in manufacturing and education

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- EWM AG
- Head of digital welding solutions
- DVS, DIN, CEN, ISO

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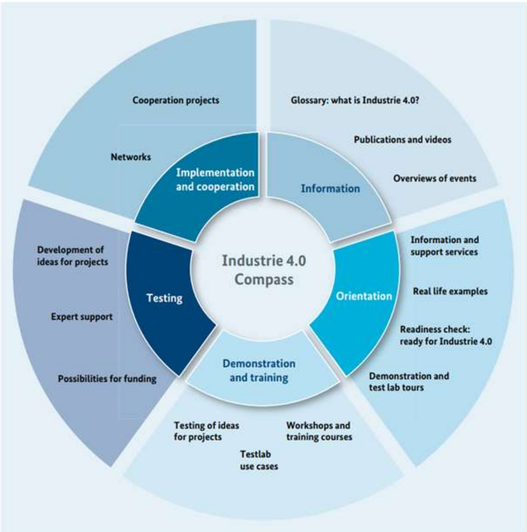
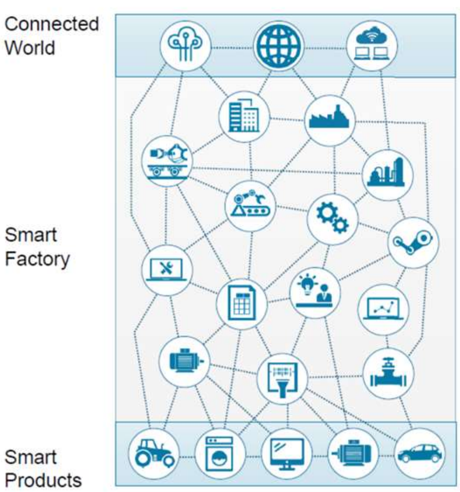
Indistry 4.0 strategy for the companies

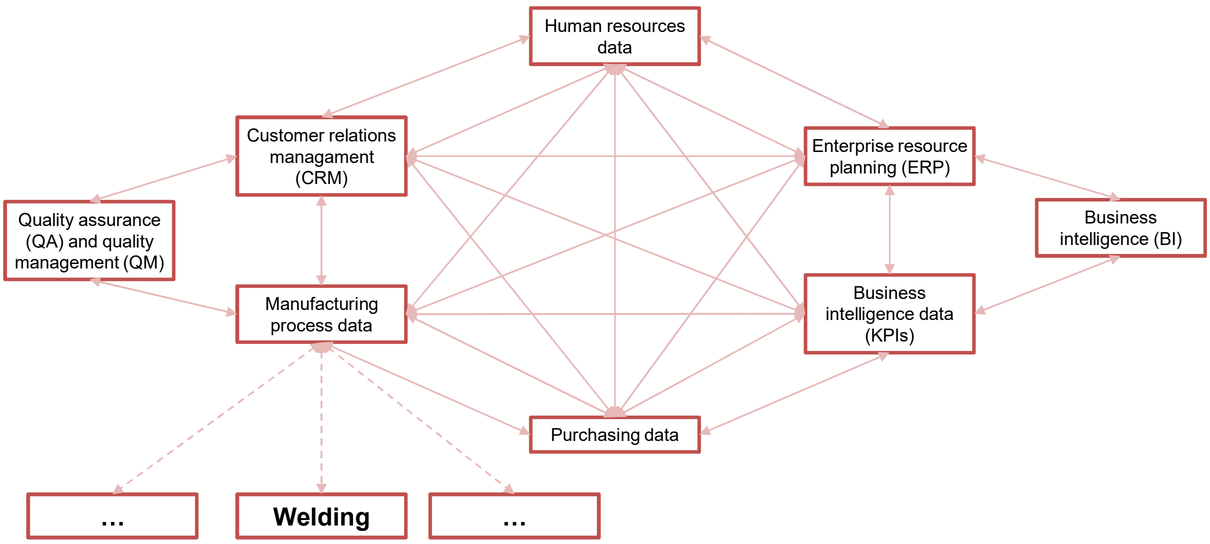


2019 Progress Report – Shaping Industrie 4.0. Autonomous, interoperable and sustainable



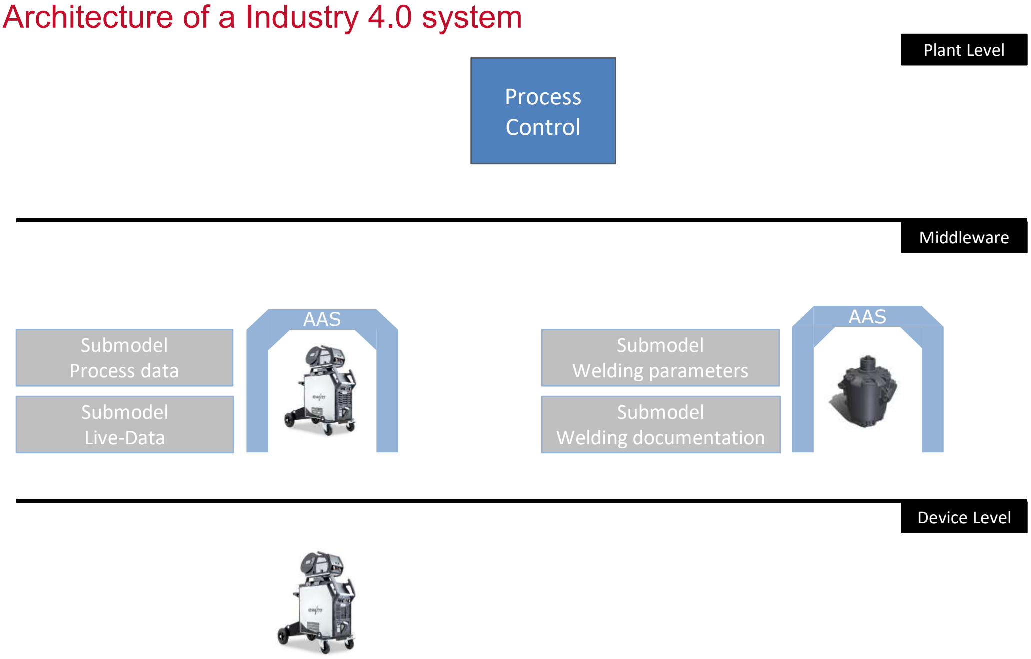
Bildquelle: Anna Salari, designed by freepik

Concept for data flow and data evaluation



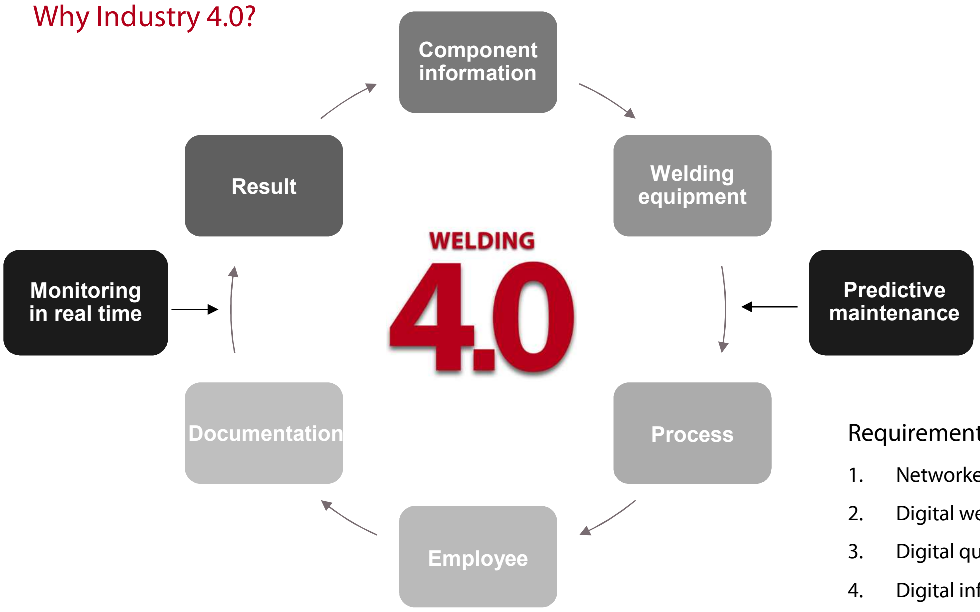
Welding goes digital

Architecture of a Industry 4.0 system



Specifics of welding

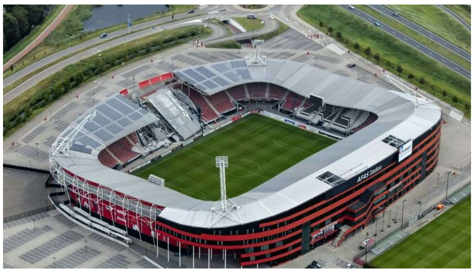
Why Industry 4.0?

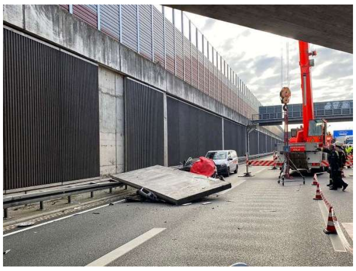


Requirements:

1. Networked equipment
2. Digital welding documentation
3. Digital qualification of welders
4. Digital information about the component

Accidents caused by bad or missing welds



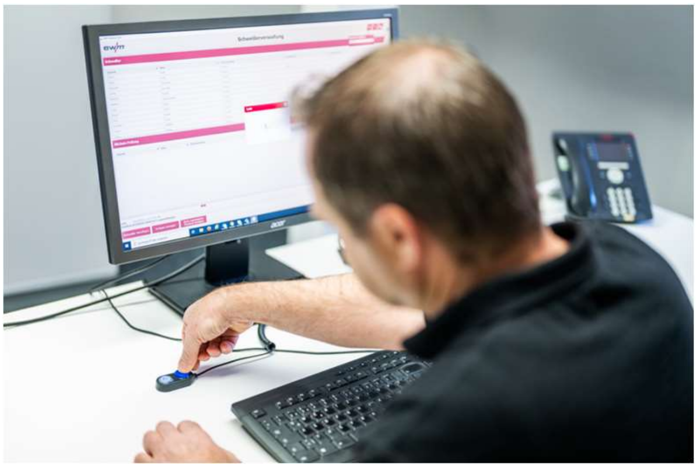


Welding 4.0 at SAF-Holland, Germany

Axle load by the tonne – for true heavyweights

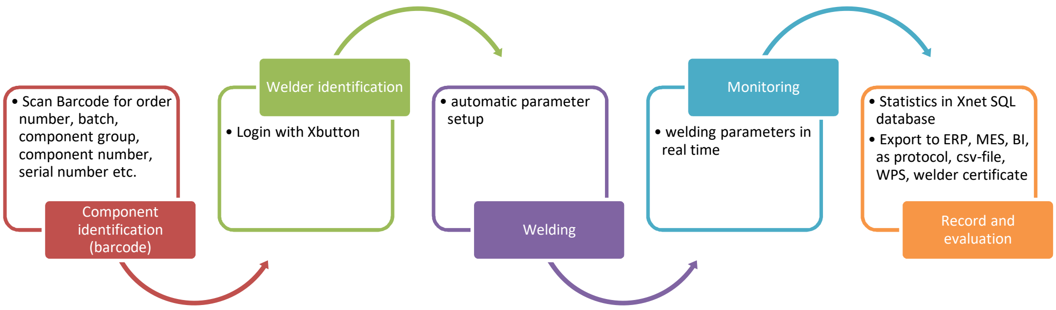
„SAF-Holland has fully adopted the zero-defect strategy. When it comes to welding processes, this strategy ensures that every weld seam is created using exactly the right welding parameters – every single time.“

Adding the welder to the datase, programing the X-Button



- Identification
- Welding parameters access management

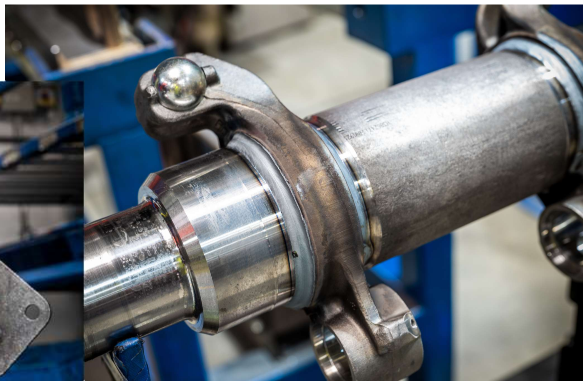
Application in the manufacturing process



Welder login with X-Button an and order number scan

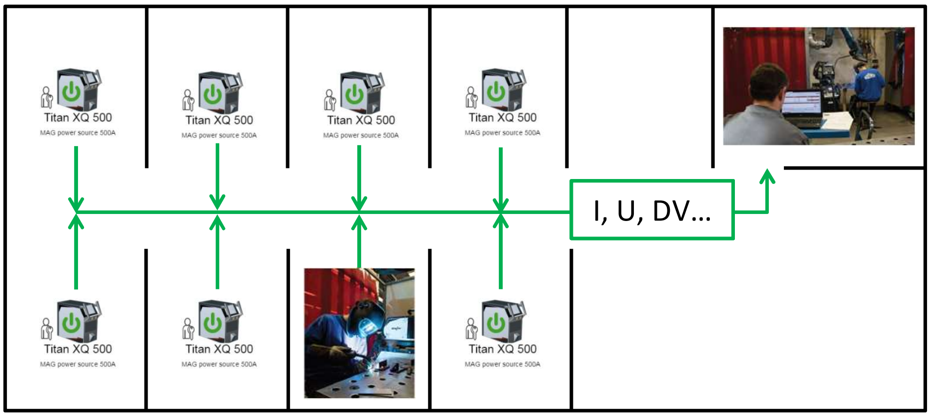
- Welding data recording
- Reference of data order number and product
- Traceability

Welding, Monitoring in real time and welding data recording



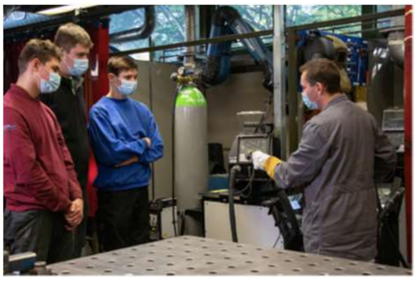
Welding equioment connected to a network and delivering welding data in real time

All activities and parameters visible and motored in real time

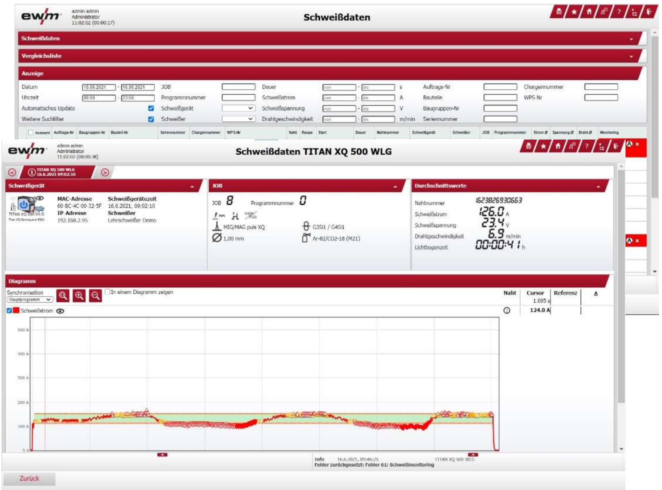


Implementation: Geschwister-Scholl-Schule in Leutkirch, Germany

- Welding with monitoring in real time
- Welding quality can be instantly inspected
- How do I create and read a WPS?

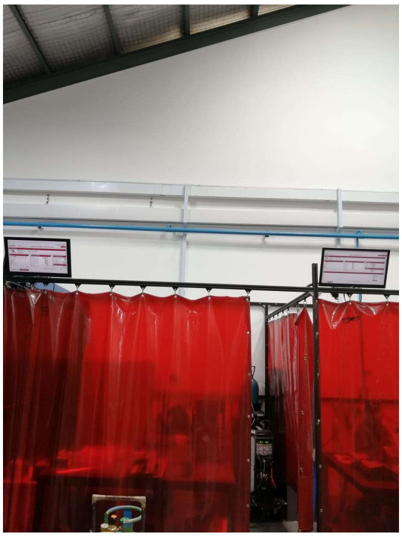


Example Monitoring / Recording



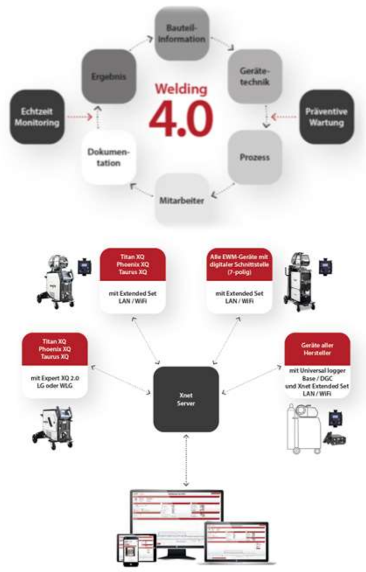
Fehler lassen sich in den Parametern feststellen und erklären.

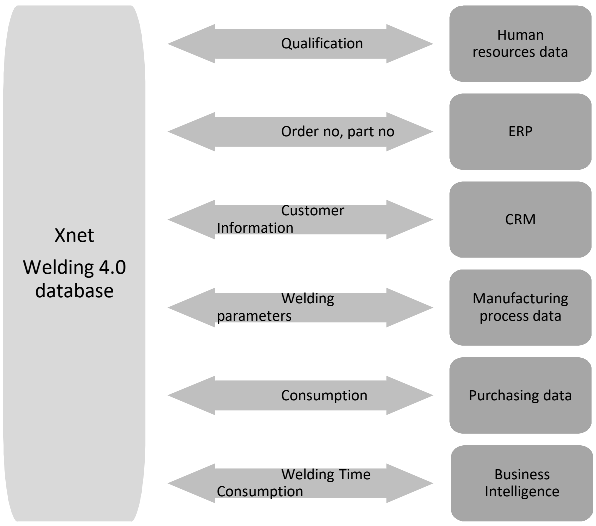
Implemetation in education and industry



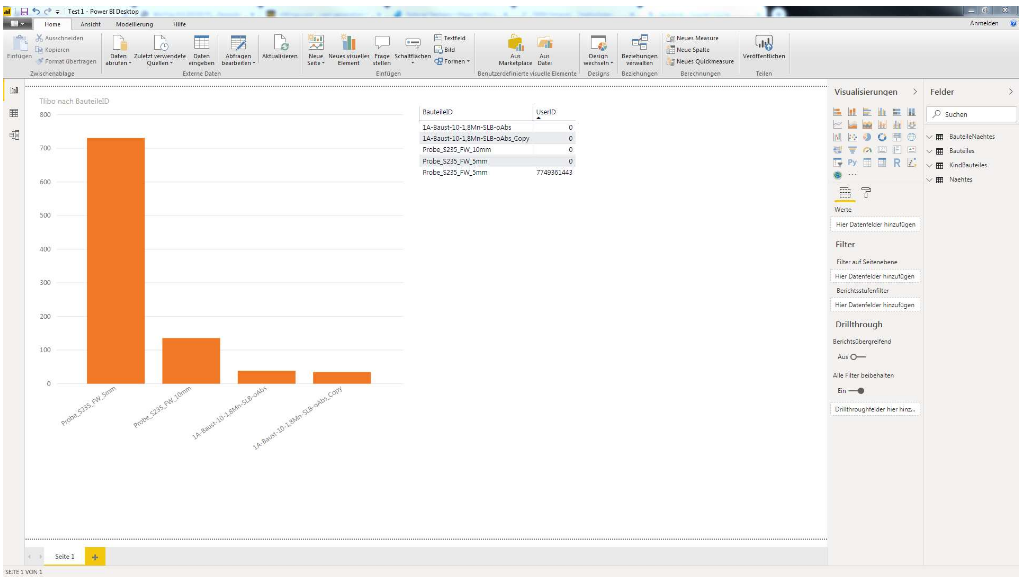
The welder is also a Xnet user.

