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Carmen A. PETRESCU (POPIȘTEANU)

TEZĂ DE DOCTORAT

Cercetări privind îmbunătățirea tehnologiei de recondiționare prin sudare a port-garniturilor de frecare de la vagoanele de călători

Research on improving welding reconditioning technology of the friction liner from passenger cars

-Rezumat-

COMISIA DE DOCTORAT

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Content

Foreword

The present doctoral thesis's main topic was a research, to improve reconditioning technology through welding of the friction linings holder from the passenger coaches.

The doctoral program consisted of preparing, presenting and taking exams and scientific reports, deepening the study, proposing and developing reconditioning technologies that can be transferred and implemented immediately in organizations that aim to repair this critical component of the safety system. During the research, several welding technologies were analyzed and verified using different welding procedures, such as shielded metal arc welding (SMAW), also known as manual metal arc welding with a coated electrode, flux-cored arc welding semi-automatic (FCAW) and automatic (FCAWm). Based on the results, an optimized reconditioning technology was developed, the results being presented at international conferences or published in journals.

Throughout the period in which I carried out the theoretical and practical research that led to the completion of the doctoral thesis, I was guided and supported in an impeccable academic manner and of high professional and human standing by Mr.Prof.Univ.PhD.Eng. Gheorghe SOLOMON, scientific coordinator of my doctoral studies and thesis.

I benefited from the permanent involvement and invaluable help of Mr. Conf.Univ.PhD.Eng. Dumitru-Titi CICIC, who was always beside me in the theoretical and experimental journey of the thesis realization, professionally guiding the research, the articles and the content of the thesis.

For the high-quality analysis and interpretation part of the metallographic tests performed in the LAMET laboratory within UPB (www.lamet.ro), RENAR accredited laboratory with Certificate no. LI 754 / 12.02.2009, I express my special thanks to Mrs. Prof. Univ. PhD. Eng. Ionelia VOICULESCU, whose advice I benefited from throughout the work and in the preliminary presentation of the thesis in committee, advice of great value to give the thesis an appropriate outfit for the final presentation.

I would like to address many thanks to my former college colleague, Mr. Conf. Univ. PhD. Eng. Gabriel GÂRLEANU, with the help of whom I performed all the welded tests and always had practical advice and guidance for the experimental aspects.
Along with advice and direct help, were also Mr. Conf. Univ. PhD. Eng. Florin BACIU from the Department of Resistance in carrying out the tests for determining the tensions and results from the analysis, Mrs. Conf. Univ. PhD. Eng Georgiana CHISIU, in performing microabrasion tests, Mr. Prof. Univ. PhD. Eng. Corneliu RONTESCU and Mr. Conf. Univ. PhD. Eng. Mihai-Ion VASILE on the part of experiments performed in the laboratories of the faculty.

The dedication to the academic and pedagogical act and the passion for our field, welding, of all those mentioned above to whom I am grateful, inspired me during this academic journey.

I also thank to Mr. PhD. Eng. Dan BĂIAȘU, Technical Director within the C.F.R. Grivita S.A. and the team within the Repair Workshop, for the special support offered throughout the research.

Last but not least, I would like to thank the family for their understanding and support and especially to my mother, an exceptional welding engineer who was the person who inspired me in my desire for excellence in the profession.

Carmen A. Petrescu (Popișteanu)

Introduction

The European Union is promoting rail passenger transport due to the environmental benefits of this transport system. Essential for increasing the competitiveness of rail passenger transport is to obtain an increased quality with the lowest possible costs, respectively to achieve the operation and maintenance of the rolling stock at the highest standards and conditions with adequate costs.

Refurbishment as a repair technology offers optimal costs but also much shorter recovery times for parts. The paper presents the experimental results obtained from research carried out with the aim of identifying a higher quality reconditioning technology, suitable for reconditioning by welding the friction lining holder from the disc brake of passenger cars.

The brake lining holder is part of the disc brake system of the passenger cars, the failure of which can cause: the braking of the train, which results in wheel wear that can repel the wheel, and / or the production of sparks that can ignite the car, or, the impossibility of braking, which can lead to serious accidents, with possible casualties and material damage, equally serious effects.

Part I covers the current state of research looking the subject thesis.

Into the Chapter 1, entitled "The current state of research on parts reconditioning in the railway field”, were presented: notional aspects regarding the construction, operation and maintenance of the passenger cars, in general, with details on the brake system; theoretical aspects regarding the repair through reconditioning of parts from passenger cars, in general, and parts of the brake system, in particular.

Chapter 2, entitled "Research on the reconditioning of cast iron parts, in general, and into the railway, in particular” analyzes and synthesize concepts notional and practices related to: properties, classification, metallurgical and technological peculiarities of welding of nodular cast iron, the material from which the friction linings holder analyzed into the thesis are made; current mode of reconditioning through welding of friction linings holder.

Chapter 3 presents the conclusions regarding the current state of the reconditioning by welding the friction linings holder from the passenger cars.

Part II includes contributions on improving the welding reconditioning technology of the friction linings holder from passenger cars.

Chapter 4 presents the main objective of the thesis, the research directions addressed, and research methodology use for realization of the proposed objective.

Into the Chapter 5, entitled "Contributions to risk management due to the replacement of welding reconditioning technology of friction linings holder” was performed the analysis of the change in accordance with the requirements of Commission Implementing Regulation EU No 402/2013 on the common safety method for risk evaluation and assessment, risk management system for technology change.

Into the Chapter 6, entitled "Research and contributions to improving the welding reconditioning of the friction liner holder for passenger cars", are present and analyzed: current premises regarding the reconditioning of the friction liner by using the SMAW welding process (determination of the deformations by 3D scanning, measurement of stresses by the drilled tensometric rosette method - Mathar method, microstructural analysis and analysis of the hardness of samples made by different welding processes), the experimental plan, materials, equipment and techniques used, the results obtained from the experiments and the analysis of the results and conclusions in the case of friction linings holder reconditioning using welding processes in shielded gas medium with tubular wire, semi-mechanized and mechanized.

Chapter 7, entitled " Experimental research on the wear behavior of refurbished friction linings holder, cost calculation and quality assurance elements”, presents: the results of the tests to determine the wear of the deposited layer by microabrasion testing; comparative economic analysis of the three reconditioning processes; the development of “Working instructions” procedures.

The last chapter, Chapter 8 ”Final conclusions and main contributions to the improvement of the welding reconditioning technology of the friction linings holder from passenger cars", presents a summary of the findings of the research, the general conclusions and the original contributions brought to the welding technology and the prospects and directions of further development.

Keywords: friction liner holder, reconditioning, improvement, welding reconditioning technologies,

Chapter 1. The current state of research on parts reconditioning in the railway field

1.1. Traffic safety, the governing principle in the railway field

Rail transport has always been both a strategic sector of national interest and an important service to the population [93]. Rail transport is considered an economical, efficient, environmentally friendly and very safe mode of transport [2], and railway safety is the central concept that governs the activity in the railway field.

Rolling stock safety is a complex concept, according to which the railway transport must be carried out without any danger to persons and goods, rolling stock, railways and the environment [119]. *The railway safety of passenger trains depends on the mode of operation, maintenance and repair of railway vehicles which are the three basic operational parts of the railway passenger transport activity, in compliance with all applicable laws and regulations.*

1.3.1. The main components of passenger cars

The construction of the wagons is different, depending on their destination, but in general, any wagon has the following parts: box, chassis, suspension and running devices, traction devices, lashing devices, collision devices, brake system, lighting and heating system.

Fig. 1.8. Shows the constructive sketch of a passenger car.

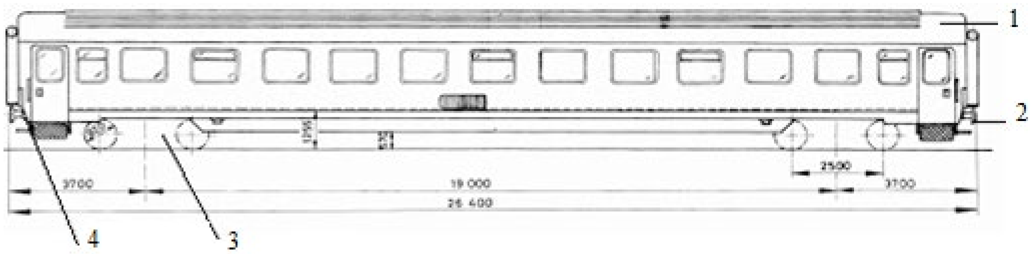


Fig. 1.8. Constructive sketch of a passenger car [94]

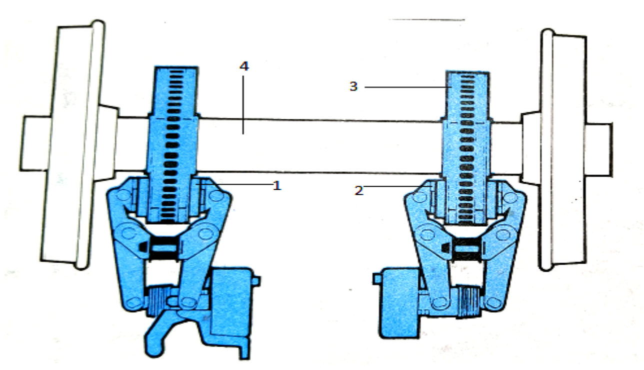


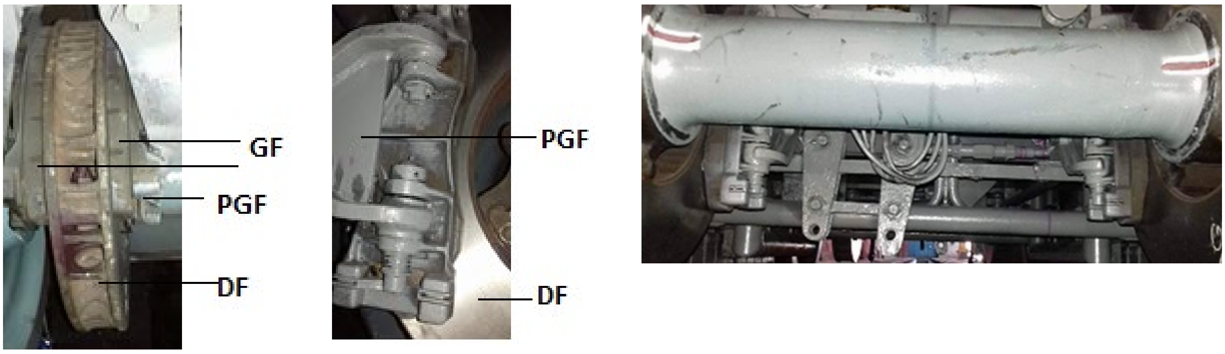
Fig. 1.9. Disc brake [48]
1.friction liner, 2. friction liner holder, 3. disc brake, 4. axis

1.4. The role of the friction liner holder in the passenger car system with disc brake, construction, operation, maintenance

1.4.3. Disc brake

Initially, the disc brake shown in Fig. 1.12., was introduced in high-speed passenger cars, then in wagons intended for suburban and freight traffic, which travels at speeds higher than 120 km/h, due to the multiple advantages presented in comparison to the brake shoe whose braking force was overtaken, especially at high speeds.