Data use and data evaluation

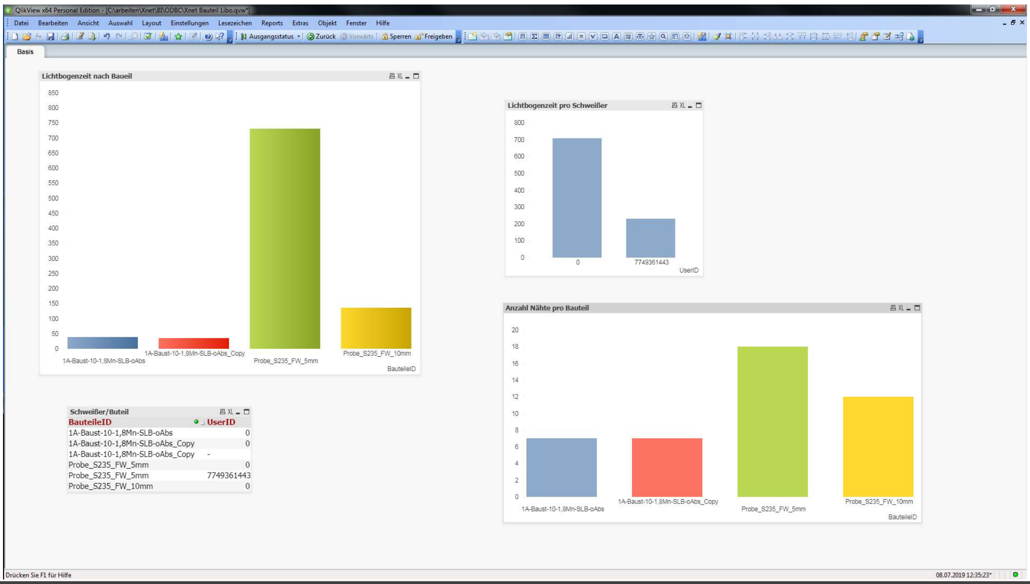




Evaluation of the ewm Xnet data with BI-tools
Example Power BI from Microsoft



Evaluation of the ewm Xnet data with BI-tools
Example Qlikview



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JOIN TRANS 2022: 6TH EUROPEAN CONFERENCE
„JOINING AND CONSTRUCTION OF RAILWAY VEHICLES“
MAY 11TH – 12TH 2022, WARSAW POLAND

Dipl.-Ing. Patric Arlt, SLV Halle GmbH, Halle, Germany

EN 15085-2:2020 - one year experiences of manufacture certification

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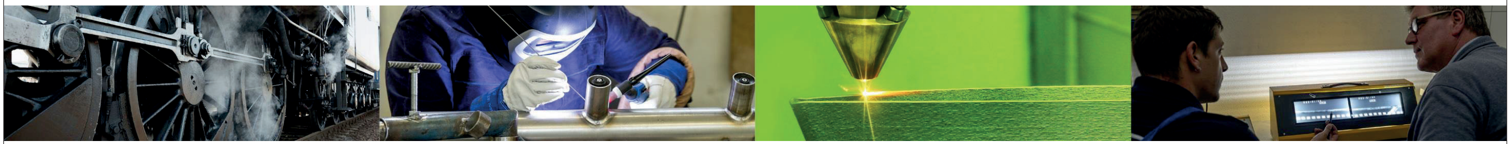

European Conference JOIN-TRANS (2022)

Joining and Construction of Railway Vehicles

European Committee for Welding of Railway Vehicles (ECWRV)

Transportowy Dozór Techniczny (Poland) SLV Halle GmbH (Germany)

EN 15085-2:2020 - one-year experiences of manufacture certification

Halle (Saale), 01.05.2022
Patric Arlt Dip.-Ing. SFI/IWE

Content

Introduction	quality requirements of welding manufacturer, EN 15085-2:2020
General overview	brief most important and main changes
MCB Audit in practice	as third-party inspection for new changes of EN15085-2:2020
ECWRV recognized MCB	of new EN15085-2:2020, Online Register

Summary and Discussion

EN 15085-2:2020 - one-year experiences of manufacture certification

Introduction quality requirements of welding manufacturer, EN 15085-2:2020

EN 15085-2: 2008 was required to redesign **according to the uniform European competition rules**

EN 15085 is **already accepted** and in application and use **by all EU member states** as a welding quality standard for welding products and components in scope od railway vehicles industry.

EU has **strict rules** to protect the entire marked for **free competition**

Therefore, the new Standard EN 15085-2:2020-12 **change the general sense and vocabulary** form

certification to qualification

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EN 15085-2:2020 - one-year experiences of manufacture certification

Introduction quality requirements of welding manufacturer, EN 15085-2:2020

EU regulate the dominant position for a large market shares by certain practice prohibitions

charge the manufacturer for **unfair high and to low prices** to eliminate competitors out of the market

→ certification is **not mandatory** anymore → only **voluntary**
→ used by internal and external parties and accredited certified bodies→ ECWRV recognized MCB

discriminate between customers

→ Confirmation to declare personal qualification and product quality belongs to the manufacturer responsibility
→ first: manufacture self declaration, second: conformity by the customer base on product and third party: certified by quality requirement audit assessment

no exchange strategic information and force certain **trading conditions** for business partners

→ Manufacturer welding personal could be qualified according to ISO14732,
→ Certified welding personal according to IIW education is not required but recommended

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Introduction quality requirements of welding manufacturer, EN 15085-2:2020

Qualification

acquire special knowledge or meet requirements to be able to execute something.
Qualifications are learned through **education, training, further education and** experience.

Certification

Is a **certification procedure for verifying and confirming** compliance with requirements that are based on a **product, process or person**.
Certification is always **limited in time**

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EN 15085-2:2020 - one-year experiences of manufacture certification

General overview brief most important and main changes

1. Requirements for **certification of manufacturer have been deleted**:	voluntary for future
2. Certification Levels (CL) are substitute for **Classification levels** (CL):	CL1 – CL2 – CL3, CL4 deleted
3. Manufacturer **activities have been new defined**:	P – M – D- S
4. New term is **Safety relevance** is implemented	based on the component high=CL1, medium=CL2, Low= CL3
5. Welding **coordinator qualification** -Annex D- assessment	Level A, comprehensive, ISO 14732 Level B, specific, ISO 14732 Level C, basic, ISO 14732

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General overview brief most important and main changes

6. **Additional Welding coordinator** is required — rWC - 1. deputy of responsible WC – other WC except D and S and CL3 for 1. deputy WC

7. Additional **Welding performance class** — CP B1; CPA, not preferred for new production, only -M-

8. First **article inspection (FAI)** shall perform — welded components according to EN15085-5

9. Finishing **welding for casting parts** — classification level, same than welded assembly

10. **size of welding manufacturer** calculation — Annex C, informative Guideline for score 1500; general welding manufacturer >1500 < small

EN 15085-2:2020 - one-year experiences of manufacture certification

MCB Audit in practice as third-party inspection for new changes of EN15085-2:2020

minimum requirements for welding Manufacturer

EN15085:2020-12
Annex B Table B 1

Classification level		CL 1	CL 2	CL 3
	Type of activity (see Table 2)			
Manufacturer's evidence of compliance (see Clause 6)	P, M, D, S	Required	Required	Required
Weld performance classes (CP) according to EN 15085-3	P, M, D, S	All	CP B2, CP C2, CP C3 and CP D	CP C2 and CP C3 with low safety category and CP D
Quality requirement	P, M, D, S	EN ISO 3834-2 EN ISO 14554-1	EN ISO 3834-3 EN ISO 14554-2	EN ISO 3834-4 EN ISO 14554-2
Responsible welding coordinator, minimum level	P, D	Level A	Level B	Level C
	S	Level B	Level C	Level C [b]
	M	Level A [a]	Level B	Level C
1st deputy of the responsible welding coordinator, minimum level	D, S	Not required	Not required	Not required
	P	Level A	Level C	Not required
	M	Level A [a]	Level C	Not required
	P (Small Manufacturer) (see Annex C)	Level C	Welder with technical knowledge and experience in welding	Not required
	M (Small Manufacturer) (see Annex C)	Level C [a]	Welder with technical knowledge and experience in welding	Not required
Others deputies, minimum level	D, S	Not required	Not required	Not required
	P, M	Sufficient number of Level C, who can cover the welding activities and the possible shifts with welding.	Sufficient number of Level C, who can cover the welding activities and the possible shifts with welding.	Not required
Welders and operators	P, M	Welders or welding operators shall be qualified according to EN 15085-4.		
Testing personnel	P, M, S	Testing personnel for welding quality tests shall be qualified according to EN 15085-5.		
Welding instruction	P, M	Welding procedure specification (WPS) and / or welding procedure qualification record (WPQR) according to EN 15085-4.		

[a] In case of welding manufacturer (M = maintenance) with several sites, welding coordination activities may be managed as follows:
- One level A responsible welding coordinator for managing welding activities at all sites;
- One level A deputy welding coordinator;
- One level B deputy welding coordinator at each site. In case of "small" site (see Annex C) one level C deputy welding coordinator;
- Other level C deputies welding coordinators if necessary.

[b] Only required for weld performance classes CP C2 and CP C3.

Safety relevance

Manufacturers and the components they weld are classified in three levels depending on the safety relevance of the welded component (see 3.1).

The classification levels are defined as follows:

CL 1 For welded railway vehicles and their welded components with high safety relevance.

CL 2 For welded components of railway vehicles with medium safety relevance. (Welded joints with high safety category according to EN 15085-3 are not permitted)

CL 3 For welded components of railway vehicles with low safety relevance. (Welded joints with high or medium safety category according to EN 15085-3 are not permitted)

Safety relevance is based on the Component and referred to Certification Level

EN 15085-2:2020 - one-year experiences of manufacture certification
MCB Audit in practice as third-party inspection for new changes of EN15085-2:2020

Safety relevance

safety relevance
description of the consequences of a failure of a welded component with respect to the effects on persons, facilities and the environment

Note 1 to entry: The safety relevance of a welded component is distinguished as follows:

Low: Failure of the welded component does not lead to any direct impairment of the overall function. Consequential events with personal injuries are unlikely

Medium: Failure of the welded component leads to an impairment of the overall function and/or may lead to consequential events with personal injuries

High: Failure of the welded component leads to consequential events with personal injuries and breakdown of the overall function

safety relevance → safety category

Possibility: CL1 component could be for welding performance class CP CD

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Differences between welding performance class CP B1 and CP B2

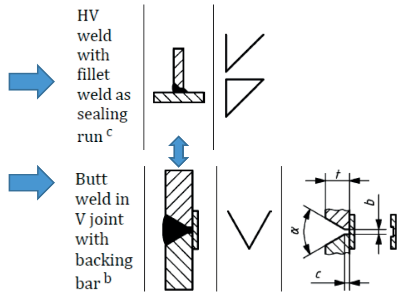
Stress categories	Safety categories		
	High	Medium	Low
High	CP A [a]	CP B2 [c]	CP C2
Medium	CP B1 [b]	CP C2	CP C3
Low	CP C1 [d]	CP C3	CP D

[a] For new manufacturing the combination of high safety category and high stress category, which leads to weld performance class CP A, is forbidden. For application in maintenance see EN 15085-6

[b] Weld performance class CP B1:
CP B1 is only applicable for welds with full penetration and full accessibility for inspection in production and maintenance.

[c] Weld performance class CP B2:
CP B2 is also applicable for welds without the possibility for a volumetric test; e. g. welds with partial penetration or fillet welds are possible; in this case a special remark "medium safety category/increase of surface test is required" shall be indicated on the drawing or technical documentation linked to the drawing

[d] Weld performance class CP C1:CP C 1 is also valid for welds without the possibility for volumetric testing; e. g. welds with partial penetration or fillet welds are possible



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MCB Audit in practice as third-party inspection for new changes of EN15085-2:2020

Type of activity	Indicator	Description
Design	D	Calculation, design and documentation for the production and maintenance of welded railway vehicles and components
Production	P	Manufacturing, modification and testing of welded railway vehicles and components (including replacement parts).
Maintenance	M	Repair of welded railway vehicles and components by welding (including testing).
Purchase and supply	S	Purchase and supply of welded components for new fabrication or maintenance activities without carrying out welding operations

The classification level for **finishing welding of cast** parts shall be the same than the entire assembly

S **Type of activity** without carrying out of **welding operations**

S on **Certificate** only possible to issue **without P and M**

Subcontracting and Sup-supplier **activities** are include P and/or M normally

D should be marked and identified for **P and/or M** application by e.g. **D(M), C(P), D(P,M)**

separate methods to determine the welding performance class CP
EN 15085-3:2020 **-P-** 4.2/4.5 and EN 15085-6:2020 -M- 5.1 a-f

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Finishing welding is execution and an **activity** and just **referred** to the **Classification Level**

- Finishing welding is **no joining** welding procedure only surface welding improvement of in cast quality
- limits of **imperfection for joining welding** procedure are regulated in ISO 5817 / ISO10042
- limits of **imperfection for castings** by welding **improvement** are regulated in **ISO 11970**
- Welding **performance class of** finishing welding not possible to develop according to EN15085-2 (**CL /CT**)
- Final **casting quality will be inspected on ISO 11970** and not on the weld limits e.g. ISO5817
- Finishing welding is **no repair** rather a casting improvement procedure by welding

Finishing welding shall be single issued on Certificate **without -P-M-D or S** application.

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Size of welding manufacturer determination according to EN 15085-2:2020 Annex C (informative)

In order to evaluate the "size of a welding manufacturer (*WM*)" the welding entity may be analysed by the following criteria and evaluated according to Formula WM. For a manufacturer with multiple sites, this evaluation should be done for each site separately.

a The total number of welders and welding operators under the responsibility of the welding coordination team (see 5.3) (The factor is minimum 1.)

b The number of activities performed: only P and/or M = 1; P and/or M plus D and/or S = 2 (The factor is between 1 to 2.)

c The number of types of welded materials: non-stainless steel, stainless steel, non-ferrous metallic alloys. (The factor is between 1 to 3.)

d The number of shifts per day: less than or equal to 2 shifts = 1; more than 2 shifts = 2. (The factor is between 1 to 2.)

e The number of welding processes used (two digits groups according to EN ISO 4063) (The factor is minimum 1.)

f A coefficient for the classification level of the welded sub-assemblies (CL 1 = 10, CL 2 = 5, CL 3 = 1)

Formula WM:

$$WM = a \cdot b \cdot c \cdot d \cdot e \cdot f$$

If this product "*WM*" is less or equal than 1500, the manufacturer should be considered as "small manufacturer".

1st Deputy of responsible WC
-minimum qualification level-

1st Deputy required for CL1 and CL2 components, additional aspects

For CL1 company owners, managers not possible for rWC coordination
- except small manufacturer-

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MCB Audit in practice as third-party inspection for new changes of EN15085-2:2020

minimum requirements of welding manufacturer EN15085:2020-12 Annex B Table B 1

1st deputy of the responsible welding coordinator, minimum level	D, S	Not required	Not required	Not required
	P	Level A	Level C	Not required
	M	Level A ᵃ	Level C	Not required
	P (Small Manufacturer) (see Annex C)	Level C	Welder with technical knowledge and experience in welding	Not required
	M (Small Manufacturer) (see Annex C)	Level C ᵃ	Welder with technical knowledge and experience in welding	Not required

other welding coordinators are be available in sufficient numbers of **min. Level C qualification**

- available on **site during the arc is in process** for manufacturing
- general function like a **welding supervisor**
- other welding coordinators **shall be fully employed** by the manufacturer
- **external other welding** coordinators should be not accepted

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Guidance for the evaluation of technical welding knowledge for welding coordinators for appropriate Level A-B-C according to EN 15085-2:2020 Annex D (informative)

The level of technical knowledge indicated in Table D.1 is defined as follows:

1: Basic knowledge of the subject

2: Application and use of principles and rules

3: Overall mastery of the subject

4: Ability to develop method and procedures

Table D.1 — Requested technical knowledge of welding coordinators with different levels of competence (see 5.3)

1 Welding processes and equipment	Level A	Level B	Level C
1.1 Cutting and other edge preparation processes			
~~Understand in detail/acquire a full knowledge of/explain/interpret the basic~~ principles and scope of application of the most common cutting and edge preparation processes used in welded construction and their principles of action, including equipment, procedures and common problems. Specifies and knows how to inspect the use of torch, plasma, gouging electrode and air arc cutting processes.	3	2	2
1.2 Heating and heat straightening			
~~Understand in detail/acquire a full knowledge of/explain/interpret the~~			

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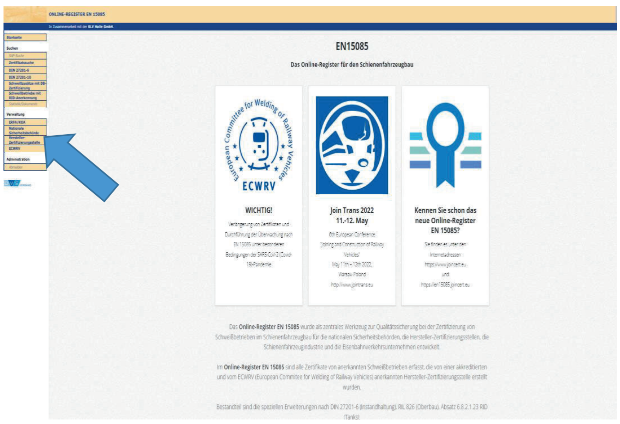

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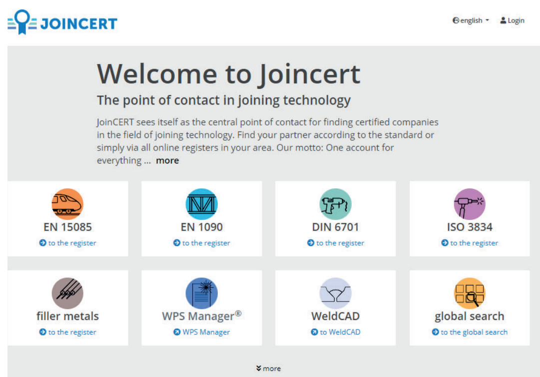

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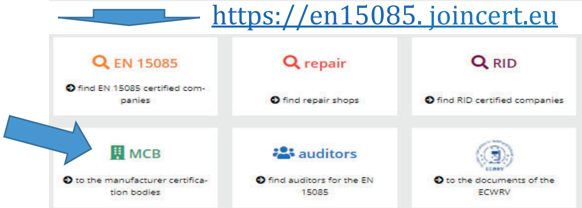

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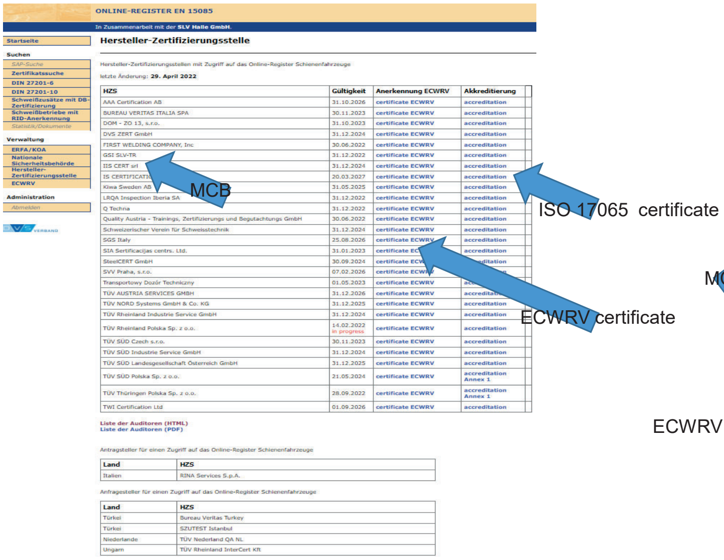

ONLINE-REGISTER EN 15085

In Zusammenarbeit mit der **SLV Halle GmbH**.

Startseite | Suchen: SAP-Suche, Zertifikatssuche, DIN 27201-6, DIN 27201-10, Schweißzusätze mit DB-Zertifizierung, Schweißbetriebe mit RID-Anerkennung, Statistik/Dokumente | Verwaltung: ERFA/KOA, Nationale Sicherheitsbehörde, Hersteller-Zertifizierungsstelle, ECWRV | Administration: Abmelden

Hersteller-Zertifizierungsstelle

Hersteller-Zertifizierungsstellen mit Zugriff auf das Online-Register Schienenfahrzeuge

letzte Änderung: **29. April 2022**

HZS	Gültigkeit	Anerkennung ECWRV	Akkreditierung
AAA Certification AB	31.10.2026	certificate ECWRV	accreditation
BUREAU VERITAS ITALIA SPA	30.11.2023	certificate ECWRV	accreditation
DOM - ZO 13, s.r.o.	31.10.2023	certificate ECWRV	accreditation
DVS ZERT GmbH	31.12.2024	certificate ECWRV	accreditation
FIRST WELDING COMPANY, Inc	30.06.2022	certificate ECWRV	accreditation
GSI SLV-TR	31.12.2022	certificate ECWRV	accreditation
IIS CERT srl	31.12.2024	certificate ECWRV	accreditation
IS CERTIFICATI[illegible]	20.03.2027	certificate ECWRV	accreditation
Kiwa Sweden AB	31.05.2025	certificate ECWRV	accreditation
LRQA Inspection Iberia SA	31.12.2022	certificate ECWRV	accreditation
Q Techna	31.12.2022	certificate ECWRV	accreditation
Quality Austria - Trainings, Zertifizierungs und Begutachtungs GmbH	30.06.2022	certificate ECWRV	accreditation
Schweizerischer Verein für Schweisstechnik	31.12.2024	certificate ECWRV	accreditation
SGS Italy	25.08.2026	certificate ECWRV	accreditation
SIA Sertificacijas centrs. Ltd.	31.01.2023	certificate EC[illegible]	accreditation
SteelCERT GmbH	30.09.2024	certificate ECW[illegible]	[illegible]editation
SVV Praha, s.r.o.	07.02.2026	certificate ECW[illegible]V	[illegible]
Transportowy Dozór Techniczny	01.05.2023	certificate ECWRV	ac[illegible]
TÜV AUSTRIA SERVICES GMBH	31.12.2026	certificate ECWRV	accredita[illegible]
TÜV NORD Systems GmbH & Co. KG	31.12.2025	certificate ECWRV	accreditation
TÜV Rheinland Industrie Service GmbH	31.12.2024	certificate ECWRV	accreditation
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TÜV SÜD Landesgesellschaft Österreich GmbH	31.12.2025	certificate ECWRV	accreditation
TÜV SÜD Polska Sp. z o.o.	21.05.2024	certificate ECWRV	accreditation Annex 1
TÜV Thüringen Polska Sp. z o.o.	28.09.2022	certificate ECWRV	accreditation Annex 1
TWI Certification Ltd	01.09.2026	certificate ECWRV	accreditation

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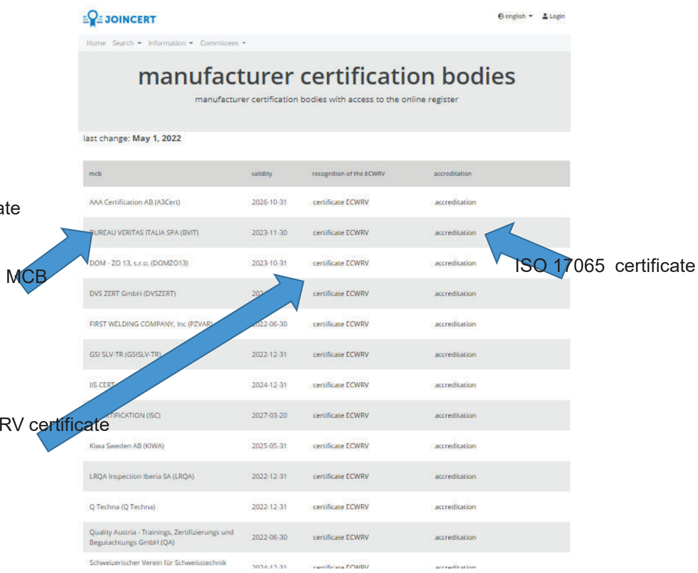

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manufacturer certification bodies

manufacturer certification bodies with access to the online register

last change: **May 1, 2022**

mcb	validity	recognition of the ECWRV	accreditation
AAA Certification AB (A3Cert)	2026-10-31	certificate ECWRV	accreditation
[illegible]UREAU VERITAS ITALIA SPA (BVIT)	2023-11-30	certificate ECWRV	accreditation
DOM - ZO 13, s.r.o. (DOMZO13)	2023-10-31	certificate ECWRV	accreditation
DVS ZERT GmbH (DVSZERT)	202[illegible]	certificate ECWRV	accreditation
FIRST WELDING COMPANY, Inc (PZVAR)	[illegible]22-06-30	certificate ECWRV	accreditation
GSI SLV-TR (GSISLV-TR)	2022-12-31	certificate ECWRV	accreditation
IIS CERT[illegible]	2024-12-31	certificate ECWRV	accreditation
[illegible]TIFICATION (ISC)	2027-03-20	certificate ECWRV	accreditation
Kiwa Sweden AB (KIWA)	2025-05-31	certificate ECWRV	accreditation
LRQA Inspection Iberia SA (LRQA)	2022-12-31	certificate ECWRV	accreditation
Q Techna (Q Techna)	2022-12-31	certificate ECWRV	accreditation
Quality Austria - Trainings, Zertifizierungs und Begutachtungs GmbH (QA)	2022-06-30	certificate ECWRV	accreditation
Schweizerischer Verein für Schweisstechnik	2024-12-31	certificate ECWRV	accreditation

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DAkkS Deutsche Akkreditierungsstelle

Deutsche Akkreditierungsstelle GmbH

Beliehene gemäß § 8 Absatz 1 AkkStelleG i.V.m. § 1 Absatz 1 AkkStelleGBV
Unterzeichnerin der Multilateralen Abkommen
von EA, ILAC und IAF zur gegenseitigen Anerkennung

Akkreditierung

Die Deutsche Akkreditierungsstelle GmbH bestätigt hiermit, dass die Zertifizierungsstelle

DVS ZERT GmbH
Geschäftsstelle Halle (Saale)
Köthener Straße 33a, 06118 Halle (Saale)

die Kompetenz nach DIN EN ISO/IEC 17065:2013 besitzt, Zertifizierungen von Produkten, Prozessen und Dienstleistungen in folgenden Bereichen durchzuführen:

Qualitätsanforderungen für das Schmelzschweißen von metallischen Werkstoffen, Anwendung von Schweißprozessen bei der Herstellung und Instandsetzung von Schienenfahrzeugen und -fahrzeugteilen;

Zertifizierung der werkseigenen Produktionskontrolle (System 2+) im Rahmen der Verordnung Nr. 305/2011 zur Feststellung harmonisierter Bedingungen für die Vermarktung von Bauprodukten (Bauproduktenverordnung)

Die Akkreditierungsurkunde gilt nur in Verbindung mit dem Bescheid vom 29.03.2018 mit der Akkreditierungsnummer D-ZE-16083-01 und ist gültig bis 28.03.2023. Sie besteht aus diesem Deckblatt, der Rückseite des Deckblatts und der folgenden Anlage mit insgesamt 4 Seiten.

Registrierungsnummer der Urkunde: **D-ZE-16083-01-00**

Berlin, 29.03.2018

Im Auftrag Dr. Heike Manke
Abteilungsleiterin

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DAkkS Deutsche Akkreditierungsstelle

Deutsche Akkreditierungsstelle GmbH

Anlage zur Akkreditierungsurkunde D-ZE-11074-03-00
nach DIN EN ISO/IEC 17065:2013

Gültigkeitsdauer: 15.02.2018 bis 14.02.2023 Ausstellungsdatum: 15.02.2018

Auf der Basis nachfolgend aufgelisteter Bewertungs- und Spezifikationsdokumentationen:

DIN EN 15085-2 2020-12	Bahnanwendungen - Schweißen von Schienenfahrzeugen und -fahrzeugteilen - Teil 2: Anforderungen an Schweißbetriebe

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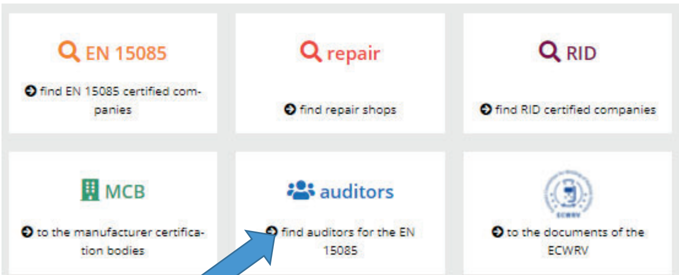
Türkei	Bureau Veritas Turkey



ECWRV recognized auditor list

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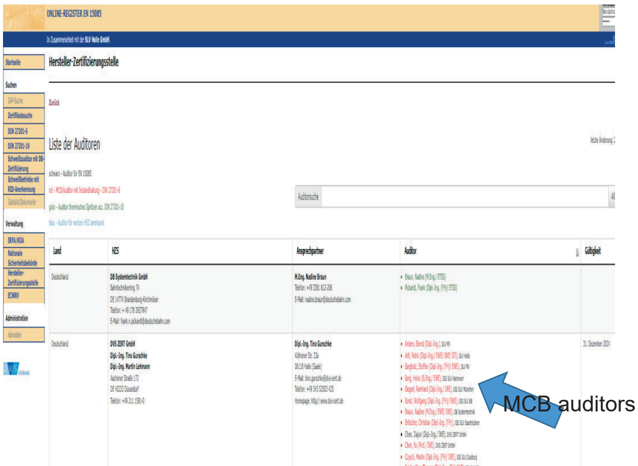

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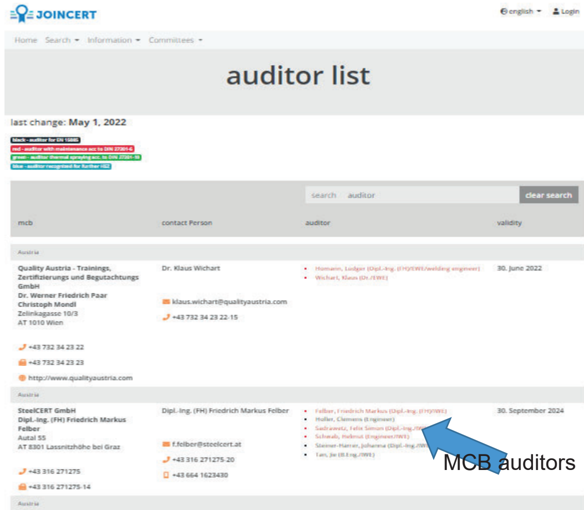

EN 15085-2: 2020-12 ECWRV auditors shall be recognized by national MCB accreditation according to ISO 17065 and according to the ECWRV Guideline part-2022 (red auditors incl. part 6 and black auditors= without part 6)

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EN 15085-2:2020 - one-year experiences of manufacture certification

Summary and Discussion

- **certification of manufacturer change to classification**
- **classification levels CL 1 CL2 CL3:**
- **safety relevance for components related to classification level**
- **welding coordinator qualification according to ISO 14731 -Annex D-**
- **additional welding coordinator is required**
- **additional welding performance class**
- **first article inspection (FAI) shall perform**
- **finishing welding for casting quality welding requirements shall be aggreged**
- **size of welding manufacturer calculation**

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Application and validation guide according to EN 15085 for the incorporation of welding processes in steel products with high mechanical performances

APPLICATION AND VALIDATION GUIDE ACCORDING TO EN 15085 FOR THE INCORPORATION OF WELDING PROCESSES IN STEEL PRODUCTS WITH HIGH MECHANICAL PERFORMANCES

E. Alberdi, A.Pedrero, MM Petite, Ordizia, Spain

1 Introduction

The objective of this article is to prepare a guide or scheme that helps manufacturers to face the challenge of going over a production of cast products, with what all this entails in terms of manufacturing times and delivery, little speed or flexibility in design changes, to a production process such as a welding process that allows flexibility and innovation in the design of parts, while gaining in competitiveness due to its lower cost and the reduction of supply times compared to the processes mentioned. For this, this article will based on an assumption.

The assumption is the following:

It will be supossed that the manufacturer will manufacture a component by casting, of material G42CrMo4-QT2, this component being assigned s/EN15085 Table1 as a component of classification level CL1, with a CPB execution class and CT2 inspection class.

Tabla 1 – Asignación de los componentes a su nivel de clasificación

CL	Componente
CL 1	Nueva construcción, conversión y reparación de los vehículos ferroviarios y sus componentes
	Ejemplos de componentes:
	– bogies (cabezales, largueros, traviesas intermedias, bastidores de bogies);
	– bastidores de locomotoras, material rodante para viajeros y vagones de mercancías (extensiones, largueros, traviesas intermedias, refuerzos, montaje);
	– cajas (paredes de los extremos y de los laterales, techo, cabina del maquinista, montaje de la placa del suelo, módulos de absorción de energía, anti-cabalgamientos);
	– montaje de vagones de mercancías (por ejemplo, placas de suelo de los transportadores de automóviles, elementos de fijación de carga);
	– órganos de choque y tracción;
	– bastidores de soporte, soportes y correas tensoras para equipos exteriores (por ejemplo, tanques, contenedores eléctricos, de aire acondicionado y de aire comprimido);
	– soportes de ejes montados, cajas de ejes, soportes de muelle, amortiguadores, amortiguadores de vibraciones;
	– equipos de frenado (freno de vía magnético, varillas de freno, triángulos de freno, cilindros de freno, barras transversales de la timonería del freno);
	– bastidores de apoyo para vehículos pesados, incluidos los vehículos de carretera/ferrocarril;
	– componentes soldados para la transmisión de tracción del bogie al vehículo (tope);
	– depósitos de combustible de los vehículos;
	– puertas de entrada y de salida (sistemas de bloqueo y elementos estructurales);
	– bastidores de escalones, pasamanos y barandillas en el exterior del vehículo o en las zonas de entrada;
	– Cajones de equipamiento y contenedores bajo bastidor, auto-soportados exteriores (contenedores de agua dulce y de aguas residuales);
	– construcción del techo (pantógrafo, paneles); por ejemplo, equipos (CL 2), bastidores (CL 1);
	– equipos exteriores de tracción y potencia (carcasa del transformador, suspensión del transformador, suspensión del motor, suspensión de la transmisión, fijación para el motor de tracción, bastidores de instrumentos);
	– piezas para la transmisión de la fuerza (acoplamiento de tracción, ejes cardán);
	– equipos de giro y vuelco (por ejemplo, vagones de mercancías);
	– deflectores de obstáculos y quitanieves;
	– soportes y anillos de amarre;
	– sistemas de escape, incluidas las tuberías;
	– areneros;
	– depósitos de gas a presión, tanques y tanques contenedores de los vehículos ferroviarios con presión de ensayo[a];
	– contenedores para materiales peligrosos[a];
	– depósitos de aire comprimido para vehículos ferroviarios[a].

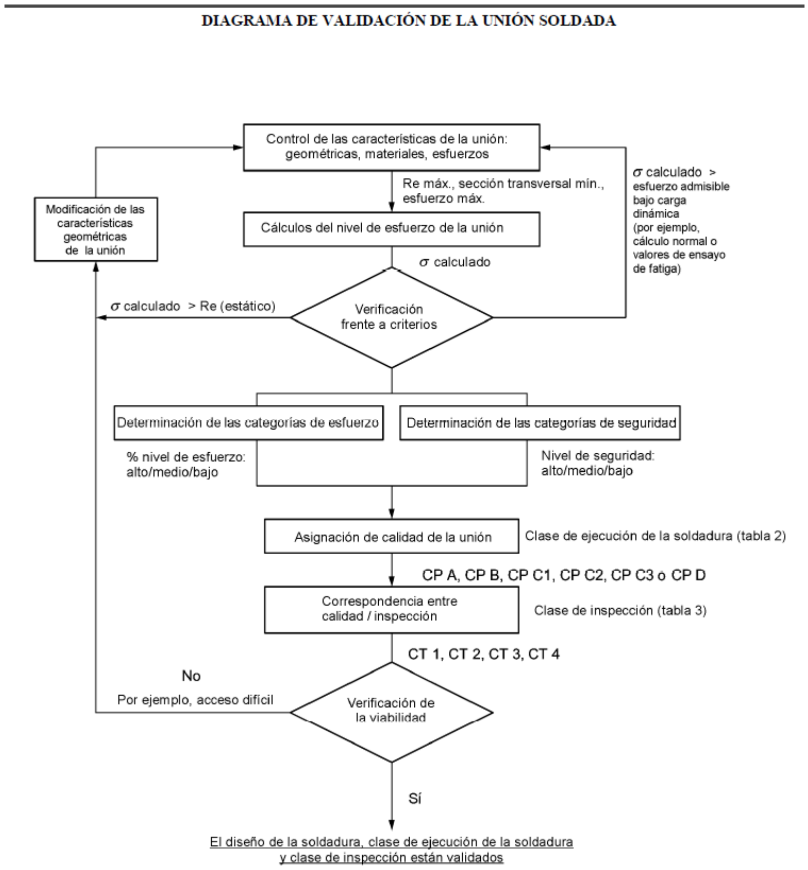
EN15085-2:2021 [1] Table1 Assignment of the components to their classification level

2 Task

<u>WELDED COMPONENT DESIGN</u>

The current design is a casting made of G42CrMo4-QT2 material with Re=780MPa and Rm=840Mpa.

The objective is to move on to a mechano-welded component that will have to comply with the joint validation diagram contained in EN15085-3:2008_Annex E [2].



[2] EN15085-3:2008_Annex (E)

In this case, the execution class and the inspection class are already defined, the steps to follow to manufacture the component will be:

- Component Layout Definition
- Determination of the loads to which the component is subjected by means of finite element simulation (abacus type, …)
- Choice of the base material to be used in the mechano welded component together with the filler metal to be used.
- Approach of the qualifications that will cover the welded joints that the component has.
- Component Manufacturing
- Inspection of the component according to the execution class and inspection class.
- Prototype validation (eg: fatigue test)

In parallel and being aware that this change in the production process cannot be executed from one day to the next, but that it takes a maturation process, it is proposed in parallel how to carry out possible small repairs in the original cast components following the guidelines set by EN15085-2:2021 [1].

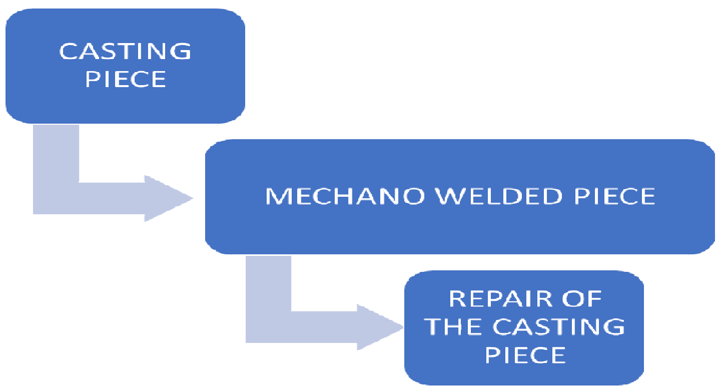


Fig1 Scheme of change of production and repairs

MANUFACTURE OF THE MECHANO WELDED COMPONENT ACCORDING TO EN15085

Design Definition

When defining the mechano welded component, in addition to being aware of the size of the initial casting piece, since the substitution, as far as possible, has to be as similar as possible so that the replacement does not suppose adaptability problems, we must be conscious of the requirements of UNE EN15085-3:2008 [2] ,where all the aspects to be taken into account are collected, so that the component works as well as possible in service. We should not forget that we are talking about components that are subject to fatigue in service. This section of the EN15085 family includes recommendations for fatigue.

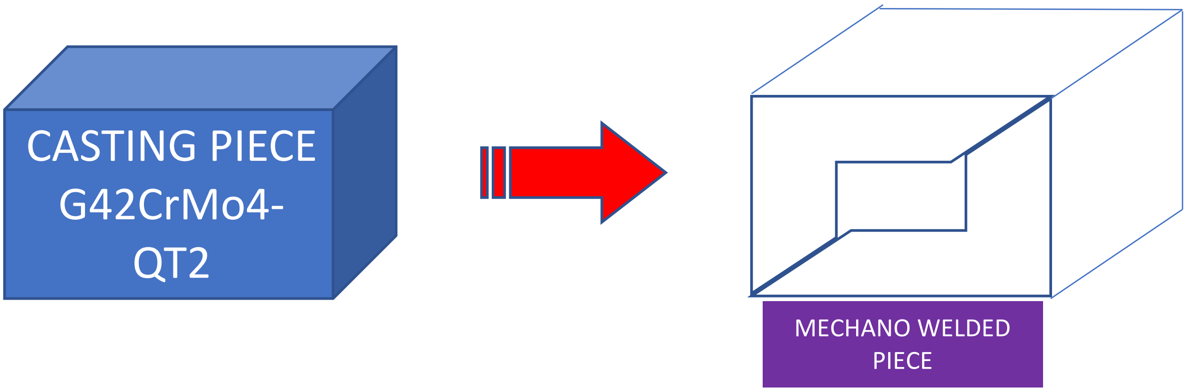


Fig2 Design sketch

In this design phase, when going from a cast piece to a mechano-welded piece, we will have to define apart from the configuration that we want to have the piece, the type of joints that are going to make up our configuration and their preparation and correct welding symbology annotation. For this we will use annex B Preparation of weld joints according to UNE EN 15085-3:2008 [2].

Once we have the design of our mechano-welded component, the next step that we have to take is to know what efforts and solicitations the piece is subjected to, with the aim of choosing the base material and filler metal that will be used to comply such design and effort requirements.

Determination of the loads to which the component is subjected by means of finite element simulation (abacus type, …)

In order to remind, the cast part to be replaced has Re=780MPa and Rm=840Mpa as mechanical properties, this will be usefull as a reference in the simulation of finite elements.

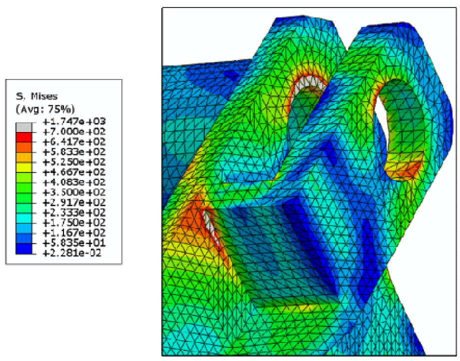


Fig3 Example image of finite element simulation

In order to carry out the simulation of finite elements, it has to be introduced the properties of the base and filler materials that are going to be used in the welded manufacturing.

In the first place, a first approach will be made thinking that the piece is a solid without joints to know the parts with greater tension so that later, a subsequent simulation is carried out with the properties of the base material, those of the filler metal that is going to be used, as well as and where the joints are in order to see if the choice has been correct or not.

In the assumption, the loads to which the cast part is subjected are around 580-600 MPa at the most critical point.

Choice of the base material to be used in the mechano welded component together with the filler metal to be used

The choice of the base material and the filler metal to be used in the manufacture are vital as the proper functioning of the part in service depends on them.

First of all, it has to be remembered that the part is a mechano welded part.

One of the most common mistakes made by engineering is to look at the stresses that it must support, but not to analyze the choice from the perspective of manufacturing according to UNE EN 15085-3 [2].

This usually causes engineering companies to choose a material that, due to its properties and applications, fits to those specifications without any problem, but the section 6.1 according to UNE EN15085-3 [2] is not taken into account.