The wear of the friction gasket depends on many factors: the pressure on the disc; traffic speed; operating temperature; disk surface roughness; gasket type; the state of aging and the previous strain. In the humid environment, wear increases by 50% [48].



a) Front view b) Lateral view c) General view

Fig. 1.12. Disc brake
FLH- - friction lining holder, DB-disc brake, FL - friction lining [34]

1.5.2. Norms, regulations of railways repair

The norm that refers to the repairs to the brake system is "Instruction for the repair of wagon brakes no. 938/1986" [66]. For welding repairs, Order no. 1013/2006 "Railway technical norm Railway vehicles. Reconditioning by welding of the component subassemblies of freight and passenger wagons. Technical requirements for welding operations" [70] applies.

The approach of reconditioning the brake friction liner by welding must be done taking into account the regulations in force. The current reconditioning process is represented by manual welding with coated electrode, followed by a mechanical processing at nominal dimensions. The quality of the repairs, carried out through the SMAW process, depends on the level of training and conscientiousness of the welder, which is why alternative solutions are sought in which the involvement of the welder is minimized.

Chapter 2. Research on the reconditioning of cast iron parts in general and in the railway field in particular

2.1. Cast irons used in the manufacture of parts in the field of railway, properties, classification

2.1.2. Spheroidal graphite cast iron

Nodular graphite cast iron has the advantage of superior mechanical properties due to the shape of the graphite. Nodular cast irons have good magnetic properties, good fluidity, and small linear contraction. The symbolization of these cast irons includes a series of literary or numerical information, Fgn followed by tensile resistance, in MPa and elongation in percent [13].

Nodular cast irons are used in the manufacture of machine parts that are subject to fatigue, wear and severe shocks, as is the case with the friction liner holder.

2.2. Metallurgical considerations regarding the weldability of cast iron, particularities in the reconditioning of cast iron

2.2.4. Reconditioning of cast iron parts by welding

Welding as a reconditioning method is very widespread because it has great advantages and the vast majority of parts can be reconditioned, the restrictions taking into account the material and the accessibility in the area. The main advantages are: the possibility of reducing the consumption of special materials by making parts from common materials and the deposition by welding of special materials the binding of the filler material according to technical and economic factors is done by ordering in terms of cost [12].

Reconditioning by welding loading consists in depositing a layer of material by welding on the surface of a part in order to compensate for wear and restore the nominal dimensions of the part, between the deposited layer and the part achieving a monolithism.

The geometric elements of a reconditioning zone by welding deposition are: layer width, layer height, penetration. Welding procedures influence the geometry of the joint, the nature and extent of the structural transformations, the level of stresses and strains and the value of the resulting mechanical characteristics (hardness, strength) [41].

2.3. Reconditioning of friction linings holder by welding

2.3.1. Overview

The Friction Liner (GF) -Friction Liner Holder (PGF) subassembly is a component part of the brake steering equipment. The friction liner holder ensures the fastening of the friction liner by means of a dovetail profile (Fig. 2.3). Due to the frictional forces, the angles of the profile wear out over time, which has the effect of improper grip, and in some cases even reaching the point of the friction lining falling, resulting in non-compliant braking function.

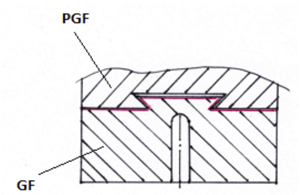


Fig. 2.3. GF-PGF assembly, dovetail profile clamping [34]

Reconditioning the friction liner holder is performed to remove wear that appears on the side of the dovetail profile. The manual arc welding process with coated electrode (SMAW) is used to load the worn and mechanically machined area with welding.

2.3.2. Used materials

According to the designer of the friction liner holder, the basic material used to make the PGF product is a nodular graphite cast iron, EN-GJS-400-15C [83]. The electrode used was EC NiFe-Cl-BG-11, according to EN ISO 1071 [84].

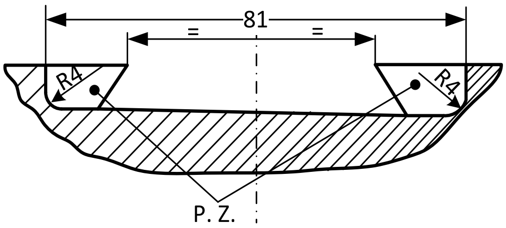
2.3.3. Welding parameters and technique

The parameters used are those in Table 2.6. and falls within the parameters recommended by the manufacturer.

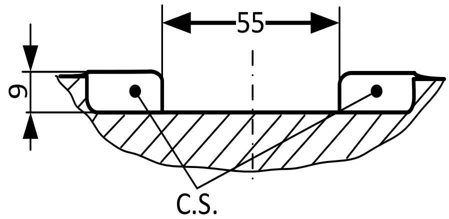
Table 2.6. Welding reconditioning technology parameters

Nr. crossing s	Electrode diameter [mm]	Intensity Current [A]		tension [V]	Current type,	Welding speed [mm / min]		power linear [J / mm]	
		Min.	Max.			Min.	Max.	Min.	Max.
1	2.5	90	110	19	DC -	120	160	684	627
2… n	3.25	115	120	21	DC -	150	180	772.8	672

The dovetail profile was removed by mechanical processing, resulting in an L profile at 90º (Fig. 2.4).



a) mechanical processing of used swallowtail profile (PZ processing zone)



b) material deposited by manual welding (CS - welding bead)

Fig. 2.4. Stages and dimensions of PGF welding reconditioning [34]

The tightening of the part was made in a device specially designed and made for this part (Fig. 2.5.).

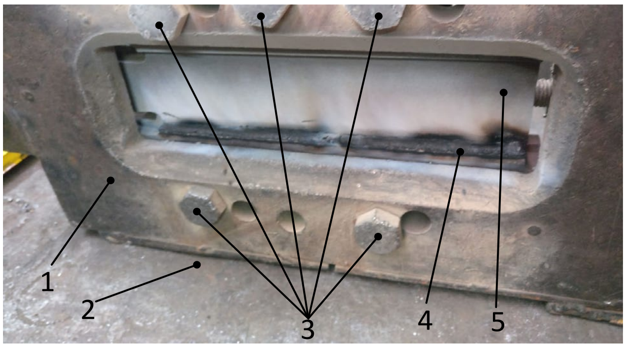
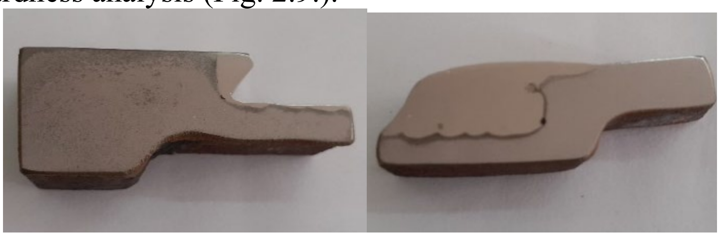


Fig. 2.5. Welded part with fixing in the device [34]
1 – clamping device; 2 – welding stand; 3-clamping system; 4 – welding bead; 5 – PGF

For better penetration, the device and the workpiece were tilted at a 90 ° angle to the horizontal plane. The deposition of the rows started with the same end, from left to right, with the removal of the slag with the hammer followed by the cleaning with a wire brush after each cord was laid, with other breaks only to replace the electrode. The welding was performed on one side until the required height was completed, then the piece was rotated 180º and cords were deposited on the other side until the same height was completed. The cooling of the part was done on the welding bench.

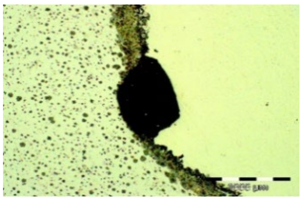
C. Reconditioned part

For a detailed analysis, samples were taken from the reconditioned part and prepared for metallographic and hardness analysis (Fig. 2.9.).

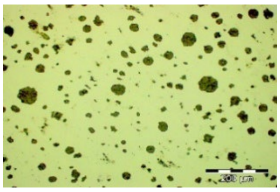


Test A Test B
Fig. 2.9. Samples taken for metallographic analysis in manual welding processed. [34]

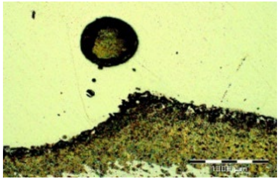
The resulting samples were subjected to metallographic analysis and hardness tests. Some macrostructural aspects are indicated in the figure Fig. 2.10.



Inclusion-type imperfection and lack of adhesion on LF 50x



MB, 200x. Nodular graphite cast iron, No chemical attack



Pore-type imperfection located in the seam in the immediate vicinity of the fusion line, 50x

Fig. 2.10. Microstructural analysis of manual welding samples [34]

The analysis of the welded samples was performed in the Accredited Laboratory for Metallographic Tests of the Polytechnic University of Bucharest - LAMET.