6.1 Choice of base metals

The base metals should fulfill the requirements of the groups of materials according to the Report CEN ISO/TR 15608 [3] and they should have an established weldability. The weldability according to the Report ISO/TR 581 [4] is considered established if the materials correspond to the appropriate EN standard and are identified as weldable metals by these standards.

First of all, the material needs to have an established weldability and the grouping has to be in accordance with EN ISO/TR 15608 [3].

The base material chosen for this case is according to UNE EN10149-2 [5] S700MC, due to its designation S700MC is weldable with a minimum of Re= 700 MPa and Rm between 750-790Mpa.

The filler metal to choose must be a material with similar properties, so that the joints made in the piece are homogeneous and metallurgical notches are not formed. In the hypothetical case that is developing, the chosen filler material is an EN ISO 16834-A [6]: G 69 4 M Mn3Ni1CrMo with a minimum tensile strength of 770Mpa.

Once the base material and the filler metal have been chosen, the finite element simulation must be carried out with these information, as mentioned above.

After verifing that the results of that simulation are satisfactory, the next step will be to carry out the preparation approach before welding following UNE EN 15085-4: Production requirements [7].

Approach of the qualifications that will cover the welded joints of the component

In order to prepare the piece to be welded, an analysis of the types of joints that has the mechano welded piece must be carried out in order to carry out an approach of different qualifications that fulfill the requirements indicated in UNE EN 15085-4: Section 4 Preparation before welding [7].

The objective of this phase is for the manufacturer of the mechano-welded piece, prior to production, to analyze, on the one hand, whether the materials to be used, with the facilities available, if weldable joints could be achieved without problems of weldability.

The parameters that must be used when manufacturing begins will be reflected it in the workshop welding specifications or welding sheets. These welding parameters, tested, will be the ones that will be also used in the qualification of welders and operators in order to verify their ability and also to see if they are capable to carry out welded production in the workshop.

In the case that is been analyzed, when carrying out the qualification approach according to UNE EN 15085-4: Section 4.2 [7]., it has been seen that it would be necessary to carry out the following qualifications following UNE EN ISO15614-1:2018 [8]:

- FILLET WELD 2mm (FW 2mm)
- FILLET WELD 8mm FW 8mm
- BUTT WELD 3mm (BW 3mm)

First of all the none destructive tests have been realized, specifically visual test and dye penetrant test in all the qualifications and in the butt weld joint the radiography test also has been realized.

In the following table there are some results of the destructive tests realized in the laboratory.

PROCEDURE QUALIFICATION FILLET WELD 2mm

Fillet weld joint qualification with a thickness of 2mm.

MACROGRAPHIC EXAMINATION

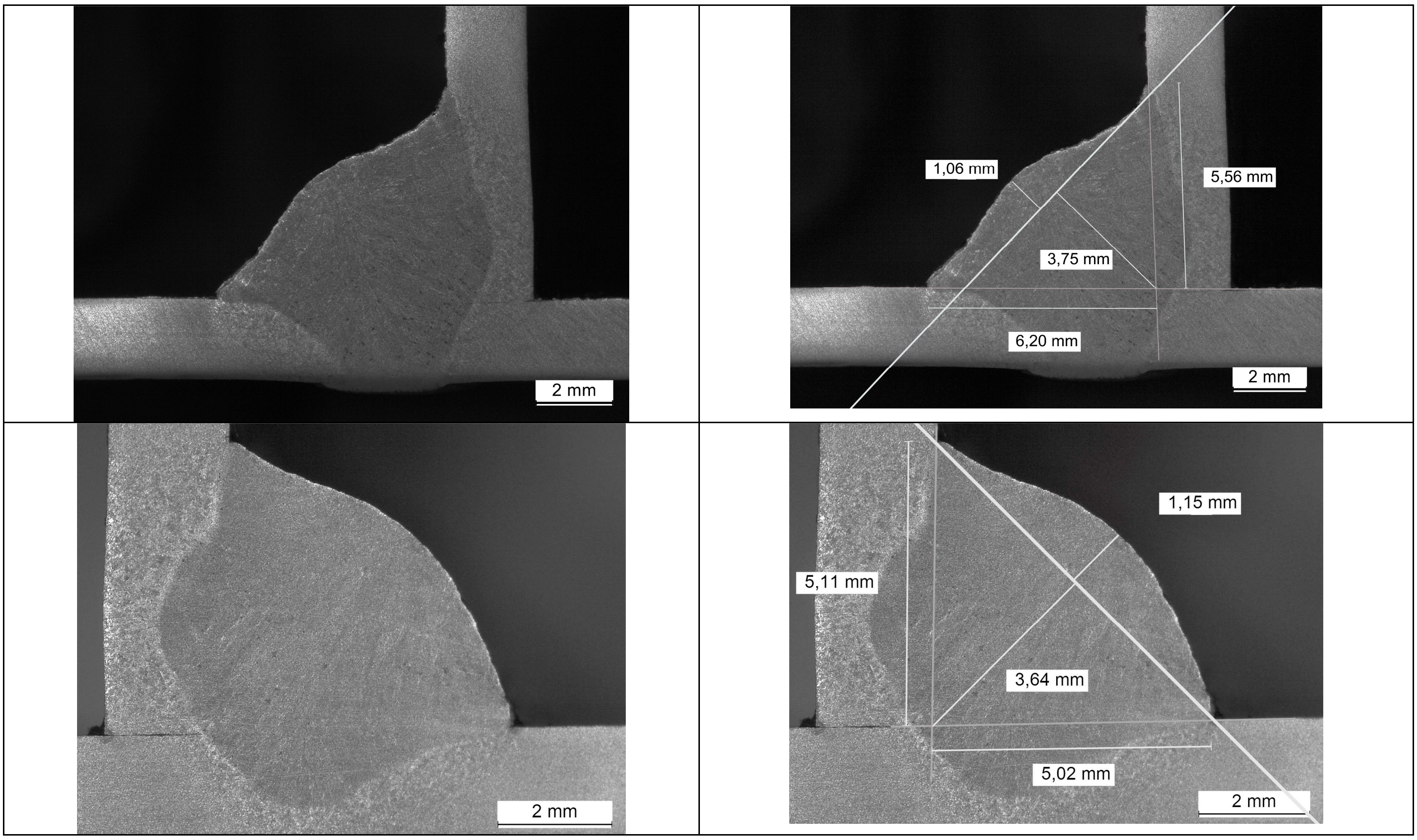


Fig4 Macrographic examination of the 2mm fillet weld sample

The macrographic examination is satisfactory according to ISO 17639 [9] .

HARDNESS TEST

Ref. Ext.	Type of hardness	Zone	M.Base1			ZAT1			Cordón			ZAT2			M.Base2		
			H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15
FW e2 (S700MC) _PM	HV10	Center	294	296	269	227	227	230	246	245	242	223	223	223	233	223	286

Table1 FW 2mm hardness test results

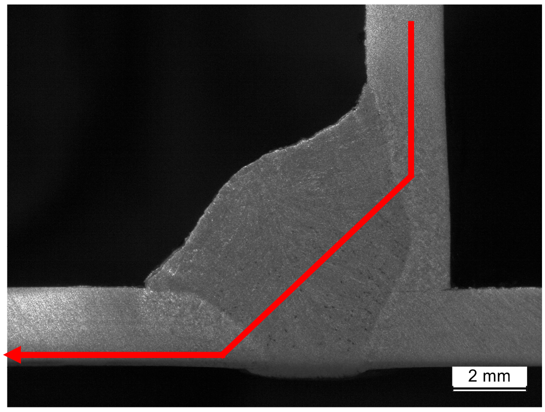


Fig5 Hardness test of the 2mm fillet weld sample

This material belongs to the group 2.2 according to ISO/TR 20172 [10] ,and as it has not any post welding heat treatment, the maximun hardness value could be 380 HV according to the table 3 of the standard UNE EN ISO 15614-1 [8]. The obtained hardness values are acceptable being lower than 380HV.

PROCEDURE QUALIFICATION FILLET WELD 8mm

Fillet weld joint qualification with a thickness of 8mm.

MACROGRAPHIC EXAMINATION

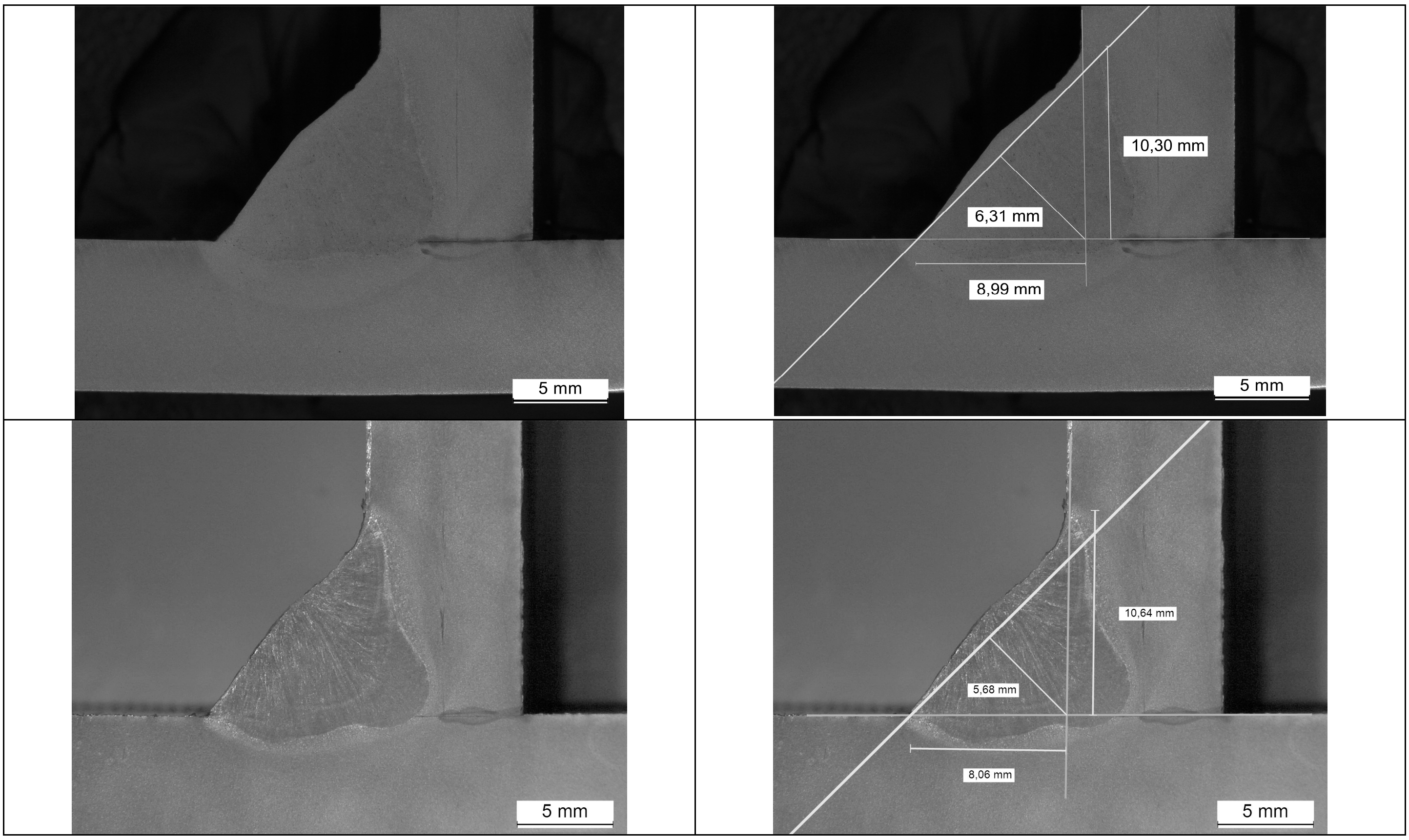


Fig6 Macrographic examination of the 8mm fillet weld sample

The macrographic examination is satisfactory according to ISO 17639 [9].

HARDNESS TEST

Ref. Ext.	Type of hardness	Zone	Base material 1			HAZ1			Welding			HAZ2			Base material 2		
			H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15
FW e8 (S700MC) _JS	HV10	Face	290	289	293	235	225	234	243	245	246	231	239	238	294	290	287
	HV10	Root	290	286	267	221	223	230	233	233	231	226	231	228	301	303	295

Table2 FW 8mm hardness test results

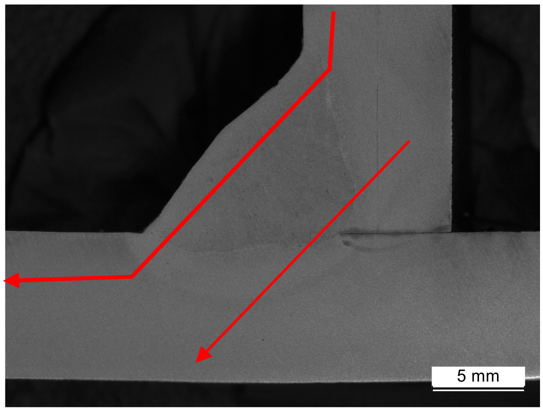


Fig7 Hardness test of the 8mm fillet weld sample

In this case also, being the same material as in the previous qualification, the obtained hardness values are acceptable being lower than 380HV.

PROCEDURE QUALIFICATION BUTT WELD 3mm

Butt weld joint qualification with a thickness of 3mm.

MACROGRAPHIC EXAMINATION

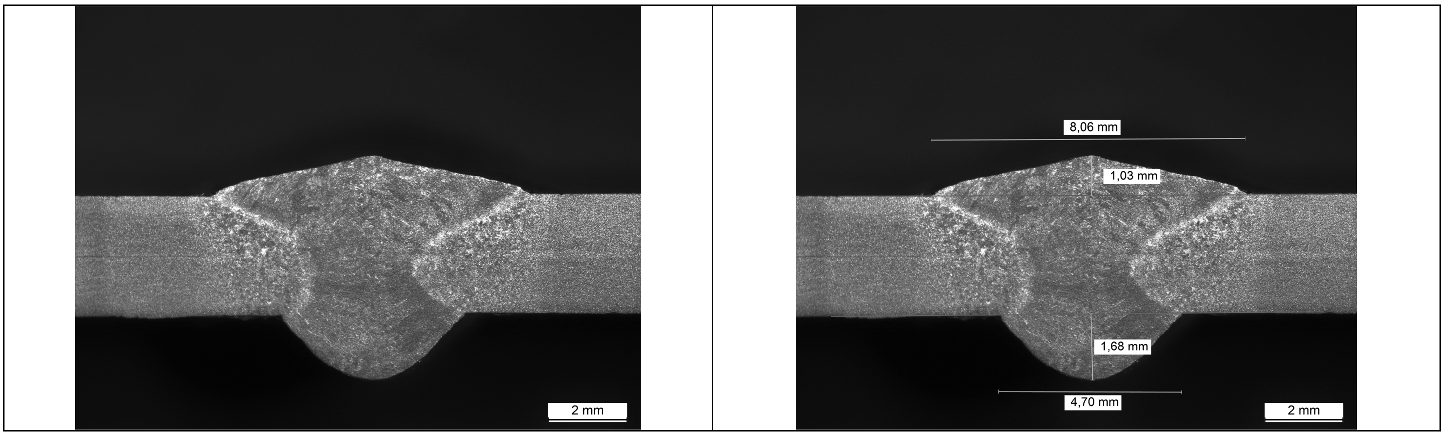


Fig8 Macrographic examination of the 3mm butt weld sample

The macrographic examination is satisfactory according to ISO 17639 [9].

HARDNESS TEST

Ref. Ext.	Type of hardness	Zone	Base material 1			HAZ1			Welding			HAZ2			Base material 2		
			H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15
BW e3 (S700MC) PM	HV10	Center	271	282	284	206	202	211	227	219	219	216	199	194	280	286	280

Table3 BW 3mm hardness test results

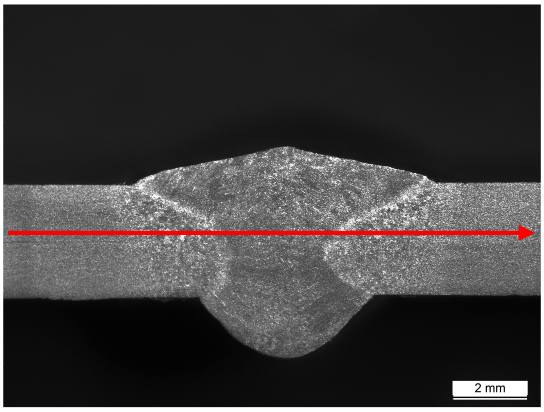


Fig9 Hardness test of the 3mm butt weld sample

In this case also, being the same material as in the previous qualifications, the obtained hardness values are acceptable being lower than 380HV.

BEND TEST

The bend test has been realized according to ISO 5173 [11] and the result has been satisfactory not having any open defect greater than 3mm.

Ref. Ext.	Localization	Tipo	b(mm)	a(mm)	D(mm)	L(mm)	α	Resultados	Observ.
BW e3 (S700MC) PM	> 25 mm extreme	TFBB	20,61	2,825	12	21	180	Satisfactory	-
	> 25 mm extreme	TFBB	19,82	2,828	12	21	180	Satisfactory	-
	> 25 mm extreme	TRBB	20,15	2,730	12	21	180	Satisfactory	-
	> 25 mm extreme	TRBB	20,34	2,838	12	21	180	Satisfactory	-

a: Thickness; b: width; D: diameter of the „mandrino“ ; L: roller distance

Table4 BW 3mm bend test results

Fig10 Images of the bend test of the 3mm butt weld sample

TENSILE TEST

In the following table there are the tensile test results realized to two samples of the 3mm thick butt weld coupon.

Ref. Ext.	a (mm)	b (mm)	S_0 (mm^2)	Fm (N)	R_m (MPa)	R_e (MPa)	L_0 (mm)	A (%)	Breaking zone
BW e3 (S700MC) PM	2,61	25,01	65,28	56794	870	835	130	15,0	Base material
	2,745	24,95	68,49	59792	873	837	130	14,0	Base material

a: Thickness; b: width;S: section; F_m: Maximun strength; R_m : Tensile stength; R_e : Yield strength; A(%): Elongation

Table5 BW 3mm tensile test results

The result of the tensile test realized according to ISO 4136 [12] are satisfactory. In the following table there are the minimun values for tensile test for the material S700MC according to EN 10149-2 [5].

Thickness	Yield strength R_e (Mpa)	Tensile strength R_m (Mpa)	Elongation A_{80} (min%)	Elongation A_5 (min%)
2-3	700	750-950	10	12

Table6 S700MC tensile test results according to EN 10149-2 [5]

Carrying out an analysis of these results, it can be affirmed that the results are satisfactory. With these satisfactory results, it is possible to move on to the manufacturing phase of the mechano-welded component.

Manufacture of the component

After preparing the welding planning documentation, incorporating the information from the approved welding specifications or the welding sheets published for use in the workshop, the manufacture of the component in its different phases or sequences will be carried out by qualified welders and operators.

Once the piece has been manufactured, it is ready for the next phase, that will be carrying out the inspections according to UNE EN 15085-5: Inspection, tests and documentation. [13]

Inspection of the component according to execution class and inspection class

For this inspection phase it has to be remembered that the mechano welded piece is cataloged by its certification level as CL1, execution class as CPB and inspection class CT2.

The tests to be carried out during the manufacturing according to UNE EN 15085-5 [13] are in the table1:

Tabla 1 – Ensayos a realizar durante la fabricación

Clase de inspección	Ensayo volumétrico RT o UT	Ensayo superficial MT o PT	Examen visual VT
CT 1	100 % [a]	100%	100 %
CT 2	10% [a b]	10 % [b]	100 %
CT 3	No requerido	No requerido	100 %
CT 4	No requerido	No requerido	100 %

In order to apply the tests of the table 1, it will be necessary to analyze whether they can be applied or not, due to the configuration or definition of the joints to be inspected or due to the limitation of the techniques to be applied, some of them cannot be applied, as for example, the volumetric tests for joints such as FW2 and FW8, applying the following tests for these cases:

- 100% visual test
- 10% superficial test

Among the superficial tests and being a magnetizable material in the supposed analysis, the magnetic particle test will be applied.

Once the mechano-welded component has been inspected and after possible repairs obtaining the CPB quality level, the validation of the prototype will be carried out.

Prototype validation (eg: fatigue test)

In this final phase, once the component has been manufactured, it has to be validated for what it has been conceived for, replace a part manufactured by casting with a mechano-welded part that works correctly in service without suffering damage that could lead to component breakage.

In this case, the piece will be subjected to loads on the fatigue equipment, subjecting the part to different cyclic loads, simulating the fatigue that it could suffer in a railway vehicle.

During the fatigue test, each time a load cycle is completed, the piece will be tested doing the same tests as those marked in UNE EN 15085-5: Table 1 [13] in order to see if there had been indications that after some cycles become defects.

In this case, there has not been seen any indication or defect being the prototype validated.

PLANNING FOR REPAIRS ACCORDING TO UNE EN 15085-2:2021[1] OF CASTING PIECE

As mentioned at the beginning of the article, the process of designing, manufacturing and validating the welded component that will replace the welded part is a long process and the manufacturer must have some parts that were initially defective and using a reparation porcess that the component can be acceptable again, being able to be used again as the initial component. These repairs would be carried out before the component is in service, not having suffered fatigue.

For this analysis, the critical points where during the manufacturing is possible to appear defects, will be evaluated in order to select the most critical and classify them and suggest a repair guideline for each of them.

In this repair guideline, different cavities made with different tools will be defined in order to design the optimal cavity that, when carrying out the repair, helps to make suitable repairs.

The phases are the following ones:

- cavity design
- Qualification of welding procedures according to UNE EN 15085-4: Section 4.2 Work Specimens [7]

Cavity design

The design of the cavity will be carried out based on the type of defect that is usually detected: linear crack, lack of punctual material...

The configuration of the cavities will be as in the following images:

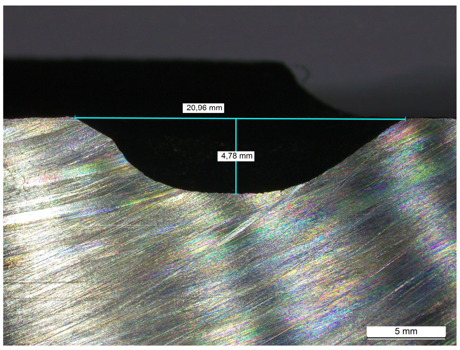


Fig11 and fig 12 Samples of cavity design

After the realization of the cavities, the repairs will be carried out by welding process.

Qualification of welding procedures according to UNE EN 15085-4: Section 4.2 Work Specimens [7]

As said previously, the casting component is made of G42CrMo4-QT2 material with a Re=780MPa and Rm=840Mpa, and according to EN15085-2 Table1 [1] it is a CL1 classification level component.

The filler material used to make the joint is EN ISO 16834-A [6]: G 69 4 M Mn3Ni1CrMo.

According to UNE EN 15085-4: Section 4.2 Work Specimens [7], this type of cavity cannot be represented with a standard specimen, but it can be represented by means of work specimens based on UNE EN ISO 15613 [14], where the cavity designed guarantee the welding conditions that will be welded.

In the analysis of the welding of the cavity, it is necessary to obtain an adequate joint, without production defects, as the one seen in the following image.

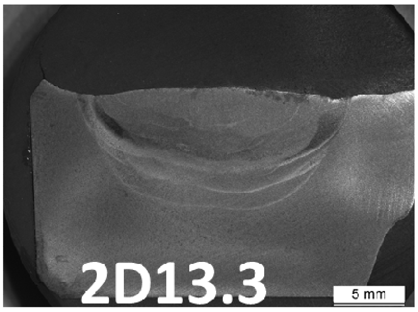


Fig13: Macrographic characterization of the cavity

Following the standard EN15613 [14], a micro-hardness characterization will also be realized in order to see if the properties after welding are good and comply with the standard.

In this phase the results were satisfactory and this phase developed in parallel to the design and manufacture of a mechano-welded component that will replace the cast part, is also favorable.

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[9] ISO 17639 Destructive tests on welds in metallic materials — Macroscopic and microscopic examination of welds

[10] ISO/TR 20172 Welding — Grouping systems for materials — European materials

[11] ISO 5173 Destructive tests on welds in metallic materials — Bend tests

[12] ISO 4136 Destructive tests on welds in metallic materials — Transverse tensile test

[13] UNE EN 15085-5 Railway applications - Welding of railway vehicles and components. Part 5: Inspection, testing and documentation.

[14] UNE EN ISO 15613 Specification and qualification of welding procedures for metallic materials — Qualification based on pre-production welding test

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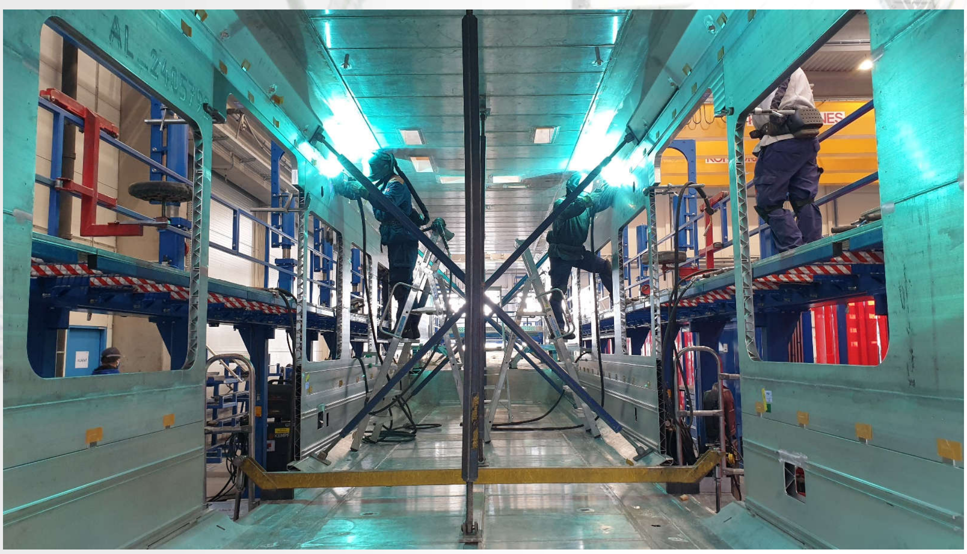
In the past and today, car bodies in railroad car construction are still using welding filler metals on spools or wire baskets.



Manual welding in car body construction

In many productions spools are still common, especially at welding gantries

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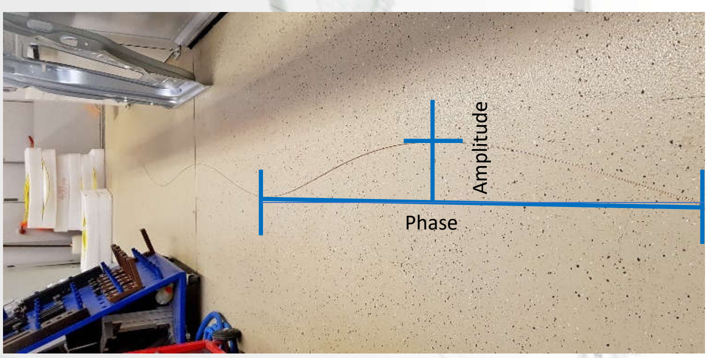
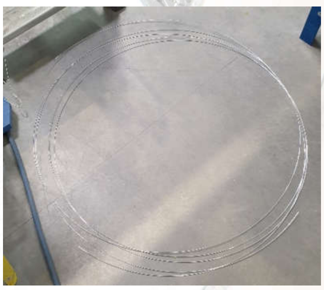
These can be spools with 7, 20 or 40 kg net wire weight. The spool diameter varies here from diameter 300 mm (7 kg), 350 mm (20 kg) or 400 mm (40 kg).

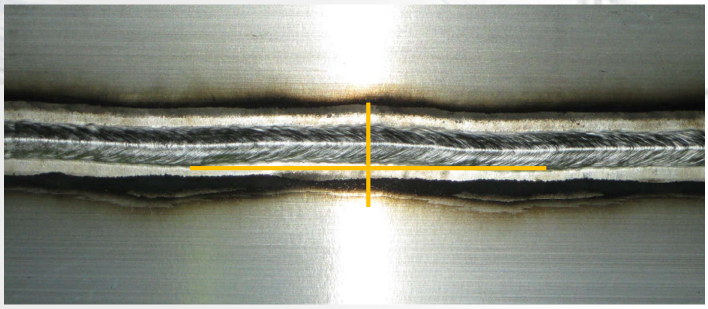
This has the advantage that no further wire feeding problems occur when unwinding the wire electrode from the spool. A method that has proven itself over decades. The disadvantage is the decreasing diameter of the spool combined with a deterioration in the positioning of the wire electrode. If only there were not the eternal danger that the employee can fall off the ladder during the spool change and have an accident. This could affect other employees who could be hit by falling objects. This means: "Increased sick leave".

Or, that an enormous amount of time is spent to fulfill work safety requirements. This means: "No production during the spool changing time".

What´s make the difference between drum and spool wires?







The problem with wire electrodes from drums is the torsional stress. This can be larger or smaller by a different drum size.
The welding result is reflected by the wire electrode lying on the floor as shown in the left upper picture.
Depending on the length of the stick out. More or less, the welding seam looks like a sine wave shape

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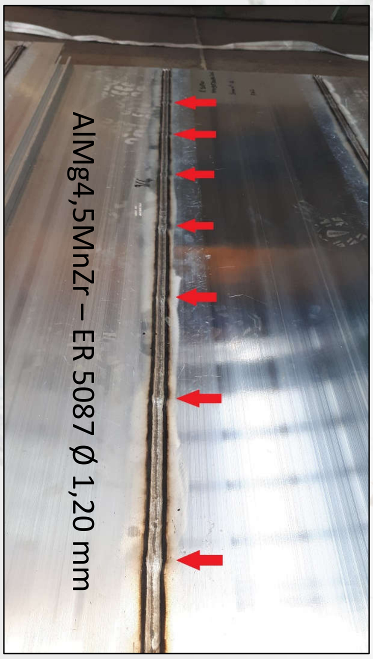
Development of the use of drum wire in the construction of Aluminium car bodies



Twin Tandem Process by
2 x ER5087 Ø 1,20 mm

Welding from the drum without any wire straightening

Development of the use of drum wire in the construction of Aluminium car bodies

Welding from the drum with a guide pulley

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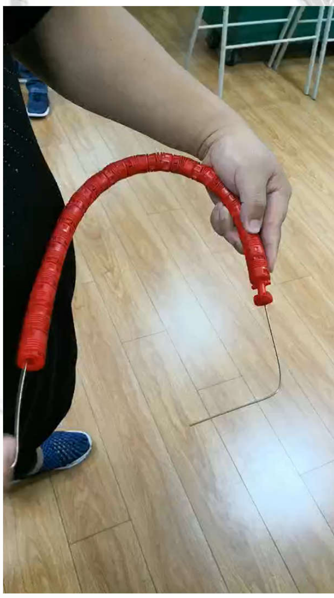
Requirements for a transformation from the spool to the drum

What to think about in advance are:

- Define targets
- Investment costs and savings
- Determine the necessary space, consider traffic routes
- Which drum size is suitable for my installation.
- Necessary load capacity of the welding gantry - System suitability
- Installation possibility of the wire conduit (HDPE Liner) and drum
- Reliable permanent removal of the torsional stress
- First wire feeding drive, a concentric setup above the drum is a must
- Selection of suitable wire conduit or rollliner (Microglide or….)
- Good and reliable partners for the installation

Influence of the wire conduit installation - drum to wire feeding system



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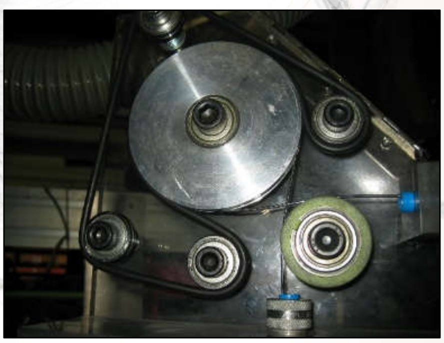
Impact of the wire feeding installation – drum to wire feeding system

Wire straightening with a guide pulley



Original

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Development of the use of drum wire in the construction of Aluminium car bodies

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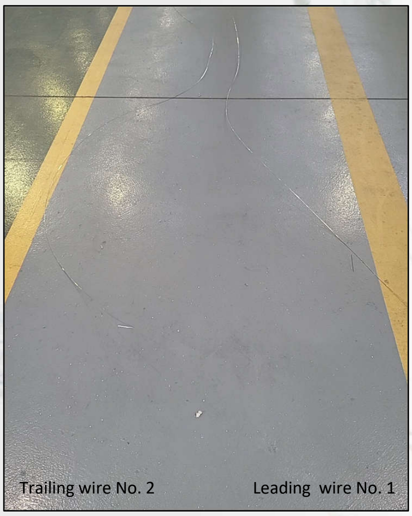
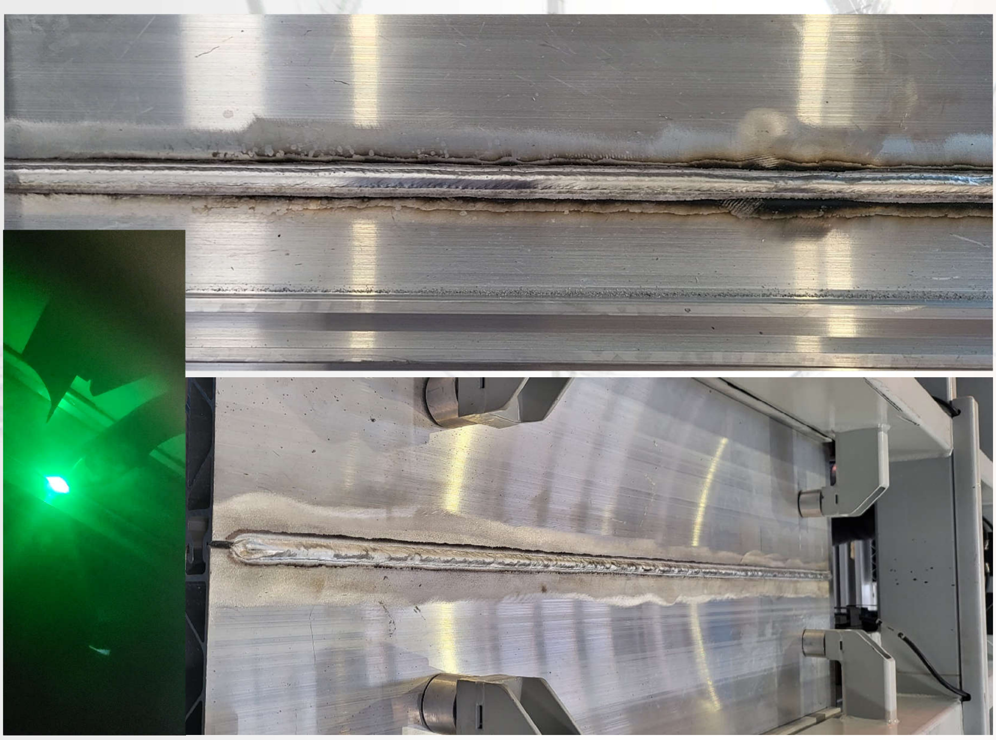
Impact of the wire feeding installation – drum to wire feeding system



Impact wire straightening by using of a guide pulley

Impact of the wire feeding installation – drum to wire feeding system



Previous Twin Wire feeding process

Safra Twin Wire

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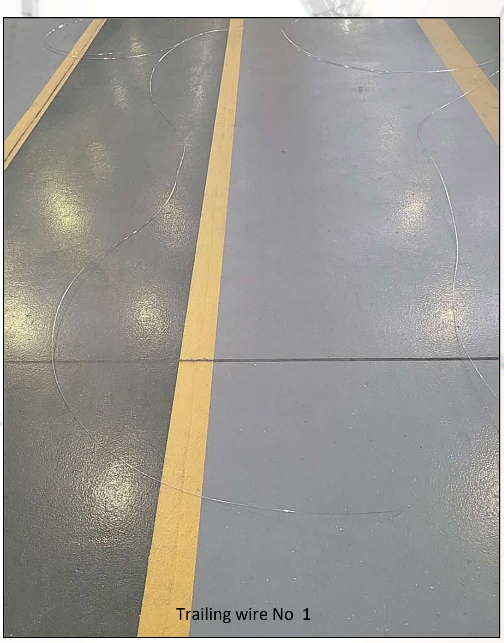
Development of the use of drums in the rail-road car production

ALUMINIUM • COPPER ALLOYS WELDING WIRE

Development of the use of drum wire in the construction of Aluminium car bodies


Trailing wire No 1


Trailing wire No 1

After wire straightening by a two plan seven roller wire straightener

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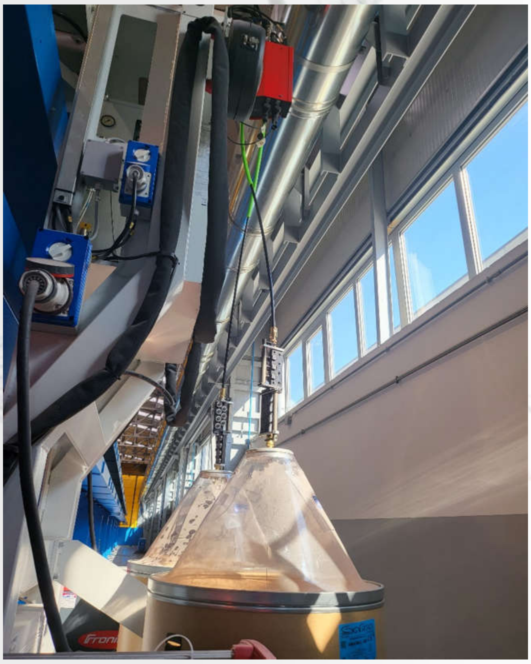
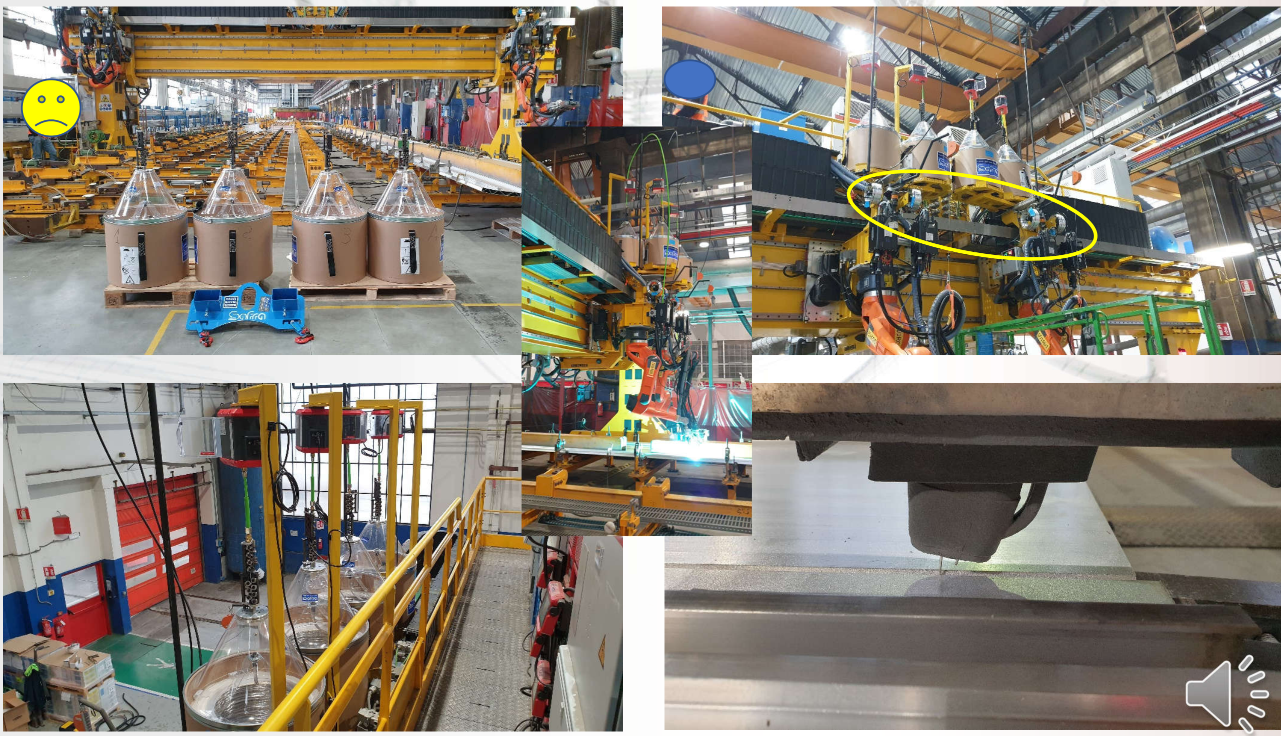
Development of the use of drum wire in the construction of Aluminium car bodies