Chapter 3. Conclusions on the current state of welding reconditioning of the friction lining holder of passenger cars

From the analysis of the current state of the welding reconditioning of the existing friction linings holder in the passenger cars, several conclusions can be drawn, the most important being the following:

- the railway field is a strictly regulated field, being governed by a principle from which no deviations are allowed: railway safety (see § 1.1);
- the European Union's priority policy is to promote rail passenger transport, thanks to the environmental benefits of this transport system. The competitiveness of the Romanian railway transport must be based on the development of maintenance activities, repair of rolling stock in conditions and at the highest possible standards, with the lowest possible costs (see § 1.2);
- the friction liner holder is a part of the passenger car brake system. Failure of a component part of the braking system will produce serious effects such as: braking of the train with the appearance of sparks producing possible fires or lack of braking which can lead to serious accidents resulting in loss of lifes (see § 1.3);
- the wear of the disc brake components is due to the forces acting on the braking of the cars as well as to the temperatures resulting from the friction between the components. Wear of the friction liner holder consists in deterioration of the shape and dimensions of the dovetail profile which ensures that the friction liner is applied to the brake disc when braking (see § 1.4);
- the activity of repairs in the railway field is regulated by several legislative acts such as Orders of the Ministry of Transport, Internal Railway Instructions, National and International Regulations, Technical Prescriptions and Technical Specifications, Standards, etc. Like any repair work, the brake lining bearing must be reconditioned by welding, taking into account all restrictions and requirements in the reference documents relating to the brake system and welding repairs;
- due to the impossibility of supplying new friction liner holder, reconditioning by welding is the only applicable option for repairing PGF; the main goal of the thesis is to develop a welding technology that will lead to a qualitative increase in the repair and wear resistance of the part after repair while reducing costs (see § 1.5);

- GJS -400-15C into the view that reconditioning is performed through welding, analyzed weldability nodular graphite cast iron and particularities into the reconditioning the cast irons, (see § 2.2);
- the reconditioning of the friction liner holder is carried out in order to eliminate the wear that appears on the side of the dovetail profile and is carried out by pre-preparation, mechanical machining by cutting, in order to eliminate wear and obtain an L profile, followed by loading both sides; after checking the deposited layers, the surplus material is removed by mechanical processing, to bring it to the nominal levels;
- at the moment, the manual welding process with coated electrode (SMAW) is used for welding and the EC NiFe-1-BG-11 electrode (EN ISO 1071) is the filter material;
- the parameters and the welding technique were presented, the resulting parts were subjected to examination with penetrating liquids and samples were taken which were analyzed metallographically, following the analyzes observing imperfections such as: pores, microcracks, inclusions, lack of adhesion (see § 2.3);
- The problems that arise in the repair area through the use of the SMAW process demonstrate the need for experimental research and determinations for a new reconditioning technology, which will reduce repair times, increase the quality of the reconditioned part, reduce costs and lead to consistently favorable results (see § 2.4).

Chapter 4 . Directions, main objective and research-development methodology of the welding reconditioning technology of the friction linings holder from the passenger cars

4.1. Research and development directions

Based on the analysis of the current state, it is estimated that the following research and development directions regarding the welding reconditioning technology of the friction liners holder from the passenger cars are relevant:

- Establishing the need to replace the welding reconditioning technology of the friction linings holder;
- Establishing the risks posed by the replacement of a welding reconditioning technology in the railway field;
- Establish alternative technologies to current technology that lead to a reduction in reconditioning times, costs and superior features;
- Development of an improved welding reconditioning technology of the friction linings holder.

4.2. The main objective of the research-development activity

Given the data and conclusions from the analysis of the current state, as well as the research and development directions regarding the welding reconditioning technology the friction linings holder from the passenger cars, it is determined that the main objective of the doctoral activity is to develop a improved welding reconditioning technology of the friction linings holder from the passenger cars.

4.3. Research and development methodology

Systematizing, the research and development methodology will consist of:

a. Research procedure:
    - analysis of documents (overviews, results, records, etc.) from the organization dealing with reconditioning (GA) by welding of PGF;

- starting an extensive bibliographic study to identify similar research;
- performing tests similar to those performed by the PGF reconditioning organization; quantitative and qualitative analysis of the obtained samples and comparison of the results with those obtained by the GA;
- identifying how to manage the potential risks posed by a potential replacement of current reconditioning technology;
- developing new PGF reconditioning technologies that reduce reconditioning time, costs and lead to superior features of the reconditioning filing;
- testing new technologies proposed to replace existing technology;
- quantitative and qualitative analysis of samples resulting from the application of new technologies;
- comparison of the results obtained from the application of new technologies with those obtained by the GA;
- establishing improved PGF reconditioning technology, developing a work instruction procedure to underpin the application of the proposed new technology;
- establishing the wear resistance of samples made with current and proposed new technologies;
- comparative economic analysis of all analyzed reconditioning technologies;

b. Selected methods:
The methods to be used are both quantitative and qualitative. The results and statistics held by the AG will be analyzed and the direction of the change in technology or the reconditioning process will be established on the basis of them. Non-destructive examination methods, VT, PT examination, deformation measurement, etc. will be used. but also methods of destructive control, determination of hardness, wear resistance, micro and macro-structural analyzes, etc.

c. Research tools:
General (EXCEL, VISIO) and customized (ARAMIS, SW, ARTCAM) IT solutions will be used, causal investigations.

d. The expected results:
Expected results are those defined in subchapter 4.1. leading to the replacement of the current reconditioning technology with the improved reconditioning technology developed in the thesis.

Chapter 5 . Contributions to risk management due to the replacement of reconditioning technology by welding a friction linings holder

Any technical, operational and / or organizational changes in the railway field which have an impact on railway safety must be examined. in accordance with Implementing Regulation (EU) no. 402/2013 [50]. The change in PGF welding reconditioning technology is a change that falls into this category and will be analyzed accordingly [36].

5.1. European and national legislation on risk management in the event of a change with an impact on railway safety

A major concern in the field of railways is understanding and eliminating the risks of rail operations. The subject of risk has increasingly become a common point of interest between entities representing the various sectors of the railway sector (construction, maintenance, railway operation).

5.2. Analysis of the change of the reconditioning technology by welding of the friction linings holder, realization of the risk management system

The first stage of the railway risk management process is the analysis of the importance of change based on the criteria set out in Regulation 402/2013 and the determination of the impact on railway safety.

5.2.1. Analysis of the change of the welding reconditioning technology

In accordance with the provisions of Regulation (EU) no. 402/2013, to decide on the significance of the change, an analysis and evaluation team of in-house experts goes through the steps and criteria indicated in Table 5.1.

The change, proposed by the doctoral thesis, consists in modifying the welding reconditioning technology the friction linings holder from the disc brake. shown in Figs. 5.3. and Fig.5.4., from passenger cars with disc brakes.

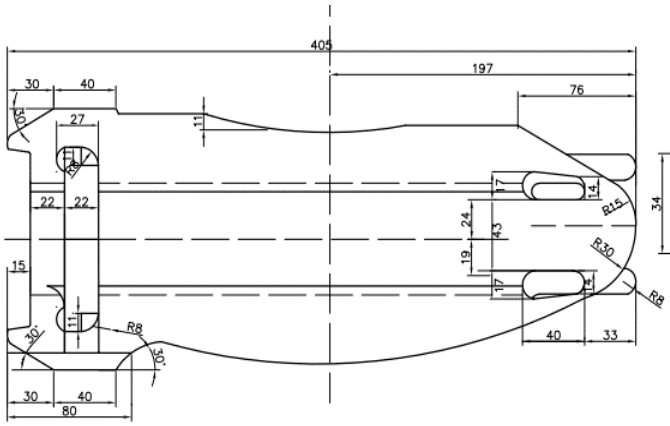


Fig. 5.3. Friction liner holder **[36]**

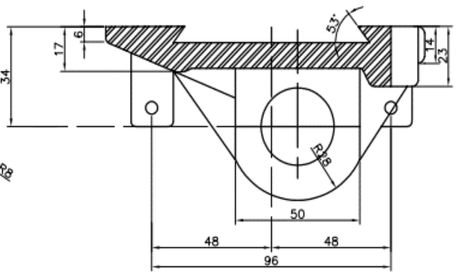


FIG. 5.4 Section XX, friction liner holder **[36]**

Table 5.1. Evaluation of change according to the criteria imposed by art. 4 (2), Regulation (EU) No 402

Nr.crt.	Criteria	Description
a.	**Consequences in case of failure:** credible pessimistic scenario in case the system under assessment suffers a failure, taking into account the existence of safety barriers outside the system under evaluation;	After the modification of the welding technology, defects may result which may affect the part so as not to ensure the functions for which it is designed and once the wagon is put back into circulation, incidents may occur with consequences on the railway system major importance
b.	**New elements used to make the change**: this concerns both the innovative aspects of the railway sector and the elements that represent a novelty only for the organization that makes the change;	Introduced new elements of change: - mechanized welding instead of manual welding (advantage of constant welding speed, constant linear energy, uniform melting of MB) - major importance
c.	**The complexity of change**	The complexity of the change is major, as the welding process changes from SMAW welding to mechanized FCAW welding and different welding equipment is required - major importance
d.	**Monitoring**: inability to monitor the change made throughout the life cycle of the system and to take appropriate action;	Monitoring is also complex, because the whole process is changing and the execution staff is also changing, so the way of monitoring is completely changing - of major importance .
e.	**Reversibility**: inability to return to the system situation prior to the change;	The change is reversible, and can be returned to manual electrode welding - low importance

Given the arguments presented in Table 5.1, we consider that the change in welding technology is an important and significant change in technical, operational and organizational that will have a potential impact on the safety of the railway system according to the criteria of Article 4 point 2 of Regulation (EU) no. 402/2013.

5.2.2. Change Risk Management System welding reconditioning technology

When it is concluded that the change is significant and has an effect on railway safety, the hazards and risks generated must be identified and analyzed, and a risk management system for the change must be developed to adequately manage the risks. Conformity of the system is assessed in relation to Implementing Regulation (EU) no. 402/2013 of the Commission. The objective of risk management in the activities carried out is to reduce the risks to an acceptable level. It is considered that changes in activity are not allowed to lead to undesirable or unacceptable risks.

A. Preliminary definition of the PGF repair system

The preliminary definition of the system in the pre-change stage must also be made in accordance with Regulation (EU) No 182/2011. 402/2013 which involves addressing the following issues: system objective, system functions, system boundaries, physical system interfaces, system environment. The change proposed by the doctoral thesis is represented by the identification of more economical, faster welding processes that lead to obtaining superior characteristics in the layers deposited in order to restore the initial geometric shape.