Solution for use in prefabrication in railroad car production



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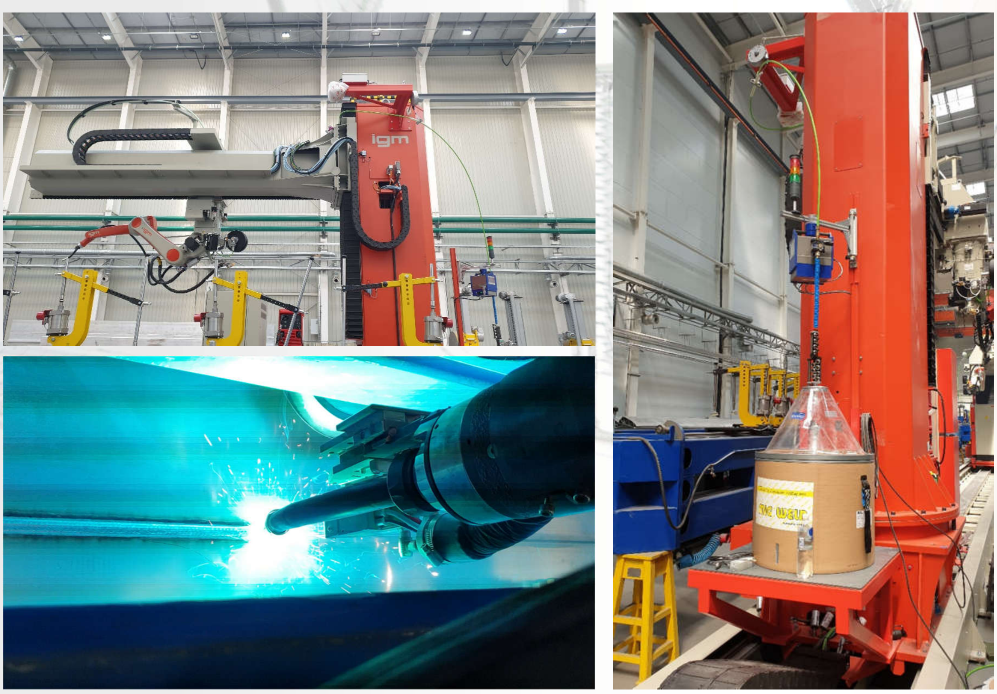
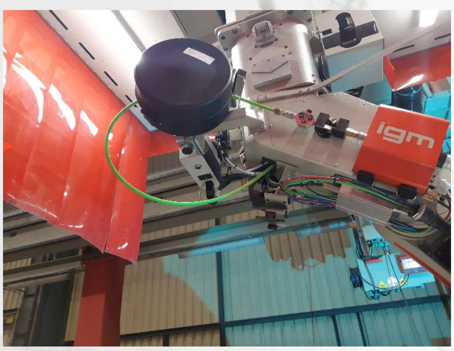
Solution for use in prefabrication in railroad car production



Solution for use in prefabrication in railroad car production



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Solution for use in prefabrication in railroad car production

Cost advantage by using of drums versus spools

Cost comparison in between Standard Spools of 7 kg, 20 kg Spool, Speed Pac "Nano" 40 kg until Speed Pac "Gigante XL"- 250 kg									
Type of Packaging:	**Spool B300-7 kg**	**Big Spool D350-20 kg**	**Big Spool K400-40 kg**	**Speed Pac 52 "Nano"**	**Speed Pac 65 "Piccolo"**	**Speed Pac 52 "Standard"**	**Speed Pac 60 "Square"**	**Speed Pac 65 "Grande"**	**Speed Pac 75 "Gigante XL"**
Weight of wire per packaging [kg]	**7 kg**	**20 kg**	**40 kg**	**40 kg**	**100 kg**	**80 kg**	**140 kg**	**200 kg**	**250 kg**
Weld wire consumption per year [kg]	**10.000 kg**								
Number of spool replacements per year [units]	1429	500	250	250	100	125	71	50	40
Time of replacement per type of packaging [min]	**30**	**30**	**30**	**15**	**15**	**15**	**15**	**15**	**15**
Time of replacement per year [min] for a yearly consumption of 10.000 kg	42.857,14	15.000,00	7.500,00	3.750,00	1.500,00	1.875,00	1.071,43	750,00	600,00
Total spool-change time [h] for	**714,29**	**250,00**	**125,00**	**62,50**	**25,00**	**31,25**	**17,86**	**12,50**	**10,00**
1.Costs related to spool replacements :									
Operational costs for robot and operator [€/h]	**85,00 €**								
Costs for spool replacement per year	**60.714,29 €**	**21.250,00 €**	**10.625,00 €**	**5.312,50 €**	**2.125,00 €**	**2.656,25 €**	**1.517,86 €**	**1.062,50 €**	**850,00 €**
2.Additional costs related to the use of drum packages :									
Purchasing price [€ / kg]	**10,00 €**	**10,11 €**	**10,19 €**	**10,29 €**	**10,29 €**	**10,29 €**	**10,29 €**	**10,29 €**	**10,29 €**
Welding wire costs per year [€ / year]	100.000,00 €	101.100,00 €	101.900,00 €	102.900,00 €	102.900,00 €	102.900,00 €	102.900,00 €	102.900,00 €	102.900,00 €
Total cost per year (Welding wire cost + spool replacement cost)	**160.714,29 €**	**122.350,00 €**	**112.525,00 €**	**108.212,50 €**	**105.025,00 €**	**105.556,25 €**	**104.417,86 €**	**103.962,50 €**	**103.750,00 €**
3.Quality / Using grade									
Cost per hour for manual repair work	**55 €**								
Manual re-work quantity [%]	5,00%	4,00%	3,80%	3,80%	0,50%	3,80%	1,20%	0,50%	0,20%
Cost for repair work per year	**4.400,00 €**	**3.520,00 €**	**3.344,00 €**	**3.344,00 €**	**440,00 €**	**3.344,00 €**	**1.056,00 €**	**440,00 €**	**176,00 €**
4. Effort for replacements of wear parts									
Parts cost for the replacement of contact tip and liner Contact tip or liner or both [€]	**12,00 €**								
Perform maintenance after a wire volume of [kg]	**7**	**7**	**7**	**7**	**15**	**15**	**15**	**15**	**20**
Amount of maintenances [Maintenance]	1429	1429	1429	1429	667	667	667	667	500
Time to replace wear parts / components [min]	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
Time to replace wear parts / components [h]	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25
Total effort in hours [h]	357,14	357,14	357,14	357,14	166,7	166,7	166,7	166,7	125,0
Total effort in money [€]	**36.785,71 €**	**36.785,71 €**	**36.785,71 €**	**36.785,71 €**	**17.166,67 €**	**17.166,67 €**	**17.166,67 €**	**17.166,67 €**	**12.875,00 €**
5. Financial lost due to not welded parts because of maintenance, spool exchange time / per station									
Possible amount of welded parts / Station per hour [Pcs]	**0,2**								
Lost of profit per part [€]	**200,00 €**								
Lost of profit per hour [€]	40,00 €	40,00 €	40,00 €	40,00 €	40,00 €	40,00 €	40,00 €	40,00 €	40,00 €
Lost of profit per year [€]	**14.285,71 €**	**14.285,71 €**	**14.285,71 €**	**14.285,71 €**	**6.666,67 €**	**6.666,67 €**	**6.666,67 €**	**6.666,67 €**	**5.000,00 €**
TOTAL COST	**216.185,71 €**	**176941,43 €**	**166940,43 €**	**162627,93 €**	**129298,33 €**	**132733,58 €**	**129307,19 €**	**128235,83 €**	**121801,00 €**
Cost savings with the use of 20 kg, 40 kg Spool, Speed Pac 52 Nano 40 kg until Speed Pac 75 Gigante XL 250 kg compared to 7 kg Spools									
Savings for a yearly consumption of	**10.000 kg**	**39244,29 €**	**49245,29 €**	**53557,79 €**	**86887,38 €**	**83452,13 €**	**86878,52 €**	**87949,88 €**	**94384,71 €**

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JOIN TRANS 2022: 6TH EUROPEAN CONFERENCE „JOINING AND CONSTRUCTION OF RAILWAY VEHICLES“

MAY 11TH – 12TH 2022, WARSAW POLAND

Dr. Axel Jahn, Dr. Mirko Riede, Dr. Elena Lopez, Dr. Jens Standfuss,

Fraunhofer IWS, Dresden, Germany

Laser based welding and additive manufacturing technologies for advanced metallic railway structures

Laser based welding and additive manufacturing technologies for advanced metallic railway structures

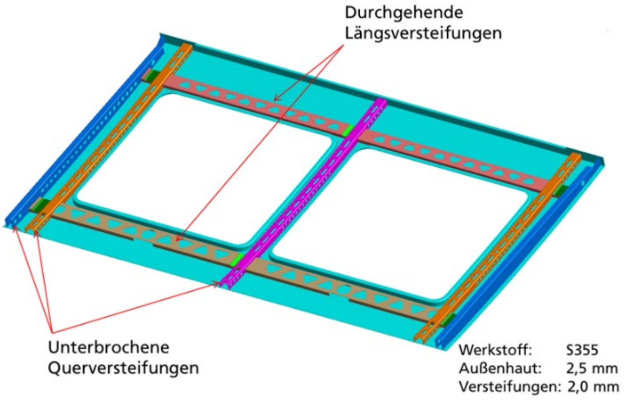
Dr. Axel Jahn, Dr. Mirko Riede, Dr. Elena Lopez, Dr. Jens Standfuss, Fraunhofer IWS, Dresden, Germany

1 Overview

The presentation shows the possibilities of laser-based manufacturing processes for the production of metallic structures in rail vehicle construction and deals with the possibilities of laser beam welding as well as additive production using the example of side wall structures.
The reduction of vehicle weight and production costs are major development drivers in the field of rail vehicle body-in-white. Low-heat joining processes such as laser beam welding in conjunction with an adapted process-compatible component design are a solution approach for the area of side walls in metallic construction, which was demonstrated in the context of a publicly funded project using the example of a tram side wall. For the innovative sidewall construction, a homogeneous outer skin sheet with closed stiffening profiles welded in the T-joint is used. By eliminating the usual joining flanges (overlap joints for resistance spot welding) and the full connection of the profiles to the outer skin sheet, a significant weight saving is possible and at the same time the structural rigidity is increased. The specially developed laser welding process guarantees high component quality and reduced manufacturing effort through distortion-free welding at high welding speeds.
On the other hand, additive processes now offer the possibility of manufacturing highly stressed areas as bionic structures in lightweight construction. Using powder-based and wire-based processes, stiffening structures can be applied directly to the outer skin. The presentation shows results of investigations for a bionic design of directly mounted stiffening structures in the area of a side wall.

2 Laser welding solutions

Laser welding design
In a joint project between research institutions and rail vehicle manufacturers, process- and load-compatible integral lightweight constructions were developed, processing methods such as laser beam welding were adapted and demonstrator components were manufactured and tested. The objective was to develop new laser-welded integral construction methods for rail-car body assemblies, e.g. side walls, and thereby tap previously unused lightweight construction potential. A necessary prerequisite for the production of integral structures is the realisation of fully enclosed T-joints between the outer skin sheet and the internal stiffening profiles. In order to simultaneously ensure the outer skin quality and minimise component distortion, laser welding without filler material was used as a particularly low-temperature joining technology.



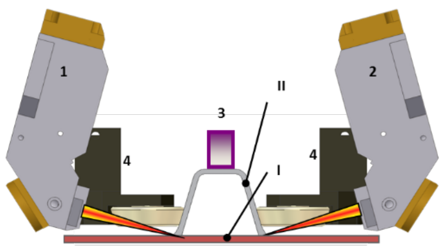


Figure 1: Light-weight design conception, developed for simultaneous laser welding and sketch of welding process for closed stringers

In order to increase the degree of lightweight construction, reduce welding distortion and increase economic efficiency in production, a new type of side wall concept was developed as a laser-welded integral construction. It is based on the stiffening of the outer skin sheet by closed profiles (U- or trapezoidal profile). The essential key points of this concept are:

- welding- and load-compatible integral structure consisting of homogeneous outer skin sheet of constant wall thickness and long, continuous stiffeners as closed U-profiles
- fully enclosed stiffening profiles by means of simultaneous welding with two lasers
- decoupled, non-welded integral nodes

Welding technology
With regard to the defined objective of realising fully enclosed T-joints with high seam quality under very limited accessibility with minimum heat input as well as high welding process speed, the process-technical approach of laser beam welding without filler material was developed. In this process, two laser beams are simultaneously focused on the profile legs at a very flat angle of incidence in order to avoid damaging the outer surface of the outer skin sheet.

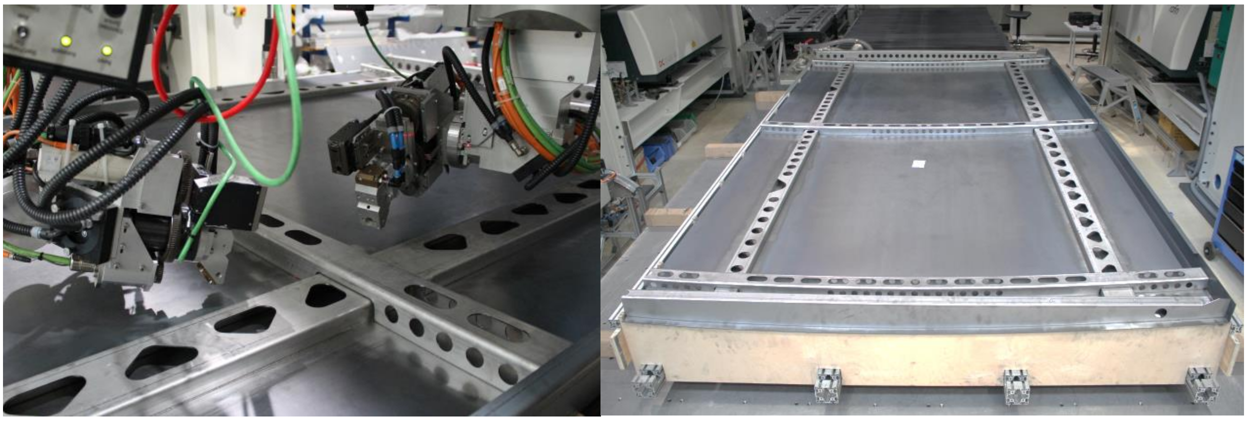


Figure 2: Welding structure of demonstrator parts, detail of integral node (left) and entire tram side wall (right), window openings are inserted subsequently

The welding of the demonstrator tam side walls (4.20 x 2.20 m) was done using the XXL gantry system of the IWS. The outer skin was slightly curved in the vertical direction according to the real construction and therefore formed a three-dimensional welding contour. The use of flexible clamping technology and sensor-guided welding optics made it possible to weld the demonstrator side walls reliably.

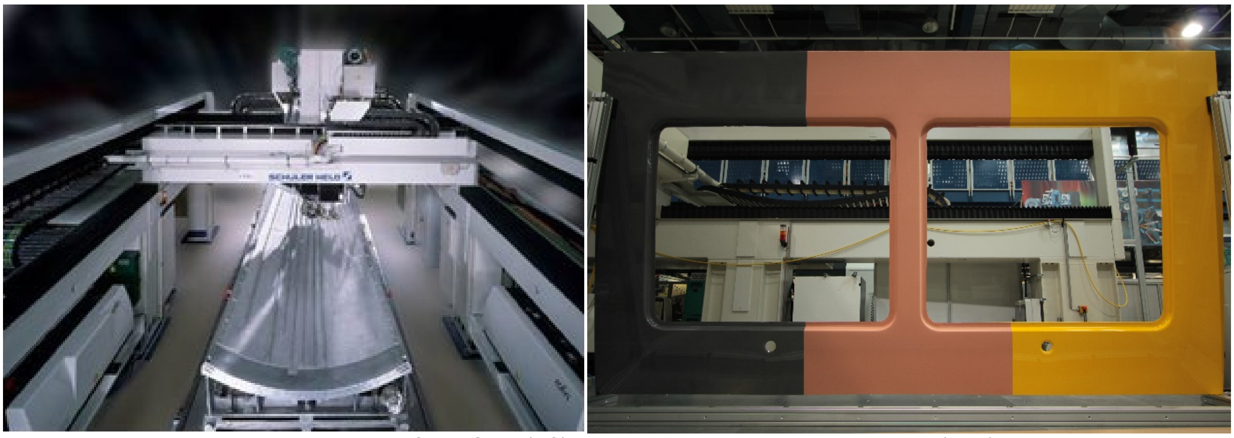


Figure 3: XXL welding machine at Fraunhofer IWS lab (left) and completed side wall demonstrator (right)

In comparison to the reference component, a weight saving of more than 10 % could be achieved through the lightweight construction. Laser welding also guarantees a very good outer skin quality of the welded integral structure. In particular, a drastically reduced component distortion compared to conventional production was achieved, without any additional straightening work. In the demonstrator structure realised, a maximum outer skin curvature of less than 1 mm per 1 m measuring length occurred.

3 Additive manufacturing solutions

DED is an additive manufacturing process that, due to its properties, has no intrinsic limits in the manufactured part dimension and it´s limited only by the used automation system (e.g. CNC, Robot arm, etc.). This characteristic allows, independently from the part dimension, to exploit the advantages of AM tech-nologies, such as: reduction of manufacturing steps and assembling, topology optimization, material waste reduction and lead times reduction.

Technology

DED processes are a subgroup of AM technologies in which the energy source and the material are fed together directly on the application point to generate a part layer by layer. Consequently, DED is already exploited in a variety of industrial sectors (aerospace, naval, automotive, etc.) for three main applications: build-up near net shape parts, complex features addition to pre-existing parts and components repair. The metal feedstock material is usually in the form of wire or powder, while different energy sources are used both in research as well as in industries. Fraunhofer IWS is focusing on lasers as energy source, hence the process name Laser Metal Deposition (LMD), given the wide range of processable materials, the high level of control over the energy input and the high flexibility in the geometrical characteristics of the deposited material that can be tailored to each part requirements.

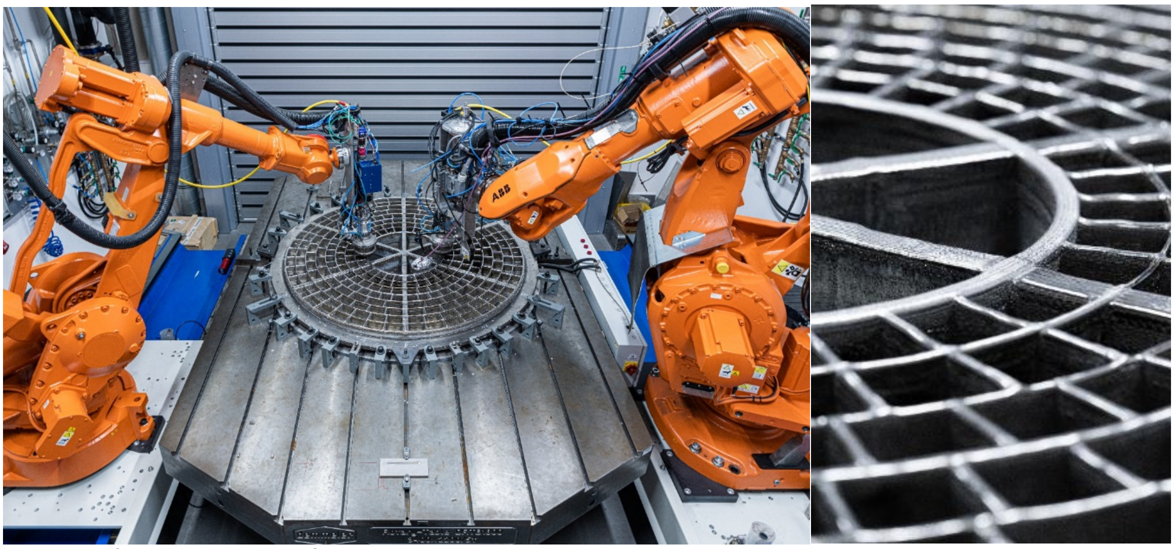


Figure 4 Left: Parallel build-up of titanium space part by Laser Metal Deposition using cooperating Twin Robot and novel shielding system “COAXshield” to guarantee required material properties. Right: Detail of large-scale demonstrator without annealing colors

Topology optimization of rail vehicles sidewall elements

Sidewalls of rail vehicles are a significant example of parts that are conventionally produced through a long manufacturing chain of cutting, chamfering, welding and assembling steps. LMD was successfully integrated in the manufacturing chain of a 1.7m wide and 2.5m high demonstrator. To do so, the deposition strategies are developed and tested for each challenging geometrical feature and then implemented into the full part. All the steps required to produce and assembly the vertical and horizontal stiffening structures were replaced with a single and automated LMD step. Moreover, a topology optimization analysis on the reinforcement geometry was performed to minimize the final weight of the component while keeping the same stiffness of the part.

Figure 5 Left: Geometrical feature of the final part manufactured by wire-LMD. Right: Full demonstrator by powder-LMD manufactured at Photon AG

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Prof. Dr. Wolfgang Rösch, Institute for Railway Vehicle Maintenance, Leipzig, Germany

Welding Processes in Railway Vehicle Maintenance in accordance to the Technical Part of the fourth Railway Package of the European Union

Welding Processes in Railway Vehicle Maintenance in accordance to the Technical Part of the fourth Railway Package of the European Union

Prof. Dr.-Ing. Wolfgang Rösch, Leipzig, Germany

1 Introduction

The fourth Railway Package oft the European Union set some binding regulations, inter alia, for the maintenance of Railway Vehicles. This applies also to welding procedures in the frame of maintenance. The regulations determine procedures regarding safety of vehicles and the responsibility of the entity in charge of maintenance (ECM) therefore. The role of a welding supplier in maintenance and his interaction with the ECM is also defined in the regulations.

2 Task

On the one hand in these regulations are given in a binding way the definitions for safety critical and safety relevant components of vehicles. On the other hand the welding standards EN 15085 gives also definitions of safety related components and their classification. The presentation shows the relationship between both rules and gives advises to the interaction between welding suppliers in maintenance tasks and the ECM of the vehicles.

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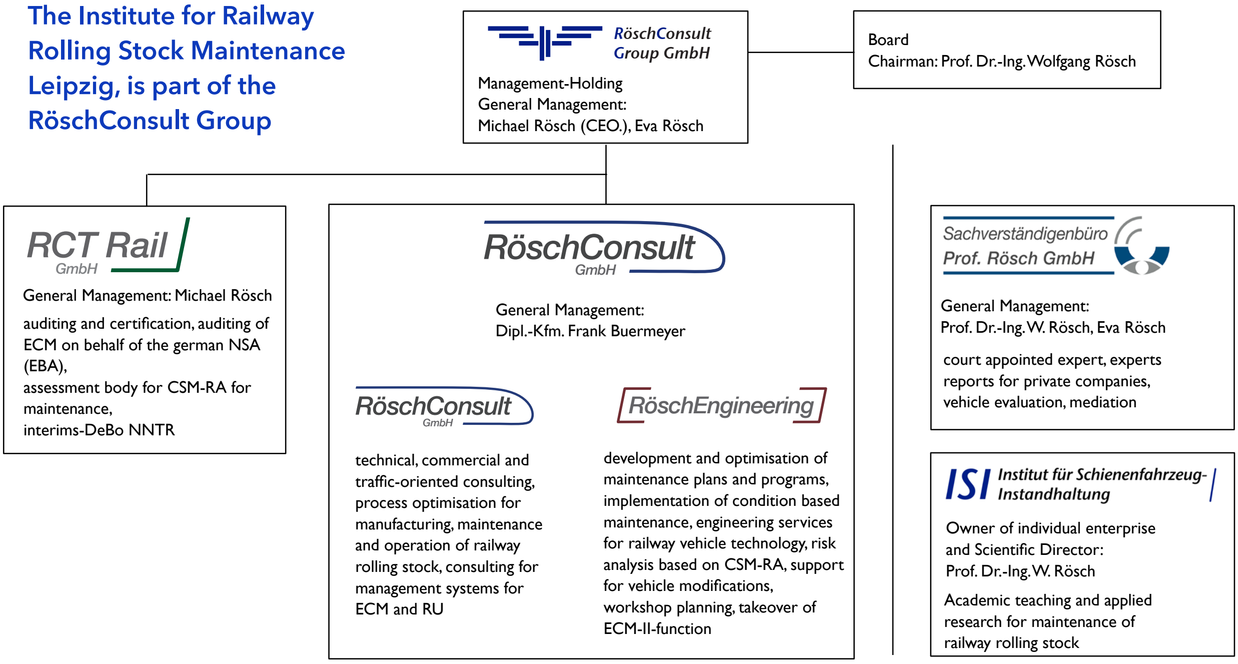
Welding Processes in Railway Vehicle Maintenance in accordance to the Technical Part of the fourth Railway Package of the European Union

Safety relevance of components in the welding standards and safety criticality of components in the EU-regulations

Prof. Dr.-Ing. Wolfgang Rösch, Institute for Railway Rolling Stock Maintenance, Leipzig, Germany

The Institute for Railway Rolling Stock Maintenance Leipzig, is part of the RöschConsult Group



EU-Regulations for Railway Safety in operation and maintenance of railway rolling stock

The technical part of the 4th railway package of the European Union is valid since June 16th 2020.

It covers new versions of Directives and Regulations / Delegated Regulations for railway safety.

A new regulation (2018/762) is binding for RU´s and IM´s containing requirements for the content and processes of their safety management systems.

All RU´s and IM´s must have a new safety certificate based on these rules after ending the current safety certificate (latest in five years).

EU-Regulations for Railway Safety in operation and maintenance of railway rolling stock

The ECM of all railway vehicles (not only freight wagons as in the past) have to fulfill the requirements of a new regulation (2019/779) regarding the content and processes of their maintenance management systems.

Latest at June 16th 2022 all ECM must be certified. For Subcontractors of ECM it is voluntary to be certified.

The european model of different responsibilities for railway safety:

The **Manufacturer (OEM)** is responsible for the safe design and manufacturing in accordance to the Technical Specifications for Interoperability (TSI) and all other technical rules and standards and the National Nominated Technical Regulations (NNTR)	The **Railway Undertaking** (**RU**) is respon-sible for the safe operation based on Dir (EU) 2016/798 and DReg (EU) 2018/762 and regulations given by the infrastructure manager	The **Keeper** is responsible for the designation of the entity in charge of maintenance (ECM), the commercial use of the vehicles and refittings out of maintenance.	**The Entity in Charge of Maintenance** (**ECM**) is responsible for the safe condition of the railway vehicles in accordance to Dir (EU) 2016/798 and DReg (EU) 779/ 2019	The **Infra-structure Manager** (**IM**) is responsible for the safe operation of the railway infrastructure based on Dir (EU) 2016/798 and DReg (EU) 2018/762

EU-Regulations for Railway Safety in operation and maintenance of railway rolling stock

If a manufacturer is working in maintenance works (e.g. also accident repairs) on a vehicle which is just commissioned and under responsibility of an ECM he is not in the role as manufacturer.

In this case the manufacturer is in the role of an maintenance supplier of the ECM in accordance to reg. (EU) 2019/779 Article 9.

EU-Regulations for Railway Safety in operation and maintenance of railway rolling stock

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for maintenance activities including repair works is the manufacturer in the role of a maintenance supplier of ECM

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EU-Regulations for Railway Safety in operation and maintenance of railway rolling stock

The ECM is fully responsible for all works of suppliers and has to control this works.

COMMISSION IMPLEMENTING REGULATION (EU) 2019/779

of 16 May 2019

laying down detailed provisions on a system of certification of entities in charge of maintenance of vehicles pursuant to Directive (EU) 2016/798 of the European Parliament and of the Council and repealing Commission Regulation (EU) No 445/2011

Article 9

Outsourcing maintenance functions

3. The entity in charge of maintenance shall remain responsible for the outcome of the outsourced maintenance activities and shall establish a system to monitor their performance.

Directive (EU) 2016/798 (Railway Safety)

The welding works can be part of function b) (welding engineering) or of function d) (welding works).

Article 14

Maintenance of vehicles

3. The maintenance system shall be composed of the following functions:

(a) a management function to supervise and coordinate the maintenance functions referred to in points (b) to (d) and to ensure the safe state of the vehicle in the railway system;

(b) a maintenance development function responsible to manage the maintenance documentation, including the configuration management, based on design and operational data as well as on performance and return on experience;

(c) a fleet-maintenance management function to manage the vehicle's removal for maintenance and its return to operation after maintenance;

(d) a maintenance delivery function to deliver the required technical maintenance of a vehicle or parts of it, including the release to service documentation.

EU-Regulations for Railway Safety in operation and maintenance of railway rolling stock

The handling of safety critical components is on a special focus in the safety management system of an ECM.

Following I will give some explanations to the relation between safety relevance in the welding standards and the safety criticality in the ECM-regulations.

EU-Regulations for Railway Safety in operation and maintenance of railway rolling stock

There is a difference in the Technical Railway Regulation between safety critical and safety related. The definition for safety critical components is as follows:

Safety critical components - definition part 1

ECM-Regulation

►B COMMISSION IMPLEMENTING REGULATION (EU) 2019/779

of 16 May 2019

laying down detailed provisions on a system of certification of entities in charge of maintenance of vehicles pursuant to Directive (EU) 2016/798 of the European Parliament and of the Council and repealing Commission Regulation (EU) No 445/2011

(Text with EEA relevance)

(OJ L 139I, 27.5.2019, p. 360)

Article 2

Definitions

For the purposes of this Regulation, the following definitions shall apply:

The definition of 'safety-critical component' provided for in section 4.2.12.1 of Annex to Commission Regulation (EU) No 1302/2014 (1) shall apply.

Safety critical components - definition part 2

TSI Loc&Pas

►B COMMISSION REGULATION (EU) No 1302/2014

of 18 November 2014

concerning a technical specification for interoperability relating to the 'rolling stock — locomotives and passenger rolling stock' subsystem of the rail system in the European Union

(Text with EEA relevance)

(OJ L 356, 12.12.2014, p. 228)

Amended by:

		Official Journal		
		No	page	date
►M1	Commission Regulation (EU) 2016/919 of 27 May 2016	L 158	1	15.6.2016
►M2	Commission Implementing Regulation (EU) 2018/868 of 13 June 2018	L 149	16	14.6.2018
►M3	Commission Implementing Regulation (EU) 2019/776 of 16 May 2019	L 139I	108	27.5.2019
►M4	Commission Implementing Regulation (EU) 2020/387 of 9 March 2020	L 73	6	10.3.2020

Safety critical components - definition part 2

TSI Loc&Pas

4.2.12. *Documentation for operation and maintenance*

(1) The requirements specified in this clause 4.2.12 apply to all units.

4.2.12.1. General

(4) The documentation also includes a list of safety critical components. Safety critical components are components for which a single failure has a credible potential to lead directly to a serious accident as defined in Article 3(12) of Directive (EU) 2016/798.

Safety critical components - definition part 3

Safety Regulation 2016/798

DIRECTIVE (EU) 2016/798 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 11 May 2016

on railway safety

(recast)

Article 3

Definitions

For the purposes of this Directive, the following definitions apply:

(12) 'serious accident' means any train collision or derailment of trains resulting in the death of at least one person or serious injuries to five or more persons or extensive damage to rolling stock, the infrastructure or the environment, and any other accident with the same consequences which has an obvious impact on railway safety regulation or the management of safety; 'extensive damage' means damage that can be immediately assessed by the investigating body to cost at least EUR 2 million in total;

Safety critical components:

A single failure has the credible potential to lead directly to

- death of at least one person or
- serious injuries to five or more persons or
- extensive damages of at least two million Euro.

Safety related components:

A failure has the potential to lead to injuries of persons or to extensive damages lower than the criteria above (e.g. definition in EN 17023 Annex B).

EN 15085-2

3.1
safety relevance
description of the consequences of a failure of a welded component in respect to the effects on persons, facilities and the environment

Note 1 to entry: The safety relevance of a welded component is differentiated as follows:

Low: Failure of the welded component does not lead to any direct impairment of the overall function. Consequential events with personal injuries are unlikely

safety relevant?

Medium: Failure of the welded component leads to an impairment of the overall function or may lead to consequential events with personal injuries

safety relevant or safety critical?

High: Failure of the welded component leads to consequential events with personal injuries and breakdown of the overall function

safety relevant or safety critical?

Reg (EU) 2019/779 (ECM)

safety relevant or safety critical?

The decision must be done by the ECM under consideration of the initial documentation of the manufacturer (if existing), not by the maintenance supplier!

►B **COMMISSION IMPLEMENTING REGULATION (EU) 2019/779**

of 16 May 2019

laying down detailed provisions on a system of certification of entities in charge of maintenance of vehicles pursuant to Directive (EU) 2016/798 of the European Parliament and of the Council and repealing Commission Regulation (EU) No 445/2011

(Text with EEA relevance)

(OJ L 139I, 27.5.2019, p. 360)

Article 4

Safety-critical components

1. For managing safety-critical components, the entity in charge of maintenance shall take into account the initial identification of safety-critical components by the manufacturer of the vehicle together with any specific maintenance instructions recorded in the technical files of subsystems referred to in Article 15(4) of Directive (EU) 2016/797.

EN 15085-2 safety relevant or safety critical?

an example:

CL	Component classification
CL 2	New build, conversion and repair of non-pressurized containers without special test pressure, e.g.: — payload container for non-dangerous materials; — other transport containers.

If an ECM should decide that a failure in a welded seam can lead directly to a derailment of the wagon (e.g. due to a specific design) and defined this component as safety critical it should not be rated by the welding supplier in CL 2, it should be rated in CL 1.

EN 15085-3 safety relevant or safety critical?

The consequence can be e.g. a change in the inspection class:

Table 2 — Weld performance classes

Stress categories	Safety categories		
	High	Medium	Low
High	CP A [a]	CP B2 [c]	CP C2
Medium	CP B1 [b]	CP C2	CP C3
Low	CP C1 [d]	CP C3	CP D

Table 3 — Correspondence between weld performance classes and inspection classes

Stress category	Safety category	Weld performance class	Quality levels for imperfections EN ISO 5817 EN ISO 10042 EN 13919-1 EN 13919-2	Inspection class Minimum requirements	Volumetric tests RT or UT Min.	Surface tests MT or PT Min.	Visual examination VT Min.
High	High	CP A	B[a]	CT 1	100%	100 %	100 %
High	Medium	CP B2	B[a]	CT 2	10 %	10 %	100 %
High	Low	CP C2	C[a]	CT 3	Not required	Not required	100 %
Medium	High	CP B1	B[a]	CT 2	10%	10 %	100 %
Medium	Medium	CP C2	C[a]	CT 3	Not required	Not required	100 %
Medium	Low	CP C3	C[a]	CT 4	Not required	Not required	100 %
Low	High	CP C1	C[a]	CT 2	10 %	10 %	100 %
Low	Medium	CP C3	C[a]	CT 4	Not required	Not required	100 %
Low	Low	CP D	D[a]	CT 4	Not required	Not required	100 %

[a] For detail see Table 4 to 6

What is needed?

The responsible welding persons should have knowledge about the ECM-regulations:

EN 15085-2 Annex D:

4 Fabrication, applications engineering Definition of technical knowledge: 1: Basic knowledge of the subject 2: Application and use of principles and rules 3: Overall mastery of the subject 4: Ability to develop method and procedures	Level A	Level B	Level C
4.4. Repair welding			
Understand in detail/understand/refer to repair welding problems both in manufacturing and in service.	4	4	3
Know how about maintenance operations and the related operating criteria.	4	3	2
Coordinate feedback from maintenance welding operations.	4	3	2
Develop weld sequence plans for repair welding	3	3	2
Knowledge about Railway Safety- and ECM-Regulations	4	3	2

additional needed (proposal for the next revision): Knowledge about Railway Safety- and ECM-Regulations

What is needed?

A closed cooperation and communication between welding suppliers and ECM in the maintenance of vehicles which are falling in the responsibility of the ECM, especially in the rating of safety criticality or safety relevance of welded components.

The ECM should know the EN 15085-Standards and the welding supplier should know the Technical Part of the fourth Railway Package of the EU.

What is relevant from the fourth railway Package for welding?

Directive 2016/798 about railway safety (current version 2020)

Directive 2016/797 about interoperability (current version 2020)

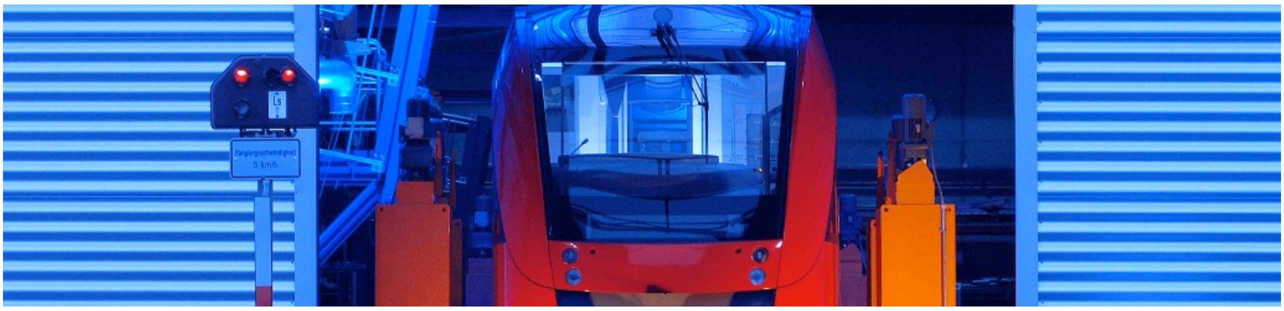
Regulation 2019/779 ECM (current version 2020)

Regulation 1302/2014 TSI Loc&Pas (current version 2020)

Regulation 321/2013 TSI Wag (current version 2020)

ERA Technical Report CEN/TR 17696 Oct. 2021

All EU-documents above can be found under www.eur-lex.



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Thanks for your attention.

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Fatigue resistance of sheet metal sections generated by press-bolts joints due to cold forming

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1 Introduction

The paper is about press elements which are applied in sheet metal construction by forming. Those fasteners belong to functional elements available in form of press-nuts as well as press-bolts. This paper is focused on press-bolt joints, which are equipped with a metric ISO thread according to DIN 13-1 [1] and available in defined property classes related to DIN EN ISO 898-1 [2]. Per definition functional elements are thread carrying fasteners which are applied by forming and operating as nut or bolt [3]. In Figure 1 and example of an industrial application for press-bolts is illustrated in a railway vehicle. The body of the vehicle is equipped with press-bolts to mount e. g. pneumatic hose (Figure 1 - right, bottom). As shown by Figure 1 (right, top) often not all press-bolts are needed for equipment. Tightened (Figure 3 - right) as well as non-tightened press-bolts (Figure 3 - left) exist in the vehicle body. For bolting of components in "thin-walled" sheet metal structures functional elements offer an extremely economical solution. They allow a higher level of automation, combined with the possibility to mount components and assemblies in prefabrication. In comparison to welded studs the investigated press-bolts support defined property classes [2, 4] and therefore offer the opportunity for high strength preloading. Also, the installation sequence is free of welding splatters, without thermal influence on the microstructure and no need to remove coatings on the component surface.

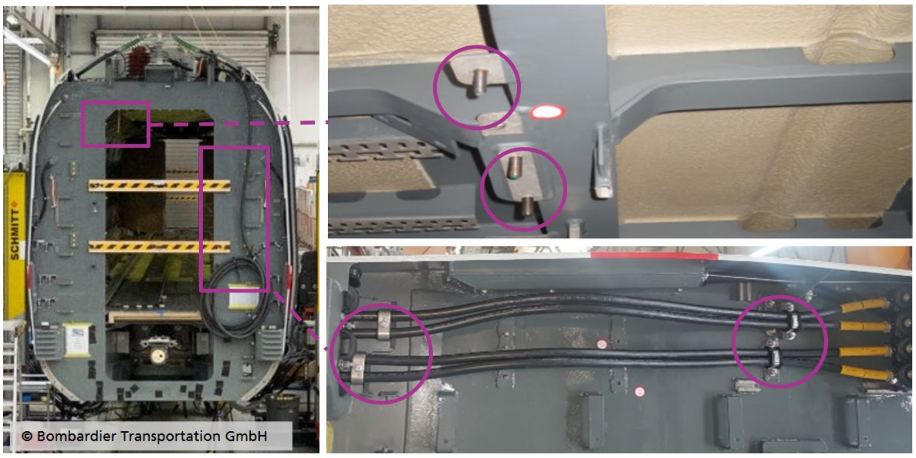

Figure 1: Example for press-bolt execution as bolted (right, bottom) and non-bolted (right, top) application in a railway vehicle

However, the fatigue strength assessment for weld studs can be carried out based on calculations, whereas hardly any experiences are available for the sheet metal sections with installed press-bolts until now. This means that a static and fatigue strength assessment, as it is state of the art for welded joints [5–11] cannot be carried out for press-bolts and thus represents the motivation for the current research project. In order to develop a strength verification, a numerical simulation of the installation sequence (Figure 2) is combined with numerical and experimental investigations to understand the static load capacity in order to verify the numerical simulation in a first step. The approach chosen for this purpose will be described within the present article.

2 Installation sequence and field of applications

As already mentioned, press-bolt are applied by an installation sequence based on cold forming [12, 13]. In the technical bulletin [14], a detailed illustration of the installation sequence is given. The installation sequence by forming into a support component is illustrated in Figure 2 according to technical bulletin DVS/EFB 3440-1 [3]. The carrier component is usually a sheet metal or construction profile.

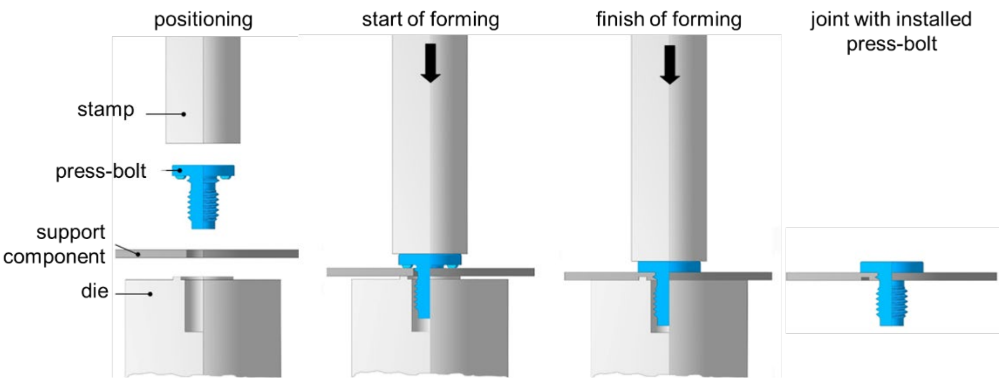

Figure 2: Installation sequence for installation of press-bolts according to DVS/EFB 3440-1[3]

After the installation process two different applications in relation to a further function of the press-bolt are possible. Both applications are illustrated in Figure 3. In application A the press-bolt will not bolted (Figure 3 - left). For application B the press-bolt is tightened with a nut for joining an attached part to the supporting structure (Figure 3 - right).