B. The process of hazard identification and risk analysis

With the help of the expertise of the members of the analysis team, using the "Brainstorming" identification and assessment technique, the possible ways of failure and the associated dangers, the risks generated and the measures for risk management are identified. Hazards that can reasonably be predicted for the entire technical system under assessment, its functions and its interfaces have been identified and classified according to legislation **[10] .**

C. Selecting the principle of risk acceptance

During the working meeting for the framing of the change and the application of the risk management process, it is established by the work team that for the risk assessment of the analyzed system, to apply **the control and acceptability of the risks through codes of practice.** The application of this risk acceptance principle has identified possible safety measures, which make the associated risks acceptable and controlled. Of these safety measures, those selected to control risks become safety requirements that must at least be met.

D. Hazard management

Starting with the assessment phase, as well as in the implementation phase and until the acceptance of the significant change taken into account, the repair company keeps and updates a record of the related hazards (Table 5.6.).

Table 5.6. Register of hazards in the repair activity by welding reconditioning of the friction linings holder on passenger wagons with disc brakes **[36]**

Nr. No.	Danger description	The origin of the dangers	Safety measure / safety requirement	The principle of risk acceptance	responsive
1	Major deviations from the values of the welding technology parameters.	Improper professional training of execution personnel, non-verification of welding equipment	Equipment inspection, testing, staff qualification.	Use of codes of practice / safety rules.	Process Engineer.
2	Locking of the welding machine in operation.	Failure to check the welding equipment before starting the welding operation.	Equipment inspection, testing, staff qualification.	Use of codes of practice / safety rules.	Maintenance engineer.
3	Additive material with improper composition.	Non-compliant supply.	Additive material checks.	Use of codes of practice / safety rules.	Head of supply service.
4	Inaccurate machining.	Uncalibrated measuring instruments.	Periodic checks of measuring devices.	Use codes of practice	Technology design engineer.
5	Determination of insufficient tests	Insufficient data from previous operation on similar failures	Expand data search area,	Use codes of practice	Designer.

Chapter 6. Research and contributions on improving the welding reconditioning of friction linings holder for passenger cars

6.1. Research on the application of reconditioning through manual welding of the friction liner holder of passenger cars

6.1.2. Reconditioning through manual welding of the friction liner holder current technology

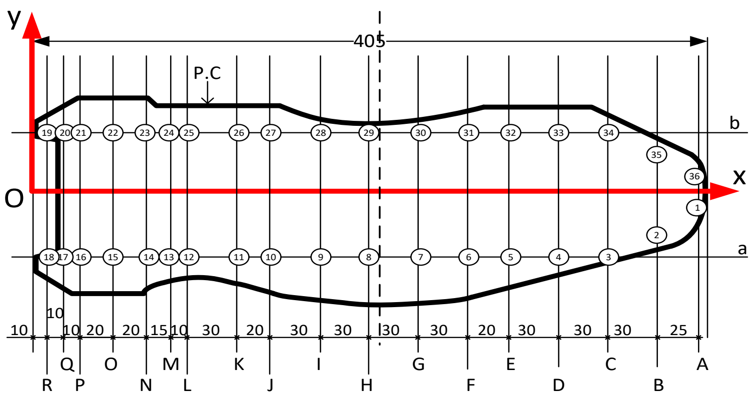
For an effective objective analysis on welding reconditioning procedure applied to PGF into this moment, it was decided performing three additional tests: one piece freely welded (without fixing into the device) (SL); a piece welded after fixing in a clamping device (DS), specially designed for decrease deformations; a piece welded into the same device subsequently milled at nominal quotes (SDF).

The goal to realize these parts into different stages and conditions was to determine the influence of different terms on results (determination present deformations and their measurement depending on the catch or not in the clamp device; the influence of reprocessing mechanical) and the procedure was the one described into the chapter 2.

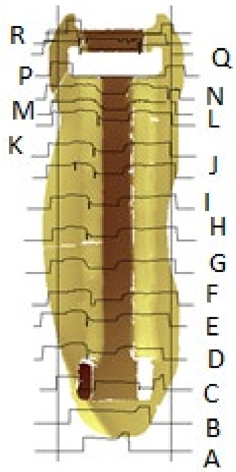
6.1.3 Measurement deformations in reconditioned parts through free welding

and into the device

Any reconditioning procedure through welding may incure deformations. Samples results were examined into the view to establish deformations, with the help of the soft ARTCAM, location measuring points respected the indications as in Fig. 6.9.



a) Location measuring points of deformations



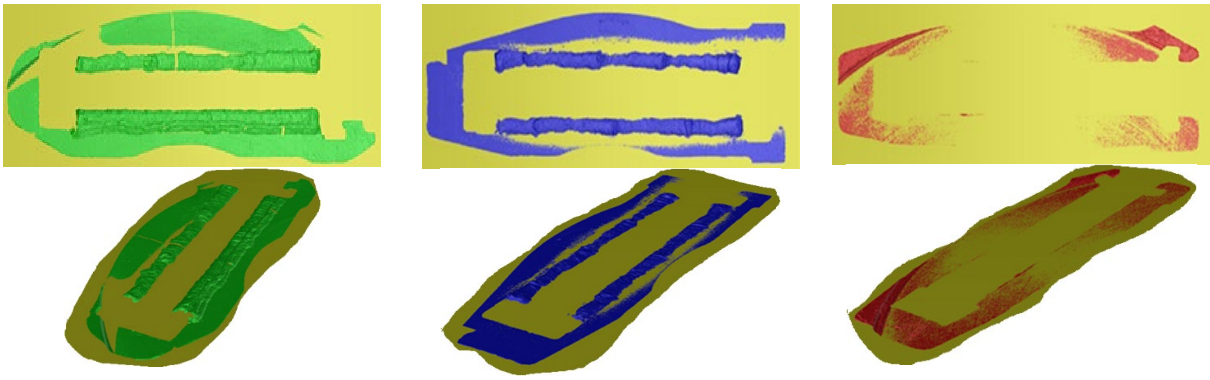
b) Sections measurement - SL

FIG. 6.9. Location measuring points of deformations

PC - contour sample; A ... R - measuring sections (directions); ⓘ- measuring points (1 ... 36), [34]

Some images obtained into the time completion 3D scans of parts are found in Fig. 6.10.

Pair colors with the pieces was made for contrast with the horizontally plan into the view to highlight visual effects of deformations.



d) SL part – deformations level e) SD part - deformations level f) SDF -part deformations level

Fig. 6.10. Aspects on deformation level [34]

Deformations are measured vertically between the horizontal plan reference and the scanned horizontal plan of the piece. Using ARTCAM soft were obtained the results present into the Table 6.4. and in Fig. 6.11., 6.12., 6.13., 6.14.

Table 6.4. Deformations values [34]

Point measurement *	x [mm]	Value [mm] ***	
		Test **	Test **
1	400	-0.07	-0.9
[......]			
8	205	-0.58	-3.02
9	175	-0.52	-2.83
[......]			
27	145	-0.31	-2.28
28	175	-0.37	-2.41
29	205	-0.44	-2.63
30	235	-0.38	-2.48
[......]			
36	400	-0.08	-0.3

* according to figure 6.9; ** coding according to point 6.1.2 .;
*** values measured into the plan (XOZ).

The color yellow mark important points with maximum values on both parts of the SL part and orange for SD part.
From the analysis of Fig. 6.11., 6.12 is observed that the deformations are bigger in value in the middle parts. From the analysis of Fig. 6.13, 6.14 is observed that bigger differences into the absolutely value between deformations SL part versus SD.

Maxim deformations value face the horizontal plan are in the case of SL part, 3.2 mm that exceeded the value maximum permissible 1.2 mm by SR EN 22768-1 / 2 [85, 86], and the maximum value of deformation into the case of SD sample is 0.58 mm, which conclude that use clamping device is mandatory on welding reconditioning of the part.

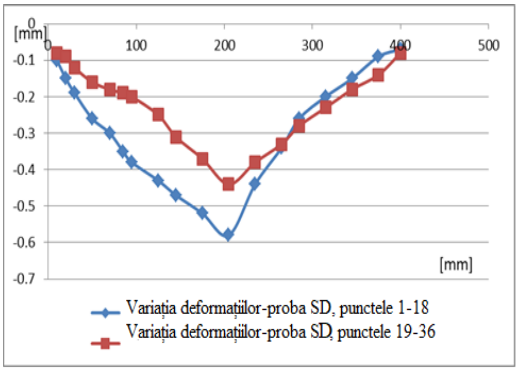


Fig. 6.11. deformation variation _ SD part [34]

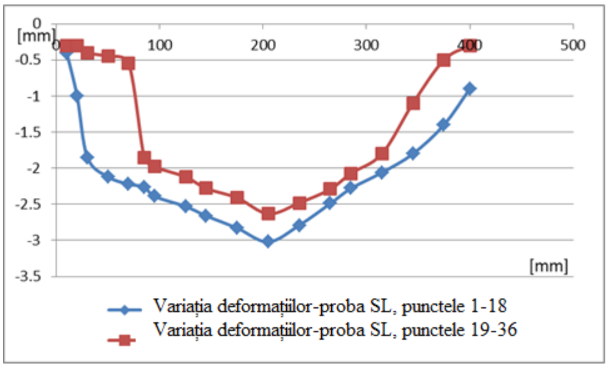


Fig. 6.12 deformation variation - SL part [34]

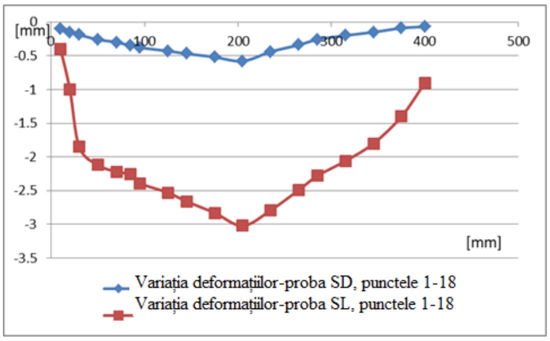


Fig. 6.13. deformation comparison - SD and SL parts in measuring points 1 - 18 [34]

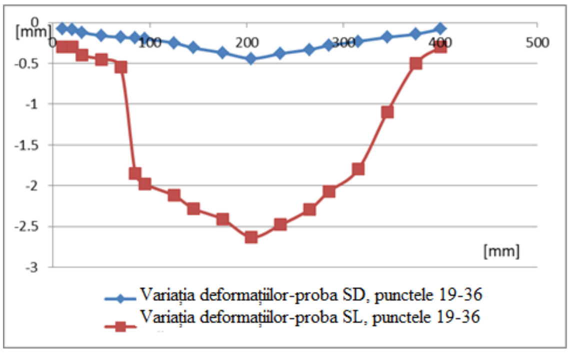
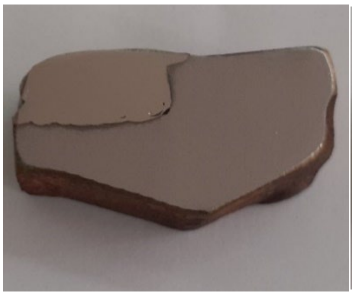


Fig. 6.14. deformation comparison - SD and SL parts in measuring points 19-36 [34]

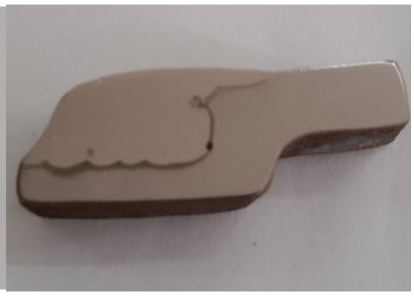
6.1.4. Determination of hardness, structure and dilution of reconditioned area by welding

From each of the three parts reconditioned SL, SD, SDF samples were taken (Fig. 6.15.) which were examined into the the LAMET laboratory, accredited by RENAR.



a) Sample A

b) Sample B

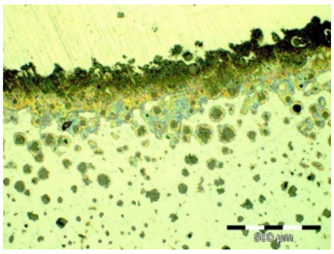


c) Sample C

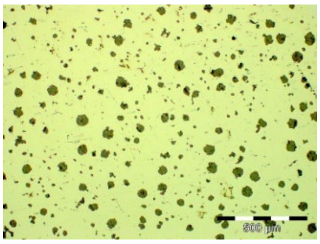
Fig. 6.15. samples collected for metallographic analyze.

a) Sample A - SD part - b) Sample B - SDF part c) Sample C - SL part.

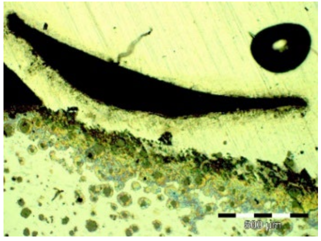
The examination was performed on the characteristic areas of the samples, on the base material (BM) on the thermal influence zone (HAZ), on the fusion line (FL) and on the welding bead (CS).
The images resulting from the microscopic analysis are shown in Fig. 6.16.



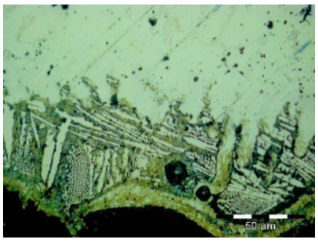
a) HAZ, 100x without chemical attack



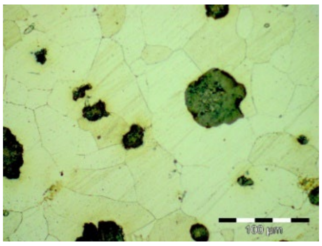
b) BM-100x, without chemical attack



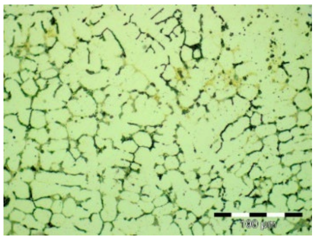
c) CS 200x



d) FL - 1000x



e) BM - 500x



f) CS - 500x

Fig. 6.16. Sample A - Ferrite nodular graphite cast iron

From the analysis of the images presented in Fig. 6.16. the following information can be deduced: there is a clear delimitation between MB and CS, Fig. 6.16 a; the base material has a ferritic structure with nodular graphite, Fig. 6.16., B and e; in the CS, imperfections such as detachment and pore were highlighted, Fig. 6.16., C; Graphite oxidation took place on the fusion line and compounds such as ledeburite and acicular cementite appeared, Fig. 6.16., D.
After microscopic examination, the sample were subjected to the hardness test, the values obtained being indicated in Table 6.6. According to the standards, the determination is made by measuring in 5 distinct points in each area of the joint, the base material (BM), the thermally influenced area (HAZ) and the weld bead (CS).

Table 6.6. important hardness determined on analysis samples A, B, C, HV $_{0.2}$ -1.961N, t = 15sec

Sample / Area	A			B			C		
	BM	fun	CS	BM	fun	CS	BM	fun	CS
Point 1	167	220	183	182	256	194	153	286	153
Point 2	173	228	174	201	422	195	168	250	159
Point 3	147	282	180	230	418	203	171	226	167
Point 4	184	292	176	220	328	208	131	373	171
Point 5	170	210	170	182	358	225	163	356	154
Value average	168.2	246.4	176.6	203	356.4	205	157.2	298.2	160.8
Value Maxim	184	292	183	230	422	225	171	373	171
Value minimum	147	210	170	182	256	194	131	226	153

From the analysis of the hardness values presented in Table 6.6., comparing the values obtained in the case of samples A, B, C it can be stated that the subsequent mechanical processing led to an increase in the hardness value in HAZ and CS, which is why cooling.

6.1.5. Determination of hardness in reconditioned samples

The current SMAW welding reconditioning process is performed by tightening the part in DS.
In sub-chapter 6.1.3., the resulting conclusion was that for the reconditioned sample SL the reconditioning procedure led to the occurrence of deformations beyond those allowed by the standards in force. An important aspect of the research was the highlighting of the specific deformations in certain points, depending on these values and the values of the residual stresses in the respective area can be appreciated based on Hook's law: $\sigma = E \times \varepsilon$ (6.1)
where: E - Young's module; $E_{cast\ iron} = 169\ kN / mm^2$ ε - relative elongation [μ m / m]
The method of measuring the remaining deformations used is the drilled tensometric rosette method (Mathar method). The experiments were performed in the Tensometry Laboratory of the Department of Materials Resistence, Faculty of Industrial Engineering and Robotics of UPB
In order to determine the size of the deformations that may occur in the reconditioned samples, 3 tensometric marks were placed (coded with a, b, c and A, B, C), positioned on a circle in points a, b, c and A, B, C at 120 °, according to Fig. 6.21. The positioning of the tensometric marks, so that the area where the hole will be made is in the middle of the cord, allows the measurement of the deformations in the points coded with ZG, according to Fig. 6.21.

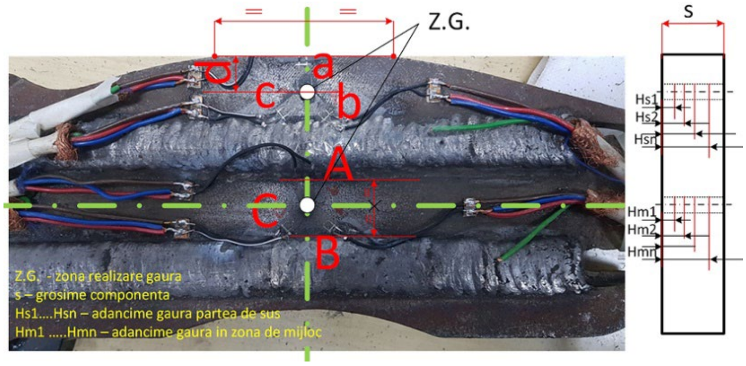
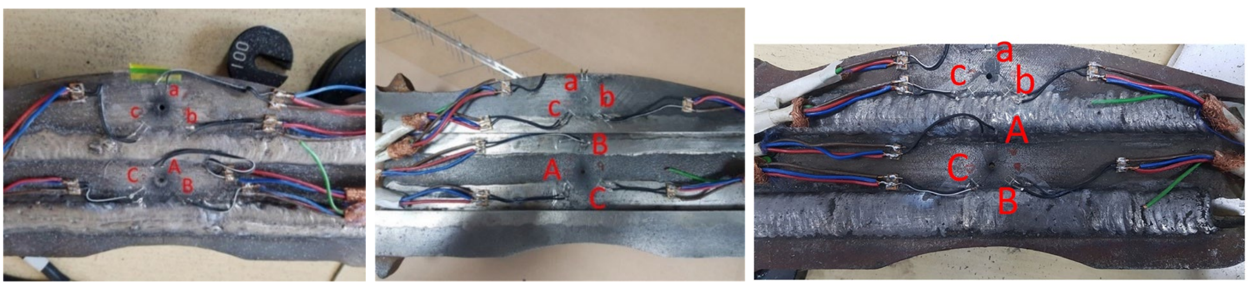


Fig. 6.21. Tensometric mark test - mark positioning, drilling depth figures

Tensometric marks a, b, c, A, B and C were positioned according to figure 6.21, resulting in the part-mark assembly shown in figure 6.22.



a) SL part b) SDF part c) SD part

FIG. 6.22. Parts with positioned tensometric marks

For each part, approx. 20,000 results were registered, the time between two recordings being 0.02 s. The values of the maximum specific deformations recorded by the tensometric marks positioned in points a, b, and c, for all the tests performed are indicated in Table 6.7., Respectively Table 6.8. for tensometric marks positioned in points A, B and C.

Table 6.7. The values of the maximum specific deformations recorded by the corresponding marks positioned in a, b, c at various drilling depths for the 3 SL, SDF, SD samples

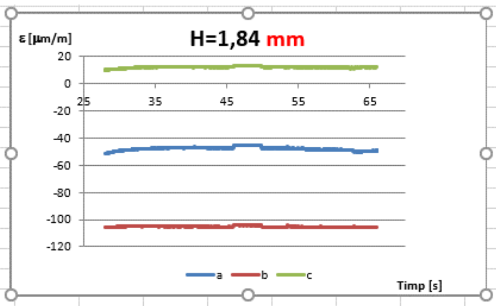
Drilling depth _ H [mm]	Specific deformation measured by the tensometric mark [µm / m]		
	a	b	c
Proba SL			
1.84	-45.12	-104.16	13.44
9.85	-169.92	-349.44	-91.2
SDF test			
2.11	190.08	340.32	394.56
3.04	141.12	316.8	339.36
SD test			
2.65	22.08	157.92	547.68
9.56	-43.2	120.48	254.4

Analyzing the results indicated in the tables above, it can be concluded that most of the specific deformations occurred are due to compression stresses, the maximum values being obtained at the maximum drilling depth. By comparing the results recorded in the SD and SDF samples, it can be stated that the process of restoration of the dove tail canal by mechanical processing of the deposited layer, led to a relaxation of the remaining specific deformations.