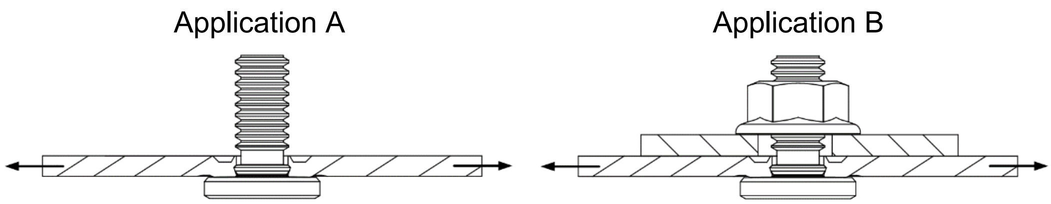

Figure 3: Non bolted (left) and bolted press-bolt joint (right) with transverse loading

The most frequent configuration is application B. In the overwhelming majority of cases the press-bolt joint represents a non-load carrying attachment. Thereby the bolted joint is only subordinated stressed by the connected part. Regardless of the application occurring in final construction, referring to the installation sequence the micro-structure and geometry around the press-bolt is influenced by forming. Moreover, the formed section of the sheet metal creates notches in the supporting structure.

3 Fatigue investigations

The herein discussed fatigue investigations were performed on non-bolted specimens according to application A. Table 1 gives an overview of the experimental program for the press-bolt dimension M8 and M10 and the sample designation. Moreover within Figure 4 the test arrangement is displayed with the test machine ZWICK/ROELL HFP on the left. On the right the design of the specimens are displayed for both investigated diameters.

Table 1: Experimental matrix and designation of test samples

dimension	M8		M10	
supplier	I	II	I	II

	number of evaluable specimens (high cycle fatigue | long life fatigue)			
DC04 s_0 = 1 mm	11 | 17		not recommended	
CR1 s_0 = 2,5 mm	10 | 15	13 |16	2 | −	6 | −
S355 s_0 = 2,5 mm	11 | 25	19 | 18	− | 16	− | 18

	designation						
Key	application	supplier	dimension	metal	thickness	orientation	no.
Example	A	II	M8	CR	2,5	0	01

The cyclic testing was performed as constant amplitude loaded test with a frequency between 65 and 95 Hz in load-controlled mode. The stress ratio was always set to R = 0,1. Aim of the testing was to describe experimentally the high cycle fatigue as well as the endurance limit respectively long life fatigue in the S-N-curve. In the high cycle fatigue between 10^4 and $2{\cdot}10^6$ load cycles testing was finish by a frequency offset of 10 Hz, which corresponds to a macroscopic technical crack.

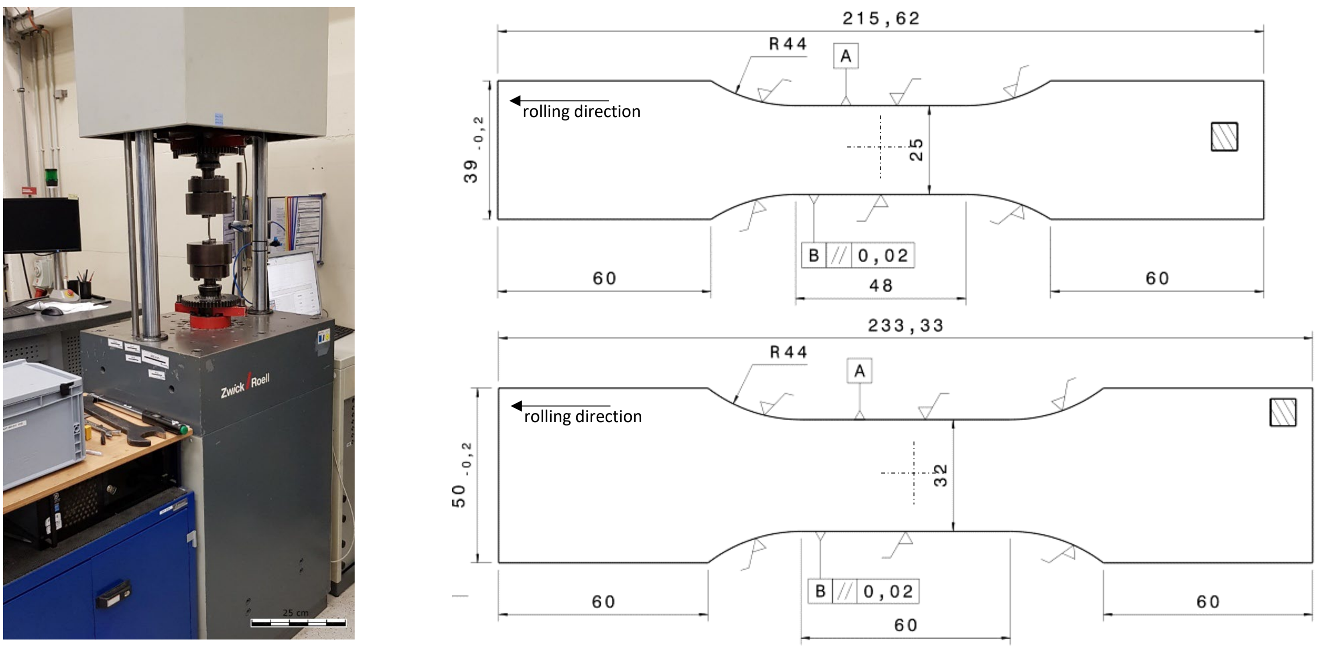

Figure 4: High-frequency pulsator ZWICK/ROELL HFP (left) and specimen for press-bolts M8 (right, top) and M10 (right, buttom)

Thereby, the individual tests were performed as string of pearls ("Perlenschnurverfahren") to describe the slope of the S-N-curve. The determination of the endurance strength was done using a statistic evaluation of run outs and fractured specimens in the transition region of the S-N-curve. Run outs were counted for $N = 2{\cdot}10^6$ load cycles. As procedure for statistic evaluation of the endurance strength the staircase method ("Treppenstufenversuche") was applied. The chosen statistical evaluations were in accordance to DIN 50100 [15]. All data points which are plotted or calculated are considered with nominal stresses referring to the gross cross-section.
The crack initiation always occurred in the formed sheet metal section as result of the cyclic tests. Thereby the fracture could locate in the longitudinal axis next to the press-bolt or sometimes in the net cross-section as well. Now the fractographical investigations are not yet completed to determine the exact location and the crack propagation. An essential question is related to the strength of the support component and its influence on the fatigue resistance. Therefore, the two steels CR and S355 as support material were compared. The experimental determined mechanical properties are given in Table 2. Both steels were used with a blank rolled surface in a nominal sheet thickness of s_0 = 2.5 mm.

Table 2: Mechanical properties of materials

s_0 = 2,5 mm	CR1				S355
rolling direction	0°	45°	90°		90°
E [GPa]	207	206	190	E [GPa]	195
R_{eH} [MPa]	222	227	221	$R_{p0,2}$ [MPa]	343
R_m [MPa]	320	329	317	R_m [MPa]	508
A_{80} [%]	42	35	44	A_{60} [%]	28

Figure 5 displays the results of the cyclic tests in S-N-curve with a probability of survival $P_Ü$ = 0,975. It should be mentioned that all fracture modes are considered in Figure 5. The steels are graphically separated, whereby the low strength steel CR is displayed with unfilled circles and dashed lines. The higher-grade steel S355 is presented with filled dots and continuous curves. Additionally, the two suppliers are separated by colour.
In dependency of the supplier Figure 5 shows different slops of the S-N-curve in high cycle fatigue. The installation sequence in combination with the characteristic bolt geometry leads to higher gradient of slope for supplier II. Anyway, for both supplier the fatigue resistance of the formed sheet metal section rises by increasing the tensile strength of the support structure. For welded components like weld-studs a rising strength of the adherend disappears in consideration of the notch sharpness in the transition to the weld seam [16–18].

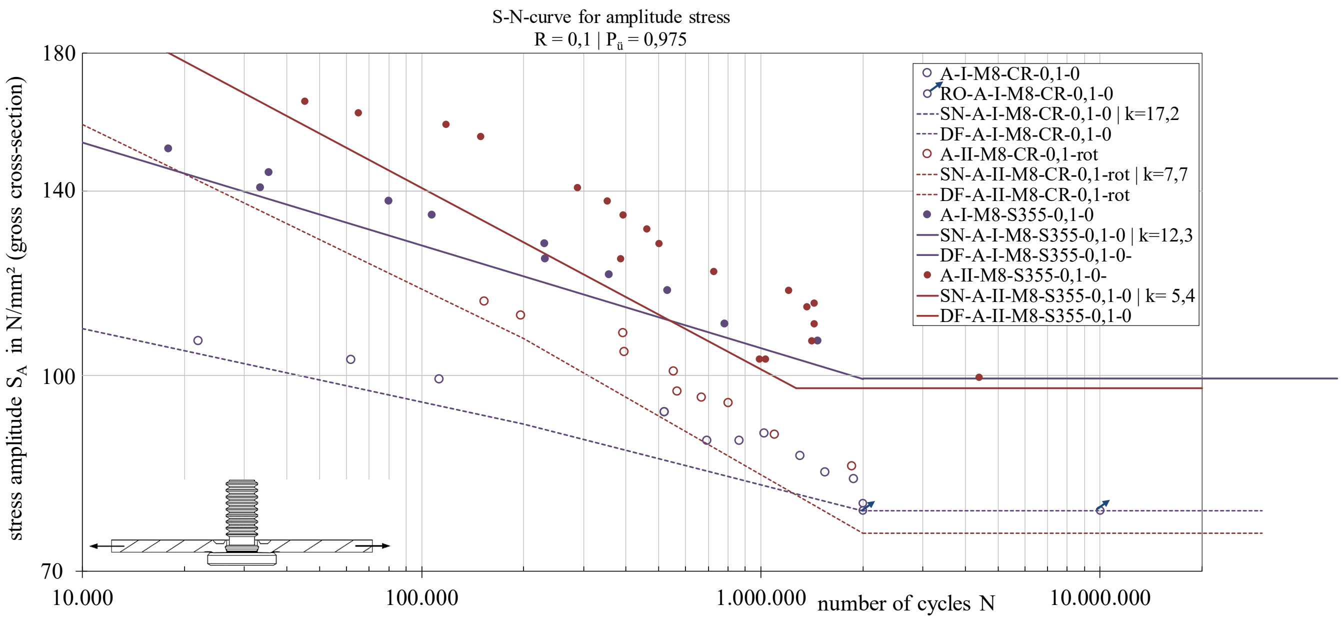

Figure 5: S-N-curves for two different steel grades and supplier

4 Numerical simulations

Numerical simulations were carried out in order to establish a valid model for determining stresses for a subsequent fatigue analysis. A simulation of the ultimate load is intended to provide information about the mechanical behaviour of the formed joint and the location of crack initiation. These results are then compared with experimental determined load-displacement-curves as well as the location of failure. In order to be able to perform a load simulation with the most accurate connection geometry, a detailed finite element (FE) model was derived from numerical forming simulation of the installation sequence (Figure 2).
The issue is whether the structural stress concept can be used as an estimation considering its mechanical assumptions. The structural stress concept is designed for welded joints and works with FE simulations in which bond contacts or merged nodes of base and weld material are used. The reason for this is that the fatigue life of welded joints is largely dependent on the geometry, metallurgical notch effect and residual stresses. As a result, the material strength has a minor role [16–18].

Therefore, the question here is whether the bond contact model provides a sufficient representation of the mechanical behaviour within the limits of the cyclic loads to be expected. The comparison of the load-displacement-curves in Figure 6 shows that the bond contact model provides the best accuracy within the limits intended for cyclic loading. The friction contact model

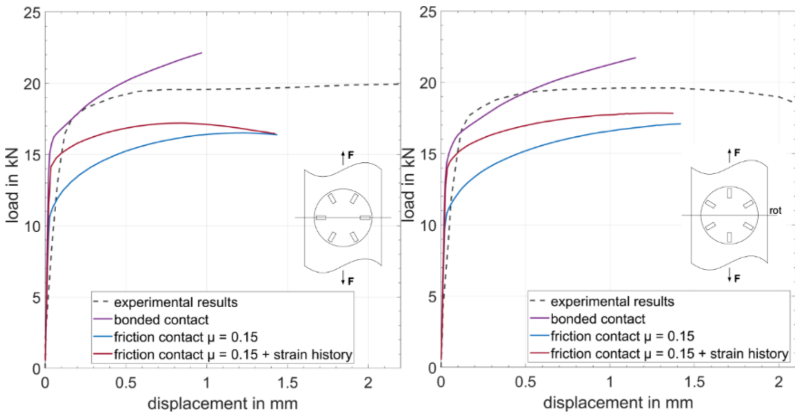

Figure 6: Comparison of the numerical and experimental load-displacement-curves for two different arrangements

(blue curve) shows with respect to the force-displacement-curves that they indicate premature quit the linear gradient. Also, the consideration of the initial strains, which represent the solidification due to the installation sequence (red curve), still shows a high discrepancy to the experimentally determined data (dashed curve). The bond contact model (purple curve) provides sufficient agreement with the load-displacement-curve for the cyclic relevant load range, in which only small displacements are permissible.

Furthermore, when comparing the experimental curves of the load-displacement-curves (dashed, left and right), a negligible difference of the load-displacement behaviour can be seen. Thus, the dependence of the different orientations of the press-bolts on the mechanical behaviour can be ruled out.

The location of the maximum principal stress in the FE model is also consistent with the incipient crack locations. For this the results of the FE analyses also provide an agreement with the bonded contact. While the assumption of a frictional contact shows the one maximum stress and thus the potential crack location in the area of the net cross section, the assumption of a bonded contact shows a maximum stress in the longitudinal section plane in front of the bolt regardless of the orientation. This numerically determined location of the initial crack location with the experimental studies on cyclic behaviour (fatigue tests) can be justified by the load-bearing effect of the bolt. This ensures that the bond contact model can be considered for cyclic stress determination. The ultimate load simulation has shown that modelling the press bolt connection via a bond contact provides the best results for estimating the correct failure location. However, a complex detailed model is impractical in terms of design analysis for the user, since local mesh refinements and complex material models are necessary. Substitute models are widely used state of the art, they reduce the modelling effort considerably and are thus available to users as a simple tool for stress evaluation [19, 20].

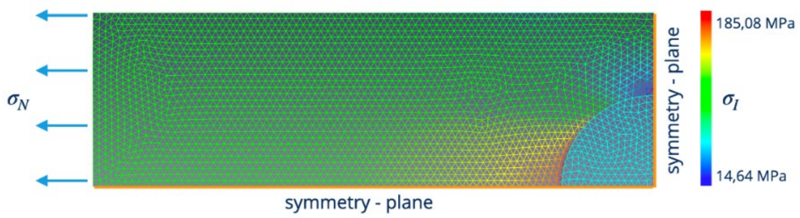

Figure 7: Shell model used for structural stress approach

For the transfer to a surrogate model, the location of the maximum stress should therefore be similar. The shell model is recommended as a substitute model, which allows the load-bearing effect of the bolt to be modelled with a circular disk. A surrogate diameter was abstracted, which describes the diameter of the crack initiation determined in experiments.

The key advantage of using a shell model is its low meshing effort and its practicability. In [20], a substitute model based on shell elements was already used for punch riveted joints. The intention is to follow a comparable modelling approach here.

The shell model (Figure 7) used in the current project was modelled with plate thickness and height of the bolt head as shell thickness. The material assignment is carried out as an elastic material, as it is also the case in common guidelines [9, 10]. In addition, the stiffness of the bolt was adjusted in such a way that a sufficiently high accuracy in terms of fatigue life estimation is later achieved. Here the Young's modulus of the bolt head was multiplied with the factor 50 compared to the sheet metal of the support structure.

The results of the fatigue tests can be fitted by S-N-curves. In order to develop an estimation method that provides a universal applicability, it is advisable to use a master S-N-curve with nominal stresses first (Figure 8, left). This represents a large number of fatigue life data points and can be used for various geometries, load cases, material thicknesses and similar. [21]

The influence of the fatigue resistance resulting from the material strength of the support structure is not considered separately according to Figure 5.

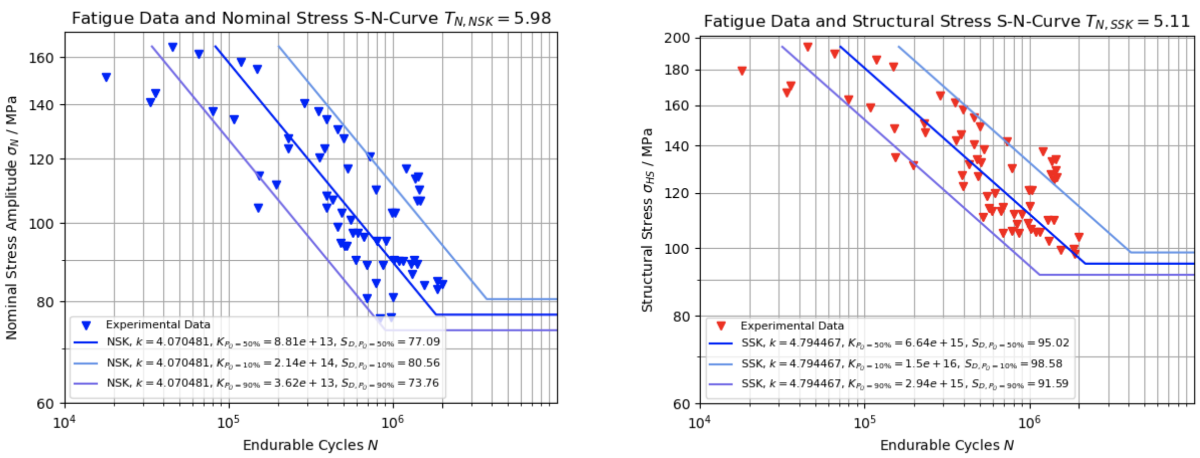

Figure 8: S-N-curves for nominal stress (left) and hot-spot stress (right) for countable data, without consideration of sheet metal strength influence

A common method to determine the reliability of an estimator is the evaluation of the scattering margin when comparing experimental and calculated fatigue life in the probability chart. Estimation by means of nominal stress concept and master S-N-curve leads here to a scattering margin of $T_{N,NSK}$ = 5.9.
The structural stress concept follows the approach of calculating a fictitious stress quantity (hot-spot-stress), which represents fatigue a value captures the stress increases due to the structure. Those quantity can be determined by various approaches, which is then compared with the fatigue resistance, e.g. structural stress S-N-curve. In analogy to the IIW guideline [10], the approach used here follows surface extrapolation to estimate the relevant hot-spot-stress. Figure 9 shows the surface extrapolation procedure as used in the IIW guideline [10].

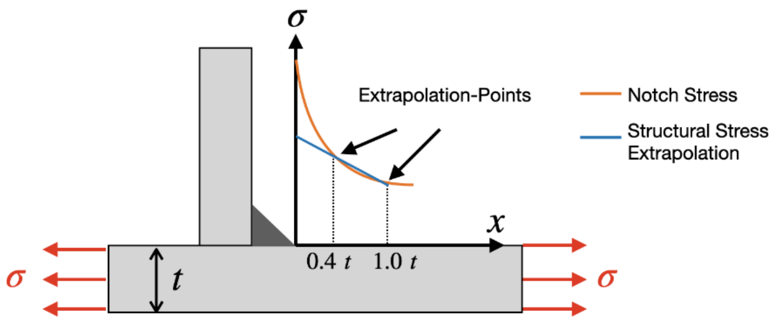

Figure 9: Surface extrapolation for determining hot-spot-stress according to IIW guideline

The structural stress concept, which applies in combination with the IIW guideline [10] for welded joints, uses specified extrapolation distances. These extrapolation distances are specified in [22] for the determination of a hot-spot-stress. In order to adapt the structural stress concept used for the application of press-bolt joints, the extrapolation distances were optimized. While the IIW guideline suggests the extrapolation, support points x_1 = 0.4·t and x_2 =1.0·t (Figure 9), a significant improvement was achieved with the support point combination x_1 = 6.05·t and x_2 = 6.15·t. The corresponding S-N-curve is illustrated in Figure 8, right.
Compared to the nominal stress approach, an improvement of the accuracy was achieved by reducing the scatter margin from $T_{N,NSK}$ = 5.98 (nominal stress approach) to $T_{N,SSK}$ = 5.1 (structural stress approach). This corresponds to an improvement in the estimation accuracy of 17 %.

5 Summary and outlook

In the present paper systematic static and fatigue investigations were carried out on cold formed press-bolt joints. First the numeric simulation model was validated by comparing the experimental load-displacement-behaviour. Then two influences on the fatigue resistance were determined here in testing. These two influences are the press-bolt supplier and the material strength of the support structure. It could be demonstrated that the material strength is able to increase the fatigue resistance in relation to the tensile strength. Also, the influence of the supplier could be highlighted in the S-N-curve by different slopes in high cycle fatigue. Especially the increasing fatigue resistance characterises a significant advantage in relation to welded studs.
Furthermore, the data were used to establish a local fatigue estimation based on the structural stress approach. It could be shown, that it is possible to summarize the fatigue data to fit nominal stress master curves for steel support structures. Additionally, a local stress approach could be introduced and specified with a local stress master curve. This local stress master curve was transferred from the nominal stresses master curve by surface extrapolation due to FE analysis. As last step, the extrapolation points were optimized with aim to reduce scattering margins and increasing accuracy of the local approach.

6 Acknowledgment

The IGF-research project (Nr. 20475BR) of the European Research Association for Sheet Metal Working (EFB), Lothringer Straße 1, 30559 Hannover has been funded by the AiF within the programme for sponsorship by Industrial Joint Research (IGF) of the German Federal Ministry of Economic Affairs and Climate Action based on an enactment of the German Parliament.

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

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