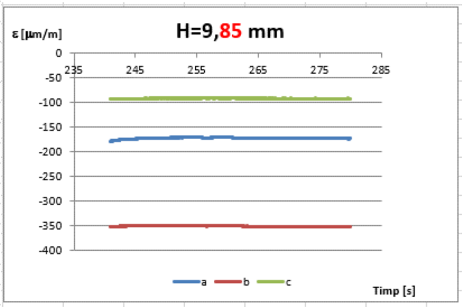
Table 6.8. The values of the maximum specific deformations recorded by the marks positioned in A, B, C at various drilling depths for the 3 samples SL, SDF, SD

Drilling depth H _ [mm]	Specific deformation measured by the tensometric mark [µm / m]		
	A	B	C
Proba SL			
3.11	-72.96	-84.96	-150.24
perforation	-136.32	-261.12	-551.04
SDF test			
4.2	300	-185.76	287.52
perforation	297.6	-228.96	164.16
SD test			
2.3	312.48	-59.04	-94.08
perforation	-196.8	-185.28	-155.52

To determine relaxation specific deformations, were performed drilling into the different stages of the part depths. Registered values recorded by all marks positioned into the points a, b, c, A, B, and C are shown in Fig. 6.24. - 6.29.



a)



b)

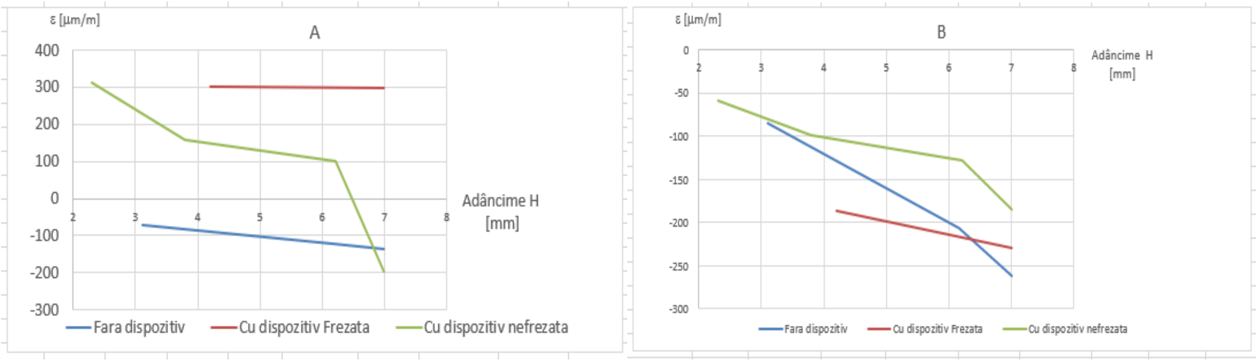
Fig.6.24.Graphs of the variation of the specific relaxation deformation after drilling at various drilling depths (SL sample) (measured on the marks positioned in a, b, c)

From the analysis of the graphs presented in Fig. 6.24. it can be seen that regardless of the drilling depth, a pattern is obtained represented by the fact that the minimum values (in absolute value) were recorded by the tensometric mark positioned in point c, the maximum values by the mark positioned in point b.

There are also noticeable differences between the sizes recorded with the 3 tensometric marks at the mark positioned in point c it is observed that the deformations have a positive sign at H = 1.84 mm being +13.44 and at H = 3.78 mm the it is negative, reaching a maximum, in absolute value, of -91.2, which indicates that the initial stresses are elongation and then compression.

In Fig. 6.30., 6.31., are illustrated the variations of the specific deformations for each mark for the three samples for comparison.

Observing the variation graphs of the specific deformations on each part for all three parts, it is found that the largest variations of the deformations are at the part tight in the device, so in this part the highest stresses are registered.



a) b)

FIG. 6.30. Graph of the variation of the specific deformations in points A and C as a function of depth at the three samples

In Table 6.9. the remaining stresses are calculated for the highest values of the specific deformations for the three samples.

The highest value for the specific deformation is 567.36 µm / m and was measured by the mark placed at point c on the reconditioned fabric by welding in the device which proves that in this test the highest residual stresses are recorded. The value of the maximum tension is **σ = 95.88 N / mm ^{2}** which is less than the flow limit Rp 0.2250 N / mm ^{2} of the cast iron from which PFG is made.

Table 6.9. Remanent tensions

Drilling depth _ H [mm]	Remanent tensions calculated for important maximum deformations _ specific [N / mm²]		
	of	b	c
Proba SL			
9.85	-28.72	-59.06	-15.41
SDF test			
2.11	32.12	57.51	66.68
SD test			
5.02	-1.95	26.28	95.88

6.2. Research on improving the quality of reconditioning by using semi-automatic or automatic FCAW welding procedures

Quality of reconditioning through welding and cost are largely influenced by the welding process applied, since this one directly influences the welding time, the consumption of filler material and energy, melting productivity and necessary personal qualification, etc. There is a general trend of manual welding reconditioning procedures with semi-automatic or automatic welding procedures [28].

6.2.1. Description of the experimental plan, materials, equipment and techniques used

In order to design and apply an appropriate welding reconditioning process leading to a CS submitted with a higher quality than those submitted by the SMAW procedure, sets of experiments were performed with three different welding procedures SMAW, FCAW and FCAWm, processed samples which were subsequently subjected to specific examinations.

A. The base material

According to the technical specification of the designer, the basic material used to make the friction lining holder is a nodular cast iron type: EN-GJS-400-15C according to EN 1563.

B. Filler material

Filler material use was: SMAW –ENiFeC1 A (cf AWS 5.15, SR EN ISO 1071/2004) [84]; FCAW and FCAW m– NiFe 60/40 (cf. DIN EN 14700, NiFeCl) [82].

C. Equipment and provision

Equipment and devices use into the experiments are indicated in Table 6.15.

Table 6.15. Equipment and devices [33]

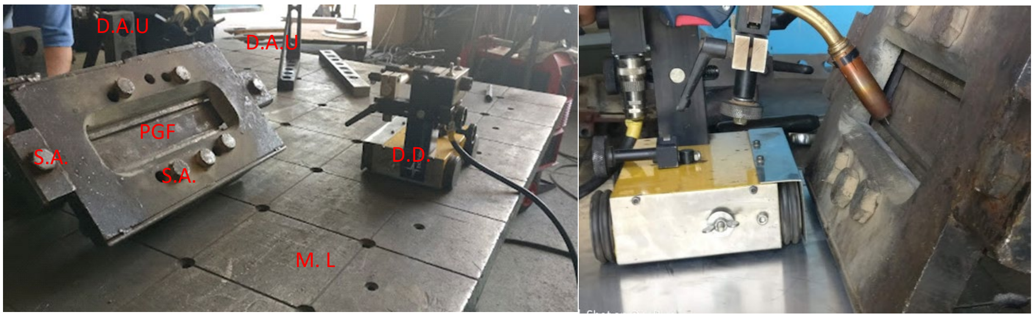
No.	Equipment / devices / observations	SMAW	FCAW	FCAW m
1	Source welding	Welding Inverter Caddy Professional 250	Aristo MIG U5000iw	
	Device displacement	-	-	Welding tractor Miggytrac

D. Techniques used

In the case of SMAW, the area required to obtain the dovetail fastening system was obtained by depositing 14 rows to obtain a width of 13 mm and a height of 9 mm. When welding FCAW (Fig. 6.38.) As well as FCAWm (Fig. 6.40.), A number of 5 and 4 rows were sufficient to obtain the nominal dimensions after the mechanical processing.

a) b)

Fig. 6.38. FCAW semi- mechanized welding
a) Manual welding of the CS by the FCAW procedure, b) CS welded by the FCAW



a) b)

Fig. 6.40. Experimental stand - reconditioning through process FCAWm
a) positioning sample into the device at 45 °, b) positioning torch welding
SA - system assembly device, ML - work table, PGF – friction liner holder, DD - device displacement welding torch (for mechanization), SAD - devices for ensuring the angle of inclination

E. Welding technology parameters

The welding technology parameters were the one recorded into the Table 6.16.

Table 6.16. Parameters use into the welding procedures [33]

Procedure	Layers	Ø [mm]	k [-]	U [V]	and [A]	v_s [mm / min]	El [Kj / mm]
SMAW 12 passes	L 1	2.5	0.8	19.00	100	140	0.651
	L 2-n	3.25	0.8	9 p.m.	120	220	0.550
Average Liniar Energy SMAW							0.615
FCAW * 4passes	L1	1.6	0.8	21.7	204	350	0.607
	L 2-n	1.6	0.8	21.5	206	345	0.616
Average Liniar Energy FCAW							0.613
FCAWm ** 3 passes	L1	1.6	0.8	26	150	305	0.614
	L 2-n	1.6	0.8	26	152	305	0.622
Average Liniar Energy FCAWm							0.619

* welding speed _ average v_s , I_s average , Ua average ; K - efficiency thermal .
** welding speed _ given by the stroller;

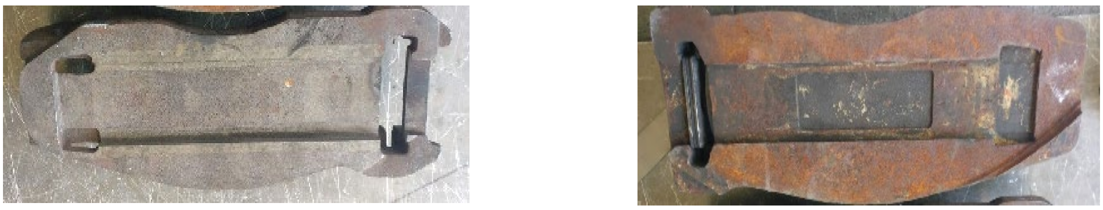
From the analysis of the values of the parameters presented in Table 6.16. it can be observed that even in the situation where the main parameters of the reconditioning technology by welding, with indices Is / Ua / vs, were different, the values of the parameter El are close, with a maximum difference of 0.006 [KJ / mm].

6.2.2. Experimental results

<u>A. The Research stages</u>

A1) Examination non- destructive of the piece

Into this stage is set if degree of wear may enable reconditioning of parts Fig. 6.44.).



Worn part that enable reconditioning   Worn part that does not allow reconditioning

Fig. 6.44. Visual examination of parts [33]

B3) Macroscopic Analysis

The macroscopic images of the cross sections and the imperfections identified in each sample are shown in Fig. 6.47. and FIG. 6.49.


a) Sample SMAW


b) Sample FCAW


c) Sample FCAW m

Fig. 6.47 Macroscopic samples images [33]

B4) Hardness test

Analyzes were performed to determine the hardness, HV 0.2 on the samples taken, Fig. 6.47. According to the standards in force regarding the establishment of hardness values, the determination requires the measurement in 5 distinct points in each area of the joint, base material (BM), thermally influenced area (HAZ) and welding bead (CS) - Fig. 6.48.

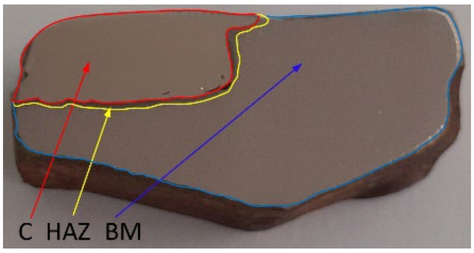


FIG. 6.48 Areas Identification C, HAZ and BM [33]

Results obtained are indicated in Table 6.18. for sample reconditioned through SMAW, in Table 6.19. for sample reconditioned through FCAW and FCAWm.

Table 6.18. SMAW test hardness

Sample	A *		B *		C *	
	Value into the		Value into the		Value into the	
Area	HAZ	CS	HAZ	CS	HAZ	CS
Point 1	220	183	256	194	286	153
[...]	[...]	[...]	[...]	[...]	[...]	[...]
Point 5	210	170	358	225	356	154
Value average	246.4	176.6	356.4	205	298.2	160.8

From the analysis of the hardness values presented in Table 6.18. and by comparing the values obtained in the case of samples A and B, Fig. 6.49., it can be stated that the subsequent mechanical processing necessary to obtain the “dovetail” type fastening system led to an increase in the hardness value in HAZ and CS, for which reason it was proposed that the processing be carried out with cooling.

A SD sample | B SDF Sample | C SL Sample

Fig. 6.49. Samples Identification SMAW procedure [33]

Table 6.19. Hardness values FCAW and FCAWm procedures HV0.2

Sample / Location	Sample FCAW		Sample FCAWm	
Location	HAZ *	C *	HAZ *	C *
Point 1	290	181	173	228
Point 2	336	190	179	229
Point 3	232	183	192	178
Point 4	293	192	195	198
Point 5	242	215	187	213
The average value	278.6	192.2	185.2	209.2

* areas identified in Fig. 6.48.

By comparing the resulting values indicated in Table 6.18 and 6.19 it can be seen that the highest value of hardnessis in C and was 229, obtained at reconditioning by the FCAWm process which highlights the higher wear resistance of the reconditioned sample.

Chapter 7. Experimental research on the wear behavior of reconditioned friction linings holder, cost calculation and quality assurance elements

In order to make the decision on the improvement of the welding reconditioning technology applied to PG, in order to complete the results already obtained, the following research was carried out: experimental research on the wear behavior of reconditioned PGF; the calculation of the costs of each process, and for quality assurance, the elaboration of a working instruction procedure, regarding the reconditioning by welding by the resulting process as optimal of those analyzed.

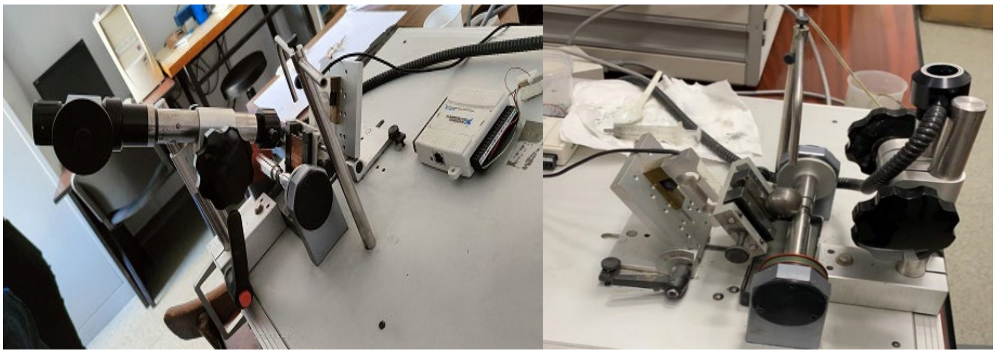
7.1. Comparative wear determinations for reconditioned friction linings holder

PGF wear is the result of the manifestation of frictional forces that occur when braking between the PGF and GF surfaces under the pressure of the brake system when applying GF to the surface of the brake disc in order to obtain the braking of the wagons. The microabrasion test was used to determine the wear resistance of the reconditioned parts by the three processes.

7.1.1. Microabrasion testing

A. Working methods. Materials

The microabrasion determinations were performed on the Calowear SCM stand, Fig. 7.1., In the laboratory of the Tribology Laboratory of the Faculty of Mechanical and Mechatronics Engineering.



a) b)

FIG. 7.1. Stand CSM Calowear

a) Positioning of the test on the stand, b) positioning of the ball on the test and the drive shaft

B. <u>Relationships used in experimental determinations</u>

$$k = \frac{V}{F_N L_f} \quad (7.1)$$

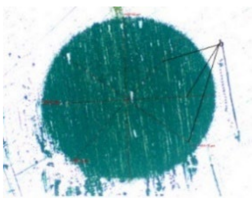
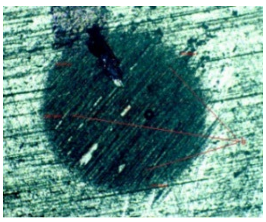
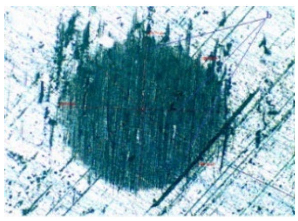
$$V = \frac{\pi b^4}{32d} \quad (7.2)$$

where: k = wear coefficient $\left[\frac{mm^3}{Nm}\right]$; V = wear volume [mm ^{3}]; b = diameter left by the ball, diameter of the wear spot [µm]; d = diameter of the ball [mm];

<u>C. The results obtained</u>

In order to determine the degree of wear, two tests were performed on samples taken from similar areas from PGFs reconditioned by the 3 welding procedures (SMAW, FCAW, FCAWm).
In Table 7.2. the two traces of wear stains obtained from the tests carried out on each sample shall be observed.

Table 7.2. Wear fingerprints from microabrasion tests on samples

Sample	Imprint appearance	
	Test 1	Test 2
A8		
A5		

Based on the values of the diameters of the wear fingerprints, by entering in the relations 7.1., 7.2. have resulted the values indicated in Table 7.3.

Table. 7.3. Values resulted on samples A8, A5, A4, A0

Nr. Crt.	Time [s]	Friction length [mm]	Load force FN [N]	Wear coefficient k [mm3 / Nm]	Volume of used material [mm3]	Wear intensity	Depth of layer [mm]
Test A8							
Mediate	**900**	**214956**	**0.499**	**0.0143591**	**0.01534**	**0.00911**	**0.0195814**
Test A5							
Mediate	900	214956	0.381	0.0331328	0.01095	0.00771	0.0165678
A4 test							
Mediate	900	214956	0.4185	0.0175786	0.01685	0.00529	0.0205517
Test A0							
Mediate	900	214956	0.5215	0.0150335	0.01685	0.00529	0.0205517

After analyzing the averages of the resulting data, it is observed that the lowest value for the wear coefficient is in the case of sample A8 (0.0143591 mm^3 / Nm), a sample reconditioned by the FCAWm welding procedure, which proves the highest wear resistance of the part reconditioned by this procedure and the volume of used material is the lowest in value (0.0153 mm^3) also in the case of sample A8 which proves that the sample obtained by the welding procedure FCAWm has a higher resistance to wear.

7.2 Calculation of costs of applying welding reconditioning procedures of friction linings holder

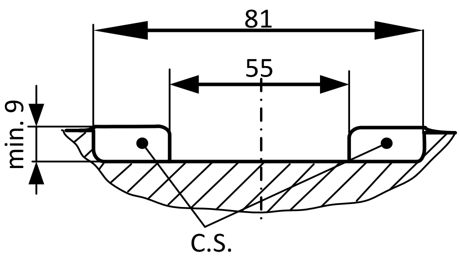
Another important criteria, in choosing / establishing an optimal technological process, in addition to quality, is represented by the cost claimed by the application in production. Until 2005, when a used PGF was found, the repair decision was to replace it with new spare parts at a cost of 135 Euro / piece. The reconditioning by procedure (SMAW) has been applied since 2005 (being elaborated and implemented after approval by CFR Grivița Workshops) repairing an average of 190 PGF per year. The proposed reconditioning for research are FCAW and FCAWm. The conclusions of Chapters 5 and 6 show that these processes have superior SMAW results in terms of the quality of PGF reconditioning. The cost analysis will complete the conclusions in order to validate the application of the improved procedure in order to recondition the PGF.

7.2.2. Calculation of material consumption, labor and costs related to the three welding procedures

From the data provided by the Technical Specification of repair shops, the recommended dimensions of the deposited cord necessary to obtain the nominal dimensions and the dovetail profile after mechanical processing are: l = 13 mm wide and h = 9 mm high (Fig. 7.2.). The defining dimensions of PGF for calculations are: total length 405 mm (Fig. 7.3).; the active length of the dovetail profile is 272 mm; the length of the weld bead is equal to that of the dovetail profile 272 mm.
The total volume of the weld bead, V_{cs}, deposited on one side to ensure the dimensions required for re-machining to the shape of the dovetail profile and the nominal dimensions and angles, is calculated with the ratio 7.3 by replacement results $V_{CS} = 272mm \cdot 13mm \cdot 9mm = 31.82\ cm^3$:

$V_{CS} = L \cdot l \cdot h\ [mm^3]$ (7.3.)
The mass of the deposited cord, M_{cs}, is calculated with relation 7.4, the replacement is $M_{CS} = 260.6$ gr:

$M_{CS} = ƒ \cdot V_{cs}$ [gr] (7.4)



Fg. 7.2. Deposition section dimensions (CS)

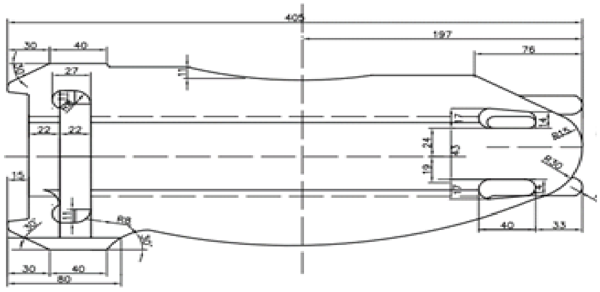


Fig. 7.3. PGF dimensions

The calculation of the mass of the electrodes and the wire used as FM and the determination of the number of electrodes and the length of the wire necessary for the deposition of the reconditioning cord whose mass was determined by the relation (7.4) were performed. Taking into account the welding speed, the time allocated to a passage was calculated as well as the total time required to complete the reconditioning cord for a flank of the SMAW sample. Taking into account the wire feed speed displayed on the screen of the welding equipment of 4.8 m / min, the time allocated to a passage was calculated as well as the total time required to complete the reconditioning cord for a flank for FCAW and FCAWm procedures.

From the analysis of the results indicated in Table 7.12. it can be concluded that the process of reconditioning by welding PGF, which leads to the lowest production costs, is FCAWm being 54% lower than SMAW.

Table. 7.12. Types and values of material consumption and labor on the 3 procedures

Nr. No.	Reconditioning procedure	SMAW			FCAW			FCAWm		
	Consumpti on allocated with:	Consumpti on	UM	Total cost [lei]	Consumpti on	UM	Cost [you]	Consumpti on	UM	Cost [you]
1.	Filler materials	24	[pcs]	210	0.52	[kg]	46	0.52	[kg]	46
2.	Protective gases	-	[m^3]	-	99	[it]	5.74	99	[it]	5.74
3.	PT examination	0.021	[m^2]	2.57	0.021	[m^3]	2.57	0.021	[m^3]	2.57
4.	Electric power for electric arc	1.89	[KWh]	3.08	0.62	[KWh]	1.01	0.54	[KWh]	0.88
5.	Electricity for calcination	1.2	[KWh]	1.95	0	[KWh]	0	0	[KWh]	0
6.	Electric power for mechanical processing [106]	6.64	[KWh]	11	6.64	[KWh]	11	6.64	[KWh]	11
7.	Welding staff work	2.48	[h]	66.52	0.88	[h]	23.48	0.84	[h]	22.59
8.	Machining machine by cutting	1.66	[h]	33	1.66	[h]	33	1.66	[h]	33
9.	Quality control operator labor	2.33	[h]	50	2.33	[h]	50	2.33	[h]	50
TOTAL				**378.12**			**172.8**			**171.78**

7.3. Elaboration of the work instruction procedure regarding the reconditioning by mechnized welding FCAWm

Given the importance of the friction liner holder and the effects that a possible reconditioning procedure by welding will have on the operation, in the case of products related to railway safety, as is the part analyzed, the development of reconditioning technology must be done following a process in which all the elements are indicated. In the specific case of PGF reconditioning, the general stages of the process are: preparation for reconditioning; the reconditioning itself; post-reconditioning operations. Once the PGF reconditioning process has been determined in detail through the FCAWm procedure, it will be formalized through a procedure set out in Annex 1.

Chapter 8. Final conclusions and main contributions to the improvement of the welding reconditioning technology of the friction linings holder from the passenger cars

The relevant conclusions regarding the doctoral research and development activity for achieving its main objective, the improvement of the welding reconditioning technology of the friction linings holder from the passenger cars, in relation to the methodological reference elements (see § 4.3) are:

- identifying imperfections in reconditioned samples due to the use of the SMAW procedure demonstrates the need for experimental research on the development of a new welding reconditioning technology that primarily eliminates imperfections and improves production times, quality, and costs.
- based on identifying and analyzing the hazards and risks generated, a risk management system has been developed to change the technology managing the risks appropriately and reducing them to an acceptable level; the principle of the codes has been used as a risk acceptance practice principle; the security measures applied make the associated risks acceptable and kept under control; the safety measures selected to control the risks become safety requirements. It has been concluded that the technical and operational risks are controlled by applying the specified practice codes and the proposed risk management system; this allows for change and the transition to new reconditioning technology (Chapter 5).

Following the statistical data from the analyses and evaluations at the time of implementation of the reconditioning through the SMAW process, considering that the reconditioning technology was developed in 2005, we considered it necessary to re-evaluate the quality of reconditioning obtained by current technology. being the following (see § 6.1):

- on examination with PT penetrating liquids, non-conformities of the type: pores, cracks, etc .;
- after analyzing deformations using the 3D method, followed by the data processing through the ARTCAM software, it was found that, in the case of the sample welded in the device, the level of deformations was minimal. variation of the clamping force of the part in the device, it is recommended to pay more attention to the stiffening activity of the part in the device;
- in the case of the freely welded sample without attachment in the device, the maximum deformation was recorded in the plane of section H (Fig.6.10.) and was 3.02 mm (higher than the maximum allowed by SR EN ISO 22081: 2021 of 1.2 mm);
- macroscopic analysis revealed that the contribution of the base material to the layer formation was different in the different areas of the part, a situation explained by the fact that the welding speed was not constant;

The implementation of the two technologies designed for FCAW and FCAWm resulted in the following conclusions (see § 6.2):

- the involvement of the welder, in the case of the FCAW procedure, led to the appearance of some imperfections in the resulting cords, the problem solved by mechanizing the reconditioning process;

- the use of a clamping and fastening device to reduce the level of deformation during welding is necessary regardless of the reconditioning technology used;
- by using the FCAWm procedure, an adequate aspect of the surface area of the reconditioning cord and the depth of penetration were obtained, which leads to the idea that this process has a number of advantages compared to the SMAW process;
- for all the samples analyzed in the paper, the average hardness value in the HAZ zone was higher than the one calculated for the CS zone;
- in the areas of material deposited with FCAW and FCAWm procedures, the analysis of the chemical composition showed an increase in the content of Mn, the chemical element that contributes to the increase in hardness and wear resistance of PGF;
- although the value of the linear energy used in the FCAW and FCAWm procedures was approximately equal, in the analysis of the hardness values, notable differences were found in the samples obtained by the two procedures.
- the results of the micro-abrasion test on samples taken from the reconditioned parts by the three procedures demonstrate that reconditioning by FCAWm welding provides increased wear resistance compared to reconditioning with the SMAW procedure; the wear coefficient was 18 %times lower, and the volume of used material was 9 %times lower at FCAWm than at SMAW. (see § 7.1)
- the results of the calculations reveal that time for FCAWm reconditioning is 52% shorter than the SMAW process time, resulting in higher productivity and 54% lower in cost (see § 7.2)

This doctoral thesis brings a series of contributions to achieve the main objective of the doctoral research and development activity, the most important of which are as follows:
1. The personal contributions made by the research carried out in the theoretical field were:
• an original synthesis of the main aspects related to railway safety as well as an original synthesis regarding the use of cast iron as basic materials for the parts of the railway industry and their weldability.
2. Personal contributions in the field of experimental research:
• evaluation of existing SMAW welding reconditioning technology;
• measurement of geometric deformations by 3D scanning and data processing in the ARTCAM software in order to determine the opportunity to use a clamping and fixing device;
• estimating the stresses developed in the welded parts (taking into account the residual stresses in the reconditioned sample under such conditions) by the drilled tensometric rosette method (Mathar method);
• design and implementation of the new FCAW and FCAWm welding technologies in the conditions of keeping the value of the linear energy constant for the two technologies;
• evaluation of the quality of the samples made by metallographic, hardness and chemical composition analyzes;
• micro-abrasion testing of samples taken from reconditioned parts by the three welding procedures to determine the wear behavior;
• performing the technical-economic analysis from the point of view of the current and previous technology in order to implement the new technology;
• elaboration of the reconditioning documentation through the new technology.

The partial results were drafted as scientific papers and were presented as follows:
• The article “Aspects regarding the wear in the operation of the suspended elements made of cast iron, for passenger cars, and the possibility of reconditioning by welding” [32], presented at the ASR Conference “SUDURA 2018”, held in Timișoara.
• Article “Risk management of friction liner welding reconditioning technology changed” [36], presented at the Conference Modtech 2020, published in IOP Conf. Ser.: Mater. Sci. Eng, indexed ISI, WOS 000625330000084;

• Article "The recovery through welding of the geometric shape on passenger railcars friction liner"[34], published in Journal of Research and Innovation for Sustainable Society 2020, indexed BDI;
• Article "Research on welding reconditioning of the friction liner from passenger cars"33], published in Scientific Bulletin – PUB, 2021, indexed ELSEVIER;
• The article "Research on the development of the welding reconditioning procedure for friction liner on passenger coaches" [35], presented at the Conference ADEM, 2021, indexed BDI;

* * *

Through its issues, approach, and results, this doctoral thesis develops the improvement of the existing welding reconditioning technology of the friction linings holder from passenger cars.

The scientific importance of this doctoral thesis is supported by the contributions to the development of welding reconditioning technologies applicable to friction liners holder used in railway passenger cars, where the requirements for operational safety are very strict.

The practical importance of this doctoral thesis lies in the fact that it offers technology and a procedure of reconditioning by welding the friction linings holder, which will lead to shorter repair times, lower costs, and higher wear resistance compared to the existing technology at this time.

The analyzes performed on the reconditioned parts with the new FCAWm welding technology have proved its superior quality compared to the current SMAW process, but there are still new research directions of interest such as:

- the use of various filler materials to improve the properties of the cord and the part;

- improving the methods of analysis and control by using high-performance software to simulate the operating conditions of PGF;

- performing new tests, also in other areas / positions in the reconditioned parts, to identify the remaining stresses by the drilled tensometric rosette method (Mathar method).

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